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Appendix H and I

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Water and wastewater servicing of the West Dapto Urban Release Area and Adjacent Growth Areas

Environmental Assessment

Appendix H

Soils and groundwater assessment

WEST DAPTO URBAN RELEASE AREA AND ADJACENT GROWTH AREAS - GEOLOGY, SOILS AND GROUNDWATER ASSESSMENT

Sydney Water

GEOTWOLL03124AB-AL
10 May 2011

Coffey Geotechnics Pty Ltd ABN 93 056 929 483
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SPECIALISTS MANAGING THE EARTH

10 May 2011

Sydney Water
Level 10, 1 Smith Street
Parramatta
2124

Attention: Jude Gregory

Dear Jude

RE: West Dapto Urban Release Area and Adjacent Growth Areas - Geology, Soils and Groundwater Assessment

Coffey Geotechnics Pty Ltd (Coffey) is pleased to present our Geology, Soils and Groundwater Assessment Report for the West Dapto Urban Release Area Project (GEOTWOLL03124AB-AL).

Should you require further information regarding our report, please contact Lucy Ellis or the undersigned.

For and on behalf of Coffey

Scott Morrison

Wollongong Office Manager

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EXECUTIVE SUMMARY

E1. INTRODUCTION AND PROJECT BACKGROUND

Coffey Geotechnics' Geology, Soils and Groundwater Assessment has been prepared for Sydney Water's West Dapto Urban Release Project to address the NSW Department of Planning Director-General's requirements in response to a Major Project Application. The West Dapto Urban Release Area (WDURA) and Adjacent Growth Areas (AGA) have been identified as priority areas for new development for the NSW Government. Sydney Water has developed an integrated water and wastewater servicing strategy for WDURA and AGAs.

E2. RISK OF ENVIRONMENTAL IMPACT

Coffey's assessment indicated that the risks of environmental impact are as follows:

- The greatest impacts are likely to be associated with watercourses, in particular, pipeline crossings of watercourses. The risk of impact is very high, due to the dynamic nature of watercourses within the study area, and includes increased erosion, channel migration or avulsion and resultant downstream sedimentation.
- Land degradation, including: erosion resulting from vegetation clearance, soil compaction and flow concentration (with a high risk of gulling and rill erosion associated with pipeline construction); dust generation, particularly associated with soils with a fine silty surface; reduced soil quality associated with soil profile inversion (moderate risk associated with project activities involving major earthworks, such as pipeline trenching or construction of pumping stations), compaction or import of construction material; down-system deposition of sediment resulting in burial of vegetation and poor rehabilitation potential.
- Artificial landform change requiring rehabilitation to a new, altered landform, as a result of semi-permanent earthworks.
- A low to moderate risk of poor rehabilitation success in areas of low fertility.
- Disturbance or exposure during excavation of contamination, salinity or Acid Sulfate Soils (the latter two likely within low-lying areas close to Lake Illawarra), potentially causing adverse downstream or down-system impacts to water quality, ecosystems, habitat and vegetation cover (see Figure R2). Pipeline construction has a high risk of contamination and Acid Sulfate Soil exposure in susceptible areas.
- Groundwater impacts are not anticipated to be great. The highest risk of impact has been assessed as the creation of preferential pathways along pipeline routes or within pipeline construction laydown areas/directional drilling sites. Other potential impacts include intersection and lowering of groundwater; groundwater contamination; and changes in recharge and evapotranspiration rates.

E3. MANAGEMENT AND MITIGATION RECOMMENDATIONS

Coffey has proposed management and mitigation measures in accordance with National and State guidelines, including DLWC (2000), Landcom (2004) and APIA (2009). The different project components often require similar construction, rehabilitation and maintenance techniques, although at differing scales. Therefore, generic management and mitigation measures have been recommended, as follows:

- Prior to the construction phase of the project Erosion and Sediment Control, Contamination, Acid Sulfate Soils and Salinity Management Plans should be prepared. These plans should set performance criteria by which to measure successful rehabilitation.
- A fluvial geomorphological assessment of watercourses and associated riparian corridors, a Landslide Risk Assessment and appropriate geotechnical investigations of soil properties should be carried out. The findings of these assessments should be used to recommend site-specific management and mitigation measures.
- Watercourse management measures should be site-specific, as creek dynamics can vary considerably between and within reaches, depending on creek geometry, bed materials and vegetation. Reaches which are particularly dynamic, intersect erodible soils or are actively eroding (e.g. along the outer banks of meander bends) should be avoided. In general, measures should be sympathetic to the natural fluvial dynamics and allow for natural channel adjustment. Artificial structures should be used sparingly and use of concrete, gabions and reno mattresses should be avoided.
- Land degradation management measures typically involve control of water flow and maintenance/rapid re-establishment of vegetation cover to reduce erosion hazard. Measures should consider natural and constructed drainage patterns, slope steepness, rainfall frequency and intensity, potential flow magnitudes, ground cover, proximity to sensitive environments (e.g. erodible soils or eroding watercourses) and land-use impacts. The main aim of erosion control measures is to retard flow velocities, impound mobilised sediment and maintain protective ground cover (ultimately self-sustaining native vegetation). Impacts can be significantly reduced if works are timed to avoid periods of heavy or prolonged rainfall.
- Management of impacts due to adverse soil conditions, such as intersection of uncontrolled fill, contamination, salinity or Acid Sulfate Soils, involves similar measures. Where adverse soil conditions are likely, targeted investigations should be carried out. The affected soil should be assessed according to relevant NSW guidelines (e.g. ASSMAC, 1998; Tulau, 2007 and DECC, 2008 for Acid Sulfate Soils) by a qualified professional. The findings should then be used to prepare a site-specific management and mitigation plan, based on the overarching pre-construction Environmental Management documentation. These plans should consider implementation of measures to prevent spread to adjacent soils or groundwater. Groundwater quality monitoring may be required, especially close to Lake Illawarra, where saline inflows may occur.
- Project activities where excavation is expected to intersect groundwater may require NOW temporary dewatering licences. In areas of high groundwater levels, engineering controls may be required to provide a barrier to groundwater flow. Groundwater level and quality monitoring may be required in areas of dewatering.

Significant environmental impacts are unlikely if the recommended management and mitigation measures are successfully implemented.

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ABBREVIATIONS

AHD	Australian Height Datum
ANZECC	Australian and New Zealand Environment and Conservation Council
APIA	Australian Pipeline Industry Association
DEM	Digital Elevation Model
DEC(C)(W)	Department of Environment, Climate Change (and Water)
DEWHA	Commonwealth Department of Environment, Water Heritage and the Arts
DIPNR	Department of Infrastructure Planning and Natural Resources
DLWC	Department of Land and Water Conservation
DPI	Department of Primary Industries
DUAP	Department of Urban Affairs and Planning
EC	Electrical Conductivity
EA	Environmental Assessment
EPA	NSW Environmental Protection Authority
GSG	Geology, Soils and Groundwater
EP&A Act	Environmental Planning and Assessment Act (1979)
LIA	Lake Illawarra Authority
NEPC	National Environment Protection Council
NOW	NSW Office of Water
RoW	Pipeline Right of Way
SEPP	State Environmental Planning Policies
TU	Terrain Units

GLOSSARY

The following glossary provides a definition of technical terms used within this report. The definitions have been adapted from online glossaries and dictionaries, including webpages of: CSIRO "The Australian Soil Classification"; Department of Primary Industries (Victoria) and Department of Environment and Resource Management (Queensland).

A Horizon	*n.*	Surface soil horizons which contain organic material. This is also referred to as 'topsoil'
Avulsion	*n.*	Rapid switch in watercourse alignment, where the channel jumps location, rather than moving progressively
B Horizon	*n.*	Subsoil horizons differing from the overlying A horizon by either colour, mineralogy, organic content or structure. This is also referred to as 'subsoil'
Batter	*n.*	An upwardly receding artificial slope
Borrow Pits	*n.*	A pit created to provide soil for use as fill at other sites
Clear or abrupt soil horizon change	*n.*	Horizon boundary less than 50mm in thickness.
Concept Approval Area	*n.*	The area covering all proposed Project components assessed under Part 3A of the EP&A Act
Escarpment	*n.*	A steep slope or cliff separating two relatively level areas of ground, resulting from erosion or faulting.
Gradational Soil	*n.*	A soil which increases in texture (becomes more clayey) with depth
GSG Assessment	*n.*	Coffey Geotechnics' Geology, Soils and Groundwater Assessment
Palaeochannel	*n.*	Former watercourse channel, infilled with alluvium
Ped	*n.*	A natural unit of soil structure formed by cracking along planes of weakness.
Plateau	*n.*	An elevated area of relatively level land, surrounded by steeper slopes or cliffs.
Project Approval Area	*n.*	The area covering Project components that are required for early development in response to development timeframes
Project Components	*n.*	Proposed water and wastewater infrastructure, including pipelines, pumping stations and reservoirs
Receptor	*n.*	Landscape element subjected to impact
Riparian Corridor	*n.*	Land adjacent to creeks and rivers. Corridor widths are defined by DIPNR (2004) and NOW (2008)
Study Area	*n.*	The area assessed during the GSG Assessment
Subsoil	*n.*	See "B Horizon"
Texture Contrast Soil	*n.*	Soils with a clear or abrupt change in texture between the A and B Horizons. A horizons are typically bleached.
Topsoil	*n.*	See "A Horizon"
Uniform Soil	*n.*	A soil with limited texture change throughout the profile

1 INTRODUCTION

This section of the report provides an overview of the West Dapto Urban Release Area Project. An overview of the Geology, Soils and Groundwater (GSG) Assessment is also provided.

1.1 West Dapto Urban Release Project Overview

The West Dapto Urban Release Area (WDURA) and Adjacent Growth Areas (AGA) have been identified as priority areas for new development by the NSW Government's Illawarra Regional Strategy (see Figure 1). The WDURA is made up of 7 development precincts, 3 of which have been rezoned (at the time of writing) to allow construction of 6,900 homes. Further rezoning will eventually allow provision of about 35,000 homes by 2050.

Sydney Water has developed an integrated drinking water and wastewater servicing strategy for WDURA and AGAs, including Tallawarra, Calderwood and Tullimbar.

1.2 Relevant Project Components

Coffey understands that the WDURA and AGA project will involve activities associated with specific project components. Project activity specifications are based on discussions with Sydney Water during the project start-up meeting and information in the Preliminary Environmental Assessment (PEA, 2009), as follows:

- It is proposed that the majority of water pipelines will be installed in road reserves, and wastewater pipelines in the vicinity of waterways (as they are largely gravity-fed);
- Coffey assumes that there will be no significant difference in construction methods between the different pipeline types;
- Water pipelines will be buried to a depth of between 1m and 2m;
- Pipeline construction footprint widths will typically be between 6m and10m
- Wastewater pipelines will be buried to a typical depth of 3m, but occasionally as deep as 5m or greater along gravity-fed routes;
- Pipelines will be typically open cut excavation and occasionally directionally drilled under wide creeks, road or other crossings. Occasional surface structures, such as aqueducts or bridged sections across creeks, may be used;
- Directional drilling pads will have a typical construction footprint of 6m by 10m;
- The pipeline design corridor will be 25m each side of the pipeline: a total of 50m in width;
- Laydown and staging areas for construction footprints may also be required;
- Pipeline trenches will be excavated in maximum lengths of 50m long by 2m wide, and will be closed within 2 weeks;
- Temporary access roads will be required during construction;
- Pumping stations will have a footprint of approximately 160m2, which may vary according to design and ground conditions. Associated pipes and pump shafts may be buried to depths of 6m, and pump station buildings will be above-ground;

- Reservoirs will typically be above-ground steel tanks, requiring sites of approximately 2 to 4ha.
- Target reservoir capacities and water level elevations will be as follows:

Reservoir	Number of tanks	Capacity	FSL
Avondale	2	• 20ML • 17ML	Between 90.5m and 92m
Marshall Mount	2	• 2 x 15ML	Between 129m and 134m
Calderwood	1	• 4ML	Between 238m and 242m

Proposed project activities relevant to the GSG Assessment include:

- Construction: site preparation, excavation, construction (buildings, tanks, etc.), ancillary works (roads, fencing, etc.), landscaping and restoration;
- Operation: Routine inspection, maintenance and repair of infrastructure.

1.3 Geology, Soils and Groundwater Assessment Aims and Objectives

The main aim of the GSG Assessment is to address the NSW Department of Planning Director-General's requirements in response to a Major Project Application by Sydney Water (Ref: S09/01026, 18 November 2009; see Section S-03 of Tender document and Coffey's Geology, Soils and Groundwater Proposal (GEOTWOLL03124AA-PAE)). This stated that:

> 'The EA shall include an assessment of water quality impacts arising from the construction and operation of the project taking into account applicable NSW Government policies. With respect to construction, risks associated with laying pipelines, including across watercourses, acid sulfate soils, salinity, erosion and sedimentation controls and management of any discharges from the project to prevent impacts to nearby watercourses, groundwater and waterbodies should be addressed.'

Coffey's scope of work included:

- An assessment of the existing geology, soils, surface and groundwater conditions of the Project Area;
- An assessment of impacts of the Project on the existing conditions, and the risk that these impacts pose to the landscape (from a geology, soils and groundwater perspective);
- Recommendations (where required) for further detailed investigations to assess areas of concern or identified data gaps; and
- Recommendations on mitigation and management measures for the Project.

Coffey understands that the geology, soils and groundwater assessment should investigate any areas directly or indirectly affected by the proposed pipeline installations and associated infrastructure. Sydney Water has asked that the following assessment priorities are used (in order of priority, see Figure 1):

- "Project Approval Area" Water and Wastewater – Tallawarra Lands; Kembla Grange, Sheaffes/Wongawilli; Dapto; West Horsley, Horsley Industrial and Cleveland and connections to the Avondale Reservoir; Water only – Avondale and connections to the proposed Marshall Mount Reservoir

- "Concept Approval Area" Wastewater only – Avondale and connections to the proposed Marshall Mount Reservoir. Water and Wastewater – Other AGAs, including Huntley, Calderwood Valley, Albion Park Tullimbar and Yellowrock Healthcare Facility
- Areas outside the WDURA or AGA that could be indirectly impacted by the development. This area has been limited to the landscape which Coffey believes could be directly or indirectly affected or which could affect the project, i.e. hillslopes or valleys above; or downslope and down-valley from the proposed components (referred to as the "Study Area" in this report).

Coffey assessed the geology, soils and groundwater within the Study Area, both in terms of the impact of the project on the environment and vice versa. The aim of the impact assessment was to gain a broad understanding of constraints, impacts and issues associated with the geology, soils and groundwater throughout the study area, and a site-specific understanding of these issues within known project activity areas, e.g. within proposed reservoir footprints.

The geology, soils and groundwater (GSG) assessment concentrated on the surface and near-surface geology, as this has the most impact on the contemporary soils and landforms of the area. This report provides recommendations for further study, but does not provide specialist comments outside the scope of the GSG assessment.

1.4 Legislative Context and Standards

The West Dapto Urban Release Area Project has been declared of State and regional planning significance, and thus is being assessed under part 3A of the *Environmental Planning and Assessment Act* 1979 (NSW) (EP&A Act). Acts, policies, guidelines and Environmental Planning Instruments relevant to the GSG study are outlined below:

1.4.1 Commonwealth Legislation

The WDURA Project requires assessment by the Commonwealth Minister for the Environment under the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act), if it is considered a "controlled action" (Pt 3).

As the impact of the proposed development upon geology, soils and groundwater appears unlikely to significantly impact upon the 8 legislated matters of declared national significance (listed under Pt 3, Div 1), it is not likely to be considered a controlled action. It, therefore, appears that the EPBC Act is not relevant to the GSG study.

1.4.2 NSW Legislation and Policy

State legislation, policies and associated guidelines considered relevant to the WDURA GSG Assessment are listed below.

Note: Part 3A of the EP&A Act means that the project is exempt from certain provisions outlined in several NSW Acts that otherwise may be considered of relevance to the GSG assessment (EP&A s75U). However, as the NSW Minister for Planning (charged with the responsibility of promoting the objects of the EP&A Act (including ecologically sustainable development [Sect 5 (a) (vii)]) has the authority to override such exemptions, such Acts and associated guidelines have been included within this section.

- *Catchment Management Authorities Act 2003* (CMA Act) – the objective of which is to establish catchment management authorities (CMAs) to provide for proper natural resource planning at catchment levels, generally through Catchment Action Plans (CAPs). The WDURA is located within the Illawarra subcatchment of the Southern Rivers Catchment, which is under the jurisdiction of the Southern Rivers CMA. The primary aim of this programme is to improve land management and address land degradation processes within the Southern Rivers Catchment through the following actions (Southern Rivers CMA, 2006):

  - Management of wind, gully, sheet and wind erosion (Soil and Land Capability response SLC3);
  - Identification of ASS risk areas and management of exposed ASS (SLC4);
  - Management of areas affected by dryland salinity (SLC5);
  - Appropriate management of soils and pastures to improve soil health and productivity.

  The impacts of the development on soil erosion, ASS, dryland salinity and soil health and structure were, therefore, considered within the GSG Assessment. Where necessary, Coffey has recommended appropriate management measures to meet CAP targets.

- *Coastal Protection Act 1979* (CP Act) – the objective of which is to protect, maintain and restore coastal regions and their associated ecosystems, ecological processes, biological diversity and water quality. The concurrence of the Minister of Climate Change, the Environment and Water when undertaking development of the coastal zone mandated under Part 3 of the CP Act, is not required for developments assessed under Part 3A of the EP&A Act.

- *Contaminated Land Management Act 1997* (CLM Act) – the objective of which is to establish a process for investigating and remediating land that the environmental planning authority (EPA) considers to be significantly contaminated. This Act is of potential relevance to the development as there are numerous areas of artificially disturbed terrain within the study site that are potentially contaminated enough to warrant regulation under the CLM Act (listed under s12). Additionally, there are possible areas of the site that, although acceptable under current land use, may require remediation to make the land suitable for the proposed development (s12(2)).

  Provisions under s60 of the CLM Act require that if the development causes land contamination, or exacerbates the risk resulting from existing contamination, at levels above those listed in the Guidelines on the Duty to Report Contamination under the Contaminated Land Management Act 1997 (DECC 2009), it must be reported to EPA. If required, guidelines published by NSW EPA (1995a), DUAP (1998), NEPC (1999), NSW EPA (2000), DECC (2006) and DECC (2008) provide information to assist in the investigation and reporting of possible land contamination.

  Responsibility any for land contamination (whether or not it is deemed to be significant) falls to the person/s who caused the original contamination (s6 (1)), unless the development is found to cause a change to the pre-existing state of the land so that any prior contamination becomes significant contamination, or is considered inappropriate for the proposed land use (s6 (2)).

Should the contamination be made worse or be considered inappropriate, Coffey considers that Sydney Water would be deemed responsible for the land contamination[1].

Should the remediation of any land found to be significantly contaminated be required, a voluntary management proposal may be prepared and submitted to EPA for approval (s17). Guidelines outlining how to prepare remedial action plans (RAPs) are provided in NSW DUAP (1998). Recommendations on how to manage land contamination are provided in DECC (2000). Specific guidelines relating to the reporting and remediation of groundwater contamination, vertical soils mixing and historic service station site are provided in DEC (2007), DECC (1997), NSW EPA (1995b) and NSW EPA (1994) respectively.

- *Fisheries Management Act 1994* (FM Act) – the objective of which is to protect and manage fisheries for the benefit of present and future generations. Permits to dredge, or damage marine vegetation or fishways required under s220ZF and s219 of the FM Act are not required for developments assessed under Part 3A of the EP&A Act. Relevant provisions relating to dredging outlined in the Fish Habitat Protection Plan No. 1 should, however, be considered within the GSG assessment, if relevant.
- *Native Vegetation Act 2003* (NV Act) – the objectives of which are to prevent broadscale clearing of native vegetation; to protect native vegetation of high conservation value having regard to its contribution to such matters as water quality, biodiversity or the prevention of salinity of land degradation; and to encourage the land rehabilitation with appropriate native vegetation. Consent to clear native vegetation required for projects under s12 of the NV Act is not required for developments assessed under Part 3A of the EP&A Act. Management and rehabilitation of riparian vegetation in regards to reducing excessive sedimentation and erosion into stream is, however, considered relevant to the GSG Assessment. Recommendations relating to riparian corridor widths and vegetation type are provided in Wollongong City Council's Riparian Corridor Management Study (DIPNR, 2004); within the Southern Rivers CAP (Southern Rivers CMA, 2006); NOW's guidelines for riparian corridors (NOW 2008); and Wollongong Development Control Plan (Wollongong City Council, 2009).
- *Lake Illawarra Authority Act 1987 (LIA Act)* – the purpose of which was to establish the Lake Illawarra Authority (LIA) with the aim of improving the management of the Lake Illawarra waters and foreshore. While the WDURA development is subject to approval by the NSW Minister rather than the LIA, the GSG assessment should consider the management objectives outlined in the Lake Illawarra Estuary Management and Strategic Plan (LIA, 2006), particularly regarding objectives related to erosion and sedimentation (s4.5).
- *NSW Salinity Strategy* (DLWC, 2000) – Management of salinity in NSW is guided by the NSW Salinity Strategy. Guidelines for the investigation and management of saline soils encountered within the GSG assessment are provided DLWC (2002).
- *NSW Groundwater Policy* – Groundwater management in NSW is guided by the State Groundwater Policy Framework Document (DLWC, 1997). A set of three component policies to the framework have been developed which identify groundwater management needs, principles

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[1] This statement is Coffey's opinion and does not represent legal advice. Coffey strongly recommends that Sydney Water seek professional legal advice regarding its duty to report under s60 of the Contaminated Land Management Act.

and guidelines. These policies commit agencies to the review and modification of related regulatory and operational activities, and to the support of cooperative management programs. These policies include:

  - Groundwater Quality Protection Policy (DLWC, 1998a);
  - Groundwater Quantity Management Policy (DLWC, 1998b); and
  - Groundwater Dependent Ecosystems Policy (DLWC, 2002).

  Appropriate management of groundwater resources as outlined within these policies should be considered within the GSG assessment of the WDURA development.

- *Protection of the Environment Operations Act* 1997 (PEO Act) – the objective of which is to protect, restore and enhance the quality of the environment by issuing environmental protection licenses for scheduled activities (listed under Schedule 1). This is considered relevant to the GSG assessment as approvals regarding water pollution and waste disposal management may be required for the development, depending on the type of, and disturbance to subsurface material underlying the project site. Specifically licences for contaminated soil treatment (Sh1 15), contaminated groundwater treatment (Sh1 16) and waste disposal (Sh1 39) may be required. Conditions that may be applied to any issued waste disposal licences are outlined in s75. Waste classifications are provided in DECC (2008a) waste classification guidelines.

  Acid sulphate soils (ASS) are a potential pollutant that may be directly or indirectly disturbed from the development. Under the PEO Act, ASS are classified as virgin natural extracted materials, thus meaning that they are exempt from waste disposal licensing (Schedule 1 s39 (1)(e)). However, ASSMAC (1998), part 4 of the guidelines outlined by DECC (2008), and remediation guidelines in Tulau (2007) provide details on how to investigate, manage and appropriately dispose of any ASS encountered.

  As with the CLM Act, the POE Act mandates reporting of any land or groundwater contaminants encountered within the study area if they are likely to cause material harm to the environment (Part 5.7).

- *Soil Conservation Act 1938* (SC Act) — the objective of which is to prevent soil erosion and land degradation. Identification and protection of particularly erodible soils or soils with high conservation value is therefore of relevance to the GSG assessment. Assessment of soil erodibility should follow guidelines published by NEPC (1999), DLWC (2000), Landcom, (2004) (the “Blue Book”) and DECCW (2008).
- *Water Act 1912* is the current relevant legislation for water extraction licences or permits that may be required for the development. These include licences or permits issued under Part 2 (with respect to surface water); licences for bores or artesian wells issued under Part 5 (with respect to groundwater), including temporary dewatering licences; or ‘water management licences’ issued under Part 9. This Act is being progressively phased out and dewatering licences will come under the *Water Management Act 2000*, effective after 1 July 2011.
- *Water Management Act 2000* (WM Act) – the objective of which is to manage the State's water in a sustainable and integrated manner, which requires protecting the health of rivers, groundwater systems and associated wetlands, floodplains and estuaries. Assessment of the project under part 3A of the EP&A Act means that approvals under the WM Act for ‘notices of decision’ under s98, ‘water supply works’ under s90 or activity approvals (controlled activities or aquifer interference activities) under s91 are not required. NOW recommends that relevant

guidelines for the "controlled activities" listed under s91, including guidelines for riparian corridors (NOW 2008), guidelines for pipelines (NOW, 2010), guidelines for instream works (NOW 2010) and guidelines for vegetation management plans (NOW 2010), still be adhered to.

1.4.3 Environmental Planning Instruments (EPI's)

State Environmental Planning Policies (SEPPs)

As the project will be assessed as under Part 3A of the EP&A Act, certain SEPPs that would otherwise be considered as relevant to the development do not apply. For instance, SEPP14 (Coastal Wetlands) would usually apply for developments affecting Lake Illawarra, defined as a Coastal Wetland, unless assessed under Part 3A of the EP&A Act (Part 6 of SEPP14). This is also the case for SEPP 71 (Coastal Protection), SEPP (Rural Lands) 2008, and SEPP 55 (Remediation of Land). As the project involves water and wastewater developments, which are permitted without consent under regulations 106 and 125 of the SEPP (Infrastructure) 2007, the development is also considered to be exempt from this planning policy.

As with exemptions made to State legislation under Part 3A, the Minister has the discretion to take into consideration provisions of all of the above discussed planning instruments (EP&A Act s75J[3] & s75O[3]).

Regional Environmental Plan

The Illawarra Regional Environmental Plan No. 1 (IREP No. 1) sets the overall regional planning framework for land use in the Illawarra. Several regulations within this plan are considered relevant to the GSG assessment. In particular:

- Reg. 101 – The escarpment, where the natural environmental amenity of… [the] escarpment area should be protected, while promoting its use for recreational purposes and accommodating the needs of the coal industry; AND be satisfied that the development will not be subject to [land]slip hazard.
- Reg. 105 - Coastal lands, wetlands and other water bodies, where natural habitats should be protected.
- Reg. 108 – Illawarra Lake, where the consent authority shall take into consideration the need to prevent excessive sedimentation of the lake.

Local Environmental Plans

Several local environment plans have been enacted for Wollongong in order to provide a framework for local land use management. Two of the LEPs, the Wollongong LEP 2009 and the Wollongong LEP (West Dapto) 2009, apply to the WDURA development. Aims within these LEPs that are considered relevant to the GSG assessment are outlined below:

- Wollongong LEP 2009:
    - To conserve and enhance remnant terrestrial, aquatic and riparian habitats, native vegetation and fauna species;
    - To ensure that significant landscapes are conserved, including the Illawarra Escarpment, Lake Illawarra, the drinking water catchment and the coastline.

- Wollongong LEP (West Dapto) 2009:
    - To achieve economically, environmentally and socially sustainable urban development on land at West Dapto and Dapto Regional Centre for the current and future residents of Wollongong;
    - To identify, protect and manage environmentally and culturally sensitive areas at West Dapto and Dapto Regional Centre, including waterways, riparian corridors, biological corridors, remnant native vegetation and associated buffers and items of environmental heritage.

The Wollongong Development Control Plan 2009 has been designed to supplement the above LEPs and establishes objectives and planning controls for development. Several chapters within this plan are considered relevant to the development. These include:

- Chapter E20 – Contaminated Land Management, which outlines procedures for the reporting and remediation of contaminated land.
- Chapter E22 – Soil Erosion and Sediment Control, which outlines strategies to:
    - Minimise the amount of sediment and contaminated water leaving construction sites;
    - Minimise soil and vegetation disturbance caused by construction;
    - Encourage prompt rehabilitation of the site through revegetation.
- Chapter E23 – Riparian Land, which outlines strategies to:
    - Protect urban creeks and riparian corridors from further degradation and improve their environmental function.
    - Maintain and enhance watercourse channels and banks to protect assets for accelerated rates of erosion, and;
    - Restore and rehabilitate degraded, fragmented and modified riparian corridors where possible.

2 METHODOLOGY

2.1 Study Area Overview

To gain a general understanding of the study area landscape, the Coffey Geology, Soils and Groundwater (GSG) Team collated and assessed available mapping, studies, data and relevant legislation. These are listed in Section 8: References. Although Sydney Water asked that Coffey concentrate on the Project Approval Area, from a practical point of view, the GSG Study required a holistic approach to assessment of the Study Area. The subsequent constraints, impacts and risk assessment focussed more on the Project Approval Area, particularly with regard to ground truthing of desk study findings in the field.

A GIS geodatabase was constructed, using available geospatial data supplied by Sydney Water and Wollongong/Shellharbour City Councils. The geodatabase was used to map potential landscape constraints, issues and impacts to assist in the assessment.

2.2 Geology and Soils Investigation Methodology

The geology of the study area was assessed using available geological and soils mapping. This mapping was checked using a review of existing information including Coffey archive records and our knowledge of the site. Geotechnical properties and characteristics of the different materials were inferred from the same sources of information or knowledge.

2.3 Landform Assessment Methodology

The landforms of the study area were assessed using a combination of aerial imagery, site observations and review of existing information. Contours were available at an interval of 1m. These were used to create a Digital Elevation Model (DEM) of the study area. The DEM was used to create topographic and slope steepness maps, which aided in landform assessment and identification.

2.4 Soils Assessment Methodology

2.4.1 Acid Sulfate Soils (ASS)

Areas potentially affected by ASS were assessed through review of:

- Relevant sections of previous reports with geological information provided by Sydney Water;
- Relevant Coffey archival information relating to geology or ASS within the study area.
- Current aerial photography;
- ASS risk maps;

2.4.2 Contamination

Areas potentially affected by soil and/or groundwater contamination were assessed through review of:

- Relevant sections of existing reports provided by Sydney Water relating to site contamination issues;
- Review of Coffey archival information on contamination investigations conducted within the study area.

