

Attachment D

Technical Proposal



Report

Stage 4 - Voluntary Management Proposal, Technical Proposal

Orica Facility, Kooragang Island, NSW

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Prepared for
Orica Australia Pty Ltd
15 Greenleaf Road
Kooragang Island NSW
43217831

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Project Manager:

URS Australia Pty Ltd

**Level 3, 116 Miller Street
North Sydney NSW 2060
Australia**

T: 61 2 8925 5500

F: 61 2 8925 5555

Project Director/Author:

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Introduction

Orica Australia Pty Ltd have completed works associated with the Stage 1, Stage 2 and Stage 3 Voluntary Remediation Agreements (VRA), (No. 26061, No. 26093, and No. 26109 respectively), at their facility located at Greenleaf Road, Kooragang Island, NSW. The VRAs addressed identified arsenic and nutrient (specifically total ammonia and nitrate) contamination. The principal features of the VRAs completed include:

- Implementation of biannual groundwater monitoring programs;
- Implementation of source control/soil remediation activities;
- Preparation of an Environment Management Plan (EMP) and Communication Plan for the identified arsenic contamination;
- Assessment of the processes responsible for natural attenuation of arsenic within the aquifer;
- Screening of long-term remediation options and recommendations for bench-scale trial for arsenic;
- Bench-scale treatability testing of ex-situ groundwater treatment technologies;
- Feasibility study of groundwater treatment alternatives for arsenic removal;
- Bench-scale treatability testing of in-situ geochemical fixation of arsenic; and
- Monitoring and reporting the performance of the completed soil remediation.

The reports prepared for the investigation and remediation works completed prior to and under the Stage 3 VRA process are provided in the bibliography presented in Section 9.

Based on the results of the investigation and remedial works completed at the end of the Stage 3 VRA, Orica proposes to enter into a Stage 4 Voluntary Management Proposal (VMP) with the Department of Environment, Climate Change and Water (DECCW). Specifically, Orica used a laboratory treatability test program to establish the effectiveness of reagents for in-situ geochemical fixation of arsenic in groundwater.

The Stage 4 VMP would comprise the implementation of an onsite in-situ geochemical fixation field trial to test the effectiveness of arsenic immobilisation. Site groundwater monitoring of the groundwater plume and performance monitoring of the effectiveness of the field trial, would also be included in the scope. The final task for the Stage 4 VMP would consist of an engineering feasibility study in which a preferred groundwater remediation approach will be recommended.

Orica proposes to develop a Remedial Action Plan that further develops the preferred approach and full-scale implementation in a Stage 5 VMP, and it is likely that an assessment of the risk of residual arsenic contamination will also be required.

1.1 Objectives of the Stage 4 VMP

The goal of the Stage 4 VMP is to conduct a field trial to assess the feasibility of full-scale in-situ remediation to mitigate migration of arsenic contaminated groundwater. A significant risk of harm has been defined in the Declaration of Remediation (Number 21087, dated 16 November 2005) as that posed by the arsenic contaminated groundwater moving towards the South Arm of the Hunter River. To achieve this goal, the primary objectives of the Stage 4 VMP are to:

- Assess the feasibility of implementation of in-situ geochemical fixation, i.e. can an effective treatment zone be established in the field;
- Assess the effectiveness of the in-situ approach, i.e. will the in-situ treatment reduce the migration of arsenic in groundwater (down-gradient of the treatment zone);
- Demonstrate that there are no significant detrimental effects on the natural groundwater conditions;
- Collect adequate data to develop full-scale in-situ remediation alternatives; and

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- Assess the feasibility of in-situ alternatives and recommend the preferred option.

It is important to note that the objective of the remediation approach is not to restore aquifer/groundwater quality to its original condition (i.e. removal of arsenic mass from the aquifer is not an objective).

1.2 Overview of Remediation Approach

The identified arsenic contamination originated from a former disposal pit, where waste arsenic liquor was disposed prior to 1994. Arsenic contamination has been delineated in soil and groundwater down-gradient of the former pit. In 2005, arsenic-contaminated soil residing near the pit, but above the water table, was remediated and removed from the site.

The arsenic-contaminated groundwater down-gradient of the former pit extends towards the South Arm of the Hunter River. Despite a relative high groundwater velocity, the migration of arsenic has been attenuated within the aquifer. Groundwater containing elevated concentrations of arsenic (>100 mg/L) is restricted to locations up-gradient (east) of Heron Road.

As part of Stage 2 VRA, the predominant process attenuating arsenic in the aquifer was identified as adsorption of the arsenic onto naturally-occurring amorphous iron. The amount of amorphous iron present in the aquifer was considered to provide a substantial amount of adsorption capacity. However, conservative 1-D geochemical groundwater flow modelling undertaken as part of the Stage 2 VRA indicated that the stability of arsenic within the aquifer over long periods is uncertain. Although rapid loss of adsorption capacity is not predicted or expected, further consideration of management options for the arsenic contamination was considered to be warranted.

The current understanding of the arsenic contamination was presented in the Conceptual Site Model on the completion of the Stage 2 VRA (URS, 2007b). Works completed as part of the Stage 3 VRA continue to support the CSM (URS, 2010).

The Stage 3 VRA included a detailed review of remediation options for the arsenic contamination identified at the Site. The review identified a number of potential options that were retained for further assessment to determine their feasibility for application at the site (URS, 2009b). A bench-scale treatability program was undertaken for each of the retained technologies. Based on the screening of remediation options, bench-scale treatability testing and subsequent feasibility studies, the preferred methodology for remediation of the arsenic contaminated groundwater at the site was considered to be in-situ geochemical fixation by iron (oxy)hydroxides (amorphous iron). The preferred reagents are ferrous chloride (FeCl_2) or zero-valent iron (ZVI), both with pre-oxidation. The method of application is likely to be an injected or a constructed reactive barrier.

The aim of the in-situ geochemical fixation remedial option is to enhance the attenuation of arsenic in groundwater within a treatment zone, and therefore, reduce the transport of arsenic in the groundwater towards the South Arm of the Hunter River.

