ARUP

Elanor Investors Group

Warrawong Plaza

Preliminary Geotechnical Desktop Study

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Important note about this report

The ground is a product of continuing natural and human made processes and therefore exhibits a variety of characteristics and properties that vary from place to place and can change through time. Geotechnical engineering involves gathering and assimilating limited facts about these characteristics and properties to understand or predict the behaviour of the ground and groundwater on a particular site under certain conditions.

Arup may report such facts obtained by observation, excavation, probing and sampling, testing or by other means of investigation. If so, they are directly relevant only to the ground and groundwater at the place where, and the time when, the investigation was carried out, and are believed to be reported accurately.

Any interpretation or recommendation given by Arup shall be understood to be based on judgement and experience and not on greater knowledge of the facts than the reported investigations would imply. The information contained within this report shall be considered as for reference only.

This report has been prepared for the use of our Client in connection with the aforementioned project and considers particular requirements and instructions. It is not intended for use by any third party and no responsibility is undertaken to any third party.

1. Introduction

1.1 Purpose of Report

Arup has been engaged by Elanor Investors Group ('Client') to provide engineering services for the concept masterplan for the proposed redevelopment of Warrawong Plaza ('the Site')

This report presents the findings of a geotechnical desktop study for the Site. It discusses the geological and geotechnical aspects of the Site, anticipated ground conditions, potential geotechnical constraints and issues, and provides recommendations for design and further site investigation. The desktop study includes a review of published mapping and reports, publicly available site investigation data and site investigation data obtained from Australian Museum.

As the proposed site design is currently at planning stage, the advice contained within this report is intended to be high-level and conceptual in nature.

1.2 Site Location

Warrawong Plaza is located in Warrawong, within the Wollongong Local Government Area (LGA), approximately 6km south of the Wollongong CBD. The Site (see Figure 1 and Appendix A Figure 001) is located at 43-65 Cowper Street Warrawong over an area of over 7 hectares bounded by Cowper St to the north, Northcliffe Drive to south and King Street to the west. The site is approximately 500m north-east of the current shoreline of Kully Bay / Griffins Bay (Lake Illawarra).

The Site comprises a two-level shopping centre with major retail tenants including Aldi, Big W, Coles, Hoyts, and JB Hi-Fi, as well as a single level basement parking lot founded at RL +2.3m AHD. Development surrounding the Site includes a range of commercial/retail buildings, low and medium density residential development and open space. NSW Land and Housing Corporation owns a large adjacent 1.5 hectare site known as 'Illawong Gardens', which comprises social housing. Redevelopment is also proposed at adjacent lots to the north and west of the Site as well as a renewal of Cowper Street.

Figure 1: Site location aerial (Ethos Urban 2023)

1.3 Proposed Development

The proposed redevelopment of Warrawong Plaza aims to transform the Site into a mixed-use residential, commercial, and retail precinct (see Figure 2). Four stages of construction are proposed, expanding the retail core to three levels in addition to development of public open space and construction of multi-storey residential apartments up to 75 metres in height. Two basement levels are proposed for parking lots founded at a depth of approximately 4 to 9 metres below ground level to RL -0.7m AHD, 3 metres below the current basement level.

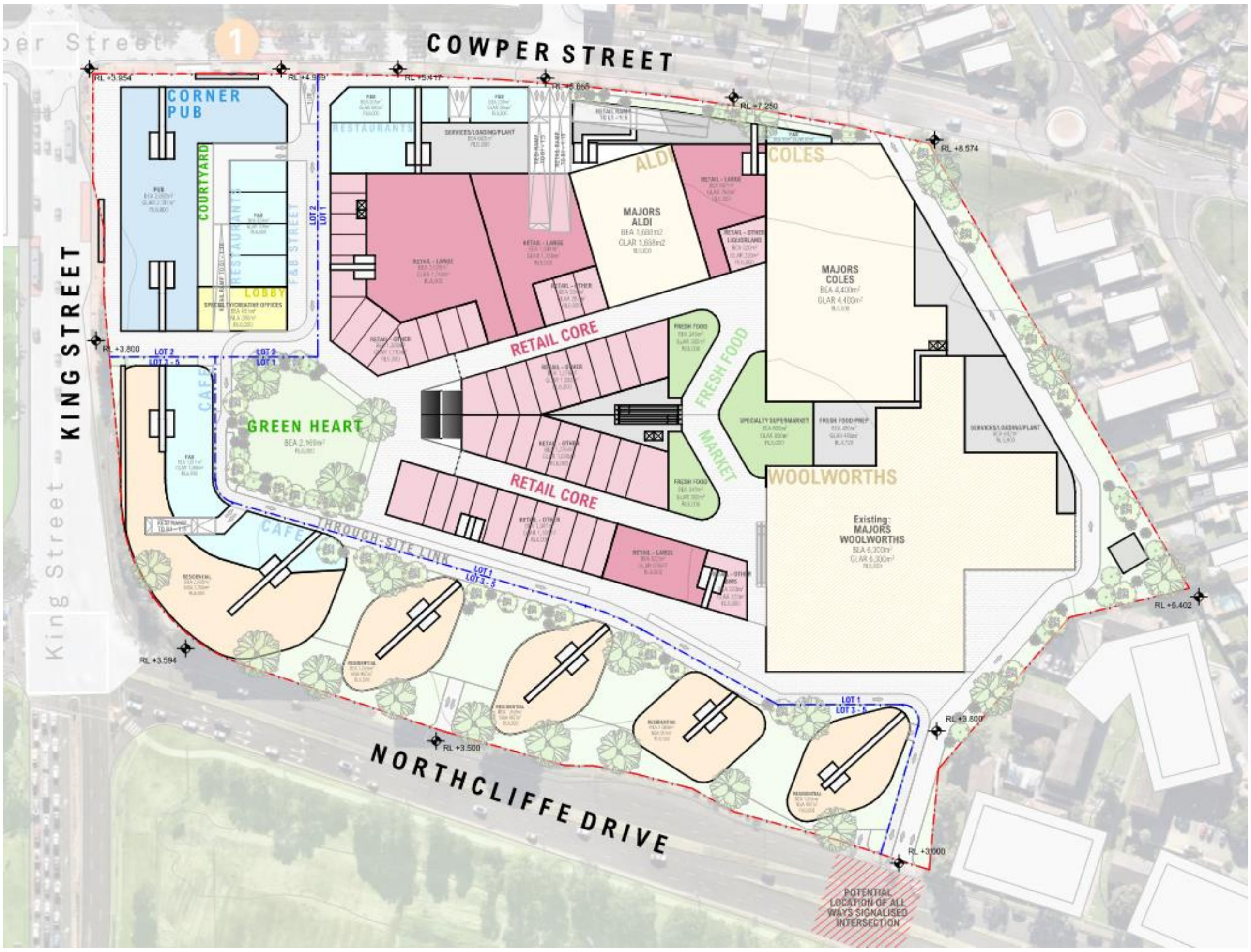

Figure 2: Plan of the proposed redevelopment of Warrawong Plaza (CHROFI 2023)

1.4 Scope of Work

The Geotechnical Desktop Study will take the form of a report and will provide an assessment of design constraints and geotechnical risks and opportunities, the following activities are included:

1. Collection and review of information:
   - Collation of publicly available online information with respect to geological setting of the Site.
   - Collation of publicly available online historical aerial photographs to review the development of the Site at various stages.
   - Review of Before You Dig Australia information obtained as part of the Civil Engineering scope to understand the location of nearby utilities.
2. Interpretation of information and advice:
   - Familiarisation with the proposed design of the structure, and developing an understanding of the geotechnical site conditions.
   - Research publicly available information on existing subterranean structures near to the Site.

- Highlight of key geological/geotechnical red flags.
- Highlight of key hydrogeological risks and planning considerations.
- High level Geotechnical conditions summary and engineering advice, including advice on high level engineering options for foundations, retaining walls, groundwater management and other basement structures.
- High level concept advice on design approach.

1.5 Sources of Information

1.5.1 Published Information

The sources listed below are referenced throughout this report:

- Recent aerial imagery: World Imagery (Maxar (Vivid Advanced) 2023), NSW 2020 Spot 6-7 Satellite Imagery (Spatial Services 2020), NSW Imagery (Spookfish 2018)
- Historical aerial imagery: NSW Historical Imagery Viewer (Spatial Services 2021)
- Topography: Sydney 1 metre Resolution Digital Elevation Model (Spatial Services 2021)
- Utilities: Before You Dig Australia (BYDA) (8 August 2023)
- Soil Landscapes of the Wollongong-Port Hacking 1:100,000 Sheet (Hazelton and Tille 1990)
- New South Wales Seamless Geology Data Package, Version 2.3 (Colquhoun, et al. 2023)
- Geology of the Wollongong and Port Hacking 1:100,000 Sheets 9029, 9129 (Sherwin and Holmes 1986)
- Acid Sulfate Soils Risk (Naylor, et al. 1998)
- Atlas of Australian Acid Sulphate Soils (CSIRO 2013)
- NSW State-wide Hydrogeological Landscapes 2020 (First Edition) (Department of Planning and Environment 2020)
- National Groundwater Information System (WaterNSW 2023)

1.5.2 Provided Information

The following project documents have been received and reviewed:

- Warrawong Plaza, Rezoning Pathways Program Urban Design Report, Rev. A, 20/01/2023 (CHROFI 2023)
- Warrawong Plaza, Architectural Drawings (existing and proposed), Rev. C, 06/09/2023 (CHROFI 2023)
- Warrawong Plaza, State-Assessed Planning Proposal – Application for Pilot Program, 20/01/2023 (Ethos Urban 2023)

The following relevant site investigations have been received and reviewed:

- Warrawong Plaza, Warrawong, Geotechnical Investigation (Construction Sciences 2022)

No as-built information of the existing structure has been made available.

