

**ESCROW SITE 1
(RECTIFIER YARD)
ANGLESEY ALUMINIUM
HOLYHEAD**

REMEDIATION STRATEGY



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CONTENTS

1	INTRODUCTION	4
2	SUMMARY OF PREVIOUS WORK	6
3	PROPOSED REMEDIATION WORKS	10
4	VALIDATION	15
5	VERIFICATION AND COMPLETION REPORTS	17

FIGURES

Figure 1: Site Location Plan

Figure 2: Escrow Areas

Figure 3: LKC Exploratory Location Plan

Figure 4: Hydrocarbon Distribution in Superficial Groundwater

Figure 5: Hydrocarbon Distribution in Bedrock Groundwater

Figure 6: Proposed Treatment Area

APPENDICES

Appendix A: Remediation Pilot Study Report

Appendix B: Chemical Oxidant Laboratory Trials Report

1 INTRODUCTION

1.1 Background

LK Consult Ltd (LKC) has been commissioned by Orthios to provide a Remediation Strategy for part of the former Anglesey Aluminium Metals (AAM) Works, Penrhos, Holyhead under an escrow agreement.

There are three portions of the former AAM Works site retained by AAM and Orthios under the escrow agreement:

- **Escrow 1 - Rectifier Yard and Boundary (Area 4 of planning application boundary):** This area contains rectifiers, transformers, a control building and a building owned and operated by National Grid. It is understood that a Transformer fire caused a spill of transformer oil into the ground and free product was present.
- **Escrow 2 – Vehicle Refuelling Area (Garage):** This area contained a historical pump island. LKC understand that any tanks in this area have been decommissioned. Diesel impacted water was noted, with free product around the pump island.
- **Escrow 3 – Compressor House:** This area contained pumps and a Compressor House. Free product comprising oil was noted in the only borehole drilled in that area.

This Remediation Strategy details the remediation works to be undertaken in the Rectifier Yard (Escrow site 1) and includes the results of pilot trials already undertaken in the area.

This remediation strategy follows on from further delineation investigation work undertaken by LKC to refine previous outline remediation options. The scope of the investigation works proposed for the escrow sites including preliminary remediation options was provided to the Local Authority, Isle of Anglesey County Council (IOACC), and National Resources Wales (NRW) prior to undertaking the work.

1.1 Site Details

The Rectifier Yard is located in the south east of the wider former AAM Works site to the south and west of the A5 at Penrhos, east of Holyhead, Anglesey (approximate National Grid Reference 226610E 381080N). Figure 1 shows the site location and Figure 2 indicates the locations of the three escrow sites within the former AAM Works.

1.2 Previous Reports

The following reports have previously been undertaken by LKC relating to the Rectifier Yard and should be read in conjunction with this Remediation Strategy:

- Preliminary Risk Assessment (PRA) report (Ref: CL-602-LKC 14 1181-01 R1, dated 8th March 2016).
- Phase 2 Geoenvironmental Investigation and Risk Assessment (Ref: CL-602-LKC 14 1181-02, dated 29th April 2016).
- Delineation Investigation and Risk Assessment Report (Ref: CL-602-LKC 14 1181-04, dated June 2017).

1.3 Aims and Objectives

The scope of this Remediation Strategy will be to detail the works required to achieve betterment under the 'As Low as Reasonably Practicable' (ALARP) principle and validation proposals. The report will include the following:

- Summary of previous work including pilot trials.
- Proposed remediation works within the Rectifier Yard.
- Proposed validation work to confirm betterment of groundwater quality in Rectifier Yard.

In order to achieve the aims of the Remediation Strategy, the following objectives will be set:

- Ensure that the design meets with current environmental and waste legislation.
- Use of appropriate environmental controls during the remediation and development programme.
- Ensure that the remediation process is transparent and fully involves all stake holders.
- Minimise the impact of the works on adjacent land (wider former AAM Works and adjacent Alpocho Works).
- Ensure that cost compared to environmental benefit is a driver in developing the final improvement design.
- Remediation works are undertaken using the 'As Low as Reasonably Practicable' (ALARP) principle.

2 SUMMARY OF PREVIOUS WORK

2.1 Delineation Investigation Work

In order to assess the ground conditions and delineate the previously identified hydrocarbon contamination intrusive investigation work was undertaken by LKC within the Rectifier Yard.

The investigation was carried out between 13th April and 18th May 2016 and comprised the following:

- 19no. window sample boreholes drilled from 1.3-5.0 mbgl (ref. WS301 to WS317 including WS306a and WS308a) to delineate shallow hydrocarbon contamination.
- 16no. window sample boreholes drilled from 0.8-4.0 mbgl (ref. WS201 to WS216) drilled across Rectifier Yard to confirm that no further contamination hotspots exist and to install shallow groundwater monitoring installations.
- 13no. open hole rotary boreholes drilled to 12-15mbgl (ref. LKRBH201-209 and LKRBH211-214) installed to allow groundwater sampling of deeper groundwater.
- 6no. rotary cored boreholes drilled to 10.8-15.1mbgl (ref. LKRBH210 and LKRBH215-219) to retrieve rock core samples for logging and install groundwater monitoring wells.

Rotary boreholes were used to penetrate the schist bedrock to allow installation of groundwater monitoring wells and rotary coring was undertaken in selected boreholes to assess shallow bedrock weathering and fractures, as well as to provide evidence for the extent of any vertical contamination.

All site investigation locations are shown in Figure 3.

2.2 Ground Conditions

The ground conditions underlying the Rectifier Yard site generally comprised made ground underlain by superficial sandy clay and silt, or silty sand. The superficial deposits were predominately underlain by weathered schist which was generally recovered as sandy clayey gravel of mica schist.

The schist bedrock was highly micaceous and the shallow bedrock was predominately found to be moderate to highly fractured. The deeper schist bedrock showed a lesser degree of fracturing with predominately sub-horizontal fracturing noted.

Shallow boreholes (window sample boreholes) generally refused on dense weathered schist or the underlying schist bedrock.

The depth of made ground and superficial deposits, including weathered schist, varies from west to east with depth to bedrock and thickness of weathered/broken schist generally deeper in the centre of the Rectifier Yard.

2.3 Identified Contamination

Visual and olfactory evidence of contamination was noted during the LKC delineation investigation as summarised below:

- WS209 (0.2-0.80mbgl) – moderate hydrocarbon odours in made ground.
- WS210 (0.2-0.8mbgl) – weathered diesel odour in made ground.

- WS303 (1.4-2.2mbgl) – weak hydrocarbon odour in natural gravel.
- WS306 (0.4-0.6mbgl) – weak hydrocarbon odour in natural gravel.
- WS306A (1.3-4.0mbgl) – weak hydrocarbon odour in natural sand and gravel.
- WS307 (1.0-1.9mbgl) – weak hydrocarbon odour in natural gravel.
- WS308 (0.3-1.3mbgl) – strong hydrocarbon odour in weathered schist.
- WS313 (1.5-1.7mbgl) – weak hydrocarbon odour in weathered schist.
- WS316 (1.5-2.3mbgl) – weak hydrocarbon odour in natural sand.
- LKRBH17 (2.0-3.0mbgl) – moderate hydrocarbon odours in weather schist.

Rock cores of the schist bedrock were also assessed for visual or olfactory evidence of hydrocarbon contamination. No evidence of any hydrocarbon contamination was noted in any of the cores recovered.

2.4 Delineation Investigation Results Assessment

Key results and findings for soil, superficial groundwater and bedrock groundwater in the Rectifier Yard following the delineation investigation are summarised below:

2.4.1 Soil

- Total TPH concentrations in soil samples tested from delineation boreholes in the Rectifier Yard ranged between <10mg/kg in number of exploratory locations to 15,000mg/kg in WS303 (0.4-1.0mbgl) within the known area of hydrocarbon contamination.
- The vertical extent of hydrocarbon contamination identified was between 0.3mbgl (WS308) and 4.0mbgl (WS306A) and, based on water strike depths and subsequent groundwater monitoring data, is associated with shallower groundwater within made ground or superficial deposits.
- No evidence of hydrocarbon contamination (e.g odours or staining) was noted within core samples of the schist bedrock taken from the Rectifier Yard.
- Only one location outside of the assumed area of hydrocarbon impact from the transformer fire recorded detectable hydrocarbon concentrations in soil, relating to a likely small scale spill of diesel, but this was not considered to be a risk.

2.4.2 Superficial Groundwater

The distribution of hydrocarbon contamination in superficial groundwater before and after delineation is presented in Figure 4.

- The maximum TPH concentration in the shallow groundwater was 4,400mg/l recorded in GABH05 in proximity to the location of the 2007 transformer fire.
- Free product was only identified in one location, AAM-REC11(S), by LKC during the monitoring and sampling of wells installed in the superficial deposits in 2016. However, TPH concentrations in GABH05 and AAM-REC03 were indicative of free product.
- The results of the groundwater analysis and monitoring demonstrate that the hydrocarbon plume has migrated to the northwest with anticipated groundwater flow but that the migration has not been significant and the plume has not moved beyond the boundaries of the Rectifier Yard.
- No PCBs were recorded above laboratory detection limits in any of the groundwater samples tested.

2.4.3 Bedrock Groundwater

The distribution of hydrocarbon contamination in bedrock groundwater before and after delineation is presented in Figure 5.

- No free product was identified during groundwater monitoring of the monitoring wells installed in the bedrock.
- No dissolved phase concentrations of petroleum hydrocarbons above laboratory detection limits were detected in any of the groundwater samples from the bedrock monitoring wells.
- No PCBs were recorded above laboratory detection limits in any of the groundwater samples tested.

2.4.4 Conclusions

The hydrocarbon plume in the groundwater in the Rectifier Yard, the source of which is assumed to be the release of transformer oils following the fire in 2008, is present in shallow groundwater within the variably permeable superficial deposits.

The results of the intrusive investigation indicate that the hydrocarbon contamination has not migrated downwards to the groundwater within the underlying bedrock.

There is also no evidence that the hydrocarbon plume has extended or migrated laterally beyond the boundaries of the Rectifier Yard. However, the distribution of the hydrocarbon contamination in the shallow groundwater compared to the results of Golders previous investigations does indicate that there has been some migration of the plume towards the northwest in the direction of assumed groundwater flow, albeit slowly.

Based on the findings of the current investigation, LKC agree with the controlled waters risk assessment by Golders for the permit surrender in 2013 in that the groundwater hydrocarbon contamination in the Rectifier Yard does not constitute a significant risk to the most sensitive receptor, the Irish Sea.

However, for betterment purposes LKC recommended that remediation under the ALARP principle is undertaken in the shallower groundwater body in the Rectifier Yard.

2.5 Pilot Study

A pilot study was undertaken in December 2016 to trial the proposed remediation techniques in the Rectifier Yard and this included hydraulic testing and chemical treatability trials.

Copies of the full Remediation Pilot Study report (ref: 17.0626, dated May 2017) and Laboratory Bench Scale Chemical Oxidation Study report (ref: A161201, dated March 2017) are presented in Appendix A and B respectively. The key findings are summarised below:

- Depth profiling of the contamination indicates the bulk of the impacts to be present within the groundwater within the more permeable superficial gravel fractions.
- The more gravelly superficial matrices do not typically exhibit high concentrations of sorbed contamination.
- Core samples recovered from the Rectifier Yard suggest areas of lower permeability soils are also present and these display limited soils impact.

- Hydraulic testing in the Rectifier Yard suggests that all areas have a very high primary permeability within the superficial deposits, with a significant radius of influence achieved under pumping.
- The high permeability indicates that a pumped solution as a means of recovering free product and dissolved phase hydrocarbons is considered suitable.
- Chemical oxidation trials have demonstrated that a peroxide based oxidant represents a highly effective means of treating the dissolved phase hydrocarbon impacts in the Rectifier Yard.

3 PROPOSED REMEDIATION WORKS

The proposed remediation and validation works for Escrow site 1 (Rectifier Yard) are outlined in the following Sections.

