Orica Australia Pty Ltd

Contamination Action Plan

Yarwun Manufacturing Facility
30 Reid Road, Yarwun, QLD

5 December 2017

52877 112133 R003 Rev 0

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52877 112113 R003 Rev 0

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Executive Summary

JBS&G Australia Pty Ltd (JBS&G) was engaged by Orica Australia Pty Ltd (the client) to prepare a Contamination Action Plan (CAP) for the land identified as Lot 138 on CTN2123, located at 30 Reid Road, Yarwun, Queensland (the site).

A site location map is presented as **Figure 1**. A site features plan which shows the site boundaries is provided as **Figure 2**.

Orica was issued a notice to conduct or commission an environmental evaluation from the Queensland Department of Environment and Heritage Protection (EHP) on 21 July 2017. The notice was issued on the grounds that "*…under section 326B of the Environmental Protection Act 1994 the administrating authority is satisfied on reasonable grounds that an activity or proposed activity is causing, or is likely to cause environmental harm"*, with the environmental harm relating to increasing concentrations of free cyanide (on site), total ammonia and nitrate (on site, at the site boundary and off site) in groundwater.

The notice listed a number of requirements for Orica to implement. The first requirement was to engage a Suitable Qualified Person (SQP) to conduct a Detailed Site Investigation (DSI). The DSI was completed by JBS&G in August 2017 (*Orica Australia Pty Ltd Yarwun Manufacturing Facility Detailed Site Investigation, 30 Reid Road, Yarwun QLD*, JBS&G Australia Pty Ltd, 31 August 2017).

The second requirement was to engage a SQP to produce a revised Conceptual Site Model (CSM). The CSM was completed by JBS&G in December 2017 (*Orica Australia Pty Ltd Yarwun Manufacturing Facility Conceptual Site Model, 30 Reid Road, Yarwun QLD*, JBS&G Australia Pty Ltd, 5 December 2017).

The third requirement was to engage a SQP to prepare a CAP (this report).

It is noted that JBS&G previously prepared a document titled 'Groundwater Remediation Action Plan' (RAP) for the site in June 2014 (JBS&G, 2014) in response to a requirement of the Environmental Authority. This CAP provides a revision of the RAP based on current site conditions and replaces all previous versions of the RAP.

The objective of the investigation is to prepare a CAP, in accordance with the reporting requirements of the National Environmental Protection (Assessment of Site Contamination) Measure as amended 2013 (ASC NEPM), which includes the following:

- An evaluation of the current controls used to mitigate groundwater contamination;
- Details of mitigation measures that are required to manage potential or actual contamination pathways; and
- Details of any procedural or structural changes that require implementation to reduce the risk of further groundwater contamination.

The objectives of this report have been taken directly from requirement 3 of the notice.

Subject to the limitations in **Section 10** and with respect to the objectives stated in **Section 1.2** JBS&G conclude that:

- Historical groundwater investigations undertaken at the site have identified:
    - Ammonia and nitrate are present in groundwater at concentrations exceeding the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality Australian and New Zealand Environment and Conservation Council (ANZECC)* trigger values for the protection of fresh water ecosystems. The highest concentrations of ammonia and nitrate are present on the site in the area of the AN Complex although

significant concentrations are present in groundwater at the site boundary and in offsite areas.

  - Free cyanide is present at concentrations exceeding the ANZECC 2000 trigger values in groundwater on the site. The highest concentrations are associated with the Cyanide Plant and the plume is completely within the site boundaries. Total cyanide has also been identified in groundwater with low concentrations identified at the site boundary.

- Primary source control works to reduce the potential for contaminants to enter the subsurface have already been undertaken on the site. However, groundwater contamination trends noted in source areas indicate further work is required to manage source releases. In order to limit future releases from AN and Cyanide source areas, a number of projects have been scheduled for further upgrades to limit future releases from AN and Cyanide source areas.

- A groundwater interception trench and treatment system has been installed on the site boundary to remove ammonia and nitrate mass flux in the perched aquifer. While early operation of the system did not achieve significant mass removal rates the recent operation of the system has resulted in mass removal rates of a similar magnitude to the calculated mass flux rates at the site boundary and is therefore consistent with the goal of decreasing mass flux from the site. However, the lack of significant water level drawdown near the trenches and the observed increase in contaminant concentrations at locations between the trenches implies that additional extraction is required.

- The additional extraction will be achieved by the installation of additional trenched portions along the site boundary between the two existing trenches.

- As free cyanide in groundwater does not currently pose an unacceptable risk to the environment MNA is considered a suitable remediation strategy.
- Validation of the success of the remediation strategies will be undertaken by ongoing groundwater monitoring and assessment of the remediation strategies in the annual groundwater monitoring report.
- Implementation of the above remediation strategies will successfully address the objectives and requirements for remediation detailed in this CAP.

1. Introduction

JBS&G Australia Pty Ltd (JBS&G) was engaged by Orica Australia Pty Ltd (the client) to prepare a Contamination Action Plan (CAP) for the land identified as Lot 138 on CTN2123, located at 30 Reid Road, Yarwun, Queensland (the site).

A site location map is presented as **Figure 1**. A site features plan which shows the site boundaries is provided as **Figure 2**.

Orica was issued a notice to conduct or commission an environmental evaluation from the Queensland Department of Environment and Heritage Protection (EHP) on 21 July 2017. The notice was issued on the grounds that "…*under section 326B of the Environmental Protection Act 1994 the administrating authority is satisfied on reasonable grounds that an activity or proposed activity is causing, or is likely to cause environmental harm"*, with the environmental harm relating to increasing concentrations of free cyanide (on site), total ammonia and nitrate (on site, at the site boundary and off site) in groundwater.

The notice listed a number of requirements for Orica to implement. The first requirement was to engage a Suitable Qualified Person (SQP) to conduct a Detailed Site Investigation (DSI). The DSI was completed by JBS&G in August 2017 (*Orica Australia Pty Ltd Yarwun Manufacturing Facility Detailed Site Investigation, 30 Reid Road, Yarwun QLD*, JBS&G Australia Pty Ltd, 31 August 2017).

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The third requirement was to engage a SQP to prepare a CAP (this report).

It is noted that JBS&G previously prepared a document titled 'Groundwater Remediation Action Plan' (RAP) for the site in June 2014 (JBS&G, 2014) in response to a requirement of the Environmental Authority. This CAP provides a revision of the RAP based on current site conditions and replaces all previous versions of the RAP.

1.1 Background

A number of groundwater investigations have been undertaken at the site. The results of these investigations have been utilised to develop a CSM which is presented in JBS&G (2017c). The CSM details the hydrogeological conditions at the site as well as the nature and distribution of contaminants in groundwater. Based on the CSM the following contamination issues have been identified:

- Ammonia and nitrate are present in groundwater at concentrations exceeding the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality Australian and New Zealand Environment and Conservation Council (ANZECC)* trigger values for the protection of fresh water ecosystems. The highest concentrations of ammonia and nitrate are present on the site in the area of the AN Complex although significant concentrations are present in groundwater at the site boundary and in offsite areas.
- Free cyanide is present at concentrations exceeding the ANZECC 2000 trigger values in groundwater on the site. The highest concentrations are associated with the Cyanide Plant and the plume is completely within the site boundaries. Total cyanide has also been identified in groundwater with low concentrations identified at the site boundary.

1.2 Objectives

The objective of the investigation is to prepare a CAP, in accordance with the reporting requirements of the National Environmental Protection (Assessment of Site Contamination) Measure as amended 2013 (ASC NEPM), which includes the following:

- An evaluation of the current controls used to mitigate groundwater contamination;
- Details of mitigation measures that are required to manage potential or actual contamination pathways; and
- Details of any procedural or structural changes that require implementation to reduce the risk of further groundwater contamination.

The objectives of this report have been taken directly from requirement 3 of the notice.

1.3 Scope

The scope of works comprised:

- Review of current controls used to mitigate groundwater contamination; and
- Preparation of a report in accordance with guidance made or approved by EHP, including the ASC NEPM.

On the basis of the notice (i.e. groundwater focused), the properties of the contaminants, and site is operational and is not subject to divestment or change in land use, this report has not considered historical soil results. It is also noted that the highest concentrations of soil contamination would be at entry points (source areas) and these areas are not effectively accessible due to site infrastructure.

The scope of works completed in this CAP report was conducted by a SQP in accordance with the EHP *Guideline for Assessing a Suitably Qualified Person* (EHP, 2016) and the *Environmental Protection Act 1994*.

2. Site Condition and Surrounding Land Use

2.1 Site Identification

The site is located in the Yarwun Industrial Estate at 30 Reid Road, Yarwun, Queensland. The site location is shown on **Figure 1**. A site features plan which shows the site boundaries is provided as **Figure 2**. The site details are summarised in **Table 2.1** and described in detail in the following sections.

Table 2.1: Summary Site Details

Lot/Plan	Lot 138 on CTN2123
Address	Yarwun Industrial Estate, 30 Reid Road, Yarwun
Local Government Authority	Gladstone Regional Council
Site Zoning	Special Purpose
Current Use	Industrial – Chemical manufacturing facility
Previous Use	Prior to Orica's occupation of the site, the site was undeveloped
Proposed Use	The site is to remain Industrial – Chemical manufacturing facility
Site Area	50.44 ha

2.2 Site Description

The site occupies an area of approximately 50 ha, of which 20 ha is currently developed. Based on information provided by Orica (URS, 2009), the site manufactures sodium cyanide, nitric acid (as an intermediate product), ammonium nitrate (AN), and, until recently, chlorine.

Development of the greenfield site began in 1990, with the construction of the cyanide and chlorine plants. The first acid plant and the first AN Plant were constructed in 1993. The second acid plant was subsequently installed, with the third acid plant and second ammonium nitrate (AN) plant constructed in 2005 and 2006.

The developed portion of the site is divided into three broad zones:

- Chemicals Complex (CC);
- AN Plant; and
- The administration area and visitor carpark.

Additional site infrastructure includes an administration building, two control rooms, workshop, store, various storage areas and a container loading and laydown area. The site has two liquid effluent treatment areas, the AN effluent ponds, located north side of the AN tank farm, and the CC effluent ponds, located east of the chlorine processing plant. The site also includes an expanded polystyrene (EPS) plant, which is located on the western boundary of the site.

2.3 Environmental Protection Licensing and Approvals

Information provided by Orica indicates that the site is subject to Environmental Authority (EA) EPPR00872013 (current version of the EA was issued on 13 November 2017), which authorises chemical manufacturing at both the AN and CC facilities. The following Environmentally Relevant Activities (ERAs) are listed on the permit for Lot 138:

- 12 (2) Plastic product manufacturing – Manufacturing, in a year, a total of 5t or more of foam, composite plastics or rigid fibre-reinforced plastics;
- 33 Crushing, milling, grinding or screening – Crushing, grinding, milling or screening more than 5000t of material in a year;
- 7 (4b) Chemical manufacturing – Manufacturing, in a year, the following quantities of fertilizer – more than 5000t; and

- 7 (6d) Chemical manufacturing - Manufacturing, in a year, the following quantities of inorganic chemicals, other than inorganic chemicals to which items 1 to 4 apply – more than 100,000t.

2.4 Identified Sources of Contamination

JBS&G completed a Detailed Site Investigation (JBS&G, 2017b), the following primary source areas (**Figure 2**) were identified based a detailed site inspection and review of current and historical groundwater monitoring trends:

- AN Plant No. 1;
- The AN Solutions Storage;
- The AN Bulk Store; and
- The Cyanide Plant and Warehouse.

2.5 Surrounding Land Use

Table 2.2 presents a summary of the land use immediately surrounding the site.

The Gladstone Area Water Board (GAWB) water treatment plant and Gladstone Regional Council sewage treatment plant are located on the eastern side of Reid Road. A cleared area between these two facilities designates the former site of the Australian Magnesium Corporation's pilot processing plant. To the north of the GAWB water treatment plant (on the corner of Gladstone Mount Larcom Road and Reid Roads) are tidal mud flats of Port Curtis.

South of the site is undulating forested land, and a railway easement. West of the site is forested land, and Rio Tinto's alumina refinery (approximately 1 km west of the site). A high voltage transmission line easement runs east-west along the southern border of the site, and a low voltage transmission line easement runs adjacent to the site's northern boundary. An electrical substation is located on the north side of Gladstone Mount Larcom Road.

Table 2.2: Surrounding Land Use

Location	Detail
North	Gladstone Mount Larcom Road, electrical substation, tidal mud flats of Port Curtis
East	Reid Road, GAWB water treatment plant, Gladstone Regional Council sewage treatment plant
South	Forested land
West	Forested land

3. Environmental Setting

3.1 Climate

Gladstone is located in the sub-tropics of northern Australia which are characterised by dry winters and wet summers. Average annual rainfall is 866 mm across an average of 59 days of rain per year. The warmer months, December to March, have high average monthly rainfalls, ranging from 107 to 177 mm (www.bom.gov.au, accessed August 2017). Rainfall during these months typically represents two-thirds of the annual total, while there is typically very little rainfall recorded between May and September.

3.2 Topography

Southwest of the site is a coastal mountain range known as Mount Larcom Range. This range grades into small foot hills to the southwest of the site which are likely to direct surface water in an east to north-easterly direction in the vicinity of the site. Prior to development, the site would have sloped to the north and east in the southern portion of the site, whilst the northern portion of the site would have been relatively flat and low lying, consistent with the adjacent undisturbed land areas. Approximately 200-300 m north of the site boundary are the tidal flats of the Port Curtis.

The current site levels have been altered by cut and fill process during the development of the site. Two benches have been cut into the hill located to the southwest of the site, where the Nitric Acid Plant No.3 is located. The surface level of the several sections of the site have involved levelling of smaller undulations by filling.

The site slopes from the hills located to the south-west and west of the site towards Reid Road on the eastern site boundary. The highest point (22 mAHD) of the site is in the south-west corner, and the lowest (5 mAHD) in the northeast corner (adjacent to the junction of Gladstone Mount Larcom Road and Reid Road).

3.3 Regional Hydrology

The receiving environment for stormwater discharged from the site is Port Curtis.

Surface water flow from the site to Port Curtis may potentially occur via two flow paths. The first is via a culvert under Gladstone Mount Larcom Road that represents the flow path for Flying Fox Creek. The second is via drains along the southern edge of Gladstone Mount Larcom Road that discharge to an anabranch of the Calliope River. Due to construction of the Wiggins Island Coal Export Terminal (WICET) flow towards the anabranch has been restricted. It is therefore anticipated that the majority of flows from the site will enter Port Curtis via Flying Fox Creek.

The WICET Environmental Impact Statement (EIS) provides a detailed description of the receiving environment and the area to the north of the culvert under Gladstone Mount Larcom Road is described as:

- An intertidal wetland;
- The higher levels are covered by extensive salt pans;
- As Flying Fox Creek becomes more defined it is lined by mangroves (e.g. Avicennia/Aegicaras/Rhisporoa/Ceriops);
- Further north (lower levels of the intertidal zone) aggregated patches of Zostera sp. seagrass are present in areas of exposed banks (mud and sand); and
- The open waters of Port Curtis are then encountered.

