REPORT

Remediation Validation Report

Arsenic Remediation Program - Orica Kooragang Island

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1.0 INTRODUCTION

Golder Associates Pty Ltd (Golder) has prepared this Remediation Validation Report RVR) on behalf of Orica Australia Pty Ltd (Orica) to document the validation of the arsenic remediation program at the north-western portion of the Orica site at Greenleaf Road, Kooragang Island, NSW (the site), **Figure 1**.

This RVR is required by Action 2(c) of a management order (MO) (Order Number 20181401 as amended via Notice 20194429 on 8 August 2019) issued by NSW EPA under Section 14(1) of the Contaminated Land Management Act 1997 (the Act) on 3 August 2018, and under Condition B8 of Development Consent SSD7831 (the Consent) issued by the Department of Planning, Industry and Environment on 10 August 2018

It presents the results of the validation program associated with the installation of an integrated cap and containment system (referred to in the MO as a hydraulic containment system and in the Consent as the containment cell) to meet the objectives of the MO and Consent.

This document is also required to facilitate the preparation of a Site Audit Statement and Site Audit Report by an NSW Environment Protection Authority (EPA) Accredited Site Auditor (Chris Jewell), under Condition 1b) of the MO and Condition B12 of the Consent.

1.1 Arsenic Remediation Program

The arsenic remediation area is located in the north-western corner of the site in the former location of a sludge disposal pit. The remediation location and layout are shown on **Figure 2**.

The remediation was undertaken between February and September 2019. The remediation program involved the construction of a containment system comprising of a soil/bentonite cut-off wall with an integrated capping system which was designed to hydraulically isolate the identified arsenic contamination. The cut-off wall component of the integrated system is approximately 12 m in depth and covers an area of approximately 4,200 m^2.

1.2 Regulatory Framework

Orica developed a Remediation Action Plan (RAP) for the remediation of the former arsenic sludge disposal pit in the north western portion of the site. The project was initiated in response to EPA MO (Order Number 20131407) issued by NSW EPA on 28 July 2014. The RAP was prepared in accordance with Action 1(e) of the MO (20131407).

As required in the RAP, an Environmental Impact Statement (Golder, 2017) was prepared to support a State Significant Development application under part 4 (Division 4.1) of the *Environmental Planning and Assessment Act 1979* to obtain development consent for the remediation project. Development Consent SSD7831 was issued to Orica on 10 August 2018 permitting the construction of a containment cell to address arsenic contamination at the site.

In addition, the NSW EPA issued a new Management Order (Order No. 20181401) and repealed the previous order (Order No. 20131407). The new Management Order required, amongst other tasks, the implementation of the RAP (Golder, 8 July 2016a) within 12 months of receiving regulatory approvals and landowner consent for the works, and preparation of the RVR within three months of completion of the construction of the hydraulic containment system. The MO was amended via Notice 20194429 on 8 August 2019 to extend the completion date to 30 September 2019.

Completion of construction of the containment cell occurred on 24 September 2019 meeting the requirements of Item 2b of the MO and Condition A6 of the Consent.

In conjunction with this RVR, a Long Term Environmental Management Plan (LTEMP) has also been prepared in accordance with Condition B9 of the Consent, and Item 2d) of the MO to facilitate the preparation of a Site Audit Statement and Site Audit Report by an NSW Environment Protection Authority (EPA) Accredited Site Auditor (Chris Jewell), under Condition 1b) of the MO and Condition B12 of the Consent.

1.3 Remediation Planning Documentation

The remediation design, approach and validation methodology were developed and presented in the following planning documents:

- Remediation Action Plan (RAP) (Golder, 2016a);
- Environmental Impact Statement (Golder, 2017);
- Reference Specification – Cut-Off Wall Construction by Soil-Bentonite Method (Golder, 2018a); and
- Technical Specification - Capping System (Golder, 2019a).

This RVR should be considered in conjunction with those reports. A more detailed review of the history of site assessment and remediation is presented in **Section 4.0**.

1.4 Validation Consultant Role

Golder performed the role of Validation Consultant (VC) (as defined in Section 11 of the RAP) during the remediation program. The role required consulting and oversight services from several combined disciplines including civil design, contaminated land assessment, hydraulic and groundwater monitoring as well as geotechnical appraisals.

The validation program focussed on the following primary components:

- Construction oversight (including adequacy assessment of the contractor’s construction quality control (CQC) report;
- Construction Quality Assurance (CQA) reviews for both the cut-off wall and capping systems; and
- The verification of system performance through monitoring of responses to integrated system installation in the local hydraulic regime (on-going).

This report presents field observations and data collected by Golder during validation works (i.e. during Golder’s role as VC). Based on the review of validation information and data, an assessment of the ‘effectiveness’ of the remediation action is presented, including an assessment of the suitability of the site for the proposed ongoing commercial/industrial land use.

2.0 OBJECTIVES

The remediation objective stated in Section 6.1 of the RAP (Golder, 2016a) was to achieve the MO objectives. More specifically, the MO required Orica to:

- "Implement works that will prevent, to the extent required by Action 1c [of the Management Order], the further offsite migration of arsenic in groundwater."

The overall objective of the validation process is to document that remediation has been successfully achieved in accordance with the approach and objectives outlined in the RAP (Golder, 2016a) and the methodology outlined within the respective cut-off wall and capping system technical specifications.

The RVR is identified as one of the deliverables required by the MO under Action 2(c), and by the Consent under Condition B8.

3.0 SITE IDENTIFICATION

The Orica site's main entrance is at 15 Greenleaf Road, Kooragang Island, NSW. The Orica site is described as Lot 2 and Lot 3 in Deposited Plan 234288. The Orica site covers an area of approximately 22 hectares. The site is located on the south eastern peninsula of Kooragang Island at the confluence of the North and South Arms of the Hunter River (**Figure 1**).

4.0 CONTAMINATION HISTORY AND CHARACTERISATION

A detailed summary of arsenic contamination associated with the former sludge disposal pit is presented in the CSM (Golder, 2013). Provided below is a summary of arsenic contamination in the area to which the MO and Consent applies. In general, this contamination is located in an approximately 4,000 m^2 area in the north-western portion of the Orica site, bounded to the north by the Incitec Pivot Limited site and to the west by the East Coast Cement site (**Figure 1**).

4.1 Former Sludge Disposal Pit

The former sludge disposal pit (**Figure 2**) was used for the disposal of solid and liquid arsenic wastes from the Vetrocoke process used at the Ammonia Plant from late 1960s to 1994, when the industrial process was changed and arsenic was no longer used.

Although the primary source of contamination has been removed (through cessation of disposal), residual arsenic sorbed to soils beneath the former pit and in the surrounding subsurface represent an ongoing source of arsenic to groundwater. Removal of a secondary source of contamination occurred in 2005 with the remediation of contaminated soil beneath the former pit (to the depth of the groundwater table), the bund walls and soil surrounding the pit by excavation, treatment and off-site disposal.

4.2 Soil Contamination

Beneath the remediated extent of the former pit, residual arsenic soil concentrations averaged 170, 540 and 130 mg/kg in Units 1, 2 and 3 (Units described in Section 5.3), respectively. Maximum arsenic concentrations recorded in soil were in the order of 1,900 mg/kg.

The estimated mass of arsenic in soil in the remediation area is 8,200 kg (Appendix A of Orica, 2013).

Further assessment of the extent of soil contamination on the site was undertaken during the development of the RAP to define the remediation program undertaken (RAP, 2016a).

4.3 Groundwater Contamination

Dissolved arsenic in groundwater is present below and down-gradient (west-northwest) of the former sludge disposal pit. Concentrations of arsenic in groundwater have ranged between 15 mg/L and 85 mg/L, with concentrations decreasing since the remediation of the former disposal pit in 2005.

The highest dissolved arsenic concentrations occur between 3 and 7 m below ground level (bgl). At depths greater than approximately 8 m bgl, dissolved arsenic concentrations are low (<1 mg/L).