If, during the implementation of the Stage 4 VMP works, it is determined that the field trial of the preferred remediation option (in-situ geochemical fixation) is unlikely to meet the objective of reducing the transport of arsenic in groundwater, an alternate strategy would be evaluated. If this occurs, the feasibility assessment of hydraulic containment with ex-situ groundwater treatment initiated under the Stage 3 VRA (URS, 2008a; 2009a/c) would be completed.

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1.3 VMP Outline

The Stage 4 VMP proposal includes the following components with respect to the implementation of a field trial to assess the feasibility of full-scale implementation. The key aspects of the Stage 4 VMP proposal are:

- **Site Groundwater Monitoring Program** – Continue biannual sampling of the identified arsenic-contaminated groundwater to monitor fluctuations in concentration and assess temporal trends.. This monitoring will also establish baseline conditions for the field trial.
- **Field Trial**
 - **Bench-Scale Testing Refinement** – Bench-scale laboratory testing will be conducted to supplement the results from the initial bench-scale program. The objectives are to optimise the iron reagent dosage, identify the preferred oxidant, optimise the oxidant dosage, and confirm the geochemistry of the treated groundwater.
 - **Approvals** – Approval from DECCW in Sydney and Newcastle (Office of Water) for placement of reagents into the subsurface for the field trial will be obtained. An indication of approval-in-principal for full-scale implementation will also be obtained, if possible.
 - **Detailed Design (Work Plan)** – A Work Plan will present field trial design and include treatment zone installation strategy, reagent selection, reagent dose, site selection, method of application (injection), application specifications (width, depth, number of injections and radius of influence) and a monitoring program to assess effectiveness of remediation program. A contingency plan to address issues that may arise would also be included – e.g. if direct injection fails, requirements for closer spaced injections or injection through wells would be implemented or physical construction of a barrier.
 - **Health, Safety, and Environment** - site operational, health and safety requirements will be established and measures to address any issues will be developed.
 - **Performance Criteria**– The metrics critical to assessment of whether the field trial has met the Stage 4 VMP objectives and the implications for long-term remediation objectives. e.g. injectability, longevity of reagents, groundwater concentrations of arsenic and other compounds, changes in general water quality parameters.
 - **Performance Monitoring** – The monitoring program to enable assessment of the effectiveness of the trial, including frequency, locations, duration of monitoring (approximately 18 months, but dependent on results), project milestones and analytes.
- **Contingency Plan** – If it is determined that in-situ geochemical fixation is unlikely to meet the objective of reducing the transport of arsenic in groundwater, the assessment of hydraulic containment with ex-situ groundwater treatment started under the Stage 3 VRA would be completed. This would likely include a pump test to assess hydrogeological characteristics of the aquifer and a field trial of the preferred ex-situ treatment methods.
- **Communication Strategy** – Although Stage 4 VMP work will be conducted on Orica property, full-scale implementation (if feasible) will likely occur on land not owned by Orica. For this reason, implementation of an effective Communication Plan will be required to keep stakeholders informed of progress of the field trial and forward planning for full-scale implementation.

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Scheduling and Reporting – The schedule will detail the timing of key activities under the VMP and reporting on the outcomes of the trial.

1.4 In-situ Geochemical Fixation Process

The following discussion presents a summary of the processes and mechanisms for arsenic attenuation and insitu geochemical fixation (IGF) using iron reagents presented in detail in Stage 3 VRP work (URS, 2009a/b).

Arsenic will be adsorbed to naturally-occurring positively charged iron phase minerals within the aquifer. Sorption to amorphous iron hydroxides ($\text{Fe}(\text{OH})_3$) and iron oxyhydroxide minerals (e.g. $\alpha\text{-FeOOH}$) are the primary mechanism of arsenic attenuation in aquifers under most environmental conditions (e.g. Hartley et. al., 2004, Wang and Mulligan, 2006, Beak and Wilkin, 2009). Co-precipitation of arsenic with iron oxides and hydroxides and precipitation of arsenic minerals also occurs (e.g. Voigt et. al., 1996). The proposed in-situ geochemical fixation methods will enhance the natural attenuation process by providing more adsorption sites and increasing co-precipitation of arsenic.

Arsenic attenuation will be affected by the following:

- **Iron mineralogy:** Arsenic sorption capacity tends to be greater for highly disordered structures which have larger surface areas, with arsenic found to desorb from ferric hydroxide precipitates as crystallisation increased (see Wang and Mulligan, 2006). However, As(V) sorption can stabilise hydrous ferric oxides, inhibiting transformation to more crystalline phases (Wolthers et al. 2007). Hydrous iron oxides have been found to be more effective at sorption of arsenic than the more stable minerals such as goethite ($\alpha\text{-FeOOH}$), with efficiency of arsenic adsorption by iron oxides determined as $\text{Fe(III)} > \text{Fe(II)} > \text{Fe}^0 > \text{goethite}$ (Hartley et. al., 2004).
- **Arsenic speciation:** The valence state of arsenic affects sorption. As(V) forms negatively charged anions in the aquifer, which have a high affinity for the positively charged surfaces of iron minerals, whereas As(III) species tend to be non-ionic and are less strongly sorbed;
- **Redox:** The oxidation reduction conditions control the geochemistry of precipitation and dissolution reactions in the aquifer. Under anoxic and reducing conditions, reductive dissolution of Fe(III) hydroxides can release Fe(II) and As(V), but attenuation of arsenic can occur once oxic or oxidising conditions are encountered. Microbial reductive dissimilation can reduce As(V) to As(III) in solution or adsorbed to Fe hydroxide surfaces, as well as Fe(III) to Fe(II).
- **pH:** The pH of groundwater will also affect arsenic sorption, with sorption tending to be higher at low pH and declining with increasing pH due to decreasing (positive) net surface charge of hydroxides (see Hartley et. al., 2004). Changing pH also alters the mineralogy of arsenic bearing iron oxides – amorphous and crystalline ferric arsenate will slowly convert to arsenic ferric oxyhydroxides as pH increases (see Robins et. al., 2001).
- **Competing anions:** Competing anions, such as phosphate, will compete with arsenic for the adsorption sites on iron minerals, thereby reducing the effective adsorption capacity of the aquifer (see Beak and Wilkin, 2009).