2. Site Information and History

2.1 Topography

A topographic map of the Site is presented in Appendix A Figure 002. The Site is located at a local topographic low bordering the original shoreline of Lake Illawarra prior to reclamation (approximately along Northcliffe Drive). A valley approximate aligns with King Street and may indicate the location of a historic stream. The elevation of the Site is generally level with a gradual dip of approximately 2% from +8.5m AHD in the north-east corner to +3m AHD at the southern / south-eastern boundary of the Site towards Kully Bay which is approximately 500m south-west of the Site.

2.2 Site History

A review of available historical imagery from 1955 to 2022 has been undertaken to assess the historical use of the Site and in the surrounding area.

Imagery Date	Description
1955	The Site appears mostly vacant with small building structures at the north-west corner of the Site. Low density residential buildings are present north and east of the Site. Reclamation is yet to occur at Kully Bay south-west of the Site and the shoreline can be seen along the present day King Street and Northcliff Drive. The area south of the Site appears to be a wetland reclaimed prior to 1955 (present day Darcy Wentworth Park).The natural shoreline appears to be located at the southwestern corner of the Site.
1966	Warrawong Plaza occupies approximately half of the Site after opening in 1960. Commercial developments have also been built to the west and north of the Site. King Street has been constructed and reclamation of Kully Bay appears to be ongoing.
1969	Warrawong Plaza has expanded with additional parking lots and an extension to the south. Northcliffe Drive has been constructed and the reclamation of Kully Bay appears mostly complete.
1972	The adjacent social housing complex south-east of the Site has been constructed.
1980	Widening of King Street as well as Northcliffe Drive in the west of the Site. Construction of a culvert south of Northcliffe Drive within Darcy Wentworth Park.
2004	Further redevelopment and extensions of Warrawong Plaza can be seen which had occurred during the late 80's and 90's.
2018	Construction can be seen occurring within the Site at the western boundary of site.
2022	Construction at western boundary within the Site can be seen to comprise a new road and new attached structures.

2.3 Third Party Interfaces

2.3.1 Buildings

Medium density residential housing (up to three-storeys) owned by NSW Land and Housing Corporation immediately borders the eastern boundary of the Site. Low density residential housings are situated within the eastern half of the Site's northern boundary, across Cowper Road. Light commercial/retail buildings are present across King Street and Cowper Street from the Site's northern and western boundaries. There are no nearby structures at the southern boundary as it is open green space known as Darcy Wentworth Park.

2.3.2 Roads

Asset owners and stakeholders of existing structures and infrastructure around the Site should be engaged due to potential impact from the proposed development.

The Site is bordered by three sealed roads – Cowper Street to the north, King Street in the west, and Northcliffe Drive in the south. The three streets service bus services.

- Cowper Street is a two-lane local road (council controlled) and is one of the two existing main accesses to the main parking lot of Warrawong Plaza. Wollongong City Council have presented plans for a renewal of Cowper Street.
- King Street is a four-lane state owned arterial road.
- Northcliffe Drive is a six-lane road and is the second existing main access to the main parking lot of Warrawong Plaza. The portion of Northcliffe Drive immediately south of Warrawong Plaza is classified as a local road, however west of King Street, it is a regional road.

2.3.3 Utilities

Details of the utilities located within and adjacent to the Site were obtained from a Before You Dig Australia (BYDA) search competed on 8 August 2023. A summary of the asset owners contacted through this search and utilities indicated as present or nearby to site is presented in Table 1.

Prior to each round of intrusive works on site, the Contractor should undertake their own searches to ensure zones of excavation are clear of services prior to excavation/intrusive works.

Table 1: Utilities present or nearby the Site (as per BYDA, 8 August 2023).

Utility Asset Owner	Note
AARNet	Fibre optic assets located in nature strip at the corner of King St and Northcliffe Drive at the opposite side of road to the Site.
Endeavor	Electrical cables in nature strip adjacent to Site boundary along Cowper Street and Northcliffe Drive. Cables in nature strip at opposite side of road along King Street. Cable crosses through eastern portion of the Site, running approximately north-south, to a substation within the eastern portion of the Site. Cabling also crosses into Site from King Street to a substation within the Site. Unknown cover to cables.
Jemena	Low pressure gas main along Northcliffe Drive on opposite side of road to Site. Low pressure gas main in nature strip at north-west corner of site (intersection of Cowper Street and King Street). High pressure gas main in nature strip on opposite side of road to south-west corner of the Site (intersection of Northcliffe Drive and King Street).
NBN Co	Fibre optic assets located in nature strip adjacent to the Site along King Street, and in nature strip on opposite side of the road to the Site along Northcliffe Drive and Cowper Street. Assets connect into the Site in the south from Northcliffe Drive.
Optus	Cabling within the nature strip adjacent to the Site along King Street and at the south-west corner along Northcliffe Drive which connections into the Site.
Sydney Water	Watermain along King Street nature strip adjacent to the Site. Sewer main running along nature strip on opposite side of road from the Site along Cowper Street, King Street and Northcliffe Drive, except at the north-west corner of the Site where it is within the nature strip immediately adjacent to the Site.
Telstra	Cabling within the nature strip adjacent to the Site at the south-west corner, as well as running within the nature strip on the opposite side of the road from Site along King Street and Cowper Street.
Transport for NSW	Traffic signals for King Street-Cowper Street and Northcliffe Drive-King Street intersections.
TPG Telecom	Cabling within nature strip adjacent to the Site at south-west corner. Cabling running in nature strip on opposite side of road to Site at Cowper St and at north-west corner.

3. Geotechnical Conditions

3.1 Geomorphology and Geology

3.1.1 Soil Landscape

The soil landscape map for the Site is presented in Appendix A Figure 004. The map indicates that the soil landscape of the Site is composed of the Gwynneville landscape which generally can be described as usually shallow (<500-1000mm thick) clay residual soil overlying bedrock (Illawarra Coal Measures), formed at the footslopes of the Illawarra Escarpment and isolated rises of the Wollongong Plain. Limitations include extreme erosion hazard, steep slopes, mass movement hazard, local flooding, reactive subsoils and impermeable and low wet bearing strength clay subsoils.

It should be noted that soil landscape mapping is based on wide scale topographic mapping and may not be representative of conditions at a site level. With reference to the geological map and other soil landscapes along the northern side of Lake Illawarra, the Fairy Meadow landscape is considered more representative. This landscape is generally described as sandy clay loams or heavy clays to a depth <1.5m, formed in a swamp environment at alluvial plans, floodplains, valley flats and terraces below the Illawarra Escarpment. Limitations include flood hazard, low wet bearing strength, highly permeable soils and high seasonal watertables.

3.1.2 Geology

A geological map for the Site is presented in Appendix A Figure 005. The map indicates that the Site is mostly underlain by the alluvial fan deposits which overlies bedrock of the Shoalhaven Group – Broughton Formation and Dapto Latite Member. It should be noted that the Geological Map is a regional scale map which may not be representative of conditions at a site level and hence geological boundaries may be shown as approximate.

Alluvial fan deposits

This unit refers to quaternary aged fluvially-deposited quartz-lithic sand, silt, gravel, clay.

Dapto Latite Member (P__gd)

The Late Permian Dapto Latite Member is the highest flow of the Gerringong volcanic facies of the Shoalhaven Group. It is basaltic in composition, and ranges in texture from aphanitic to porphyritic with a crystalline groundmass. It contains vesicles mostly as elongated stringers parallel to flow, sporadically infilled with carbonate, sporadic columnar jointing.

Broughton Formation (Pshr)

The Broughton formation, also referred to as Budgong Sandstone in older literature, is a sandstone of fluvial to terrestrial origin. It is composed of sediments derived from local igneous rocks. It is the youngest (upper-most) unit of the Shoalhaven Group deposited during the Late Permian.

The unit can be described as a yellow-brown, red-brown or green-grey, lithic to feldspathic sandstone (sporadically quartzose). It varies from fine to coarse grained, though is generally coarse grained. Bedding is laterally discontinuous, ranging in thickness from a few centimetres to 3m, often with considerable impact from bioturbation. Erratic pebbles and boulders of igneous composition up to 300mm diameter are common. The formation contains minor, thin, interbedded, laminated siltstones, thin lenticular conglomerates, and a number of tabular latite bodies. Fossils are abundant in darker, siltier portions of the sandstone. (Hazelton and Tille 1990)

The Broughton formation contains interbedded latite flow members such as the Dapto Latite Member encountered towards the top of the unit.

3.1.3 Geological Structures

The Geological map shows the Mount Tomah Monocline approximately 900m north of the Site (north-east / south-west trending, dipping south-east).

3.1.4 In-situ Stress

It is well recognised that the virgin in-situ stress field in the Sydney Basin comprises high horizontal locked-in tectonic stress. Based on published literature (Oliveira and Parker 2014), the major principal stress component at the Site is inferred to be oriented N to NE and of magnitude two to five times vertical overburden pressure. This high horizontal stress state strongly influences the induced ground movements due to excavation and tunnelling works.

It should be noted that the referenced literature is focussed around the Sydney CBD. In situ stress conditions in the Wollongong region are not documented in published literature and the influence of volcanic flows is unknown.

3.2 Acid Sulfate Soils

Published information indicates no identified occurrence of acid sulfate soil (Naylor, et al. 1998) and low probability of PASS (CSIRO 2013) (refer to Appendix A Figure 006a and 006b).