The identified key contaminants in this area are considered to be hydrocarbons with identified Light Non-Aqueous Phase Liquids (LNAPLs) noted in several locations throughout the available dataset. The objective of these remediation works is to remove all measurable LNAPL and achieve a significant reduction in residual dissolved phase contaminant concentrations within the groundwater under the ALARP principle.

4.1 Remediation

4.1.1 Proposed Treatment Methodology

Following a review of all available investigation data for the Rectifier Yard and the results of the pilot study the following remediation methods are considered to be the most effective to achieve betterment in the Rectifier Yard:

- **Dual Phase Vacuum Extraction (DPVE)** to recover LNAPL and hydrocarbon impacted groundwater.
- **In-Situ Chemical Oxidation (ISCO)** to treat soil sorbed and groundwater borne dissolved phase contamination.

Other methods such as total fluids pumping, downgradient trench recovery and product skimmers were considered, but experience suggests that these will not achieve the remediation goals within a reasonable timeframe (years rather than months to validate).

4.1.2 System Technology – LNAPL Removal

DPVE provides an intensive method of total fluids recovery, which can achieve maximum permissible rates in low and variable permeability soils. The operating principle involves the application of close to absolute vacuum at the interface between the unsaturated and saturated zones. This is achieved using narrow diameter lances, sealed within designated treatment wells connected to a vacuum pump. The vacuum generated at the lance tip, installed at the groundwater interface, subsequently transmits across the capillary fringe to perform the following functions:

- Any LNAPL present would be drawn towards the abstraction lance(s) under the vacuum pressure gradient. This process is enhanced by the horizontal movement of product within the saturated layer, which reduces the influence of surface tension relative to vertical flow situations.
- Groundwater would be drawn towards the lance tip under the vacuum gradient, exposing the capillary fringe and underlying saturated soils. Maximum groundwater abstraction rates using DPVE are generally 50% greater than those achieved by conventional borehole pumps.
- The DPVE technology also facilitates groundwater depression, where required
- The high vapour flow rates generated through the lance tips would recover released soil gases and volatilise any adsorbed volatile contaminants. This would control vapour migration, effectively confining it within the treatment area.

- The circulation of air through the unsaturated zone also increases the biodegradation potential of organic contaminants. This is stimulated by the replacement of hydrocarbon vapours by oxygenated air, thereby encouraging aerobic respiration by any indigenous bacteria.

The following DPVE equipment may be used on the site and the system will have a capacity to vacuum extract approximately 350m³ per hour to reflect the large treatment area:

- 1 soundproofed container to house DPVE plant.
- 1 suction-side steel gas/liquid separation hydrocyclone installed with high level cut-off float switches and valves for transfer pump control.
- 1 vacuum pump, fitted with high temperature cut-outs.
- 1 discharge-side gas/liquid separation steel hydrocyclone c/w ultrasonic high level cut-off float switch, float switches & valves for transfer pump control and high pressure cut-out.
- 1 Centrifugal pump for liquid discharge to oil/water separator.
- 1 Centrifugal pump for water transfer from oil/water separator.
- 2 Granular Activated Carbon vessels for liquid-phase adsorption.
- 1 Granular Activated Carbon vessel for gaseous-phase adsorption.
- 1 Product storage vessel.

Following uplift from the wells via vacuum lances the mixture of liquid and gas is separated via hydrocyclonic knockout pots. The total fluids from the knockout pots are then pumped into an oil/water separator which will remove any phase separated product and allow for silts to settle before being transferred to the GAC units for polishing prior to discharge.

Recovered product would be stored in separate secure barrels or a bunded tank, which would contain overfill protection and be emptied by a suitably licensed waste contractor, in accordance with Duty of Care procedures.

Existing monitoring wells displaying LNAPL will be used as abstraction points, along with additional newly installed abstraction points. It is proposed to install up to an additional ten abstraction wells, installed to the top of the competent schists for this purpose, with spacings and frequency in line with the findings of the Pilot Study.

The extent of the proposed treatment area is indicated on Figure 6.

4.1.3 System Technology Chemical Oxidation

Pilot testing works in the Rectifier Yard have identified a high permeability within the subsurface ensuring that the ground will readily accept injected oxidants and efficient treatment can be achieved with maximum contact between oxidant and contaminant within the groundwater.

Following the removal of measurable product peroxide based chemical oxidation will be used through fixed point injection to generate Fenton's like free-radicals and contaminant oxidation (e.g. hydroxyl radical). In line with the recommendations of the pilot study the treatment zone, as defined on Figure 6, is anticipated to require multiple oxidant applications to achieve the required result. Injections would commence on the outside of the plume and concentrically moved inward to ensure that no contaminant is displaced in an uncontrolled manner without being oxidised. This will prevent any migration of untreated contaminants outside of the treatment area.

Oxidant injection will be undertaken using fixed well points, which would comprise newly installed wide diameter, high permeability installations, with robust seals, through the permeable strata overlying the competent schists. It is envisaged that a maximum of thirty new boreholes with installations will be required across the treatment area for oxidant injection. Where suitable and acceptable, some existing wells may be utilised as injection points.

Oxidants will be stored and mixed onsite, in controlled, fenced and bunded areas. At this stage, it is assumed a water and electric supply will be available onsite for this purpose. Oxidant volumes will be injected into the designated wells in suitable volumes to ensure treatment of the entire target pore space in line with the pilot study recommendations.

The oxidant will react very rapidly upon contact with contaminant in the subsurface and would be expected to have become exhausted within a period of seven days post injection. It is expected that to treat all target wells with a single application would take approximately 1-2 weeks (subject to water supply). Repeat injections will be undertaken concurrently to achieve rapid reductions in contaminant concentrations.

4.1.4 Operation Timeframe and Validation

Installation and commissioning of the DPVE system on site is anticipated to take four weeks inclusive of well installation.

It is anticipated that the DPVE system, once fully commissioned would operate for a period of up to 6 months although it is considered likely based on the results of the pilot study that the system may run for a much shorter period.

The ISCO operation would be undertaken over a period of up to two months with validation thereafter. This does not include drilling time, which could be conducted during DPVE works. Chemical oxidation works should not be conducted whilst LNAPL removal works are ongoing.

Validation monitoring following cessation of works would be for a twelve month period with monthly intervals at well locations to be agreed with the regulators. The validation regime will include measuring of phase separated product using an oil/water interface probe and checked with a product bailer and groundwater analysis for contaminants of concern.

4.1.5 Operational Monitoring and Reporting

Once commissioned, the DPVE system will be monitored weekly for the first month to optimise system performance and fortnightly thereafter. A monthly update report will be issued to all stakeholders detailing system progress with monthly laboratory data and product thicknesses, or chemicals oxidation progress, where relevant.

Monitoring will include groundwater sampling and NAPL thickness dips from across the treatment areas to monitoring ongoing performance of the programme as suitable intervals. Additionally, further monitoring may be undertaken as required by the Environmental Permit as detailed below.

4.1.6 Licensing

It is considered that an environmental permit will be required to undertake these works.

A temporary trade effluent discharge licence may also be required during DPVE works, if existing agreements in place at the site cannot be used for the remediation works.

As it is anticipated that the DPVE treatment will take less than 12 months, the abstraction of water should fall outside the licensing regime as it is anticipated the volume will be 20m^3 per day.

4.1.7 Treatment Compound

A treatment compound measuring approximately 20 metres by 20 metres will be required for the DPVE system and any associated welfare. The location of the compound should be agreed with Orthios Eco Parks and will depend on any other operations occurring on the site at the time of the remediation. All vessels used in the remediation works will be fully bunded.

ISCO treatment plant would need to be present during the injection phase only and would occupy a similar footprint to the above.

All compounds will need to be accessible by HIAB mounted low loader trucks for position and removal of plant.

4.1.8 Waste Streams

Waste management operations will be limited to the physical and chemical treatment of contaminated soil and groundwater.

The waste streams generated by the remedial methods proposed are identified as:

- Contaminated groundwater.
- GAC impacted with contaminants.
- Treated wastewater.
- Treated soil vapour.
- NAPL collected in the product storage tank.
- Consumables.

The on-site waste treatment system comprises the following plant.

- Granular activated carbon (GAC) units.
- NAPL/water separators and product storage tank.

During and following treatment, gaseous phase waste will be vented to atmosphere (via GAC filtration if necessary); treated groundwater will be disposed of to sewer. Free product (LNAPL) and spent GAC would be removed off-site for disposal. The disposal would be fully compliant with current Duty of Care requirements.

Granular Activated Carbon Unit

It is anticipated that a minimum of two Granular Activated Carbon vessels would be required for the treatment process.

A liquid phase GAC unit should be used to treat the abstracted groundwater and a gaseous phase GAC unit would be installed and be separate from the other treated waste systems. After treatment, soil vapours will be vented through a stack. A PID shall be used to measure the concentration of contaminants and monitoring of the soil vapour to monitor for breakthrough.

Oil/Water Separator

The separator comprises one tank complete with baffles, weir, product skimmer, high-level cut-off float switch and float switch for transfer pump control. LNAPL floats to form a layer on the surface where it is subsequently skimmed to a product storage tank. The product storage tank/ barrels will be emptied and tankered away for disposal when necessary under duty of care requirements.

4.1.9 Potable Water Risk Assessment

The Rectifier Yard, although one of the areas covered by the escrow agreement, was within a boundary subject to a planning application for the development of a Renewable Energy Plant. Therefore, potential risks to human health were also considered as part of the assessment and a potential risk to potable water supplies was identified in the Rectifier Yard. However, it should be noted that no new development is proposed in this area and it is unlikely that new potable water pipelines will be laid.

If any new potable water pipes are laid in the area, once the route of any pipes are known, Welsh Water should be consulted and a Welsh Water Potable Water Risk Assessment completed to determine the level of protection required for new supplies.

As a precaution, existing potable water supplies in the Rectifier Yard area should be sampled and tested for the following contaminants:

- Arsenic, cadmium, chromium (total and hexavalent), copper, lead, mercury, nickel, selenium, vanadium, zinc, aluminium, fluoride, pH, banded petroleum hydrocarbons (TPHCWG), BTEX, MTBE, cyanide, phenols, speciated PAH, hardness, total organic carbon (TOC) and PCBs (7 Congeners and WHO12).

The samples should be taken from potable water supplies in the control building adjacent to the Rectifier Yard and before sampling the taps should be allowed to run for an appropriate time to ensure that the sample is representative of potable water from within below ground pipes.

Results of the precautionary existing potable water testing will be compared to UK Drinking Water Standards (UKDWS). If any unacceptable levels of contamination are identified in the existing potable water supplies, further risk assessment and/or remediation recommendations will be provided.

It should be noted that the results and any further assessment relating to potable waters risk in the Rectifier Yard will be reported in the final Site Completion Report for the planning boundary site rather than the Verification Report for the escrow site remediation.

4 VALIDATION

Remediation works undertaken on site will need to be validated to ensure the objectives have been met and that betterment has been achieved under the ALARP principle. Validation of any remediation should be undertaken by a competent consultant and should be reported in the Verification Report or Site Completion Report.

5.1.1 Validation of Groundwater Remediation

The remediation works in the Rectifier Yard will aim to achieve betterment in accordance with the ALARP principle. The validation of the proposed remediation works are detailed below.

Free Product Recovery

Free product recovery will aim to reduce free phase mass and to achieve asymptotic mass recovery conditions. In the context of demonstrated mass recovery rates it is the point at which the free product recovery curve declines to such a reduced level that will probably be maintained at this level for a considerable length of time without further significant reduction.

This level would be considered to represent a residual concentration that the gross contamination within the source zone would not be cost effective to continue treating and the majority of the mass amenable to extraction would already have been removed by this point.

The quantity of free product recovered will be recorded continuously during the remediation works and recovery will only cease once asymptotic conditions are considered to have been met.

Validation Groundwater Monitoring

Validation monitoring following cessation of works would be for a twelve month period at monthly intervals at existing monitoring well locations within the Rectifier Yard. The selected remedial techniques were selected to contain remedial works within this area and any impact to groundwater outside this area is considered to be negligible.