The Insitu Geochemical Fixation process proposed for this site consists of two primary steps including oxidation of As(III) to As(V) and then adsorption onto iron hydroxide compounds. The addition of an oxidiser will ensure that the redox conditions will be optimal for the formation of As(V) and therefore maximise the adsorption or fixation of dissolved arsenic. Currently two oxidisers are under consideration including hydrogen peroxide (H_2O_2) and potassium permanganate (KMnO_4).

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The addition of iron reagents into the aquifer matrix will increase the available adsorption sites for arsenic and increase co-precipitation of arsenic, thereby enhancing the attenuation capacity. The attenuation mechanisms for the two preferred reagents – ferrous chloride and zero-valent iron - are discussed below.

- **Ferrous Chloride:** In solution under acidic to neutral and oxidising conditions, Fe(II) (e.g. FeCl_2) is readily oxidised to Fe(III) by oxygen, forming ferric oxyhydroxide. Arsenic adsorption to the ferric hydroxide and co-precipitation of arsenic precipitates (e.g. FeAsO_4) occurs.
- **Zero Valent Iron:** The mechanisms for immobilisation of As using Fe^0 (ZVI) are more complex than for other iron based reagents as they involve a series of oxidative dissolution (corrosion) reactions at the Fe^0 surface followed by co-precipitation or adsorption of As (see Su and Puls, 2001).
 - The corrosion reactions cause an increase in pH and Fe(II) concentrations, and decrease in redox potential. Aqueous species at the particle surface (such as Fe(III)) are typically reduced, though arsenic is often an exception. Fe(II) formed at the corrosion surface reacts with OH^- anions to form ferrous hydroxide ($\text{Fe}(\text{OH})_2$), and can be followed by further oxidation to various Fe(II)/Fe(III) mineral phases (see Beak and Wilkin, 2009). Thus, the dominant method of As(III) and As(V) immobilisation is via adsorption onto iron corrosion products formed at the Fe^0 surface and co-precipitation with the secondary Fe phases.
 - Iron oxide and carbonate precipitation on the surface of the Fe^0 particle causes cementation, which can both decrease reactivity of the iron particle and reduce permeability of the aquifer material, which may have implications for long-term performance of ZVI arsenic immobilisation. The presence of HCO_3^- and CO_3^{2-} in solution can increase Fe^0 corrosion due to disruption of the iron oxide passivation layer around the Fe^0 particle. Sulphate reducing bacteria in Permeable Reactive Barriers (PRBs) has been reported, which may promote formation of iron sulphides and subsequent adsorption of arsenic. Relatively high concentrations of SO_4^{2-} and HCO_3^- are present in groundwater at the site.

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Site Groundwater Monitoring Program

A biannual groundwater monitoring program (January 2010, July 2010, January 2011, July 2011 and January 2012) will be implemented for the identified arsenic contamination. It is noted that the January 2010 has been completed. The monitoring program will be consistent with the Stage 3 VRA monitoring program, and will involve sampling groundwater using low flow techniques from wells located down-gradient of the former arsenic disposal pit, and will include on- and off-site wells. While separate from performance monitoring of the field trial, biannual groundwater monitoring will be conducted in conjunction with field trial monitoring whenever possible. Figure 1 presents groundwater monitoring wells at the site and in surrounding areas.

Onsite wells MW27, MW27A, MW45, MW48 and off-site wells MW54, BP7-3, BP7-6, BP7-9, BP5-3, BP5-6, BP5-9, MW50, MW21A, POMW7, POMW61-9, POMW61-12, POMW60-3, POMW60-6, POMW60-9, POMW60-12, POMW63-3, POMW63-6, POMW63-9, POMW63-12, POMW62, POMW58-6, POMW58-9, POMW58-12, POMW59-3, POMW59-6, POMW59-9 and POMW59-12 will be included in the biannual monitoring program.

Groundwater samples will be analysed for total dissolved arsenic. Arsenic speciation analysis and other parameters may be undertaken in order to assist in the assessment of the performance of the field trial.

The future monitoring requirements will be reviewed after completion of each monitoring round, and subject to the results and evidence of trends, the sampling frequency and location of monitoring points may be modified. Approval to changes to the monitoring program would be sought from DECCW prior to implementation.

Tabulated results of the January 2010, July 2010, January 2011, July 2011 and January 2012 monitoring programs will be provided by 31 March 2010, 31 August 2010, 28 February 2011, 31 August 2011 and 29 February 2012, respectively.

The results of the bi-annual groundwater monitoring program will be presented in the report at the completion of the field trial program, April 2012.

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Field Trial

The main component of the Stage 4 VMP is the undertaking of a field trial to assess the feasibility of full-scale implementation of the preferred in-situ remediation options for the site – principally, in-situ geochemical fixation. The proposed field trial will entail installation of two treatment zones, one assessing ZVI and the other FeCl_2 , within the arsenic groundwater plume at the Orica facility. A control zone will be used to compare the treatment against natural attenuation. Performance monitoring will enable assessment of the feasibility of the in-situ remedial options.

The following sections describe the components of the proposed field trial.

3.1 Conceptual Design

3.1.1 Conceptual Design Summary

The basic design parameters for the conceptual design of the field trial are presented in the table below. The location of the proposed field trial is shown in Figures 1 and 2.