The receiving environment is a low-gradient, intertidal area that extends from Gladstone Mount Larcom Road to the foreshores of Port Curtis. The sediment substrate is comprised of mud and sand. Sparse salt marsh vegetation is present near the discharge point, but is largely barren for 1.0 km to the uppermost reaches of the mangrove stands. The mud/sand flats are dissected by the drainage system (Flying Fox Creek) from the culvert, but elsewhere drainage patterns are indistinct.

Saline waters cover parts of the flats at high tide and during Spring tides waters flood through the culvert. Stormwater discharged through the culvert or other low lying point is expected to mix with fully saline waters over the flats at high tides, but at low tides stormwater would be channelled predominantly down rivulets in the flats.

Beyond the predominantly barren flats, the north-easterly trending rivulet becomes a larger meandering (serpentine) drainage (Flying Fox Creek) that enters an extensive area of mangroves. The meandering drainage continues beyond the mangroves in intertidal and subtidal elevations in a channel that is navigable by small craft.

3.4 Stormwater

Natural drainage surrounding the site is poorly defined, reflecting low surface runoff conditions and high infiltration rates within the surface soil layers. Down-slope accumulation and sub-surface outflow zones, reflected by more abundant Melaleuca species, occur in the area surrounding the tidal mud flats to the northeast of the site (near the junction of Gladstone Mount Larcom Road and Reid Roads). The construction of the Gladstone Mount Larcom Road appears to have altered the natural drainage pathways and subsequently effected the diversity of the ecosystem within the receiving environment. There appears to have been a gradual change in the composition of the community, which has adapted to the longer periods of water logging. On the northern side of the Gladstone Mount Larcom Road, expansive mud flats extend more than 1.5 km to the mangrove lined shore of the Port Curtis estuary.

Stormwater at the CC is collected via a network of pits and conveyed by underground concrete pipes (invert of approximately 2 m bgl) following local topography to the Stormwater Retention System (SWRS) and licensed stormwater discharge point, CC1 in the northeast. Stormwater from CC and the surrounding area also drains into the CC1 SWRS via aboveground drainage.

Stormwater from the administration area and carpark discharges from the site. The administration area drains via underground pipes to the eastern side of Reid Road near the weighbridge entrance to the site. The carpark drains via a shallow swale drain to the table drain on the western side of Reid Road.

Stormwater at AN is collected via a network of pits and conveyed by underground concrete pipes (invert of approximately 2 m bgl) following local topography to Dam 1, Dam 2 and the licensed discharge point ANP1/ANP2.

"First flush" systems have been installed at the CC and AN discharge points which are designed to capture the initial rainfall off plant areas and hold stormwater in retention basins prior to testing/discharge from the site.

3.5 Receptors

Surface water and groundwater from the site discharges into the forested land located approximately 300 metres from the site to the north east and east. After entering this mixing zone water ultimately discharges to the intertidal waters of Port Curtis. Because of the location of the site and the nature of the receiving aquatic environment it is considered unlikely that direct human exposure would occur.

The potential key receptors of ammonia, nitrate and/or cyanide in the receiving environment include:

- Aquatic fauna such as macroinvertebrates (e.g. insect larvae) and fish (likely to only be present in permanent water bodies);

- Semi-aquatic fauna such as frogs and wading waterbirds;
- Terrestrial fauna (e.g. birds, reptiles and mammals) that utilise the water for drinking and/or bathing;
- Aquatic plants (e.g. bulrush); and
- Terrestrial plants that utilise the water (e.g. *Eucalyptus* spp. and *Melaleuca* spp.).

The receiving environment for stormwater discharged from the site, after passing through the mixing zone, is Flying Fox Creek/Port Curtis.

3.6 Regional Geology

The geology of the site is presented on the Rockhampton 1:250 000 Geological Series Map (GSQ, 1974) and on Geology maps available on the Queensland Globe. These maps indicate that the site is underlain by the Devonian Doonside Formation comprised of red, green and white cherts, jasper, mudstone, siltstone, lithic sandstones, tuff and limestone. In the lower (northern) portion of the site, the Doonside Formation appears to be overlain by Quaternary sands, silts, muds and gravels. Quaternary materials are likely to be alluvium derived from former creeks, and may form preferential pathways for groundwater flow and contaminant migration. Based on the cut and fill earthworks undertaken to achieve the current site levels, near surface soils are likely to have been reworked.

Quaternary sands, silts, muds and gravels which comprise the tidal flats of Port Curtis are located to the north of the site.

The stratigraphy encountered during investigations at the site is summarised in the following table (URS, 2009).

Table 3.1: Site Lithology

Material	Depth (m bgl)	Description
PAVEMENTS	0 – 0.3	Asphaltic cement and concrete pavement
FILL	0 – 1.5	Gravely clay sand, reworked natural soils.
GRAVELLY CLAY	0.5 – 10	Gravelly clay, with varying sand and silt content with depth and location, gravel 3-10 mm, red to grey some mottling. Varying moist to wet throughout profile. Soft to stiff.
CHERT (possibly some Mudstone)	3.0 – 23	Extremely to highly weathered chert (possible some mudstone), within a matrix of extremely weather chert and red/brown to grey clay.

3.7 Acid Sulphate Soils

Review of the Australian Soil Resource Information System[1] indicates that the site is located within an area with extremely low probability of occurrence of acid sulphate soils.

3.8 Regional Hydrogeology

Areas of the site are underlain by up to three groundwater units including: perched; shallow; and deep aquifers. The deep aquifer is present in the rock beneath the site and is characterised by low hydraulic conductivity. Historical investigation of the deeper lithological units have confirmed that groundwater contamination from the site is confined to the perched / shallow aquifer(s).

3.8.1 Perched Aquifer/Groundwater

A perched groundwater unit has been identified in the reworked gravelly clay fill materials and the upper portion of the residual gravelly clays. The inferred groundwater flow direction in the perched

[1] http://www.asris.csiro.au/ (accessed August 2017)

aquifer during both the wet and dry seasons is in a northeast direction towards Port Curtis, generally following the filled natural drainage pathway, at a hydraulic gradient ranging between 0.005 and 0.01.

There does not appear to be a continuous perched groundwater unit in the vicinity of the Cyanide Plant.

Significant variation (three orders of magnitude) in hydraulic conductivity and calculated groundwater flux has been observed in the perched aquifer. The large variation in groundwater flux at different locations is related to the lithology of the perched aquifer (fill; reworked gravelly clay) and the presence of preferential groundwater flow pathways:

- Overall, preferential flow occurs through the natural drainage pathway backfilled for site construction, towards the north east. Downgradient of the Cyanide Plant the plume has two branches, one migrating to the north beneath Cyanide Alley (P12 had a hydraulic conductivity of 10 m/day, though P13 has a very low K) and one migrating east beneath Rankin Road;
- Preferential flow is inferred to occur in backfilled sub-surface utility trenches, in particular in the vicinity of P13 in Cyanide Alley, and P73 and P75 at Heron Drive; and
- Identified preferential pathways at the AN Plant include those associated with a former cutoff drain and reworked fill in the area near P50 as well as associated with the area near P71.

The following table presents a summary of the hydrogeological characteristics of the perched aquifer at the site (URS, 2009).

Table 3.2: Perched Aquifer Hydrogeological Characteristics

Depth (m bgl)	Geology	Gradient	Hydraulic Conductivity (m/day)	Horizontal Seepage Velocity (m/year)***
0.5 to 4.0	Fill, including reworked gravelly clay and upper residual gravelly clay	0.007 to 0.01 (Dry Season) 0.008 to 0.02 (Wet Season)	0.06 to 95 *0.12* - 13***	0.2 to 2000 *2.2* - 237***

Notes: *Geomean of low flow (<1m per day) conditions
**Geomean of high flow (>1 m per day) conditions
***Calculation is based on an average gradient of 0.01 and an effective porosity of 0.2

Groundwater elevations vary seasonally, with higher elevations in the wet season compared to the dry season. Water level hydrographs (in the vicinity of Reid Road) for the wet season indicate that the perched aquifer responds very rapidly to rainfall events (JBS&G, 2014). Peak water levels are observed soon after a rainfall event followed by a relatively rapid decline (although the resulting water level remains higher than that before the rainfall). In paved areas (the manufacturing areas of CC and AN) the rainfall response may be less. Recharge of the perched aquifer in the plant area will be limited to unpaved areas upgradient of the plant, through cracks in roads and potentially leaks from subsurface pipes and sections of stormwater drains above the water table.

3.8.2 Shallow Aquifer/Groundwater

A shallow groundwater unit is present within the residual gravelly clays at depths between approximately 2 and 12 m. The inferred shallow groundwater flow direction is in a north-east direction towards Port Curtis. Water level hydrographs (in the vicinity of Reid Road) for the wet season indicate that the shallow aquifer responds slowly to rainfall and is more affected by seasonal variations than individual events.

The hydraulic conductivity calculated for the shallow groundwater is likely to be representative of the natural gravely clay soils encountered beneath the site. The significantly lower hydraulic conductivity of the shallow aquifer (0.02 m/day) suggests the majority of groundwater flux occurs in the overlying perched aquifer (hydraulic conductivity of 0.1 to 100 m/day). However, since there are no aquitard features between aquifer units, some vertical hydraulic connection between perched and shallow aquifers is likely.

The following table presents a summary of the hydrogeological characteristics of the shallow aquifer (URS, 2009).

Table 3.3: Shallow Aquifer Hydrogeological Characteristics

Depth (m bgl)	Geology	Gradient	Hydraulic Conductivity (m/day)	Horizontal Seepage Velocity (m/year)**
2.0 to 8.0	Residual gravelly clay and reworked gravelly clay fill	0.008 to 0.015 (Dry Season) 0.004 to 0.02 (Wet Season)	0.004 to 0.2 *0.02**	0.05 to 10 *0.39**

Notes: *Geomean conditions
**Calculation is based on the average gradient and an effective porosity of 0.2

3.9 Contaminant Distribution

3.9.1 Nitrate and Ammonia Groundwater Plume

Perched Groundwater

Nutrients (ammonia and nitrate[2]) in the perched groundwater unit were noted at the following concentrations in July 2017:

- NOx (as N): <0.01 mg/l to 1,000 mg/l (P95); and
- Ammonia (as N): <0.01 mg/l to 845 mg/l (P48).

NOx concentrations at the perched groundwater wells sampled exceeded the Groundwater Monitoring Plan (GWP) (JBS&G, 2016) Assessment Criteria in July 2017, except wells P19, P64, P66, P73, P78, P79 and P87.

The nature and extent of nitrate/NOx in the perched aquifer is similar to that described in the Revised Conceptual Site Model (URS, 2009). The distribution of NOx in groundwater appears to be migrating within the two preferential pathways:

- From the ANP1 area towards the north and then north-east as indicated by concentrations generally greater than 100 mg/l in the plant area (P55 and P95), car park and offsite between P88 and P80 along Reid Road in the east. Nitrate/NOx concentrations were less than GWP Assessment Criteria in perched groundwater well P87 in the forested woodland east of Reid Road and P78 and P79 along Reid Road to the north; and
- From the AN processing area towards the east in the vicinity of P50 to P86 and offsite in the vicinity of P62.

Ammonia concentrations at P12, P33, P48, P50, P55, P61, P69, P70, P71, P80, P88, P89, P94, P95, P103, P104 and P105 exceeded the Groundwater Monitoring Plan (GMP) Assessment Criteria in July 2017.

[2] Or NOx (nitrate and nitrite), which has been analysed since 2011. Since nitrite has been shown to represent a very small portion of NOx, NOx concentrations in groundwater are considered equivalent to nitrate concentrations.

The nature and extent of ammonia in the perched aquifer is similar to that described in the Revised Conceptual Site Model (URS 2009). In general, the distributions of ammonia and nitrate in groundwater at the site are similar. Historically, monitoring locations in offsite areas were characterised by significantly lower ammonia concentrations than nitrate concentrations, though the relative proportion of ammonia has increased since the Revised Conceptual Site Model was prepared within the preferential flow pathway at the car park and offsite at P88.

Ammonia concentrations exceeding 100 mg/l are reported in a zone extending from the ANP1 area (P55 and P95) towards the north-east to the car park and offsite at P88.

Shallow Groundwater

The distribution of nutrients in the shallow aquifer is of a similar pattern to that observed in the perched aquifer. However, this is not attributed to horizontal migration but is likely the result of vertical migration from the perched groundwater (URS, 2009).

Nutrients in the shallow groundwater unit were noted at the following concentrations in July 2017:

- NOx (as N): <0.01 mg/l to 823 mg/l (S3[3]); and
- Ammonia (as N): <0.01 mg/l to 625 mg/l (S3).

Elevated concentrations (exceeding 100 mg/L) of NOx within shallow groundwater were reported in the vicinity of ANP1 (S55), the car park (S48 and S71), east of the AN processing area (S33, S4, S53) and offsite at S61. NOx concentrations at S3, S4, S12, S14, S16, S25, S33, S35, S46, S47, S48, S51, S53, S54, S55, S61, S62, S69, S70, S71, S80, S85, S86, S88, S89, S93, S94, S95, S103 and S105 exceeded the GWP Assessment Criteria in July 2017.

Elevated concentrations (exceeding 50 mg/L) of ammonia within shallow groundwater were reported in the vicinity of ANP1 (S55) and the car park (S48 and S71). Ammonia concentrations at S3, S4, S12, S14, S16, S33, S35, S46, S47, S48, S53, S55, S61, S69, S71, S89, S93, S94, S95, S103 and S104 exceeded the GWP Assessment Criteria in July 2017.

3.9.2 Cyanide Groundwater Plume

Perched Groundwater

Cyanide in the perched groundwater unit was noted at the following concentrations in July 2017:

- Total cyanide: <0.004 mg/l to 7.64 mg/l (P12);
- WAD cyanide: <0.004 mg/l to 2.02 mg/l (P12); and
- Free cyanide: <0.004 mg/l to 1.48 mg/l (P12).

Free cyanide concentrations at P12 and P75 exceeded the GWP Assessment Criteria in July 2017.

Based on the current and historical analytical data, the primary source of cyanide contamination in the perched aquifer is considered to be the Cyanide Plant area. Maximum total, WAD and free cyanide concentrations have historically been reported in monitoring well P11 located in backfill around the solids dissolving tank in the centre of the Cyanide Plant (Note: P11 was not sampled during July 2017 as this well is not included in the Groundwater Monitoring Plan (JBS&G, 2016)). Monitoring well P12 located immediately north of the Cyanide Plant, has also reported significant total cyanide concentrations (exceeding 400 mg/L in June 2013, however, following source control work concentrations of cyanide in P12 have reduced by almost two orders of magnitude in 2017).

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[3] S3 is potentially screened across both the perched and shallow groundwater unit. The second highest concentrations in July 2017 were Ammonia (as N) 181mg/l (S95), NOx (as N) 521mg/l (S61)

Downgradient of the Cyanide Plant, a zone of elevated total cyanide extends in the perched aquifer to the east across Rankin Drive (located within the site) and to the north-east towards the site boundary, with total cyanide historically detected above the laboratory reporting limit (LOR) at P64, P65 and P66. The zone of elevated WAD and free cyanide concentrations in the perched aquifer is generally less extensive than for total cyanide, with distribution in the vicinity of the Cyanide Plant and in the north-east to P75.