Post remediation groundwater analysis will also be used to demonstrate betterment. The groundwater monitoring regime will include measuring of phase separated product using an oil/water interface probe and product balers.

Post remediation groundwater samples will be taken a minimum of 14 days after development of the wells. Prior to sampling of groundwater, monitoring wells will be purged to allow a representative groundwater sample to be taken. Continuous measurement of parameters such as electrical conductivity (EC), pH, temperature and dissolved oxygen will be undertaken during purging to demonstrate equilibrium conditions (as a minimum EC will be tested as per the guidance). Samples will be taken once these parameters have stabilised.

All post remediation groundwater samples will be tested for the following suite of contaminants:

- Banded petroleum hydrocarbons (TPHCWG), BTEX and MTBE.

The proposed groundwater remediation and validation in the Rectifier Yard will be detailed in a separate Verification Report for approval once betterment is considered to have been achieved.

5.1.2 Potable Water Pipes

Copies of all correspondence with Welsh Water should be retained and copies included within the final Site Completion Report.

Additional risk assessment will also be undertaken following the testing of existing potable water supplies in the Rectifier Yard and this will also be provided in the Site Completion Report for the Renewable Energy Plant planning boundary.

5 VERIFICATION AND COMPLETION REPORTS

A Verification Report will be provided once the remediation goal of betterment to the ALARP principle has been met in the Rectifier Yard. This will include:

- The summary of groundwater hydrocarbon plume delineation work.
- Results of the pilot studies of proposed remediation techniques.
- Description of groundwater remediation works in the Rectifier Yard.
- Volumes of free product recovered from treatment area.
- Details of chemical oxidant injection including volumes and types of oxidant used.
- Results of groundwater validation including dipping records and certificates of analysis.
- Potable water risk assessment.

The aim of the Verification Report will be to demonstrate to escrow account stakeholders that the required remediation works in the Rectifier Yard have been undertaken as per the agreed strategy.

In addition, as the Rectifier Yard is within the planning boundary for the proposed Renewable Energy Plant development, the Verification Report will also be used as evidence, along with an overall Site Completion Report, to prove to the Local Authority that the site has been suitably remediated to the extent that construction works may commence. This is in accordance with the National Planning Policy Framework (NPPF)¹ as below:

- The site is suitable for its new use taking account of ground conditions and land instability, including from natural hazards or former activities such as mining, pollution arising from previous uses and any proposals for mitigation including land remediation or impacts on the natural environment arising from that remediation.
- After remediation, as a minimum, land should not be capable of being determined as contaminated land under Part IIA of the Environmental Protection Act 1990.
- Adequate site investigation information, prepared by a competent person, is presented.

The submission of these reports to the relevant Regulators will also allow appropriate planning conditions to be discharged.

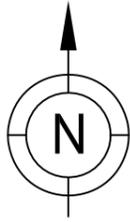
¹ DCL (2012). "National Planning Policy Framework." Department of Communities and Local Government. March 2012.

FIGURES



Figure 1: Site Location Plan, Anglesey Aluminium, Holyhead

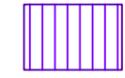
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Holy Island
(Ynys Gybi)



KEY

 Escrow Sites

Sampling Locations and features annotated by LK Consult Ltd are approximate and are based upon observed measurements unless otherwise stated. Do not scale from this drawing and work from marked dimensions only. All dimensions and features should be confirmed on site by the Contractor. Where this drawing includes information provided to LK Consult Ltd by others, LK Consult Ltd gives no warranty, representation or assurance as to the accuracy of such information.



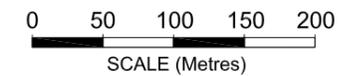
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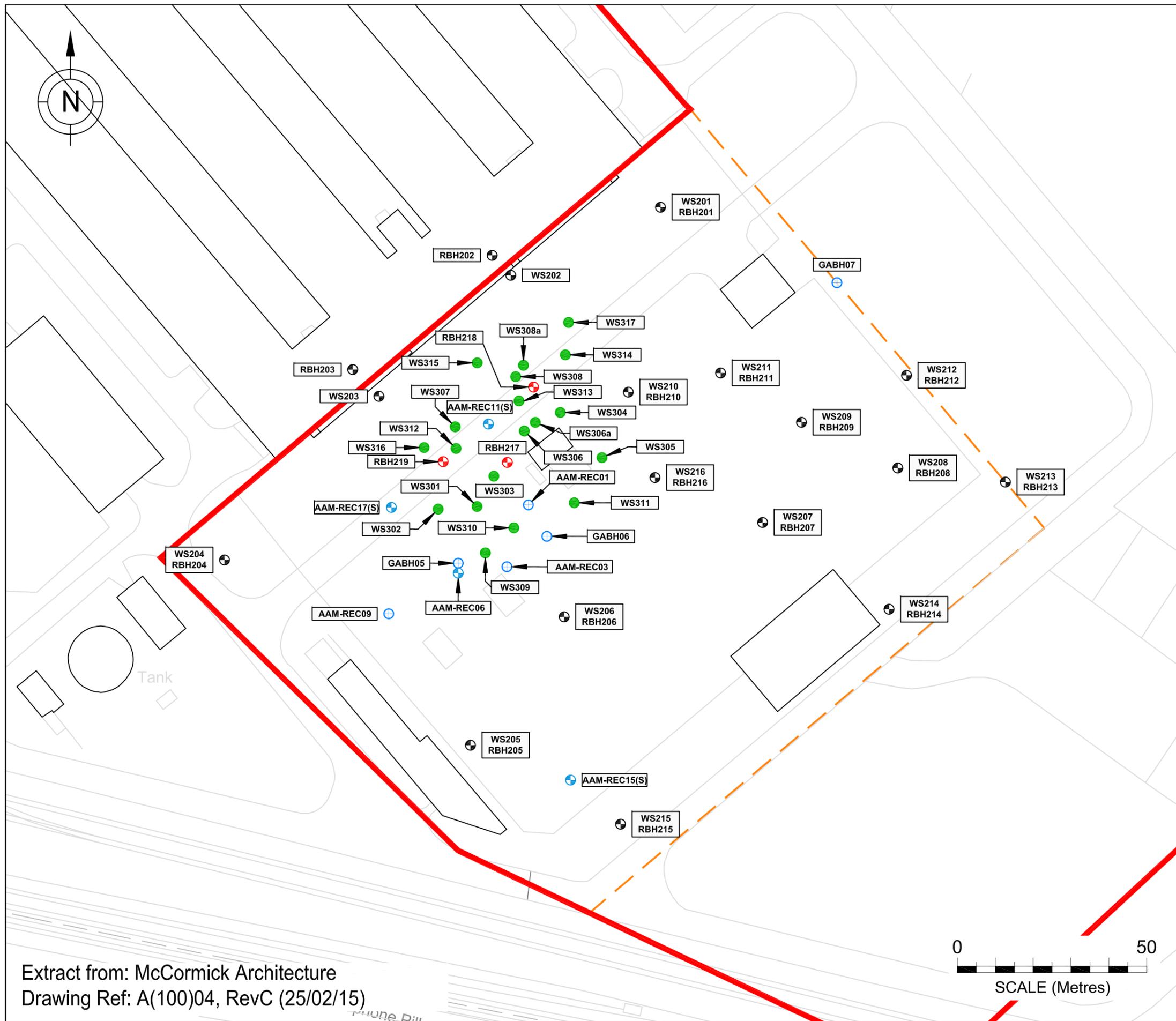
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AC	PQ	May 2016	

Extract from: McCormick Architecture
Drawing Ref: A(100)04, RevC (25/02/15)





KEY

	Site Boundary
	Rectifier Yard Extents
	Dual Installation (Shallow & Deep)
	Installation (Deep)
	Existing Dual Installation (Shallow & Deep)
	Existing Monitoring Well (Shallow)
	Delineation Window Sample Borehole

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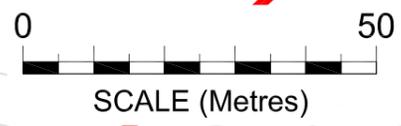
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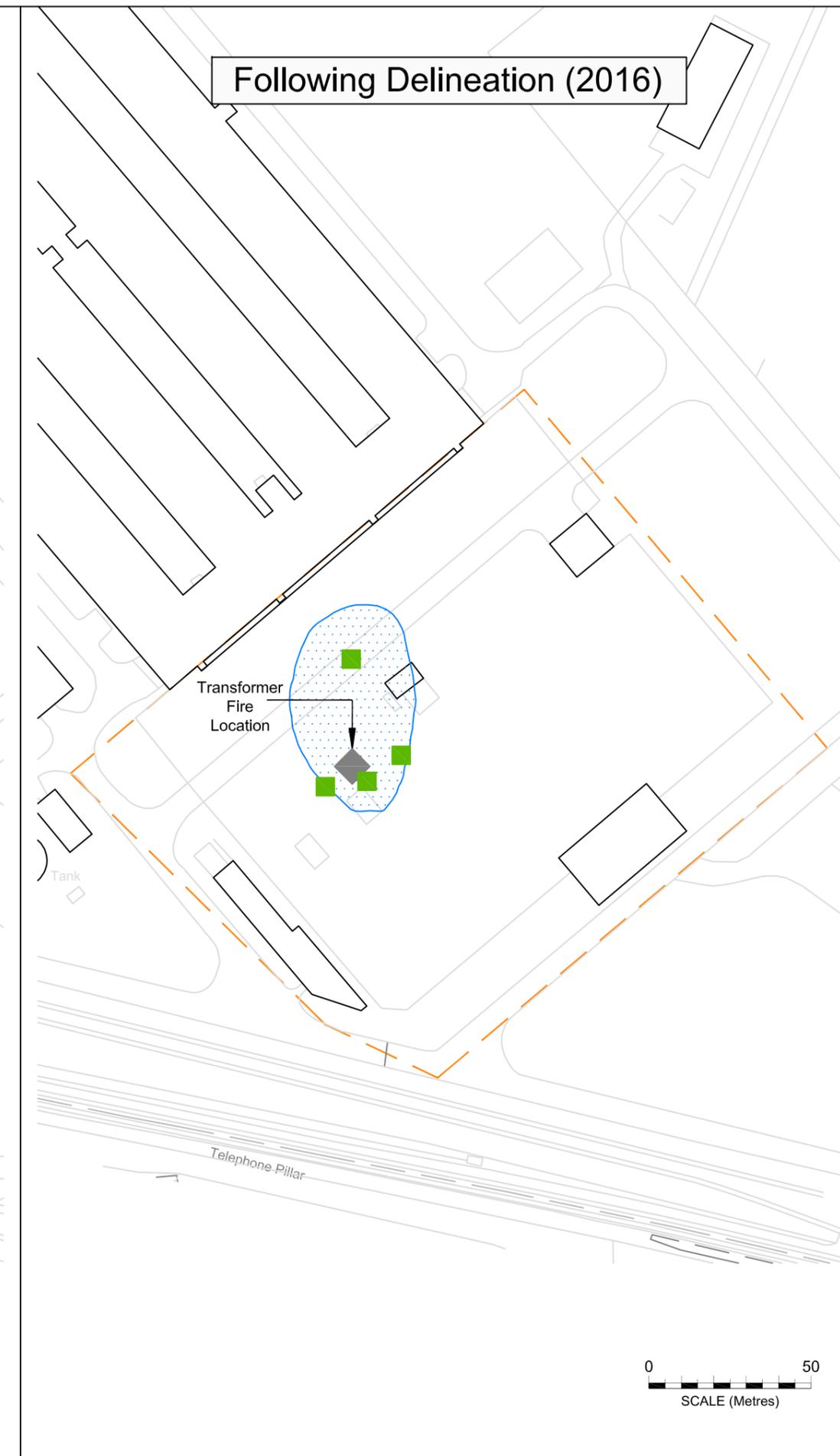
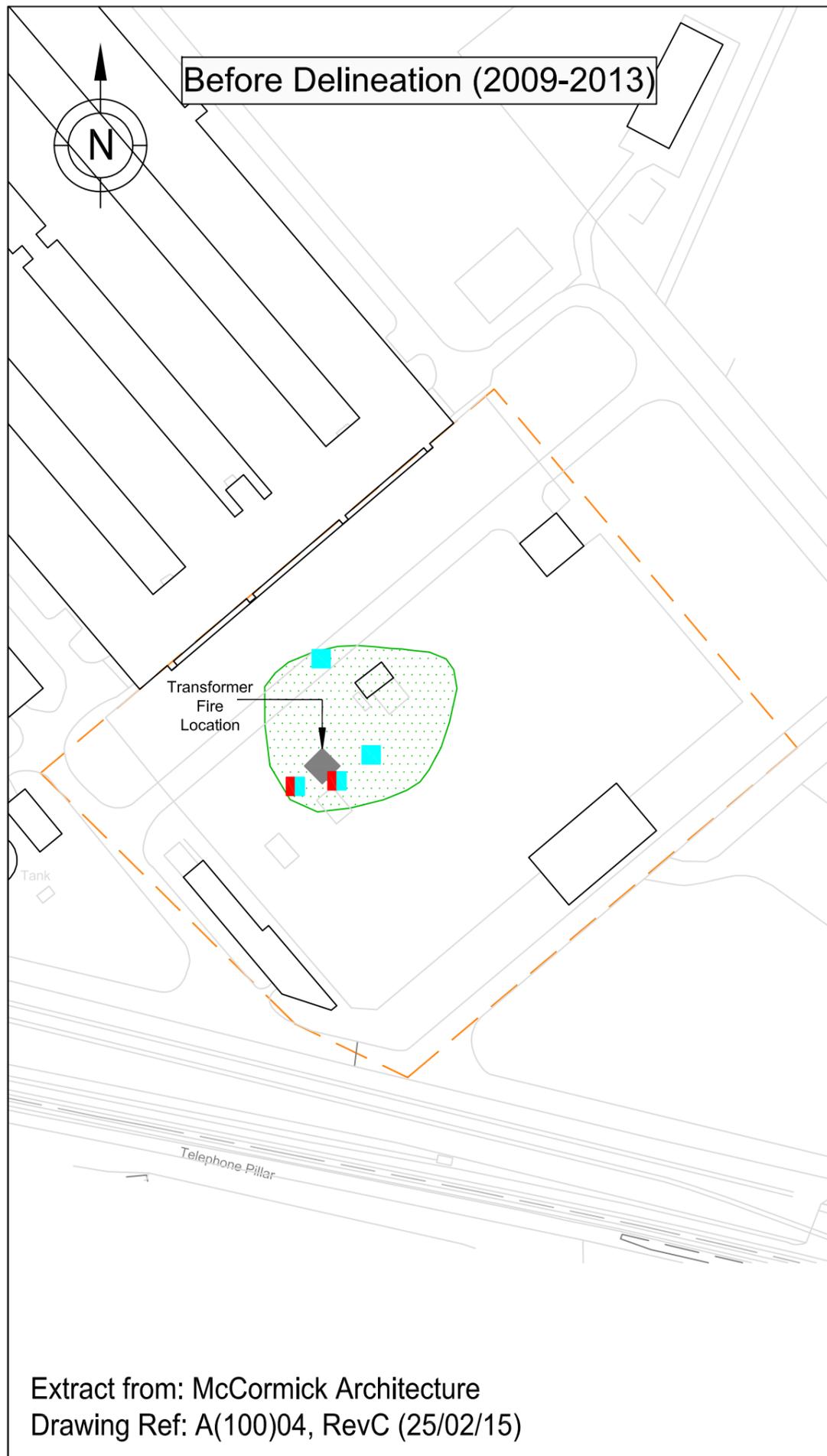
Site: **Anglesey Aluminium, Holyhead**