Conceptual Design	
Objectives	- To install and assess performance of a field trial of in-situ geochemical fixation - Assess feasibility of full-scale implementation to meet overall remediation objectives
Location	At the Orica Kooragang Island facility. The most likely site is downgradient of the former arsenic disposal pit and upgradient of monitoring wells MW45 and MW54 (see Figure 2).
Duration	Approximately 18 months, with intermediary milestones at 3 and 6 months.
Treatment zones - Area - Target depth interval - Control	- Two zones (one for each reagent – FeCl_2 and ZVI) of approximately 15 m by 5 m - From approximately 1 to 9 m below grade (8 m interval) to target core of arsenic contamination - A control zone, to assess natural attenuation of arsenic, will be included between the treatment zones
Reagents (pending bench-scale refinement work)	- Oxidant: hydrogen peroxide or potassium permanganate - Ferrous chloride (FeCl_2) and sodium hydroxide (NaOH) buffer (if necessary) - Zero-valent iron (ZVI)
Application Method	- Direct injection of reagents using direct-push technology (e.g. Geoprobe) will be trialled. - Field-trial of a constructed permeable reactive barrier or use of injection wells will be retained as a contingency in the case that reagents cannot be injected effectively.
Injection Strategy (pending bench-scale refinement work)	A total mass for FeCl_2 and ZVI of the order of 10,000 kg per reagent will be injected at approximately 8 injection points per treatment zone.
Performance Monitoring	- Injection parameters - A network of nested monitoring wells upgradient, within, and downgradient of the treatment zone to assess groundwater analytical characteristics, and hydrogeological parameters - Soil samples to assess iron and arsenic content

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The field trial conceptual layout is presented in Figure 3.

The Work Plan (see Section 3.4) will describe detailed design parameters, implementation methods and details of the monitoring network.

3.1.2 General Sequence of Work

It is envisaged that the field trial will occur in three stages:

1. An initial stage for installation and baseline sampling of monitoring wells to assess groundwater flow direction and arsenic concentrations in the proposed treatment areas to ensure the treatment zones intersect the arsenic plume and are perpendicular to the flow direction. These wells will also assist in assessment of the ability to inject the reagents (i.e. injection radius of influence) and be used for performance monitoring.
2. The main stage includes the injection of reagents to immobilise arsenic, installation of additional monitoring wells and collection of soil samples.
3. The final stage includes the ongoing performance monitoring of the field trial, along with reporting.

3.1.3 Reagents

Based on Stage 3 VRP in-situ treatability work (URS, 2009b) and Stage 4 VMP bench-scale refinement testing, the preferred reagents will be selected. While FeCl_2 and ZVI are the preferred iron compounds, the required mass and optimum concentration of each iron reagent, and the concentrations and type of oxidant and buffering chemicals, will be determined during the bench-scale refinement testing.

Ferrous chloride is commercially available as a 32-percent (by weight) solution, while zero valent iron is a proprietary product in powder form (<0.45 micron) designed to be injected as a slurry.

Reagents will be temporarily stored onsite before being mixed with potable water immediately prior to application. Appropriate health, safety and environmental controls and management practices will be developed and implemented during the trial.

3.1.4 Injection Method

The application method for in-situ geochemical fixation will be a series of reagent injections completed using a direct-push drilling rig, such as a Geoprobe, and specialised mixing equipment. Figure 3 presents the proposed conceptual layout of the field trial. The reagent will be mixed then injected at a pressure and flow rate sufficient to achieve the desired radius of influence starting from the base of the treatment zone then moving upwards at each injection point. The target radius of influence is 2.0 m. Depending on the results of performance monitoring, additional injection events of reagent and/or oxidant may be required. At this time it is anticipated that one additional injection of FeCl_2 over the 18 month life of the trial may be required, while only one injection of ZVI is expected. This will be assessed as part of progress reporting (see Section 7).

3.1.5 Monitoring Network

A network of nested 32-mm and 50-mm monitoring wells will be installed to enable performance monitoring. The nested wells will enable monitoring in the upper and lower depth profile of the

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approximately 8 m deep treatment zone. Figure 3 presents a plan view of the proposed monitoring network.

3.2 Bench-Scale Refinement

Stage 3 VRP in-situ treatability work (URS, 2009b) showed that the preferred reagents for in-situ remediation of arsenic were the iron-based reagents FeCl_2 and ZVI. However, further laboratory work was recommended in order to refine the reagent dose, oxidation and buffering for field-trial design purposes, and also to confirm that no detrimental effects will occur to the aquifer. Proposed laboratory work for Stage 4 VMP is presented in the following table. Prior to conducting laboratory work a testing matrix and protocol will be developed.

Bench-scale Test		Type
1. Refine optimal reagent dose	Optimise the effective dose for FeCl_2 and ZVI	SBT at optimal dose estimated from Stage 3 Scoping Tests (URS, 2009b).
2. Optimise pre-oxidation and buffering	Determine whether permanganate can be used for oxidation purposes with the proposed iron reagents, and if it is more effective than hydrogen peroxide	SBT test with permanganate pre-oxidation (using preferred reagents FeCl_2 or ZVI).
	Optimise oxidation (i.e. minimise chemical oxidant requirement)	SBT with varying oxidant concentrations at optimum FeCl_2 /ZVI dose.
	Optimise buffering (i.e. minimise chemical buffer requirement)	SBT with varying buffer concentrations at optimum FeCl_2 /ZVI dose.
3. Assess long-term stability of immobilised arsenic		Sequential Batch Test (SBT) (back flushing) with up to 100 pore volumes of groundwater .
4. Assess affects of reagents on the aquifer		Groundwater back-flushing tests of selected SBT samples, analysing for a suite of potential contaminants of concern in residual groundwater.

Additional information will also be obtained:

- Reagent suppliers specification of products (oxidants, buffer and iron reagents); and
- Certificates of analysis of reagents (if available).

As it is critical that the characteristics of groundwater used for these tests are representative of field conditions, fresh groundwater will be used for this laboratory work. Once assessment of bench-scale testing results has been completed, the detailed design of the field trial can be implemented.

3.3 Approvals

Regulatory approval will be required for undertaking the field trial (injection of oxidants, buffers and iron reagents into the aquifer). As part of the Stage 4 VMP, the process of determining and obtaining the required regulatory approvals will be obtained on submittal of the Work Plan, although the approvals process may be commenced earlier.