3.3 Rainfall and Temperature

The site lies within Zone 5 of the Australian climatic zones (warm temperate).

The data has been taken from the Port Kembla (BSL Central Lab) weather station (station no. 68131) and Port Kembla Signal Station (station no. 068053) which are located approximately 2km from the Site. The recorded average monthly rainfall (1963 to 2022) ranges from 52mm (July) to 142mm (March). The recorded mean maximum temperature ranges from 16.7°C (July) to 24.4°C (February).

3.4 Hydrology and Flooding

The Site is located approximately 500m north-east of Kully Bay (Lake Illawarra) and less than 2km west from the coast (Pacific Ocean).

Lake Illawarra is a coastal lagoon that is hydraulically linked to the Pacific Ocean via a narrow tidal entrance which in 2007 was rehabilitated to allow a permanent opening to the ocean. Prior to this, it is understood that lake water levels fluctuated greatly. At present, Lake Illawarra is tidal, with average daily peak-to-peak variations of around 1.2m or more.

The existing below ground carpark of the Site is associated with a history of flooding from stormwater runoff. According to a recent flood study for Kully Bay, the Site is within the Probable Maximum Flood (PMF) extent but outside of the 1% Annual Exceedance Probability (AEP) extent. Flood events may also affect accesses along Northcliffe Drive. The study has reported peak water levels in the streets surrounding the Site, as shown in Table 2.

It is noted that a flood study was undertaken in 2017 for Warrawong Plaza by the same author, however this document was not available to be reviewed for this desk study. It is noted that a Flood Study has been undertaken by another Consultant for this project.

Table 2: Peak water levels (m AHD) at streets surrounding the Site (Rhelm 2019)

Location	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Cowper Street	5.68	5.69	5.69	5.69	5.70	5.74
King Street	3.81	3.84	3.86	3.88	3.91	4.20
Northcliffe Drive	3.05	3.07	3.09	3.11	3.13	3.35

3.5 Past Geotechnical Investigations

Available geotechnical investigation data for the Site was reviewed for interpretation of the ground conditions. This investigation data is summarised in Table 3 below and locations are presented in Appendix A Figure 007. Laboratory testing included Atterberg Limits, field moisture content, soil aggressivity and point load strength index.

Table 3: Summary of past geotechnical investigations

ID	Type	Source	Termination Depth [mbgl[2]]	Inclination [deg]	Surface Elevation [m AHD]	Easting [m][3]	Northing [m][3]	Groundwater Strike* [mbgl[2]]
DCP01	DCP[1]	(Construction Sciences 2022)	1.5	-90	Not specified	306294.6	6181861.5	Unknown
BH02	Borehole		7.1	-90	3.2	306363.4	6181862.0	1
BH03	Borehole		11.6	-90	4.5	306385.0	6181875.5	1
BH04	Borehole		7.6	-90	4.2	306369.7	6181886.7	2.5
BH05	Borehole		9.95	-90	4.3	306350.9	6181896.7	0.5
BH06	Borehole		5.65	-90	8.5	306289.7	6181992.8	Not encountered
BH07	Borehole		13	-90	3	306326.2	6181815.3	0.5

Notes:

[1] Dynamic Cone Penetration Test

[2] Metres below ground level

[3] Coordinate system GDA2020 MGA Zone 56. Locations of investigations and corresponding coordinates are approximate and have been referenced from plans provided in the associated reports.

* Groundwater depths are first strikes during drilling, and are generally not representative of the water table, but are a useful indicator.

3.6 Subsurface Profile

The subsurface profile encountered during the investigations across the whole site is summarised in Table 4 below. Key observations are outlined below:

- Fill / pavement was encountered in all boreholes, generally road base of a limited thickness of 400mm, except for BH06 at the far north of the Site where it was 1m thick and of primarily clay in composition.
- Alluvium was encountered in boreholes, described as a Sandy CLAY, ranging in thickness between 1.5m and 5.9m, with the deepest profile encountered in BH07 at the southern portion of the Site, and the shallowest profile encountered in BH06 at the north of the Site. The consistency of the alluvium was generally firm, though soft portions were also encountered. All instances were moist of the plastic limit a lab testing showed high moisture contents indicating potentially high degree saturation. All instances were also described as high plasticity therefore may have high shrink-swell potential.
- Residual soil was also encountered in all boreholes, described as a Sandy CLAY, ranging in thickness between 2m and 6m, with the deepest profiles encountered in the eastern most boreholes. The consistency of residual soil was generally stiff. All instances were moist of the plastic limit a lab testing showed high moisture contents indicating potentially high degree saturation. All instances were also described as high plasticity therefore may have high shrink-swell potential.
- Sandstone was the dominant bedrock across the Site with very little to no weathered profile. The sandstone was high to very high strength, however defect spacing was often closely spaced (<200mm). The top of rock dips from RL+3.0m at the north of the Site (BH06) to RL -7.0m at the south (BH07).
- Considering the poor coverage of past boreholes across the whole Site and the observed variability in ground profile, there are significant unknowns of the ground conditions in the western portion of the Site. It is expected that the thickness of alluvium and depth of rock will increase towards the western end of the Site due the valley/historic stream. Alluvium at this western end may be relatively coarser grained.

Table 4: Encountered ground conditions

ID	Geological Unit	Depth Encountered (mbgl)	Material Description
DCP01	Slab	0.0 to 0.4	CONCRETE
	Unknown	0.4 to 0.6	Stiff
	Unknown	0.6 to 1.0	Very Stiff
	Unknown	1.0 to 1.5	Hard, refusal at 1.5m
BH02	Fill (Pavement)	0.0 to 0.2	CONCRETE
	Fill (Roadbase)	0.2 to 0.6	Gravelly SAND
	Alluvium	0.6 to 3.4	Sandy CLAY – soft becoming firm with depth, high plasticity, moisture content greater than plastic limit
	Residual Soil	3.4 to 7.1	Sandy CLAY – stiff, high plasticity, moisture content greater than plastic limit
BH03	Fill (Pavement)	0.0 to 0.1	Asphalt
	Fill (Roadbase)	0.1 to 0.4	Gravelly SAND
	Alluvium	0.4 to 2.4	Sandy CLAY – soft becoming firm with depth, high plasticity, moisture content greater than plastic limit
	Residual Soil	2.4 to 8.6	Sandy CLAY – stiff to very stiff, high plasticity, moisture content greater than plastic limit
	Sandstone	8.6 to 11.6	SANDSTONE – slightly weathered, high to very high strength
BH04	Fill (Pavement)	0.0 to 0.1	Asphalt
	Alluvium	0.1 to 3.0	Sandy CLAY – firm becoming stiff with depth, high plasticity, moisture content greater than plastic limit
	Residual Soil	3.0 to 7.6	Sandy CLAY – stiff, high plasticity, moisture content greater than plastic limit
BH05	Fill (Pavement)	0.0 to 0.3	Asphalt
	Alluvium	0.3 to 4.0	Sandy CLAY – firm, high plasticity, moisture content greater than plastic limit
	Residual Soil	4.0 to 6.0	Sandy CLAY – stiff, high plasticity, moisture content greater than plastic limit
	Sandstone	6.0 to 6.8	SANDSTONE – extremely to moderately weathered, low strength
	Sandstone	6.8 to 9.95	SANDSTONE – slightly weathered, high to very high strength
BH06	Fill (Pavement)	0.0 to 0.28	CONCRETE
	Fill	0.28 to 1.25	Gravelly Sandy CLAY – medium plasticity
	Alluvium	1.25 to 2.8	Sandy CLAY – firm, high plasticity, moisture content greater than plastic limit
	Residual Soil	2.8 to 5.5	Sandy CLAY – stiff, high plasticity, moisture content greater than plastic limit
	Sandstone	5.5 to 5.65	SANDSTONE – extremely weathered, inferred very low strength
BH07	Fill (Pavement)	0.0 to 0.2	CONCRETE
	Fill (Roadbase)	0.2 to 0.6	Gravelly SAND

ID	Geological Unit	Depth Encountered (mbgl)	Material Description
	Alluvium	0.6 to 6.5	Sandy CLAY – firm, high plasticity, moisture content greater than plastic limit
	Residual Soil	6.5 to 10.0	Sandy CLAY – stiff becoming very stiff with depth, high plasticity, moisture content greater than plastic limit
	Sandstone	10.0 to 13.0	SANDSTONE – slightly weathered, high strength

4. Hydrogeology and Groundwater

4.1 Hydrostratigraphy

The hydrostratigraphy underlying the Site comprises fine grained alluvial deposits overlying low permeability residual soils and sandstone bedrock. A summary of the hydrostratigraphy underlying the Site is presented in Table 5, based on the mapped geology of the Site and site-specific geotechnical investigations. The inferred hydraulic conductivity characteristics for each unit are qualitatively based on lithology descriptions and publicly available data.

Table 5: Summary of the hydrostratigraphy underlying the Site

Stratum	Encountered Thickness (m)	Characteristics
Fill	0.3 to 1.0	Gravelly SAND and Gravelly Sandy CLAY
Alluvium	1.5 to 5.9	Unconsolidated alluvial Sandy CLAY • May be deeper and coarser-grained in western portion of site
Residual soil	2.0 to 6.2	Sandy CLAY derived from the underlying bedrock • Lower permeability.
Sandstone	-	Slightly weathered, high to very high strength, closely spaced fractures • Permeability likely to decrease with depth.

4.2 Water Sharing Plans

The Site is located within the Water Sharing Plan (WSP) for the Greater Metropolitan Region (NSW Government 2023) associated with the porous rock Sydney Basin South Groundwater Source, as well as Greater Metropolitan Region Unregulated River Water Sources (NSW Government 2023) associated with the Lake Illawarra Water Source. The natural sediment (alluvium) on site is not classified as a water source within the WSP.