Shallow Groundwater

Cyanide in the shallow groundwater unit was noted at the following concentrations in July 2017:

- Total cyanide <0.004 mg/l to 4.55 mg/l (S14);
- WAD cyanide <0.004 mg/l to 0.043 mg/l (S25); and
- Free cyanide <0.004 mg/l to 0.048 mg/l (S25).

Free cyanide concentrations at S12, S14, S16, and S25 exceeded the GWP Assessment Criteria in July 2017.

The distribution of cyanide compounds in the shallow groundwater generally follows the same pattern as the perched aquifer, although cyanide compounds appear to have a limited extent towards the north-east (cyanide compounds are less than the LOR at S65/S66 at the production plant boundary), and total cyanide may have migrated further east and south-east (as indicated by elevated total cyanide concentration at S54, adjacent to the administration office).

4. Requirement for Remediation

The justification/requirement to undertake groundwater remediation at the site is presented in the following sections. For more detailed discussion of the distribution of groundwater contamination and analysis of trends in concentrations reference should be made to the CSM (JBS&G, 2017) and the Annual Groundwater Monitoring report (JBS&G, 2017a).

Groundwater from the site discharges to a wooded area to the east of Reid Road and south of Gladstone Mount Larcom Road. This area has been subject to significant disturbance both locally (e.g. road construction and industrial development) and in downgradient areas (i.e. coal terminal construction) that have resulted in historical and recent hydrological changes. These hydrological changes have significantly altered surface water flow regimes with subsequent and ongoing changes in the distribution of flora and fauna in this area.

Modifications to local drainage (notably as a result of road construction as well as more recent works for the Wiggins Island Coal Export Terminal (WICET)) have resulted in restriction of flows to Flying Fox Creek meaning that the area east of Reid Road and south of Gladstone Mount Larcom Road is generally wetter than other wooded areas at Yarwun. Stands of trees and other vegetation that are inundated during the wetter parts of the year essentially dry off during prolonged dry periods. However, the discharge area is likely to remain damp in comparison to other wooded areas at other parts of Yarwun.

Based on a review of the Environmental Values presented in CSM (JBS&G, 2017) the appropriate criteria for groundwater is ANZECC/ARMCANZ (2000) 90% trigger values for the protection of Fresh Water ecosystems. However, the Curtis Island, Calliope River and Boyne River Basins Environmental Values and Water Quality Objectives (WQO) (EHP 2014) and ANZECC/ARMCANZ (2000) 95% trigger values for the protection of Marine Water ecosystems are relevant for the receiving environment (Flying Fox Creek/Port Curtis). It is noted that the average concentrations presented in Port Curtis Integrated Monitoring Program (PCIMP) for Port Curtis are also relevant to assessment of surface water.

4.1 Nutrients

Remediation of nutrients (ammonia and nitrate) in groundwater is required for the following reasons:

- Although significant source control works have been undertaken at AN source areas, concentrations of nutrients in source area wells remain significantly higher than the water quality trigger values presented in ANZECC (2000);
- Statistically significant increasing trends have been identified for ammonia and nitrate at monitoring wells located in AN source areas and at the site boundary. These wells are located down hydraulic gradient of AN and the observed trends are representative of ongoing plume migration from the source zones;
- Statistically significant increasing trends have been identified for ammonia and nitrate at a number of offsite wells;
- Calculations of mass flux of nitrate (and ammonia) across the site boundary (assuming no operation of the remediation system) indicates the potential for substantial migration of contaminants (>10,000 kg/year of nitrate and a similar mass of ammonia) from the site to the low-lying area east of Reid Road; and
- Considering the above, ammonia and nitrate in groundwater potentially pose a risk to aquatic organisms in the receiving environment. As a result, remediation is required to address nutrients in groundwater at the AN Complex.

4.2 Cyanide

While free cyanide does not currently pose a risk to the offsite receiving environment, remediation of free cyanide in groundwater may be required in the future, should the ongoing monitoring program identify that the free cyanide plume is expanding or increasing in concentration, for the following reasons:

- Although significant source control works have been undertaken at Cyanide source areas, concentrations of free cyanide in source area wells remain significantly higher than the water quality trigger values presented in ANZECC (2000); and
- The 2017 Annual Groundwater Monitoring Report (JBS&G, 2017a) reported increasing trends in free cyanide concentrations in the source zone and at locations immediately downgradient of the source zone. Review of the monitoring data indicates that the increasing trends are largely the result of an increase in concentration prior to 2014. Although the reported concentrations were higher than the relevant trigger value, the reported concentrations were relatively stable between 2014 and 2017.

5. Remediation Options Assessment

5.1 General

The majority of available remediation technologies for ammonia, nitrate and cyanide have been focussed on ex-situ treatment of effluent and solid waste, or pump and treat methods, rather than in-situ groundwater treatment methods. Many commercially available treatment technologies, while technically feasible for implementation at the site, may not be practicable or commercially proven since the treatment criteria for many remediation technologies in other industries are typically significantly higher than those required for the receiving environment near the Yarwun site.

Potential remedial options for contaminants in groundwater include:

- Source Control.
- Ex-Situ Approaches:
  - Source area (soil) excavation and offsite disposal or treatment.
  - Groundwater extraction and treatment.
- In-Situ Approaches:
  - Chemical Oxidation.
  - Bioremediation.
  - Permeable Reactive Barrier.
  - Phytoremediation.
  - Monitored Natural Attenuation.
  - Hydraulic Isolation.

5.2 Options Assessment Summary

The ASC NEPM states that the process of assessment of site contamination should be placed within the context of the broader site assessment and management process. In particular, the preferred hierarchy of options for site clean-up and/or management (as outlined below) should be considered:

- Onsite treatment of contamination so that it is destroyed, or the associated risk is reduced to an acceptable level; and
- Offsite treatment of excavated soil, so that the contamination is destroyed, or the associated risk is reduced to an acceptable level, after which soil is returned to the site; or

If the above are not practicable,

- Consolidation and isolation of the soil onsite by containment with a properly designed barrier; and
- Removal of contaminated material to an approved site or facility, followed, where necessary, by replacement with appropriate material;

Or,

- Where the assessment indicates remediation would have no net environmental benefit or would have a net adverse environmental effect, implementation of and appropriate management strategy.

When deciding which of the above options to select, the ASC NEPM requires that the sustainability of each be considered, balancing the benefits and effects of undertaking the option.

Table 5.1 presents a summary of the remediation options available for the site.

Table 5.1: Remediation Options Assessment

Remediation Option	Description	Assessment for AN	Assessment for Cyanide
Source Control	Primary source control works to reduce the potential for contaminants to enter the subsurface have already been undertaken (refer to **Section 6**). However, increasing groundwater contamination trends noted in source areas indicate further work is required to manage source releases.	In order to limit future releases, additional AN source area works are required (refer to **Section 6.2**).	In order to limit future releases, additional Cyanide source area works are required (refer to **Section 6.2**).
Source Area (Soil) Extraction	This option would involve the excavation of soils containing AN and Cyanide located within the perched aquifer at the primary source areas. This would reduce contaminant mass in the aquifer and require offsite disposal of excavated soil.	Implementation of this option is not feasible due to the presence of significant infrastructure and major above and below ground services. Given excavation of soil would require offsite disposal to landfill, this option would be low on the ASC NEPM hierarchy of options for site clean-up and/or management.	Implementation of this option is not feasible due to the presence of significant infrastructure and major above and below ground services. Given excavation soil would require offsite disposal to landfill, this option would be low on the ASC NEPM hierarchy of options for site clean-up and/or management.
Groundwater Extraction and Treatment	Groundwater extraction with aboveground treatment is considered an appropriate method to remove mass flux in groundwater.	A groundwater interception trench and treatment system has been installed on the site boundary to decrease AN mass flux in the perched aquifer. The groundwater interception trench and treatment system are discussed further in **Section 7.2**. Onsite treatment is the preferred strategy in the ASC NEPM hierarchy of options for site clean-up and/or management. This technique may be suitable for source control (and offsite remediation). However, due to the presence of significant infrastructure and major above and below ground services, access to suitable extraction locations within source zones would be limited. Extraction wells would be more practical within source zones, however, it is noted that wells are more sensitive to localised hydrogeological	A source and plume groundwater extraction system with aboveground groundwater treatment would require the installation of a groundwater extraction system in the perched aquifer within and immediately downgradient of the source zones. However, extraction rates would be influenced by spatial and temporal variability in groundwater and contaminant fluxes observed at the site. Source zone access would also be limited due to the presence of significant infrastructure and major above and below ground services. Consideration would also need to be given to how extracted groundwater is treated. Options include using the AN treatment plant, using a small-purpose built plant or the existing Cyanide effluent treatment tank.

Remediation Option	Description	Assessment for AN	Assessment for Cyanide
		conditions such as preferential flow pathways.	
In-Situ Chemical Oxidation	In-situ chemical oxidation involves the injection of chemicals into the subsurface to oxidise contaminants in groundwater. Application methods include direct injection, injection wells and infiltration trenches. Recirculation systems which incorporate a downgradient extraction well and upgradient reinjection may also be used. For in-situ oxidation of source areas, accessibility is expected to be limiting, and a recirculation application system via an infiltration trench or series of wells immediately upgradient of the source area, and downgradient extraction wells may be appropriate (although additional hydrogeological assessment would be required to determine whether sufficient groundwater flow could be induced to allow delivery of oxidant to the contaminated zone).	In-situ chemical oxidation is most commonly used to treat organic contaminants. In-situ chemical oxidation is not a viable option for nutrient remediation.	Implementation of this option is not feasible due to the following reasons: • Health and safety issues with handling chemicals and compatibility with other chemicals on site. • Accessible areas for chemical injection will be difficult in the source area. • Natural oxidant demand, which will consume the oxidant and result in increased costs. • Compatibility between oxidants and subsurface infrastructure and utilities. • The highly heterogenous hydrogeology within the perched aquifer means that fluid oxidants will primarily migrate in high conductivity zones, which means treatment of low permeability zones will be diffusion limited.
In-Situ Bioremediation	Plume-wide in-situ bioremediation at the site would involve addition of amendments either via a series of extraction wells, aboveground dosing system and injection wells, or direct reagent injections. Given access limitations within the source zones itself due to aboveground infrastructure, a series of upgradient injection wells or an infiltration trench may be the most practicable application.	While in-situ bioremediation is a favoured option for treatment of nutrients in groundwater, the high mass flux of ammonia and nitrate from the source zone to the site boundary would require that significant ongoing injection of amendments be undertaken (with the associated high biological growth within the aquifer). In-situ bioremediation options are therefore not considered feasible until such time as the mass of contaminants is significantly reduced.	In-situ bioremediation is typically characterised by lower lifetime costs than pump-and-treat, low energy usage, ability to couple cyanide destruction with ammonia denitrification, there are no waste products (although formation of ammonia may occur), remediation is faster than pump-and-treat, there is minimal site disturbance and it can be utilised for plume-wide remediation. In-situ bioremediation is considered a potentially feasible remedial measure for mass removal in the source area and plume

Remediation Option	Description	Assessment for AN	Assessment for Cyanide
			due to its potential to treat contamination in-situ and its compatibility with site infrastructure. A feasibility assessment (laboratory based) has been undertaken with soil and groundwater collected from the cyanide source area.
Permeable Reactive Barrier (PRB)	A PRB would comprise a permeable reactive zone in the subsurface to immobilise the contaminant by oxidation, sorption, venting or precipitation mechanisms. Scenarios utilising PRBs are as follows: • A PRB downgradient of the source zone would minimise further migration in the perched aquifer. • A PRB at the toe of the plume would minimise potential further migration towards the site boundary.	The advantages of a PRB system is that they can be designed to be passive, can be cheaper to operate than pump and treat methods (depending on lifetime of reactive media) and do not require permanent aboveground infrastructure. However, there are also long-term performance issues with PRBs, such as plugging due to biological growth or precipitates (which would cause mounding of the water table – a potential issue at the site during the wet season when the perched water table is near ground surface) and disposal of contaminated by-products. Spatial and temporal variability in groundwater and the high contaminant fluxes observed at the site would limit the success of PRB as the permeability of the PRB must be higher than that of the preferential flow pathways and the mass of reactive media must be sufficient to treat the flux of contaminant.	A PRB for the cyanide plume could include zero valent iron which is relatively easy to install and commission. However, source zone access is limited due to the presence of significant infrastructure and major above and below ground services. While PRBs have been used extensively for organic contaminants, nutrients and metals, there is limited understanding of field performance of PRB systems specifically for cyanide. Field trials to assess the feasibility of this approach would usually be recommended.
Phytoremediation	Phytoremediation of contaminants in soils is also possible given that most plants possess metabolic pathways that utilise cyanide and nutrients. A phytoremediation system would require planting of phreatophytic plants (for hydraulic control) or cyanogenic species (for uptake and degradation) at the source area and along the plume.	Site infrastructure above the source area and plume prevent the use of phytoremediation for nutrient remediation at the site. A phytoremediation system has a potential to be used on the site boundary and offsite areas. However, this passive technique would be limited due to the high mass flux of ammonia and nitrate in groundwater and	Site infrastructure above the source area and plume prevent the use of phytoremediation for cyanide remediation at the site.

Remediation Option	Description	Assessment for AN	Assessment for Cyanide
		an extraction system would be more efficient in these locations.	
Monitored Natural Attenuation (MNA)	MNA involves assessment to ascertain attenuation mechanisms and long-term monitoring to confirm attenuation of the plume is occurring.	The current high mass flux of contaminants in the source zone and plume is such that MNA alone is not appropriate. This has been demonstrated by the statistically significant increasing concentrations at the site boundary and in offsite areas. MNA could only be considered once mass flux rates have significantly reduced.	This is the current and proposed remediation strategy at the Site. In the case that the plume continues to expand in size and increasing concentrations trends are observed then contingency plans should be implemented.
Hydraulic Isolation	Installation of a sheet pile cut-off wall or low permeability barrier keyed into the shallow aquifer around the boundary of the source areas.	Due to the intrusive nature of installation, access limitations, presence of numerous underground services and geotechnical considerations, hydraulic isolation of the source zone is not considered feasible.	Due to the intrusive nature of installation, access limitations, presence of numerous underground services and geotechnical considerations, hydraulic isolation of the source zone is not considered feasible.

The preferred remedial strategy was selected based on the ASC NEPM hierarchy of options for site clean-up and/or management. The preferred remedial options were those that included onsite treatment of contamination so that it is destroyed, or the associated risk is reduced to an acceptable level.

In summary, the following remedial options were selected:

- AN Plume:
  - Source Control – Focused on the on the primary source areas identified in **Section 2.4**.
  - Groundwater Extraction and Treatment – Groundwater interception trench installed along the eastern site boundary and onsite treatment of extracted groundwater.
- Cyanide Plume:
  - Source Control – Focused on the on the primary source areas identified in **Section 2.4**.
  - Monitored Natural Attenuation – MNA strategy including implementation of a monitoring program to assess its ongoing applicability as a remediation strategy at the site.