- Review of selected historical aerial photographs;
- Review of Wollongong and Shellharbour City Council zoning maps;
- Review of NSW EPA records for declared sites within the study area boundaries under the Contaminated Land Management Act.

2.5 Groundwater Assessment Methodology

Groundwater in the study area was assessed using available information on local geology, topography, rainfall and other relevant data, including the NSW Office of Water-registered bore database, site observations and information from previous investigations. The constraints and groundwater impact assessments were conducted taking into account the hydrogeological conceptual model and the nature of the proposed development.

The Albion Park Post Office automatic weather station (AWS) 68000 is located on the southern boundary of the study area (see Figure 1), at an elevation of 8m AHD. Climate data has been recorded at this location since 1892 (Bureau of Meteorology (BoM), 2011). No pan evaporation data is available from the Albion Park station and limited pan evaporation data is available in the study area. Pan evaporation data was sourced from the University of Wollongong (website), which is located approximately 7 km to the north east of the study area.

2.6 Terrain Mapping

During assessments of this type, it is frequently useful to split the landscape into areas which have broadly similar characteristics, properties and constraints, known as “terrain units” (TUs). For the purposes of the GSG Assessment, Coffey has used the terrain unit mapping of the Soil Landscapes of the Kiama 1:100,000 Sheet (Hazelton, 1992). The given Soil Landscape descriptions were checked against Coffey archive information for consistency. The Soil Landscape mapping is based on the dominant geomorphic processes responsible for forming the landscape and the geological parent material. The mapping and associated information also provides an overview of the geotechnical properties, soil types and likely constraints associated with each unit. Landscape properties, particularly soil types, can vary appreciably within a TU. Therefore, areas which are too small to be delineated at the given scale (in this case 1:100,000) have not been mapped (Hazelton, 1992).

2.7 Field Visit

The GSG Study Area was visited on 14 March 2011 to ground truth the findings of the desk study. The site visit targeted high constraint areas and areas at high risk of environmental impact within the Project Approval Area (see Figure 2 and Appendix A). Our observations were used to ground truth the findings of the desk study (i.e. Sections 3, 4 and 5) and provide additional information for Section 6.

2.8 Constraints Assessment Methodology

Coffey assessed the potential landscape constraints on the project, which also provided an indication of landscape sensitivity: sensitive areas of the landscape, e.g. erodible soils or areas prone to landsliding, are typically those which pose the greatest constraints. The intrinsic landscape variability means that localised areas of high constraints can occur within a generally low constraint area, and *vice versa*.

The constraints mapping was largely based on TUs (i.e. Soils Landscape mapping units). Constraints were assessed using information in Hazelton (1992), supplemented by information in existing reports;

Coffey archive information, and information from Sydney Water. Publically available and industry-accepted Acid Sulfate Soils risk mapping was available, but not for other constraints. The available information was used to define a Constraints Ranking, based largely on the documented landscape behaviour and response, for the following issues:

- Steep Slopes;
- Landsliding and Slope Instability
- Faults and Seismic Hazard
- Watercourses
- Salinity
- Erodibility and Erosion Hazard
- Acid Sulfate Soils (1:25,000 risk mapping)
- Land Contamination
- Groundwater
- Trafficability
- Foundations
- Trenchability and Trench Stability
- Rehabilitation Success
- Site-Specific Recommendations

The ranking was intended to provide generalised, indicative guidance on the likely problems that may be encountered. Site-specific constraints have been recorded, where known. However, it is possible that other constraints are present within the Study Area.

2.9 Potential Environmental Impacts and Risk Assessment

Coffey used the findings of the desk and field assessments to carry out an assessment of the potential impact of the project on the environment and the consequent risk that the project poses to the landscape. The risk assessment was based on International (and Australian-accepted) Standard Risk Assessment techniques (ISO/IEC 31010, 2009):

- Potential impacts were identified, based on the geology, soils and groundwater sensitivity within the context of the proposed project activities;
- Where impacts were measurable to a degree, the probability of the impact occurring was assessed. The consequence of such an impact was then considered, based on the severity, geographical extent and duration of the impact.
- The risk of environmental impact, being the product of probability and consequence, was calculated.

3 EXISTING ENVIRONMENT

This section describes the surface and near-surface geology; and the existing landforms, soils and groundwater of the study area. The study area is situated within 2 different physiographic regions associated with landform formed by different rock types and geomorphological processes. These are summarised as follows:

Table 3.1 Summary of Study Area Environmental Characteristics

Landscape Characteristics	Physiographic Region	
	Illawarra Escarpment	**Coastal Plains**
Surface Geology (see Figure 3.1)	Hawkesbury Sandstone overlying Narrabeen Group sedimentary sequences and Illawarra Coal Measures, with a thick talus (i.e. colluvial landslide debris) apron blanketing the mid to lower slopes	Sedimentary sequences of the Shoalhaven Group interbedded with latites of various composition, overlain by thick alluvial (channel and flood) and estuarine sediments
Rainfall	Rainfall increasing over the escarpment, associated with orographic uplift. Average annual rainfall of 1600mm at the escarpment crest with prominent peaks and spurs receiving up to 1800mm per year (Reinfelds and Nanson, 2004)	Mean annual rainfall is approximately 1100mm (Albion Park weather station – elevation 8mAHD)
Relief (See Figure 3.2)	Relief is strongly linked to geology: steep slopes and higher elevations are generally associated with resistant sedimentary and volcanic rock; and low-lying areas with lower-strength rock	
	Sharply concave slopes with near-vertical cliff bands rising to over 730mAHD	Rising from sea level to over 120m at Mt. Brown
Landform	Strongly geologically-controlled escarpment features, with thick talus aprons interspersed by cliff bands associated with resistant rock bands	Strongly geologically-controlled, with resistant latite remnants forming outlier hills, e.g. Mt. Brown rising above low-lying plains
Geomorphology	Prone to slope instability, with rock falls and landslides. Upper reaches of watercourses are high energy, incised, capable of transporting large boulders and prone to rapid vertical and lateral erosion or avulsion. Middle reaches have broad channels with narrow floodplains	Steeper slopes prone to landsliding. Watercourses are generally small and prone to overbank flooding. Channel change is typically imperceptible. Channels typically sit atop a narrow ribbon of coarse sediment within fine-grained flood deposits
Soils	Shallow skeletal soils near rocky outcrops, texture contrast soils (often ferrous or poorly drained), with some gradational soils.	Variable, depending on formation processes; skeletal soils associated with rocky outcrops, uniform and gradational soils on upper slopes; texture contrast soils on lower slopes. Acid sulfate soils below 10mAHD
Soil Landscape Units[1] (See Figure 3.3)	Cambewarra, Faulconbridge, Hawkesbury, Illawarra Escarpment, Warragamba	Albion Park, Bombo, Fairy Meadow, Gwynneville, Shellharbour, Wattamolla Road
Groundwater	Fractured rock aquifers - groundwater within fractures or extremely weathered seams within the bedrock. Unpredictable, disturbed groundwater levels within talus.	For the unconsolidated sediments, shallow groundwater depths are likely to exist in the low lying study areas adjacent to Lake Illawarra and in the vicinity of watercourses.
Land-use	Largely intact sclerophyll forests with 3 large mines (Wongawilli, Avon and Huntley/Avondale).	Largely cleared farmland with areas of residential housing. Large areas of fill are associated with e.g. mines, power stations and landfill.

1. Soil Landscape Units taken from Hazelton (1992)

3.1 Geology

The contemporary surface and near-surface geology has been assessed using:

- 1:50,000 Kiama Geological Series Sheet 9028-I (Bowman, 1974a) and Wollongong-Port Hacking Geological Series Sheet 9029-9129 (Stroud *et al*.,1985);
- Notes on the Kiama 1:50,000 Geological Mapping (Bowman, 1974a);
- 1:25,000 digital coastal Quaternary geology mapping (Troedson *et al*., 2004);
- 1:250,000 digital bedrock geology mapping;
- Coffey's knowledge of the study area.

3.1.1 Contemporary Surface Geology

The geology of the study area is dominated by near-horizontal Permo-Triassic sedimentary and volcanic sequences (see Figure 3.1). Therefore, surface and near-surface bedrock is elevation-dependent, as follows:

Table 3.2 Surficial Geology of the Study Area

Geological Era/Period	Group or Formation	Characteristics	Study Area Location
Quaternary (2 Million years ago (Mya) to Present)	Alluvium	Variable sediments depending on process of deposition, ranging from: • Very fine estuarine deposits on delta and swamp lands near lake Illawarra; • Fine-grained flood deposits; • Coarse sediment columns; • Very coarse, deep talus, ranging from 6m deep in the north of the study area to 2m in the south; • Deep, coarse colluvium	• Adjacent to Lake Illawarra • Low-lying floodplains; • Beneath watercourses; • Accumulated on benches of the Illawarra Escarpment (appreciably greater extent than mapped in Figure 3.1) • Blanketing the lower slopes of the Illawarra Escarpment
Triassic (251-205Mya)	Hawkesbury Sandstone	Quartzose sandstone with occasional mudrock lenses	Upper cliffs of the Illawarra Escarpment
Permo-Triassic	Narrabeen Group	Sandstone and claystone sedimentary sequences	Stepped mid-slopes of the Illawarra Escarpment
Permian (298-251Mya)	Illawarra Coal Measures	Interbedded sandstone, mudrock, claystone and coal sequences,	Lower slopes of the Illawarra Escarpment
	Shoalhaven Group	Consisting of: • Budgong Sandstone (with minor siltstones and conglomerates) interbedded with latites of variable composition (felsic, mafic or porphyritic); • Berry Siltstone	• Lower elevation areas of the site, with isolated remnant latite hills e.g. Mt. Brown • Lowest elevation areas e.g. Albion Park

The proposed project components (see Section 1.2: Relevant Project Components) are largely located on lower elevation Budgong Sandstone overlain by Quaternary alluvial (largely fluvial) deposits. These deposits tend to increase in clay content away from Illawarra Lake, with silty estuarine deposits closer to the lake. Localised silts and sands may be found further inland, probably deposited by large floods,

3.1.2 Geological Structure and Faulting

Minor faulting may be found in the study area, largely associated with tension-relief along the Illawarra Escarpment. The majority of faults are perpendicular to the escarpment face, with several limited parallel faults of limited extent in front of the escarpment. It is not anticipated that these faults will be active during the lifespan of the project. The proposed project components are not located over mapped faults.

3.1.3 Geotechnical Rock and Soil Properties

General Rock and Soil Geotechnical Properties

The ground conditions within the study area are dependent on the associated rock and soil properties, as follows:

- Soft soils are common in low lying areas east of the Princes Highway, where compressible silty clays or clayey silts containing organic material can be up to 6m thick;
- Colluvial and talus deposits on the mid to lower slopes of the Illawarra Escarpment can have variable clast sizes and properties, with some strong, resistant boulders in a high plasticity clay matrix. Coffey's investigations have indicated that talus blankets the mid-slopes of much of the Illawarra Escarpment within the Study Area, covering a far greater extent than mapped in Figure 3.1 (which indicates current published DPI geological mapping for the Southern Coalfields). Coffey's field observations indicate that the toe of the large talus lobe extending towards the Kembla Grange and Sheaffes/Wongawilli areas is at a higher elevation than mapped. However, Sydney Water has borehole evidence that the toe may extend further than mapped (Borehole AB2, Kembla Grange, 1971);
- Floodplain deposits can have spatially variable composition and properties: surface layers can be naturally compacted; thin (<1m) compressible layers can occur, with deeper compressible estuarine clays and silts close to the lake; and deep, highly permeable sands may be buried 3m-4m below ground surface (e.g. just to the north of Horsley);
- Budgong Sandstone tends to become progressively stronger with depth. Residual soils grade into extremely weathered then highly weathered rock: backhoe refusal can occur typically between 1m and 2m depth in elevated areas. Fresh rock at the surface is rare;
- Latites can be very high strength; resistant remnant slabs, boulders and cobbles can occur near the surface, generally within a clayey silt matrix;
- Clays in the Study Area are typically high plasticity and can be reactive (i.e. prone to shrink/swell with changes in moisture content). Moderate to highly reactive clays are typical of the low-lying Coastal Plains.

Fill/Disturbed Terrain Geotechnical Properties

Within the study area, there are variably-sized areas of artificially disturbed terrain. These are generally associated with construction sites, mines or random filling of low elevation areas on rural properties. As urban and industrial development of the region has been rapid, a significant proportion of the disturbed areas have not been mapped. The surface sediments in these areas are typically uncontrolled fill, i.e. of variable composition and unknown compaction. These areas may be prone to erosion, subsidence, contamination and drainage issues.

Fill of variable composition is associated with the Tallawarra Coal-Fired Power Station (see Figure 3.1). Uncontrolled fill has been used to reclaim land adjacent to the power station structures. This fill contains boulders and cobbles. To the south of the power station, ash ponds cover much of the Duck Creek floodplain (i.e. to the east of the Princes Highway).

Large coalwash emplacement (fill) areas are found adjacent to the Huntley, Avondale and Wongawilli coal mines, on the lower slopes of the Illawarra Escarpment (see Figure 3.1). Mine subsidence has not been recorded within the study area and, therefore, mine subsidence should not be an issue.

3.2 Landform

3.2.1 Assessment-Specific Landform Features and Geomorphological Processes

Escarpment

An escarpment is a long steep slope or cliff along the edge of a plateau, representing a resistant layer of rock. The Illawarra Escarpment dominates the landscape along the western fringe of the study area.

Landslides

The steep slopes of the Illawarra Escarpment and outlying hills, combined with the differential drainage and interbedded geological composition have resulted in some highly landslide and rock fall-prone zones. Factors which increase the susceptibility of an area to landsliding include:

- Steep slopes, although landslides in the study area have been known to occur on slopes as low as 10° (or lower when associated with artificial slope destabilisation);
- Higher permeability sandstone overlying less permeable shales, claystones or mudstones, with failures particularly associated with high plasticity clays. This geological banding is typical of the Illawarra Escarpment. Also, along the flanks of Mt. Brown (an outlier hill), high plasticity clay is found above medium to high strength Budgong Sandstone. In some areas, smooth geological interfaces between the sandstone and clay have historically acted as preferential slip zones, exacerbated by preferential drainage along the soil/rock boundary;
- High groundwater levels, marshy areas, impeded drainage (often associated with the geological variability, past landslides or artificial disruption to drainage);
- Slope destabilisation, e.g. placement of fill at the head of a slope, or excavation of a cutting at the slope toe (in particular the latter), especially if associated with geological conditions susceptible to landsliding. Cuttings for residential subdivision access roads on the western flanks of Mt. Brown resulted in local failures occurring.

The above factors can typically cause a slope to reach its stability threshold. During intense rain storms, the groundwater levels can rise rapidly in these areas, as water from upslope that accumulates as infiltration is retarded by low permeability material beneath the talus. Therefore, slope failures in the region have historically been triggered by intense, prolonged rainfall; i.e. a slope can remain in a condition of limited stability until a rain event occurs.

Within landslide areas, remnant talus and colluvial deposits may be present on ridges. However the deeper deposits of talus and colluvium are found within the valleys as landslides are typically funnelled along depressions in the landscape. The colluvium and talus are frequently eroded within watercourses subsequent to failure. Delineation of landslide material is, therefore, complicated, often requiring site-specific assessment of geomorphological processes and ground investigation.

Runoff (Sheetwash), Rill and Gully Erosion

Erosion is related to vegetation cover, rainfall intensity, soil type and slope steepness and length. Runoff erosion, or sheetwash, occurs when unconfined flow over bare or sparsely vegetated ground strips the surface soil layers.

Gullies are narrow deep trenches, forming either along incised watercourses or as a result of erosion into previously intact ground. Upstream erosion of gully headcuts can cause expanding incised networks to form. Once initiated, the incised gully system sets up a positive feedback, whereby water gains energy when flowing over gully headcuts (the upstream limit of the gully), increasing erosivity and causing the headcut to retreat upstream. Therefore, prevention of gullying is considerably easier than its rehabilitation. Gullies have a natural course of evolution which, over decades, results in self-stabilisation (assuming no further disturbance).

Rills are similar to gullying, but at a smaller scale (rills are defined as minor trenches that can be ploughed out).

Landscape changes which can lead to increased erosion and gully formation are as follows:

- Destruction of protective surface vegetation, whether through bushfire or artificial clearance;
- Flow concentration, increasing the energy available for erosion, e.g. along tracks

These processes are exacerbated in sodic, dispersive, highly erodible texture contrast soils. The structure and chemical composition of this type of soil makes them susceptible to subsurface piping/tunnelling; and surface rill and gully erosion, particularly once the vegetation cover is removed. The likely spatial distribution of these processes is discussed further in Sections 3.5 and 4.6.

Watercourses

The watercourses of the study area have variable characteristics depending on the fluvial processes and surrounding landscape characteristics. Typically, the creeks can be sub-divided into 3 distinct reaches; the upper reaches associated with the very steep slopes of the Illawarra Escarpment; the middle reaches with an abrupt change in slope at the base of the escarpment; and the lower reaches within the low-lying coastal plains. The creeks have highly variable flow regimes: large floods can occur relatively frequently and are ‘flashy’ in nature (i.e. they rise and fall very rapidly). This strongly affects the channel morphology of watercourses in the study area, as follows:

- The steep, high energy, upper reaches of the watercourses in the study area are typically located on broad, coarse gravel to boulder lag deposits. These lag deposits are resistant to vertical erosion. As a result, bank erosion and lateral channel migration are common. Channels can avulse (i.e. completely change their course) during floods, if the channels become blocked with debris (e.g. trees). During the 1984 flood, some creek upper reaches cut new channels into bedrock where avulsions were triggered by debris-dammed bridges, such was the force of flow (Nanson and Hean, 1985).

- At the base of the escarpment, where there is an abrupt decline in slope, flooding can cause extreme channel changes, with appreciable deposition of coarse sediment and rapid lateral erosion.
- Along the upper and mid-reaches the watercourses have a multi-level trench (or macro channel) formed in response to variable discharge. A sinuous low-flow channel sits within a deeply incised high flow trench. This trench can typically accommodate a 1 in 100 year flood event (Nanson and Hean, 1985);
- Vegetation growth along the mid- to lower reaches can be rapid. Deep sediment can be deposited as floods decline and rapid elevation of the floodplain surface can occur, as stabilising vegetation is rapidly established (DIPNR, 2004; Reinfelds and Nanson, 2004).
- Along the lower reaches, channels are smaller, low sinuosity and typically do not migrate. The channels have aggraded with the post-glacial rise in sea level and sit above a narrow coarse sand and gravel column, flanked by finer flood deposits. The floodplain areas can have a dense, naturally compacted surface layer.
- Over the past 50-60 years, high magnitude flood events causing substantial damage to urban areas have occurred with a historical frequency of approximately 8 years (Reinfelds and Nanson, 2004). The most recent flood event occurred on 21 March 2011, with severe disruption to the Dapto area, damage to property and loss of life.

Wind Erosion

Wind erosion is not generally problematic within the study area, as the soils typically have a cohesive surface. In areas where silty or loam-rich topsoils, or sandy soils are present, removal of surface vegetation could result in wind erosion, in particular where project activities cause soil structure disturbance.

3.2.2 Physiography, Topography and Geomorphology

The Study Area landforms are strongly linked to the underlying geology, particularly rock type and geological structure, and geomorphological evolution of the area (see Figure 3.2).

The landscape within the study area is characterised by 2 different physiographic regions:

- Illawarra Escarpment – the eastern edge of the deeply dissected Hawkesbury Sandstone Woronora plateau;
- Coastal Plain – lying between the escarpment and the sea.

Illawarra Escarpment

Along the western limits of the GSG study area, Hawkesbury Sandstone forms a high-elevation plateau. The Illawarra Escarpment forms the eastern edge of the plateau, with Narrabeen Group and Illawarra Coal Measures cropping out along the escarpment face. The steep escarpment slopes are prone to rockfall and landslides. Episodic slope failure driven by gully erosion has caused westwards retreat of the near-vertical sandstone cliffline, forming distinct bowl-shaped valleys with a deep talus apron along the mid and lower slopes. The talus consists of rock blocks up to tens of metres across in a clay matrix. Downslope, the talus gives way to colluvium, which blankets the lower escarpment slopes.

Remnant bedrock ridges frame the valleys, extending near-perpendicularly to the escarpment, particularly in the southern section of the study area.

Watercourses rise on the upper slopes of the escarpment, falling steeply to the Coastal Plains below. These channels tend to be coarse-bedded and incised with high-energy environments. At the break of slope at the base of the escarpment, these gullies have deposited appreciable thicknesses of very coarse sediment.

Coastal Plain

The Coastal Plain has been formed by westwards retreat of the escarpment. The landforms of the eastern margins of the plain have been strongly affected by geologically recent fluctuations in sea level, which resulted in the formation of Lake Illawarra. Palaeo-estuarine deposits related to higher sea-levels may be found along the eastern sections of the study area. These deposits can form acid sulfate soils (discussed further in Section 3.2.5: Acid Sulfate Soils)

The low-relief plains are broken by higher-relief areas associated with more resistant geology. Remnant latite caps the steep-sided outlier hills and benches, such as Mt. Brown. The steep side-slopes of these hills are susceptible to landsliding. The Berry Siltstone and Budgong Sandstone formations form steeply undulating topography.

Watercourses running through the Coastal Plains generally have small, stable channels, which do not change appreciably in alignment or geometry over time. As a result, overbank flooding is common. The channels tend to sit atop a gravel column.

3.2.3 Soil Types and Characteristics within the Study Area

Soil characteristics are strongly related to parent material, formation process and relief (McDonald *et al*., 1990). Parent material in the study area includes the following:

- Felsic (Acidic), Intermediate and Mafic (Basic) Volcanic Rocks (typically latites);
- Sedimentary Rocks;
- Alluvium and Colluvium.

In addition, the undulating, occasionally rugged, relief has resulted in small pockets of variable soil types. A summary of soil types in relation to the various landscape components is included in Section 3.5: Landscape Mapping

Interpretation of the available data, combined with field observations of existing soil exposures, indicates that soils in the study area can be separated into 3 broad groups. These groups along with their typical characteristics, constraints and properties (interpreted from other proponent's reports) have been summarised below. The soils have been described according using descriptions from Hazelton (1992) and checked using field investigation information from HLA (2005). Terrain Units (TUs) refer to those mapped and described in Section 3.5.

Soil Type 1 – Texture Contrast Soils

Texture contrast soils are characterised by an abrupt boundary (a boundary depth of less than 50mm) between A and B soil horizons. Surface soils typically comprise sandy or loamy textures underlain by more heavily textured subsoils (typically clay). In general, these soils are relatively infertile and thus have limited rehabilitation potential. In the Study Area, texture contrast soils are typical on steep colluvial slopes and on mid- to lower slopes elsewhere. Other characteristics of this soil type are as follows:

- Moderately deep to deep soil profiles (>0.5m);
- Thinner upper horizons on steep slopes;
- Surface and subsurface soils are typically acidic (strongly acidic in TU Faulconbridge (fb)) and sodic within TUs Albion Park (ap) and Bombo (bo);
- Soils are prone to erosion and can be hardsetting;
- Found on concave slopes overlying the Berry Siltstone (TU ap); on lower slopes and drainage plains overlying Budgong Sandstone (TUs Shellharbour (sh), Wattamolla Road (wt)) and latite (TU bo); overlying talus deposits (TU Illawarra Escarpment (ie)), and on upper slopes overlying Illawarra Coal Measures (TU Gwynneville (gw)).

Soil Type 2 – Uniform and Gradational Loams and Clays

Soils in this group have a uniform or weakly gradational loamy to clayey texture. HLA found that soils in the study area were typically loam surface soils grading to clay at depth. Two subgroups within this soil type were identified within the study area based on their clay content.

2.1 Loams and Clay Loams

Uniform sandy clay loam profiles occur on latite ridge crests and upper slopes of the Berry Siltstone. Gradational sandy loams to sandy clay loams are found atop the Hawkesbury Sandstone plateau.

- Shallow to moderately deep soil profiles (TUs ap <0.3m; bo <0.5m ; fb <1m).
- Uniform soils generally consist of structured, friable sandy clay loams.
- Soils can be sodic and acidic (TU bo), or strongly acidic (TUs ap and fb), with variable fertility and erodibility.
- Found in TUs ap, bo, gw (on hilltops), ha and fb.

2.2 Clay Loams and Clays

This soil type typically occurs on latite slopes and benches (TUs bo, Cambewarra (ca), gw); and on gentle slopes overlying Budgong and Hawkesbury sandstone (TUs Hawkesbury (ha), ie and sh). Characteristics of this soil group are listed below:

- Variably deep soil profiles (TUs bo <1.2m; ca <2m ; gw <0.6m; ha <0.5m; ie <1.2m; sh>1m).
- Consists of gradational, sandy clay to clay loam (TU bo), sandy clay loam to light clay (TU gw) or sandy loam to clay profiles (TUs ca, ha, ie, sh).
- Soil materials can be strongly acidic (TUs bo, ha, ie and sh).
- Low to moderate fertility with an extreme erosion hazard for non-concentrated flows;
- Found in TUs bo, ca, gw, ha, ie, sh

Soil Type 3 – Sands and Sandy Loams

Soils within this group have been subdivided based on their parent material and process of formation.

3.1 Alluvial Sands and Loams

These deposits comprise alluvial and swampland deposits that typically occur on the low-lying, gently undulating coastal plain terraces extending below the Illawarra Escarpment (TU Fairy Meadow (fa)). Characteristics of this soil group are listed below:

- Moderately deep soil profile (<1m);
- Generally occur as loose deposits overlain by a thin layer of sandy loam;
- Low fertility and erodibility;
- Found in TU fa.

3.2 Residual Sands and Sandy Loams

Uniform sand deposits formed from the underlying quartzose sandstone bedrock extend across the ridge and plateau surfaces of the Woronora Plateau (TU fb) and Hawkesbury Sandstone crests and ridges (TU ha). Similarly uniform sandy loam deposits extend across the ridges and in localised positions on the mid- and lower slopes overlying the Illawarra coal measures and on Narrabeen Group ridge crests (TU Warragamba (wb)). Characteristics of this soil group are listed below:

- Shallow soil profile (fb <0.1m; ha <0.2m; gw & wb <0.5m).
- Loose-grained and permeable with some organic matter (fb, ha); or friable and moderately to strongly pedal with organic matter (gw & wb).
- Low fertility and strongly acidic (fb, ha, wb); or moderately fertile and approximately pH-neutral (gw);
- Low to moderate erodibility (although loose or friable, the structure, porosity and organic content reduce the erodibility);
- Found in TUs fb, gw, and ha.

3.2.4 Salinity

Available soils mapping (Hazelton, 1992) does not indicate a salinity problem within the study area, despite the fact that soils of the Coastal Plain are likely to be saline, given their process of formation, i.e. of estuarine or marine origin. HLA (2005) mapped highly saline soils near Horsley and in the Avondale Road area. Coffey has no archive record of salinity in the area, but this is not routinely tested in geotechnical investigations.

Saline soils are related to geology, vegetation coverage, catchment hydrology (in particular, groundwater flow) and terrain: contributing factors tend to be very catchment-specific (DLWC, 2002; Charman and Murphy, 2007). In general, salinity is related to the following:

- Rock weathering (especially of marine sedimentary rocks)

- Rising groundwater which can mobilise salts stored within the ground, e.g. vegetation clearance, can reduce evapotranspiration rates and cause groundwater rise (vegetation change can also cause a fall in groundwater levels). Response to vegetation change is site-specific: small changes in vegetation may have large effects in some catchments but minor effects in others;
- Wind-blown sources: salt or saline sands;
- Geomorphology and topography: groundwater, surface water and salts mobilised by this water tend to accumulate in low-lying areas.

Within the Study Area, salinity is likely to be associated with low-lying former and contemporary estuarine, coastal and marine areas in TUs fa and sh (although the latter is not documented). Visual indicators of salinity (e.g. vegetation die-off, surface salt crusting) were not observed during this assessment.

3.2.5 Acid Sulfate Soils

ASS occur naturally and contain iron sulfides which can oxidise on exposure to air, generating sulfuric acid. ASS typically occur in marine or estuarine sediments of recent geological age (Holocene), within soil horizons below 5m AHD. The presence of ASS within the study area was assessed using NSW Department of Land and Water Conservation (DLWC) ASS 1:25,000 Risk Maps (2008) (see Figure 3.3).

The majority of the study area has been mapped as ‘no known occurrence of ASS’. Some sections of the study area are mapped as being affected by ASS with varying degrees of environmental risk and are typically in the north east, central east and south east of the study area (Kembla Grange, Yallah, Koonawarra and Albion Park) (DLWC, 2008), i.e. associated with estuarine deposits.

Recent site observations in the study area have indicated that the risk of ASS could be greater than indicated by the available risk mapping (Carl Hapley, University of Wollongong, *pers. comm.* 16 February 2011). High pyrite concentrations in sandy point bar sequences were observed significantly further in land and at higher elevations than the mapping indicates (along Mullet Creek at William Beach Park, close to the Princes Highway, mapped as being at low risk of ASS). Pyrite concentrations are likely to be even higher in associated muddy deposits. These observations have yet to be investigated further.

3.2.6 Land Contamination

Land contamination within the Study Area is associated with past or present anthropogenic activities. Potential Areas of Environmental Concern (AEC) and associated potential Chemicals of Concern (COCs) are typically associated with landuses or activities associated with Local Council zoning. Coffey’s assessment has been based on available Wollongong and Shellharbour City Council Local Environment Plan (LEP) Zoning. In some cases, it appears that zones have been classified to allow for future landuse change, e.g. to the west and north of Horsley, areas zoned as “Residential” are known to be greenfield Rural sites at present. These areas are apparent from the cadastral layout: residential areas have been broken into small land parcels, whereas rural areas have not been subdivided to the same extent. Coffey has not attempted to reclassify Council zoning, as site-specific historic information is not available for all sites and the extent of zoning “future proofing” is not known.

Table 3.3 summarises potentially contaminating sources relating to landuses/zoning. Appendix A includes an expanded version of this table outlining typical descriptions and AECs. A map showing a summary of site zoning is shown in Figure 3.4.