4.3 Groundwater Levels

Approximate indications of groundwater levels are available from first strikes during drilling (Table 3) from the previous geotechnical investigation completed at the Site. In the southern half of the Site, the water table is likely to be relatively shallow and may range from higher than 0.5 metres below ground level (mbgl) to around 2.5mbg, within alluvium. At the north-east corner of the Site, groundwater was not observed during drilling of a borehole of 5.65m depth that terminated at top of rock, however this does not preclude the presence of groundwater. It should be noted that these groundwater levels were recorded during drilling activities and may not be reflective of the natural groundwater level across the Site.

Groundwater levels at the Site may have a tidally varying (diurnal) component due to the nearby Lake Illawarra. Fill used for reclamation occurs directly south of the Site. Such fill can have large hydraulic conductivity, effectively shortening the distance to a tidal boundary. However, it is probable that terrestrial rainfall patterns will contribute the largest to groundwater level fluctuations, but this would require confirmation via site monitoring. The influence of tidal forces on groundwater levels will be attenuated further inland, meaning the greatest diurnal variation in groundwater levels is likely to be on the south-western side of the Site. The influence of tidal forces will be damped to some extent if there is a sheet-pile wall (or similar groundwater flow barrier) installed along the bank of Kully Bay.

The groundwater medium is likely to be highly responsive to rainfall events, particularly in coarser-grained alluvium, which is potentially present at the western portion of the Site.

4.4 Groundwater Quality

Published information indicates a moderate salinity hazard (Department of Planning and Environment 2020) (refer to Appendix A Figure 008).

There is no available testing on groundwater salinity. Limited soil testing on site has indicated non-saline residual soil and moderately saline alluvium (Construction Sciences 2022), however this may not be indicative of groundwater salinity. Several groundwater bores surrounding Lake Illawarra (WaterNSW 2023) have described salinity:

- GW109768 – located 2km south-west of the Site within clay soil (mapped as coastal sand deposit), groundwater described as ‘salty’.
- GW107727 – located 4.5km west of the Site within clay soil (mapped as alluvial fan), groundwater described as ‘fresh’.
- GW102289 – located 5km west of the Site within rock (mapped as alluvial floodplain), salinity readings of 300 mg/L in sandstone (fresh), and 500 and 1600 mg/L in deeper siltstone (fresh to slightly saline).

Saline water along the Pacific Ocean shoreline and Lake Illawarra creates a mixing (or interface) zone between the dense saline seawater and non-saline groundwater. In natural undisturbed areas the mixing zone generally dips downward moving inland, with fresher groundwater above it and more saline groundwater below it. The position of the mixing zone will vary over time in response to tide levels, river stage levels and groundwater levels. Pumping and other artificial groundwater withdrawals can cause the mixing zone to migrate inland, which is known as saline intrusion. Considered management of groundwater levels at the Site will be required in order to minimise adverse impacts on groundwater quality from potential saline intrusion. Sea water typically has a salinity of around 35,000 mg/L.

4.5 Groundwater Receptors

4.5.1 Registered Groundwater Bores

A total of 9 registered groundwater bores have been identified within 1000 m of the Site, as shown in Appendix A Figure 009. The use of the bores includes:

- 7 for monitoring
- 2 with an unknown use

Groundwater levels between 3 and 4m below ground level were recorded at three bores in 2011 approximately 950m north-east of the Site. Other bores did not have recorded groundwater levels or other information.

4.5.2 Wetlands

Wetlands are located immediately south-west of the Site at Kully Bay park. Lake Illawarra and Coomaditchy Lagoon are listed as wetlands of National Importance (Department of Climate Change, Energy, the Environment and Water 2019).

4.5.3 Groundwater Dependent Ecosystems

A search of groundwater dependent ecosystems (GDE) in the area was undertaken using the BoM GDE Atlas (Appendix A Figure 010). Kully Bay, approximately 500m south-west of the Site, is listed as an aquatic moderate potential GDE with adjacent areas listed as high potential terrestrial GDE.

A moderate potential terrestrial GDE is present approximately 300m north-east of the Site. A low potential aquatic GDE as well as low to high potential terrestrial GDE areas are located approximately 650m south-east of the Site associated with the Coomaditchy Lagoon.

4.6 Hydrogeological Conceptual Model

The hydrogeological conceptual model for the Site is summarised in Table 6.

Table 6: Hydrogeological conceptual model summary

Element	Description
Groundwater levels and flow	Groundwater levels are relatively shallow towards the south end of the Site (majority of boreholes indicate less than 1mbgl). Flow is likely towards Kully Bay (south-west of the Site). Groundwater levels may exhibit moderate tidal fluctuations. These fluctuations attenuate further inland. Groundwater levels are likely highly responsive to rainfall events.
Hydrogeological units	Alluvium is expected to be the primary groundwater medium due to potentially higher permeability than underlying residual soil and rock. The alluvium may be connected with localised areas of coarse-grained fill. The groundwater medium is bounded to the north by lower permeability higher rock level and thinner alluvial deposits. Fill material used for reclamation (extending from the current lake shoreline to the southern site boundary) may have potentially high permeability, which may influence the Site.
Hydraulic controls on groundwater levels and salinity	The Pacific Ocean has an average water level of 0m AHD and the tide level has been recorded to vary between -0.2 and +2.2 mAHD at Port Kembla (Bureau of Meteorology 2023). Sea water typically has a concentration of 35,000 mg/L. Lake Illawarra has an average daily tidal fluctuation of around 1.2m or more. Lake Illawarra salinity is expected to be strongly influenced by the Pacific Ocean. Design flood levels will vary around the Site (see Section 3.4). Saline water from the Pacific Ocean and Lake Illawarra will create a mixing (or interface) zone with fresher groundwater, that generally dips downward moving inland. Underground infrastructure, such as sewers, may locally control groundwater levels and salinity concentrations
Groundwater recharge and salinity	The groundwater is mostly recharged by rainfall and run-off from the Kully Bay catchment area. Available information indicates that groundwater may be fresh or saline.
Sea level rise and climate change	Sea level is expected to rise and climate change is expected to increase rainfall intensity.

5. Hazards, Risks, Constraints

Geotechnical hazards, risks, constraints and constructability and design considerations are described which may inform the decision-making process on project feasibility, constraints, constructability.

5.1 Summary of Hazards, Constraints, Risks

A summary of hazards, constraints and risks identified for the Site are outlined in Table 7 below. Further discussion is provided in succeeding subsections.

Table 7: Hazards, constraints and risks for the Site

Hazards / Constraints	Potential Risks	Description	Mitigation
Limited geotechnical investigations across the Site and no available site-specific investigation in central and western portion of Site.	Uncertainty in geological profile, material parameters for design Limited depth of past investigations	Uncertainty in the geological model would impact the choice of design and construction solutions and limit our understanding of all the risks identified in this table. Uncertainty in strength parameters for design impacting on choice of foundation and retention systems, as well as soil shrink-swell potential which will primarily impact structures that may be founded near ground surface. Additionally, limited durability and contamination laboratory testing has not been undertaken previously. Groundwater and soil chemistry testing should be undertaken to inform structural durability design and understand the need for any site treatment of groundwater prior to discharge and to aid applications for discharge licence (if required). Due to the history and age of the Site, contamination testing should be undertaken to inform design and construction methodology.	– Undertake additional investigations with associated laboratory testing
Existing fill (poorly compacted, heterogenous)	Unsuitable founding material Excessive or differential settlement Potentially unsuitable for reuse as backfill Trench instability	Prior investigations indicate the presence of existing fill. This may be heterogeneous and may be highly variable in engineering characteristics. Existing fill is not suitable for founding structures due to risk of excessive or differential settlements (noting that fill across the Site is likely to be limited to shallow depths and thus is assumed not founding structure). Existing fill may also be deemed as unsuitable material when excavated may not be suitable for backfill. A site-specific assessment of the material is required to classify and assess its competency. Careful consideration should be made to the existing fill within the southern side of the Site placed during reclamation works shall be further investigated as it may be poorly compacted and contain industrial byproducts (and potentially contaminated material).	– Undertake additional investigations with associated laboratory testing – Existing fill not to be used as founding material
Uncertain profile of alluvium and underlying weakened rock / deep weathering profiles	Uncertain depth and extent of alluvium Uncertain rock quality Deep soil profile Inadequate foundation conditions Potential soft, compressible soils	Potential for poorer ground conditions, weakened bedrock and a deeper soil profile in the western portion of the Site due to the inferred historic stream. Soft, compressible soils may be encountered in alluvial deposits which can result in excessive settlement and can influence retention system options. Coarse grained alluvium expected in western portion of the Site associated with the centre of the interpreted alluvial fan. Variations of the soil types and thickness are anticipated which may lead to differential settlement.	– Undertake additional investigations
Deep soil profile	Inadequate foundation conditions Stability issues	The lowest basement level is proposed at -0.7m AHD. Based on the available investigations, this would likely be founded on existing alluvium or residual soil. The existing alluvium is unsuitable for	– Undertake additional investigations – Alluvium not to be used as founding material