It is currently considered that the following regulatory approvals are likely to be required:

- **Injection of reagents** – approval will be required for the installation of monitoring bores and the injection of oxidants/reagents. Discussions with the NSW Office of Water, now part of the DECCW, has indicated that their notification of and approval for the field trial can be obtained via the bore licensing process (NSW Office of Water, 2010). Further DECCW approval will be obtained by acceptance of this VMP proposal and submittal of the Work Plan.

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- **Other regulatory authorities** – although considered unlikely to affect the proposed field trial, the following requirements would be checked as part of the approvals process:
 - Dangerous goods notification, dependant upon the reagent quantities – Workcover NSW.

Since no new infrastructure will be required, field trial activities are of a small-scale, and the trial will only to be conducted on Orica property, planning approvals are not necessary. Orica confirmed this conclusion with Newcastle City Council (NCC 2010). However, prior to implementation of the field trial, the Environmental Coordinator for the NCC will be formally notified of the work.

Since the field trial will be conducted on Orica's property approval from surrounding Land Owners will not be required. Land Owners will be kept informed with respect to the trial via the Communication Strategy (Section 6).

The approvals process for the field trial will be commenced as part of this Stage 4 VMP, but Orica cannot make any assurances that approvals will be granted or obtained within the time frame of this VMP.

It is noted that should full-scale implementation of in-situ geochemical fixation occur, it will likely be conducted at an off-site location(s) (e.g. along Heron Road). Therefore, an indication from DECCW and other Stakeholders for their "in-principal" agreement for the concept of full-scale implementation will be obtained, if possible.

3.4 Detailed Design (Work Plan)

Planning and detailed design of the field trial will be completed and presented in a Work Plan once the bench-scale refinement work is finalised. The draft Work Plan will be submitted to the DECCW for review prior to implementing the trial. The plan will include detailed design specifications and methodologies for conducting the trial including:

- **Objectives**
- **Project team**
- **Trial Location**
- **Configuration** – dimensions and target depth interval; layout of the ZVI, FeCl₂ and control zones
- **Reagents** – type, description, quantity, concentration, oxidant, buffer requirements, supplier details
- **Injection strategy** – injection as a barrier, injection configuration, radius of influence, number of injection points
- **Application method** – direct-push/injection method and equipment, reagent mixing method and equipment, injection parameters such as injection pressure and flow rate
- **Performance monitoring** – performance metrics, groundwater and soil monitoring plan and schedule
- **Monitoring network design and installation** – design and installation of monitoring wells
- **Health, safety and environment** – Orica hazard study process; health, safety and environment plan; subsurface utility clearance requirements
- **Contingency** – alternate injection technologies (pulsed injection), alternate injection strategy (e.g. closer injection spacing, change reagent concentration, and use of injection wells); constructed barrier if direct injection is not feasible
- **Schedule** – for injection activities, installation of monitoring wells and performance monitoring; project milestones

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- **Communication** – communication of field trial progress with stakeholders
- **Reporting requirements** – progress/milestone reports to DECCW

While the conceptual design was presented in Section 3.1.1, detailed design will be dependent on the results of the bench-scale refinement work. In addition, monitoring of wells installed prior to the direct-push injection phase of the work will enable refinement of the treatment zone and injection point configuration (i.e. to ensure the treatment zones intersect the arsenic plume and are perpendicular to groundwater flow direction). The refinement of the field trial configuration will occur after completion of the Work Plan and immediately prior to injection work.

3.5 Health, Safety and Environment

Appropriate health, safety and environmental controls and management practices will be used. These will include:

- Hazard studies in keeping with Orica's operational requirements
- Underground utility clearances
- Storage and handling of reagents
- A health, safety and environment plan that clearly delineates hazardous working zones during the injection process.

The primary hazards of concern involve the handling and temporary storage of reagents including FeCl_2 solution (low pH (<2) and corrosivity) and exposure to inhalation of ZVI powder.

3.6 Performance Criteria

The success of the field trial will be evaluated against the trial objectives and the ultimate goal of the Stage 4 VMP to assess the feasibility of full-scale implementation of the in-situ geochemical fixation, including:

- **Implementability** – assess whether the in-situ geochemical fixation remedial options can be implemented in the field in a feasible and efficient manner.
- **Treatment Effectiveness** – assess whether transport of arsenic in groundwater down-gradient of the treatment zone is reduced.
- **Potential Adverse Effects** – confirm that the in-situ remedial option has no significant detrimental impacts on the aquifer.

The performance metrics, to assess the success of the field trial, are discussed below.

Implementation

- **Reagent optimisation** – assess whether efficient use of reagents is feasible (i.e. cost effective), minimise requirements of iron reagents, oxidants and buffers, and determine the most efficient reagent of ZVI or FeCl_2 (the greatest decrease in arsenic concentrations compared to mass of reagent applied).
- **Injectability** – assess the ability to apply the reagents to achieve adequate distribution within the aquifer to immobilise arsenic and meet remedial objectives. Direct injection is the preferred

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application method, although injection through wells or constructed barrier will be retained as contingency methods.

Treatment Effectiveness

- **Reagent longevity** – assess the effective life of reagents and the requirement for reapplication of the reagents.
- **Stability** – assess short-term (0 - 4 months) and medium-term (4 -16 months) stability of immobilised arsenic.
- **Groundwater Concentrations** – assess the ability of the reagents to reduce the dissolved phase arsenic present within, and downgradient, of the treatment zone.

Effects

- Assess the effects of the reagents on the geochemistry of the aquifer (pH, ORP, conductivity, major ion chemistry, dissolved and total iron and other metals).
- Assess the hydrogeological effects of the implementation of the treatment zone (what effect does the treatment zone have on local groundwater flow).

The method and plan for obtaining the information to assess performance of the field trial is discussed in Section 3.7.