Table 3.3 Summary of Potentially Contaminating Landuses/Activities and Potential COCs associated with Local Council Zoning

Potentially Contaminating Activity[1]	Zoning[2] Where Activity May Apply						Potentially Affected Media		Potential Chemicals of Concern[3]
	Rural	Residential	Industrial	Business	Special Purpose	Environment /Recreation	Soil	Groundwater	
A Building Materials	x	x	x	x	x	-	x	-	Lead, zinc, asbestos and OCP
B Fill	x	x	x	x	x	x	x	-	TPH, BTEX, PAH, OCP, OPP, PCB, heavy metals and asbestos
C Waste Disposal	x	-	x	-	x	x	x	x	TPH, BTEX, PAH, OCP, OPP, PCB, heavy metals, complex cyanides, ammonia, herbicides, fungicides, pathogens and asbestos. Combustibility issues at coal wash emplacement areas. Methane generation issues at landfill sites.
D Materials Storage	x	-	x	-	x	-	x	-	TPH, BTEX, PAH, OCP, PCB, heavy metals and asbestos
E Chemical Application	x	-	-	-	x	-	x	x	Heavy metals, OCP, OPP, herbicides and fungicides
F Septic	x	x	x	x	x	-	x	x	Typically nutrients and pathogens. May include TPH, BTEX, PAH, OCP, OPP, heavy metals etc. if wastes inappropriately disposed
G Fuels/Chemicals	x	x	x	x	x	-	x	x	Fuels – TPH, BTEX, PAH, VHC Others – OCP, Herbicides
H Livestock Treatment	x	-	-	-	-	-	x	-	OCP and arsenic

NOTES:

1. Potentially Contaminating Activities classed as follows:
    - A Potential weathering of hazardous building materials and demolition of former site structures
    - B Fill of unknown origin and quality
    - C Disposal of wastes
    - D Storage of miscellaneous materials & equipment
    - E Possible application of pesticides and/or other agricultural chemicals
    - F Potential leaks or seepage from septic tanks
    - G Use and storage of other fuels/chemicals
    - H Treatment of livestock with pesticides
2. Zoning based on 1990, 2009 and 2010 Wollongong City Council LEP Zoning and 2000 Shellharbour City Council LEP Zoning
3. TPH = Total Petroleum Hydrocarbons; BTEX = Benzene, Toluene, Ethylbenzene, Xylene; PAH = Polycyclic Aromatic Hydrocarbons; Heavy Metals = arsenic, cadmium, chromium, copper, lead, nickel, mercury, zinc; OCP = Organochlorine Pesticides; OPP = Organophosphate Pesticides; PCB = Polychlorinated Biphenyls; VHC = Volatile Halogenated Hydrocarbons

Coffey's review of relevant information has indicated that some specific potentially contaminating activities/landuses are in close proximity to the proposed pipeline alignments and are considered to be of relevance to the project. These are summarised in Table 3.4 (overleaf) and the AECs are shown in Figure 3.5. Rural landuse currently predominates across the Study Area; historically largely grazing with a low likelihood of contamination. However, there are areas where the historic activities are not known and contamination is possible.

Table 3.4 Summary of Specific Potentially Contaminating Landuses/Activities and Potential COCs within the Study Area

Potentially Contaminating Landuse/ Operation		Description	Location of Specific AECs (See Figure 3.5)	Potentially Contaminating Activities								Overall Likelihood of Contamination*
				A - Building Materials	B - Fill	C - Waste Disposal	D - Materials Storage	E - Chemical Appl.	F - Septic	G - Fuels/Chemicals	H - livestock Treatment	
1	Former piggery	Former piggery operated in rural portion of Kembla Grange. Site contains remnants of former infrastructure. Historical aerial photographs suggest infilling of former dam.	Central parts of 340 West Dapto Road, Kembla Grange (Lot 1 DP657171) where the piggery formerly operated.	x	x	x	x	x	x	x	-	High likelihood of contamination from former activities in specific areas of the site. Site noted as 'suspected contaminated land' on Wollongong Council planning certificate.
2	Market Garden	Market garden operates within Kembla Grange and has been observed to have greenhouses.	Eastern end of Darkes Road	x	x	x	-	-	-	x	-	Moderate to high likelihood of contamination from former activities in specific areas of the site.
3	Former Power Station	Former coal fired power station operations (includes former demolition and disposal of wastes containing asbestos). Former Tallawarra power station (now operated as a gas fired power station by TRUenergy).	Eastern end of Yallah Bay Road, Yallah.	x	x	x	x	-	-	x	-	Moderate to high likelihood of contamination from former activities in specific areas of the site. Site listed on DECCW website and noted as 'suspected contaminated land' on Wollongong Council planning certificate.
4	Existing and former Mine Operations	One operational and two former coal mines are known to be located within the study area.	Wongawilli Colliery (operational); Huntley (former) and Avondale (former). Land located in central western part of study area.	x	x	x	x	-	x	x	-	High likelihood of contamination. Sites noted as 'suspected contaminated land' on Wollongong Council planning certificate.
5	Emplacement areas	Mainly disposal of waste materials from coal mining and steelmaking (also includes other fill areas)	Wongawilli ; Huntley/ Avondale and Avon are coal wash emplacement areas associated with local coal mines and coal washeries. Large emplacement area (coal wash and steelmaking slag) located adjacent to West Dapto Road/Wyllie Road, Kembla Grange. Multiple fill stockpiles off West Dapto Road north of Horsley.			x						Moderate to High likelihood of contamination. Sites noted as 'suspected contaminated land' on Wollongong Council planning certificate.
6	Whytes Gully Landfill/ steel pipe manufacturing	Municipal landfill accepting household wastes. Issues include wastes/ leachate generation and range of other potentially contaminating activities, including fuel storage.	Land located off Reddalls Road, Kembla Grange	-	x	x	-	-	-	x	-	High likelihood of contamination within the landfill itself and operation areas. Moderate likelihood of contamination within steel manufacturing site. Lower likelihood of contamination in non operational areas. Groundwater and down-system impacts could be present. Site noted as 'suspected contaminated land' on Wollongong Council planning

	Potentially Contaminating Landuse/ Operation	**Description**	**Location of Specific AECs (See Figure 3.5)**	**Potentially Contaminating Activities**								**Overall Likelihood of Contamination***
				A - Building Materials	**B - Fill**	**C - Waste Disposal**	**D - Materials Storage**	**E - Chemical Appl.**	**F - Septic**	**G - Fuels/Chemicals**	**H - livestock Treatment**	
												certificate.
7	Golf Courses	Two golf courses operate within the study area and may have a history of e.g. fuel storage and chemical application.	Kembla Grange Golf Course and Calderwood Golf Course	x	x	-	x	x	-	x	-	Low to moderate likelihood of ground and groundwater contamination
8	Former Abattoirs	Former abattoirs – activities may include fuel storage and disposal of wastes and effluent	At least 2 (possibly 3) former abattoirs are noted to have been located in the Yallah area.	x	x	x	x	-	x	x	-	Moderate to high likelihood of contamination. Sites noted as 'suspected contaminated land' on Wollongong Council planning certificate.
9	Airport	Illawarra Airport within study area	Princes Highway, Albion Park	x	x	-	-	-	-	x	-	Moderate likelihood of contamination particularly near fuel storage areas.
10	Electrical Substations	-	A relatively large electrical substation is located off Yallah Road, Yallah. Smaller substations are likely located throughout the study area but have not all been specifically identified in this assessment.	-	-	-	-	-	-	x	-	Moderate likelihood of contamination from the storage on use of oils. Historical oils may contain PCBs.
11	Roads and Railway Lines		Roads are present across most of the study area. Rail lines comprise private and state rail networks.	-	x	x	-	-	-	-	-	Low to moderate likelihood of contamination. Rail lines can have impacted ballast materials from historical use of brake pads containing asbestos. Fuel spillages (particularly) on private lines may also have occurred. Some areas adjacent to rural roads can commonly be used for illegal dumping of wastes.
12	Petrol Stations		Petrol stations are in close proximity to proposed pipeline routes in Albion Park	x	x	-	-	-	-	x	-	High likelihood of contamination primarily from storage and use of fuels, oils and lubricants.

* This is not an assessment of financial risk associated with the AEC in the event contamination is detected, but a qualitative assessment of probability of contamination being detected at the potential AEC, based on the site history study and site observations.

3.3 Rainfall and Evaporation

The Illawarra Region prone to high intensity localised rainstorms and associated flash flooding (Nanson and Hean, 1985; Reinfelds and Nanson, 2004). The escarpment is a locus for frequent, high intensity rainfall events (Reinfelds and Nanson, 2004).

Table 3.4 (overleaf) lists the mean rainfall and pan evaporation recorded at Albion Park and the University of Wollongong respectively. Mean rainfall is approximately 1102mm. Mean monthly rainfall is highest from January to June and lowest in winter and spring. Evaporation also varies with the seasons and is highest in the spring and summer months (from October to February). Mean annual evaporation is 1278 mm, which exceeds mean annual rainfall.

Table 3.5: Mean Rainfall at Albion Park and Evaporation at University of Wollongong

	Rainfall (mm)	Pan Evaporation (mm)
Monthly		
January	103	152
February	124	120
March	126	105
April	101	84
May	96	71
June	106	63
July	71	74
August	67	90
September	61	108
October	78	127
November	85	129
December	80	158
Annual		
Mean	1102	1278

3.4 Hydrogeology

Based on local topography and geology, two main aquifer systems have been identified previously in the study area (Camp Scott Furphy, 1993; HLA, 2005). A shallow aquifer consists of unconsolidated sediments such as gravels, clays and sands within approximately 5m of the ground surface. Deeper aquifers are associated with rock fractures within the Budgong Sandstone or the underlying Berry Siltstone sandstones and siltstones. For the purposes of the current assessment, the shallow aquifer is of greater importance, as the proposed development includes excavations that will generally be shallower than 6m (see Section 1.2).

3.4.1 Groundwater Use

A survey of groundwater bores within the study area registered with the NSW Office of Water (NOW) was carried out as part of the current assessment. The search results indicated 139 bores registered for a variety of purposes, including domestic, stock, irrigation, industrial, recreation, groundwater monitoring and town water supply. The NOW work summary sheets are presented in Appendix B and a summary table of the data is presented in Appendix C. Registered bore locations are presented in Figure 3.6.

The majority of registered groundwater bores have been drilled to depths greater than 10m and are screened in the deeper rock aquifers. The bore registered for town water supply, GW075139, is located at Kembla Grange (the north eastern part of the study area) and was completed at a depth of 193m. A total of 22 bores are listed as being 10m or less, and are mainly registered for monitoring purposes.

3.4.2 Groundwater Levels and Flow

Groundwater levels in the study area are related to unconsolidated sediments and deeper underlying rock aquifers. In the unconsolidated sediments, shallow groundwater depths are likely in the low-lying areas adjacent to Lake Illawarra and in the vicinity of watercourses. Low lying areas less than 10mAHD are illustrated in Figure 3.7. High water tables are also likely to be associated with gravel deposits deposited by high elevation watercourses towards the west of the study area.

Based on previous Coffey investigations and registered bore data, groundwater levels in the low-lying alluvial/estuarine sediments generally range between 1m and 3m below ground level (bgl). Based on soil landscape characteristics (see Section 3.5: Landscape Mapping), seasonally high water tables are associated with the TUs fa and ap.

In elevated areas of the study area (away from watercourses), Coffey archive information has indicated that it is likely that groundwater will occur in fractures or extremely weathered seams within the Budgong Sandstone or the underlying Berry Siltstone sandstones and siltstones. Groundwater within the residual clay above the bedrock may be considered as an ephemeral perched groundwater system dependant on rainfall recharge, although most rainfall would run off due to the steep slopes and nature of the clay soils (which have low infiltration rates).

As discussed in Section 3.2.1 (Landslides), in areas of talus and landsliding (e.g. along the Illawarra Escarpment and the flanks of Mt. Brown), groundwater can be disrupted, with unpredictable groundwater levels that can rise rapidly during heavy rainfall events.

Groundwater flow in the study area is generally easterly, towards the various watercourses and Lake Illawarra.

3.4.3 Groundwater Quality

Available groundwater quality data was limited for the desktop review assessment. Based on available registered bore data, groundwater quality in the study area ranges from saline to fresh depending on proximity to Lake Illawarra and bore depth. The tidal limits of the various watercourses influence groundwater salinity; e.g. Duck Creek is tidal to approximately 2km inland from Lake Illawarra. Groundwater in this area is typically saline with a neutral pH.

Contaminated groundwater may be associated with the potentially contaminated areas identified in Section 3.2.6: Land Contamination.

3.4.4 Groundwater Dependent Ecosystems

Groundwater Dependent Ecosystems (GDEs) are defined as ecosystems whose current composition, structure and function are reliant on a supply of groundwater (Eamus, 2009). Limited information for GDEs in the study area was available for the current assessment. The Draft Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources identifies a potential GDE in the vicinity of Macquarie Rivulet (NSW Office of Water, 2010). The exact location of the GDE is not known, but is thought to be outside the potential impact area of project activities. Potential dependency on groundwater is likely for terrestrial vegetation types in the Study Area, including the SEPP 14 wetlands north of Macquarie Rivulet and in the vicinity of Lake Illawarra (again, outside the anticipated project influence). The estuarine alluvial wetlands are likely to be more dependent on tidal inundation of saline waters rather than groundwater dependency.

3.4.5 Hydrogeological Conceptual Model

Recharge

Groundwater recharge to the unconsolidated alluvial/estuarine aquifer can occur via the following processes:

- Direct rainfall infiltration;
- Runoff from the hills to the west reporting to the alluvial/estuarine aquifer; and
- Recharge from bedrock.

Groundwater flow in the study area is expected to be dominantly within the alluvial/estuarine aquifer. The upper layers of the underlying bedrock may provide minor groundwater recharge in dryer times but are expected to have lower overall permeability compared with the alluvial/estuarine aquifer.

Discharge

Discharge of groundwater from the alluvial/estuarine aquifer occurs via the following processes:

- Lateral flow to Lake Illawarra and other surface water bodies including Mullet Creek, Duck Creek, Marshall Mount Creek and drainage channels;
- Evapotranspiration by vegetation with sufficient root depth;
- Evaporation from ponded water;
- Leakage to bedrock.

The upper layers of the underlying bedrock may accept groundwater leakage from the alluvial/estuarine aquifer in wetter times and are expected to have lower overall permeability compared with the alluvial/estuarine aquifer.

3.5 Landscape Mapping

The NSW Soil Landscape mapping (Hazelton, 1992) provides an ideal summary of the different units within the study area. Although the terrain units are based on geomorphic formation process and geology, they also indicate areas which have the following broadly similar characteristics:

- Geology: bedrock outcropping and engineering properties.
- Landform: slope steepness, topography, geomorphological process.
- Soils: physical, chemical and engineering properties.
- Constraints: potential issues associated with the landscape which could affect the project, including Acid Sulfate Soils, erosion and slope instability.

For the purposes of the GSG assessment, Coffey has split the units according to physiographic region, then further subdivided by soil landscape unit, each with a unique set of potential constraints, impacts and issues, as shown in Table 3.5 and Figure 3.8.

Table 3.6 Summary of Soil Landscape Mapping Terrain Unit Characteristics

Soil Landscape	Code	GSG	Project	Landform	Geology	Soils	Constraints and Sensitivity to Impact
Coastal Plain[2]							
Depositional Landscape[2]							
Fairy Meadow	fa	✓	✓	Low-lying broad plains, valley flats and terraces below the Illawarra Escarpment	Budgong Sandstone	Alluvial loams and siliceous sands on terraces, gradational and poorly drained texture contrast soils on drainage plains	• Flooding • High permeability soils • High seasonal water tables • Low wet bearing strength • Low fertility
Wattamolla Road	wt	✓	✓	Undulating to rolling hills with long sideslopes and broad benches	Budgong Sandstone	Texture contrast	• Localised landslides • Localised flooding • Low wet bearing strength
Erosional Landscape							
Bombo	bo	✓		Low rolling hills with benches, platforms and coastal cliffs	Latite	Shallow uniform and gradational soils on crests and upper slopes; texture contrast soils on mid - lower slopes	• Shallow soils • Rock falls • Rock outcrops • Low wet strength
Shellharbour	sh	✓	✓	Low rolling hills with long sideslopes and broad drainage plains	Budgong Sandstone	Deep gradational soils on crests, upper slopes and mid-slopes, with texture contrast soils on lower slopes and drainage plains	• Localised water erosion • Localised shallow soils • Localised landslides • Highly expansive • Low permeability • Sodic subsoils • Low wet strength
Gwynneville	gw	✓	✓	Undulating to steep hills with rounded ridges, structural benches and occasional rock outcrops	Illawarra Coal Measures and Dapto Latite	Shallow, poorly drained gradational and texture contrast soils on upper slopes; shallow uniform soils on mid - lower slopes; areas of skeletal soils	• Highly erodible • Localised steep slopes • Landslides • Local flooding • Expansive/impermeable subsoils • Low wet bearing strength
Albion Park	ap	✓	✓	Sharply concave slopes with long gentle footslopes	Berry Siltstone	Texture contrast	• Waterlogging • Seasonally high watertable • High expansion
Illawarra Escarpment							
Colluvial Landscape							
Illawarra Escarpment	ie	✓	✓	Steep to very steep slopes	Quaternary Talus	Deep colluvial texture contrast soils with weakly developed uniform soils where talus is recent	• Widespread landslides • Rock falls • Steep slopes • Highly erodible • Reactive soils • Low to moderate fertility
Warragamba	wb	✓		Narrow convex crests and ridges with steep colluvial side slopes	Narrabeen Group	Weakly developed uniform soils on crests; gradational soils and ferrous texture contrast soils on upper slopes; poorly drained texture contrast soils on lower slopes	• Landslide-prone • Highly erodible • Steep slopes • Some rock outcrops

Soil Landscape	**Code**	**GSG**	**Project**	**Landform**	**Geology**	**Soils**	**Constraints and Sensitivity to Impact**
Colluvial Landscape (ctd.)							
Hawkesbury	ha	✓		Rolling to very steep hills, with narrow valleys and crests. Horizontal benches and broken scarps from rock outcropping. Boulders and cobbles cover up to 50% of surface	Hawkesbury Sandstone	Shallow skeletal soils on crests and ridges. Poorly drained gradational and texture contrast soils on sideslopes. Siliceous sands along valley flats. Ferrous or poorly drained gradational soils on shale outcrops	• Erodible • Landslides • Localised steep slopes • Rock outcrops • Shallow, stony • Highly permeable • Seasonal waterlogging • Low fertility
Residual Grounds							
Faulconbridge	fb	✓		Gently undulating crests and ridges	Hawkesbury Sandstone	Shallow sandy uniform and gradational soils with skeletal sandy soils associated with rock outcrops	• Shallow soils • High permeability soils • Low fertility • Rock outcrop
Erosional Landscapes							
Cambewarra	ca	✓		Steep to very steep hills with broad benches	Latite	Deep gradational or texture contrast soils on upper slopes and benches; skeletal soils on rocky outcrops	• Rock falls • Landslides • Water erosion • Shallow soils • Low wet strength
Other							
Water[3]	w	✓	✓				• Acid Sulfate Soils
Disturbed Terrain[4]	xx	✓	✓	Artificially disturbed to a depth of at least 1m	Various		• Uncontrolled fill • Landslides • Subsidence • Low fertility • Poor drainage • Incomplete mapping due to rapid change

1. No investigative fieldwork was carried out for this study. Soil classifications are based on the findings of the relevant, publicly available studies and field observations of soil exposures.
2. Definitions and Landscape Type are taken from Hazelton (1992).
3. Disturbed Terrain can be found throughout the study area and the exact extents are not well known.
4. “Water” refers to major waterbodies (i.e. lake Illawarra), rather than creeks, dams or groundwater

4 ENVIRONMENTAL CONSTRAINTS AND DESIGN CONSIDERATIONS

This section of the report assesses environmental constraints within the study area i.e. the impact of the environment on the project. It is anticipated that these constraints will be considered during the Design Phase of the project. The mapped Terrain Units (TUs) have been used to provide a general overview of the likely characteristics, constraints and likely impacts on the project activities. The variability of geology, soils and landforms within each TU means that constraints will not generally apply across the entire unit.

A constraints ranking was assigned to each unit, which indicated the severity and manageability of the constraint, as follows:

- Negligible (N)– Little or no constraint associated within the unit
- Low (L) – Slight constraint that can be overcome, or controlled with standard design/management practices or mitigation measures
- Moderate (M) – Substantial constraint that can be overcome or controlled with a combination of standard and special design/management practices or mitigation measures
- High (H) – Substantial constraint that requires special design/management practices to be overcome or controlled/mitigation measures
- Very High (VH) – Substantial constraint that cannot usually be overcome or controlled, even with special design/management practices or mitigation measures. These areas are generally classified as "No Go" areas.

A summary of the constraints identified within each TU is given in Table 4.1:

Table 4.1 Summary of Environmental Constraints within the Study Area

Code	GSG Study Area	Project Approvals Area	Terrain		Soils		Constructability		Rehabilitation (Low Fertility)	Shallow Groundwater
			Steep Slopes	Landslide or Rockfall	Erodibility	ASS	Trafficability	Foundations		
Coastal Plain										
Depositional Landscape										
fa	✓	✓	N	N	L	H	H	M	H	H
wt	✓	✓	H	M	M/H	N	H	M	L	N
Erosional Landscape										
bo	✓		H	M	M/H	N	M	M	M	N
sh	✓	✓	M	M	VH	N	M	M	M	N
gw	✓	✓	H	H	M	N	M	M/H	M	N
ap	✓	✓	M/H	N	M	N	H	M	L	M
Illawarra Escarpment										
Colluvial Landscape										
ie	✓	✓	VH	VH	L/M	N	M	H	M	N
wb	✓		VH	H	L/M	N	H	H	H	N
ha	✓		VH	H	L/M	N	M	H	VH	N
Residual Grounds										
fb	✓		N	N	L	N	L	L	VH	N
Erosional Landscape										
ca	✓		VH	H	L/M	N	M	M/H	M	N
Other										
w	✓	✓	-	-	-	H	-	-	-	
xx	✓	✓	-	-	-	-	-	-	-	

1. Units w and x are not ranked: w is water (i.e. Lake Illawarra) and does not fall within the scope of our study (other than ASS); xx is disturbed terrain and the extent and impact of alterations is unknown.

4.1 Steep Slope Constraints

Steep slopes are associated with the Illawarra Escarpment, remnant ridges and the sideslopes of outlying latite-capped hills (see Figure 4.1).

It is recommended that more detailed surveys of infrastructure routes and facility footprints be undertaken prior to their detailed design. Our topographic constraints ranking provides general guidance, with the degree of constraint as follows:

- Negligible – Average slopes <2°, localised slopes <5° – TU fa, fb
- Low – Average slopes between 2° and 5°, localised slopes <20°
- Moderate – Average slopes between 5° and 10°, Maximum slopes <25°, TU sh
- High – Average slopes over 10°, Maximum slopes >25° – TU ap, bo, gw and wt
- Very High – Average slopes over 20° – TU ca, ie, ha and wb

4.2 Landsliding and Slope Instability Constraints

Landslides and rockfalls within the study area are associated with the Illawarra Escarpment and steep slopes of outlying hills. As discussed in Section 3.1.3: Geotechnical Rock and Soil Properties, the talus extent on published geological maps does not indicate the true extent of landslide material, which blankets the mid and lower slopes of the Illawarra Escarpment.

Landslides have historically been triggered by prolonged or intense rainfall, and can be associated with inappropriately designed or managed earthworks. Site-specific assessments are recommended prior to final design and construction, particularly in areas with steep slopes and geological conditions conducive to landsliding, especially where sidelong ground issues (i.e. where the pipelines run across, rather than perpendicular to slopes) could result in pipeline damage or rupture. General guidance to the susceptibility of the TUs to landsliding, based on Hazelton (1992), is as follows (see Figure 4.2):

- Negligible –TU fa, ap and fb
- Moderate – TU bo, sh and wt
- High – TU ca, gw, ha and wb
- Very High –TU ie

Coffey has not attempted to provide more detailed landslide assessment, as this would require extensive mapping and modelling. The Australian Landslide Database (Geoscience Australia) has recorded some, but not all, of the known landslides in the locality. However, mapped locations of these recorded landslides do not appear to be at the actual location of the failure in some cases.

4.3 Faults and Seismic Hazard Constraints

Fault creation or reactivation is not considered to represent a significant problem in the Study Area.

Sydney Water is investigating the earthquake hazard of the region. However, publically available information indicates that the region is subject to low to medium-magnitude earthquakes. Since 1995, 21 earthquakes have occurred in and around the Study Area (Geoscience Australia, 2011). These earthquakes display a fairly even spatial distribution, ranging in magnitude (M) from 0.7M to 3.9M. The 3.9M earthquake occurred approximately 1km southwest of Avondale in February 2002 and has been classified as “significant” (i.e. with a magnitude of 3.5 or greater (Geoscience Australia, 2011)). Several other “significant” earthquakes have occurred within the broader area surrounding the Study Area, most notably:

- 2 earthquakes occurred approximately 22km west of Albion Park near Kangaloon (5.8M, May 1961) and Burrawang (4.8M, July 1968).
- An earthquake with a magnitude of 5.5 occurred in March 1973 approximately 60km north-west of Wollongong CBD at the southern end of Lake Burragorang.
- 2 earthquakes occurred approximately 20km north of Wollongong near Lake Cataract in March 1999 (4.8M) and November 1981 (4.6M).
- 5.7M and 5.3M earthquakes occurred in Newcastle (approximately 185 km northeast of Wollongong and in a similar environmental setting to the Study Area) in December 1989 and August 1994 respectively.

These records indicate that earthquakes large enough to damage project components could affect the Study Area. It is, therefore, recommended that pipelines and associated infrastructure are engineered to withstand future seismic activity.

4.4 Watercourse Constraints

The watercourses within the study area have several characteristics which may pose a problem to the project, as follows:

- Watercourses are generally incised between 1m (along the lower reaches) and 6m (along mid and upper reaches);
- Upper and mid-reaches have dynamic channels, prone to lateral erosion and avulsion. Banks can retreat by several metres at a time during flood events, generally along the outer bank of meander bends. This propensity for channel migration should not be underestimated during design.
- Lower reaches are prone to frequent overbank flooding.
- Palaeochannels (i.e. infilled former channels, often cutoff meanders (oxbow lakes)) are frequent throughout the study area, in particular within the low-lying areas of the Coastal Plains. The infill sediments may be appreciably different from the surrounding soils and resistant coarse material may be present.
- Silty clay alluvial deposits, in particular levee sequences, can be friable and erodible. These sediments may be associated with contemporary creeks or abandoned palaeochannels. The surficial layers of levee deposits can be naturally compacted, through weathering and settlement of the fine material.
- Flash flooding can occur in response to the intense rain storms typical of the Illawarra Region. During these events, very sudden, rapid rises in creek water levels occur, with dangerously fast flow velocities. Flooding of this nature could pose a danger to workers and cause damage to equipment, as well as affecting project progress.

Watercourse constraints occur throughout the study area and site-specific mapping has not been carried out.

4.5 Salinity Constraints

Salinity refers to the concentration of soluble salts in the soil water. The main salt involved in salinity is sodium chloride, but sulfates, carbonate and magnesium salts can also occur in some soils. Salinity can adversely affect plant growth and/or land use. At high concentrations, soil salinity can increase the potential for corrosion of buried steel and/or concrete.

There was insufficient information in the available information to be able to categorise specific areas according to their salinity hazard (including data from groundwater records, which is considered unreliable). Saline soils are likely to be associated with low-lying former and contemporary estuarine, coastal and marine areas in TUs fa and sh (see Section 3.2.4: Salinity. Coffey found no records of salinity problems in the Study Area (see Section 3.2.4: Salinity). However, saline soils have been observed in the study area (near Horsley and in the Avondale Road area (HLA, 2005)) and, particularly given the proximity of saline Illawarra Lake, it is anticipated that salinity problems could occur in estuarine deposits (which are similar in extent to ASS, see Section 3.2.5: Acid Sulfate Soils).

Salinity can have the following effects on the project:

- Salt-affected soil retards plant growth, reducing vegetation cover and, in extreme, cases can cause land to be completely unproductive. This may affect rehabilitation attempts of saline soils.
- Saline land can be susceptible to wind and water erosion, if vegetation cover is reduced.
- Soils with high salinity as a result of sodium chloride (i.e. soil sodicity) have a tendency to disperse in water due to weak sodium bonds between clay particles. This increases the risk of subsurface erosion.
- Saline soils can cause corrosion of footings and other susceptible surface infrastructure.

4.6 Erodibility and Erosion Hazard Constraints

4.6.1 Soil Erodibility Constraints

The erodibility of a material indicates its potential to erode. This is related to the soil/rock physical/chemical properties (particularly the exchangeable sodium content), as discussed in Section 3.2.3: Soil Types and Characteristics. The highest erodibility soils in the Study Area are clay-rich sodic texture contrast soils and friable silty alluvial soils. The lowest erodibility soils tend to be granular with a high organic content (which binds the soil)

The constraints ranking for erodibility is based on the natural soil properties (i.e. without natural or artificial modification), as follows (see Figure 4.3):

- Low – TUs fa, fb and sandy or well-structured clay soils of TUs ca, ha, ie, wb
- Moderate – TUs ap, gw and areas of TUs bo, ca, ha, ie, wb, wt
- High – friable and/or sodic clays and sandy clay loam soils of TUs bo, wt
- Very High – friable, sodic sandy loam soils of TU sh and friable alluvial soils associated with creeks (indicated on Figure 4.3 using the designated riparian corridor (where available), as the extent of these soils has not been mapped).