Title: **Sampling Location Plan**

Job No.: LKC 14 1181	Scale (See Scale Bar): 1:1000 @ A3	Figure: 3	Revision:
Drawn By: AC	Checked By: AF	Drawn: May 2016	

Extract from: McCormick Architecture
Drawing Ref: A(100)04, RevC (25/02/15)





KEY

- Rectifier Yard Extents
- Estimated Plume Extent (Before Delineation)
- Plume Extent (After Delineation)
- Free Product (2009)
- Free Product (2013)
- Free Product (2016)
- Transformer Fire Location

Sampling Locations and features annotated by LK Consult Ltd are approximate and are based upon observed measurements unless otherwise stated. Do not scale from this drawing and work from marked dimensions only. All dimensions and features should be confirmed on site by the Contractor. Where this drawing includes information provided to LK Consult Ltd by others, LK Consult Ltd gives no warranty, representation or assurance as to the accuracy of such information.



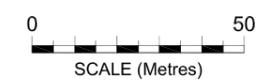
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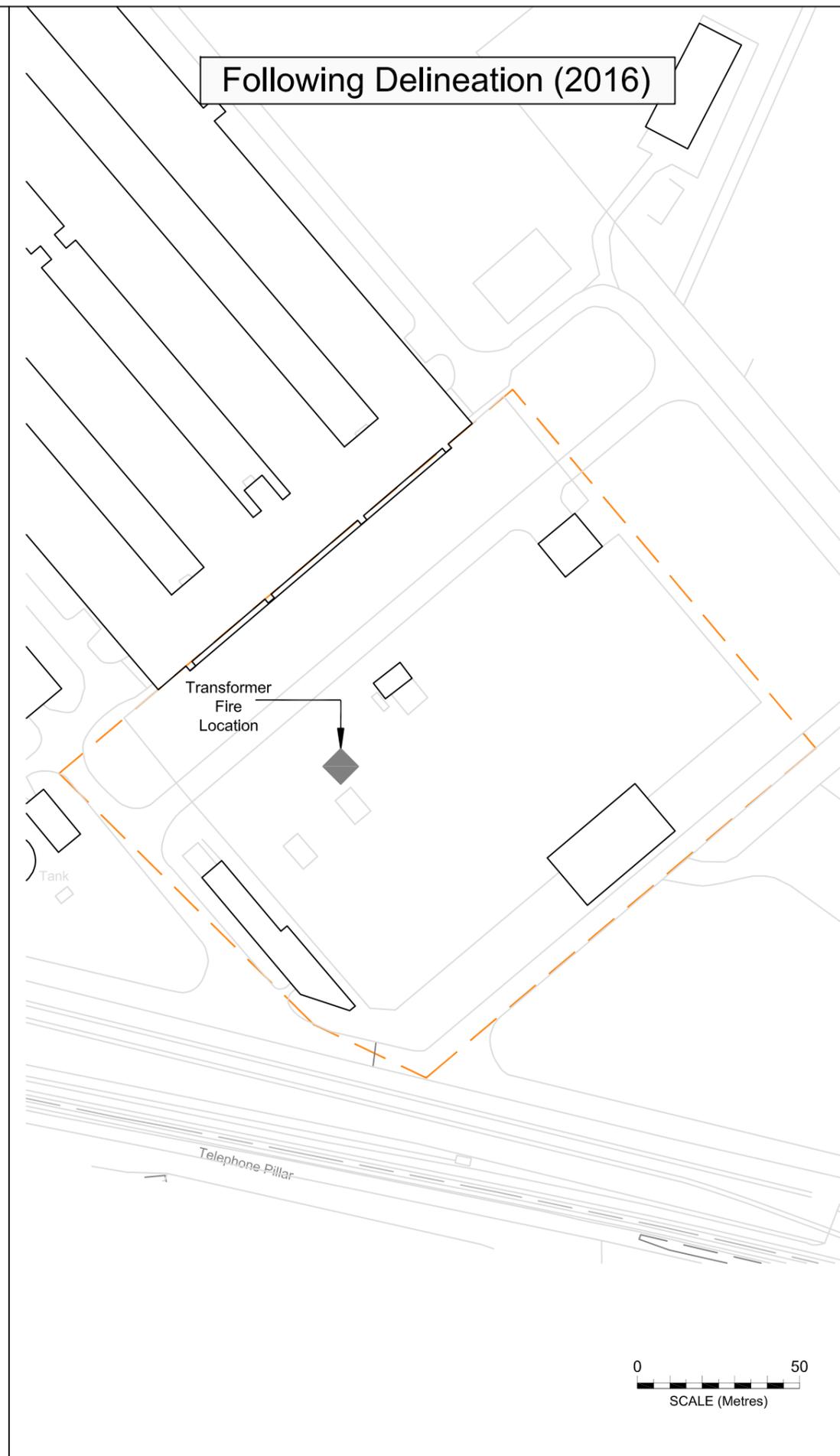
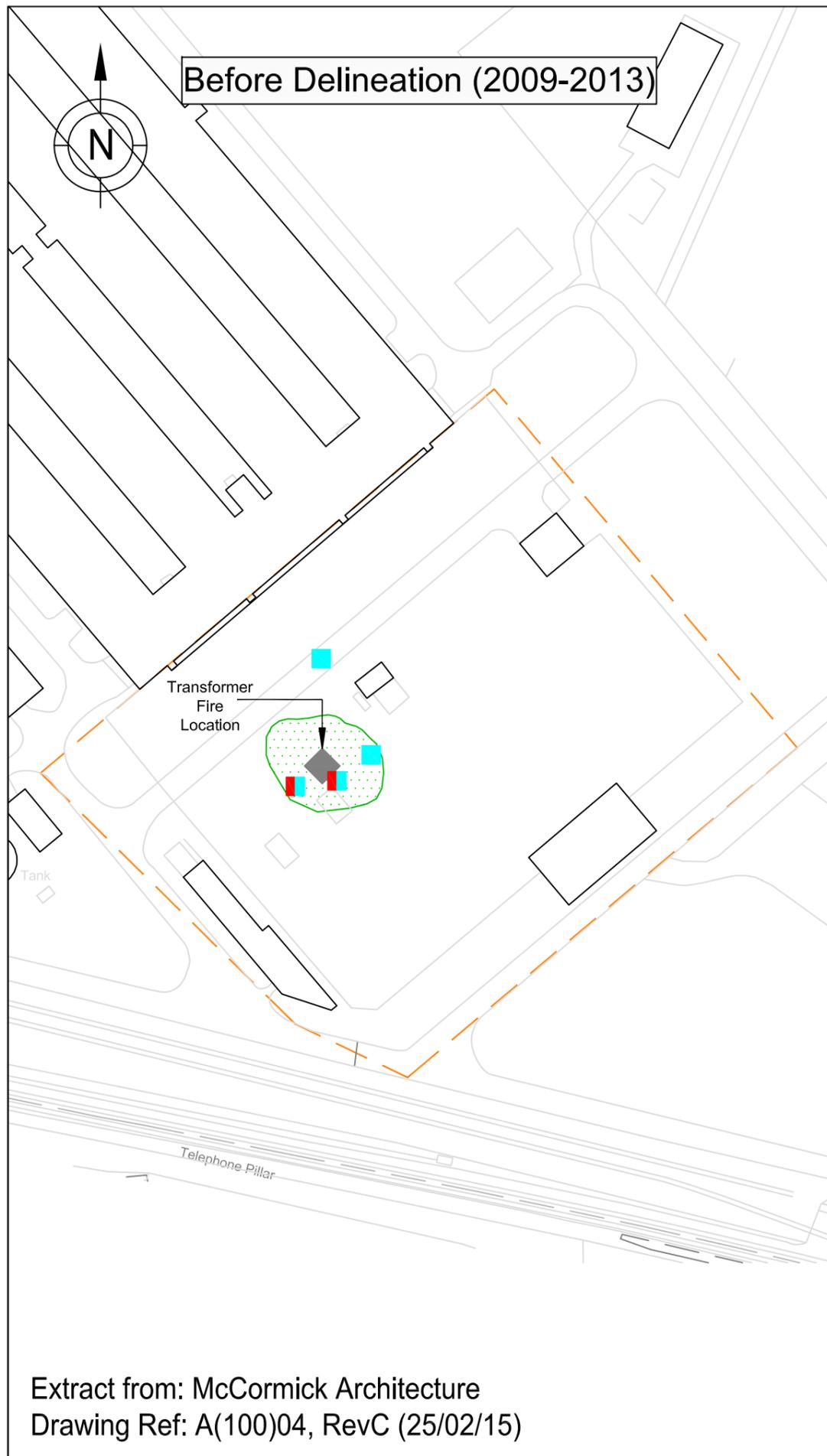
Site: **Anglesey Aluminium, Holyhead**