3.7 Performance Monitoring

A monitoring program will be implemented to enable collection of sufficient data to assess the performance of the field trial. The performance monitoring program will be described in detail in the Work Plan, however, performance monitoring will include:

- Groundwater monitoring – sampling and gauging a network of monitoring wells (see Figure 3) before (baseline), during and after reagent injections
- Soil sampling – collection of soil samples within the treatment zone
- Injection parameters (e.g. pressure, flow rate)

The monitoring network will consist of nested monitoring wells upgradient, within, and downgradient of the treatment zone to assess groundwater analytical characteristics and hydrogeological parameters. While Figure 3 presents the indicative monitoring network and the table below presents the general monitoring program, the exact monitoring locations, schedule and analytes will be presented in the Work Plan and will be dependent on the ongoing monitoring results.

A small number of monitoring wells will be installed prior to injection work to determine groundwater flow direction and baseline arsenic concentrations in the proposed treatment areas to ensure the treatment zones intersect the arsenic plume and are perpendicular to the flow direction. Installation of additional monitoring wells, and collection of soil samples, will occur during the injection phase of work.

In order to ensure replication and repeatability of field trial results, the program will include:

- Two baseline sampling events, as detailed in Section 2, within 6 months of the start of injections to establish clear baseline conditions.
- A Control Zone will be established outside the treatment zones with similar monitoring configuration (upgradient, inside, and downgradient of delineated zone). The Control Zone

3 Field Trial

water quality will be used to monitor changes in the local groundwater quality for comparison with the treatment zones water quality.

Month (from injection)	Task	Date
-3	Initial Installation of performance monitoring wells. Conduct first performance baseline monitoring event	June 2010
- 2	Conduct biannual site groundwater monitoring round with second performance baseline monitoring event.	July 2010
0	Reagent injection and installation of the remainder of the monitoring wells	September 2010
0	1 st performance monitoring event (immediately after injection work)	September 2010
1	2 nd performance monitoring event	October 2010
2	3 rd performance monitoring event	November 2010
4	4 th performance monitoring event (also biannual arsenic groundwater monitoring round)	January 2011
7	5 th performance monitoring event	April 2011
10	6 th performance monitoring event (also biannual arsenic groundwater monitoring round)	July 2011
13	7 th performance monitoring event	October 2011
16	8 th (final) performance monitoring event also biannual arsenic groundwater monitoring round)	January 2012

While the table above presents the proposed monitoring program, more frequent monitoring of water quality parameters (indicators of changes in geochemistry that could trigger additional monitoring) and water levels may be conducted. The initial plan will be to monitor groundwater parameters every two weeks.

3.8 Contingency

If the initial direct injection method cannot be implemented effectively (e.g. cannot inject reagent or inadequate reagent distribution in the aquifer), then other application options will be considered, including:

- Alternate injection strategy (e.g. closer injection spacing);
- Alternate injection technologies (e.g. 'pulsed injection' or 'induced hydraulic gradients' technologies);
- Application of reagents using injection wells; and/or
- Application of reagents using a constructed permeable reactive barrier.

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Feasibility Study

The feasibility of implementing in-situ geochemical fixation at full-scale and to meet the overall project objectives will be assessed on completion of the field trial. The objective of the feasibility study will be to assess whether in-situ geochemical fixation will be an appropriate full-scale remedial method for meeting the remediation objectives of the site. Results of the bench-scale and field trial will be used as a basis for developing appropriate remediation approaches and alternatives. These alternatives will be evaluated using the general criteria of technical-effectiveness, implementability, remedial design approach (a series of barriers, source area grid treatment, etc.), stakeholder acceptance and cost. Specifically, the general criteria are defined as follows:

- 1) Effectiveness
 - a. Meet short-term and long-term remediation objectives:
 - (i). Reduction of arsenic transport and decrease in arsenic concentrations in groundwater
 - (ii). No adverse effects to the aquifer
 - b. Stability of immobilised arsenic
 - c. Longevity or persistence of reagents
 - d. Reliability/Proven Effectiveness
- 2) Implementation
 - a. Ability to inject and achieve sufficient distribution of reagents in aquifer
 - b. System footprint and aesthetics, including accessibility to land not owned by Orica
 - c. Reagent replenishment and maintenance
 - d. Availability of reagents and direct-injection contractors
- 3) Stakeholder Acceptance
 - a. DECCW
 - b. Newcastle City Council
 - c. Adjacent property owners
 - d. Other approval requirements
- 4) Cost
 - a. Capital Cost
 - b. Annual Operation and Maintenance Cost
 - c. Lifecycle Cost

The feasibility study will present the preferred remediation option with a list of conclusions and recommendations.

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Contingency Plan

If the in-situ remedial options are not determined to be feasible for the identified arsenic contamination, then the feasibility of ex-situ remedial options developed in Stage 3 VRP work will be further assessed with the following proposed work:

- Conduct a pump test to assess the hydrogeological characteristics of the aquifer and pumping requirements in the vicinity of the proposed hydraulic containment system;
- Conduct a pilot-trial of the preferred ex-situ treatment system using extracted groundwater from the pump test;
- Undertake dewatering trials of the sludge generated from the pilot-trial;
- Apply and obtain an immobilisation approval from the DECCW for the sludge generated from the pilot-trial; and
- Assess the feasibility of the preferred ex-situ remedial option based on the pilot trial and pump test.

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Communication Strategy

Effective and regular communication will be maintained with affected stakeholders throughout the proposed Stage 4 VMP works outlined in this document. A Stage 4 VMP Communication Plan will be developed, with liaisons to be timed to coincide with activities as they occur during the Stage 4 VMP works. This will involve meetings at least every six months as well as meetings at key milestones during the implementation of works with key stakeholders, including the DECCW. Adjacent property owners will also be informed of progress throughout the implementation of the field trial program.

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Scheduling and Reporting

The proposed schedule for the implementation of the Stage 4 VMP tasks is presented in Figure 4. It is noted that the timing of some tasks will be dependent on other stakeholders such as regulatory authorities, completion of prior tasks and results of performance monitoring.