The predominant arsenic species in groundwater is As (III) (arsenite) with a minor portion as As(V) (arsenate), which is consistent with the original arsenic source (arsenic trioxide) and the groundwater geochemistry (mildly reducing). Both As(III) and As(V) are inferred to be present, predominantly as oxyanions (including their hydrogen substituted forms), in groundwater (Golder, 2013).

4.4 Fate and Transport of Arsenic

Despite a relatively high average groundwater velocity, the migration of arsenic is significantly attenuated within the aquifer. This is supported by the distribution of arsenic in soil and groundwater down-gradient of the former sludge disposal pit (Golder, 2013).

Transport

The arsenic (either as a release of arsenic trioxide solution during operation of the sludge disposal pit or as a result of the subsequent leaching of arsenic from the contaminated soils below the pit) has entered into the vadose zone below the former pit and then the saturated zone (groundwater). Dissolved arsenic then migrated with the groundwater flow. Arsenic has adsorbed to aquifer materials along the flow path until the attenuation capacity of the aquifer is exceeded such that the arsenic plume has migrated more slowly than the groundwater flow.

A portion of arsenic in groundwater migrating downward vertically from Unit 1 is inferred to have been partitioned onto the fine-grained (silts and clays) soils of Unit 2, which are inferred to represent a significant secondary source of arsenic. This inference is supported by generally higher arsenic concentrations within the silty/clayey sediments of Unit 2. Limited arsenic has continued to migrate into Unit 3.

Attenuation Mechanisms

Investigations have confirmed that the predominant process attenuating arsenic in the aquifer is adsorption onto naturally-occurring iron minerals (particularly hydrous ferric (oxy) hydroxides (HFO)) (Golder, 2013). The amount of HFO present in the aquifer was considered to provide substantial arsenic adsorption capacity, approximately 330 mg arsenic per kg of soil (CSIRO, 2007), though it is expected to be highly variable and it is noted that significantly higher soil concentrations (>1,000 mg/kg) have been reported[1].

Other mechanisms such as adsorption of arsenic to organic matter, sulfides, clays and other minerals are considered not to be the dominant factor in attenuating arsenic within the aquifer, however, may contribute directly or indirectly to fate and transport of arsenic, in particular within Unit 2 fine-grained sediments.

Although Unit 2 is inferred to have a high arsenic attenuation capacity due to the presence of a high portion of fine grained sediments, a portion of adsorbed arsenic is likely to be more weakly bound to clays, and organic matter. The combination of the higher arsenic attenuation capacity, and lower hydraulic conductivity, of Unit 2 sediments means that Unit 2 represents an ongoing, long-term source of arsenic groundwater contamination.

Changes in the geochemical condition of the aquifer may alter the presence or capacity of aquifer materials to provide adsorption sites for the attenuation of arsenic (i.e. dissolution of HFO) and/or cause desorption of arsenic.

[1] Reported soil concentrations of samples collected from the saturated zone contain pore water which will contribute to the apparent soil analytical result, particularly where there are elevated arsenic groundwater concentrations.

5.0 SITE SETTING

A detailed description of the site land use, surrounding areas, history of use and geology and hydrogeology is provided in the Conceptual Site Model (CSM) (Golder, 2013). A brief summary is provided below, however, if further detail is required the CSM should be referred to.

Kooragang Island was originally a series of smaller islands which formed part of the Hunter River Delta. The southern portion of Kooragang Island was subsequently reclaimed[2] in the late 1950s and early 1960s from the original landform of a series of tidal mud flats using dredged sand from the Hunter River. Since the reclamation, the southern portion of Kooragang Island, including the area occupied by the site, has been developed for heavy industrial use, including port facilities, chemical manufacturing and storage, waste recycling and hazardous waste treatment.

5.1 Current Land Use

The Orica site is used for the manufacturing of ammonia and nitric acid as intermediate products in the production of ammonium nitrate for use in the mining sector. The Orica site is classified as a major hazard facility (MHF) as the site produces the scheduled materials ammonia and ammonium nitrate at rates that exceed threshold quantities specified in Schedule 15 of the *Work Health and Safety Regulation 2011*.

5.2 Surrounding Land Use

The southern portion of Kooragang Island, including the Orica site, is zoned ‘Special Activities’ under the New South Wales State Environmental Planning Policy (Major Projects) Amendment (Three Ports) 2009 under the Environmental Planning and Assessment Act 1979. The objective of this zoning is to facilitate development to maximise use of the port facility, particularly special land uses that are not allowed for in other zones as well as ensuring separation from residential areas and other sensitive land uses.

The Orica facility is surrounded (**Figure 1**):

- **To the west**: by East Coast Cement facility, immediately to the west of the remediation area, then by Heron Road where port related facilities are used for bulk goods handling at two Port of Newcastle (PoN) berths (Kooragang Berths No.2 and No.3) located adjacent to the South Arm of the Hunter River.
- **To the north**: by Incitec Pivot Limited (IPL) which operates a fertiliser storage and distribution facility. The land immediately to the north on the IPL site is primarily vacant open space. In addition, Air Liquide leases a fenced property on the IPL site to the north of the Ammonia Plant for purification, storage and despatch of carbon dioxide.
- **To the east:** by Greenleaf Road, followed by a grassed foreshore area, and the Park Fuels facility which including a number of large fuel tanks and associated bunding situated within the land owned by the PoN and then the North Arm of the Hunter River.
- **To the south**: by warehousing operated by Toll for the storage of bulk goods, followed by Heron Road and the Walsh Point Reserve. The Walsh Point Reserve represents both the southern extent of Kooragang Island and the point at which the North and South Arms of the Hunter River converge.

5.3 Hydrostratigraphy

The site is underlain by appreciable thicknesses of sedimentary materials overlying bedrock at approximately 35 to 40 m below ground surface. Detailed investigations (Golder, 2016b) have allowed the unconsolidated materials to be divided into hydrostratigraphic ‘units’ which exhibit common hydrogeological characteristics.

- Unit 1: Fill and Reclaimed sands;

[2] Based on review of available historical aerial photographs

- Unit 2: Estuarine silt and clay;
- Unit 3: Alluvial sand;
- Unit 4: Coarse fluvial sand;
- Deeper sands and clays; and
- Permian Bedrock.

A detailed hydrostratigraphy for the area beneath the former disposal pit was developed and is summarised in the following table. A more detailed description of the lithologies characterised in each of the units is provided in the remediation investigations report (Golder, 2016b). The data were also represented as a series of hydrogeological cross sections.

Table 1: Summary of Hydrostratigraphic Units

Hydrostratigraphic Units	Description	Classification	Typical Hydraulic Conductivity
Unit 1 **Fill and reclaimed sand**	Various loose fill (including localised slag and ash) and reclaimed sand of coastal origin with shell fragments.	Aquifer, porous medium, unconfined.	3×10^{-5} m/s to 8×10^{-5} m/s
Unit 2 **Estuarine silt and clay**	Fine-grained estuarine sediments predominantly comprising of silts and clays, black in colour. The lower part becomes gradually coarser (i.e. sandier).	Aquitard, porous medium.	**Upper part:** likely two orders of magnitude lower than Unit 1 **Lower (sandier) part:** 10^{-5} m/s
Unit 3 **Alluvial sand**	Fine- to medium-grained alluvial sand, grey in colour, sub-rounded, occasionally interspersed with bands of clay and minor sandy silt.	Aquifer, porous medium, confined.	8×10^{-5} m/s to 2×10^{-4} m/s
Unit 4 **Coarse fluvial sand**	Dense medium- to coarse-grained fluvial sands, with rounded gravels and pebbles, pale brown in colour.	Aquifer, porous medium, confined.	Over 10^{-4} m/s
Deeper Sands and Clays	Interbedded strata comprising of: - **Upper part:** yellow brown uniform fine-grained sand (possibly of terrestrial origin), - **Middle part:** grey fine- to medium-grained sand with rounded coal fragments, and - **Lower part:** interspersed black silty clay and sandy clay with minor bands of sand.	Succession of thin aquifer zones and aquitards, porous medium, confined.	N/A
Permian Bedrock	Fine- to medium-grained weathered sandstone, green-blue in colour, dry (predominantly recovered as pulverulent material).	Aquifer, fractured rock medium.	N/A

N/A – Not Available

It concluded that the hydrostratigraphic units that have the most relevance to the understanding of arsenic distribution and movement are Unit 1 to Unit 4.