6. Source Control and Procedural Review

6.1 Completed Source Control Works

Orica has completed a number of preventative source control works at the site including:

- Installation of new concrete laydown areas (installed in 2012/2013);
- Recoating Cyanide Plant ground flooring (2008);
- Repaired floors in NA tank No.1 (2005) and AN Plant No.1 (2012);
- Repair Bulk Store 1 floor (2010/2011)
- Lined the AN Solutions bund (2008); and
- Replacement of Cyanide Plant effluent treatment tanks (2008/2009), sales liquor tank (2011) and Cyanide effluent drain (2010).

These control works have focused on the primary source areas identified in **Section 2.4**.

6.2 Performance Review

Statistical analyses undertaken in the Annual Groundwater Monitoring Report (JBS&G, 2017a) identified increasing trends for ammonia and nitrate in AN source areas including P93/S93 (ammonia and nitrate), P95/S95 (ammonia and nitrate), S53 (ammonia), S81 (nitrate) and S94 (ammonia). Statistical analyses has also identified increasing trends for cyanide in cyanide source areas including P14 (free and total cyanide) and S16 (free and total cyanide). Review of the monitoring data indicates that the increasing cyanide trends are largely the result of an increase in concentration prior to 2014. Although the reported concentrations were higher than the relevant trigger value, the reported concentrations were relatively stable between 2014 and 2017.

The increasing trends noted in source areas indicate further work is required to manage source releases.

6.3 Proposed Source Control Works

In order to limit future releases from AN and Cyanide source areas, **Table 6.1** presents a summary of primary locations identified as potential sources where works could be undertaken to limit future releases from AN and Cyanide source areas.

Table 6.1: Source Control Works

Location	Project	Description
AN Complex	Fertiliser Upgrade	Increase capacity of AN Plant No.1 Fertiliser System to minimise the time AN contaminated water is held back in the AN Plant No.1 building and the AN Solution Tanks Bund. This project is under construction and nearing completion.
AN Complex	AN Solutions Tank Bund Sealing	Reseal the concrete bunding that contains all large AN Solution Tanks to improve the integrity of this bunded area.
AN Complex	AN Solutions Tank Pump Bund	Re-seal / re-grout the pump bund to improve the integrity of this bunded area.
AN Complex	Replacement of AN Plant No2 Redissolving Tank	The current AN Plant No.2 Redissolving Tank has historically leaked, although this is within a concrete lining and historical groundwater monitoring downstream of AN Plant No.2 has not indicated any significant source. Repairs have been attempted but overall success of repairs in unknown.
AN Complex	AN Plant No1 Ground Floor Stage 2	A more significant project to increase the integrity of the AN Plant No1 ground floor.
CC Complex	Stormwater System Trench	The smaller trenches inside the main Cyanide building are lined with plastic. Integrity is difficult to gauge from a visual inspection only.

Location	Project	Description
	Lining Main Cyanide Building	
CC Complex	Ground Floor Leak Points	Address any potential leak paths associated with electrostatic earths, concrete covers, concrete lining.

6.4 Proposed Procedural Review

In additional to the proposed source control works detailed in **Section 6.3**, **Table 6.2** presents a summary of proposed procedural changes planned to be implemented to limit future releases from AN and Cyanide source areas.

Table 6.2: Procedural Review

Location	Project	Description
AN Complex	AN Plant No1 Ground Floor Stage 1	An operations (procedural & maintenance) based project to keep the ground floor and trench as dry as possible. Scope would include removing any ongoing liquid leaks (eg steam traps), emptying the trench annular space on a regular basis, emptying the trench on a regular basis, operating procedures to minimise the use of liquid in cleaning ground floor, minor repairs to grouting, Regular and ongoing integrity inspection of AN Plant No1 Trench.
AN Complex	AN Bulk Store Tunnel Drain and Weighbridge Sump	Complete a thorough integrity inspection and undertake repairs on the AN Bulk Store Tunnel and Weighbridge Sump.
CC Complex	Integrity Inspections	Conduct detailed integrity inspections on the high-risk assets with the Cyanide Plant.

6.5 Validation

In accordance with the ASC NEPM, the success of the proposed source control works and procedural changes will be assessed based on trends of contamination in groundwater in source zones. Results of the assessment will be reported in the annual groundwater monitoring report.

The key performance measures will be assessed by the monitoring program presented in **Table 6.3.**

Table 6.3: Summary of Remediation System Performance Measures (Source Control)

Performance Measure	Assessment Process
Are concentrations increasing and if so do the changes pose a potential environmental risk?	If trend analysis and statistical assessment (adopting the guidance presented in USEPA 530/R-09-007) indicates that concentrations are increasing then the decision is Yes. In this circumstance a comparison to trigger levels and the potential fate of transport of the contaminants will be undertaken to determine the significance of the change. Recommendations for additional monitoring and/or remediation may be appropriate. Otherwise the decision is No.

7. Remediation of Nutrients in Groundwater

7.1 Remediation Objectives

The remediation objectives for nutrients in groundwater at the site were previously presented as short and long-term objectives (Golder, 2011a). The objectives have been refined based on the current site condition and overall objectives of the CAP, as follows:

- The short-term remediation objective is to reduce the mass flux of ammonia and nitrate migrating offsite in groundwater until primary source control is achieved and decreasing ammonia and nitrate concentrations in onsite groundwater are observed. The performance of the short-term remediation measure should be assessed on the basis of achieving a reduction of ammonia and nitrate mass flux in groundwater across the site boundary.
- The long-term remediation objective is, to the extent practicable, improve the quality of groundwater migrating off the site. The performance of the long-term remediation measure should be assessed on the basis that the ammonia and nitrate mass flux does not pose an unacceptable ecological risk.

7.2 Remediation System

The selection and justification for the preferred remediation approach for nutrients (ammonia and nitrate) in groundwater at the site is detailed in the following documents:

- *Remediation of Nutrients in Groundwater, Orica Yarwun – Preferred Remedial Strategy. Golder Associates Pty Ltd 13 May 2011 Ref: 117623026_001_L_Rev0 (Golder, 2011a); and*
- *Orica Yarwun – Remediation of Nutrients in Groundwater: Groundwater Extraction and Treatment preliminary Design Tasks. Golder Associates Pty Ltd 5 September 2011 Ref: 117623026_002_R_Rev0 (Golder, 2011b).*

The groundwater interception trench and treatment system corresponds to that presented in Remediation of Nutrients in Groundwater (Golder, 2011b). The trenches were constructed on the site in early-2012 and commissioned by the end of 2012. Extraction and treatment commenced in mid-2013.

The location of the remediation system is illustrated on **Figure 3**. As built drawings for the interception trenches are provided in **Appendix A**.

The system is summarised as follows (Golder, 2011b):

- *Design basis – to achieve a decrease in mass flux from the site.*
- *Description – P71 trench 50 m long, 0.3 m nominal width, an average of approximately 2.7 m deep, with a pumping location (0.5 m width) at the centre. P50 trench 50 m long, 0.3 m nominal width, an average of approximately 2.5 m deep, with a pumping location at the northern end.*
- *Locations – Across the northern preferential centred around P71 and extending to intercept backfill around the carpark stormwater system. Across the southern preferential flow path intersecting P85 and P50 and the stormwater pipes at ANP1.*
- *Flow rate – maximum 25/60 kL/day or sufficient to achieve a water level of 3.8 mAHD in the capture trench.*
- *Monitoring – water level monitoring at a minimum of eight perched monitoring wells and two wells installed in the backfill of the stormwater system at each trench location.*

As detailed in Golder (2011b) the installed system was deemed to be pilot scale and intended to initially operate to allow collection of data suitable for determining long term remediation requirements. The data was required due to the variability in ground conditions at the site and their influence on contaminant concentration and required pumping rates. Estimates of groundwater flow rates across the eastern boundary of the site indicated potential flows of up to 200 kL/day. Most of this flow was expected to occur at the preferential flow paths and in particular the northern (P71) trench area.

Groundwater pumped from the interception trenches is directed to a purpose built water treatment plant. Treated water is discharged to the Trade Waste Facility (TWF), via the AN effluent management system, in accordance with the Environmental Authority.

7.3 Performance Review and Recommendations

A detailed review of the performance of the remediation system was undertaken as part of the Annual Groundwater Monitoring Report (JBS&G, 2017a) and CSM (JBS&G, 2017c).

The treatment plant has recently been uprated with the result that significantly increased flow rates have been achieved since June 2017. Current flow rates to the plant are approximately 50 and 25 kL/day from the northern and southern trenches respectively. At these flows the mass of ammonia and nitrate being removed from groundwater is of the order of 6,700 and 8,700 kg/year respectively. Prior to the uprate of the treatment plant mass removal rates were substantially lower.

It is noted that trench flows have been observed to vary based on climatic conditions with significant increases occurring immediately following heavy rain. Insufficient data is currently available to determine whether the changes in inflows to the trenches are associated with changes in contaminant concentrations.

Water level maps for February 2016, January 2017 and July 2017 are presented in **Appendix B**. Review of the water level maps presented indicates that groundwater levels (and therefore flow paths) in areas not directly adjacent to the trenches have not been significantly altered by their operation. While only one data set (July 2017) is available for the period when the treatment plant was operating at the increased rates, review of water level hydrographs (**Appendix B**) for piezometers located close to the trenches indicates that water level drawdown during pumping is relatively minor (i.e. the water level change in the trench pump pit(s) is very large (1.5 m) while changes to levels immediately outside the trench are small (0.5 m)). While this observation is typical of low permeability aquifers it may also be due to poor hydraulic connection between the trench and aquifer.

While early operation of the system did not achieve significant mass removal rates the recent operation of the system has resulted in mass removal rates of a similar magnitude to the calculated mass flux rates at the site boundary and is therefore clearly consistent with the goal of decreasing mass flux from the site. However, the lack of significant water level drawdown near the trenches and the observed increase in contaminant concentrations at locations between the trenches implies that additional extraction is required. Whether the increased extraction is achieved by improving operation of the existing trenches and/or installation of additional trenches in the area between the southern and northern trenches should be made based on detailed consideration of the site hydrogeology. As concluded in CSM (JBS&G, 2017c) the risk to environmental values are dominated by small scale features (preferential flow paths) and as these features are not easily identified by site investigations, the installation of additional trenched portions along the site boundary is likely to be the preferred option to ensure that risks to environmental values can be appropriately managed.

The installation of additional trenches should include the following features:

- Installation of two approximately 50 m trenches between the exiting southern and northern trenches to intercept groundwater currently migrating between the two existing trenches.

- The depth of the trenches should be deeper than the existing trenches and should be a minimum depth of 3.2 m.
- Trench backfill should be selected and installed to allow groundwater to flow freely to the pump point.
- Groundwater should be extracted from the centre of each trench. The pump location must be installed such that water levels in the pump pit can be maintained below the base of the trench (if required).
- Water level monitoring locations must be installed within the trench backfill at each end of the trenches as well as directly adjacent to the pumping point.
- Additional monitoring wells (four per trench) should be installed adjacent to the trenches to ensure that performance of the trenches can be adequately assessed.

7.4 Validation Assessment

In accordance with the ASC NEPM, the success of the proposed nutrient remediation strategy will be assessed based on water levels/flow paths and mass flux rates in the vicinity of the extraction trenches as well as an assessment of groundwater concentrations. Results of the assessment will be reported in the annual groundwater monitoring report.

The key performance measures will be assessed by the monitoring program presented in **Table 7.1.**

Table 7.1: Summary of Remediation System Performance Measures (Nutrients)

Performance Measure	Assessment Process
Are concentrations increasing and if so do the changes pose a potential environmental risk?	If trend analysis and statistical assessment (adopting the guidance presented in USEPA 530/R-09-007) indicates that concentrations are increasing then the decision is Yes. In this circumstance a comparison to trigger levels and the potential fate of transport of the contaminants will be undertaken to determine the significance of the change. Recommendations for additional monitoring and/or remediation may be appropriate. Otherwise the decision is No.
Is the groundwater interception system operating effectively?	If an assessment of the reduction in annual mass flux of ammonia/nitrate over the site boundary (at the trenches) indicates a decrease of >75% then the decision is Yes. Otherwise the decision is No. In this circumstance recommendation for changes to the system operation will be provided.
Is the groundwater interception system preventing mixing of groundwater with surface water and the migration of contaminated surface water into the receiving environment?	If concentrations of contaminants at the surface water discharge point to the receiving environment (REMP1) are below REMP trigger values, then the decision is Yes. Otherwise the decision is No. In this circumstance recommendation for changes to the system operation will be provided.

8. Remediation of Cyanide in Groundwater

A detailed review of potential remediation options for free cyanide in groundwater at the site was undertaken by Golder Associates in 2011 (*Cyanide Groundwater Remediation Options* dated 15 September 2011 ref 117623077_R_Rev0) (Golder, 2011). This document was developed prior to construction of the SWRS and was focused on the elimination of discharge of contaminated groundwater to the stormwater system at the site.

JBS&G prepared a Groundwater RAP in June 2014 (JBS&G, 2014). The RAP was prepared in response to a requirement of the Environmental Authority for the site and included a detailed review of potential remediation options for free cyanide in groundwater. This CAP provides a revision of the RAP based on current site conditions.

8.1 Remediation Objectives

As discussed in **Section 4** it is considered unacceptable to allow the free cyanide plume to expand significantly further. If it did, significant remedial measures would need to be implemented.

In order to prevent expansion of the free cyanide plume the groundwater remediation objective is to reduce free cyanide concentrations in the perched aquifer at the site to reduce potential for unacceptable environmental risks caused by offsite migration of groundwater.

Given that free cyanide presents a much more significant toxicological risk than complexed cyanide, the remedial objective is to ensure the reduction in free cyanide concentrations/mass rather than total cyanide.

8.2 Preferred Remediation Options

The current and proposed remediation strategy at the site is monitored natural attenuation (MNA). This strategy is considered appropriate as the reported contaminant concentrations and distribution do not pose an unacceptable environmental risk. However, it is noted that free cyanide concentrations have increased at some locations and as a result it is recommended that further assessment of remediation options are progressed in parallel with MNA. In the case of the source area and plume, the preferred remediation strategy for further assessment is groundwater extraction and treatment or in-situ bioremediation.

In-situ bioremediation is considered an appropriate strategy to decrease contaminant concentrations in the source area and downgradient plume for the following reasons:

- As there is currently no unacceptable environmental risk, sufficient time is available to assess an in-situ methodology and develop an implementation strategy, should the contaminant concentrations and distribution present an unacceptable risk in the future.
- The relatively low impact of the methodology is best suited to the highly developed facility.
- Offers synergies with mitigation of groundwater impacts to stormwater at Cyanide Alley by addressing the source of contamination.
- Will result in reducing cyanide concentrations in the source area to levels more amenable to passive remedial technologies (potentially over a period of several years) including MNA.
- Will meet stakeholder expectations.

In-situ bioremediation pilot trials have been completed by Geosyntec Consultants and are described in the following reports:

- *Treatability testing of aerobic in-situ bioremediation of cyanide in groundwater, Orica Yarwun Manufacturing Facility* dated 16 November 2016, Geosyntec Consultants Pty Ltd (Project Number GSY0014) (Geosyntec, 2016a).