The proposed completion date for the Stage 4 VMP is 31 March 2012, though this will depend on approvals and the outcomes of critical tasks. While a period of approximately 18 months is considered necessary to assess the performance of the field trial, milestones throughout the Stage 4 VMP will be used to assess progress, trigger additional work as required, and serve as reporting events. Proposed milestones and reporting schedule are included in the following table.

Month (from injection)	Milestone	Purpose	Reporting
-	Bench-scale refinement	Optimise reagent, oxidant and buffer requirements	None
-	Work Plan	Detailed design, specifications, planning etc	Work Plan
-	Approval	Approval for field trial	None
-	Baseline monitoring	Install and monitor wells to refine field trial configuration and obtain baseline data	None
0	Injection of Reagents	Establish treatment zones	None (verbal communication with DECCW)
0	Directly after injection of reagents	Evaluate success in injection methodology, in terms of injection rate and distribution. The outcome may trigger contingency for trial of alternate application methods.	None (verbal communication with DECCW)
1	One month after injection of reagents	Ongoing monitoring of trial effectiveness	None
2	Two months after injection of reagents	Ongoing monitoring of trial effectiveness	None
4	4 months after field trial implementation	Assess implementation and present initial performance data. Poor performance triggers contingency for additional injections or trial of alternate methods.	Progress Report #1 – factual letter report presenting initial performance data
7	Seven months after field trial implementation	Present ongoing performance data. Poor performance triggers contingency for additional injections or trial of alternate methods.	Progress Report #2 - factual letter report presenting performance data
10	Ten months after field trial implementation	Present ongoing performance data. Poor performance triggers contingency for additional injections or trial of alternate methods.	Progress Report #3 - factual letter report presenting performance data
13	13 months after field trial implementation	Ongoing monitoring of trial effectiveness	None
16	16 months after field trial implementation (end of field trial)	Present and assess performance data. Conduct a feasibility assessment of in-situ geochemical fixation remedial options. If in-situ remediation is not feasible, then the contingency is for additional feasibility assessment of ex-situ remedial options. Present the results of the bi-annual monitoring program.	Final Report on the interpretation and evaluation of Field Trial and bi-annual groundwater monitoring program. Feasibility Study (see Section 4).

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Limitations

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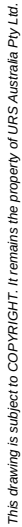
The methodology adopted and sources of information used by URS are outlined in this report. URS has made no independent verification of this information beyond the agreed scope of works and URS assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to URS was false.

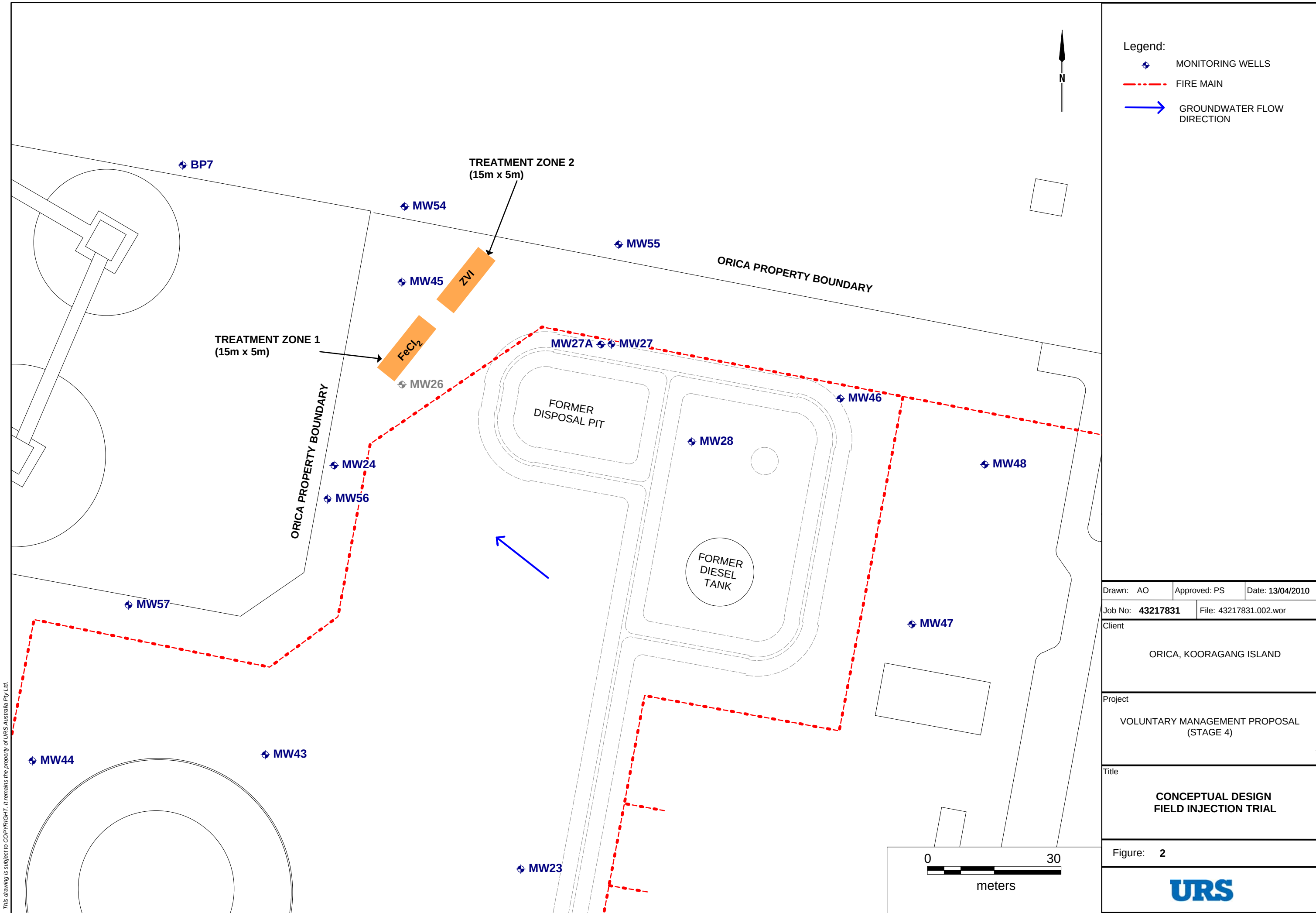
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Figures