A review of the hydraulic data from the data loggers as well as from the site-wide ‘dip-round’ allowed interpretation of flow characteristics in each of the characterised units.

6.0 REMEDIATION REQUIREMENTS

6.1 Remediation Objectives/Goals

The stated overall objective of the MO (20131407) was to "Implement works that will prevent, to the extent required by Action 1c [of the Management Order], the further offsite migration of arsenic in groundwater".

To achieve the MO objectives and based on the selected 'cap and contain' remediation option, the specific remediation objective was to install a cap and containment system designed within the practicable constraints associated with the conditions at the site.

The cap and containment system effectively segregates the residual source of arsenic from the surrounding groundwater system by significantly reducing the flux of groundwater through the identified arsenic contamination. The reduction in the groundwater flux through the source area reduces the mass flux of arsenic contamination migrating off site.

6.2 Remediation Extent

The extent of the remediation was developed in consideration of the following:

- Remediation Objectives (Section 6.1).
- Consideration of the practicalities of the remediation option selected (Cap and Containment) (Section 4.5 of the RAP).
- Remediation investigations to delineate the extent of arsenic contamination at the former arsenic sludge disposal pit (Section 5.1 of the RAP and Modules B and E (Golder, 2016b)).
- Groundwater modelling to understand the likely reduction in the flow of groundwater through contaminated soil with the construction of the remediation system (Section 5.4 of the RAP).
- Practicable constraints associated with existing site infrastructure and boundary restrictions (Section 6.2.2).

A detailed description of the considerations that have defined the extent of remediation incorporated into the remediation design is presented in Section 8.0 of the RAP. Provided below are the key elements which have defined the extent of remediation, and as such, the alignment and depth of the containment wall.

6.2.1 Contamination Assessment

The remediation investigations, as presented in Modules B and E (Golder, 2016b), considered the extent of arsenic contamination in the vicinity of the former sludge pit. For the eastern, southern and vertical 'extent' of contamination a qualitative assessment approach was taken, identifying 40 mg/kg as the concentration of arsenic in soil requiring remediation (i.e. isolation into the containment cell).

The 40 mg/kg criterion was derived from previous column and leach testing work undertaken on contaminated soils. It was estimated that leaching of arsenic from soils containing 40 mg/kg would be negligible and would be readily naturally attenuated by the residual soils. This was supported by ASTM distilled water leaching undertaken to delineate arsenic present in shallow soils (Golder, 2016c).

The eastern and southern extent of remediation is presented in Plate 4, Section 8.2 of the RAP. It was also noted that there were surficial soils (< 1 m bgl) to the east and south of the proposed extent of remediation that contained arsenic concentrations greater than 40 mg/kg (nominally < 250 mg/kg). As part of the remediation it was proposed to excavate these soils and place them in the containment cell.

The vertical depth of the contamination was assessed to be approximately 8 m bgl. The required final target depth of the cut-off wall was therefore determined to be 12 m bgl. This depth was selected to provide a reasonable margin beyond the characterised depth of arsenic contamination and was also based on consideration of the hydrostratigraphy, conceptual model and associated groundwater modelling outputs.

6.2.2 Practicable Constraints

The remediation investigations indicated that arsenic contamination was present up to the northern and western site boundaries. Based on the requirements of the MO, and Remediation Objectives, the extent of achievable remediation along the northern and western boundaries was limited by the access limitations associated with the wall construction methodology.

Notwithstanding these limitations, the intent of the remediation approach was to hydraulically isolate the majority of the secondary source beneath the former sludge pit and the groundwater modelling had indicated that further off-site migration from the arsenic contaminated soils outside the containment cell would be reduced.

Another practicable design constraint resulting from the existing surface water infiltration area and above ground site infrastructure was the alignment of the north-eastern and south-eastern corners of the containment wall. The ‘chamfer’ in the south-east corner was to allow sufficient space for the reconstruction of the access road and for the off-set required for the existing ammonia plant flare. The chamfer in the north-eastern corner allowed integration of the cell’s surface water management system with the existing surface water infiltration area. The modifications made to the north-eastern and south-eastern corners of the cell design due to these site constraints did not unacceptably compromise the containment of arsenic contaminated soils, or the remediation objectives.

7.0 REMEDIATION WORKS COMPLETED

This section briefly summarises the works completed to achieve the remediation objective. A more detailed description is provided in the remediation planning documentation (Refer **Section 1.3**), as well as the construction quality reports presented in **Appendices A** and **B**.

The remediation comprised the construction of an integrated cut-off wall and capping system, designed to prevent, to the extent practicable, further offsite migration in groundwater of arsenic, associated with the former sludge disposal pit.

7.1 Pre-remediation works

As noted in Section 6.2.1 of the RAP, identified surficial soils (< 1 m bgl) to the east and south of the proposed extent of remediation were required to be excavated and placed within the containment cell. The work completed to excavate, validate and re-instate these excavations was undertaken in 2016 prior to the commencement of construction. The scope and results of this program of works have been documented in a separate report titled "*Early Stage Excavation Validation, Arsenic Remediation Project, Orica Kooragang Island"* (Golder, 2018b), and is presented in **Appendix E**.

In summary, 1,600 m^3 of soil was excavated from the area to the east of the cut-off wall alignment to the extent practicable. The excavation surfaces were validated including sampling from the base and walls of the excavation.

7.2 Integrated System Design

On the basis of the remediation framework and considerations presented in the RAP (Golder, 2016a), Golder prepared concept and detailed designs for the integrated containment cell. The designs were incorporated into Tender Specifications (Section 1.3), which Orica used as the basis for a commercial tender process.

The purpose of the integrated remediation system was:

- Cut-off Wall: To restrict groundwater ingress and egress through the arsenic contaminated soil in the on-site source area.
- Capping: To restrict surface water infiltration to groundwater in the source area.

7.3 Cut-off Wall Installation

The general cut-off wall alignment was installed along alignment shown below in Figure A. The cut-off wall was designed to be 250 m long and to encompass a square shape approximately 4,200 m^2 in areal extent, bound by the East Coast Cement property boundary to the west and the Incitec Pivot Limited (IPL) property boundary to the north.