4.6.2 Soil Susceptibility to Water Erosion: Erosion Hazard Constraints

The properties of a soil determine its erodibility, but this can be significantly affected by landform, vegetation and artificial influences. Erosion hazard can be affected by the following factors:

- Slope steepness and length: low erodibility soils on shallow slopes may become highly erodible on steep, long slopes, where runoff has the opportunity to accelerate and increase erosive power. Conversely, high erodibility soils on shallow hilltops can have a low erosion hazard.
- High energy landforms, such as creeks, can cause erosion even in low erodibility soils. Soil erodibility affects the rate of bank failure and likelihood of associated gullying: erodible soils have a greater potential to erode rapidly and form tributary gully networks, whereas erosion is more likely to be confined to the creek channel in low erodibility soils.
- Removal of protective vegetation coverage.
- Anthropogenic change artificially causing any of the above (increase in slope, creation of high energy landform or removal of vegetation). For example, earthworks creating steep, bare cuttings may be prone to erosion. Likewise, pipeline trenches are analogous to incised creek channels, with steep erosion-prone “banks”, even in low erodibility soils.
- Intense rainfall has a high erosive power and can thus cause erosion on low erodibility soils, especially when associated with other factors such as steep slopes and low vegetation coverage.

Taking these factors into consideration, a general constraints ranking for erosion hazard is as follows:

- Low – TUs fa, fb
- Moderate – TUs ap, bo and areas of TU wt
- High – TUs ca, ha, sh, and areas of TU wt
- Very High – TUs gw, ie, wb

However, since local influences (e.g. creeks and artificial alteration) can have a significant impact on the erosion hazard, this has not been mapped.

4.7 Acid Sulfate Soil Constraints

Areas where pipelines are within or in close proximity to areas mapped as having a probability of encountering ASS could require appropriate assessment and management. However, mapped ASS is limited to eastern sections of the study area. ASS, if disturbed, can produce aggressive soil conditions which may be detrimental to concrete and steel components of structures, foundations, pipelines and other engineering works. Appropriate selection and design of materials need to be considered in these areas.

In the majority of the study area where ASS has been mapped, ASS may not actually be encountered due to the relatively shallow depth of proposed excavation. Most areas mapped as ‘low probability’ of ASS occurrence fall in areas where ASS would be greater than 3m below the ground surface. Wastewater pumping stations would have a higher risk of encountering ASS in these areas.

4.8 Land Contamination Constraints

Several potentially contaminating activities have been identified from assessment of the current Land Use Zoning Maps. For a project of this nature, land contamination could affect the project by, e.g. causing delays due to unexpected finds and disposal costs of contaminated spoil. Assessment during the Design phase of the project (typically including site-specific historical assessment, and intrusive sampling and testing to the intended depth of soil disturbance) can limit these constraints. Coffey believes that the majority of the pipeline alignment crosses land that is not owned by Sydney Water. Therefore, Sydney Water should only have responsibility for the management or cleanup of any contaminated land directly affected by the proposed works.

4.9 Groundwater Constraints

Groundwater within the study area may pose a problem to the project during construction, as follows:

- Shallow groundwater is likely to be associated with low-lying areas of the Coastal Plains; in the vicinity of both low-lying and higher elevation watercourses; and within talus (where the water table can be unpredictable). Excavations for pipeline and wastewater pumping stations should consider the potential for high water tables.
- Permeable layers may be encountered throughout the study area, including deeper sediments associated with watercourses such as Mullet Creek. For example, sand layers in the vicinity of Robins Creek (a tributary of Mullet Creek) in Horsley may result in high groundwater inflows for the wastewater pipeline excavations in this area.
- Palaeochannels are frequent throughout the study area, in particular within the low-lying areas of the Coastal Plains. The infill sediments may be appreciably different from the surrounding soils and more permeable coarse material may be present, resulting in high groundwater inflows during trenching or excavations.
- Temporary dewatering licences may be required by the NSW Office of Water (NOW) for any excavations which intercept groundwater (e.g. wastewater pumping stations and deep wastewater pipelines). Consultation with NOW is recommended for activities which could cause dewatering. The *Water Act 1912* is the current relevant legislation for the dewatering licence. However, under the new Draft Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources (NOW, 2010) the *Water Management Act 2000* will be effective after 1 July 2011. Further details of temporary dewatering licence requirements are discussed in Section 6.1.8.
- Excavations adjacent to Lake Illawarra may result in greater groundwater inflows and should take into account saline conditions. Excavations within 250m of Lake Illawarra foreshore may require an assessment of the potential for salt water intrusion to occur as a result of dewatering as part of the temporary dewatering licence. Consideration should be given to relocating the wastewater pump station off Yallah Bay Road to at least a distance of 250m from Lake Illawarra.
- Consideration should be given to the potential for encountering contaminated groundwater from potentially contaminated areas (see Section 4.9: Groundwater).
- The proposed pipeline alignments appear to coincide with registered bore locations in some areas, for example in Albion Park (GW072794 and GW107819; see Figure 3.5). Should

existing bores be identified along the proposed pipeline route, it is recommended that appropriate measures are taken to notify bore owners, confirm that the bore is no longer in use or alter the pipeline route.

Groundwater constraints occur throughout the study area and site-specific data collection and analysis is considered impractical at this stage of the project.

4.10 Trafficability Constraints

Trafficability problems in the study area (other than traversing steep or rugged slopes) can be caused by soft soils or waterlogging. Waterlogging is a seasonal problem in lower permeability soils (e.g. associated with TUs ap and ha) and a permanent problem in some low-lying areas (e.g. TU fa). Sodic or clay soils can become very soft and slick when wet, particularly for rubber-tyred vehicles.

The constraints rankings for the TUs reflect the anticipated worst-case conditions following prolonged or intense rainfall, as follows (see Figure 4.4):

- Low – Shallow, dense, gravelly soils – TU fb
- Moderate – Moderate to deep uniform or gradational soils which are less prone to waterlogging – TUs bo, ca, gw, ha, ie, sh
- High – Moderate to deep texture contrast soils which are prone to waterlogging, or deep waterlogged mud – TUs ap, fa, wb, wt

4.11 Foundation Constraints

Foundation-related constraints are likely to include:

- Soft soils and groundwater inflows in low-lying areas;
- Reactive clays;
- High strength rock, particularly where depth to rock is variable on the Coastal Plains (from an excavatability point of view);
- Potential for differential settlement on low-lying floodplains.

It is recommended that, prior to detailed design of project activities, detailed geotechnical ground investigations are carried out to assess site-specific foundation conditions.

The constraints ranking is based on the occurrence of the above constraints (see Figure 4.5). TUs with steep, rugged terrain (e.g. TUs steep gw and ca slopes, ha, ie, wb) have been given a high foundations constraint ranking due to the unsuitability of the landscape for building construction (Hazelton, 1992), as well as the soil properties.

- Low – TUs fb
- Moderate – TUs ca and gw (on shallower slopes), ap, bo, fa, sh, wt
- High – TUs ca and gw (on steeper slopes), ie, ha, wb

4.12 Trenchability and Trench Stability Constraints

Trenchability is generally inversely related to trench stability, and related to the underlying geotechnical ground characteristics – i.e. high strength rock can be difficult to excavate, but can sustain a steep trench batter. Trenchability constraints will generally be more applicable to wastewater pipelines. As wastewater pipelines require deeper burial than water pipelines, there is a greater chance of encountering rock, and the constraint is likely to be appreciably higher. For this reason, Coffey has not provided a trenchability ranking, as units that may be a negligible or low constraint ranking for water pipelines may be a high or very high ranking for wastewater pipelines.

In the study area, trenchability and trench stability constraints are as follows:

- In low-lying areas, in particular close to Lake Illawarra (east of the Princes Highway), soils and low strength rock may experience trench stability problems, particularly in areas of high groundwater.
- Landslides have created a talus and colluvium apron along much of the Illawarra Escarpment. The coarse deposits (ranging from gravel to very large boulders) may prove difficult to excavate or drill through.
- Upper and middle reaches of watercourses may have deposited a thick coarse (gravel to boulder) layer, which can extend several metres below ground level. Lower reaches sit atop a gravel column. This deep, coarse layer may be problematic for trenching or directional drilling;
- Budgong Sandstone tends to become progressively stronger with depth: excavator refusal is typically at between 1m and 2m depth in areas with a residual profile. Therefore, the trenchability constraint for water pipelines will be lower for water pipeline construction than for wastewater pipelines.
- Latites can weather to form large slab corestones, boulders and cobbles within a clayey silt matrix in the upper zones (<2m) of the weathered latite. These rock slabs are typically very high strength and may require a >20 tonne excavator to break up by hammering or remove. Difficult trenching should be anticipated, with rugged trench edges likely in these materials. The latite outcrops tend to be limited to hilltops and it is anticipated that only limited sections of the pipeline will intersect the latite.

4.13 Rehabilitation Success

Soils within the study area have different fertility, which will affect their potential for rehabilitation success. The constraints ranking is based on information provided in Hazelton (1992), as follows (see Figure 4.6):

- Low – Moderate to high fertility – TUs ap, wt
- Moderate – Moderate fertility – TUs bo, ca, gw, ie, sh
- High – Low fertility – TUs fa, wb
- Very High – Very low fertility – TUs ha, fb

4.14 Site-Specific Recommendations

Coffey has assessed the proposed pipeline and project component locations within the context of the above constraints and the uncertainties surrounding the proposed design (see Figure 4.7). It is recommended that the following issues are considered:

- Many pipelines, in particular wastewater pipelines, run close to or cross creeks and are likely to encounter constraints specific to these high-energy, dynamic landforms. The majority of creek crossings were not assessed in detail during this study, as there are a large number of crossings proposed. Those that were assessed supported our general observation that creeks in the area are characterised by erodible, friable silt-rich bank sediments. Creek reaches which are prone to movement (indicated by e.g. numerous abandoned meander scars), or which have particularly wide trenches are likely to require specific design measures, e.g. along Mullet Creek between Avondale and Brownsville (very high constraint areas are indicated on Figure 4.7). It is recommended that site-specific assessments are carried out where project components cross or run adjacent to creeks. Further site-specific issues are as follows:
    - A section of the wastewater pipeline runs close to a tributary of Mullet Creek and apparently beneath an area of fill (probably uncontrolled) to the northwest of the Avondale Road/Huntley Road intersection. Realignment is recommended.
    - A section of the wastewater pipeline between Larkins Road and the Princes Highway appears to run through 2 dams. Realignment is recommended.
    - A section of the wastewater pipeline close to the Whytes Gully Landfill site appears to run through a settlement pond.
    - Sections of the water and wastewater pipeline are aligned close to potentially eroding outer banks of meander bends in the Sheaffes/Wongawilli area (northwest of West Dapto Road). Realignment is recommended.
- Project components should be positioned on ridge crests, which are likely to have fewer constraints (steep slopes, landslides, foundation conditions). For example, the Avondale reservoir appears to be located on the side of a steep hill, with a ridgeline just to the north. It is recommended that site-specific assessments are carried out to assess landslide and erosion risk in these areas and project components are re-located if practicable.
- The westernmost wastewater pumping station (SPS09CS) and the associated pipeline (rising main and gravity) are located in an area with steep slopes which are prone to instability (at the head of the Calderwood Valley/Macquarie Pass). The pipeline route crosses several incised watercourses. Similar conditions are found along several high elevation pipeline sections (see Figure 4.7). Alternative alignments should be considered, particularly for the westernmost pumping station and pipeline alignment. Should this not be possible, it is recommended that site specific assessments are carried out to assess landslide and erosion risk.
- Short sections of wastewater pipeline and adjacent water pipeline may intersect talus at the foot of Mt. Kembla. This area may be prone to instability.
- Sections of the proposed wastewater pipeline run through the Wongawilli and Avondale Mine Emplacement Area. Sections of wastewater and water pipeline run through fill associated with the Tallawarra Coal Fired Power Station (ashponds and uncontrolled fill) (see Figure 3.1 and 4.7). This has potential contamination, subsidence/fill settlement and slope stability issues.

- The proposed pipeline alignments appear to coincide with registered bore locations, e.g. in GW072794 and GW107819, Albion Park (see Figure 3.5). It is recommended that appropriate measures are taken to notify bore owners, confirm that the bore is no longer in use or alter the pipeline route.
- Relocation of the wastewater pumping station off Yallah Bay Road (TWLN009) such that it is further than 250m away from the Lake Illawarra shoreline, to reduce saline intrusion and remove the requirement for assessment as part of the temporary dewatering licence.
- Appropriate dewatering measures will include meeting environmental standards for groundwater disposal options. Consultation with the NOW prior to commencement of dewatering activities is recommended.
- Saline soils may pose a problem in low-lying areas adjacent to Lake Illawarra. The occurrence of saline soils is poorly documented, but is known to occur north of Horsley.
- Proposed pipeline locations that fall within areas mapped to have a probability of encountering ASS (as mapped by DLWC, 2008) are as follows (see Figure 4.7):

High Probability	Wastewater rising main (SPS1TWL) adjacent to Lake Illawarra near Lakeside Drive, Koonawarra
	Water pipeline off Yallah Bay Road, Yallah
	Wastewater pumping station (SPS02CS) and pipelines off Calderwood Road, Albion Park
Low Probability	Wastewater pumping station (TWLN009) off Yallah Bay Road, Yallah
	Water and wastewater pipelines in areas of Albion Park
	Wastewater pipelines in areas of Kembla Grange
	Wastewater pumping station (SPS08CS) and pipelines off the Illawarra Highway, Albion Park

The above list indicates those sites that may pose a significant constraint during the project (particularly during construction phase). However, Coffey's assessment of site-specific constraints was not exhaustive, and other, similar, sites may be found. Detailed assessments for each constraint-type are recommended.

5 RISK ASSESSMENT

This section of the report assesses the potential impact of the project on the environment and the consequent risk that the project poses to the landscape. It is expected that the design phase would have a low impact, as activities (e.g. feasibility studies) are limited to ground and field-based investigations and assessments. The greatest impacts are likely to occur during the construction phase, when the disturbance footprint is the largest. Following construction, partial rehabilitation of sites will reduce impact during the operations and maintenance phases of the project.

The impact that a project activity has on the environment (i.e. geology, soils and groundwater) is related to the susceptibility (i.e. sensitivity) to change of the landscape element. This is related to the associated environmental constraints (see Section 4: Environmental Constraints and Design Considerations). Many environmental constraints associated with the project activities will occur throughout the study area and for the lifetime of the project. Therefore, they should be a constant consideration.

Project components include:

- Pipelines;
- Temporary pipe laydown and staging areas (including directional drilling pads);
- Pumping Stations;
- Reservoirs;
- Access Roads and Tracks.

The construction, operation/maintenance and rehabilitation/decommissioning of project components requires specific project activities (see Section 1.2). Many project activities have similar impacts, since they can involve similar tasks. For example, most construction activities involve ground disturbance. These types of impacts have been termed as generic impacts. The distinguishing factors in assessing impact in these cases are generally the spatial and temporal extent of disturbance; and the sensitivity of the landscape to change. Temporary laydown areas disturbed during pipeline construction will impact the environment significantly less than larger, permanent pumping stations. Invasive activities, such as earthworks, will have a semi-permanent impact on the landscape.

In addition to the generic impacts, there are also likely to be activity-based impacts. These will occur when a specific activity related to an activity is undertaken, e.g. pipeline trenching. The impact of these activities is only related to these specific activities.

5.1 Generic Environmental Impacts – Land Degradation

Any project activity which causes ground disturbance will have the potential to cause land degradation. Project-wide potential impacts are, therefore, largely associated with ground disturbance leading to land degradation. Ground disturbance can cause the following land degradation impacts:

5.1.1 Erosion

Erosion is a geomorphological process. Erosion processes within the study area can be divided into: surface (river, runoff/sheetwash, rilling and gullying), subsurface (piping/tunnelling) and wind (see Section 3.2.1: Landform Features). Any project activity which involves ground disturbance and/or vegetation removal has the potential to trigger or exacerbate erosion. Eroded material can be redeposited downslope, downstream or down-wind. Both erosion and sedimentation can have a negative impact on project assets. The impact of an activity will be controlled by a combination of the erodibility of the affected materials, as well as the actual process of erosion.

During flood events, overbank flows are common along the lower reaches of watercourses. If these flows are concentrated, e.g. through culverts, or along surface depressions or access tracks, velocities and water volumes will increase, thereby increasing the likelihood of erosion. Once initiated, rills and gullies promote flow concentration and are difficult to remediate successfully. Sections 5.1.2 – 5.1.4 discuss project activities which may exacerbate erosion or increase erosion rates.

5.1.2 Introduction of Preferential Pathways for Water Flow

Project activities which create surface depressions could form preferential paths for runoff, e.g. wheel rutting of access tracks, poorly compacted pipeline routes and foundation pads. This is particularly problematic on slopes which cause acceleration of runoff. Uncontrolled concentration of flow can cause erosion, or flows away from dams and water collection points. Flash flooding during construction could cause erosion associated with e.g. as-yet unprotected excavations.

5.1.3 Reduced Vegetation Coverage

The erosion potential of project sites may be increased as a result of vegetation clearing. Where vegetation coverage is less than about 70%, the risk of erosion is anticipated to increase appreciably (DPI, 2011). Vegetation removal is likely to have the following effect:

- Removal of surface coverage: reducing protection from rainsplash erosion and leading to an increase in surface flow velocities and erosivity;
- Removal of root structures, which generally stabilise the ground and near-surface soils.

Soil loss from bare areas can be an order of magnitude greater than from mulched or vegetated areas.

5.1.4 Soil Compaction

Project activities that subject the ground to loading (e.g. access tracks, lay-down areas, pumping stations and reservoirs) can cause soil compaction. Once compacted, it can be difficult to return the material to its original compactive state.

At the other end of the scale, uncompacted material is also prone to erosion, e.g. new spoil heaps which have not settled to an equilibrium consolidation state.

Sections 5.1.1 – 5.1.4 often occur in combination. For example, loose, bare materials are particularly prone to erosion. Often, rills are initiated on bare surfaces, such as new spoil heaps. This concentrates surface runoff, increasing the likelihood of further erosion and gullying.

5.1.5 Dust

Dust can be generated when surface soils lose cohesion due to surface disturbance in dry conditions. Project activities including topsoil stripping, vehicle traffic, pipeline trenching and earthworks (see Section 6.1.2: Land Degradation) are likely to cause dust generation. Once soil loses structure and turns to dust, it is difficult to manage and is generally unsuitable for use in rehabilitation.

Soils with a fine silty surface are most prone to dust generation, in particular texture contrast soils with a loam-rich surface layer.

5.1.6 Fragile and Unfavourable soils

Soils within the study area have been identified as being potentially:

- Friable and erodible;
- Reactive;
- Sodic;
- Saline;
- Acid sulfate or potential acid sulfate soils.

Disturbance of these soils is likely to exacerbate these unfavourable properties and may hinder rehabilitation.

5.1.7 Reduced Soil Quality

There are several activities which can cause a reduction in soil quality (other than those mentioned in Sections 5.1.4 – 5.1.6):

- Inversion of the soil profile and backfill materials during reinstatement can cause patchy exposure of sodic, saline or contrasting sub-soils, leading to increased erodibility and irregular vegetation growth. This is particularly the case along watercourses and their floodplains, which can have high spatial variability in soil character.
- Some areas of the project development area will require construction materials to be imported, e.g. road base. This material is considered poor quality material for plant growth, and will require particular attention during rehabilitation.

5.1.8 Increased Sedimentation

Once eroded, sediment is transported downslope/downstream, usually within watercourses, and deposited when flow velocities decrease (APIA, 2009). In these areas, sedimentation may cause burial of vegetation, and reduce revegetation success. This is more likely within the low-lying areas of the Coastal Plains (TU fa) and at the base of the Illawarra Escarpment. The ultimate downstream sediment sink for sediment eroded from the study area is likely to be Lake Illawarra.

5.1.9 Acid Sulfate Soils

Disturbance or poorly managed construction practices and use of acid sulfate soils can generate sulfuric acid, which can lower soil and water pH and produce acid salts, resulting in high salinity. The low pH, high salinity soils can reduce or altogether preclude vegetation growth.

If not appropriately managed, ASS disturbed during construction activities could have adverse impacts on the environment, particularly downstream of the disturbed area if acidic runoff is generated. Generation of the acid conditions often releases aluminium, iron and other naturally occurring elements from the otherwise stable soil matrices. High concentrations of some such elements, coupled with low pH and alterations to salinity can be detrimental to aquatic life. In severe cases, affected waters flowing off-site can have a detrimental effect on aquatic ecosystems.

5.1.10 Land Contamination

Contaminated soil or groundwater that is disturbed through construction works could have an adverse impact on the environment if not appropriately managed. Of particular concern are activities which may cause contaminated soils to be spread to adjacent areas; or eroded, then transported downslope or carried into and along waterways. Contaminated groundwater can also be intersected through dewatering works and be dispersed onto nearby areas or make its way into receiving waters.

Environmental incidents may occur during construction (or post-construction) works, associated with contaminant leakage. Leaks are typically associated with vehicles, e.g. a hydraulic hose on an excavator may burst resulting in release of several tens of litres of oil to the surrounding area. Should the contaminant release occur adjacent to a watercourse, then the impact could extend beyond the immediate area.

5.1.11 Reduction in Groundwater Levels and Groundwater Quality

Excavations during construction of reservoirs, wastewater pumping stations and pipelines could have a short-term impact on the groundwater system, if groundwater is intercepted. If trenches are excavated through potentially contaminated areas or ASS, the groundwater quality could be adversely impacted due to mobilisation of groundwater contaminants or acidic water.

Groundwater levels can be altered by decreases in groundwater recharge due to an increase in impermeable surfaces and decreases in evapotranspiration rates due to clearing of vegetation. Based on the small footprint of permanent infrastructure such as reservoirs and pump stations, changes to recharge and evapotranspiration rates are expected to be low and should not impact the shallow aquifer system in the long-term.

5.2 Potential Impacts of Pipelines

Project activities specific to the construction of pipelines may result in impacts not covered in the above generic or construction impacts. Pipeline-specific activities include:

- Route preparation (vegetation clearance, earthworks etc.)
- Trenching;
- Use of temporary laydown areas.
- Reinstatement (backfilling, rehabilitation);

The following impacts should be considered in relation to pipelines:

5.2.1 Trenching-Induced Landslides

If trenches are not suitably designed and engineered, landslides may be triggered in susceptible areas, i.e. slopes generally steeper than 10°, particularly where talus is present, with an awareness that landslides can be triggered on lower angled slopes following slope-destabilising artificial alteration. In these areas, site-specific landslide assessments are recommended, particularly where the pipeline traverses sideslope areas.

5.2.2 Differential Settlement of Backfill and Padding

It is likely that backfilled and filled areas will not be returned to original soil density levels. Differential settlement of fill could cause depressions or mounds to form which could potentially lead to drainage concentration and gullying or waterlogging.

5.2.3 Activation of Preferential Pathways in Subsoil

Burying a pipeline in subsoil may create a preferential pathway for subsurface flow. Water which accumulates and flows alongside the buried pipeline pathway may result in piping (tunnelling) erosion. Collapse of the subsurface void may lead to pipeline exposure. There is a greater possibility of this occurring in sodic and dispersive soils. In the study area, sodic soils are associated with Soil Type 1 Texture Contrast Soils, which are found on concave slopes overlying the Berry Siltstone (ap); on lower slopes and drainage plains overlying Budgong Sandstone (sh, wt) and latite (bo); and Soil Type 2.1 Loams and Clay Loams, associated with TU bo.

5.2.4 Watercourse and Riparian Corridor Impacts

The proposed pipeline alignment runs across and alongside watercourses in places. The majority of erosion within the study area is concentrated along creek banks. These features are, therefore, likely to be negatively impacted by pipeline construction, as follows:

Pipelines Crossing Creeks

- Introduction of preferential pathways for water runoff, possibly leading to formation of tributary gullies or increased bank erosion. Flash flooding during construction could exploit the open trench or other ground-disturbing activities;
- Disruption of the erosion-resistant gravel column or layer, possibly leading to preferential localised erosion;
- Localised bed scour and/or creation of localised bed-steepening, possibly resulting in nickpoint (waterfall) retreat and upstream bank destabilisation.

Pipelines Parallel or Within Creeks

- Pipelines excavated along watercourse channels are likely to cause irreversible alteration of the system dynamics. However, the proposed alignments do not appear to be aligned along (i.e. within) watercourses channels;
- Where excavated into the floodplain, preferential floodwater pathways could be created, possibly leading to erosion or even avulsion.

Riparian Corridor Impacts

Construction of pipeline through or along a watercourse system may require localised removal of protective riparian vegetation and disruption of the riparian corridor. These areas will be subject to increased likelihood of erosion until the vegetation is replaced, or appropriate mitigation measures are taken. Associated impacts include disruption of floodplain dynamics, riparian habitat and habitat connectivity.

5.2.5 Groundwater Impacts

Groundwater Levels

Shallow groundwater depths are likely to exist in the low-lying study areas adjacent to Lake Illawarra and in the vicinity of watercourses (see Figure 4.7). High water tables are also likely to be associated with gravel deposits of the high elevation watercourses towards the west of the study area. The proposed pipeline excavations are likely to intersect shallow groundwater in these areas. However, the drawdown band of influence should be limited by the short-term nature of the proposed trenching. This assumes that pipeline trenches are excavated in maximum lengths of 50m long by 2m wide, and will be backfilled within two weeks (see Section 1.2: Relevant Project Components). Impacts of the pipeline trenches on groundwater levels are, therefore, assessed as being negligible in the medium-to-long-term.

Impacts, should they occur, are likely to be as follows:

- Exposure of Acid Sulfate Soils (ASS);
- Temporal changes in water chemistry, but these are expected to stabilise rapidly;
- Salinity issues, including downward mobilisation of salts;
- Reduction in rehabilitation potential associated with ASS and salinity.

Salinity issues are considered unlikely to be a problem due to the short-term nature of excavations and dewatering. If dry conditions prevail in saline soils for an extended period prior to excavation activities, it is possible that concentrated salts could be transported into the trench by surface water infiltrating through the unsaturated zone above the water table.

Preferential Pathways

During pipeline excavation through potentially contaminated areas (discussed in Section 5.1.10: Land Contamination), it is important to avoid creation of preferential pathways for groundwater to discharge directly to receptors such as watercourses or Lake Illawarra.

Groundwater Quality

Wastewater pipelines pose a risk to groundwater quality during operation due to potential sewage releases if breaching of pipelines or localised flooding occurs. Impacts could then be transferred to soils through which the contaminated groundwater flows. The risk of sewage release should be assessed by the designers and construction managers.

5.3 Potential Impacts of Laydown Areas/Directional Drilling Pads

The potential impacts to the landscape as a result of project activities associated with pipe laydown and staging areas, and directional drilling pads are discussed within Section 5.1: Generic Environmental Impacts.

5.4 Potential Impacts of Pumping Stations

Pumping station construction-specific activities include:

- Site preparation (vegetation clearance, excavation etc.);
- Construction;
- Rehabilitation.

5.4.1 Topographic Alteration and Slope Instability

The greatest impact to the landscape resulting from pumping station construction is likely to be semi-permanent localised alteration of topography, should earthworks be required to level the sites. Earthworks in landslide-susceptible areas may cause slope destabilisation, ultimately resulting in slope failure. The proposed wastewater pumping station SPS09CS at the head of the Calderwood valley/Macquarie Pass is the most likely to require earthworks that result in topographic alteration and potential slope instability.

5.4.2 Groundwater Impacts

Coffey understands that the deepest proposed excavations at wastewater pumping stations will be to an approximate maximum depth of 6m below ground level (bgl). Mitigation measures may be required to limit drawdown during construction. Assuming the pump station excavations are lined, long-term impacts are expected to be negligible.

Groundwater levels in low-lying areas may be as high as 1m below ground surface. Based on steady state groundwater equations, the potential radius of influence of groundwater drawdown from the perimeter of the excavation in these areas has been assessed. The following assumptions were adopted for the calculations:

- Average groundwater level 1m bgl;
- Dewatering to a sump level of 7m bgl;
- Hydraulic conductivity of 0.1 m/day (considered a conservative value);
- Initial aquifer thickness of 9m;
- Uniform rainfall infiltration rate of 0.0003 m/day (10% of annual average rainfall).

Taking into account the listed assumptions, Coffey has calculated that groundwater levels should recover at a distance of approximately 100m from the excavation. The maximum drawdown at the excavation would be 6m below the current groundwater level. During extended dry periods, the radius of influence may be further than 100m. Potential impacts of a reduction in the groundwater level on Acid Sulfate Soils (ASS) are discussed further in Section 5.3.2.

Coffey has calculated that long term groundwater inflow would range from 0.1 L/s to 0.5 L/s. During high rainfall events, an increase in groundwater inflow may occur. However, the rate of groundwater inflow is not expected to exceed 1 to 2 L/s, unless local flooding occurs.

The key factors affecting potential groundwater inflow are the depth of the excavation below the existing groundwater level and the assumed permeability of the alluvial/estuarine sediments. The adopted hydraulic conductivity of 0.1 m/day is considered reasonable. However, localised increased permeability and thus larger groundwater inflow discharges could occur during excavations.

The likely impacts of localised groundwater drawdown are discussed in Section 5.2.5.

5.5 Potential Impacts of Reservoirs

The potential impacts to the landscape as a result of project activities associated with reservoirs fall largely within those discussed in Section 5.1: Generic Environmental Impacts. Component-specific landscape impacts may include:

- Consolidation of soils due to weight of tank and water;
- Potential erosion of batters prior to revegetation;
- Slope instability associated with earthworks (excavation of lower slopes or loading of upper slopes). This is most likely at the Avondale Reservoir site, located in steeply undulating terrain.
- Localised disruption of groundwater recharge and evapotranspiration rates.
- As with pumping stations, the greatest impact to the landscape is likely to be semi-permanent localised alteration of topography from earthworks required to level the site, particularly at the Avondale Reservoir site.

5.6 Potential Impacts of Temporary and Permanent Roads and Tracks

Permanent infrastructure refers to construction of permanent, sealed roads. Temporary infrastructure refers to access tracks built for the construction phase of the project. Many of the anticipated impacts of permanent and temporary infrastructure are outlined in Section 5.1: Generic Environmental Impacts. There is a low possibility that tracks requiring benching into steep slopes, particularly on sidelong ground in landslide-susceptible areas, may result in slope destabilisation.