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Job No: 43217831	File: 43217831.002.wor	
Client		
ORICA, KOORAGANG ISLAND		
Project		
VOLUNTARY MANAGEMENT PROPOSAL (STAGE 4)		
Title		
CONCEPTUAL DESIGN FIELD INJECTION TRIAL		
Figure: 2		
		

Figure 3: Proposed Conceptual Design Detail

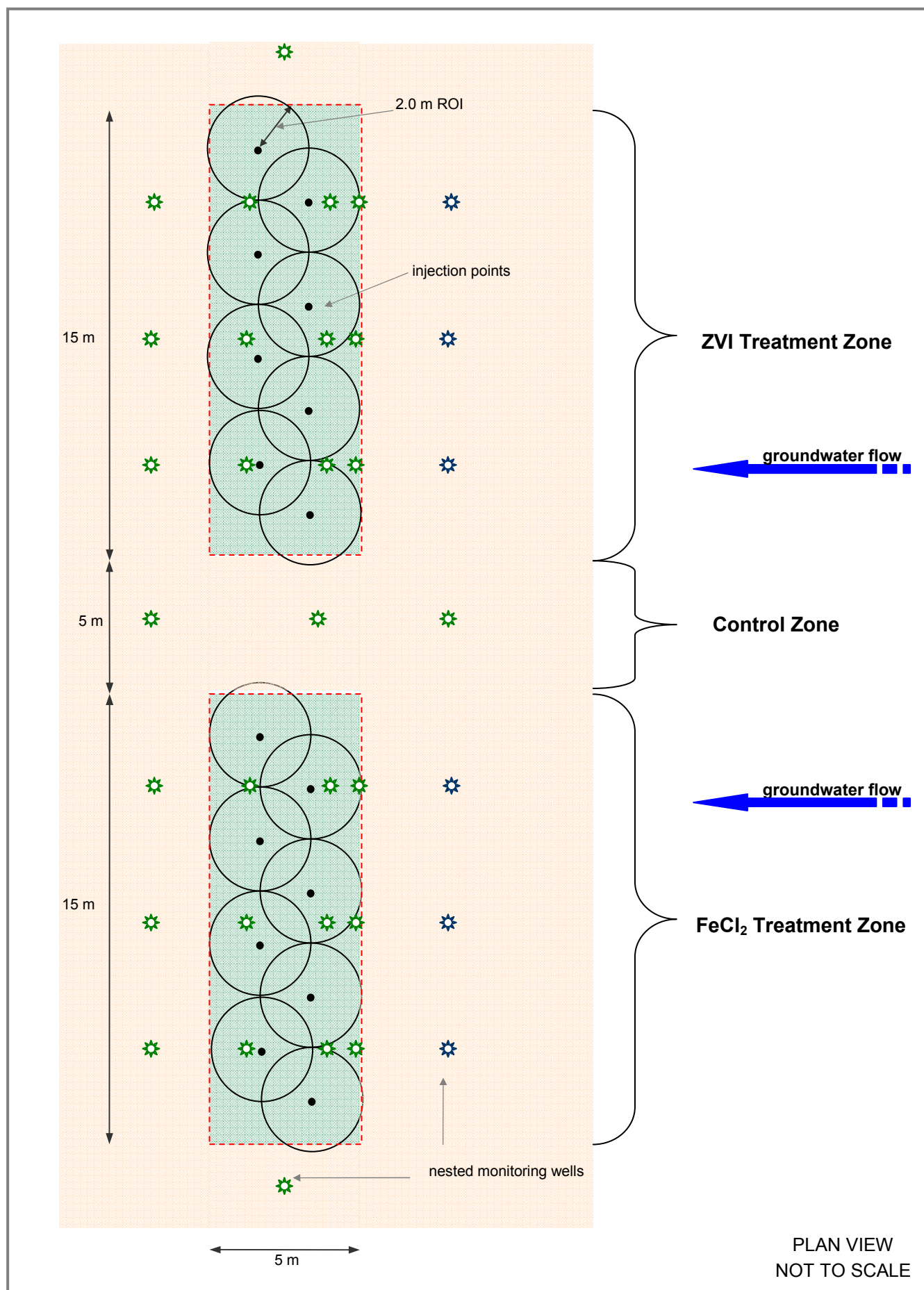


Figure 4

Proposed Schedule for Stage 4, Voluntary Management Plan, Orica - Kooragang Island

		2010												2011												2012												
		March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September	October	November	December			
Stage 4 VMP Proposal	Submission and agreement of Stage 4 VMP with DECCW																																					
	Site Groundwater Sampling Analysis																																					
Site Groundwater Monitoring	Submit - Fabricated Results to DECCW																																					
	Approvals Process																																					
In-situ Field Trial	Bench-scale Testing																																					
	Regulators																																					
	Develop Work Plan																																					
	Submit - Work Plan																																					
	Detailed Design																																					
	Installation	Installation of baseline monitoring network																																				
		Baseline monitoring																																				
	Performance Monitoring	Injection of Reagents																																				
		Installation of final monitoring network																																				
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	Performance Monitoring - Event 7																																					
	Assessment and Monitoring	Performance Monitoring - Event 8																																				
Field Trial Progress Report 1																																						
Field Trial Progress Report 2																																						
Reporting	Field Trial Progress Report 3																																					
	Field Trial Final Performance Report																																					
Feasibility Study	Assessment of feasibility of in-situ remedial option																																					
	Submit - Feasibility of In-situ Remedial Options Report																																					

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URS Australia Pty Ltd
Level 3, 116 Miller Street
North Sydney NSW 2060
Australia

T: 61 2 8925 5500

F: 61 2 8925 5555

www.ap.urscorp.com