Hazards / Constraints	Potential Risks	Description	Mitigation
	Potential soft, compressible soils	founding the structure. Depending on the expected loading, shallow foundations on residual soil may be unsuitable and deep foundations would be required. Excavations will require retention systems installed prior to excavation to prevent stability issues during excavation. Additional investigations are required to investigate the rock level across the Site and determine suitable founding materials.	
In-situ stress relief	Considerable lateral movement Impact on nearby structures and assets	Locked-in in-situ stress (see Section 3.1.4) may be variable and can result in considerable lateral movement, increasing in magnitude with the depth of excavation. This should be considered at the location of deepest excavation of rock in the north-east corner of the Site. In the north-east site corner, in situ stress relief may also increase the hydraulic conductivity (K) of underlying rock. Shallow rock K may increase to values comparable to surrounding higher K unconsolidated media.	– Undertake additional investigations
Unknown groundwater conditions	Variability across site Need for temporary and permanent approach to groundwater management including cut off retention system (or less likely dewatering) Poor excavatability Stability issues	Past investigations did not investigate groundwater and are limited to observations during drilling. Groundwater conditions across the Site may influence choice of basement structures and require additional assessment to determine the impact of the development on groundwater. Risks are likely to increase during or for a period after prolonged or heavy rainfall. Seepage flows tend to follow preferential pathways through defects and can be encountered within excavations in soil and fractured sandstone. This can lead to instability and upheave of excavations and may require dewatering during construction or an appropriate retention system. The hydraulic conductivity of the Sandy Clay alluvium, and shallow bedrock, are unknown. Should they be high, significant groundwater management may be required. The nature of fill material is unknown, therefore if dewatering is envisaged, ground stability at the southern site boundary will require consideration, depending on the extent of excavations. Ground conditions are unknown at the western portion of the Site closer to the location of a historic stream which may indicate relatively higher groundwater levels as well as coarser-grained sediments. Adequate drainage and dewatering in conjunction with a sealed retention system during construction may be necessary to avoid seepage and saturated conditions and to accommodate groundwater pressures.	– Undertake additional investigations including groundwater level monitoring over extended time periods. – Hydrogeological modelling to assess impact – Permanent design of tanked basement

Hazards / Constraints	Potential Risks	Description	Mitigation
		Saturated conditions may lead to strength reduction of soil and rock, poor excavatability in saturated clays, and instability. The permanent basement structure is recommended to be tanked (sealed) retention system. The development must be assessed for impact to surrounding areas. A hydrogeological impact assessment (including comprehensive investigation in line with construction requirements document) will be required to satisfy DPE and WaterNSW, even if the excavation is undrained, WaterNSW are likely to require that the development has been assessed in line with their Minimum Requirements for Building Sites document (January 2021). Saline or contaminated groundwater may also require treatment prior to discharge. The hydrogeological impact assessment must assess impact of any dewatering and the retention and basement design on groundwater receptors (including water supply bores, GDEs and acid sulphate soils) and groundwater levels and flow in the groundwater medium. The proximity of the wetlands is noted as an elevated risk to this assessment. With increasing impacts from climate change (rising sea level and greater rain intensity), the variation in the groundwater table will become more extreme, leading to issues with durability, drainage and uplift. Consideration must be given to future groundwater levels, not just the current regime.	
Unknown groundwater medium characteristics	Hydraulic conductivity of the alluvium, and other media to be intersected by excavation. Significant inland transmission of tidal fluctuation (assisted by introduced fill). Variability across site Treatment of water	Unknowns and uncertainties that will impact hydrogeological assessment of the Site requiring further investigation include: – Groundwater level range and characteristics – Groundwater quality – Groundwater medium hydraulic properties, particularly the alluvium. – Presence of artificial hydraulic controls near the Site including underground infrastructure and basements – Design of the Kully Bay bank protection, including any groundwater flow barriers such as sheet-pile walls	– Undertake additional investigations
Construction staging	Settlement/ground movement or damage on existing structure	The redevelopment is proposed to be undertaken in stages, in which parts of the existing mall will remain in operation. Excavation of the proposed basement may potentially undermine foundations and may induce settlements and stresses in the existing	– Numerical analyses to quantify potential impact – Investigation of existing foundations

Hazards / Constraints	Potential Risks	Description	Mitigation
	Ground borne vibration form excavation and demolition works Additional loading on temporary retention system Constraints on retention system	structure. This will constrain support options for the retention and may require underpinning works. Investigation of existing foundations is necessary. Loading of the existing structure requires consideration in design of the temporary retention system. Detailed numerical analysis will be required to assess the load influences, resulting ground movements/stresses, and additional support requirements for the development.	
Interface with existing and proposed infrastructure and properties	Settlement/ground movement or damage of infrastructure and buildings Ground borne vibration form excavation and demolition works	The proposed development is adjacent to existing structures and infrastructure (owned by others) which may be impacted by construction. These add constraints to the project and require liaison with asset owners.	– Undertake dilapidation surveys – Survey of existing utilities – Numerical analyses to quantify potential impact – Early liaison with asset owners – Selection of excavation and demolition methodology and assessment/protection of sensitive finishes etc on neighbouring structures – Consider instrumentation and monitoring regime including action plan to mitigate against unacceptable impacts on adjacent infrastructure and property.
Ground-bourne vibration from excavation and demolition works	Ground-borne vibrations lead to damage to existing structures or infrastructure	Ground-borne vibration risks from excavation works especially, plus any demolition works.	– Manage through selection of methodology and assessment/protection of sensitive finishes etc. on neighbouring structures and assets.
Flooding	Inundation of basement Softening and swelling of soils due to saturation Additional pressures on retention Increased uplift pressures on deep foundations Erosion (e.g. piping) Damage to structures	Due to being located at the base of a valley, the Site is susceptible to flooding from stormwater runoff. This is supported by a recent history of flooding of the existing basement carpark. The Site is also within the PMF extent of Kully Bay. In addition to operation and access issues, flooding may weaken (soften) unsaturated soils as well as cause sudden swelling. Flooding may also lead to erosion and damage to structures.	– Undertake flood assessment – Civil works, retaining system and foundations to be designed for suitable flood levels –

Hazards / Constraints	Potential Risks	Description	Mitigation
		Suitable design flood levels should be considered in design of the retention system and foundations (e.g. for uplift).	
Reuse of existing structures	Reliance on existing structures, partially demolished to retain soils and provide foundation support to ongoing operations on Site. Uncertainty in current structural details/capacity for new loading regime and remaining durability of existing structure.	Due to the construction sequencing and staging of excavation works.	– Identify and investigate relevant parts of the existing structure – Plan construction sequence and associated retention design holistically across the Site as well as locally to confirm load paths retained.

5.2 Ground Movements

Ground movements will likely need to be limited to manage impact on adjacent structures, roads, utilities and other assets. There are a number of factors that contribute towards ground movements from excavations, including:

- Existing ground conditions and variability – typically greater settlement during excavation in soil rather than rock;
- Existing in-situ, locked in stresses within the rock mass – may be variable and can lead to considerable lateral movement;
- The location and size of surface excavation – larger and deeper excavations will result in greater ground movement to a greater lateral extent;
- The proposed retention support system and construction sequence for excavations; and
- Groundwater management within excavation.

For the proposed development, ground movement is anticipated to occur during the following stages of construction:

- Demolition of the existing structures;
- Construction of the proposed basements; &
- Operation of the building.

During demolition and excavation, ground movement will occur due to unloading of the foundations and vibration during removal of the existing building and footings. Retention systems will need to be designed to support existing foundations and retaining walls. The retention system must also support the fractured rock and soil until better quality rock or sandstone is encountered and can be excavated vertically without support (Class III Sandstone or better). A detailed understanding of sensitivity of existing structures and infrastructure to ground movements will be developed through understanding detail.

Additional movement will occur due to the relief of in situ locked in horizontal stress. The influence of stress redistribution on the neighbouring structures should be assessed during the design process. This may be required early in the design process to inform the stakeholder engagement process.

5.3 Constructability and Design

5.3.1 Excavation

Construction of the two-level basement will require excavation to depths of more than 4m to 9m below surrounding ground surface level, and 3m below the existing basement level.

Excavation is anticipated to extend through fill then soft to firm alluvial clays and firm to stiff residual soils and will extend below the groundwater table. Excavation in these materials will be readily achieved using conventional earthmoving equipment such as hydraulic excavators with bucket attachments. Where high to very high strength rock is expected to be encountered (i.e. towards north-east corner of the Site), rock excavation equipment would be required. As parts of the existing building are expected to be operational during construction, noise and vibration may need to be limited. Impact on the existing structure during the various proposed construction stages should also be considered.

As the groundwater level on site is expected to be above the level of the base of the basement excavation, active dewatering and lowering of the water table on site would be be required where a drained retention system is adopted to facilitate construction and trafficability during construction. This will induce settlements at ground level, impacting nearby properties, roads and live utilities, with the level of impact dependent on the rates and volumes of water extraction.

It is considered more appropriate to adopt a groundwater retaining 'cut off' (or effective cut off) wall to manage groundwater ingress through the temporary stages until the permanent basement structure is in place (refer to Sections 5.3.2 and 5.3.3).

Careful consideration will be required of excavation stability and groundwater management through the staged excavation process. This may include temporary structures that are not required into the long term.

5.3.2 Permanent Basement Design

It is recommended that the permanent basement is tanked (sealed) to prevent the permanent lowering of the groundwater table through water inflows, loss of ground due to sediment ingress and ongoing maintenance and disposal of groundwater and sediments throughout the life of the structure. The permanent basement design will require regulatory approval (see Section 5.3.5).

A tanked basement would require tension piles or vertical anchors combined with a thickened base slab to provide sufficient uplift resistance against the groundwater pressures. If dewatering during construction is undertaken, it must continue until the permanent structure is in place to result the uplift forces.