Title: **Hydrocarbon Distribution in Superficial Groundwater (Rectifier Yard)**

Job No.: LKC 14 1181	Scale (See Scale Bar): See Scale Bar	Figure: 4	Revision:
Drawn By: AC	Checked By: CH	Drawn: Jun 2017	

Extract from: McCormick Architecture
Drawing Ref: A(100)04, RevC (25/02/15)





- KEY**
-  Rectifier Yard Extents
 -  Estimated Plume Extent (Before Delineation)
 -  Free Product (2009)
 -  Free Product (2013)
 -  Transformer Fire Location

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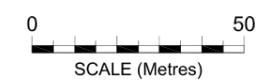


Client: **Orthios**

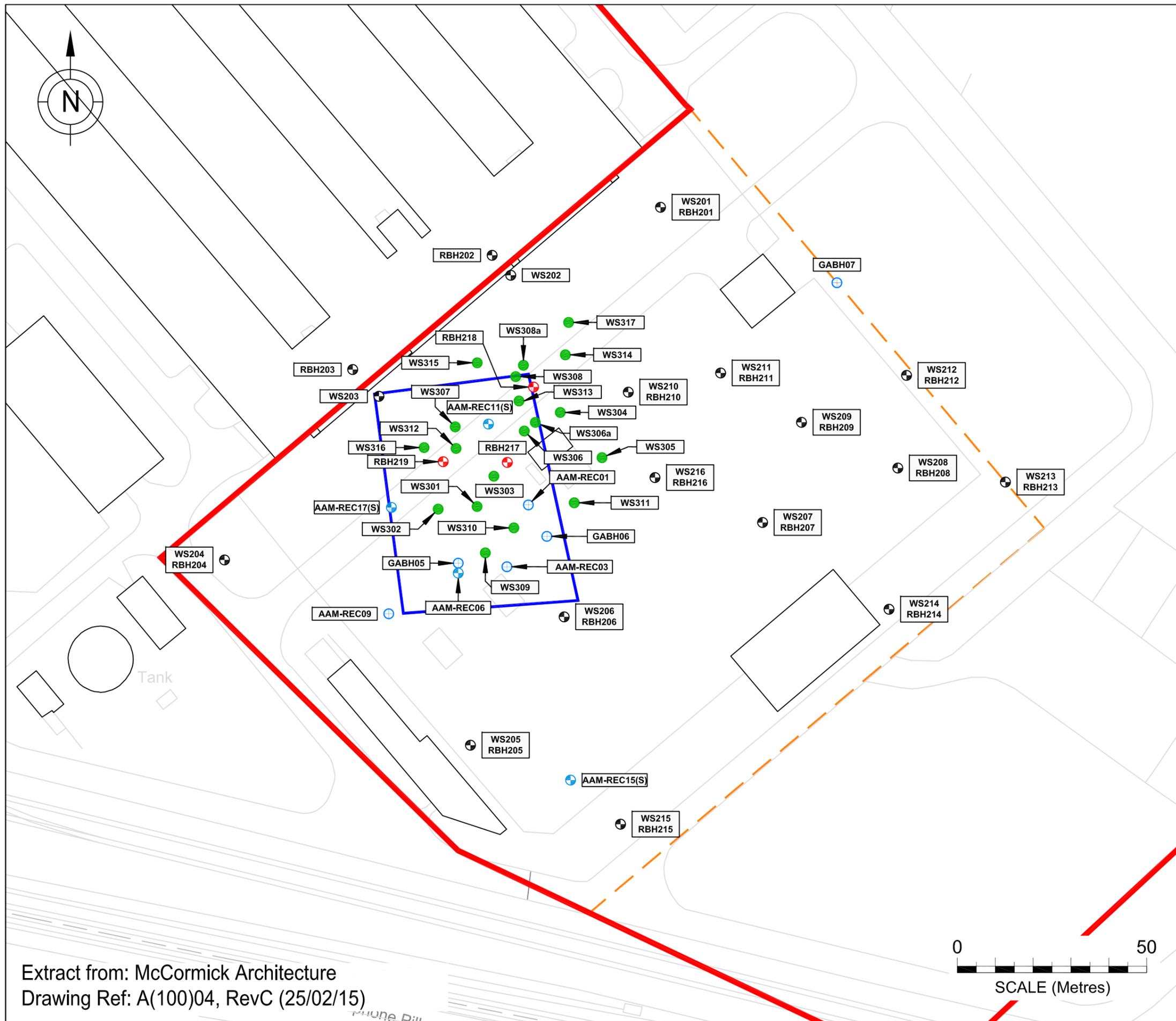
Site: **Anglesey Aluminium, Holyhead**

Title: **Hydrocarbon Distribution in Bedrock (Rectifier Yard)**

Job No.: LKC 14 1181	Scale (See Scale Bar): See Scale Bar	Figure: 6	Revision:
Drawn By: AC	Checked By: CH	Drawn: Jun 2017	



Extract from: McCormick Architecture
Drawing Ref: A(100)04, RevC (25/02/15)



KEY

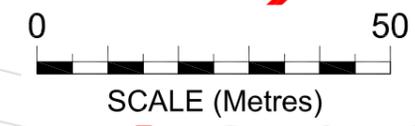
- Site Boundary
- Rectifier Yard Extents
- Dual Installation (Shallow & Deep)
- Installation (Deep)
- Existing Dual Installation (Shallow & Deep)
- Existing Monitoring Well (Shallow)
- Delineation Window Sample Borehole
- Extent of ISCO Area

Sampling Locations and features annotated by LK Consult Ltd are approximate and are based upon observed measurements unless otherwise stated. Do not scale from this drawing and work from marked dimensions only. All dimensions and features should be confirmed on site by the Contractor. Where this drawing includes information provided to LK Consult Ltd by others, LK Consult Ltd gives no warranty, representation or assurance as to the accuracy of such information.



Client:				Orthios			
Site:				Anglesey Aluminium, Holyhead			
Title:				Proposed Treatment Area			
Job No.:	LKC 14 1181	Scale (See Scale Bar):	1:1000 @ A3	Figure:	6	Revision:	
Drawn By:	AC	Checked By:	CH	Drawn:	Jun 2017		

Extract from: McCormick Architecture
 Drawing Ref: A(100)04, RevC (25/02/15)



APPENDIX A

REMEDIATION PILOT STUDY REPORT



**REMEDICATION
PILOT STUDY**

**Escrow Areas:
RECTIFIER YARD
Anglesey Aluminium
Penrhos Works
Holyhead**

For

LK Group

May 2017

17/0626

Geo² Remediation Limited

11, The Mending Rooms, Sunny Bank Mills, Town Street, Farsley, Leeds, LS28 5UJ
Tel 0113 257 5397

LK Group

Remediation Pilot Study

Escrow Areas:

RECTIFIER YARD

Anglesey Aluminium

Penrhos Works

Holyhead

April 2017

Report ref no. 17/0626

Contents

- 1.0 Introduction**
- 2.0 Known Contaminant Impacts**
- 3.0 Depth Profiling**
- 4.0 Pump Testing**
 - 4.1 Slug Tests
 - 4.2 Falling Head Test
 - 4.3 Step Test
 - 4.4 Summary of Hydraulic Conditions
- 5.0 Vacuum Testing**
- 6.0 Treatability Trial**
 - 6.1 Model Development
 - 6.2 Technologies Assessed
 - 6.3 Treatment Results
- 7.0 Conclusions**
- 8.0 Limitations**
- 9.0 References**

- Appendix A Figures**
- Appendix B Borehole Logs**
- Appendix C Photo Appendix**
- Appendix D Hydraulic Testing**
- Appendix E Treatability Trial**

LK Group

Remediation Pilot Study

Escrow Areas:

RECTIFIER YARD

Anglesey Aluminium

Penrhos Works

Holyhead

May 2017

Report ref no. 17/0626

1.0 Introduction

Geo² Remediation Limited was commissioned by the LK Group to conduct a Remediation Pilot Study of identified contaminated areas that form portion of the Anglesey Aluminium Site. These works targeted three areas, each reported separately. This report details pilot works undertaken in the Rectifier Yard area.

The Anglesey Aluminium site is located on the east side of Holyhead island, as shown on Figure 1 and 2 in Appendix A. The property is currently derelict and undergoing demolition for future reuse as part of Orthios Eco Park.

This testing has been undertaken to aid design and implementation of a suitable remediation programme to ensure maximum environmental improvement can be achieved at this site. The objectives of the remediation are understood to be removal of all Light Non-Aqueous Phase Liquid (LNAPL) and also to undertake remedial works that will achieve maximum betterment following the 'as low as reasonable practicable (ALARP)' principle.

Initial feasibility scoping suggested that the most suitable methods of remediation would include, physical pumped treatment to recover LNAPL coupled with chemical injection as a means of treating the dissolved phase and soil-sorbed impacts.

In order to permit an effective treatment design, this Remediation Pilot Study comprises the following stages:

- Additional intrusive investigation;
- Contaminants Depth Profiling;
- Hydraulic Testing;
- Chemical Treatability Trials.

2.0. Known Contamination Impacts

Significant earlier investigation addressing various portions of the wider aluminium site have been undertaken since 1994 by a number of contractors, mainly URS and Golder Associates. These reports, summarised by the LK Group in a 'Review of Previous Works' identified three key areas potentially requiring treatment.

Additional information from each of the other areas (the 'Garage' and the 'Compressor House') obtained by the LK Group has been reported separately and was used to aid determination of drilling locations and testing schedules.

The following section provides a brief summary of the known impacts in the Rectifier Yard area. Using this information as a baseline further characterisation works have been undertaken, concurrently with additional investigation works by The LK Group, in line with Escrow Sites: Scope of Works document 20.05.2016.

The Rectifier Yard is located in the south east of the site and currently predominantly occupied by a live electric sub-station.

Ground conditions comprise clayey sands and gravels or reworked clays, with the gravels principally comprising weathered mica schists. The underlying deposits comprise competent mica schist deposits between 1.5-4.5mbgl. Deeper rotary drilling demonstrated these deposits to extend to in excess of 15.00mbgl.

Contamination in this area is understood to stem from a fire in 2007 resulting in a transformer oil spill (non-PCB containing). Over the years since this release, the impact has formed a plume within the superficial deposits and perched groundwater, understood to be perched above the competent schists. The identified impact was observed as a plume of LNAPL up to 0.6m in thickness although most recent sampling (2016) only identified LNAPL in one location (AAM-REC 11S). Additionally, a widespread dissolved phase hydrocarbon plume was observed as shown on Figure 4.

It is understood that the underlying schists are not considered to be impacted, earlier evidence to the contrary are suggested by the LK Group to be due to cross contamination.

3.0 Depth Profiling

To characterise the distribution of the contaminant impact vertically within the soils matrix, cores of soil, recovered from the target horizon using dynamic sampling techniques, were sealed and rapidly frozen.

Freezing of cores allows for the preservation of the vadose zone and phreatic zone within the soil structure, which may then later be targeted with forensic scale sampling and analysis. Sampling undertaken subsequently under laboratory conditions allows for recovery of discrete samples collected at frequencies of up to every 100mm. Using this technique ensures that the location of the contaminant impact can be targeted accurately ensuring that any proposed remediation will exactly target the contaminated horizon/s (rather than, for example, simply targeting the groundwater or most permeable horizon).

All samples were submitted for analysis for speciated hydrocarbons (TPH-CWG): the major contaminants of concern. All samples were analysed at a suitably accredited laboratory and full laboratory certification is appended to this report.

Information from earlier works by The LK Group allowed the most contaminated horizons to be targeted for preservation, effectively screening out the less contaminated areas.