- *Recommendations for pilot trial design for aerobic in-situ bioremediation of cyanide in groundwater, Orica Yarwun Manufacturing Facility* dated 16 November 2016, Geosyntec Consultants Pty Ltd (Project Number GSY0014) (Geosyntec, 2016b).

The Geosyntec assessment concluded that the treatability study results indicated the potential for enhanced aerobic biodegradation to treat dissolved cyanide species in groundwater at the site. Given the limited scientific literature available regarding field implementation of in-situ treatment techniques for cyanide contaminated groundwater, it was recommended that a field pilot trial would need to be completed to provide design parameters prior to a decision on full-scale implementation.

With respect to the contingency strategy of groundwater extraction and treatment to remediate the cyanide plume JBS&G previously completed a high-level review of existing reports regarding extraction and ex-situ treatment of cyanide impacted groundwater. While the extraction/pumping system design is well advanced and capable of being readily installed (if required) the methodology to treat extracted water requires further investigation. This is considered acceptable as MNA continues to be an applicable remedial strategy for the cyanide plume.

8.3 Proposed Remediation Program

The tasks required to be undertaken to remediate cyanide contamination in groundwater at the site are as follows:

1. As free cyanide in groundwater does not currently pose an unacceptable risk to the environment MNA is considered a suitable remediation strategy.
    a. MNA requires implementation of a monitoring program to assess its ongoing applicability as a remediation strategy at the site. The GMP (JBS&G, 2016) for the site is considered to be a suitable monitoring program.
    b. The Annual Groundwater Monitoring will review the data collected during the monitoring program. For MNA to be considered suitable for ongoing remediation at the Site the plume must be shown to be stable or contracting.
    c. If monitoring suggests plume concentrations are increasing or the plume is expanding then further remediation works will be required. These works would initially include the completion of a field pilot trial of in-situ bioremediation and pending the results of this trial the implementation of full scale in-situ bioremediation or groundwater extraction and treatment.

8.4 Validation

In accordance with the ASC NEPM, the success of the proposed cyanide remediation strategy will be assessed based on trends of cyanide contamination in groundwater. Results of the assessment will be reported in the annual groundwater monitoring report.

The key performance measures will be assessed by the monitoring program presented in **Table 8.1**.

Table 8.1: Summary of Remediation System Performance Measures (Cyanide)

Performance Measure	Assessment Process
Are concentrations increasing and if so do the changes pose a potential environmental risk?	If trend analysis and statistical assessment (adopting the guidance presented in USEPA 530/R-09-007) indicates that concentrations are increasing then the decision is Yes. In this circumstance a comparison to trigger levels and the potential fate of transport of the contaminants will be undertaken to determine the significance of the change. Recommendations for additional monitoring and/or remediation may be appropriate. Otherwise the decision is No.

9. Conclusions

Subject to the limitations in **Section 10** and with respect to the objectives stated in **Section 1.2** JBS&G conclude that:

- Historical groundwater investigations undertaken at the site have identified:
    - Ammonia and nitrate are present in groundwater at concentrations exceeding the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality Australian and New Zealand Environment and Conservation Council (ANZECC)* trigger values for the protection of fresh water ecosystems. The highest concentrations of ammonia and nitrate are present on the site in the area of the AN Complex although significant concentrations are present in groundwater at the site boundary and in offsite areas.
    - Free cyanide is present at concentrations exceeding the ANZECC 2000 trigger values in groundwater on the site. The highest concentrations are associated with the Cyanide Plant and the plume is completely within the site boundaries. Total cyanide has also been identified in groundwater with low concentrations identified at the site boundary.
- Primary source control works to reduce the potential for contaminants to enter the subsurface have already been undertaken on the site. However, groundwater contamination trends noted in source areas indicate further work is required to manage source releases. In order to limit future releases from AN and Cyanide source areas, a number of projects have been scheduled for further upgrades to limit future releases from AN and Cyanide source areas.
- A groundwater interception trench and treatment system has been installed on the site boundary to decrease ammonia and nitrate mass flux in the perched aquifer. While early operation of the system did not achieve significant mass removal rates the recent operation of the system has resulted in mass removal rates of a similar magnitude to the calculated mass flux rates at the site boundary and is therefore consistent with the goal of decreasing mass flux from the site. However, the lack of significant water level drawdown near the trenches and the observed increase in contaminant concentrations at locations between the trenches implies that additional extraction is required.
- The additional extraction will be achieved by the installation of additional trenched portions along the site boundary between the two existing trenches.
- As free cyanide in groundwater does not currently pose an unacceptable risk to the environment MNA is considered a suitable remediation strategy.
- Validation of the success of the remediation strategies will be undertaken by ongoing groundwater monitoring and assessment of the remediation strategies in the annual groundwater monitoring report.
- Implementation of the above remediation strategies will successfully address the objectives and requirements for remediation detailed in this CAP.

10. References

ANZECC/ARMCANZ (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality Australian and New Zealand Environment and Conservation Council (ANZECC) & Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ).*

Golder Associates Pty Ltd (2011a) *Remediation of Nutrients in Groundwater, Orica Yarwun – Preferred Remedial Strategy*. Golder Associates Pty Ltd 13 May 2011 Ref: 117623026_001_L_Rev0.

Golder Associates Pty Ltd (2011b) *Orica Yarwun – Remediation of Nutrients in Groundwater: Groundwater Extraction and Treatment Preliminary Design Tasks*. Golder Associates Pty Ltd 5 September 2011 Ref: 117623026_002_R_Rev0.

Golder Associates Pty Ltd (2011c) *Cyanide Groundwater Remediation Options* dated 15 September 2011 ref 117623077_R_Rev0.

NEPC (1999) *National Environmental Protection (Assessment of Site Contamination) Measure* as amended 2013 (ASC NEPM).

JBS&G (2014) *Orica Australia Pty Ltd Yarwun Manufacturing Facility Groundwater Remediation Action Plan* dated 30 June 2014 JBS&G Pty Ltd (Ref 43418-57998 Rev1)

JBS&G (2016) *Orica Australia Pty Ltd Yarwun Manufacturing Facility Groundwater Monitoring Plan* dated 25 October 2016 JBS&G Pty Ltd (Ref 42685-55708 Rev3)

JBS&G (2017a) *Yarwun Manufacturing Facility Annual Groundwater Monitoring Report* dated 29 June 2017 JBS&G Pty Ltd (Ref 53025-108920 Rev1)

JBS&G (2017b) *Yarwun Manufacturing Facility Detailed Site Investigation dated* 31 August 2017 JBS&G Pty Ltd (Ref 52877-109702 R001 Rev0)

JBS&G (2017c) *Yarwun Manufacturing Facility Conceptual Site Model dated* 5 December 2017 JBS&G Pty Ltd (Ref 52877-109702 R002 Rev0)

URS (2009) *Revised Conceptual Site Model, Orica Yarwun Facility,* URS Australia Pty Ltd dated February 2009.

11. Limitations

This report has been prepared for use by the client who has commissioned the works in accordance with the project brief only, and has been based in part on information obtained from the client and other parties.

The advice herein relates only to this project and all results conclusions and recommendations made should be reviewed by a competent person with experience in environmental investigations, before being used for any other purpose.

JBS&G accepts no liability for use or interpretation by any person or body other than the client who commissioned the works. This report should not be reproduced without prior approval by the client, or amended in any way without prior approval by JBS&G, and should not be relied upon by other parties, who should make their own enquires.

Sampling and chemical analysis of environmental media is based on appropriate guidance documents made and approved by the relevant regulatory authorities. Conclusions arising from the review and assessment of environmental data are based on the sampling and analysis considered appropriate based on the regulatory requirements.

Limited sampling and laboratory analyses were undertaken as part of the investigations undertaken, as described herein. Ground conditions between sampling locations and media may vary, and this should be considered when extrapolating between sampling points. Chemical analytes are based on the information detailed in the site history. Further chemicals or categories of chemicals may exist at the site, which were not identified in the site history and which may not be expected at the site.

Changes to the subsurface conditions may occur subsequent to the investigations described herein, through natural processes or through the intentional or accidental addition of contaminants. The conclusions and recommendations reached in this report are based on the information obtained at the time of the investigations.

This report does not provide a complete assessment of the environmental status of the site, and it is limited to the scope defined herein. Should information become available regarding conditions at the site including previously unknown sources of contamination, JBS&G reserves the right to review the report in the context of the additional information.

Figures

Source: Base Image www.nearmap.com - Imargery Date 7-8-2013. Accessed 29-8-2013

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Scale: 1:45,000

Datum: MGA94 Zone 56 - AHD

A3			
B	Original Issue - R02	RF	17-11-2017
Rev	Description	Drn.	Date

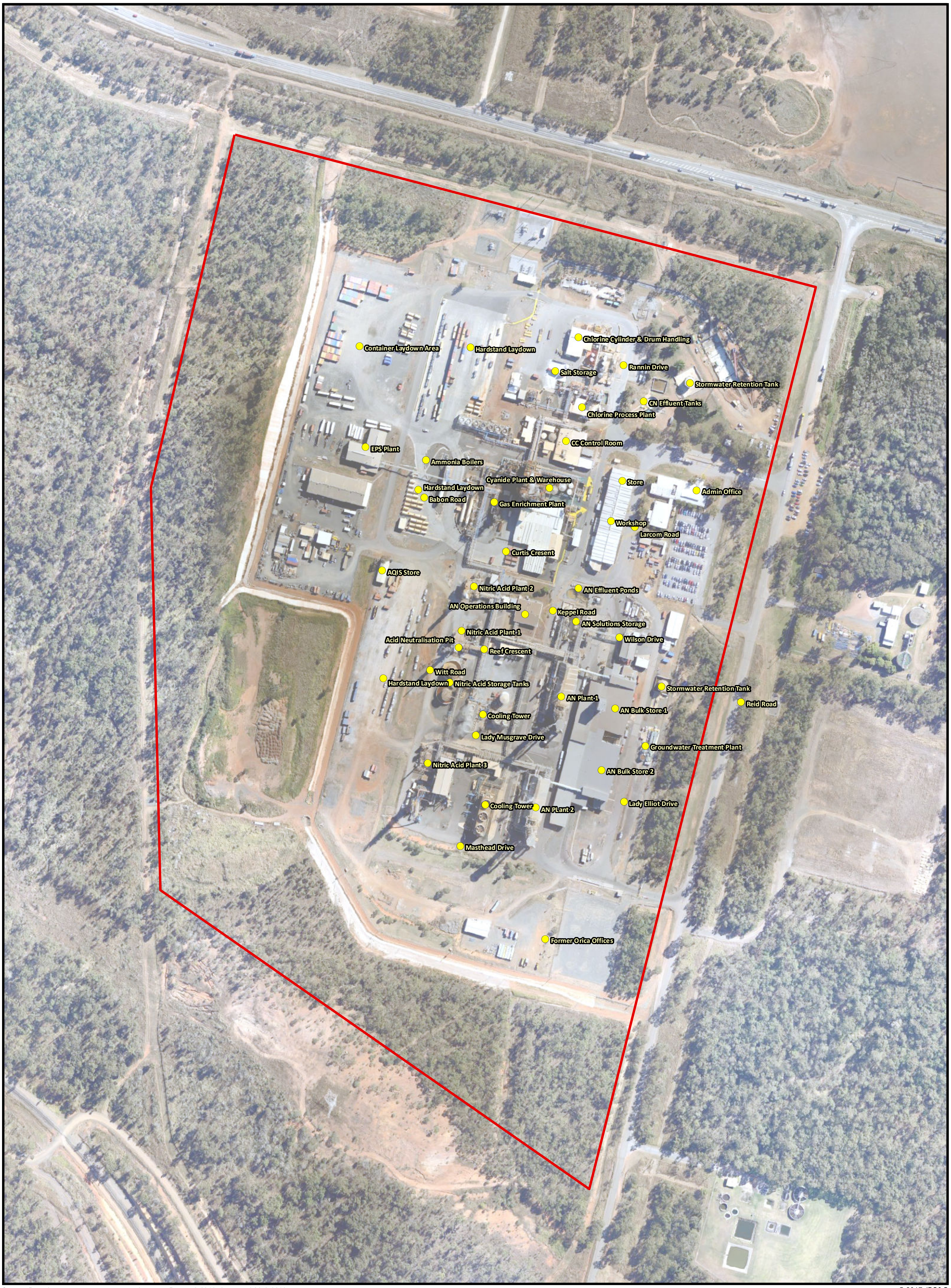
Legend:
Approximate Boundary - Lot 138 CTN2123

JBS&G **Figure 1: Site Location**

Client: Orica Australia Pty Ltd

Project: 30 Reid Road, Yarwun, QLD (Lot 138 on CTN2123)

Job No: 52877 File Name: 52877_01



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Rev	Description	Drn.	Date
B	Original Issue - R02	RF	17-11-2017

Legend:

Approximate Boundary - Lot 138 CTN2123

Site Features

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Figure 2: Site Features

Client: Orica Australia Pty Ltd

Project: 30 Reid Road, Yarwun, QLD (Lot 138 on CTN2123)

Job No: 52877

File Name: 52877_02

Source: Base Image www.nearmap.com - Imagery Date 7-8-2013. Accessed 29-8-2013

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Rev	Description	Drn.	Date
B	Original Issue - R02	RF	17-11-2017

Legend:

- Approximate Boundary - Lot 138 CTN2123
- Trench Locations
- Groundwater Monitoring Well Location

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Figure 3: Groundwater Monitoring Well Locations