5.3.3 Stability and Retention

A suitable retention system will be required around the basement perimeter to support the soil and adjacent foundations. Cut off retaining walls are recommended which would need to extend to an appropriate depth into low permeability strata to achieve hydraulic cut off, anticipated to be within the cohesive clays or bedrock rock at depth. Suitable options include secant piles or diaphragm walls which could be installed prior to excavation and then used during construction and incorporated into the permanent basement design.

Exposed vertical cuts without support may be suitable in the sandstone encountered on Site where defect spacing is great enough without adverse combinations of discontinuity and groundwater ingress is manageable. Further information will be required on the quality of the sandstone and hydrogeologic conditions to enable assessment of this for this Site. It is advisable for a geotechnical engineer to undertake progressive inspection of the excavation to confirm where localised stabilisation measures may be required (e.g. rock bolting and/or shotcreting).

Anchoring if required may be limited by site constraints such as the existing structure and adjacent infrastructure. Internal propping may be required. Any temporary anchors beyond the property boundaries must be de-stressed and decoupled from the structure following construction, with the permanent structure and basement slabs providing lateral restraint in the long term. Approval from adjacent land-owners would need to be sought prior to installing anchors beneath their properties.

Design of the retention system will need to consider the sensitivity to movement of adjacent structures and utilities that surround the Site. Existing fills, particularly those placed during reclamation towards the south end of the Site, may be poorly compacted and contain industrial by products and will be susceptible to stability issues from excavation and dewatering. Consultation with relevant stakeholders will need to be undertaken to confirm acceptance criteria and constraints which will inform the design of the retention system.

5.3.4 Foundations

Fill and soft-firm alluvium are considered unsuitable founding materials for the scale of structure proposed. Residual soil may be suitable where the structure is lightly loaded.

At this stage without further information to the west and central portions of the Site, it is assumed that the structure would be required to be founded primarily on deep foundations (piles) socketed into the bedrock. Piles across the structure should be founded on a consistent sandstone class to ensure that there is minimal differential settlement. Settlements in the order of 1% of the pile diameter can be expected. It is recommended that all the founding material at the shaft and base of each foundation is inspected by a geotechnical engineer.

5.3.5 Groundwater Management

Groundwater levels at the southern end of the Site are relatively shallow (majority of boreholes indicate less than 1m below ground level) and will vary based on the tidal range in the area. Groundwater quality within the groundwater medium is currently unknown but may be fresh thus works will need to prevent adverse impacts to groundwater levels and water quality. The proximity of saline water in the Pacific Ocean and Lake Illawarra will require careful management of groundwater levels to minimise saline intrusion into the groundwater medium. Abstracted groundwater may also require treatment prior to disposal off site.

Temporary ‘bailing’ of water within the excavation during construction will likely be required to remove groundwater in the excavation for dry working conditions. Should local dewatering be adopted instead of bailing, the dewatering design, impact of lowered groundwater levels on nearby receptors (including acid sulfate soils) and the disposal of abstracted water will require consultation and approval with relevant regulatory agencies including WaterNSW and the Department of Planning and Environment (DPE). Groundwater drawdown mitigation during construction dewatering may be required (such as sheet piling, secant piling / diaphragm wall, reinjection, and other methods). Abstraction of groundwater will likely require a water access license and a permit to discharge will be required to dispose of the pumped water.

A tanked basement is recommended for the permanent basement design to prevent permanent lowering of groundwater levels (which could have adverse impacts on groundwater quality from saline intrusion and acid sulfate soils). Regulatory approval of the permanent basement design will need to be sought from DPE and WaterNSW. A large tanked basement will form a groundwater flow barrier and the impact of groundwater mounding and differential groundwater levels either side of the basement will need to be assessed and demonstrated to DPE and WaterNSW.

To demonstrate the impact of any temporary dewatering to the groundwater and the permanent basement design a detailed hydrogeological impact assessment will likely be required to address the DPE Minimum Requirements for Groundwater Investigations and Reporting (October 2022). Additional ground investigations comprising groundwater monitoring and groundwater medium testing would be required to meet the minimum requirements of the DPE for groundwater investigations.

5.3.6 Aggressivity to Steel/Concrete Structures

Limited existing durability testing in existing alluvium (one test) indicates that it is classified as non-aggressive to concrete piles and of mild aggressivity to steel piles (in accordance with AS 2159). Testing within residual soil (two samples) indicates that it is non-aggressive to concrete and steel piles (in accordance with AS 2159). Additional ground investigations will need to include collection and laboratory testing of appropriate samples of soil and groundwater for aggressivity to inform the durability design of steel/concrete structures.

Climate change and sea level rise may impact groundwater quality. Saline intrusion due to sea level rise may cause the groundwater at the Site to become more saline, which may adversely affect the durability of structural materials.

5.3.7 Adjacent Structures and Utilities

Several assets are in close proximity to the Site which include live utilities surrounding as well as various residential and commercial developments adjacent to the Site. The relevant stakeholders will need to be consulted to confirm acceptance criteria and constraints with analysis and assessment where required to demonstrate the development will have no adverse impact on their asset/s (e.g. through ground movement and/or ground-borne vibration etc.).

5.3.8 Site Seismicity

In accordance with AS1170.4 Clause 4.2 for earthquake design actions in Australia, the site sub-soil class is assessed as ‘Class Ce – Shallow Soil’ where the depths of soil on the Site do not exceed those listed in Table 4.1 of AS1170.4.

6. Recommendations

6.1 Additional Ground Investigations

To address the geotechnical risks and uncertainties above, additional ground investigations are recommended as a minimum:

- Boreholes drilled to appropriate depth below anticipated founding levels and deepest retention toe levels around the Site to confirm top of rock levels and quality of rock to inform design of foundations and retention systems.
- Seismic Cone Penetration Tests (CPTs) and Seismic Dilatometer Tests (DMTs) to top of rock to understand properties of superficial deposits to inform retention and foundation design.
- Continuous groundwater monitoring and testing of the groundwater medium to develop a detailed hydrogeological model of the Site.
- Collection and laboratory testing of appropriate samples of soil and rock to understand the material characteristics for design.
- Collection and laboratory testing of appropriate samples of soil below the groundwater level to confirm the presence of potential acid sulfate soils when oxidised by dewatering of the Site.
- Laboratory testing of appropriate soil/groundwater samples to determine durability requirements for concrete/steel structures, and to assess groundwater salinity.
- Investigation of existing building foundations.

It should be noted that separate investigations for contamination and waste classification will be needed, which have not been addressed in this report.

6.2 Geotechnical

To address geotechnical uncertainty and risks, the following is recommended:

- Groundwater cut-off basement retaining walls (e.g. secant wall piles, diaphragm wall) which can be used during construction (temporary works) and incorporated into the permanent basement design to retain soil and groundwater.
- Deep (piled) foundations embedded in bedrock to resist loading of the structure as well as hydrostatic uplift (tanked basement, see Section 6.3 below).
- Undertake a geotechnical impact assessment to assess impact on surrounding utilities and structures as well as on the existing structure due to proposed construction staging.
- Produce an instrumentation and monitoring regime to protect existing assets.

6.3 Hydrogeology

To address hydrogeological uncertainty and groundwater risks, the following is recommended:

- Temporary groundwater retaining ‘cut off’ (or effective cut off) wall for construction. General dewatering is not advised due to potential to impact sensitive receptors nearby.
- A tanked basement be adopted for the permanent basement design.
- Additional groundwater testing be undertaken including groundwater monitoring with continuous readings, groundwater sampling, and groundwater medium testing for hydraulic properties.
- Undertake a hydrogeological impact assessment to refine the conceptual understanding of the hydrogeological conditions and numerically assess the risks of temporary dewatering, the permanent basement design and sea level/climate change impacts to groundwater receptors and the groundwater

medium. The result of the hydrogeological impact assessment will be used to inform the temporary and permanent design and support the regulatory approval for the designs and a water access license.

- Engagement with DPE and WaterNSW for the temporary and permanent basement designs, and associated water access licenses and discharge permits. The engagement process will largely be driven by the development of the hydrogeological conceptual model and associated impact assessment.

6.4 Survey of Existing Utilities

A BYDA assessment of existing utilities has been completed as part of this desk study. This survey must be updated prior to any works on site. Survey locators will be required prior to the commencement of works to verify the location of utilities. Asset owners should also be consulted to verify construction details and the condition of their assets.

6.5 Continued Involvement of Stakeholders

The proposed development will impact nearby structures and utility assets, and therefore approval from these authorities and stakeholders will be required for the development to proceed. This should be flagged as a known approvals and technical risk to the project. Their continued involvement and acceptance during the investigation, design, monitoring, and construction process should be prioritized at all stages to mitigate and minimise disruption and abortive works. Interface agreements and agreed criteria for allowable impact to their assets should be obtained at early stages.