Impacts will generally be related to ground disturbance, in particular erosion caused by vegetation clearance, soil compaction and drainage concentration, and creation of dust. It is anticipated that, although permanent infrastructure will have a greater spatial and temporal influence, the surface treatment is likely to be engineered to reduce damage. Temporary tracks may not have as robust a design, and could result in erosion if inappropriately managed.

5.7 Impact Risk Matrix

Coffey assessed the risk of environmental impact of the different project components on the study area. Risk is a product of likelihood and consequence of the impact occurring, i.e.

Risk = Probability of Impact Occurrence x Consequence

The impact risk has been assessed by considering the following:

Probability of Impact Occurrence

The likelihood of an impact occurring was assessed, based on the findings of our desktop study. The following ratings have been used:

Table 5.1 Qualitative Scale of Hazard Probabilities

Probability	Score	Indicative Description
Rare	1	The impact *may* occur, but only under exceptional circumstances
Unlikely	2	The event *might* occur
Possible	3	The event *could* occur
Probable	4	The event is *likely* to occur
Almost Certain	5	The event is *expected* to occur

Consequences

A qualitative scale of consequences has been used based on the following:

- Severity of Impact – considers the scale or degree of change from the existing situation as a result of the impact. This could be both positive and negative, and is related to the landscape sensitivity and magnitude of impact.
- Geographical Extent – considers if the effect is widespread, regional, local or limited.
- Duration – considers the timescale of the effect, i.e. if it is temporary, short or long term.

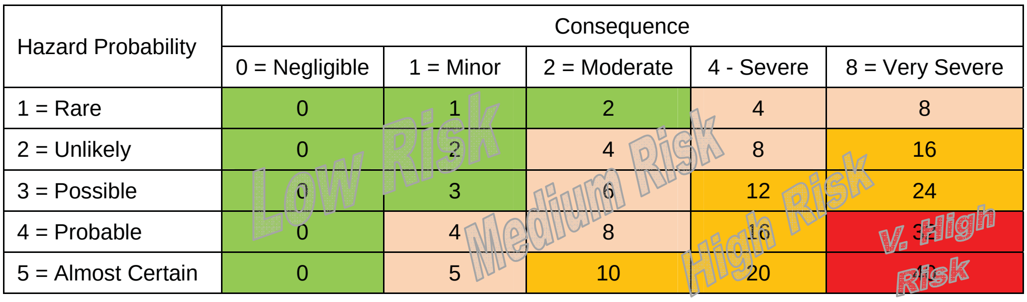
Table 5.2 Qualitative Scale of Consequences

Anticipated Impact	Description	Score
Negligible (N)	Impact to the landscape unlikely to be detectable or significant, and adverse impacts are unlikely to occur.	0
Minor (L)	• Impact to the landscape detectable but small-scale and unlikely to be significant. • Damage is limited in spatial extent, e.g. limited to the project activities with restricted footprint areas. • Recovery short-term, i.e. up to 3 years.	1
Moderate (M)	• Impact to the landscape detectable but not severe. • Damage is locally significant: project activities may have large footprints, or the impact may extend outside the project activity footprint. • Recovery is medium-term, i.e. up to 10 years.	2
Severe (H)	• Impact to the landscape is severe, e.g. major land degradation. • Impact is regional and may be detected up to 10km from the project activity. • Recovery, if possible, is likely to take up to 25 years.	4
Very Severe (VH)	• Project activity likely to have large impact on the landscape, possibly leading to system collapse. • Impact is widespread and may be detected over 10km away from the project activity. • Full landscape recovery is unlikely.	8

Risk of Environmental Impact

The product of the probability and consequence values produce an overall impact value, as follows:

Table 5.3 Qualitative Risk Score Matrix



Hazard Probability	Consequence				
	0 = Negligible	1 = Minor	2 = Moderate	4 - Severe	8 = Very Severe
1 = Rare	0	1	2	4	8
2 = Unlikely	0	2	4	8	16
3 = Possible	0	3	6	12	24
4 = Probable	0	4	8	16	32
5 = Almost Certain	0	5	10	20	40

5.7.1 Impact Risk Assessment Summary

Our assessment has indicated that the most likely impacts of the project, that are measurable to a degree and taking the known landscape variability and constraints into consideration, are as follows:

- The greatest impacts are likely to be associated with watercourses and could include increased erosion associated with pipeline crossings; channel migration or avulsion; downstream sedimentation (which will depend largely on the change in erosion rates); and disruption of the riparian corridor (see Figure R1). Many pipelines, in particular wastewater pipelines, run close to or cross incised waterways. Creeks in the area are characterised by erodible, friable silt-rich bank sediments. Creek reaches which are prone to movement (indicated by numerous abandoned meander scars) or which have particularly wide trenches are considered to be at greatest risk of impact, in particular along Mullet Creek between Avondale and Brownsville (as indicated on Figure R1). Disruption of the riparian corridor may affect the geomorphological functioning of the creek system, typically through floodplain erosion that may lead to channel migration or avulsion. However, environmental impacts will be largely ecological (affecting vegetation and, thus, habitat and habitat connectivity) or related to flood risk (i.e. hydrological).
- Gullying or rill erosion from introduction of preferential pathways, in particular resulting from pipeline construction;
- Artificial landform change requiring rehabilitation to a new, altered landform, as a result of semi-permanent earthworks, in particular in areas of steep, undulating relief, e.g. Calderdale pumping station (SPS09CS) and at the Avondale Reservoir site (see Figure R1)
- Disruption of steep slopes (generally steeper than 10°, although occasionally slopes shallower than 10°) could result in slope destabilisation and landsliding, particularly where the geological and drainage conditions indicate susceptibility to slope failures, e.g. wastewater pumping station SPS09CS and associated pipelines, and wastewater pipeline and adjacent water pipelines at the foot of Mt. Kembla (see Figure R1);
- Activities which reduce soil quality, such as compaction, alteration or inversion of the soil profile during reinstatement, potentially leading to erosion or low rehabilitation success.
- Poor rehabilitation success in areas of low soil fertility;

- Disturbance or exposure of ASS close to Lake Illawarra, potentially causing adverse downstream impacts to water quality, ecosystems and vegetation cover. The risk of environmental impact corresponds to the level of constraint, with specific risk areas as follows (see Figure R2):

High Risk	Wastewater rising main adjacent to Lake Illawarra near Lakeside Drive, Koonawarra
	Water pipeline off Yallah Bay Road, Yallah
	Wastewater pumping station (SPS02CS) and pipelines off Calderwood Road, Albion Park
Low Risk	Wastewater pumping station (TWLN009) off Yallah Bay Road, Yallah
	Water and wastewater pipelines in areas of Albion Park
	Wastewater pipelines in areas of Kembla Grange
	Wastewater pumping station (SPS08CS) and pipelines off the Illawarra Highway, Albion Park

- Intersection with contamination during excavation resulting in down-system contamination (i.e. down-slope or downstream).
- Groundwater issues, including intersection of groundwater and potential for lowering the water table; creation of preferential pathways; contamination of groundwater due to sewage release or excavation through contaminated ground; changes in recharge & evapotranspiration (see Figure R3).

Table 5.4 provides an assessment of the impact risk assessment. This table assumed that the project components are located with an area assessed as being susceptible to the named hazard (see Section 4: Environmental Constraints and Design Considerations), e.g. the assessment of landslide risk assumed that a pipeline will be excavated through the susceptible areas along talus or colluvial slopes of the Illawarra Escarpment, remnant ridges or outlier hills. Equally, some impacts could occur through the study area, e.g. soil inversion. This risk assessment presents what Coffey believes to be the worst case scenario, without implementation of management or mitigation measures. We have not considered the risk of cumulative impact on existing major infrastructure projects (e.g. Eastern Gas Pipeline).

Table 5.4 Risk Matrix showing Anticipated Impact of Project Components on the Study Area

Anticipated Risk of Impact		**Pipeline**			**Pumping Stations**			**Reservoirs**			**Laydown/ Directional Drilling**			**Access Roads**		
		Probability	Consequence	**Risk**	Probability	Consequence	**Risk**	Probability	Consequence	**Risk**	Probability	Consequence	**Risk**	Probability	Consequence	**Risk**
Watercourses	Erosion	4	8	**32**	-	-	**-**	-	-	**-**	-	-	**-**	4	2	**8**
	Channel Realignment	2	5	**10**	-	-	**-**	-	-	**-**	-	-	**-**	1	5	**5**
Gullying or Rill Erosion – Preferential Pathways		4	4	**16**	3	2	**6**	3	2	**6**	2	2	**4**	4	2	**8**
Artificial Landform Change[2]		5	1	**5**	5	2	**10**	5	4	**20**	-	-	**-**	4	2	**8**
Landslides		3	8	**24**	2	2	**4**	2	2	**4**	1	1	**2**	2	4	**8**
Reduced Soil Quality		4	2	**8**	4	1	**4**	3	1	**3**	2	1	**2**	-	-	**-**
Rehabilitation Success		4	2	**8**	3	1	**3**	3	1	**3**	3	1	**3**	4	2	**8**
ASS		4	4	**16**	3	4	**12**	-	-	**-**	1	4	**4**	1	4	**4**
Land Contamination		3	4	**12**	2	2	**4**	2	2	**4**	2	2	**4**	3	2	**6**
Groundwater	Intersection	3	1	**3**	4	1	**4**	-	-	**-**	4	1	**4**	-	-	**-**
	Preferential Pathways	4	2	**8**	-	-	**-**	-	-	-	4	2	**8**	-	-	**-**
	Contamination	1	2	**2**	1	2	**2**	-	-	-	-	-	**-**	-	-	**-**
	Recharge/ET Change	3	1	**3**	3	1	**3**	3	1	**3**	3	1	**3**	3	1	**3**

Notes:

1. “-“ indicates that impacts are not likely to be associated with project component
2. Landform change will be semi-permanent: recovery is assumed to be to a new, altered landform at sites requiring major earthworks

The above list indicates those sites that may pose a significant constraint during the project (particularly during construction phase). However, Coffey’s assessment of site-specific constraints was not exhaustive, and other, similar sites could be found. Detailed assessments for each constraint-type are recommended.

6 MANAGEMENT AND MITIGATION RECOMMENDATIONS

This section provides management recommendations for mitigation of environmental and project impacts. These recommendations fall into several categories as listed below.

- **Avoid**: design and plan the project so that the hazard has no impact.
- **Eliminate**: remove the hazard completely.
- **Accommodate**: consider designs which reduce the impact of the hazard to an acceptable level.
- **Reduce**: implement measures to reduce the impact of the hazard to an acceptable level.

The proposed measures are in accordance with the DLWC (2000); Managing Urban Stormwater: Soils and Construction (Landcom, 2004; often referred to as the “Blue Book”); Australian Pipeline Industry Association (APIA) Code of Environmental Practice for Onshore Pipelines (2009) and other relevant national and state guidelines.

Our TU mapping is at an appropriate scale for the study area. This mapping gives an indication of the likely geology, soils and groundwater constraints that will be encountered and possible impacts. Consideration should also be given to the variability of conditions which can occur within a mapping unit: localised high constraint or sensitive areas can occur within a low/negligible constraint area, and *vice versa*. Coffey has used the Kiama 1:100,000 Soils Landscape Mapping TU boundaries, which are subjective, based on information available at the time (Hazelton, 1992). Site-specific information can indicate inaccuracies to these boundaries. Site management during the construction and later phases of the project should be site-specific. Site-specific assessments of the landscape characteristics and properties should, therefore, be carried out prior to detailed design and construction.

This section proposes generic measures to manage the conditions that are anticipated to be encountered. If implementation of these measures is unsuccessful, the risk of environmental damage will be broadly related to the level of constraint, i.e. there will be a higher risk of environmental damage in an area with a higher constraint ranking.

6.1 Recommendations for All Activities

The following measures apply to all project components and should be considered in all phases of the project; from construction, post-construction rehabilitation, operation and maintenance through to decommissioning. Project activity-specific mitigation measures are discussed in Section 6.2 onwards.

6.1.1 Avoidance of High-Constraint Areas

Where practicable, the project should be designed and planned to avoid areas with high and very high constraint levels to reduce the potential environmental impact. However, as noted above, the level of constraint can vary within a mapping unit, e.g. the proposed Calderwood Reservoir site is within a TU which typically has a high landslide constraint; and moderate to high erodibility and foundation constraint. However, Coffey’s findings indicate that the reservoir site is located on a ridge top, meaning that the site-specific landslide constraint would be negligible; soils are likely to be well-structured, slightly sodic, stony, shallow silty clay loams with moderate erodibility and moderate (or even low) foundation constraints. Potential environmental impacts resulting from construction of the site are, therefore, likely to be lower than the constraints rankings indicate. Detailed constraint or aspect-specific assessments are, therefore, recommended.

6.1.2 Land Degradation Management and Mitigation

Land degradation could potentially occur throughout the Study Area, associated with project activities that cause ground disturbance. Coffey recommends that the following control measures are implemented throughout the project:

Erosion Control Measures

- The erosion control measures recommended in this section should be implemented during all phases of construction, rehabilitation and maintenance phases of the project.
- Management of drainage (i.e. measures to retard and control water flow or runoff) is key and should be considered first, then erosion and sedimentation controls (APIA, 2009);
- Erosion control measures should consider: natural and constructed drainage patterns; soil erodibility; slope steepness and length; rainfall frequency and intensity; potential flow magnitudes; vegetation cover; proximity to sensitive environments and land-use impacts.
- Disturbance should be reduced to essential areas only. Areas should be cleared progressively, with construction activities commencing as soon as is practicable following clearance.
- Erodible soils and sensitive reaches of watercourses should be avoided where practicable. A buffer zone should be left around these sensitive areas. Buffer zones should be site-specific, dependent on ground and landform conditions, and scale, duration and timing of disturbance.
- Project components should be placed to avoid disrupting overbank flood paths (IECA, 2008).
- Grasses and other ground-cover vegetation should be re-established on bare areas as soon as possible following construction, especially during wetter summer months (Landcom, 2004). This can reduce overland flow velocities, act as silt traps and stabilise the soil surface (IECA, 2008).
- If necessary, erosion control measures, such as the use of erosion matting (such as Jute Mesh) or sediment socks (sand-filled UV-resistant fabric tubes), should be used (Landcom, 2004).
- Erosion control measures should be designed to reduce the sediment load of runoff. This may require the construction of temporary silt fences, contour banks, detention dams or sediment settlement ponds, particularly in areas of sodic soils (Landcom, 2004).
- Erosion and sediment control, and planting and seeding rehabilitation plans should be prepared during the design phase of the project and implemented during and following construction.

Erodible Soil Management Measures

- Sodic and dispersive soils (associated with Soil Type 1 Texture Contrast Soils in TUs ap, bo, sh and wt, and Soil Type 2.1 Loams and Clay Loams associated with TU bo) should be avoided where possible, especially if reworking is necessary (e.g. for earthworks and backfill).
- Application of soil ameliorants such as gypsum should be considered for sodic soils as these can reduce dispersivity, waterlogging and crusting (IECA, 2008).

Gully Management and Mitigation Measures

- Gully creation should be avoided. Gullies, once initiated, are difficult to manage (see Section 3.2.1: Landform Features).
- Site-specific assessment is required to assess the rate of erosion and appropriate management measures.

- Minor gullies or those which are not eroding rapidly can often be controlled by stock exclusion fencing and planting of ground-cover vegetation. Erosion-control matting can be used while vegetation becomes established.
- Aggressively eroding gully networks can require major engineering structures, which often only provide temporary solutions.

Topographic Constraint Management Measures: Steep Slopes and Undulating Ground

Steep slopes (>20°) and undulating ground are anticipated to present particular management issues, in particular associated with surface water runoff and resultant soil erosion. On steep slopes of the Study Area, natural vegetation has generally been left relatively intact and clearance or disturbance of this protective layer could contribute to slope destabilisation. Avoidance of these landforms is, therefore, recommended. Where avoidance is not practicable, the project design should incorporate measures to reduce land degradation (See Section 6.1.1: Recommendations for All Activities) and slope instability (see project activity-specific recommendations in Sections 6.2.1 and 6.3.1).

Timing of Disturbance – Rainfall and Flooding

The Illawarra Region is characterised by intense rainstorms and associated flash flooding (most recently on 21 March 2011). Soils within the Study Area can become waterlogged, causing the ground become soft, slippery and possibly impassable in susceptible areas. Construction works and access to sites should be timed to avoid wetter periods, where practicable, to reduce the likelihood of erosion, slope failures and project delays due to difficult access. The following recommendations should be considered to reduce adverse environmental impacts and also reduce the risk of harm to workers.

During and following rainfall events likely to cause flash flooding, creeks should not be crossed and construction should be halted. However, the unpredictability of these intense storms presents a challenge. It is recommended that rainfall and flood management procedures are implemented to clearly establish protocols for cessation and restart of work.

Intense and/or prolonged rainfall events have historically triggered landslides in the area. Ground disturbing works in high landslide constraint areas should avoid such periods. Work stoppage and restart protocols should be implemented for specific rainfall amounts, i.e. designated rainfall thresholds should be adopted, above which work is ceased. The University of Wollongong's Landslide Research Team have designated regional thresholds for cumulative rainfall amounts over 6 hours, 24 hours, 3 days, 7 days, 30 days, 60 days and 90 days (see p10, Chowdhury and Flentje, 2006); shorter duration thresholds are generally more applicable to shallow slides or debris flows, and longer thresholds to deep-seated slides or slide-flows. However, local conditions may result in appreciably different threshold magnitudes at individual landslide sites.

Site-specific assessment of likely landform response to rainfall events is, therefore, recommended prior to commencement of work in susceptible areas.

Soil Compaction Mangement

- Vehicle trafficking on compressible soils should be avoided, in particular when soils are wet or waterlogged. Construction vehicles should avoid parking in such areas and conditions
- Smaller, lighter construction machinery with tracks rather than rubber tyres should be used where practicable.
- Spreader boards should be used where practicable.

- Load limits should be set to reduce heavy trafficking on compressible soils.
- Revegetation or rehabilitation should be undertaken as soon as is practicable. Rehabilitation measures should be site-specific, depending on the degree of compaction and soil type. Some soils respond well to rehabilitation measures such as tilling, but in other soils, this may retard vegetation growth.

Dust Management and Mitigation Measures

- Project disturbance time should be reduced as far as is practicable.
- Revegetation or rehabilitation should be undertaken as soon as is practicable to reduce the exposure time of bare soil.
- Water can be sprayed onto exposed soils to reduce dust generation (APIA, 2009). Water should be of good quality (e.g. with an electrical conductivity (EC) comparable to that of typical irrigation water used in the locality) and not sprayed as concentrated flow.
- Integrity of access tracks should be maintained, with regular grading and wetting (using water trucks) during intensive operations such as construction and maintenance.
- Appropriate site vehicle weight and speed restrictions should be implemented (APIA, 2009)
- To improve the integrity of permanent access tracks, dust stabiliser additives may be required to improve structural stability.

NSW Guidelines for Soil Erosion Assessment, Management and Mitigation

Site-specific soil erodibility and erosion hazard assessments should be carried out in areas mapped as having soil erosion issues, as per the following guidelines.

- NEPC, Guideline on the Investigation Levels for Soil and Groundwater (1999)
- DLWC, Soil and Landscape Issues in Environmental Impact Assessment (2000)
- Landcom, Managing Urban Stormwater: Soils and Construction (2004) (the “Blue Book”)
- DECCW Managing Urban Stormwater: Soils and Construction Volume 2A: Installation of Services (2008)

These guidelines do not give specific sampling densities appropriate for a project of this nature. Should further ground-truthing of the mapping herein be required (in addition to the checks that Coffey has already made with archive records and existing available data), DLWC (2000) recommends varying soil sample spacing for preliminary assessments depending on land use, ranging from 0.5-1 samples per km^2 and 0.5-1 soil profiles per $5km^2$ in open spaces to 50-100 samples and 10-20 per ha in highly intensive construction areas. However, the guideline also indicates that soils investigations should be appropriate for the cost and scale of the project. In this case, Coffey recommends that investigations are targeted at project locations which are likely to increase erosion hazard in areas of erodible soils, e.g. pipeline construction (particularly of wastewater pipelines) through clay-rich sodic texture contrast soils or friable silty alluvial soils.

6.1.3 Soil Management

Careful management and handling of soil resources within the study area can greatly reduce the environmental impact of the project. Effective soil management can reduce erosion; protect water courses from sediment laden runoff and improve chances of successful rehabilitation. In areas with a high rehabilitation constraint, i.e. existing soils have low fertility, the available soil should be carefully managed and conserved.

Topsoil Management

Topsoil should be stripped in areas where larger scale disturbance is planned (e.g. prior to cut and fill or construction of laydown areas) to provide material for rehabilitation. Prior to soil stripping, soil type, depth and resources should be identified. Where practicable, appropriate management measures should be implemented to protect the long term viability of topsoil (see below). Vehicular traffic should be excluded, where practicable, from areas where soils are to be stripped. Traffic should also be limited on soils that are sensitive to structural degradation.

Additional project-specific strategies that could be considered are outlined in Table 6.1.

Table 6.1 Soil Resource Management Strategies

Prior to Soil Stripping	During Soil Stripping and Stockpiling	Stockpiled Soil Awaiting use in Rehabilitation Works
Carry out a site-specific assessment of topsoil resources in areas of large disturbance to: • Quantify soil resources • Establish appropriate handling procedures • Characterise the suitability of soil resources for rehabilitation works • Formulate project-specific stripping and stockpiling guidelines, including the nomination of appropriate depths, scheduling, location of areas to be stripped and stockpile locations	• Exclude vehicular traffic from areas where soils are to be stripped, where practicable. • Traffic should also be excluded from soils that are sensitive to structural degradation • Reduce vegetation clearance • Use loaders and trucks, rather than scrapers, to reduce soil structure degradation • Handle soil when it is moist, rather than wet or dry, to avoid decline of soil structure • Selective stockpiling of soil according to soil type and salinity levels • Stockpiling of soils in a manner that does not compromise the long-term viability of the soil resource	• Implement measures to ensure long-term viability of soil resources.

Topsoil and Spoil Storage

During the project, excavation will produce spoil which requires short to long term storage for use in later rehabilitation activities. This material should be managed as follows:

- Stockpiles should be located out of work areas and be clearly marked.
- Stockpiles should be located away from watercourses and drainage lines (APIA, 2009). They should not be located in areas which may dissect ecosystem corridors or damage adjacent vegetation.
- Topsoil, subsoil and earthworks spoil should each be stored in separate stockpiles throughout the project (APIA, 2009).
- Topsoil should be mulched and stockpiled in thin layers (APIA, 2009). Stockpiles should be generally no more than 3 metres in height, in order to reduce problems associated with anaerobic conditions.
- Stockpiles should be constructed with a “rough” surface to reduce erosion hazard, improve drainage and promote revegetation.

- Sediment control measures should be implemented, such as the installation of silt fences around stockpiles to control potential loss of stockpiled soil through erosion prior to vegetative stabilisation.
- Stockpiles should be deep-ripped to create aerobic conditions prior to reapplication of the stockpiled soil for rehabilitation.
- Where necessary, an appropriate soil ameliorant should be applied to dispersive soil stockpiles.

Topsoil Stripping Depths

The suitability of soils for rehabilitation is as follows:

- Any soil material from sand to light clay is suitable, although amelioration may be required.
- Soils of medium to heavy clay texture are generally not suitable as they are too coarsely structured to maintain soil/seed contact, are hard when dry and have low permeability. This can restrict vegetation re-establishment.

Prior to excavation or ground disturbance, topsoil characteristics and depths should be investigated. Site-specific assessments are recommended in areas of large-scale disturbance.

NSW Guidelines for Soil Management

- Guidelines given in Section 6.1.2, in particular Landcom (2004) and DECCW (2008)

6.1.4 Soil Salinity Management and Mitigation

Coffey has not discovered information which indicates that salinity is a major issue in the Study Area, despite the known presence of estuarine and marine rock and soils. Therefore, should saline soils be encountered, potential management strategies are as follows:

- In areas where salinity issues are possible (i.e. low-lying areas along the Coastal Plains), investigations should be carried out as per DLWC (2002) Site Investigations for Urban Salinity guidelines. This guideline recommends varying soil sample spacing depending on land use, ranging from 6-18 samples and 1.5-3 soil profiles per km^2 in open spaces to 50-100 samples and 10-20 per ha in highly intensive construction areas. However, the guideline also indicates that soils investigations should be appropriate for the cost and scale of the project, and alternatives, such as Electro-Magnetic Induction surveys, can be used, if appropriate;
- Prior to major earthworks, ground investigations should be carried out in those soils identified as being saline to establish the depth at which saline conditions occur.
- Excavated saline subsoil should be capped with suitable topsoil material when backfilling. This will support plant growth and provide a less-hostile medium for plant roots during establishment.
- Stockpiled saline subsoil should be bunded both up- and downstream to reduce runoff ponding and salt ingress.
- Salt-tolerant plant species should be used during revegetation (Landcom, 2004).

6.1.5 Acid Sulfate Soils Management and Mitigation

The principal management strategy for areas where acid sulfate soils may exist is avoidance. However, this may not be practicable in many cases. Therefore, areas where the risk mapping shows ASS (see Figure R2) would require assessment to confirm the presence of ASS within the anticipated depth interval. NSW ASS management and mitigation guidelines are given in ASSMAC (1998), Tulau (2007) and DECC (2008). For linear projects, the ASSMAC (1998) guidelines recommend sampling every 50m to 100m, subject to soil characteristics and soil disturbance. Likely hotspots should also be targeted. If dewatering works that could lower the water table are likely to expose ASS, hydrogeological studies are recommended.

Common management measures for excavated acid sulfate soils along pipeline routes include:

- Returning the excavated acidic soils to below the water table or the environment from which they were originally excavated within a short timeframe; and
- Neutralisation of the acid sulfate soils (as per ASSMAC, 1998 Guidelines) e.g. by adding lime and either re-use in trench works or disposal offsite to a licensed landfill.

An ASS Management Plan for the construction phase of the project should be prepared and implemented. Successful implementation during this early phase should preclude the need for ASS management during latter (operations, decommissioning and rehabilitation) phases of the project.

6.1.6 Soil Contamination Management and Mitigation

The principal management strategy for areas where contamination may exist is avoidance. As with ASS, this may not always be practicable. In areas where there is potential for contamination (as identified in Sections 4 and 5), appropriate soil or groundwater contamination assessments should be carried out. Coffey recommend that preliminary site-specific observations and screening are carried out along each pipeline route. Sampling should then be targeted within areas assessed as being of a higher likelihood of contamination.

A Contamination Management Plan (similar to an unexpected finds protocol) should be prepared and incorporated into the Project Environmental Management documentation. The Contamination Management Plan should outline general protocols regarding identification of potentially contaminated soils (based on visual and olfactory evidence).

The following key contamination management strategies are recommended:

- Fill should be stockpiled separately to underlying natural soils as fill materials may have a higher likelihood of being contaminated in certain areas (e.g. AECs identified in Sections 4 and 5). Natural soils may have a different waste classification from fill, and separation could save costs if surplus soil is generated;
- Contaminated soils, where encountered, should be stockpiled separately. These soils should also be appropriately managed to reduce erosion and sediment transport (see Section 6.1.2: Land Degradation). Measures should be taken to reduce the likelihood of spread of contamination e.g. placement of separation layers (e.g. plastic sheeting) and/or bunds around the stockpile. Smaller stockpiles can be covered with plastic sheeting for protection.
- As Sydney Water is not responsible for existing contamination on land owned by others, it may be possible to use certain types of contaminated soils for trench backfill in the areas where they originated. In general, these contaminated soils should not warrant remediation to reduce environmental risk for future land use under current zoning. This would only be the case if the original site contamination conditions are not exacerbated to an extent that warranted reduction of environmental risk through remediation. However, Sydney Water may consider that it has a corporate responsibility to advise the affected landowner if the contamination was previously unknown. Sydney Water should manage contamination issues such as:

  - Workers handling potentially contaminated materials;
  - Appropriate contaminated soil/groundwater disposal;
  - Maintaining or improving ground conditions, rather than having a negative impact, in particular where alteration of ground characteristics could affect land-use, e.g. creating a preferential pathway for contaminant migration along the pipeline route, placing contaminated soils on the surface.

- Contaminated soils which cannot be re-used on site should be classified as waste and disposed to an appropriately licensed facility;
- If contaminated soils are discovered during excavation, management advice should be sought from an experienced environmental consultant, particularly if the type and extent of contamination is not known. As a broad guideline, visual/olfactory evidence of contamination may include, but not be limited to: soils or groundwater with unusual odours; stained, discoloured or brightly coloured soils; and soils containing wastes such as drums, building materials or fibre cement. Visual and olfactory indicators of contamination should be listed in the Contamination Management Plan.
- Contaminant leakages during construction or post-construction works are frequently associated with operation of heavy equipment. Regular vehicle checks (particularly of hydraulic hoses) should be carried out e.g. as part of pre-start safety checks and after any incident which may have caused damage. Spill kits should be carried, particularly in vehicles with hydraulic systems.
- Contamination assessments should comply with NSW guidelines made or endorsed under the CLM Act (1997), including:
  - Guidelines on the Duty to Report Contamination under the *Contaminated Land Management Act 1997* (DECC, 2009)
  - Waste Classification Guidelines Part 1 (DECC, 2008)
  - Guidelines for the Assessment and Management of Groundwater Contamination (DEC, 2007)
  - Guidelines for the NSW Site Auditor Scheme (DEC, 2006);
  - Guideline on the Investigation Levels for Soil and Groundwater (NEPC, 1999)
  - Managing Land Contamination Planning Guidelines: SEPP 55 Remediation of Land (NSW Environmental Protection Authority (EPA), 1998)
  - Guidelines for Consultants Reporting on Contaminated Sites (NSW EPA, 1997);
  - Sampling Design Guidelines (NSW EPA, 1995)
  - Guidelines for Assessing Service Station Sites (NSW EPA, 1994)

6.1.7 Uncontrolled Fill Management and Mitigation

General

Throughout the Study Area, there are areas of uncontrolled fill of various sources. These areas should be avoided, where practicable. It is recommended that geotechnical assessments of fill are carried out to inform the design phase of the project. However, as many of these areas are unmapped, management protocols should be adopted. These should include measures to identify and control spread of contaminants (discussed below and in Section 6.1.6-6.1.8).