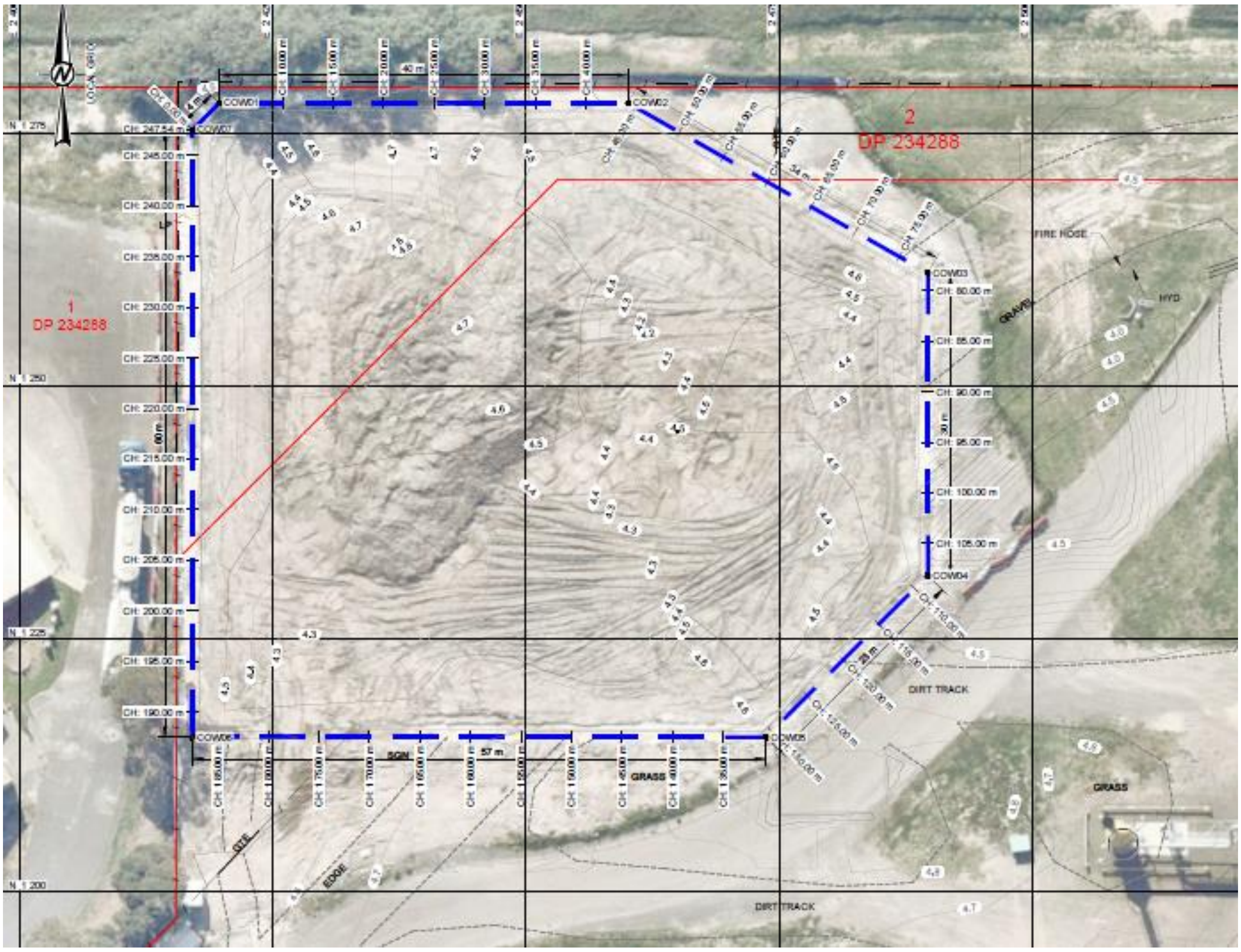

Figure-A: Cut-off Wall Alignment

The selected wall installation technology was soil-bentonite trench excavation and backfill, formed by progressively excavating a trench below ground level using a long reach excavator or crane clamshell bucket and placing ‘backfill material’ to create a low permeability soil-bentonite wall. The selection of the cut-off wall method was consistent with requirements nominated in the RAP.

The cut-off wall was designed to extend to a depth of 12 m below ground level. The target permeability for the wall was 1 x 10^{-9} m/s or less (measured using groundwater sourced from site).

Menard Oceania was appointed by Orica as the contractor to undertake installation of the cut-off wall, which commenced on 6 February 2019 and was completed on 13 April 2019. Excavation commenced at the mid-eastern boundary (CH210) and progressed in a clockwise direction.

Throughout the excavation process, the stability of the excavated trench was maintained by filling it with controlled density bentonite slurry. The backfill material comprised a mixture of excavated trench material, bentonite slurry and imported clay to achieve a workable material with controlled density, slump and percentage fines, allowing backfill material to be placed by long reach excavator bucket and form a controlled ‘backfill slope’ within the slurry-filled trench. Laboratory permeability testing was undertaken on samples of placed backfill material to assess permeabilities achieved.

7.4 Capping System Installation

A multi-layered capping system was selected to meet the design objectives with the key components shown in the profile in Figure B. Capping System design is presented in the drawings and capping system technical specification (Golder, 2019a).

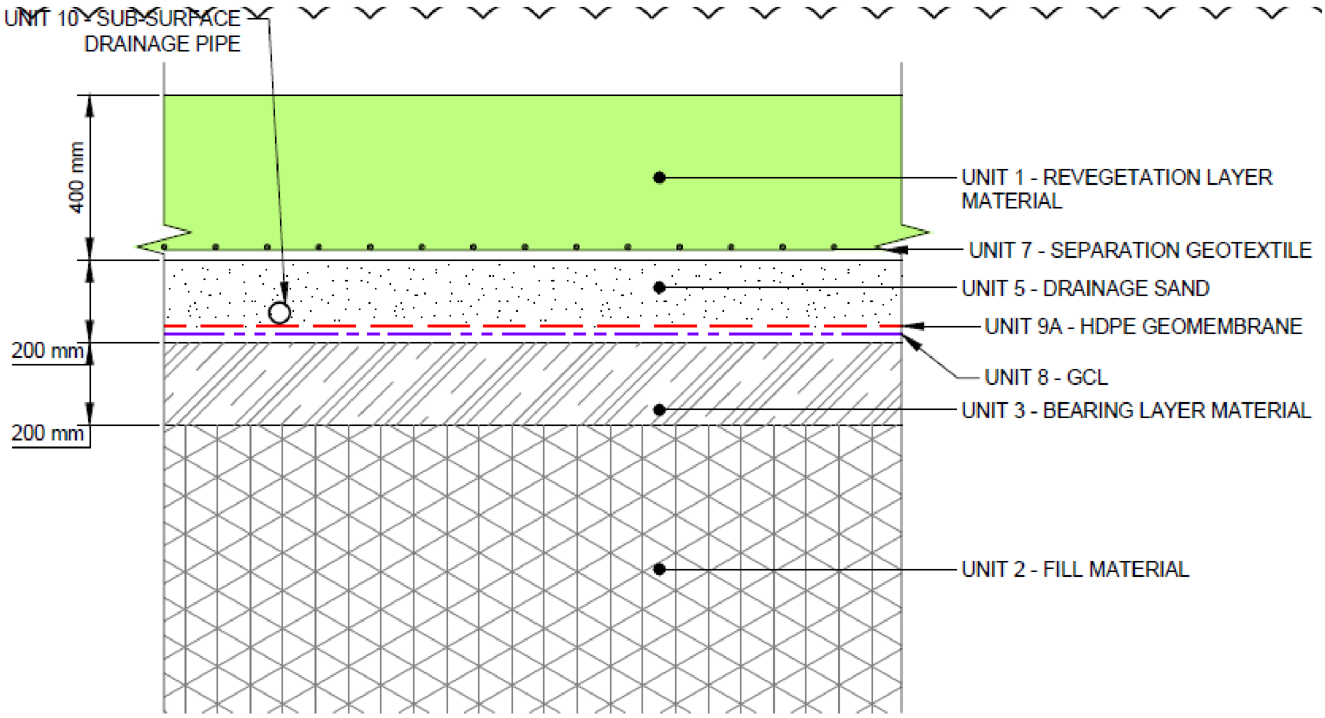

Figure B: Cap Profile (Extract from Drawing 15-43252-Rev05)

The following table summarises the system components and their primary and secondary functions.

Table 2: Capping System Summary

Component / Layer	Remediation objective addressed			Primary Function	Secondary Function
	Surface Water Infiltration	Direct Contact	Future Site Use		
Unit 1 – Revegetation Layer	X	X	X	- protective cap over geosynthetic liner materials - green space (no proposed land use)	- surface water drainage
Subsurface Drainage Layer [Unit 5 - Drainage Sand]	X	X	X	- drainage of water infiltrating through revegetation layer	- protect geosynthetic liner materials
Sealing Layer [Unit 9A -	X	X		- water infiltration barrier	- none

Component / Layer	Remediation objective addressed			Primary Function	Secondary Function
	Surface Water Infiltration	Direct Contact	Future Site Use		
HDPE[3] Geomembrane and Unit 8 - GCL[4]]					
Bedding Layer [Unit 3 – Bearing Layer material]		X		- suitable foundation and surface for deployment of geosynthetic lining material	- separation to underlying fill material

A composite of geosynthetic materials was installed over the entire remediation area connecting to the upper portion of the cut-off wall, the upper reaches of which form the vertical components of the containment cell.