Sampling analysis has been plotted onto interactive depth profiling logs appended to this report as excel spreadsheets. Complete borehole logs for locations drilled by Geo² are included in Appendix B.

All logging has been undertaken in line with best practice guidance in BS 5930:2015.

A total of six boreholes (WS316-WS321) were drilled across the area, as shown in Figure 4, in Appendix A. All these locations were targeted across the area considered to be most contaminated as a result of earlier investigation.

Drilling recovered 1m long cores for subsequent laboratory analysis from each of the six boreholes. After screening the quality of recovery, the core's geology is recorded and is summarised below on Table 1. Those shaded in grey were not deemed suitable for detailed analysis.

Location	Depth (m)	Geology
W216	2.0-3.0	Silty GRAVELS.
WS219	1.0-1.5	GRAVELS.
WS220	2.0-3.0	Interface between SAND and underlying SILTS, predominantly water saturated.
WS317	2.0-3.0	Interface between clayey GRAVEL and silty SAND (becoming wet).
WS318	2.0-3.0	SILT deposits.
WS320	2.5-3.5	SILTS over SANDS. Wet.

Table 1. Core Sampling from Rectifier Yard

Analysis of cores, demonstrates that the peak of the identified impact is located between 2.75m and 3.35m within the soil cores at maximum concentrations in excess of 1,000mg/kg (WS316). Peak concentrations in WS220 and WS320 were at approximately 500mg/kg and only trace concentrations of contaminants were encountered within the cores from WS317 and WS318.

These findings reflect the data obtained by The LK Group which indicates pockets of variability within the plume, with the highest concentrations of contamination associated with the more permeable gravel horizons, typically present across the area from circa 2.0mbgl (from surface in some locations). The contamination is not principally located within the soil matrix.

4.0 Pump Testing

A programme of pump testing was scheduled in the Rectifier Area to enable an assessment of the hydraulic setting of the contaminated plumes to be made, as this will provide important consideration in determining radius of influence in a future remediation system and the likely volumes of water to be recovered. Vacuum testing was also conducted to determine air transmissivity through soil pore spaces.

This testing was to comprise, the following:

- Slug tests

In order to determine conductivity, a series of slug tests were undertaken across the area. Slug testing was selected as a rapid means of testing a number of locations and repeatedly, to determine the recharge rate within the aquifer.

- Step Tests

These are undertaken using an electrical pump to abstract from a single pumping borehole at a known speed. Use of pressure transducers in the pumping well and nearby observation points means that the degree of drawdown and radius of influence can be determined. Operation at a set flow rate is conducted until equilibrium is achieved, after which point the rate is increased. This process is repeated at higher flow rates, or steps, until sufficient drawdown is achieved. Data for recovery can be obtained following completion of the step test.

- Falling head tests.

Falling head tests may be undertaken to observe the response of the aquifer to a rapid increase in head level within the target borehole. This provides an alternative means of determining transmissivity.

All testing was undertaken in line with best practice guidance in BS 14686: 2003.

Boreholes selected for pump testing are shown on Figure 4, Appendix A. These were selected from across the plume to ensure good coverage of the impact and to identify regional variation. Boreholes for which soil bore logs were available, and also which were of a suitable depth, were selected to ensure the data collected was representative of the target aquifer.

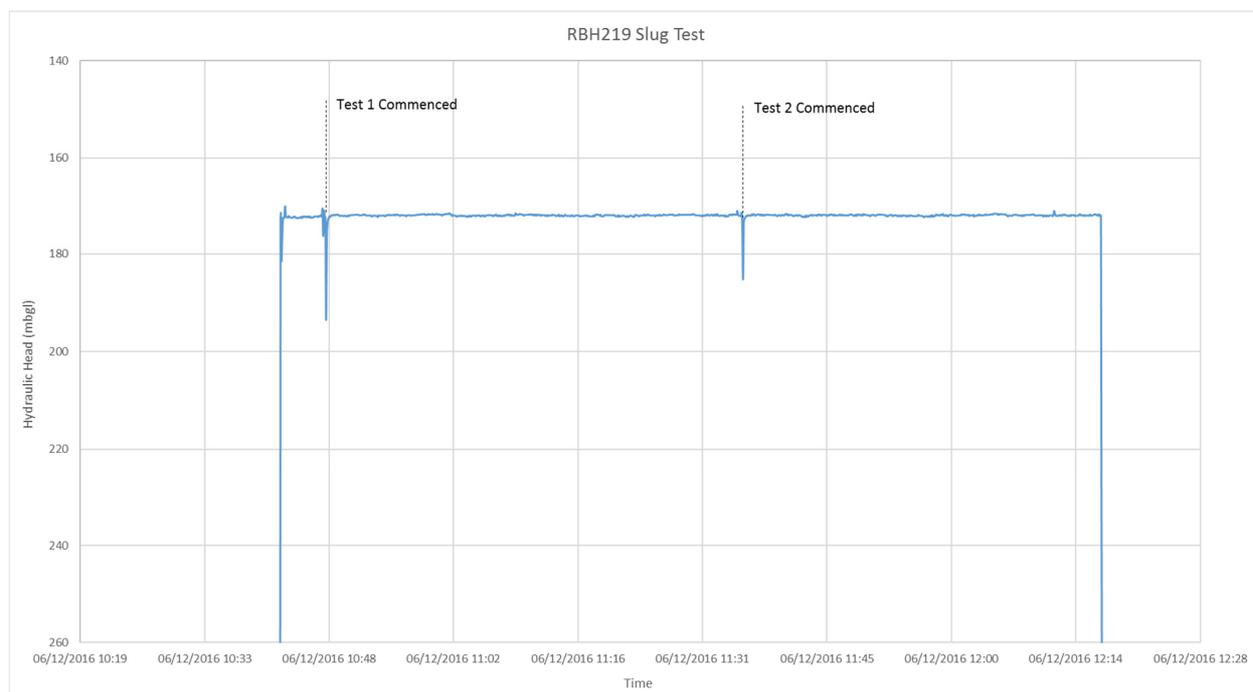
4.1 Slug Tests

A slug test, where a set volume of water is removed from the water column in a well before being allowed to recharge, was conducted on a total of three wells in the Rectifier Yard on 07/12/2016. Changes in hydraulic head were monitored during this test using Shlumberger Water Services pressure transducers. These instruments are set at fixed heights in testing wells and measure barometric pressure relative to a fixed surface pressure monitor and subsequently calculate changes in hydraulic head. Data retrieved yielded response curves, displayed overleaf, that could be then fitted to calculated type curves using Aquifer analysis software.

Using these standard curves, based on known conditions, estimates can be made from inputted primary data of local hydraulic conductivity. Where possible, tests were allowed to run to

completion with multiple tests run on individual wells to increase reliability. In some instances however, recharge was found to be too slow to allow for multiple tests or even for tests to fully run to completion. The following tables and graphs detail the findings of the investigation.

RB219



Graph 1 - Graph displaying changes in hydraulic head in RB219 during performed Slug Tests

Graph 1, above, presents the data for slug testing in RB219. Two test runs can be seen here with rapid rebound. Fitting these data to Bouwer S-type curves in Aquifer yielded values for hydraulic conductivity displayed in Table 2 below. Graphs displaying these type-curve fittings can be found in Appendix D.

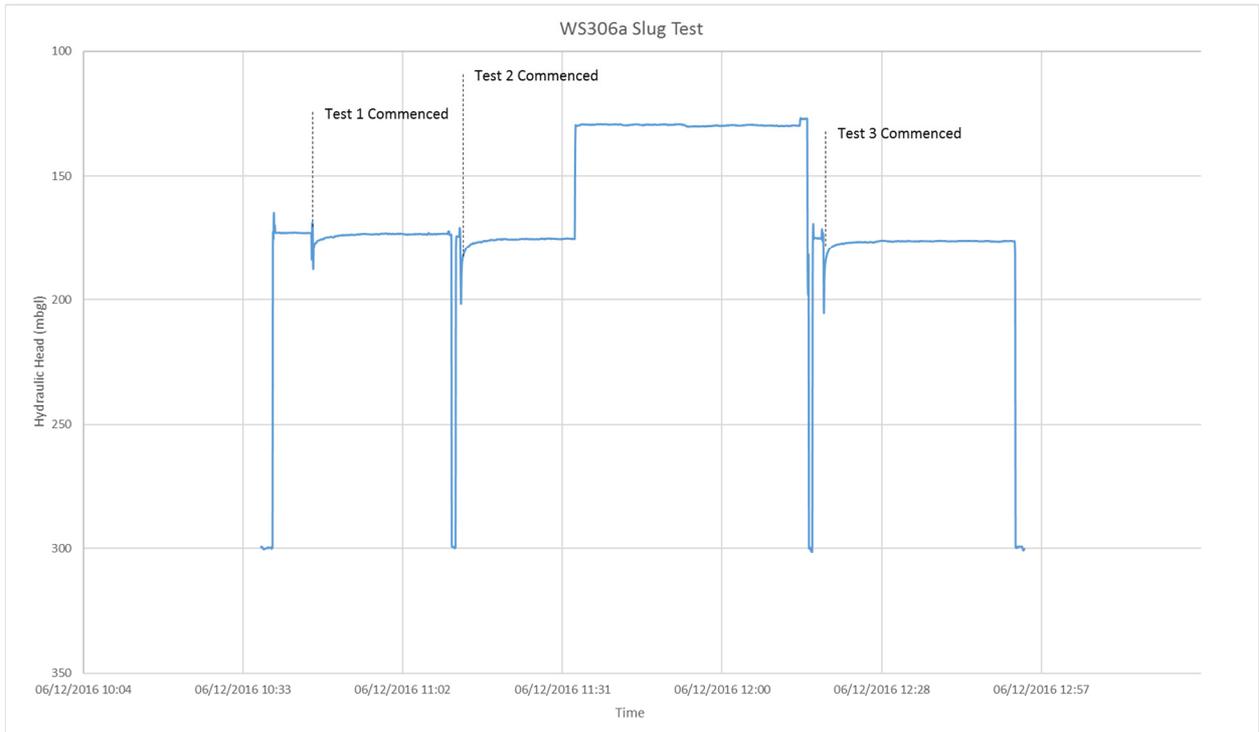
Well	Hydraulic Conductivity RB219		
	Test 1	Test 2	Average
Hydraulic Conductivity (m/d)	23.085	19.458	20.618
Initial Displacement (m)	0.0829	0.0305	0.0567

Table 2 - Table detailing calculated hydraulic conductivity and initial displacement calculated from data obtained from Slug Tests conducted on RB219

The average hydraulic conductivity here was found to be 20.5m^{-day}. This well was found to have 10m of water head prior to test commencement.