Mine Emplacements

In mine waste (coalwash) emplacement areas, tailings deposits comprising fine silts may be present that can be difficult to re-compact. Stockpiled materials and open trenches should be protected from runoff so that the fine black silt is not carried off-site. Coalwash has a combustible content and materials with high combustibles can experience spontaneous combustion when exposed to air, or can be ignited by fire. Testing should be considered before excavating in emplacement areas to assess the soil silt content and total combustibles.

6.1.8 Groundwater Management and Mitigation

Groundwater Management

Proposed activities involving excavation could have a short-term impact on the groundwater system. Excavation management should consider the potential for high water tables and associated controls for groundwater inflows (shoring, sheet piling, dewatering activities).

Groundwater quality monitoring during dewatering should be considered, as groundwater disposal requires attainment of appropriate environmental standards, as per NSW guidelines (DLWC, 1998a; NEPC, 1999; ANZECC, 2000). Potential issues with groundwater quality which may require treatment prior to disposal (including reinjection, if considered) include: changes in pH, total dissolved solids (TDS) and precipitation of iron. Depending on the results, groundwater may need to be taken off-site for disposal, rather than discharged to stormwater or surface water systems. Groundwater may also require pumping to a temporary holding pond/tank.

Specific recommendations and groundwater management strategies for pipelines and wastewater pumping stations are outlined in Section 6.2.7 and Section 6.3.1.

Temporary Dewatering Licence Requirements

Temporary dewatering licences may be required by NOW for any excavations which intercept groundwater. The necessity to obtain the licence is at the discretion of NOW and will depend on the dewatering volume and length of dewatering time. Should reinjection be considered, a licence will be required. Consultation with NOW is recommended.

The following list gives guidelines for documents that NOW are likely to require prior to dewatering excavations for the proposed wastewater pump stations:

- Council and NSW Department of Planning approval documents for the proposed construction works.

- A geotechnical groundwater report predicting of the impacts of pumping on any licensed groundwater users or Groundwater Dependent Ecosystems (GDEs) in the vicinity of the site. Potentially adverse impacts would require modification of the project.
- A geotechnical report assessing the potential for salt water intrusion as a result of the dewatering (for sites within 250m of any marine or estuarine foreshore area). Project activities leading to salt water intrusion would not be allowed and the project would need to be modified.
- Descriptions of the proposed dewatering methods and actual volume of groundwater to be pumped from the dewatering works; the works locations; the discharge rate (L/s); duration of pumping; the amount of lowering of the water table; and the anticipated quality of the pumped water.
- If reinjection is proposed, descriptions of the actual volume of pumped water (tailwater) to be reinjected; reinjection locations; disposal rate (L/s); duration; and anticipated quality of untreated or treated water to be reinjected.
- Monitoring of groundwater levels beneath the proposed development site/s prior to construction (minimum of 3 weekly measurements of groundwater levels at a minimum of 3 locations across the site/s). This requirement is for sites where the proposed development extends greater than one floor level into the existing ground level. Groundwater monitoring will be required at each of the five wastewater pumping stations, as the locations have separate DP and lot numbers. It is recommended that additional specific conditions are assessed following consultation with the NOW.

Specific recommendations and groundwater management strategies for pipelines and wastewater pumping stations are outlined in Section 6.2.7 and Section 6.3.2.

6.1.9 Construction Materials – Borrow Pit Management

Borrow pits may be used as a source of construction materials during the project. These should be managed as follows:

- Borrow pits should be located away from problem areas (e.g. steep slopes or highly erodible soils).
- If significant quantities of material are required, the excavations should be designed to direct surface water runoff to managed control points.
- Erosion control measures should be implemented.
- Pits which expose sodic or saline subsoils should be bunded. These adverse soil conditions are more likely within Soil Type 1 Texture Contrast Soils in TUs ap, bo, sh and wt, and Soil Type 2.1 Loams and Clay Loams associated with TU bo.
- Rehabilitation of pits should be carried out as soon as is practicable. This should include:
  - Ground surface re-profiling avoiding the creation of steep, unstable slopes;
  - Topsoil respreading;
  - Revegetation;
  - Erosion control measures, including erosion bunds and contour ripping.

6.1.10 Excavation Backfilling Management

Excavation backfilling should be managed as follows:

- In all locations, excavated soil should be replaced in the order in which it was excavated. Soil profiles should be recreated as far as is practicable. Subsoil should not be present at the surface.
- The land surface should be reprofiled to pre-construction contours, as far as is practicable. Soil mounding to allow for settling may be required in some areas.
- Soils should be compacted to pre-construction levels, where possible.
- Backfilled and filled areas should be inspected regularly for subsidence and re-filled if necessary (see Section 6.6: Monitoring and Maintenance Programme).

6.1.11 Rehabilitation

Following decommissioning of the project components, rehabilitation should be carried out where practicable, as follows:

- Surface structures should be removed from the site.
- Soils should be replaced in the order of excavation, where practicable, to increase the success of rehabilitation measures. Subsoil should not be present at the surface.
- Ground levels should be restored to their pre-existing elevation.
- Drainage lines should be re-established.
- Medium to long-term erosion control measures should be implemented (see Section 6.1.2: Land Degradation).
- A planting and seeding plan should be developed for vegetation re-establishment.

6.2 Pipeline Management Recommendations

Management recommendations specifically related to pipeline construction are as follows:

6.2.1 Erosion Management

Pipeline-related erosion may be reduced by adopting the management practices below:

- Vegetation should be cleared in sections to reduce the spatial extent of bare ground at any one time.
- Grading, trenching and backfilling should be carried out as rapidly as is practicable, to reduce erosion.
- During construction, vehicle access to the pipeline easements should be provided at regular intervals to reduce compaction and formation of wheel ruts along the easement.
- Windrow-cleared vegetation should be placed along the edge of working areas to control runoff.
- Trench-breakers/plugs will reduce erosion and allow fauna and personnel escape.

6.2.2 Steep Slopes and Landsliding

Where the pipeline route is forced to cross steep slopes (>10°), the following measures should be considered to reduce environmental impact:

- Pipelines should be routed along ridgelines, where possible. Ridgelines typically have shallower slopes than the surrounding hillsides.
- Routing along ridgelines is also recommended to reduce sidelong ground issues i.e. triggering of landslides perpendicular to the pipeline, possibly causing rupture.
- Where routing along hillsides is unavoidable, the pipeline should be benched into the hillside. Bench dimensions and batters should be designed to reduce the likelihood of slope destabilisation and possible triggering of landslides.
- Site-specific landslide risk assessments should be carried out in susceptible areas (in particular in the Calderwood Valley/Macquarie Pass area), in accordance with Australian Geomechanics Society (AGS, 2007) Landslide Risk Management guidelines

The Wollongong City Council-sponsored Landslide Research Team at the University of Wollongong has coarse landslide susceptibility mapping for the Study Area (at 25m resolution). The Team plans to carry out detailed geological and existing landslide mapping over the next year in order to refine the coarse model (Prof. P. Flentje, *pers. comm.*, March 2011). It is recommended that Sydney Water consider approaching the Team with regard to obtaining the resultant mapping, should this be available within the project timeframe.

6.2.3 Backfill and Padding Management

Infilling of the pipeline trench should be managed as follows:

- Fauna should be removed before backfilling.
- Appropriately-sized trench bedding and padding material should be used to avoid damage to the pipe coating.
- If practicable, saline, acidic or sodic soils should not be used for backfill padding.
- Soils should be replaced in the order of excavation, where practicable, to increase the success of rehabilitation measures.
- Backfill should be compacted to pre-disturbance conditions, as far as is practicable, to avoid preferential erosion.
- Backfill should be compacted to the level of the surrounding ground, to reduce trench subsidence and concentration of flow. Regular, ongoing inspection of the pipeline corridors should be carried out following construction, and subsidence depressions infilled and compacted to the level of the surrounding ground.
- Subsoil should not be exposed at the ground surface following backfilling. Any subsoil left exposed should be capped with topsoil.

6.2.4 Management of Trenching in Reactive Clays

Where the pipeline alignment crosses highly reactive clays, the pipeline should be buried below the zone of seasonal moisture change, where practicable, to avoid heave. If these measures cannot be implemented, non-plastic, granular bedding materials may be required. Alternatively, the pipeline design should consider the presence of reactive soils. The site-specific shrink-swell properties of clays should be assessed.

6.2.5 Trench Stability Management

In areas of soft or loose soils, the trench walls may require battering back or shoring to limit trench collapse.

6.2.6 Watercourse Management

Management and mitigation of impacts to creeks within the study area may be challenging due to the dynamic nature of upper and middle reaches, combined with the behavioural response of the erodible bank and resistant coarse bed sediments. The following measures are in accordance with the DIPNR Riparian Corridor Management Study (2004), Southern Rivers CMA (2006); Landcom (2004); NOW (2008) and Wollongong City Council (2009) guidelines (where relevant):

- Where practicable, project components should avoid designated riparian corridors (DIPNR, 2004). NOW publish guidelines for riparian corridor definition under the Water Management Act 2000, (NOW, 2008) which may not apply under Part 3A, but still provides a useful guideline. Wollongong and Shellharbour City Councils have already defined the riparian corridor within the Study Area according to the NOW guidelines. The DIPNR Riparian Corridor Management Study (2004) also provides guidelines for riparian corridor definition and management.
- A geomorphological assessment of creek dynamics and likely response to the proposed works should be carried out to inform Sydney Water's design process. Coffey has calculated that there are 284 pipeline creek crossings in the Project Approval Areas alone (with well over 550 pipeline creek crossings in the Study Area). The assessment should also consider the response and inter-dynamics of the floodplain and riparian corridor in the affected areas. Coffey recommend that a cost-effective assessment is structured as follows:
    - Watercourse categorisation by geomorphological type (typically reach-based, split by catchment), based on historical migration and erosion rates (assessed using available historical aerial photographs); contemporary processes acting; channel material properties; and riparian corridor characteristics;
    - Sub-reach assessment of site-specific crossings, focussing on those reaches assessed to be particularly dynamic or sensitive to impact;
    - Geotechnical ground investigations assessing channel material properties (particularly depth to the gravel layer/column) targeted on crossings assessed as being of high constraint or having high risk of impact;
    - Findings should be used to provide information on historical channel movements, contemporary process/form relationships and likely future locations/rates of erosion.
- Protective structures which restrict natural channel dynamics (e.g. grade control structures which limit scour and fill during floods) should be avoided where practicable.
- Protective structures should be designed with the dynamicism of the creek channels in mind. The zone of creek influence should not be underestimated. Where a smaller active channel is located within a larger high-flow trench, the trench should be used to delineate the creek.
- Should hard engineering, such as concrete, be used to protect pipelines at creek crossings, the material should not be exposed at the bed or banks to avoid preferential erosion or scour. This

type of structure can cause the waterfall and scour pool formation, possibly leading to associated bank erosion;

- NOW do not condone the use of concrete, gabions or reno mattresses within the riparian corridor as these restrict channel adjustability and introduce artificial materials into the channel. Part 3A of the EP&A (1979) Act may override the need for NOW Controlled Activities Approval, but consideration should still be given to the use of alternative materials, e.g. geofabrics or rock armouring, or "soft" engineering (i.e. use of vegetation and biodegradable geofabrics for channel stabilisation).
- Alterations to creek channels should consider NSW Fish Habitat Protection Plan No. 1 (DPI, 1995), in particular with regard to fish passage around permanent structures and dredging.
- Directional drilling beneath creeks should extend well below the coarse lag or ribbon deposits, where practicable. Should this not be possible, care should be taken to avoid disruption of the naturally resistant channel bed within the likely depth of scour and allowing for potential future channel change.
- Similarly, directional drilling should extend well beyond the creek trench, where practicable.
- Rehabilitation within the riparian corridor should consider the pre-disturbance vegetation, geomorphology, hydrology and water quality. Objectives should include maintaining riparian connectivity, habitat, channel stability and water quality. Rehabilitation should consider DIPNR (2004), Southern Rivers CMA (2006); Landcom (2004); NOW (2008) and Wollongong City Council (2009) guidelines.
- Should future design changes be considered, it is strongly recommended that pipelines are not realigned along watercourse channels

6.2.7 Groundwater Management

Groundwater Levels

To reduce the drawdown band of influence associated with pipeline trench excavation, trenching should be carried out in sections which are a maximum of 50m long and 2m wide. Trenches should be backfilled within 2 weeks.

Registered Bores

The proposed pipeline alignments appear to coincide with registered bore locations in some areas, for example in Albion Park (GW072794 and GW107819; see Figure 3.5). Should existing bores be identified along the proposed pipeline route, it is recommended that appropriate measures are taken to notify bore owners, confirm that the bore is no longer in use or alter the pipeline route.

Preferential Pathways

During pipeline excavation through potentially contaminated areas (discussed in Section 5.1.10, Figure R2) it will be important not to create preferential pathways for the groundwater to discharge directly to receptors such as watercourses and Lake Illawarra. Mitigation measures include limiting excavation in potentially contaminated areas and, if excavation is to take place, engineering controls, such as sheet piles, to provide a barrier to groundwater flow.

Any disturbance to potentially contaminated areas should take into account groundwater issues and avoid creating preferential pathways for groundwater to discharge directly into the surrounding receiving environment.

Groundwater Quality

Wastewater pipelines may pose a risk to groundwater quality during operation due to potential sewage releases, if pipeline breach or localised flooding occurs. The risk of sewage release and appropriate containment strategies should be assessed by the designers and construction managers.

6.2.8 Rehabilitation of Pipeline RoW

The pipeline RoW should be rehabilitated as follows:

- Where possible, mulched surface vegetation should be spread over the RoW following backfilling to reduce rainsplash erosion.
- Vegetation coverage should be maintained over the pipeline easement.

6.2.9 NSW Guidelines for Pipeline Construction

- Guidelines given in Section 6.1.2, in particular DECCW (2008).
- In addition, it is recommended that NOW Controlled Activities Guidelines for Laying Pipes and Cables in Watercourses (2010) is taken into consideration (despite being overridden by Part 3A).

6.3 Pumping Station Management Recommendations

6.3.1 Acid Sulfate Soils Management

Project activities that could result in lowering of the water table in areas likely to be affected by ASS should be assessed on a site-specific basis, based on the level of ASS risk and the proposed construction methods (including type of disturbance). Developments in these areas that are likely to disturb underlying natural soils or have an impact which lowers the groundwater level may require further specific assessment and where necessary, development of ASS management plans to avoid adverse impact to local and down-system soils and groundwater.

Three of the proposed wastewater pumping stations near Yallah Bay Road; Calderwood (between Marshall Mount Creek and Macquarie Rivulet); and further south in Calderwood (adjacent to Macquarie Rivulet) may require site-specific ASS assessments. In addition to the generic ASS management and mitigation measures discussed in Section 6.1.5, it is recommended that groundwater monitoring bores are established in the vicinity of the excavations. This will allow groundwater level monitoring during construction. The ASS Management Plan should include a contingency plan to respond to adverse impacts.

6.3.2 Groundwater Management

Temporary dewatering licences may be required for wastewater pumping stations at the discretion of NOW, as they are anticipated to intercept groundwater.

Should localised increased permeability be encountered and greater-than-anticipated groundwater inflow discharges occur during excavations, groundwater inflows should be observed during construction activities and dewatering pumping options revised accordingly. This would include revising inflow rates in the temporary dewatering licence.

6.4 Reservoir Management Recommendations

6.4.1 Steep Slopes and Landsliding

In general, reservoirs have been located on low-relief landforms. However, the Avondale Reservoir appears to be located within an area characterised by steeply undulating topography, possibly on or near talus deposits. If possible, the location of this reservoir should be moved to the lower-relief ridgeline just to the north.

General recommendations are as follows:

- Reservoirs should be located on shallow slopes, where possible. Ridgelines typically have shallower slopes than the surrounding hillsides.
- Earthworks should be designed to avoid slope destabilisation, i.e. cuttings should not be placed at slope toes and fill should not be placed on upper slopes. This could increase landslide susceptibility on even low angled slopes.
- Site-specific landslide risk assessments should be carried out in susceptible areas (i.e. Avondale Reservoir Site). As discussed in Section 6.2.2, Sydney Water should consider approaching the Wollongong University Landslide Research Team regarding their upcoming detailed landslide mapping project covering the Study Area.

6.5 Management Recommendations for Roads and Tracks

Management measures for the construction, operation and rehabilitation of permanent and temporary infrastructure, such as access tracks, have been largely outlined in Section 6.1: Generic Recommendations.

Roads or tracks which are likely to be in place in the medium-to-long-term should be surfaced with erosion and water-resistant material, such as asphalt or Two Coat Chip Seal. This material should be removed and disposed of at an appropriate facility during rehabilitation.

6.6 Monitoring and Maintenance Programme

Erosion is a natural process which is likely to occur throughout the life of the project, even with the implementation of management strategies. A baseline erosion monitoring program should be undertaken in the study area to establish contemporary erosion rates. NSW Guidelines for monitoring and maintenance can be found in DLWC (2000) and Landcom (2004)

Disturbed and rehabilitated areas should be monitored regularly for both short- and long-term adverse landform change, particularly in areas that are particularly sensitive to erosion; are susceptible to landsliding, salinity, ASS; or which have low rehabilitation potential. Defects should be reported and remediated as soon as is practicable. Landform change can occur rapidly, especially during intense storms or prolonged rainfall. Inappropriate land management can also contribute to rapid change. Inspection of sensitive areas should be considered after each intense rainstorm. The monitoring schedule should, therefore, reflect the likely rate of change and vary accordingly.

Monitoring should include:

- Location, type and rates of erosion;
- Effectiveness and integrity of erosion control measures;
- Settlement of backfill over pipelines and other buried services;
- Soil tests (EC) in sensitive areas to assess operations-related salinity (DLWC, 2002);
- Runoff water quality;
- Groundwater levels and quality in the vicinity of wastewater pump stations.

Maintenance of defects observed during the monitoring should be routinely carried out, including:

- Repair of erosion-control structures;
- Removal of sediment build-up behind erosion control measures involving damming of water, to maintain retention capacity;
- Reinstatement of eroded soil or landforms;
- Re-levelling within areas of differential settlement over pipelines and other buried services;
- Revegetation of areas where ground coverage is inadequate.

In addition to monitoring and maintenance, it is recommended that performance criteria are set to indicate successful rehabilitation. The main target should be to produce a safe, non-polluting landform with self-sustaining soil fertility and a low stability hazard.

It is recommended that performance criteria should include:

- Creation of stable landforms which reduce erosion as far as is practicable. Erosion control measures should remain effective in the long-term.
- A safe landform which reduces the likelihood of accident and injury.
- A non-polluting environment which reduces suspended solids in runoff water to pre-disturbance levels, as far as is practicable.
- Self-sustaining soil fertility, such that nutrient cycling promotes consistent vegetation cover. The site should be self-sustaining for its designated land-use, as far as is practicable, with no management inputs required over and above those in adjacent undisturbed areas.
- Preservation of soil and groundwater chemistry such that soil nutrient levels can support vegetation and pre-disturbance soil pH and EC levels can be achieved.

A holistic approach is recommended when defining and monitoring performance criteria within the context of this study. This will assist in the creation of a balanced rehabilitated landform and environment. The findings and recommendations of other specialist reports should also be considered.

Lessons learnt during initial phases of the project regarding the success of various erosion control measures should be assessed and incorporated into subsequent phases. This strategy should limit repetition of ineffective management and mitigation measures.

6.7 Collation of Sydney Water Data and Information

Following discussions with Sydney Water, Coffey understands that many decades of geotechnical borehole, site-specific site remediation and management information has been recorded for the Study Area. It may prove cost-effective for Sydney Water to collate this information. Construction of a GIS-based geodatabase would enable spatial visualisation of the information. This should be beneficial in several ways:

- Spatial and aspect-related assessment of previous environmental impacts;
- Reduction in future environmental impact, as fewer ground investigation locations may be required;
- Refinement of constraint and impact mapping earlier in the project, thus giving a greater chance of addressing environmental issues during the project design phase, reducing the risk of environmental impact and improving targeted management procedures.

7 SUMMARY OF POTENTIAL ENVIRONMENTAL IMPACTS AND RECOMMENDED MANAGEMENT/MITIGATION MEASURES

Table 7.1 provides a summary of project-related potential environmental impacts; the likely location of such impacts; and the recommended management and mitigation measures.

Table 7.1 Summary of Project-Related Potential Environmental Impacts

Ref.	Aspect	Potential Environmental Impact	Likely Location or Project Component/Activity	Section & Figure Ref.	Recommended Management or Mitigation Measures	
					Design Considerations	Project Activities
1.1	Land Degradation: Erosion	General	Any project activity or component that involves ground disturbance	S5.1.1 S6.1.2 Figure R1		Prepare erosion control and planting and seeding plans during the design phase of the project, to be implemented during and following (respectively) construction. Plans should follow standard NSW guidelines, including DLWC (2000) and Landcom (2004)
1.2		Rainsplash or Runoff Erosion	Project activities or components which remove surface vegetation cover (the majority of components) or cause soil profile inversion (e.g. pipeline trench backfilling or earthworks)	S4.6.1 S5.1.1-3 S6.1.2-3 S6.2.3 Figure R1	• Avoid overbank/overland flood/flow paths; • Avoid erodible soils, in particular friable soils (with a low organic content and weak structure), reactive soils, sodic or dispersive soils.	• Carry out soil erodibility/erosion assessments according to NSW guidelines (DLWC, 2000; Landcom, 2004 and DECCW, 2008). The number of investigation locations should be appropriate for the cost and scale of the project, targeted at activities likely to increase erosion hazard in erodible soils. • Disturb only essential areas; • Reinstate the soil to its pre-disturbance profile; • Reinstate vegetation or erosion protection measures as soon as is practicable (target ground coverage of at least 70%); • Implement mitigation measures indicated in Section 6.1.2: Erosion Control Measures
1.3		Rill Erosion	As 1.1 but involving some flow concentration, typically on steeper slopes; or which compact or loosen soil, e.g. • Access tracks • Surface depressions (e.g. settlement along pipeline alignment) • Uncompacted spoil heaps or earthworks	S5.1.1-4 S5.4 S5.5 S6.1.2-3 S6.5 Figure R1	• As 1.2	• As 1.1 AND • Avoid creation of linear, compacted depressions; and creation of steep, bare slopes; • Roads in place for medium to long-term should be surfaced with erosion and water-resistant material (and this material removed and disposed of at an appropriate facility during rehabilitation) • Implement mitigation measures indicated in Section 6.1.2: Erosion Control Measures

Ref.	Aspect	Potential Environmental Impact	Likely Location or Project Component/Activity	Section & Figure Ref.	Recommended Management or Mitigation Measures	
					Design Considerations	Project Activities
1.4		Gully Erosion	As 1.1 and 1.2 BUT where activities cause considerable flow concentration or creation of a preferential pathway for flows (in particular in steep slope areas).	S5.1.1-4 S6.1.2-3 Figure R1	• As 1.2 AND • Avoid dispersive, sodic soils prone to gullying • Avoid steep, eroding watercourse reaches	• As 1.2 and 1.3 AND • Avoid creation of gullies. As soon as minor gullies are observed carry out site-specific assessment of erosion rates and suitable management measures; • Avoid creation of artificial nickpoints (waterfalls) within flow paths • Implement mitigation measures indicated in Section 6.1.2: Gully Management Measures
2	Timing of disturbance	• Erosion associated with flash flooding and trafficking of waterlogged soils • Slope failures/ landsliding	• Creek crossings • Soils prone to waterlogging (associated with TUs ap, fa, wb and wt) • Project components located in landslide-susceptible areas (see 18)	S6.1.2 Figure R1	• Avoid soils prone to waterlogging, creeks and landslide-prone areas when heavy and/or prolonged rain is forecast	• Carry out site-specific assessment of landform response to rainfall events; • Establish work stoppage and restart protocols for creek works and activities in landslide-prone areas, which should include rainfall thresholds.
3	Land Degradation: Soil Compaction	Alteration of soil profile and characteristics, including reduction in permeability and rehabilitation potential	Activities that subject the ground to loading, e.g. • Vehicle movement along access tracks • Laydown areas • Structures, in particular reservoirs Soft, compressible soils are typical of low-lying Coastal Plains	S5.1.4 S5.4 S5.5 S6.1.2	• Avoid soft, compressible soils • Avoid construction when soils are wet or waterlogged	• Carry out site-specific assessments to establish suitable rehabilitation and revegetation measures.
4	Land Degradation: Dust	Difficult soil manageability and reduction of rehabilitation potential	Activities that involve disturbance of silty and loam-rich topsoils or soils composed of loose fine sand in dry conditions, e.g. • Topsoil stripping • Vehicle traffic • Pipeline trenching/benching • Earthworks	S5.1.5 S5.5 S6.1.2	• Avoid dust-creating activities on soils with a fine-grained topsoil	• Reduce project disturbance times and exposure of bare soil; • Spray bare surfaces (e.g. tracks) with good quality water; • Implement vehicle weight/speed restrictions appropriate for track surface; • Use dust stabiliser additives, if necessary, to improve structural stability
5.1	Reduced soil quality	Poor or irregular vegetation growth	Activities that may result in soil profile inversion, e.g. • Trench backfilling • Earthworks	S5.1.6-7 S6.1.3	• More likely in soils which have a distinct profile, e.g. gradational and especially texture contrast soils	• Replace soils to their pre-disturbance profile, particularly where unfavourable subsoils (e.g. sodic, saline or ASS) are present
5.2		Poor rehabilitation potential	Activities that require import of construction materials, e.g. • Road base for access tracks • Concrete pad footings for buildings	S5.1.7 S5.5 S6.1.3		• Imported materials should be removed, as soon as is practicable • Site-specific rehabilitation plans should be prepared

Ref.	Aspect	Potential Environmental Impact	Likely Location or Project Component/Activity	Section & Figure Ref.	Recommended Management or Mitigation Measures	
					Design Considerations	Project Activities
6	Down-system deposition of eroded sediment: Sedimentation	• Burial of vegetation • Poor rehabilitation potential • Reduced water quality	Low relief areas downslope or downstream of potential erosion (in particular, low-lying areas of the Coastal Plains); Lake Illawarra	S5.1.8		• Implement effective erosion control upstream • Limit use of machinery in creek beds • Locate earthworks and stockpiles away from watercourses
7	Saline Soils	• Reduction in vegetation cover and poor rehabilitation potential • Water/wind erosion • Dispersivity • Corrosion	Insufficient information regarding known saline areas in the Study Area, but likely to be associated with low-lying former and contemporary estuarine, coastal and marine areas in TUs fa and sh. Saline soils have been found near Horsley and in the Avondale Road area (HLA, 2005)	S3.2.4 S4.5 S6.1.4	• Avoid areas likely to be saline	• Conduct salinity assessments as per DLWC (2002) guidelines. Sample spacing is dependent on land-use and proposed development, and should be appropriate for the cost and scale of the project.
8	Exposure of Acid Sulfate Soils	• Acid drainage • High salinity • Long-term heavy metal and groundwater contamination • Very poor rehabilitation potential • Associated ecosystem damage	Ground-disturbing activities in known or potential acid sulfate soil areas, especially those which may cause a drop in groundwater levels, in particular: • Deeply excavated pipelines (wastewater) or wastewater pumping stations where dewatering is likely e.g. wastewater pumping station SOS02CS and pipelines off Calderwood Road, Albion Park; Wastewater pipeline, Koonawarra • Shallow excavations in high risk areas, where it is more likely that shallow ASS will be found e.g. water pipeline off Yallah Bay Road; • Excavations in low risk areas, including wastewater pumping station TWLN009, Yallah; Water and wastewater pipelines in the Albion Park area, and wastewater pipelines in the Kembla Grange area; Wastewater pumping station SPS08CS and wastewater pipelines off the Illawarra Highway, Albion Park	S5.1.9 S5.3.3 S6.1.5 Figure R2	• Avoid areas mapped as being at risk of ASS, especially high risk areas.	• Conduct site-specific ASS assessments, with sampling e.g. every 50m – 100m along pipeline routes (spacing dependent on soil characteristics and proposed disturbance) as per ASSMAC (1998) recommendations • Model groundwater levels in dewatering areas; install groundwater monitoring bores in high risk areas where significant dewatering is likely • Return excavated acid soils to below water table within a short timeframe • Neutralise ASS with a suitable ameliorant (e.g. lime) • Design and implement an Acid Sulfate Soils Management Plan as per NSW ASS guidelines (ASSMAC, 1998; Tulau, 2007; DECC, 2008).