Eco Line Solutions Pty Ltd (the Contractor) was appointed by Orica to undertake installation of the geosynthetic materials for the vapour barrier system, which commenced on 23 July 2019 and was completed on 27 July 2019. Milleen Constructions Pty Ltd (main earthworks contractor) were engaged to undertake the associated civil works, including construction of the bearing layer and completion works.

7.5 Monitoring Network Infrastructure Installation

To verify the remediation system hydraulic performance, a groundwater monitoring network was installed around the containment cell. The network consists of a series of nested wells at strategic locations on either side of the completed cut-off wall, to allow internal and external 'piezometric' water levels to be compared (**Figure C1, Appendix C**). The purpose of the monitoring system is to allow collection of groundwater elevation data to demonstrate that the containment cell is performing optimally and as per the design.

The installation of the groundwater monitoring network is detailed in **Appendix C** and includes the following:

- Well Installation: Location of nested wells, borelogs and well construction and development details
- Data Loggers: deployment of groundwater data loggers and a barometric logger.

It is noted that each nested well included three pairs of piezometers installed to target the 3 main groundwater units present in the area as follows:

- Unit 1 – wells screened from 2.5 m to 4.5 m below the original ground level. These wells have the nomenclature of -3 (e.g. MWCC01-**3**IN)
- Unit 2 -– wells screened from 5.5 m to 7 m below the original ground level. These wells have the nomenclature of -6 (e.g. MWCC01-**6**IN)

[3] High density polyethylene

[4] Geosynthetic Clay Liner

- Unit 3 – wells screened from 8 m to 10 m below the original ground level. These wells have the nomenclature of -9 (e.g. MWCC01**-9**IN).

8.0 VALIDATION APPROACH

8.1 Introduction

The framework for verification and validation of the cap and containment system was presented in Sections 9 and 11 of the RAP (Golder, 2016a).

Validation of the construction of the containment system would chiefly be achieved through:

- Review of the proposed mix design, works planning documentation, oversight of the construction process by an appropriately qualified engineer; and a review of the adequacy of the constructors CQC reports and documentation;
- Verification, through assessment and preparation of the construction quality assurance (CQA) documentation, that the design features have been successfully incorporated into the construction.

Validation of the hydraulic performance of the containment system based on:

- Measurement of the local groundwater elevations, inside and outside the cut-off wall, to assess hydraulic performance of the containment system.

It was noted that collection of hydraulic data will likely be required over a period of time and would generally be included in post-construction monitoring plans as described in Section 10.0.

8.2 Overall Validation Framework

Provided in Table 3 is the framework for the validation data collection, as required by the RAP, with reference to the relevant validation documentation.

Table 3: Validation Framework

Remediation Validation			Remediation Validation Report	
Key Validation Aspect	**Decision**	**Input to Decision**	**Document/ Information**	**Report Location**
Cut-off Wall				
Review of design specification	Are the proposed designs adequate to address the identified design requirements?	Mix testing and technical work method statement prior to construction.	Mix Design Report and Technical Work Method Statement (Menard Oceania)	Appendix A
Contractor CQC program	Are the construction methods and materials in accordance with the design requirements and is the means of their implementation appropriate to achieve the required outcome?	Inspection, testing, hold points and documentation.	Contractor CQC report (Menard Oceania)	Appendix A
CQA program	Was the construction methodology appropriately implemented?	Inspections, duplicate testing and review documentation and outputs.	CQA report (Golder)	Appendix A

Remediation Validation			Remediation Validation Report	
Key Validation Aspect	**Decision**	**Input to Decision**	**Document/ Information**	**Report Location**
	Have the design features been appropriately achieved in the construction?			
Capping System				
Review of design specification.	Are the proposed designs adequate to address the identified design requirements?	Preparation of quality management system for cap construction.	Construction Quality Management system including Inspection and Testing Plans for identified tasks	Appendix B
Contractor CQC program	Are the construction methods and materials in accordance with the design requirements and is the means of their implementation appropriate to achieve the required outcome?	Inspection, testing, hold points and documentation.	Contractor CQC report (Milleen, including Ecoline)	Appendix B
CQA program	Was the construction methodology appropriately implemented? Have the design features been appropriately achieved in the construction?	Inspection and review documentation and outputs	CQA report (Golder)	Appendix B
Groundwater Monitoring				
Assessment of the hydraulic performance of the wall	Has construction of the cut-off wall effectively hydraulically isolated the contamination (i.e. are there changes in the groundwater flow regime and is the external aquifer hydraulically disconnected from the internal cut-off wall zone).	Hydraulic head data Hydraulic conductivity of materials	Monitoring well network. Hydraulic monitoring data set. Testing of permeability of cut-off wall	Appendix C Appendix F Appendix A
Monitoring of groundwater quality downgradient of the cut-off wall.	Has the cut-off wall design and construction been effective in hydraulically isolating the inferred source materials? It is noted this will be achieved through	Groundwater quality data	Long-term Environmental Management Plan. Groundwater quality monitoring to be undertaken in 2020.	Separate document. LTEMP (Golder, 2019b)

Remediation Validation			Remediation Validation Report	
Key Validation Aspect	**Decision**	**Input to Decision**	**Document/ Information**	**Report Location**
	implementation of the monitoring requirements of the LTEMP.			
Material Tracking				
Validation of imported materials	Have appropriate materials been imported onto the site?	Source material documentation and inspection Imported material quality data	Source documentation, inspection records and laboratory analysis	Appendix D

8.3 CQA Process

The performance of the overall containment system is fundamentally dependent on the quality of construction of the cut-off wall and capping systems. As such, the construction quality management systems form an integral part of the validation process. The construction quality requirements are presented in the RAP (Golder, 2016a) in Section 9.2 (Cut-off wall) and Sections 9.3 and 9.4 (Capping System).

The quality system requirements have been refined in subsequent technical specification documents. These documents have identified detailed and specific roles and responsibilities with respect to quality management and have included:

- Golder, 2018a. Reference Specification. Orica Kooragang Island: Arsenic Management Order – Cut-Off Wall Construction by Soil-Bentonite Method. Revision 4. Golder Associates Pty Ltd. 22 November 2018.
- Golder, 2019a. Capping System Technical Specification. Orica Kooragang Island - Arsenic Remediation Project. Revision 7. Golder Associates Pty Ltd. 14 June 2019.

In both documents, quality management requirements form part of the contractor's responsibilities (i.e. Construction Quality Control (CQC)). Third party inspection and review requirements (i.e. Construction Quality Assurance (CQA)) are also identified.

8.3.1 Cut-off Wall Construction Validation Review

Golder performed the vole of Validation Consultant for the duration of the cut-off wall construction. Validation was mainly achieved through periodic site visits and ongoing review of site records, and comprised:

a) Review of the proposed design and oversight of the construction process by an appropriately qualified engineer; and

b) Verification, through detailed review of the construction quality assurance (CQA) documentation, that the design features have been successfully incorporated into the construction.

Golder prepared a detailed report presenting the field observations, analytical data, Quality Control and Quality Assurance test results and the review of the Contractor's Cut-off Wall construction Completion Report (CCCR) (Menard, 2019). The Cut-off Wall CQA report (Golder 2019) is presented in **Appendix A**. The report outlines the process through which verification of the various features including wall thickness and target permeability was achieved and presents commentary on the suitability of the cut-off wall to provide the intended functions of a subsurface hydraulic cut-off wall for lateral groundwater flow control.