WS306a



Graph 2 - Graph displaying changes in hydraulic head in WS306a during performed Slug Tests

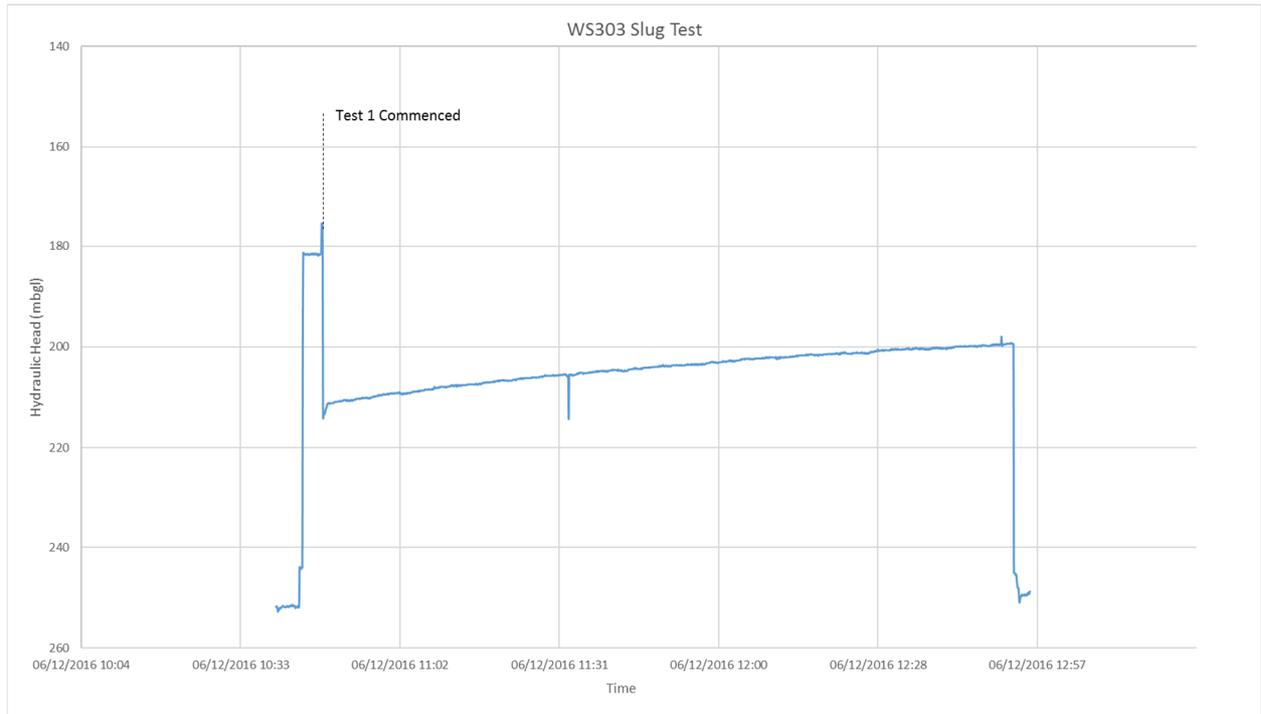
Graph 2, above, presents the data for the slug testing in WS306a. Three test runs can be seen here with rapid rebound. Fitting these data to Bouwer S-type curves in Aquifer yielded values for hydraulic conductivity displayed in Table 3 below. Graphs displaying these type-curve fittings can be found in Appendix D.

Well	Hydraulic Conductivity WS306a			
	Test 1	Test 2	Test 3	Average
Hydraulic Conductivity (m/d)	1.508	3.289	3.999	2.932
Initial Displacement (m)	0.046	0.012	0.147	0.683

Table 3 - Table detailing calculated hydraulic conductivity and initial displacement calculated from data obtained from Slug Tests conducted on WS306a

The average hydraulic conductivity here was found to be 2.9m^{-day}. This well was found to have 3m of water head prior to test commencement.

WS303



Graph 3 - Graph displaying changes in hydraulic head in WS303 during performed Slug Tests

Graph 3, above, presents the data for the slug testing in WS303. A single test run can be seen here with rapid rebound. Fitting these data to Bouwer S-type curves in Aquifer yielded values for hydraulic conductivity displayed in Table 4, below. Graphs displaying these type-curve fittings can be found in Appendix D.

Well	Hydraulic Conductivity WS303
Hydraulic Conductivity (m/d)	0.04
Initial Displacement (m)	1.5

Table 4 - Table detailing calculated hydraulic conductivity and initial displacement calculated from data obtained from Slug Tests conducted on WS303

The average hydraulic conductivity here was found to be $0.04\text{m}^{-\text{day}}$. This well was found to have 1.5m of water head prior to test commencement.

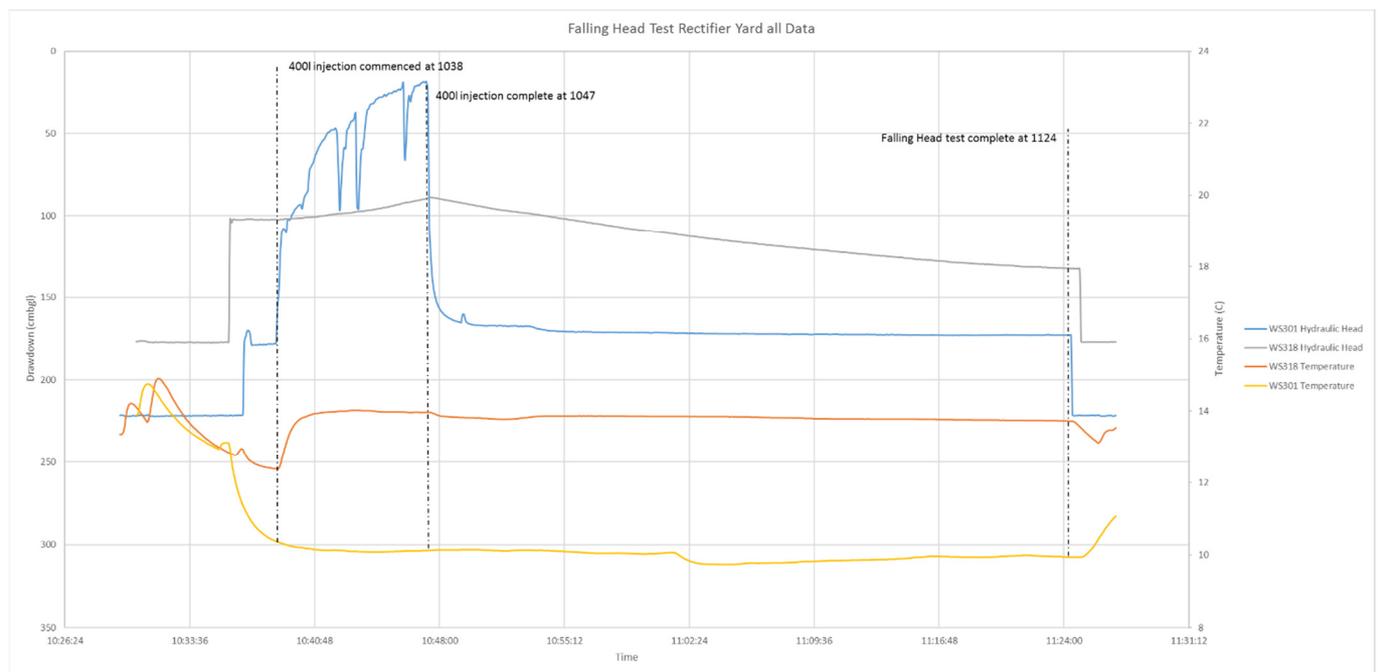
4.2 Falling Head Test

A falling head test was conducted in the Rectifier Yard area. This test consisted of injecting 400 litres of water into a WS301 at approximately $46\text{ l}^{-\text{min}}$, taking approximately 10 minutes, before allowing the hydraulic head to equilibrate to its previous reading.

Changes in hydraulic head pressure and temperature were monitored during this test using Shlumberger Water Services pressure transducers. Measurements were taken from the injection well and in nearby wells. This test was allowed to run to completion and took approximately 3 hours.

WS301

Graph 4, below, details the readings taken from divers set in the injection well (WS301) and a nearby well approximately 10m away (WS318).



Graph 4 - Graph detailing changes in hydraulic head and water temperature prior to and following the injection of water during a falling head test in the Rectifier Yard

The transmissivity of the aquifer could be calculated using data that formed the response curve for WS301 shown in the above graph. Using Aquifer, the data and parameters returned the transmissivity and storage coefficient presented in Table 5, below.

Well	Hydraulic Transmissivity (sq m/d)	Storage Coefficient
WS301	447.27	8.45×10^{-10}

Table 5 - Hydraulic transmissivity calculated from data obtained from WS301 during the falling head test conducted in the Rectifier Yard area.

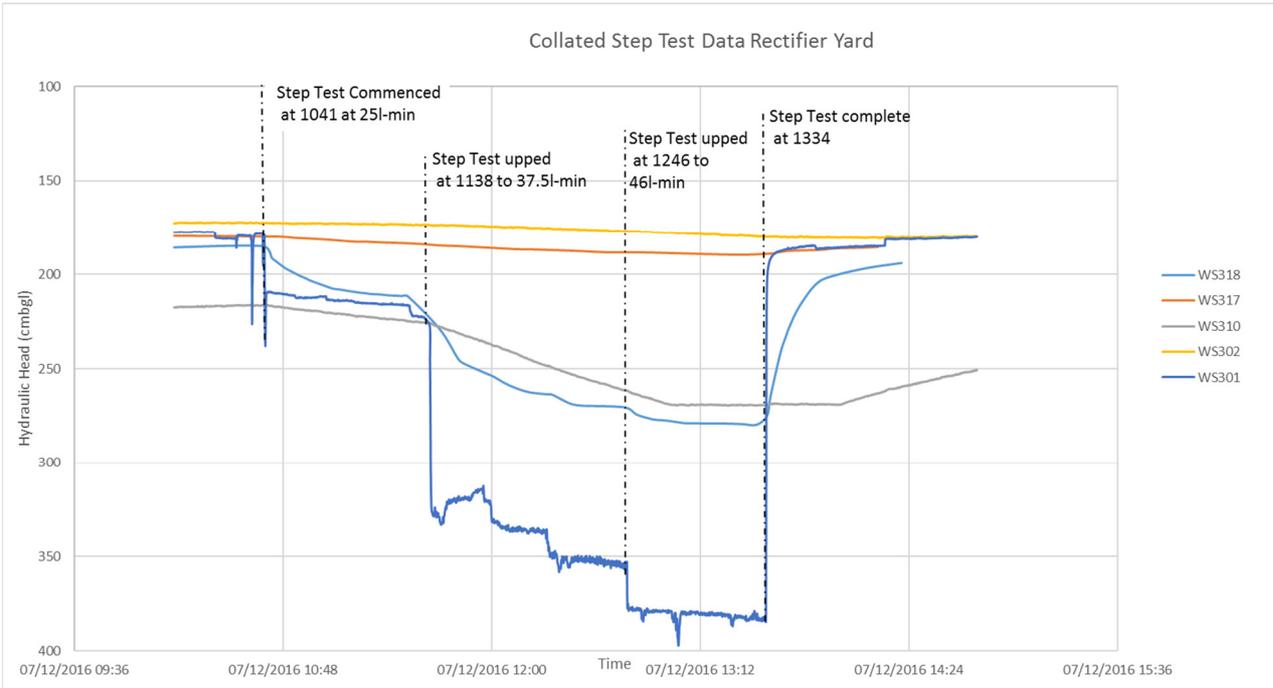
Transmissivity was found to be very high at 447.27 sq m/d. Water was pumped into the well and found to dissipate into the strata with an initial substantial rise in hydraulic head, almost reaching the wellhead. On completion of pumping, hydraulic head in WS301 rapidly dropped as water moved into the aquifer. Hydraulic head was found to be higher on completion of the test than at the beginning. This is speculated to be a sampling artefact arising from the pumping in of water dislodging the diver slightly and as such may be discounted.

4.3 Step Test

A step test was conducted in the Rectifier Yard area by pumping from WS301 and monitoring this and surrounding wells. The test consist of pumping water at a set rate for a prolonged period until a steady piezometric surface is reached in the pumping well. At this point pumping speed is increased until a new, lower, hydraulic head is reached. This is repeated a final time at a maximum pump speed to assess the likely limits of the aquifer.

During pumping, the hydraulic head is measured in the pumping well and also in surrounding wells either with an interface probe or with Shlumberger Water Services pressure transducers. Multiple wells were monitored during the test for response, with some having fewer data points than others. Wells RB219 and WS316 in particular were measured infrequently due to their distance from the pumping area. WS302 and WS318 were measured frequently with an interface probe. WS301, WS310 and WS317 were measured using Shlumberger Water Services pressure transducers and as such recorded changes in hydraulic head every five seconds.

A graph presenting the data collected during the Rectifier Yard step test is displayed below in Graph 5.



Graph 5 - Graph detailing changes in hydraulic head in a pumping well and nearby boreholes observed during a step test conducted in the Rectifier Yard area

Graph 5 shows hydraulic head being lowered in WS301 during the step test in a series of stages, to a maximum drawdown of 2.06m. Pumping began at 25l/min (phase 1), was increased to 35.5l/min (phase 2) before being increased again to 46l/min (phase 3); running for around one hour for each stage. The initial drawdown is observed to be very quick in WS301, dropping hydraulic head in the well by a metre in one instance in a matter of seconds as the pumping rate is increased. Subsequent drawdown in the well once this initial drawdown is complete was found to be slow however. The gradient of drawdown for a trendline calculated for each phase of the step test is not shown to change significantly as can be observed in Table 6, below.