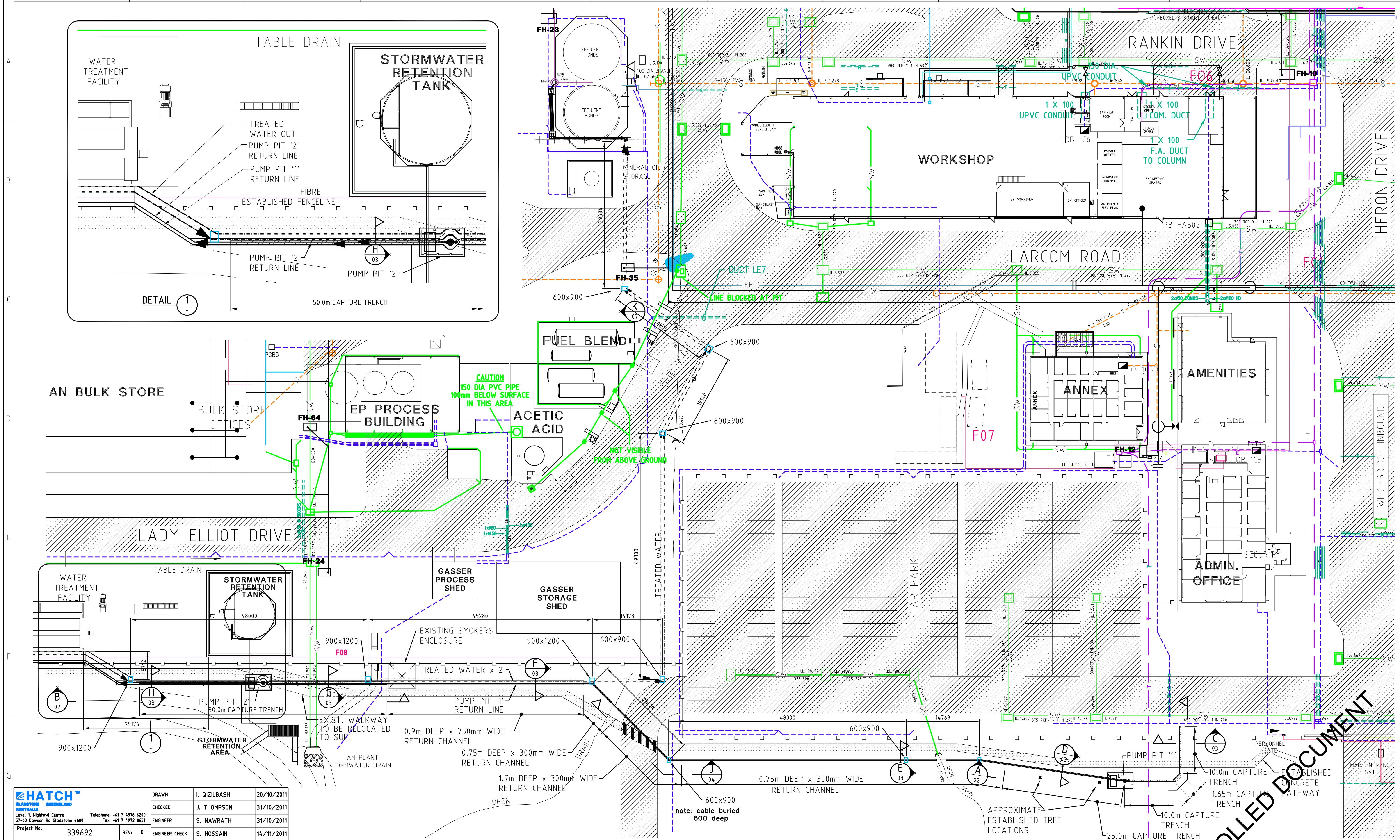
Client: Orica Australia Pty Ltd

Project: 30 Reid Road, Yarwun, QLD (Lot 138 on CTN2123)

Job No: 52877

File Name: 52877_03

Appendix A Groundwater Interception Trench as Built Drawings



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ENGINEER CHECK	S. HOSSAIN	14/11/2011

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PLANT: SITE
SECTION: - -
THIRD ANGLE PROJECTION
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TITLE
GROUND WATER CAPTURE AND REMEDIATION
SITE LOCATION PLAN
SHEET 1 OF 7

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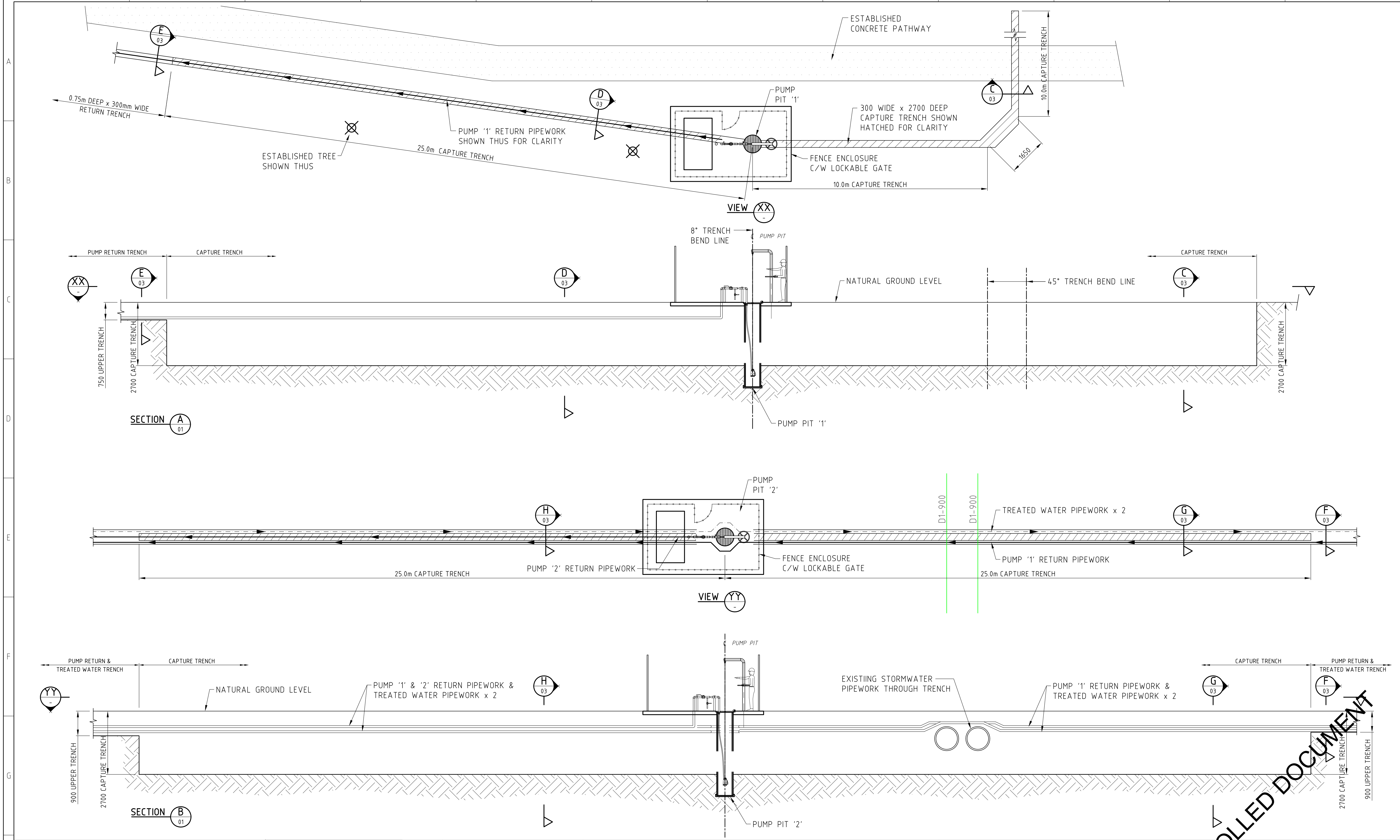

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TRENCH SECTIONS	5370-11-50225
SITE LOCATION PLAN	5370-11-50223

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TITLE
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TRENCH LONG SECTIONS
SHEET 2 OF 7

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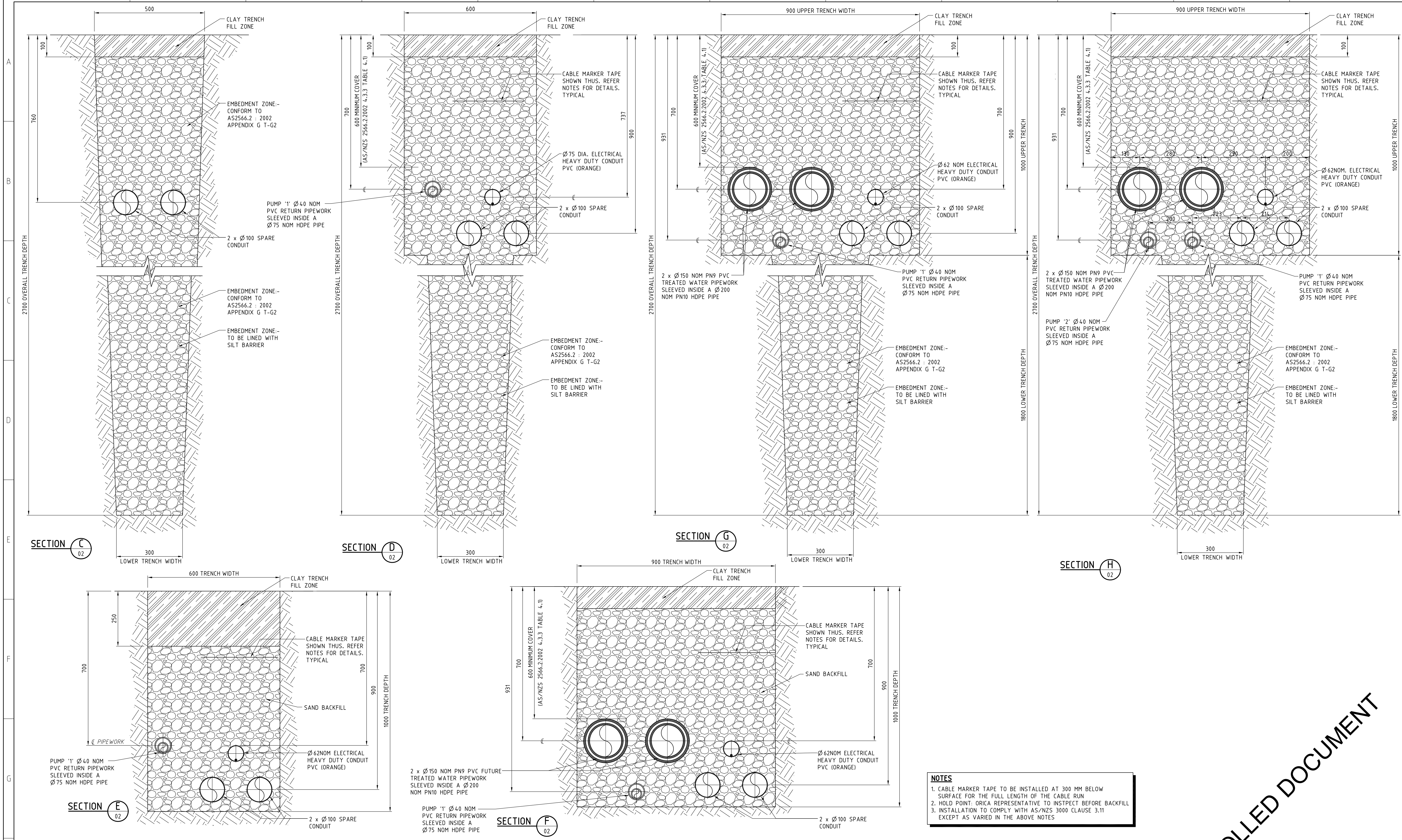

NOTES

1. CABLE MARKER TAPE TO BE INSTALLED AT 300 MM BELOW SURFACE FOR THE FULL LENGTH OF THE CABLE RUN
2. HOLD POINT: ORICA REPRESENTATIVE TO INSTPECT BEFORE BACKFILL
3. INSTALLATION TO COMPLY WITH AS/NZS 3000 CLAUSE 3.11 EXCEPT AS VARIED IN THE ABOVE NOTES

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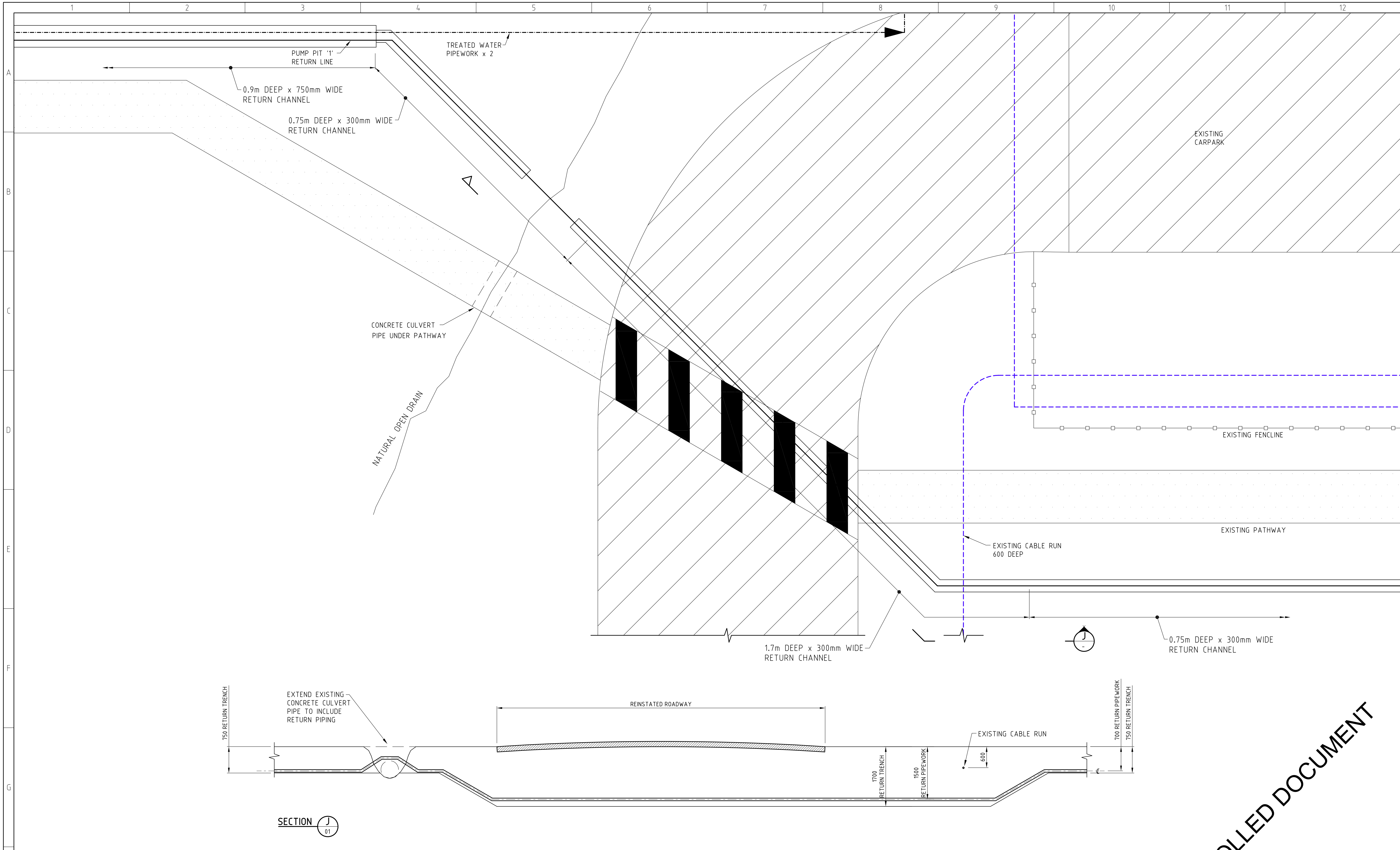