8.3.2 Capping System Construction Validation Review

Similar to the cut-off wall, validation was mainly achieved through:

a) Review of the proposed design and oversight of the construction process by an appropriately qualified engineer; and

b) Verification, through detailed review of the construction quality assurance (CQA) and Construction quality control (CQC) documentation, that the design features have been successfully incorporated into the construction.

Golder prepared a detailed report presenting inspection observations, full-time construction quality assurance field records and review of the Contractor's construction Completion Reports for the geosynthetic lining installation (Ecoline, 2019) and for the earthworks and finishing works (Milleen, 2019). The Capping System CQA report (Golder 2019) is presented in **Appendix B**. The report outlines the validation approach and objectives as well as quality control measures and records for the cap construction works.

8.4 Hydraulic Verification Monitoring

As described in Section 7.5, a groundwater monitoring network was installed around the containment cell to enable the hydraulic performance of the containment system to be assessed.

8.4.1 Hydrostratigraphy

The borelogs recorded during the installation of the monitoring network are presented in **Appendix C**. The stratigraphy encountered was consistent with the Hydrogeological Conceptual Model (HCM) developed as part of the Remediation Investigations (Golder, 2016b), and summarised in Section 5.3. The HCM formed the basis for the groundwater modelling undertaken for the design of the containment system in the RAP (Golder, 2016a).

8.4.2 Groundwater Modelling

The preliminary assessment of expected effects of the installed cut-off wall was informed by hydrogeological modelling performed by A.D.Laase (Laase, 2016).

The modelling programme provided an initial indication of the likely general effects of the cut-off wall on the local hydrogeological regime and provided one of the main bases for design of the monitoring well network. Whilst it is not the intent of the validation program to directly compare the outcomes of the modelling with field measurements and observations, some of the key aspects of the groundwater modelling and consideration of the HCM include:

- The detection of responses to rainfall events that may be recorded in the external wells, but which would be expected to be less prevalent in the data collected from inside the wall. It is noted that the timing of installation of the capping system is a key factor in this assessment as rainfall events prior to cap installation could affect conditions either side of the wall.
- A flattening of the groundwater table(s) inside the cell relative to external conditions.
- An increase in the external hydraulic gradient across the cell (in the direction of groundwater flow); and/or potential increase in gradients around the perimeter of the cell.
- Water levels in Units 1 and 2 will be lower inside the cell walls by an order of 1 to 2 m, while water in Unit 3 will be slightly higher on the inside.

8.4.3 Hydraulic Monitoring Program

The down-well monitoring data loggers for measuring changes in groundwater levels as well as barometric pressure within the containment cell have been installed as described in **Appendix C**.

The loggers were downloaded, and data processed on an approximately monthly basis during the early portion (July 2019 through November 2019) of the program. Each annual dip point on the hydrographs corresponds to a hydraulic data download event, when a dip meter was used to manually gauge the depth to water in the wells as a means of verifying and calibrating the level logger outputs.

8.5 Material Tracking

The approach for validating materials imported to site for the construction of the containment system or spoils that were generated during the construction are detailed in Section 10 of the RAP (Golder, 2016a). This included spoil generated during the construction of the cut-off wall, relatively low-level arsenic contaminated soils excavated from contiguous areas of shallow soil impacts located outside the cut-off wall alignment, and imported materials required for the construction of the containment system elements or to enable construction to be undertaken.

8.5.1 Material beneath Capping System

Spoil from two sources were placed beneath the capping system as part of the remediation program and included:

- **Surficial low-level arsenic contaminated soil:** Approximately 1,600 m^3 of soil containing low level arsenic was excavated from the area to the east of the cut-off wall alignment. The excavation and movement of these soils to the footprint of the containment cell is documents in Section 7.1 and detailed in **Appendix E**.
- **Cut-off Wall Construction Spoil:** 1,427 m^3 of spoil from the construction of the cut-off wall was placed beneath the cap during the construction of the cut-off wall. This material was required to be dried out prior to construction of the capping system and was incorporated in Unit 2.

8.5.2 Imported Materials for Construction

Various bulk materials (soil/rock) were required to be imported to the site for the construction of the containment system. These soil and rock materials were utilised in the cut-off wall and capping layers, as well as to provide a working platform for construction equipment. The soil and rock were classified as Virgin Excavated Natural Materials (VENM) in accordance with the requirements of Section 10.3 of the RAP (Golder, 2016a). A detailed account of the validation process is provided in **Appendix D**.

8.5.3 Reuse of On-site Soil

Two stockpiles of grubbed surface soils were re-used as part of Unit 1 (revegetation layer) of the cap. The two stockpiles comprised materials that were grubbed from the surface of the remediation area before remediation works commenced and included:

- **Stockpile of Topsoil (T)**: Approximately 200 m^3 was excavated from a depth of approximately 0.1 m from the footprint of the remediation area and stockpiled.
- **Stockpile 2 (S2)**: Approximately 80 m^3 of stockpiled grubbed soil from the working pad area.

The characterisation of this soil for re-use is documented in **Appendix D**.

9.0 VALIDATION RESULTS

9.1 Surficial Soils outside Cut-off Wall

Approximately 1,600 m^3 of surficial soils containing arsenic concentrations exceeding 100 mg/kg to the east and south of the proposed extent of remediation were excavated to the extent practicable and placed within the containment cell. Validation sampling of the base and walls of the excavation was undertaken.

Arsenic concentrations greater than the assessment criterion (a 100 mg/kg was adopted for individual samples as described in Appendix E) were reported in five validation samples from the final excavation surfaces. However, the excavations were considered to have reached the ‘extent practicable’ due to services, or the presence of groundwater, and that the remaining arsenic concentrations were considered unlikely to result in elevated leachable arsenic concentrations in groundwater.

The validation results of this program of works are documented in report titled “*Early Stage Excavation Validation, Arsenic Remediation Project, Orica Kooragang Island”* (Golder, 2018b), and is presented in **Appendix E**.

9.2 Cut-off Wall CQA Review Outcome

The ‘stand-alone’ cut-off wall validation report is presented in **Appendix A**.

On the basis of the assessment of field observations, CQC/CQA test results and the construction documents presented, it is considered that:

- Observations made during the course of the construction program were appropriate and sufficiently frequent to support a high-level of confidence that the cut-off wall construction documentation is satisfactorily complete and accurate to support the quality assurance assessment;
- Sufficient and appropriate sampling / testing has been conducted to facilitate confirmation that the cut-off wall is expected to service its objectives; and
- Evaluation of CQA and CQC observations and test data has identified a number of non-conformances with the Cut-off Wall Reference Specification. Assessment of each of these items concluded that they are generally minor and in no case likely to impact upon the performance of the cut-off wall. It is therefore considered that the constructed cut-off wall will meet the overall performance requirements of the Cut-off Wall Reference Specification.

With specific reference to the design characteristics directly related to the discussion of hydraulic monitoring outcomes (Section 9.4), it can be noted that:

- The construction depths (i.e. the depth to which the cut-off wall soil bentonite backfill extended below ground surface) of 12 m was achieved – refer Section 5.3.3 (**Appendix A**); and
- The hydraulic permeability results (CQC and CQA) varied between 1.6 x 10^{-10} m/s and 9 x 10^{-11} m/s with an average value of 3.5 x 10^{-10} m/s, which is lower (i.e. better) permeability than the 1 x 10^{-9} m/s target criterion.

9.3 Capping System CQA Review Outcome

The ‘stand-alone’ capping system validation report is presented in **Appendix B**.

Review of the construction quality assurance records and test results indicate the capping system was constructed in accordance with the Specification (Golder, 2019a) with some minor non-conformances noted in the capping system validation report.