Ref.	Aspect	Potential Environmental Impact	Likely Location or Project Component/Activity	Section & Figure Ref.	Recommended Management or Mitigation Measures	
					Design Considerations	Project Activities
9.1	Land Contamination	• Contamination disturbance • Down-system spread of contamination, e.g. along pipeline as a preferential pathway	Ground disturbing activities in contaminated land. Likely areas of contamination are associated with: • Hazardous Building Materials • Uncontrolled Fill • Waste Disposal • Storage of Miscellaneous Materials • Application of Pesticides and other Agricultural Chemicals • Septic Tank Leaks • Use and Storage of Fuels/Chemicals • Livestock Pesticide Treatment Within the Study Area, contamination issues are possible at the following locations: • Piggery • Tallawarra Power Station • Mine Areas and Emplacements • Golf Courses • Former Abattoirs • Electrical Substations • Road and Railway Lines – throughout the Study Area • Petrol Stations	S3.2.6 S5.1.10 S6.1.6-7 Figure R2	• Avoid potentially contaminated sites	• Prepare and implement a Contamination Management Plan outlining general protocols for visual identification and management of contaminated soils, as per relevant NSW Guidelines (EPA, 1994; 1995; 1997; 1998; NEPC, 1999; DEC, 2006; 2007 and DECC, 2008; 2009) • Assessments should be carried out where contaminants are likely, and management advice sought if contamination is discovered during the project • Contaminated soils should be stockpiled separately, appropriately managed to reduce erosion and sedimentation; • Contaminants may be used for fill where ground conditions are not made worse • Advise landowner of previously unknown contamination • Contaminated soils which cannot be re-used should be classified as waste and disposed of at an appropriately licensed facility
9.2	Groundwater contamination	• Reduction in groundwater quality • Mobilisation/release of contaminated groundwater	Activities which involve dewatering works, e.g. • Deeply excavated wastewater pipelines • Wastewater pumping stations	S5.1.10 S5.1.11 S5.2.5 S6.1.8 Figure R2	• Avoid saline, sodic or ASS areas where groundwater interception is likely	• Consider groundwater quality monitoring during dewatering, including changes in pH, TDS and iron precipitation • Dispose of groundwater offsite if groundwater quality is poor (as per NEPC, 1999; ANZECC, 2000) • Management as per NSW Guidelines (DLWC, 1998a; NEPC, 1999; ANZECC, 2000)
9.3	Leaks: Sewage release; vehicle leaks	Soil and groundwater contamination	• Vehicles during post-design phases of the project, e.g. hydraulic hose rupture • Wastewater pipelines during operations	S5.1.0 S5.2.5 S6.1.6 S6.2.7		• Regular equipment checks should be carried out and spill kits should be spill kits should be readily available in areas where heavy equipment is being operated. • Sydney Water's design and construction team should assess the risk of contaminant leakage/release and design/implement appropriate management plans

Ref.	Aspect	Potential Environmental Impact	Likely Location or Project Component/Activity	Section & Figure Ref.	Recommended Management or Mitigation Measures	
					Design Considerations	Project Activities
10	Uncontrolled Fill	• Erosion • Contamination (see 9.1 and 9.2) • Combustion	Mine emplacements, areas of residential and agricultural fill (many undocumented)	S3.1.3 S6.1.7 Figure R2	• Avoid areas of fill where practicable	• Fill properties should be investigated • Carry out geotechnical testing to assess particle size distribution, presence of combustibles and contamination • Fill should be stripped and stored separately to natural soils • Implement erosion control measures to reduce spread of contaminants (see 9.1 and 9.2)
11	Changes in groundwater levels	• Changes in groundwater chemistry • Dryland salinity (see 7) • ASS (see 8) • Reduction in rehabilitation potential	Activities which involve dewatering works, e.g. • Deeply excavated pipelines (wastewater) or wastewater pumping stations which may intersect groundwater (most likely all pumping stations)	S5.1.11 S5.2.5 S5.3.2 S6.1.8 S6.2.7 S6.3.2 Figure R3	• Avoid areas mapped as being of high or medium risk of ASS • Avoid areas where saline soils are likely to be present	• Carry out trenching in sections which are a maximum of 50m long and 2m wide. Backfill within 2 weeks. • Establish groundwater level and chemistry monitoring bores in the vicinity of excavations during construction; • Obtain temporary dewatering licence, if necessary, after consultation with NOW. • Devise and implement a Groundwater Management Plan to establish response protocols for adverse impacts (partially covered in ASS and Salinity Management Plans)
12	Changes in groundwater recharge and evapotranspiration	• Footprint of project components are considered too small to have appreciable effect on groundwater levels	Project components which cause the ground surface to become impermeable and/or where vegetation is removed.	S5.1.11 S5.4		• Impact minor, does not warrant further consideration
13.1	Activation of preferential pathways in subsoil	• Piping (tunnelling) erosion • Settlement and creation of surface depressions • Spread of contamination	Pipeline trenching through dispersive or contaminated soils	S5.2.3 S6.1.13 S6.2.7	• Avoid sodic, dispersive soils	• As 9.2, but soil investigations should be targeted on areas of likely sodic, dispersive soils as well as contaminated soils
13.2		• Rapid groundwater discharge to watercourses or Lake Illawarra		S5.2.3 S6.2.7	• Avoid sodic, dispersive soils	• Design and implement engineering controls to provide a barrier to groundwater flow

Ref.	Aspect	Potential Environmental Impact	Likely Location or Project Component/Activity	Section & Figure Ref.	Recommended Management or Mitigation Measures	
					Design Considerations	Project Activities
14	High Groundwater Levels	• High groundwater inflows • Collapse of excavations (slope failure)	Project components which intersect permeable layers, e.g. • Deeper sediments along Mullet Creek • Sand layers along Robins Creek, Horsley (a tributary of Mullet Creek) • Palaeochannel sediments Areas of high groundwater levels, e.g. • Low-lying areas of the Coastal Plains • Unpredictable locations within Talus	S4.9 S4.14 S5.2.5 S6.1.8 Figure R3		• Excavations may require controlled dewatering, shoring and potentially use of sheet piling to reduce the likelihood of collapse
15	Dewatering Groundwater Disturbance	• Reduced groundwater levels up to 100m from excavation and further during dry periods	Dewatering associated with wastewater pumping stations, in particular associated with permeable soils	S5.3.2 S6.1.8 S6.3.2 Figure R3		• Monitor groundwater inflows during construction activities and revise dewatering pumping options accordingly.
16	Project activities close to Lake Illawarra	• High groundwater inflows • Salt water intrusion	Pipeline and pumping station (TWLN009) off Yallah Bay Road	S4.9 Figure R3	• Where possible, relocate project activities and components to at least 250m from Lake Illawarra	• Wastewater pump station will require assessment of salt water intrusion potential as part of temporary dewatering licence, if less than 250m from Lake Illawarra
17	Pipelines running through existing groundwater bores	Loss of environmental monitoring location	Groundwater bores in Albion Park • GW072794 • GW107819	S4.14 S6.2.7 Figure R3	• Avoid groundwater bores	• Notify bore owners • Confirm bore is no longer in use
18	Landslides	• Triggering of new landslide • Reactivation of existing landslide	Activities which involve adding material to upper slopes or cutting away toe slopes, particularly along the Illawarra Escarpment, e.g. • Pipeline trenching and benching for tracks, especially along side-slopes • Earthworks e.g. for reservoirs or pumping stations. Avondale Reservoir Site; Calderdale Pumping Station (SPS09CS) and associated pipeline; Within and adjacent to mapped talus near Kembla Grange	S5.2.1 S5.3.1 S5.4 S5.5 S6.2.2 S6.4.1 FigureR1	• Avoid landslide-susceptible areas, i.e. slopes > 10°, particularly where talus is present, with an awareness that landslides can be triggered on lower angled slopes following slope-destabilising artificial alteration • Locate project components on lower-angled benches and ridges within steep slope areas	• Avoid removing material from toe slopes or adding material to upper slopes • Where it is not possible to relocate project components, earthworks should be designed to reduce the likelihood of slope destabilisation • Carry out site-specific Landslide Risk Assessments in accordance with AGS (2007)
19	Earthquake Hazard			S4.3		• Pipelines and associated infrastructure should be engineered to withstand future seismic activity.

Ref.	Aspect	Potential Environmental Impact	Likely Location or Project Component/Activity	Section & Figure Ref.	Recommended Management or Mitigation Measures	
					Design Considerations	Project Activities
20	Differential Settlement of Pipeline Backfill and Padding	Undulations in ground surface possibly leading to drainage concentration (see 1.2 and 1.3) or waterlogging	Pipeline reinstatement activities	S5.2.2 S6.1.10 S6.2.3 S6.6	• Avoid reactive soils	• Carry out site-specific geotechnical assessment of soil properties • Import granular bedding if in-situ soils are unsuitable • Bury pipeline below zone of seasonal moisture change • Mound backfill to allow for settling, if required • Compact backfill to pre-construction levels where possible • Monitor backfilled areas for subsidence or heave
21	Artificial landform change	Temporary to semi-permanent alteration of topography and landform	Activities which involve earthworks: the scale of earthworks being directly related to the scale of impact, e.g. • Pipeline trenching is anticipated to have a temporary topographic impact; • Roads and tracks are anticipated to have a longer-term impact; • Pumping stations and borrow pits are anticipated to have a semi-permanent but small-scale impact e.g. Calderdale Pumping Station (SPS09CS); • Reservoirs are anticipated to have the greatest spatial impact, which will also be semi-permanent e.g. Avondale Reservoir	S5.3.1 S5.4 S6.6 Figure R1	• Avoid areas of steep or undulating relief, which require levelling • Avoid areas where adverse associated landform change could result, e.g. landslide-susceptible areas • Locate project components on low relief benches, ridges or low-lying areas	• Design earthworks to reduce the likelihood of adverse associated landform change (see 6) • Rehabilitated site should be designed to be self-sustaining, stable landforms
22	General Watercourse Recommendations	See 22.1 – 22.7	Project activities which cross watercourses, or which run through designated riparian corridor	S5.2.4 S6.2.6 Figure R1		Carry out a phased fluvial geomorphological assessment of watercourses in the Study Area • Initially catchment and reach-based • Sub-reach assessment of crossings in dynamic/sensitive reaches • Final phase geotechnical assessment of channel material properties targeted on high constraint/risk of impact areas

Ref.	Aspect	Potential Environmental Impact	Likely Location or Project Component/Activity	Section & Figure Ref.	Recommended Management or Mitigation Measures	
					Design Considerations	Project Activities
22.1	Watercourse Erosion	Bank destabilisation; nickpoint (waterfall) retreat	Activities which create locally steep channel sections (bed or bank) or which cross eroding channel reaches. There are 284 pipeline creek crossings in the Project Approvals Area alone and site-specific assessment of these crossings has not been carried out at this stage. Mullet Creek between Avondale and Brownsville is particularly wide and appears highly dynamic.	S5.2.4 S6.2.6 Figure R1	• Avoid erodible soils, reaches of contemporary erosion (e.g. outer banks of meander bends) and historically dynamic reaches (subject to geomorphological assessment of likely future channel behaviour) • Relocate watercourse crossings away from eroding sub-reaches where practicable	• Where necessary, implement soft engineering measures designed with watercourse dynamicism in mind, rather than implementing hard engineering solutions
22.2			Implementation of hard engineered structures which may cause preferential erosion	S5.2.4 S6.2.6	• Avoid sodic, dispersive soils	• Avoid structures which restrict the natural adjustability of the channel • Avoid the use of concrete, gabions or reno mattresses, as their use is not condoned by NOW, as these restrict channel adjustability and introduce artificial materials into the channel. • Design structures to trench, not inner-channel geometries
22.3		Creation of tributary gullies	See 1.4	S5.2.4 S6.2.6	See 1.4	See 1.4
22.4	Excavation along watercourses	Irreversible alteration of watercourse system dynamics	Pipelines (or other project components) excavated along watercourses (none in proposed alignment)	S5.2.4 S6.2.6		• Should pipeline realignments be required, alignments along (within) watercourse channels should not be considered
22.5	Disruption of erosion-resistant creek bed gravel column or layer	Preferential localised erosion	Pipeline creek crossings	S5.2.4 S6.2.6 Figure R1	• The majority of watercourses in the area are thought to be located on erosion-resistant gravel lag or columns	• Avoid disturbance of gravel deposits: directional drill beneath deposits and beyond the creek trench where practicable • If trenching is necessary, reinstate to pre-disturbance conditions as far as is practicable. Implement erosion control measures (see 1.1 and 1.2)
22.6	Floodplain Erosion	Creation of preferential flow pathways possibly leading to floodplain erosion or channel avulsion	Trenching parallel and adjacent to watercourses, particularly through highly erodible soils.	S5.2.4 S6.2.6 Figure R1	• Avoid floodplains comprising high erodibility soils • Avoid aligning pipelines parallel to watercourses within active floodplains: realign outside 100-year flood zone where practicable	• Reinstate soil and vegetation to pre-disturbance profiles and patterns where practicable

Ref.	Aspect	Potential Environmental Impact	Likely Location or Project Component/Activity	Section & Figure Ref.	Recommended Management or Mitigation Measures	
					Design Considerations	Project Activities
22.7	Disruption of Riparian Corridor	Erosion and sedimentation associated impacts to ecology and habitat	Activities within the designated riparian corridor	S5.2.4 S6.2.6 Figure R1	• Avoid designated riparian corridors	• Where activities or components must be located within the Riparian Corridor, DIPNR (2004); Southern Rivers CMA (2006); NOW (2008) and Wollongong City Council (2009) guidelines should be considered. Consultation with NOW is recommended. • Rehabilitation should consider pre-disturbance vegetation, geomorphology, hydrology and water quality, and consider DIPNR (2004), Landcom (2004) and NOW (2008) guidelines)
23	Pipeline route intercepts dams/ponds	• Damage to farm dams and disruption of local water balance	• Between Larkins Road and the Princes Highway • Near Whytes Gully Landfill	S4.14 Figure 4.7	• Realign pipeline away from farm dams.	

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8.6 Reviewed for Background Appreciation of Study Area

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Figures

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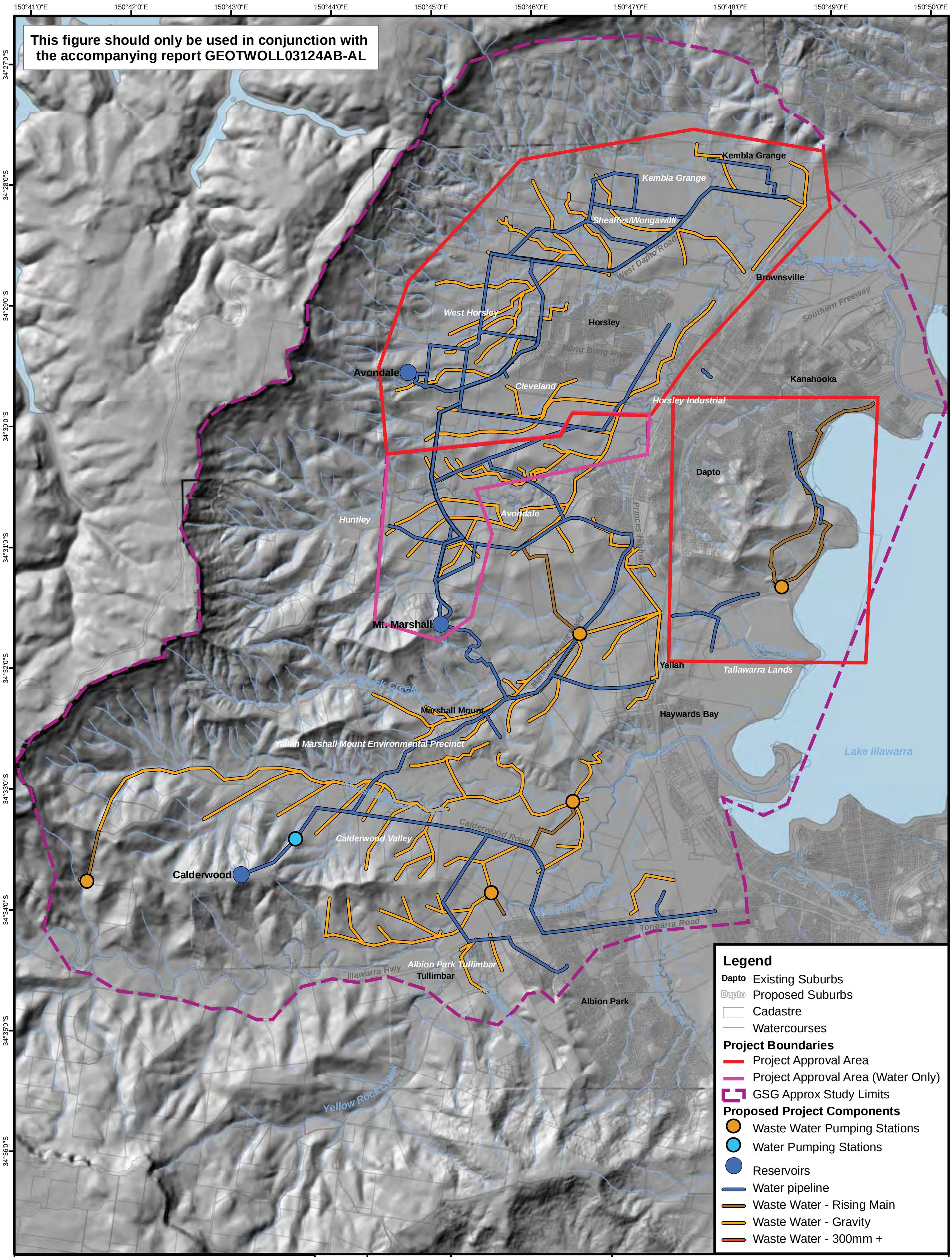

km

0 0.5 1 1.5 2

N
W E
S

Projection: MGA Zone 56

Source of data:
1. Contours and cadastre supplied by Sydney Water
2. All other data supplied by Wollongong and Shellharbour City Councils

Drawn	LAE
Approved	SM
Date	May 10, 2011
Scale	1:75,000
Original Size	A4

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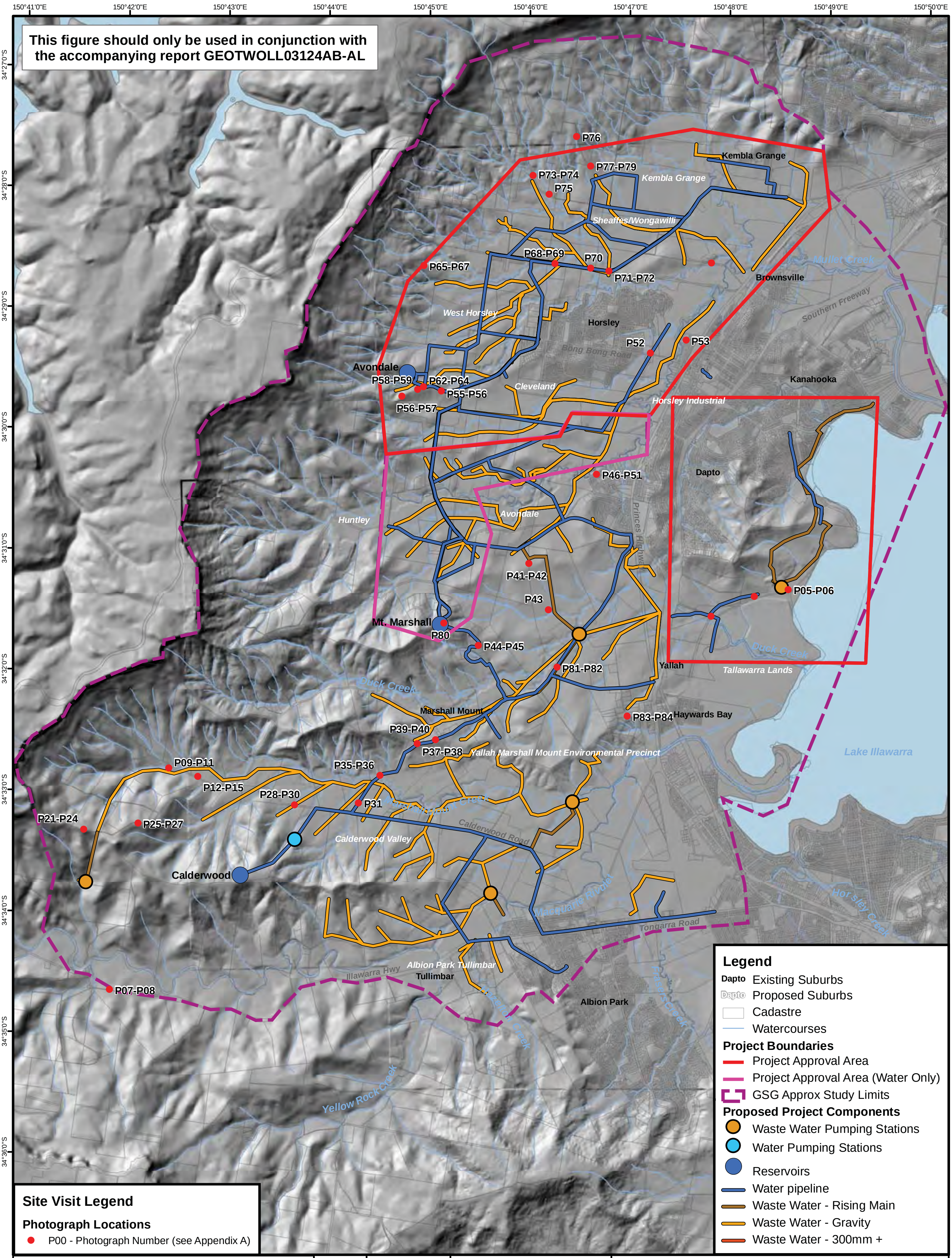
WDURA and AGA
Geology, Soils and Groundwater Assessment

Title
Location Map of the GSG Study Area

Project No.
GEOTWOLL03124AB

Figure No.
Figure 1



This figure should only be used in conjunction with the accompanying report GEOTWOLL03124AB-AL

Projection: MGA Zone 56

Source of data:
1. Site visited on 14 March 2011. Numbered locations refer to photographs in Appendix A
2. Contours and cadastre supplied by Sydney Water
3. All other data supplied by Wollongong and Shellharbour City Councils

Drawn	LAE
Approved	SM
Date	May 10, 2011
Scale	1:75,000
Original Size	A4

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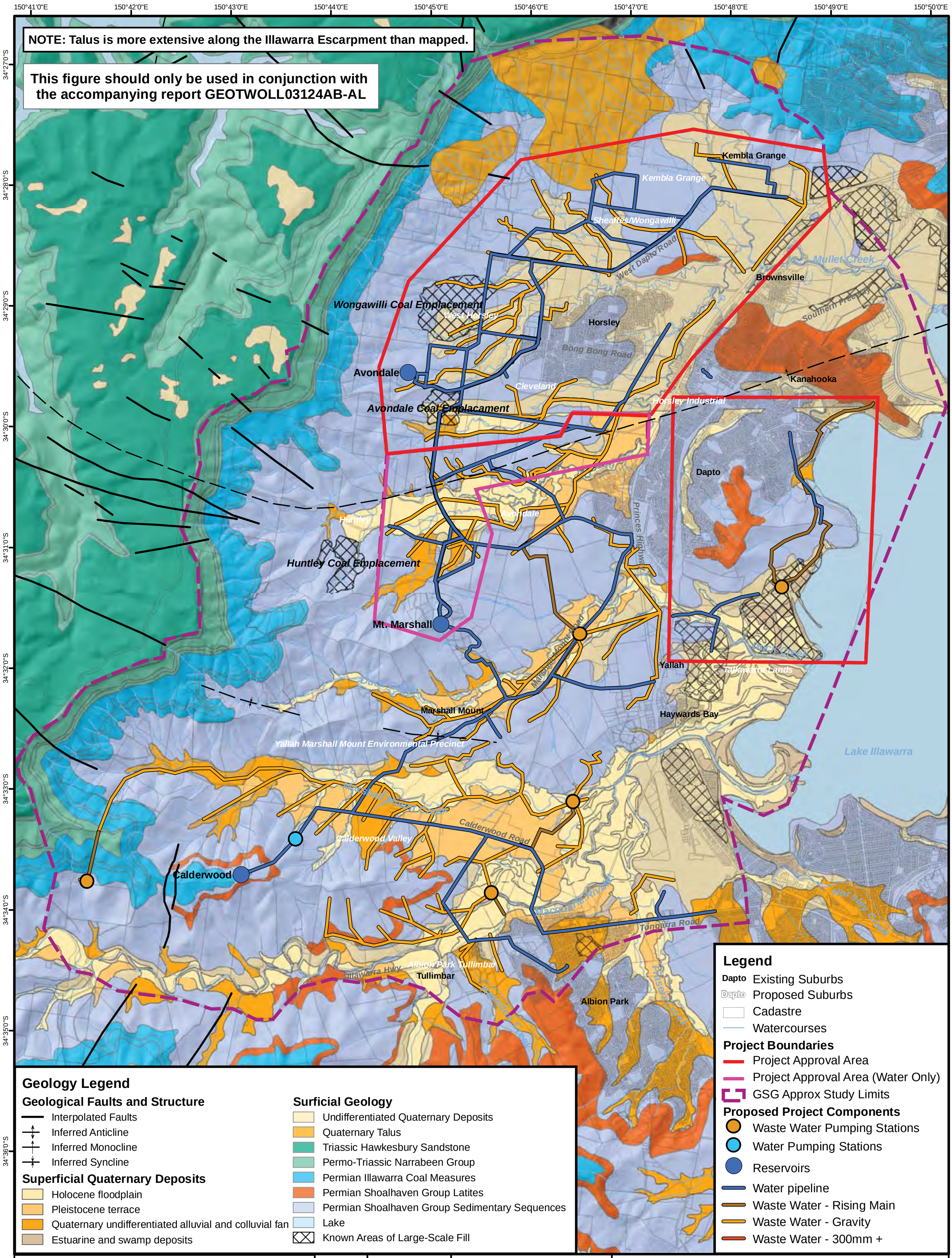
Title **Site Visit Locations in the GSG Study Area**

Project No. GEOTWOLL03124AB

Figure No. **Figure 2**



NOTE: Talus is more extensive along the Illawarra Escarpment than mapped.

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km
0 0.5 1 1.5 2

N
W E
S

Projection: MGA Zone 56

Source of data:
1. Coal Wash Emplacements digitised by Coffey, other fill from 1:25,000 ASS Mapping and Kiama 1:100,000 Soil Landscape Mapping
2. Contours and cadastre mapping supplied by Sydney Water
3. Geology: DPI Southern Coalfields 1:100,000 and NSW 1:250,000 Statewide Geology; Quaternary Deposits: 1:25,000 Coastal Quaternary Geology
4. All other data supplied by Wollongong and Shellharbour City Councils

Drawn	LAE
Approved	SM
Date	May 10, 2011
Scale	1:75,000
Original Size	A4

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Title
Surficial Geology of the Study Area

Project No.
GEOTWOLL03124AB

Figure No.
Figure 3.1

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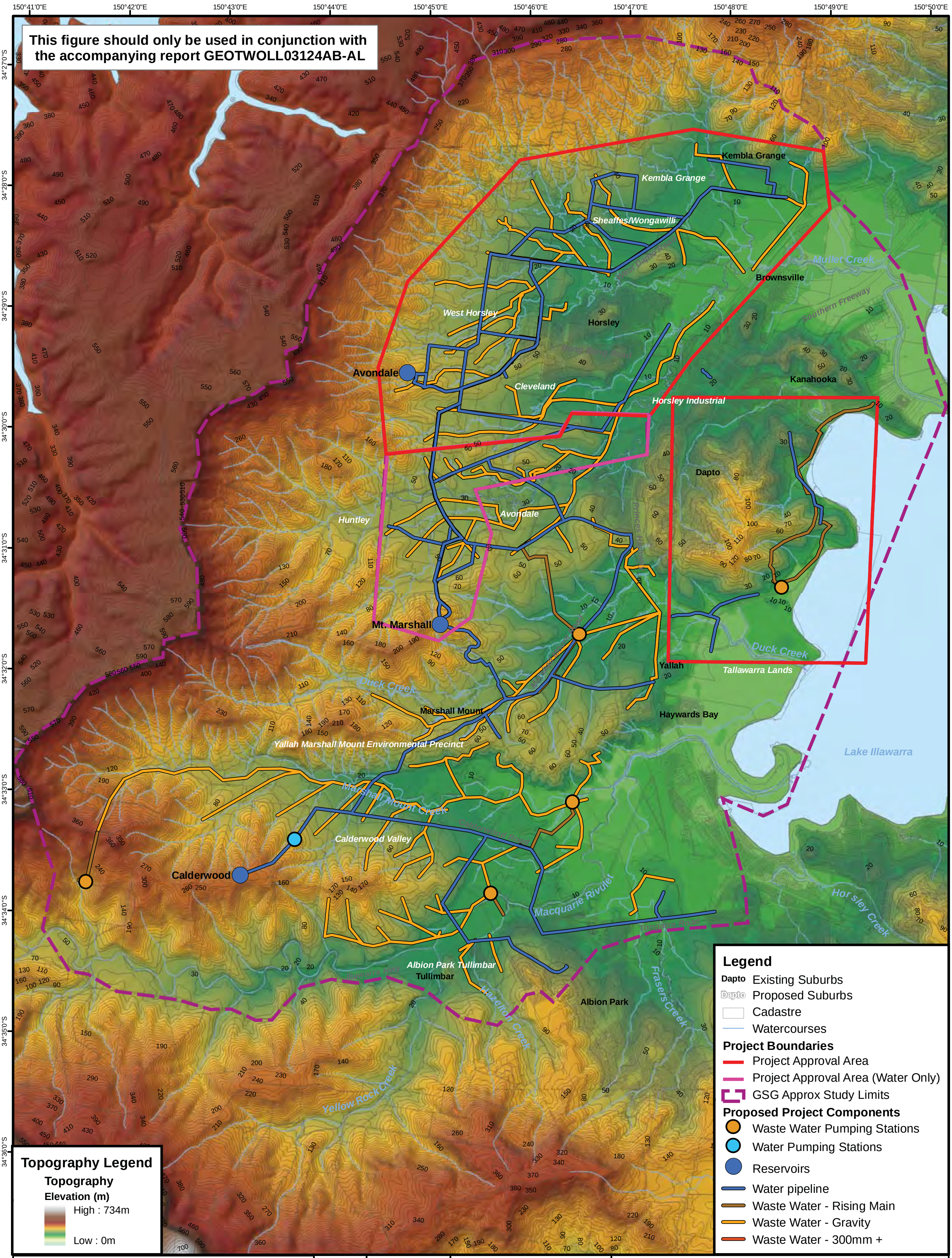

km
0 0.5 1 1.5 2

N
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S

Projection: MGA Zone 56

Source of data:
1. Topographic DEM created from contours supplied by Sydney Water
2. Cadastre supplied by Sydney Water
3. All other data supplied by Wollongong and Shellharbour City Councils

Drawn	LAE
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Date	May 10, 2011
Scale	1:75,000
Original Size	A4

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Topography of the Study Area