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Appendix A

GIS Figures

Legend

- Site Boundary
- Lot

A	15/09/2023	EK	MS	JA
Issue	Date	By	Chkd	Appd

Metres

0 20 40 60 80 100

ARUP

Level 5, Barrack Place,
151 Clarence St,
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Tel +61 (2)9320 9320
www.arup.com

Client
Elanor Investors Group

Job Title
Warrawong Plaza

Figure Title
Site Plan

Scale at A3	Figure Status
1:2,000	**Draft**

Coordinate System
GDA2020 MGA Zone 56

Job No	Figure No
296838	**001**

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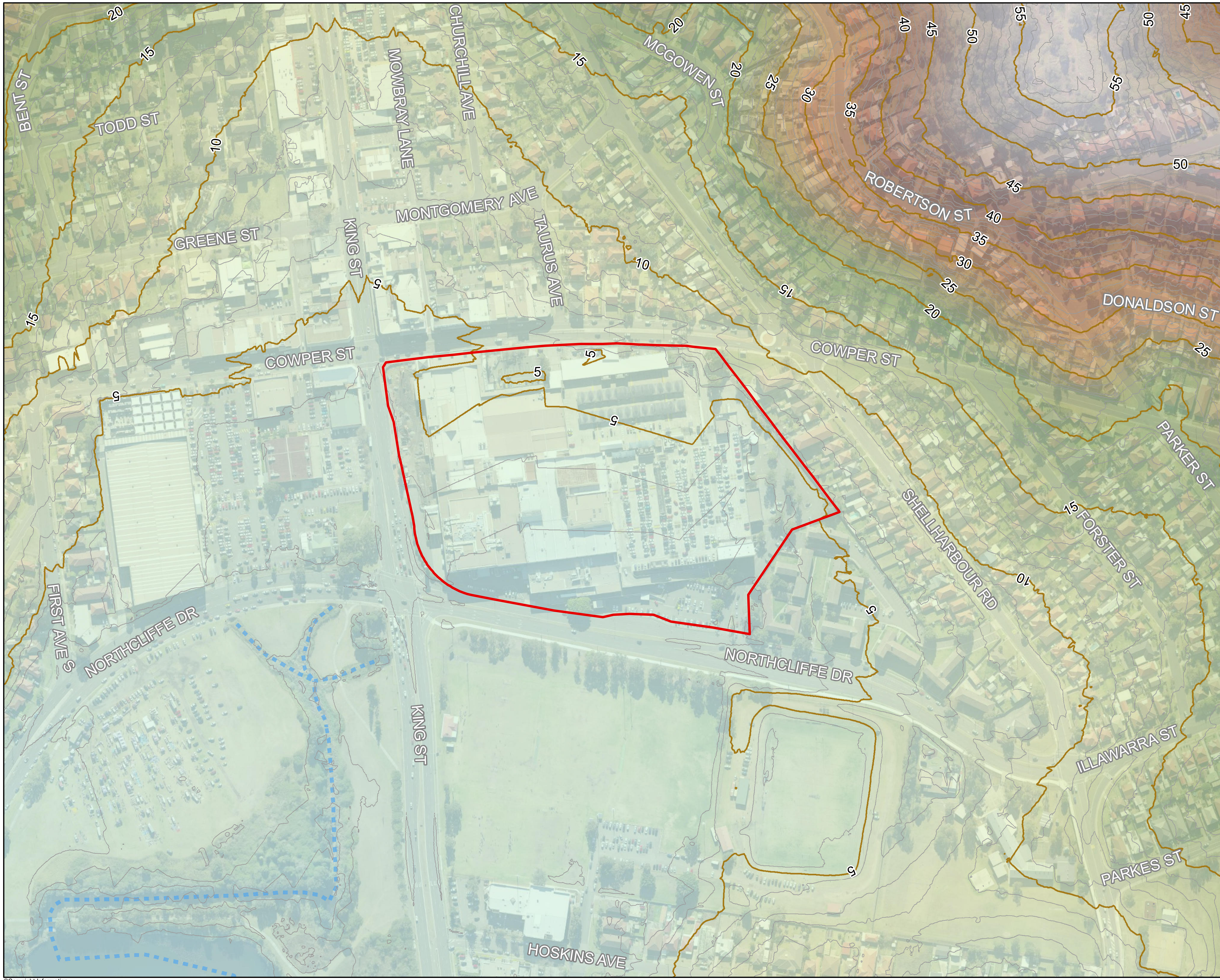

Legend

- Site Boundary
- Drainage Lines
- Contour (5m interval)
- Contour (1m interval)

Elevation (m AHD)

High : 60
50
40
30
20
10
Low : 0

A	15/09/2023	EK	MS	JA
Issue	Date	By	Chkd	Appd

Metres
0 20 40 60 80

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Job Title
Warrawong Plaza

Figure Title
Topography

Scale at A3	Figure Status
1:3,000	**Draft**

Coordinate System
GDA2020 MGA Zone 56

Job No	Figure No
296838	**002**

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Legend

Site Boundary

A	15/09/2023	EK	MS	JA
Issue	Date	By	Chkd	Appd

Metres

0 20 40 60 80

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Client
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Job Title
Warrawong Plaza

Figure Title
Historical Imagery - 1955

Scale at A3	Figure Status
1:2,000	**Draft**

Coordinate System
GDA2020 MGA Zone 56

Job No	Figure No
296838	**003-1955**

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Legend

Site Boundary

A	15/09/2023	EK	MS	JA
Issue	Date	By	Chkd	Appd

Metres

0 20 40 60 80

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Client

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Job Title

Warrawong Plaza

Figure Title

Historical Imagery - 1966

Scale at A3	Figure Status
1:2,000	**Draft**

Coordinate System

GDA2020 MGA Zone 56

Job No	Figure No
296838	**003-1966**

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Legend

Site Boundary

A	15/09/2023	EK	MS	JA
Issue	Date	By	Chkd	Appd

Metres

0 20 40 60 80

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Job Title
Warrawong Plaza

Figure Title
Historical Imagery - 1969

Scale at A3	Figure Status
1:2,000	**Draft**

Coordinate System
GDA2020 MGA Zone 56

Job No	Figure No
296838	**003-1969**

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Site Boundary

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Issue	Date	By	Chkd	Appd

Metres

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Job Title
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Figure Title
Historical Imagery - 1972

Scale at A3	Figure Status
1:2,000	**Draft**

Coordinate System
GDA2020 MGA Zone 56

Job No	Figure No
296838	**003-1972**

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Site Boundary

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Metres
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Figure Title
Historical Imagery - 1975

Scale at A3	Figure Status
1:2,000	**Draft**

Coordinate System
GDA2020 MGA Zone 56

Job No	Figure No
296838	**003-1975**

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Site Boundary

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Metres

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Figure Title
Historical Imagery - 1980

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1:2,000	**Draft**

Coordinate System
GDA2020 MGA Zone 56

Job No	Figure No
296838	**003-1980**

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Figure Title
Historical Imagery - 2004

Scale at A3	Figure Status
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Coordinate System
GDA2020 MGA Zone 56

Job No	Figure No
296838	**003-2004**

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Figure Title
Historical Imagery - 2005

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Coordinate System
GDA2020 MGA Zone 56

Job No	Figure No
296838	**003-2005**

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Site Boundary

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Figure Title

Historical Imagery - 2018

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1:2,000	**Draft**

Coordinate System

GDA2020 MGA Zone 56

Job No	Figure No
296838	**003-2018**

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Site Boundary

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Job Title
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Figure Title
Historical Imagery - 2019

Scale at A3	Figure Status
1:2,000	**Draft**

Coordinate System
GDA2020 MGA Zone 56

Job No	Figure No
296838	**003-2019**

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Site Boundary

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Issue	Date	By	Chkd	Appd

Metres

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Figure Title
Historical Imagery - 2020

Scale at A3	Figure Status
1:2,000	**Draft**

Coordinate System
GDA2020 MGA Zone 56

Job No	Figure No
296838	**003-2020**

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Legend

Site Boundary

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Issue	Date	By	Chkd	Appd

Metres

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Figure Title
Historical Imagery - 2022

Scale at A3	Figure Status
1:2,000	**Draft**

Coordinate System
GDA2020 MGA Zone 56

Job No	Figure No
296838	**003-2022**

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Legend

Site Boundary

Soil Landscapes

AEOLIAN (kn)

DISTURBED TERRAIN (xx)

RESIDUAL (gw)