Golder’s full-time site presence and periodic site inspections as Validation Consultant, along with review of the Contractor’s documentation including construction material source and as-delivered test reports is sufficient for Golder to form an opinion that the works were completed in accordance with the Specification and design (Golder, 2019a). The CQA records confirm that the capping system was constructed in accordance with the design intent to reduce surface water infiltration and provide physical separation of the contaminated soil.

9.4 Hydraulic Monitoring Results

9.4.1 Hydrographs

The hydrographs for each of the nested wells located on the eastern, western and southern side of the containment cell are presented in **Appendix F**. The geomembrane (Unit 9) was completed by 27 July 2019. As such internal water levels post this date can be considered to be representative of the commencement of significantly reduced rainwater infiltration into the containment cell. The hydrographs are presented for the period of 19 July 2019 to 14 November 2019. It is noted that the cut-off wall had been installed prior to the installation of the monitoring wells and dataloggers, however, the capping system was being constructed during this period and well development was also undertaken.

Key groundwater level monitoring results for each of the nested wells can be summarised as follows:

MWCC01 – Eastern Wall (up- hydraulic gradient)

- Response to two heavy rainfall events (30 August to 1 September (99 mm) and 17 to 18 September (40 mm)) can clearly be observed in MWCC01-3OUT and MWCC01-6OUT located on the outside of the containment cell compared to little or no observed response in the corresponding wells inside the containment cell (MWCC01-3IN and -6IN). Effects of rain events are not observable in either MWCC01-9IN and -9OUT.
- The groundwater levels in the paired eastern well sets (MWCC01-3 and MWCC01-6) inside and outside of the cell appear to be responding independently post completion of the cap liner in late July. This indicates that the groundwater within the cell has been effectively separated from the surrounding groundwater by the cut-off wall (i.e. different head present within the same hydrostratigraphic units inside and outside of the cell). Groundwater levels in MWCC01-3IN appear to be slowly decreasing post completion of the cap liner.
- Tidal effects are evident in MWCC01-6IN, MWCC01-9IN and -9OUT.
- Groundwater levels in MWCC01-3 are in the order of 0.6 m to 0.8 m higher than MWCC01-6 and MWCC01-9 consistent with previous observations between Unit 1 and Units 2 and 3, and that the presence of the estuarine silt and clay (Unit 2) are continuing to act as an aquitard.

MWCC02 – Western Wall (down- hydraulic gradient)

- Response to two heavy rainfall events can clearly be observed in MWCC02-3OUT located on the outside of the containment cell compared to little or no observed response in the corresponding well within the containment cell (MWCC02-3IN). Effect of rain events are not observable in either MWCC02-6IN, -6OUT, -9IN and -9OUT.
- The difference in groundwater levels between MWCC02-3IN and MWCC02-3OUT inside and outside of the cell appear to be responding independently post completion of the cap liner. This indicates that the groundwater within the cell has been effectively separated from the surrounding groundwater by the cut-off wall (i.e. different head present within the same hydrostratigraphic units inside and outside of the cell). Groundwater levels in MWCC02-3IN appears to be slowly decreasing post completion of the cap liner.

- Tidal effects are evident in MWCC02-6IN, -6OUT, -9IN and -9OUT.
- Groundwater levels in MWCC02-3 are approximately 0.8 m higher than MWCC02-6 and MWCC02-9 consistent with previous observations that the presence of the estuarine silt and clay (Unit 2) are continuing to act as an aquitard.

MWCC03 – Southern Wall (across-hydraulic gradient)

- Response to two heavy rain fall events can clearly be observed in MWCC03-3OUT located on the outside of the containment cell compared to little or no observed response in the corresponding well in the containment cell (MWCC03-3IN). Some evidence of the response to rain events is observed in MWCC03-6OUT, compared to MWCC03-6IN. Effect of rain events are not observable in either MWCC03-9IN and -9OUT.
- The difference in groundwater levels between MWCC03-3IN and MWCC03-3OUT inside and outside of the cell appear to be responding independently post completion of the cap liner. This indicates that the groundwater within the cell has been effectively separated from the surrounding groundwater by the cut-off wall (i.e. different head present within the same hydrostratigraphic units inside and outside of the cell). Groundwater levels in MWCC03-3IN appears to be slowly decreasing post completion of the cap liner.
- Tidal effects are evident in MWCC02-6OUT, -9IN and -9OUT, whereas MWCC02-6IN does not appear to be showing evidence of tidal effects.
- Groundwater levels in MWCC03-3 are approximately 0.8 m higher than MWCC03-6 and MWCC03-9 consistent with previous observations that the presence of the estuarine silt and clay (Unit 2) are continuing to act as an aquitard.

Note: spikes in MWCC03-6IN reflect falling head tests undertaken to confirm well function.

9.4.2 Groundwater Level Contours and Hydraulic Gradients

Groundwater contours based on the manual dip measurement of the standing water level (SWL) across the monitoring network are summarised in **Table F1** and presented in **Figures F1 to F3** in **Appendix F** for the Unit 1, Unit 2 and Unit 3 hydrostratigraphic units. The groundwater contours presented in **Figure F1 to F3** are from measurement of SWL completed on 14 November 2019. In summary the groundwater contours indicate:

Unit 1 – comprising MWCC01 to MWCC03 -3IN and -3OUT,

- Within the containment cell, a flat gradient has developed at 1.6 m AHD. The groundwater level within the containment cell is lower, in the order of 0.1 to 0.3 m, than the groundwater level outside the cell on the eastern and southern side of the cell (MWCC01 and MWCC03), and slightly higher than water level on the western side (MWCC02).
- Outside the containment cell there appears to be a gradient to the west, consistent with regional groundwater flow direction prior to construction of the cell, towards the South Arm of the Hunter River. Some mounding of groundwater appears to be occurring to the east, up-hydraulic gradient, of the containment cell in MWCC01-3OUT.

Unit 2 – comprising MWCC01 to MWCC03 -6IN and -6OUT,

- Within the containment cell, a flat gradient has developed at 0.75 mAHD. The groundwater level within the containment cell appears to be approximately 0.4 m lower than the up-gradient water level measured in MWCC01-6OUT, but some 0.25 m higher than the groundwater levels measured in the wells across and down-gradient of the cell (MWCC02-6OUT and MWCC03-6OUT).

- Outside the containment cell there appears to be a gradient to the west, consistent with groundwater flow direction prior to construction of the cell, towards the South Arm of the Hunter River. Some mounding of groundwater appears to be occurring to the east, up-hydraulic gradient, of the containment cell in MWCC01-6OUT.

Unit 3 – comprising MWCC01 to MWCC03 -9IN and -9OUT,

- Within the containment cell, a relatively flat gradient has developed at 0.6 to 0.7 mAHD. The groundwater level within the containment cell appears to be slightly higher, 0.15 m, than the groundwater level outside the cell.
- Outside the containment cell the gradient is reasonably flat at approximately 0.45 mAHD, with a very slight gradient to the west. This is consistent with gradients measured elsewhere in this Unit given the relative difference between groundwater elevations and water levels within the Hunter River. As discussed above, tidal effects are generally observed within Unit 3 and are likely to influence measured water levels.

9.4.3 Assessment of the Containment System

The hydraulic verification of the containment system as described in **Section 8.4** is mainly concerned with patterns of hydraulic head redistribution. While it is early in the monitoring process, approximately 2 months since the installation of the geomembrane, Table 4 provides a framework to outline the hydraulic verification outcome matrix and allow effects to be tracked during the remainder of the hydraulic verification process.