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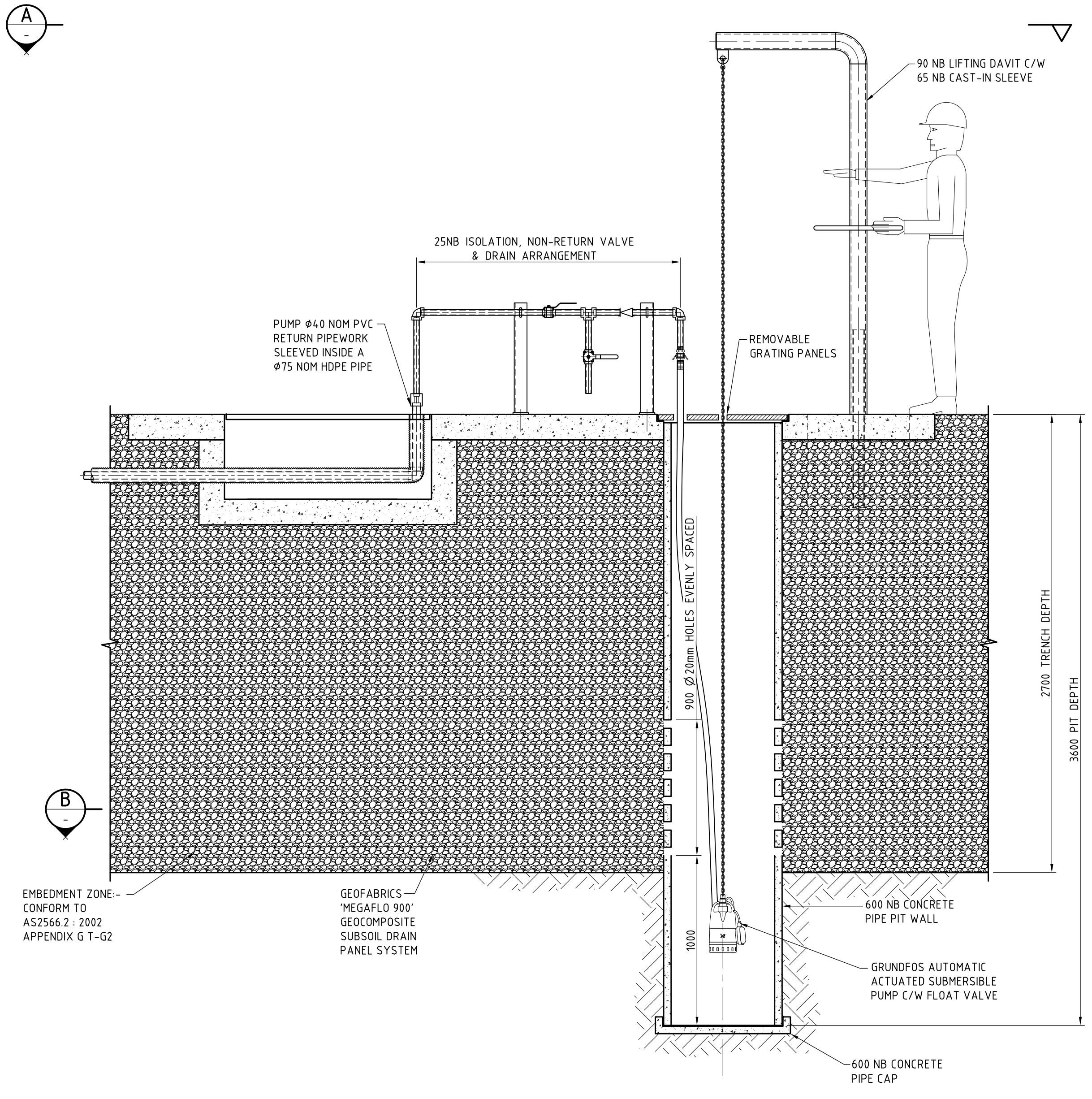

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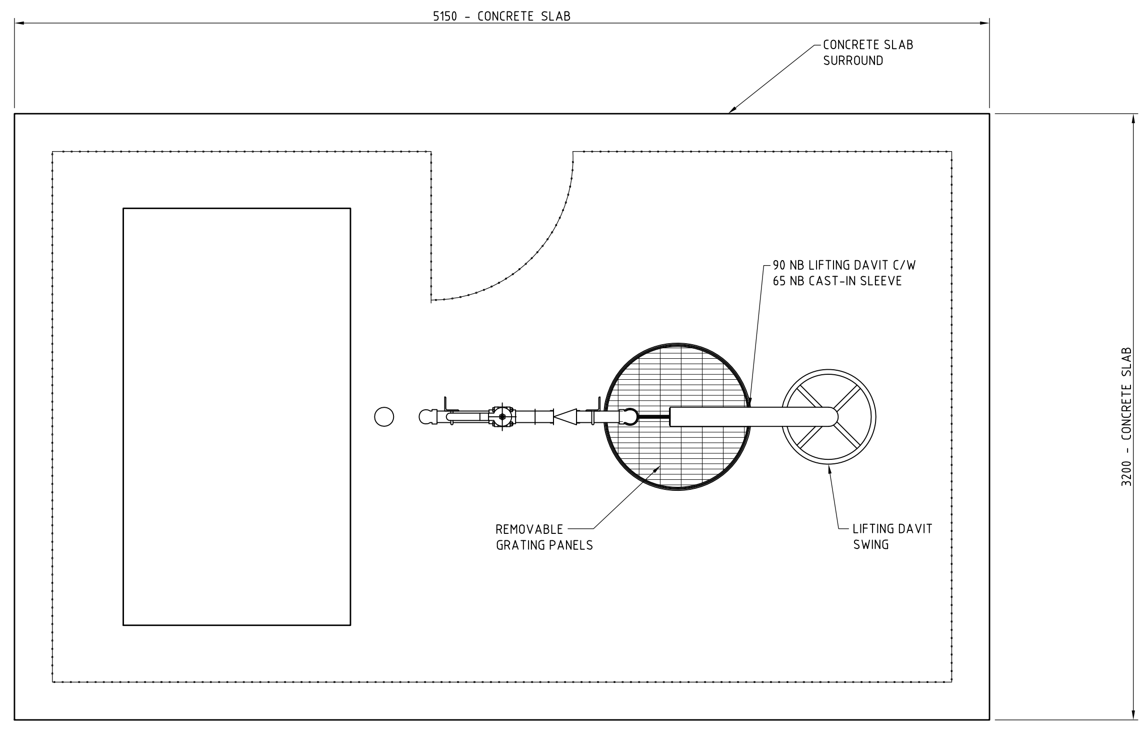

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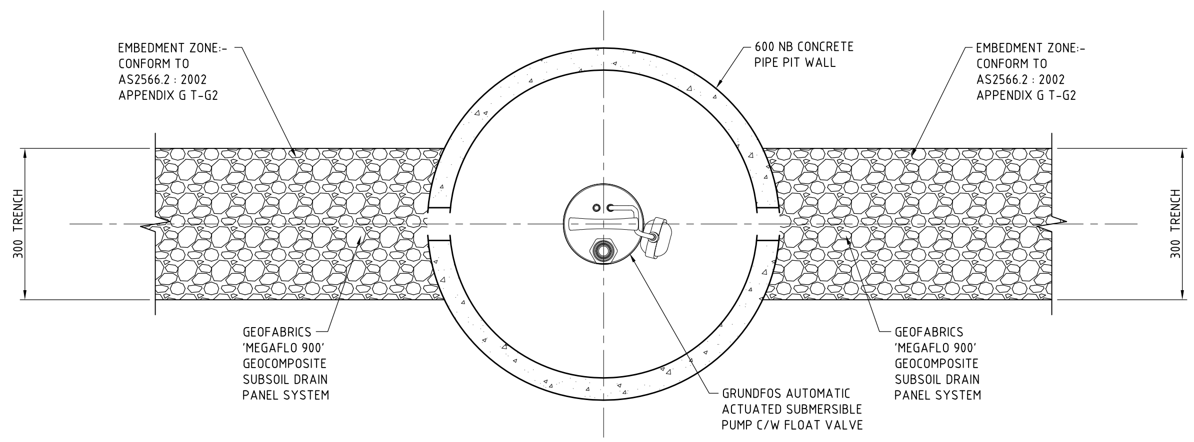

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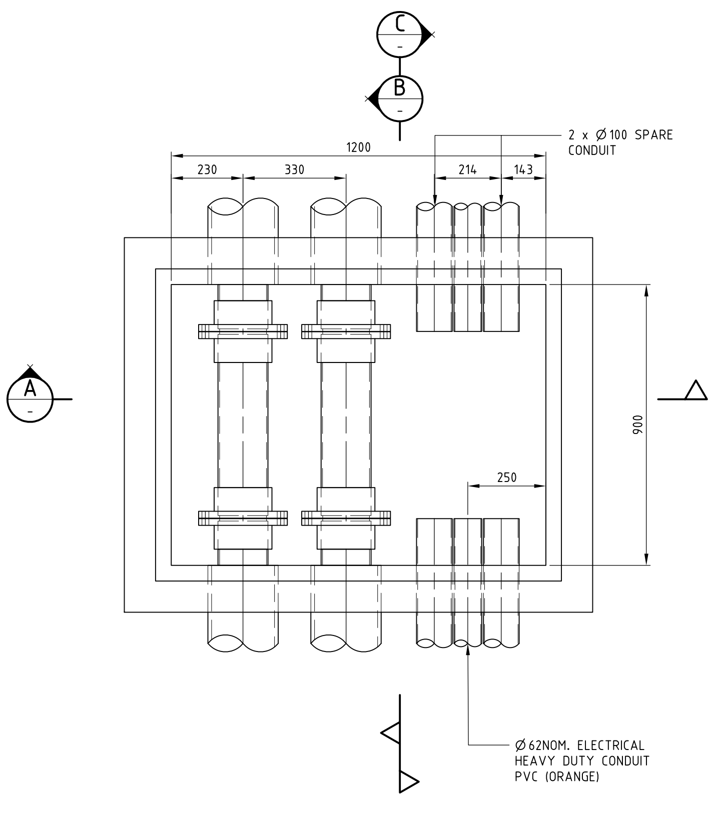

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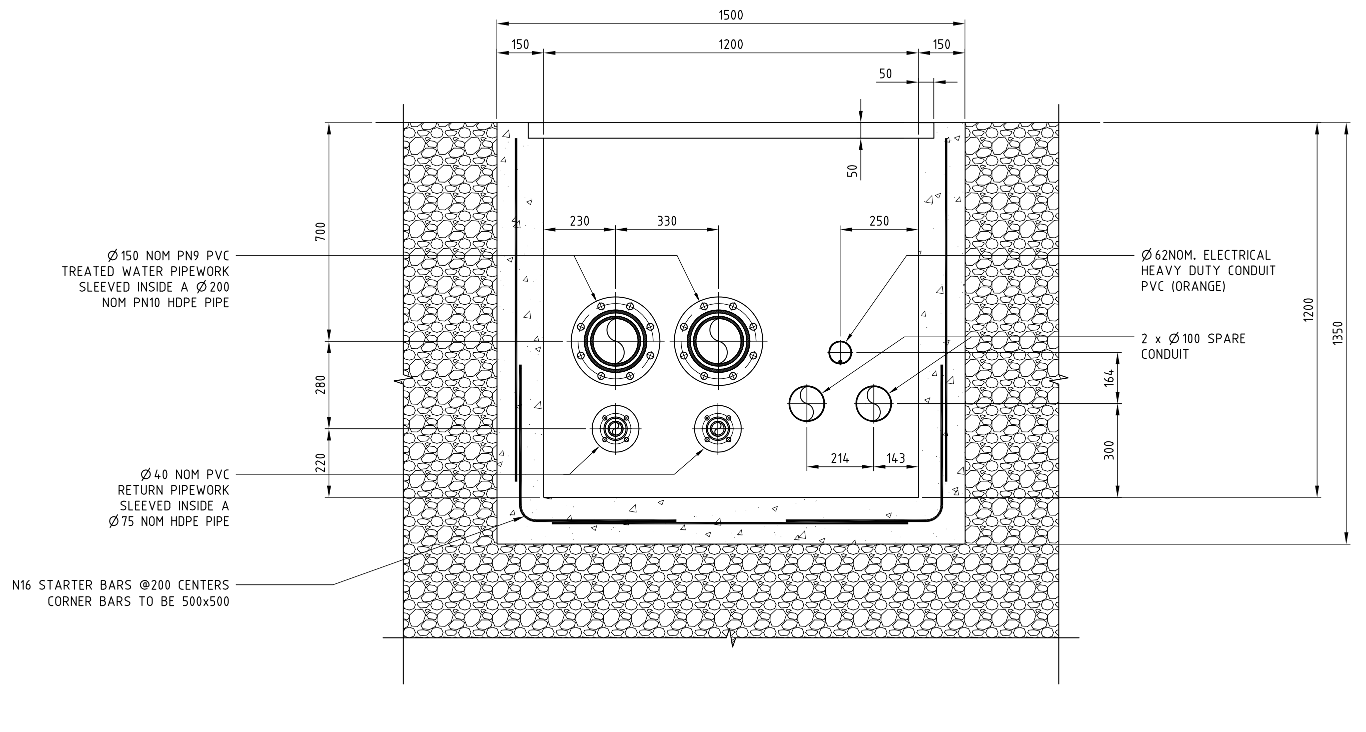

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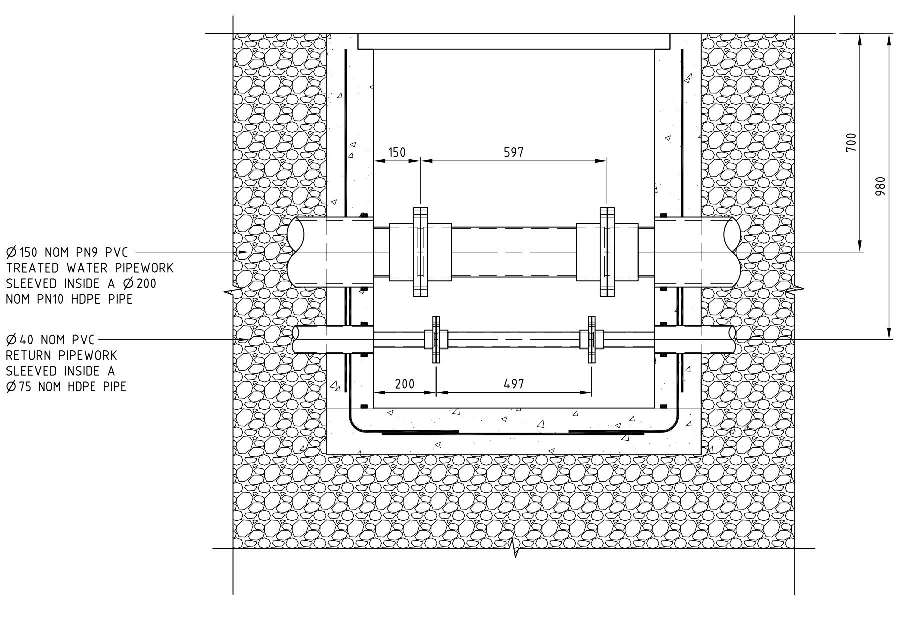