WATER

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Issue	Date	By	Chkd	Appd

Metres

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Job Title

Warrawong Plaza

Figure Title

Soil Landscape

Scale at A3	Figure Status
1:3,000	**Draft**

Coordinate System

GDA2020 MGA Zone 56

Job No	Figure No
296838	**004**

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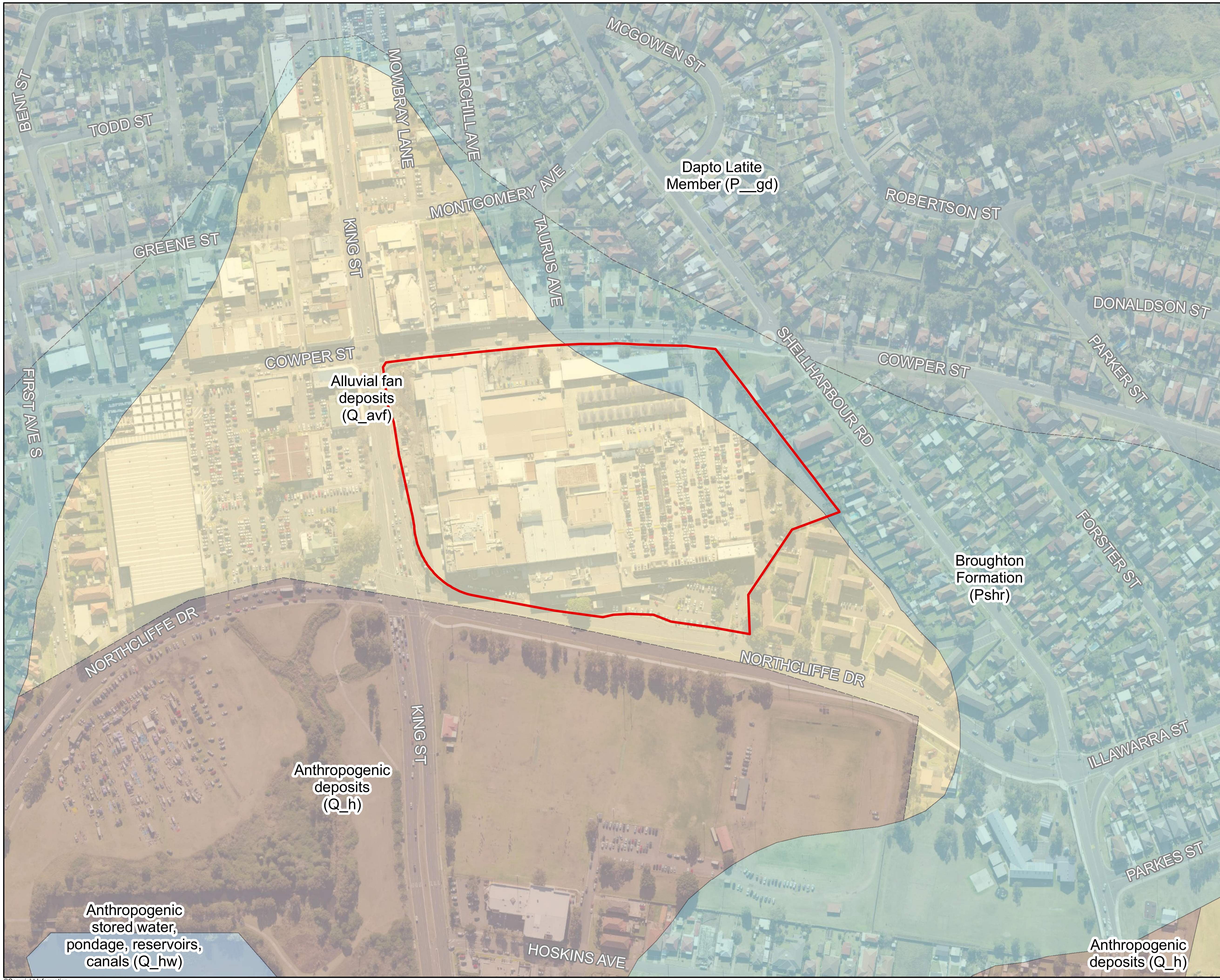

Legend

- Site Boundary
- Geological boundary, position accurate
- Geological boundary, position approximate

Geological Units

Cenozoic Sedimentary Province

- Anthropogenic deposits - fill on Quaternary deposits (QH_hf)
- Alluvial fan deposits (Q_avf)
- Anthropogenic deposits (Q_h)
- Anthropogenic stored water, pondage, reservoirs, canals (Q_hw)

Permo-Triassic Basins

- Dapto Latite Member (P__gd)
- Broughton Formation (Pshr)

Issue	Date	By	Chkd	Appd
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Metres

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Job Title
Warrawong Plaza

Figure Title
Geological Map

Scale at A3	Figure Status
1:3,000	Draft

Coordinate System
GDA2020 MGA Zone 56

Job No	Figure No
296838	005

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Legend

Site Boundary

Acid Sulfate Soil Risk

High Probability of PASS

Low Probability of PASS

Issue	Date	By	Chkd	Appd
A	15/09/2023	EK	MS	JA

Metres

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Job Title
Warrawong Plaza

Figure Title
Acid Sulfate Soil Risk (CSIRO)

Scale at A3	Figure Status
1:3,000	Draft

Coordinate System
GDA2020 MGA Zone 56

Job No	Figure No
296838	006a

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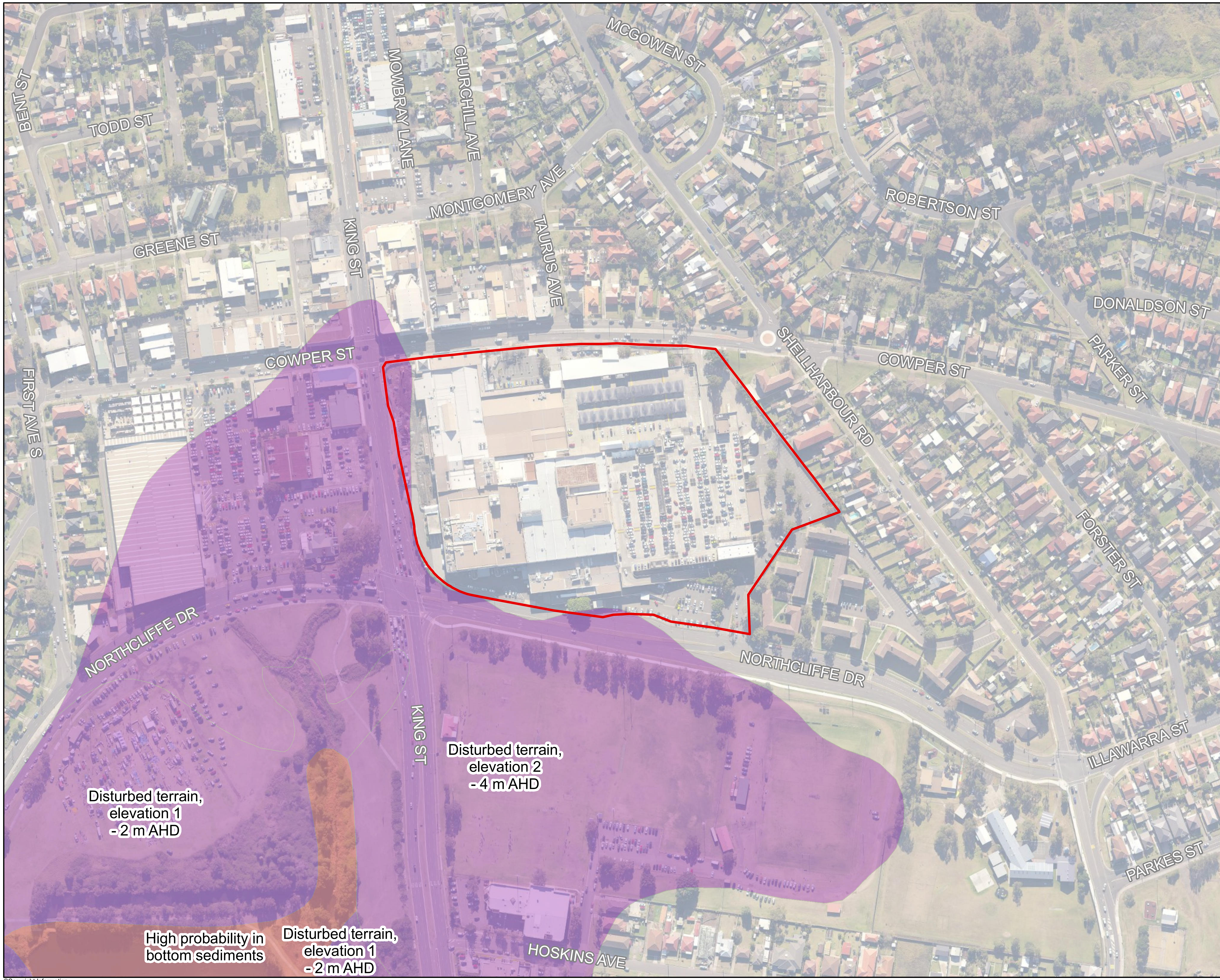

Legend

Site Boundary

Acid Sulfate Soil Risk

High probability of occurrence

Disturbed terrain

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Issue	Date	By	Chkd	Appd

Metres

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Job Title
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Figure Title
Acid Sulfate Soil Risk (Naylor et al.)

Scale at A3	Figure Status
1:3,000	**Draft**

Coordinate System
GDA2020 MGA Zone 56

Job No	Figure No
296838	**006b**

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Legend

Site Boundary

Existing Geotechnical Investigations

Borehole

Borehole (cored)

Dynamic Cone Penetration (DCP)

Issue	Date	By	Chkd	Appd
A	15/09/2023	EK	MS	JA

Metres

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Job Title

Warrawong Plaza

Figure Title

Existing Geotechnical Investigations

Scale at A3	Figure Status
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Coordinate System

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Job No	Figure No
296838	**007**

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Legend

Site Boundary

Overall Salinity Hazard

Moderate

Water

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Metres

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Job Title
Warrawong Plaza

Figure Title
Salinity Hazard

Scale at A3	Figure Status
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Coordinate System
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Job No	Figure No
296838	**008**

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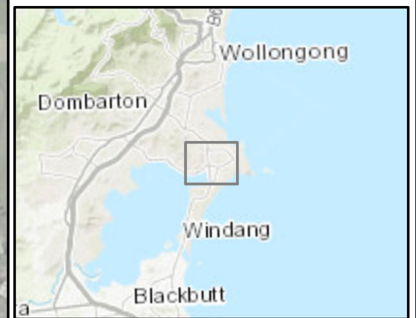
Legend

- Site Boundary
- NGIS Groundwater Bores (within 1km)
- NGIS Groundwater Bores (other)
- Watercourse



Issue	Date	By	Chkd	Appd
A	15/09/2023	EK	MS	JA

Metres

0 120 240 360 480

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Job Title
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Figure Title
Groundwater Bores

Scale at A3	Figure Status
1:10,000	Draft

Coordinate System
GDA2020 MGA Zone 56

Job No	Figure No
296838	009

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Legend

Site Boundary

Groundwater Dependent Ecosystems (GDE)

Aquatic

- Low potential GDE - from national assessment
- Moderate potential GDE - from national assessment

Terrestrial

- Low potential GDE - from regional studies
- Moderate potential GDE - from regional studies
- High potential GDE - from regional studies

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Metres
0 60 120 180 240

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Job Title
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Figure Title
Groundwater Dependent Ecosystems

Scale at A3	Figure Status
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Coordinate System
GDA2020 MGA Zone 56

Job No	Figure No
296838	010

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