Table 4: Hydraulic Verification Outcomes Matrix

Identified Potential Effect	Emerging Patterns? (Y/N)	Evidence / Comments
The detection of responses to rainfall events that may be recorded in the external wells, but which would be expected to be less prevalent in the data collected from inside the wall.	Yes	Evidence of the effect of rainfall is presented in the hydrographs. Two large rain events have occurred post construction of the containment cell. A clear response to rainfall can be seen in the Unit 1 wells located outside the containment cell compared to the wells located within the containment cell. The effect of rainfall in the Unit 2 outside wells can also be observed at some locations, however, given that Unit 2 is an aquitard the lack of response in these wells is not an indication of the performance of the containment cell.
A flattening of the groundwater table(s) inside the cell relative to external conditions.	Yes	A flattening of the water table was evident in the Unit 1 and Unit 2 within the Containment cell, whereas, a gradient to the west / north-west was still evident in the wells located outside the containment cell, as present in **Figures F1 and F2**. In Unit 3, the flattening of the groundwater table inside the system appears to be occurring (**Figure F3**), however, has not been as pronounced as in Units 1 and 2. This is likely a combination of the fact that the Unit 3 wells (screened 8 to 10 m bgl) are closer to the base of the wall (12 m bgl) and possible tidal influence which can be observed in the hydrographs for Unit 3 wells.

Identified Potential Effect	Emerging Patterns? (Y/N)	Evidence / Comments
An increase in the external hydraulic gradient across the cell (in the direction of groundwater flow) and/or potential increase in gradients around the perimeter of the cell.	Yes	An external regional gradient continues towards the west consistent with the groundwater flow direction established prior to the construction of the containment cell. Furthermore, in Units 1 and 2 there appears to be some mounding occurring on the eastern- up-gradient side of the containment cell (MWCC01-3OUT and -6OUT).
Water levels in Units 1 and 2 will be lower inside the cell walls by an order of 1 to 2 m, while water in Unit 3 will be slightly higher on the inside.	Possible	There appears to be a lowering of the water levels within the containment cell (relative to corresponding external wells) in Units 1 and 2. However, it should be noted that groundwater levels outside the cell, particularly in Unit 1 will be significantly influenced by rain events. As such, the recent history of rain events will need to be considered when assessing the difference in water levels inside and outside of the cell. For Unit 1, the groundwater level appears to be in the order of 0.1 to 0.3 m lower than the surrounding groundwater levels. For Unit 2, groundwater levels on the up-gradient side of the cell appear to be 0.5 m lower inside the cell, whereas, at the down-gradient side groundwater levels are 0.25 m higher within the cell. This is likely to be as a result of mounding occurring on the up-gradient side of the cell. For Unit 3, groundwater levels within the cell appear to be approximately 0.15 m higher than the surrounding groundwater levels.

Based on available data, evidence of hydraulic head redistribution as a result of construction of the containment cell is considered to be emerging. The following main expected effects have already been identified:

- Difference in response to rain events inside and outside of the containment cell.
- A flattening of the hydraulic gradient (i.e. groundwater table) inside the containment cell in comparison with historical hydraulic gradients and external conditions;
- Possible mounding of groundwater levels on the up-hydraulic gradient side of the containment cell; and
- Differences in groundwater level measured in the well sets on either side of the wall with lowering of groundwater levels in Unit 1 and possible Unit 2, and an apparent increase in groundwater levels in Unit 3 compared to outside the cell. However, fluctuations of water levels outside the cell in Unit 1 due to rain events are likely to influence these relative levels.

The assessment outlined above presents several lines of evidence supporting the emergence of a sustained redistribution of local hydraulic head during and following the installation of the containment cell. The emerging lines of evidence are consistent with the potential effects postulated in the groundwater modelling (Laase, 2016) and are considered to support the successful installation of the containment system.

The ongoing hydraulic monitoring and the secondary evidence of chemical monitoring will continue to be undertaken as defined within the LTEMP (Golder, 2019b).

9.5 Materials Validation

9.5.1 Imported VENM

A summary of the material (soil/rock) imported onto site is presented in **Appendix D**. Further details of the source of the imported VENM, documentation, inspection and sampling undertaken to validate the VENM, as well as identified the volumes imported and the use within the remediation program are provided in Table D1 **Table D1** (**Appendix D**).

As concluded in Appendix D, based on the documentation presented by Orica providing confirmation by the individual source quarries that the imported material is classified as VENM under the NSW EPA waste classification guidelines. Inspections of this material confirm it was consistent with the descriptions provided in the documentation provided by the various quarries and that no evidence of contamination or of foreign deleterious materials were present. The results of the chemical analysis further supported the VENM classification and met the criteria for imported material within the RAP. It is considered that the imported VENM was suitable for use as part of the remediation system constructed.

9.5.2 Re-use of On-site Soil

The characterisation of the soil for re-use was documented in Technical Memorandum “Assessment of Soil Stockpiles for On-site Reuse at Arsenic remediation Areas, Orica Kooragang Island” dated 2 August 2019 and included in **Appendix D**. Based on the results of the characterisation, arsenic was presented at concentrations ranging between 10 mg/kg and 45 mg/kg with an 95 % upper confidence limit on the mean of 25 mg/kg, which is less than the concentration adopted for the assessment of remediation requirements in the RAP (Golder, 2016a) of 40 mg/kg. Concentration of other metals were generally below the added contaminant limited (ACLs) for commercial /industrial land use (NEPC, 2013) with the exception of zinc.

As the stockpiled material contained low arsenic concentrations and generally low metal concentrations, and as the stockpile volume would comprise approximately 15 to 20 % of the revegetation layer, it was considered that the material was suitable for re-use within Unit 1 (the revegetation layer).

10.0 OVERALL ASSESSMENT

Design Adequacy

Adequacy review prior to commencement of construction has indicated that the proposed remediation approach, associated designs and supporting documentation were of an appropriate level of detail and quality.

Inspection and review activities undertaken by Golder during and after the construction of the containment cell have indicated the construction methods and materials were in accordance with the design requirements.

Construction Quality Assurance

The CQA reviews for the Cut-off Wall and Capping System have indicated that installation has been implemented appropriately and in accordance with the detailed designs. Hydraulic permeability targets were met in the cut-off wall materials.

Hydraulic Verification

Evidence of patterns of hydraulic head redistribution post the construction of the containment system have been recorded and are documented herein (**Appendix F**). The assessment outcomes are considered to provide preliminary verification of the containment cell performance metrics outlined with the RAP (Golder, 2016a). Ongoing hydraulic monitoring will occur as part of the LTEMP (below).

Materials

A materials tracking process was implemented during the construction of the containment cell. Presented in **Appendix D** is a summary of the materials imported to the site as part of the construction and the on-site re-use of site soils and that the remediation objectives are considered to have been met. Specifically, it is considered that the materials (soil and rock) imported to the site for the construction of the cut-off wall and capping system met the classification of VENM and were suitable for use at the site.

Assessment

Overall, the design, installation and testing of the remediation system (containment cell) is considered to have successfully met the requirements of the RAP, that is, demonstrated that the implementation of the selected remediation action will prevent, to the extent required by Action 1c of the Management Order, the further offsite migration of arsenic in groundwater.

The outcome of the ongoing hydraulic monitoring will ultimately inform a review of hydraulic monitoring requirements into the future. The details are presented in the LTEMP.

On-going Maintenance, Management and Monitoring

A Long-Term Environmental Management Plan (LTEMP) has been prepared to provide a framework to minimise risks to on- and off-site human-health and environmental receptors through the management, maintenance and monitoring of the containment cell. Included within the LTEMP is the requirement for management measures to be in place on lands surrounding the containment cell which further restrict the potential soil and groundwater exposure pathways to human-health receptors.

The LTEMP is required to be implemented by Orica to make sure that the containment cell is managed in a manner so that the integrity of the containment cell is not compromised. The LTEMP also has an going monitoring requirement to confirm the long-term functionality of the containment cell.

11.0 REFERENCES

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12.0 LIMITATIONS

Your attention is drawn to the document titled “Important Information Relating to this Report”, which is included in **Appendix G** of this report. The statements presented in that document are intended to inform a reader of the report about its proper use. There are important limitations as to who can use the report and how it can be used. It is important that a reader of the report understands and has realistic expectations about those matters. The Important Information document does not alter the obligations Golder Associates has under the contract between it and its client.

Signature Page

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