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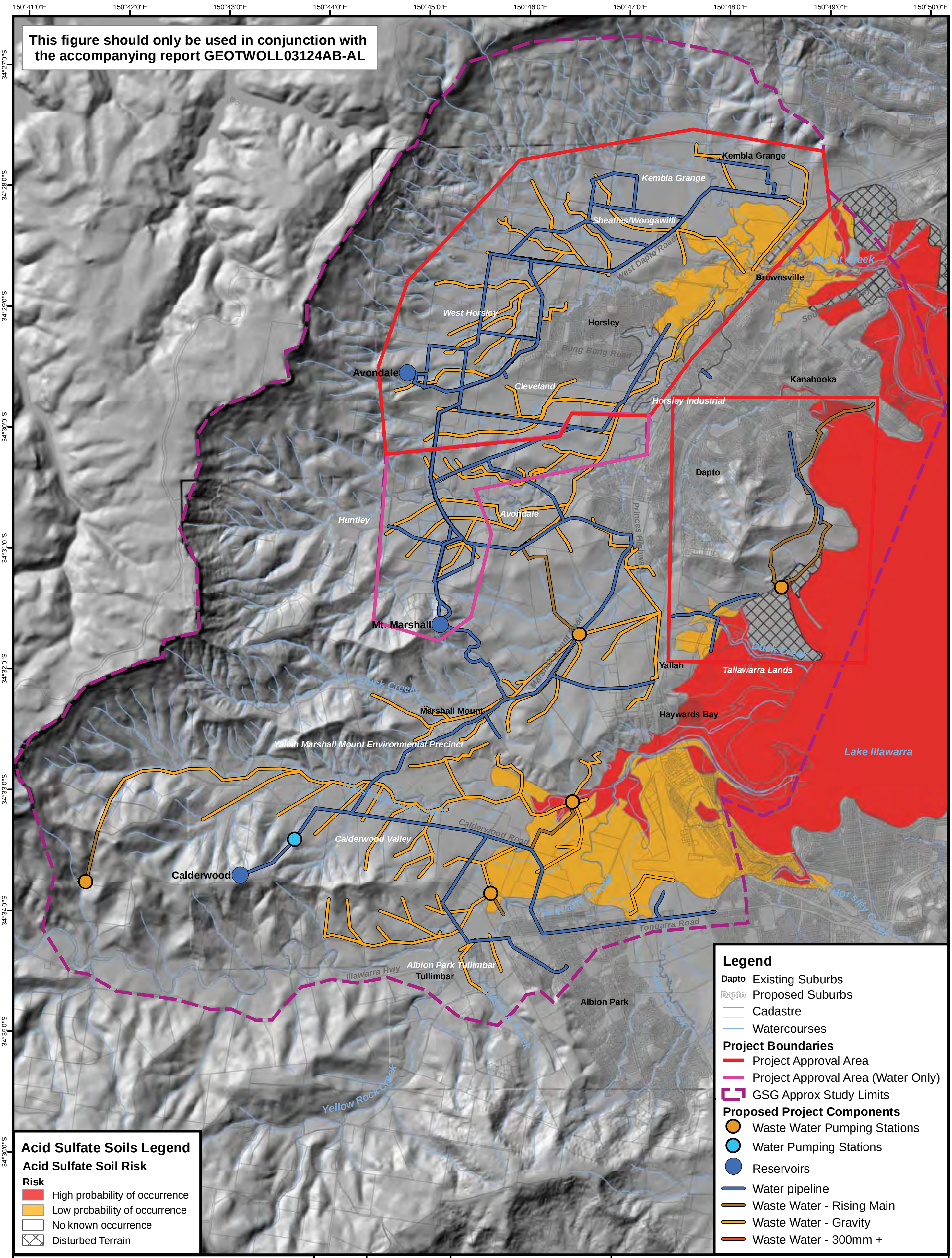
Figure No.
Figure 3.2



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km
0 0.5 1 1.5 2

N
W E
S

Projection: MGA Zone 56

Source of data:
1. Contours and cadastre supplied by Sydney Water
2. Acid Sulphate Soils: DECC 1:25,000 risk maps
3. All other data supplied by Wollongong and Shellharbour City Councils

Drawn	**LAE**
Approved	**SM**
Date	**May 10, 2011**
Scale	**1:75,000**
Original Size	**A4**

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Title
Risk of Acid Sulfate Soils in the Study Area

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Figure No.
Figure 3.3

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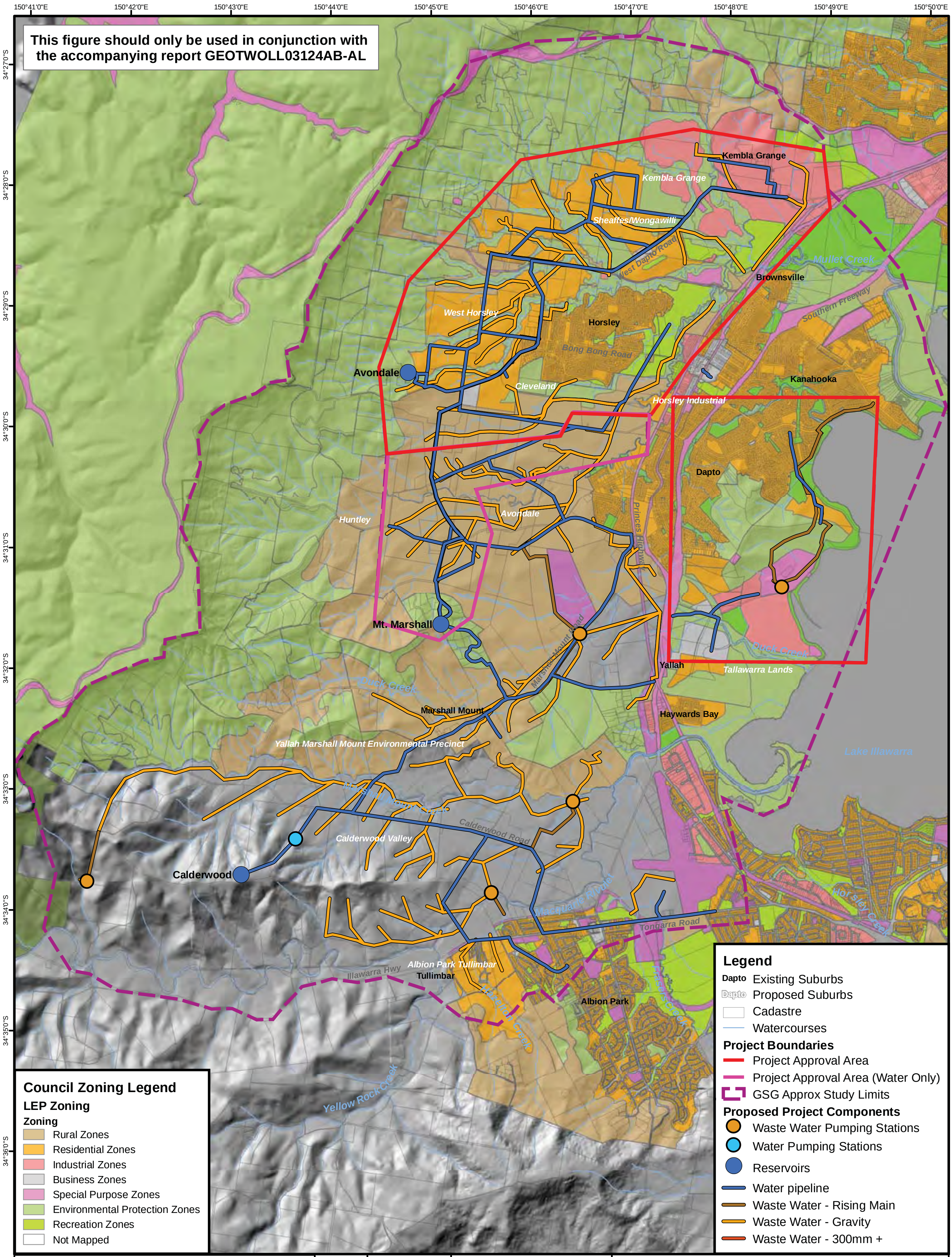

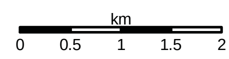

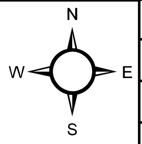

Projection: MGA Zone 56

Source of data:
1. Contours and cadastre supplied by Sydney Water
2. Zoning based on 1990, 2009 and 2010 Wollongong City Council LEP Zoning
and 2000 Shellharbour City Council LEP Zoning
3. All other data supplied by Wollongong and Shellharbour City Councils

Drawn	LAE
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Date	May 10, 2011
Scale	1:75,000
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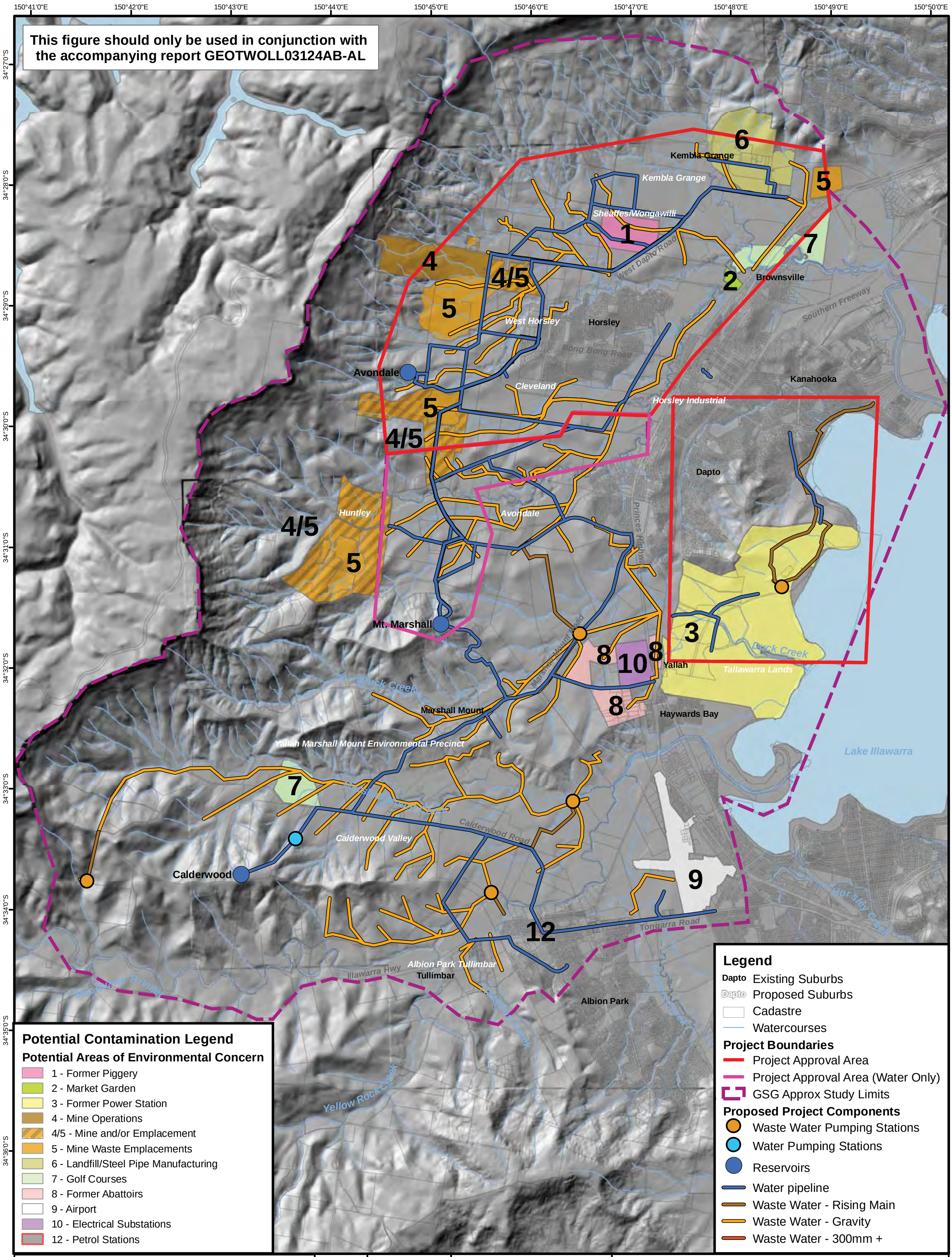
Geology, Soils and Groundwater Assessment

Title
LEP Zoning in and near the Study Area

Project No.	Figure No.
GEOTWOLL03124AB	**Figure 3.4**



This figure should only be used in conjunction with the accompanying report GEOTWOLL03124AB-AL

km
0 0.5 1 1.5 2

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Projection: MGA Zone 56

Source of data:
1. Potential Areas of Environmental Concern mapped by Coffey
2. Contours and cadastre supplied by Sydney Water
3. All other data supplied by Wollongong and Shellharbour City Councils

Drawn	LAE
Approved	SM
Date	May 10, 2011
Scale	1:75,000
Original Size	A4

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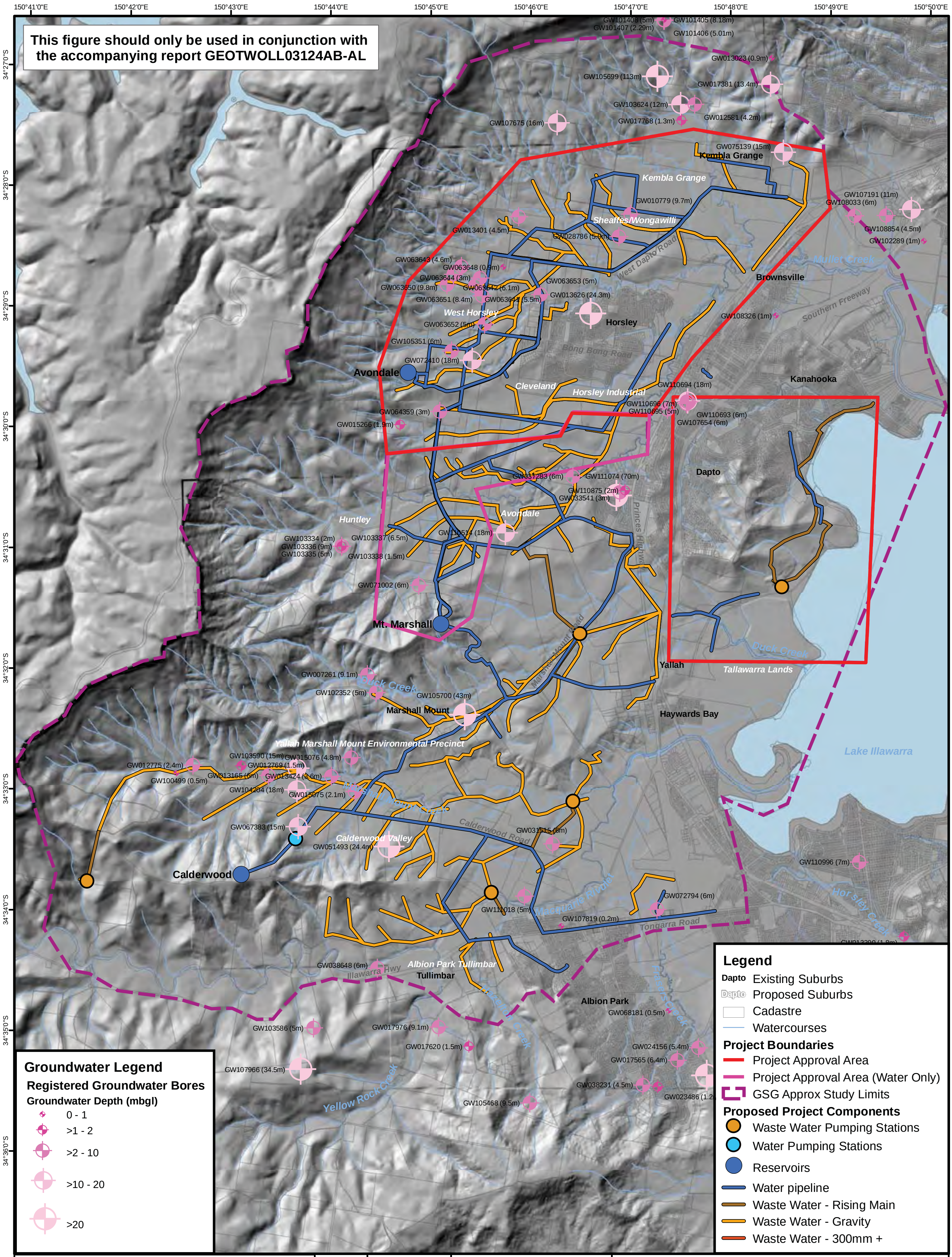
Title
Potential Contamination Sites in the Study Area

Project No.
GEOTWOLL03124AB

Figure No.
Figure 3.5



This figure should only be used in conjunction with the accompanying report GEOTWOLL03124AB-AL

km
0 0.5 1 1.5 2

N
W E
S

Projection: MGA Zone 56

Source of data:
1. Registered Bore data supplied by NSW Office of Water
2. Cadastre supplied by Sydney Water
3. All other data supplied by Wollongong and Shellharbour City Councils

Drawn	LAE
Approved	SM
Date	May 10, 2011
Scale	1:75,000
Original Size	A4

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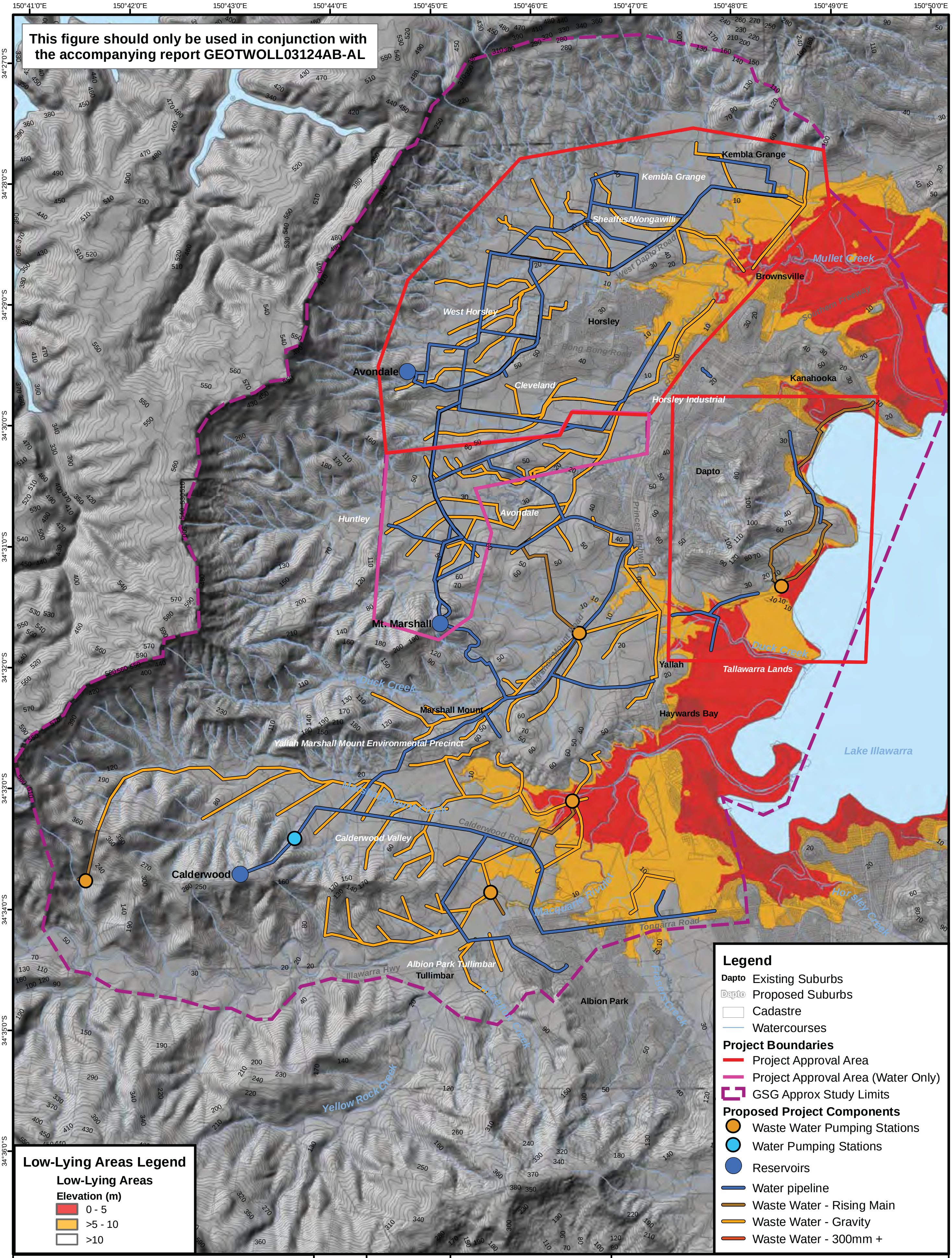
Geology, Soils and Groundwater Assessment

Title **Registered Bores in and near the Study Area**

Project No. GEOTWOLL03124AB

Figure No. **Figure 3.6**



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km
0 0.5 1 1.5 2

N
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Projection: MGA Zone 56

Source of data:
1. Contours and cadastre supplied by Sydney Water
2. All other data supplied by Wollongong and Shellharbour City Councils

Drawn	LAE
Approved	SM
Date	May 10, 2011
Scale	1:75,000
Original Size	A4

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Geology, Soils and Groundwater Assessment

Title: **Low-Lying Areas within the Study Area**

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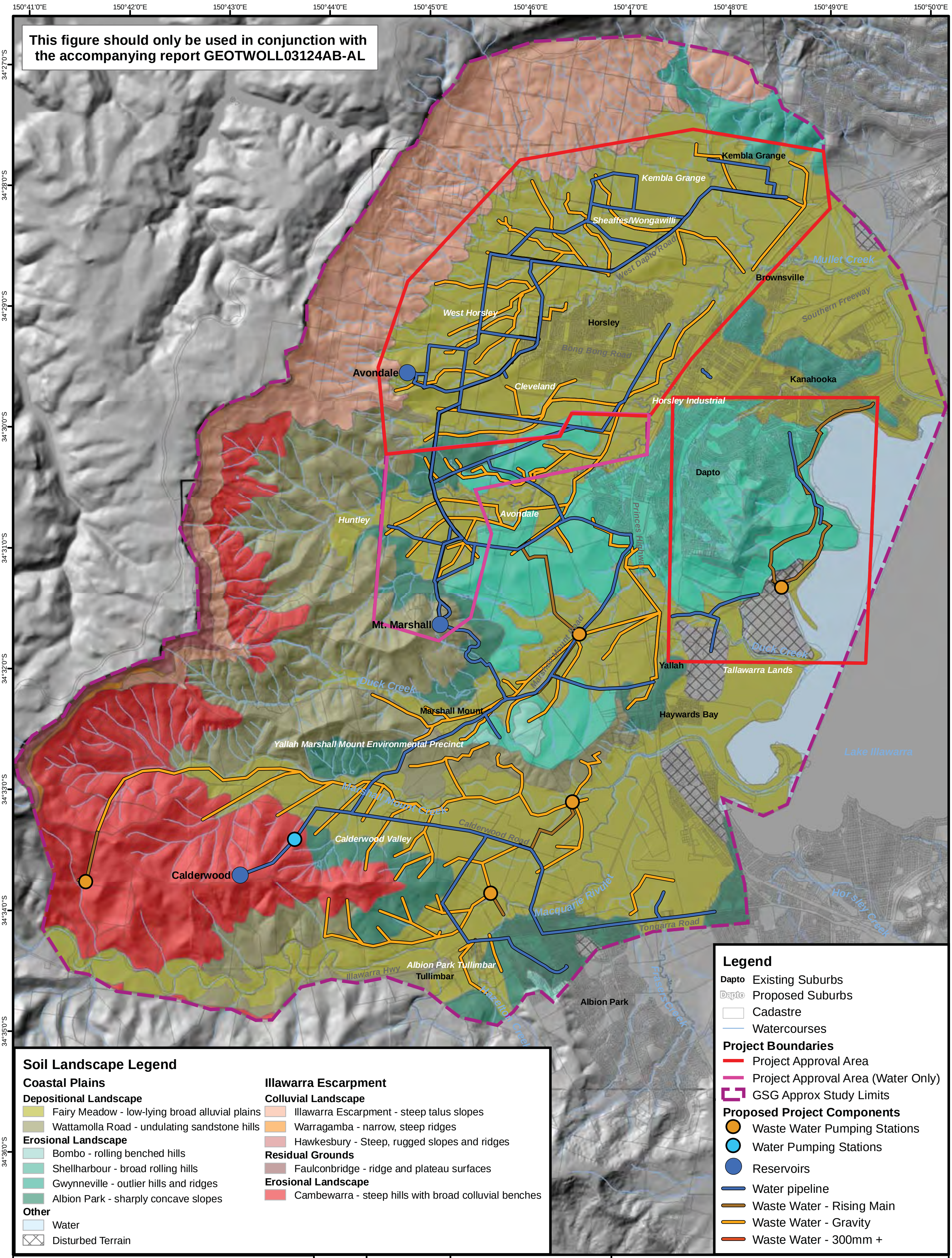
Figure No. **Figure 3.7**

This figure should only be used in conjunction with the accompanying report GEOTWOLL03124AB-AL



Projection: MGA Zone 56

Source of data:
1. Contours, cadastre and Soils Landscape Mapping supplied by Sydney Water
2. Soils Landscape Mapping: Hazelton (1992), Kiama 1:100,000 Soil Landscapes
3. All other data supplied by Wollongong and Shellharbour City Councils

Drawn	LAE
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Date	May 10, 2011
Scale	1:75,000
Original Size	A4

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Project: WDURA and AGA
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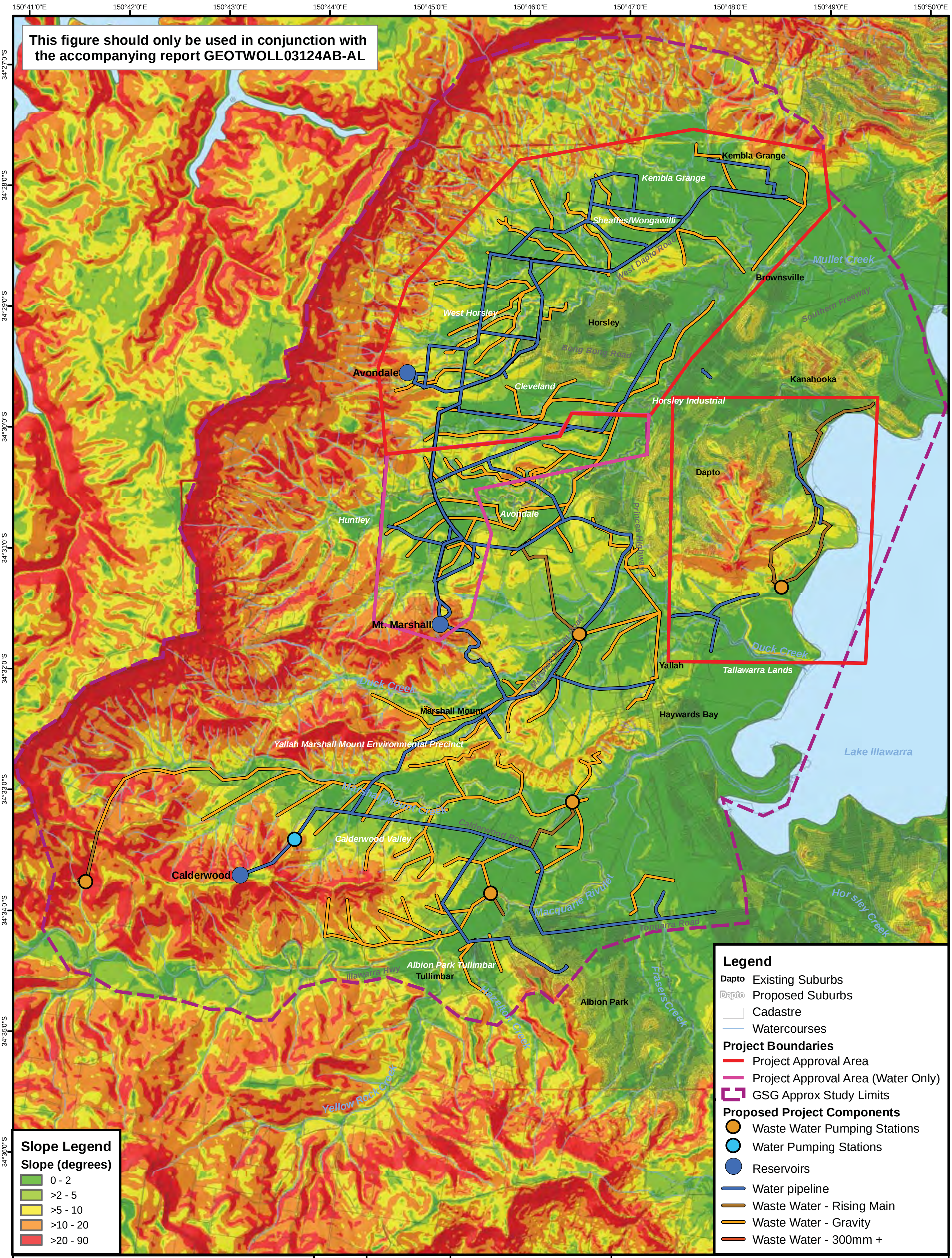
Title: **Soil Landscape Units of the Study Area**

Project No. GEOTWOLL03124AB

Figure No. **Figure 3.8**



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km
0 0.5 1 1.5 2

N
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Projection: MGA Zone 56

Source of data:
1. Slope steepness derived from contours supplied by Sydney Water
2. Cadastre supplied by Sydney Water
3. All other data supplied by Wollongong and Shellharbour City Councils

Drawn	LAE
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Date	May 10, 2011
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Geology, Soils and Groundwater Assessment

Title
Slope Steepness in and near the Study Area

Project No.
GEOTWOLL03124AB

Figure No.
Figure 4.1