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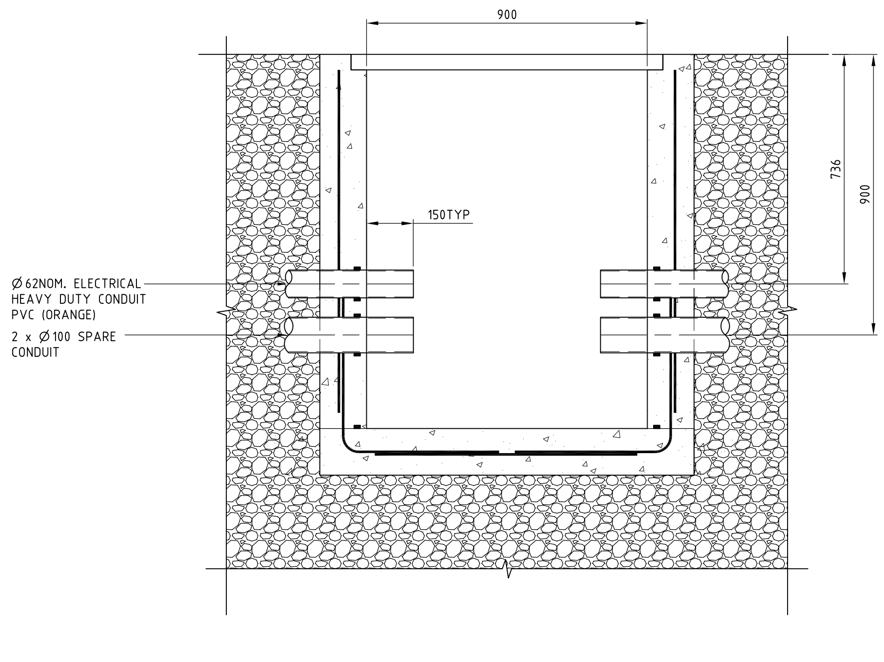

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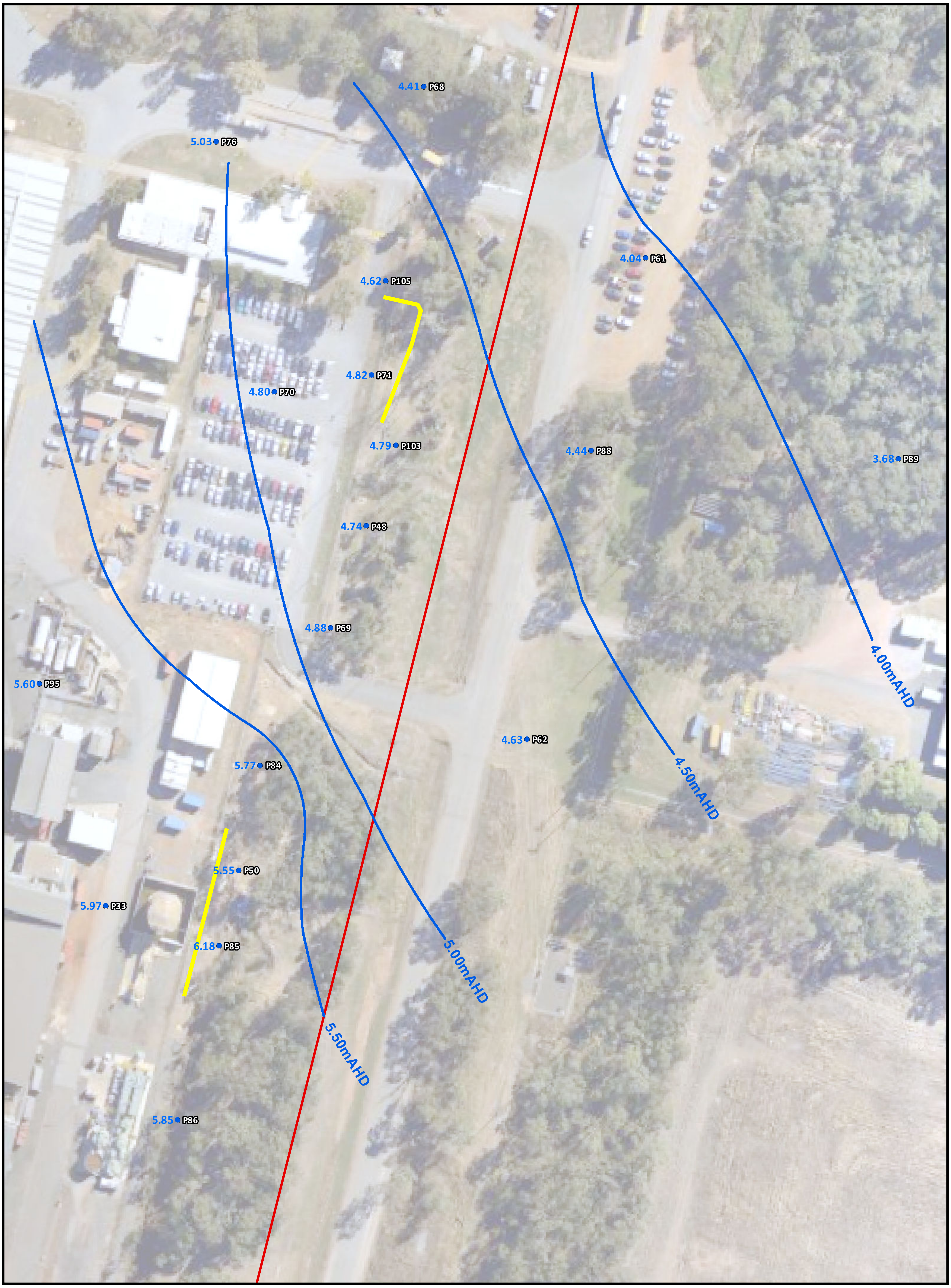
Appendix B Groundwater Elevation Maps



Source: Base Image www.nearmap.com - Imagery Date 7-8-2013. Accessed 29-8-2013

0 5 10 20 m
Scale: 1:1,000
Datum: MGA94 Zone 56 - AHD

A3

Rev	Description	Drn.	Date
B	Original Issue - R02	RF	17-11-2017

Legend:
- Approximate Boundary - Lot 138 CTN2123
- Trench Locations
- Groundwater Elevation (mAHD)
- Groundwater Elevation (mAHD)

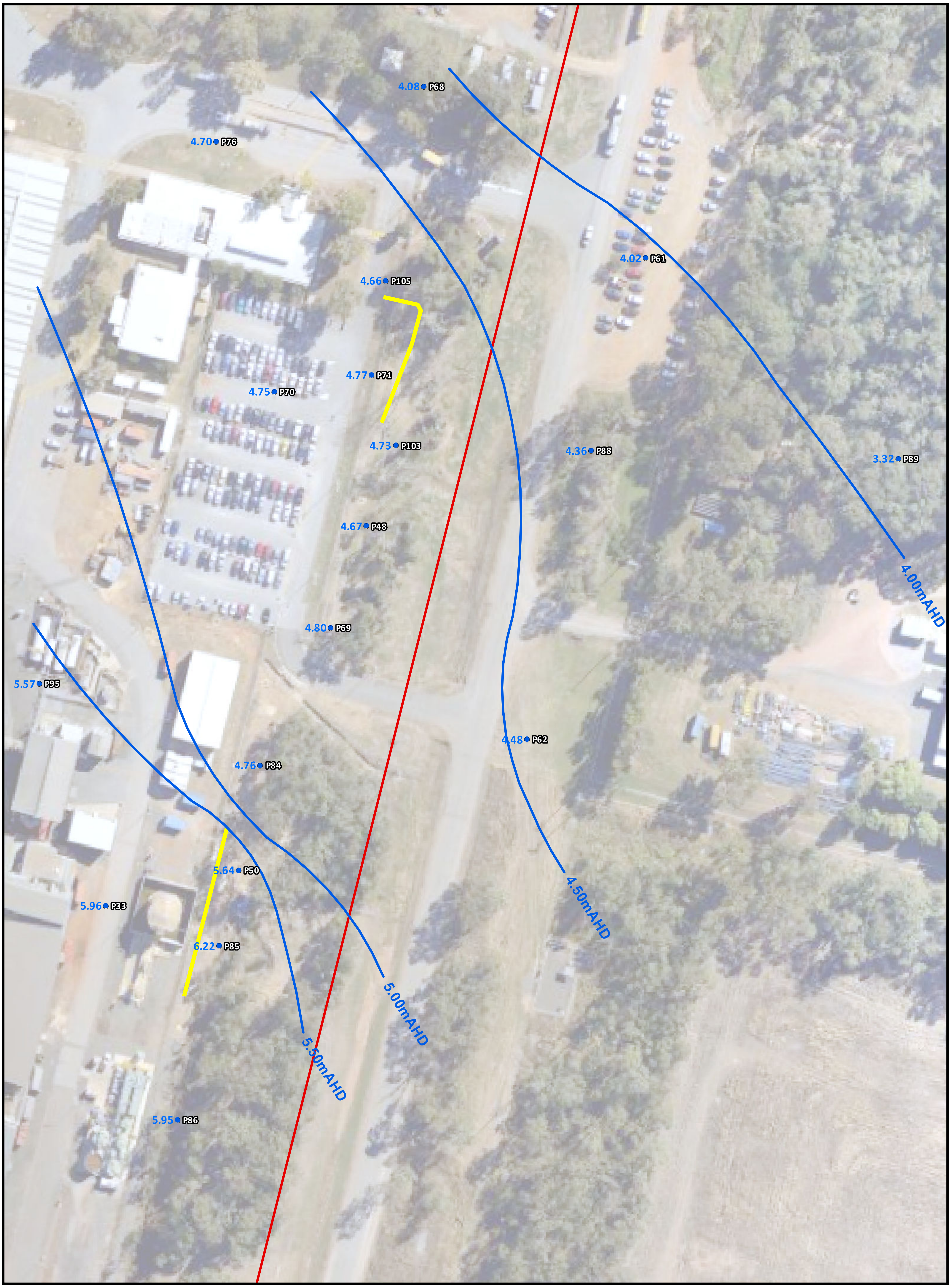
JBS&G

Figure: Groundwater Elevation (mAHD) - Feburary 2016

Client: Orica Australia Pty Ltd

Project: 30 Reid Road, Yarwun, QLD (Lot 138 on CTN2123)

Job No: 52877 File Name: 52877_February 2016



Source: Base Image www.nearmap.com - Imagery Date 7-8-2013. Accessed 29-8-2013

0 5 10 20 m

Scale: 1:1,000

Datum: MGA94 Zone 56 - AHD

A3

Rev	Description	Drn.	Date
B	Original Issue - R02	RF	17-11-2017

Legend:
- Approximate Boundary - Lot 138 CTN2123
- Trench Locations
- Groundwater Elevation (mAHD)
- Groundwater Elevation (mAHD)

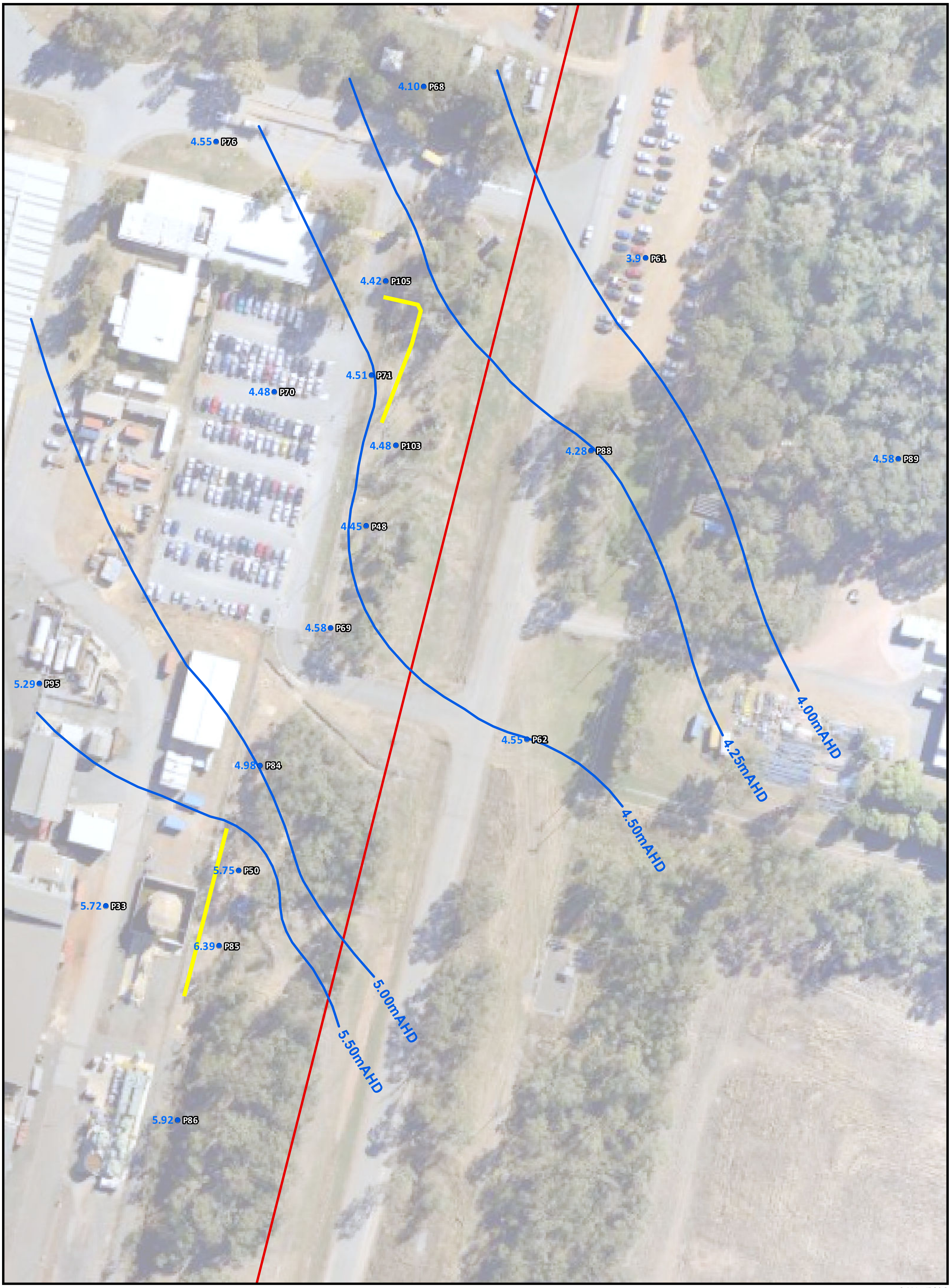
JBS&G

Figure: Groundwater Elevation (mAHD) - January 2017

Client: Orica Australia Pty Ltd

Project: 30 Reid Road, Yarwun, QLD (Lot 138 on CTN2123)

Job No: 52877 File Name: 52877_January 2017



Source: Base Image www.nearmap.com - Imagery Date 7-8-2013. Accessed 29-8-2013

0 5 10 20 m

Scale: 1:1,000

Datum: MGA94 Zone 56 - AHD

A3

Rev	Description	Drn.	Date
B	Original Issue - R02	RF	17-11-2017

Legend:

- Approximate Boundary - Lot 138 CTN2123
- Trench Locations
- Groundwater Elevation (mAHD)
- Groundwater Elevation (mAHD)

JBS&G

Figure: Groundwater Elevation (mAHD) - July 2017

Client: Orica Australia Pty Ltd

Project: 30 Reid Road, Yarwun, QLD (Lot 138 on CTN2123)

Job No: 52877 File Name: 52877_July 2017

Document Distribution

Rev No.	Copies	Recipient	Date
A	1 x electronic	Sarah Jones	28 November 2017
0	1 x electronic	Sarah Jones	5 December 2017

Document Status

Rev No.	Author	Reviewer	Approved for Issue		
		Name	Name	Signature	Date
A	Stuart Derham	Greg Dasey	Greg Dasey	DRAFT for client review	28 November 2017
0	Stuart Derham	Greg Dasey	Greg Dasey		5 December 2017