Well	Pump Rate (litres/min)	Time From	Time To	Gradient
WS301	25	10:41	11:38	$y = 272.25x - 1E+07$
WS301	37.5	11:38	12:18	$y = 405.73x - 2E+07$
WS301	37.5	12:18	12:46	$y = 167.87x - 7E+06$
WS301	46	12:46	13:34	$y = 131.42x - 6E+06$

Table 6 - Table detailing the changes in drawdown rate shown by calculating the gradient of a drawn trendline for a given period of the step test undertaken on WS301 in the Rectifier Yard area.

After the pump was turned off there was a rapid rebound in hydraulic head to the level recorded prior to the test despite having pumped approximately 6m³ over the duration of the test. Approximately 92% of maximum drawdown from the starting conditions is calculated to have recovered within two minutes. The curve generated from this rebound and from an earlier event in the test where the pump operated for a few seconds before being shut off were found to be suitable for use in calculating hydraulic conductivity. These have been fitted to a Bouwer S-type curve in Aquifer with graphs and analyses presented at the end of this section. Additionally, a similar recovery curve available from WS318 was not found to be suitable for such purposes and so this data was not fitted to a curve.

Wells nearby to the pumping well were monitored during the test for drawdown. These showed drops in hydraulic head and changes in the gradient of drawdown that correspond to changes in pump speed from WS301.

WS318, recorded with an interface probe and 1.36m distant the pumping well, over the test experienced a maximum drawdown of 0.94m and showed a smooth curve of drawdown at 25l/min, beginning to level off by the end of the first phase of the test. Drawdown during the second phase of the test at 37.5 l/min was found to be more rapid, as evidenced by the steeper gradient. As the second phase lapses, the gradient of the curve of the drawdown is shown to decrease. In the third phase of the test at 46l/min there is shown to be an initial rapid drop in hydraulic head, before a more gentle decline for the duration of the phase, indicating that the test had neared completion in each phase of the test. On ending the third phase of the test, rebound was found to be relatively swift; recovering around 50% of the maximum drawdown within 8 minutes, 85% of the maximum drawdown in 20 minutes and 92% of the total after 50 minutes.

WS310 was located 2.3m from the pumping well and was recorded using a Shlumberger Water Services pressure transducer set to record every 5 seconds. Over the course of the test a

maximum drawdown of 0.52m was recorded. As can be seen from Graph 5, this well was found to respond to increases in pumping speed with an increase in drawdown gradient. No curve was exhibited during each phase of the test. The gradient of trendlines drawn for phase 2 and for part of phase 3 are displayed in Table 7, below and illustrate the change in rate.

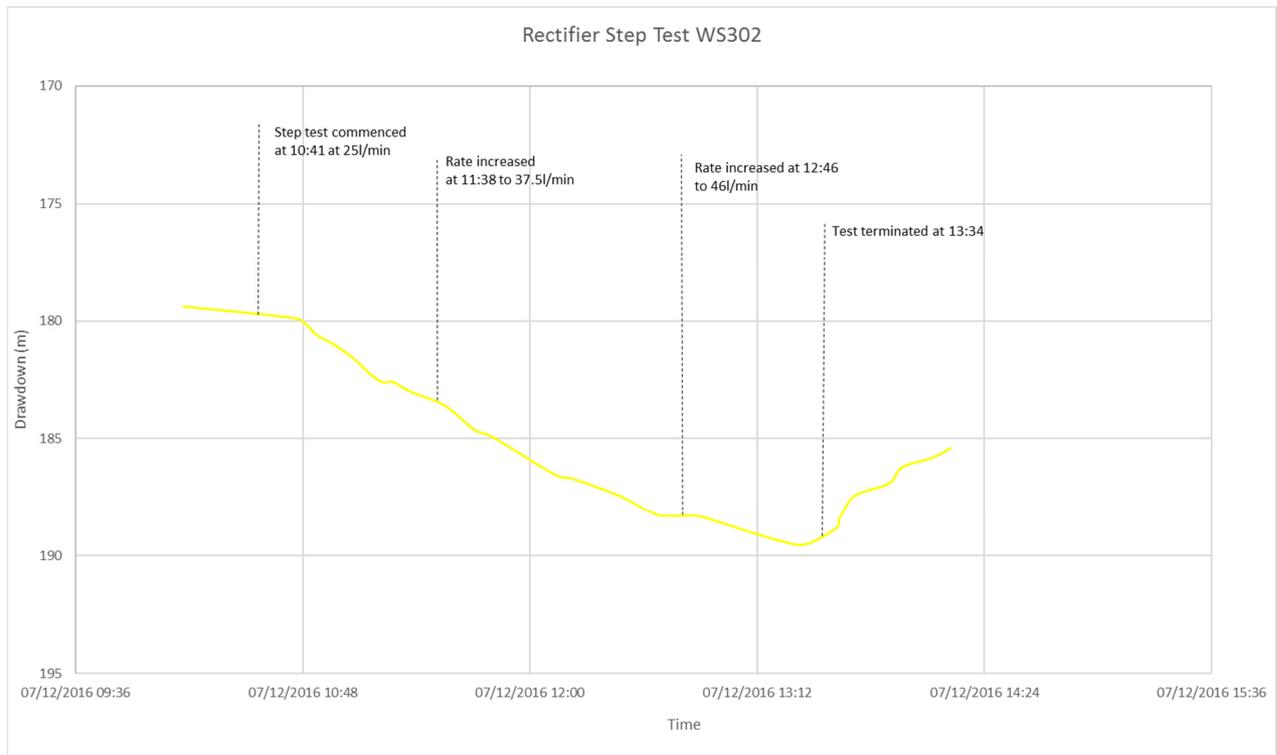
Well	Pump Rate (litres/min)	Time From	Time To	Gradient
WS310	37.5	11:38	12:46	$y = 698.05x - 3E+07$
WS310	46	12:46	13:01	$y = 780.27x - 3E+07$

Table 7 - Table detailing the changes in drawdown rate shown by calculating the gradient of a drawn trendline for a given period of the step test undertaken on WS310 in the Rectifier Yard area.

15 minutes into phase 3 of the pump test, drawdown was found to halt at around 2.70mbgl. This levelling off of the data at this point corresponds with the hydraulic head declining past the depth of the diver set to 2.70mbgl (base of the well is recorded as being 2.77mbgl). This indicates that hydraulic head continues to decline in the subsurface beneath the base of the well. This also accounts for the lag in recharge seen after the pump is switched off with a response only being registered after 15 minutes. If the rate of fall in hydraulic head recorded for the initial 15 minutes of phase 3 of the step test is projected beyond the point at which the diver surfaces, hydraulic head can be approximated to fall to 2.82mbgl and so a maximum drawdown of 0.65m.

WS317 was located 12.5m away from the pumping well and was recorded using a Shlumberger Water Services pressure transducer set to record every 5 seconds. Over the course of the test a maximum drawdown of 0.074m was recorded. As can be seen from graph x, this well was found to respond to increases in pumping speed with an increase in drawdown gradient. The limits of pumping influence are thought to have been reached at 46l/min here with limited drawdown being recorded through much of phase 3.

WS302 was located 11.2m away from the pumping well and was recorded with an interface probe. Readings were taken only slightly less frequently than in WS318 and a maximum drawdown of 0.101m was achieved. Set against other wells with greater drawdown on Graph 5, the profile of the data for WS302 appears in a steady decline. Graph 6, overleaf, shows this data set to a different scale and here responses to changes in pump speed in WS301 can be seen more clearly.

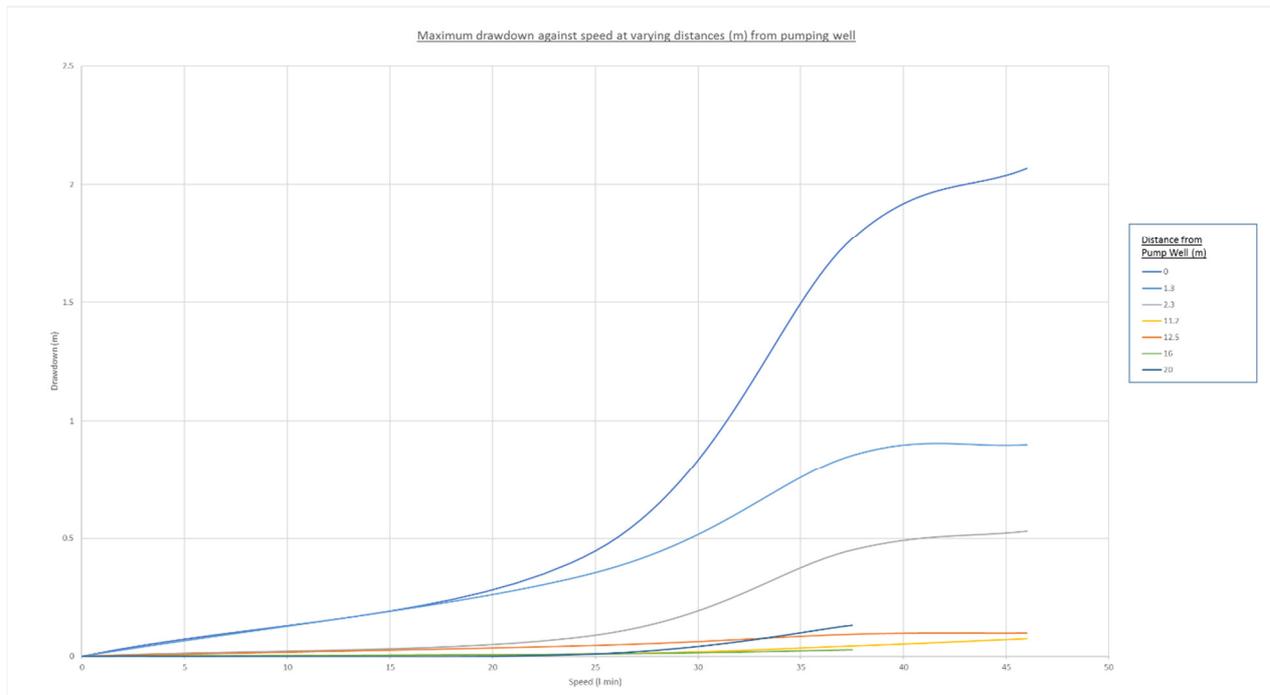


Graph 6 - Graph detailing changes in hydraulic head in WS302 during the step test conducted in the Rectifier Yard area. The drawdown axis has been adjusted from that used in Graph 12 to better graphically illustrate the impact of pumping from WS301 on WS302

A slight increase in gradient of drawdown is noted as the pump rate is increased in phase 2 to 37.5l/min, similarly in phase 3 as the pumps rate is increased to 46l/min. Rebound is shown to occur relatively rapidly, regaining around 0.04m or 40% of total head in around 40 mins. Slight discrepancies are present on the above graph as the decline and rise in hydraulic head at the beginning and end of the test seems to precede the starting and stopping of the pump. This is an artefact of having fewer data points for this well between manual monitoring and the trendline connecting the data points smoothing unrecorded changes.

WS316 and RB219, located 16m and 20m distant the pumping well respectively, were monitored very infrequently during the step test. As such, data for these wells has not been plotted on graph 5. A decline in hydraulic head is recorded in these wells over the test, however, with 0.028m of drawdown recorded in WS3161 and 0.131m drawdown recorded in RB219. This indicated a wide maximum range of possible influence.

The data used for the step test shown in Graph 5 was additionally processed to obtain values for maximum drawdown for each phase of testing for each well. Due to scarce data available for WS316 and RB219, not all plotted curves are complete. The graph detailing the likely drawdown influence at varying speeds and distances is displayed in Graph 7, overleaf.

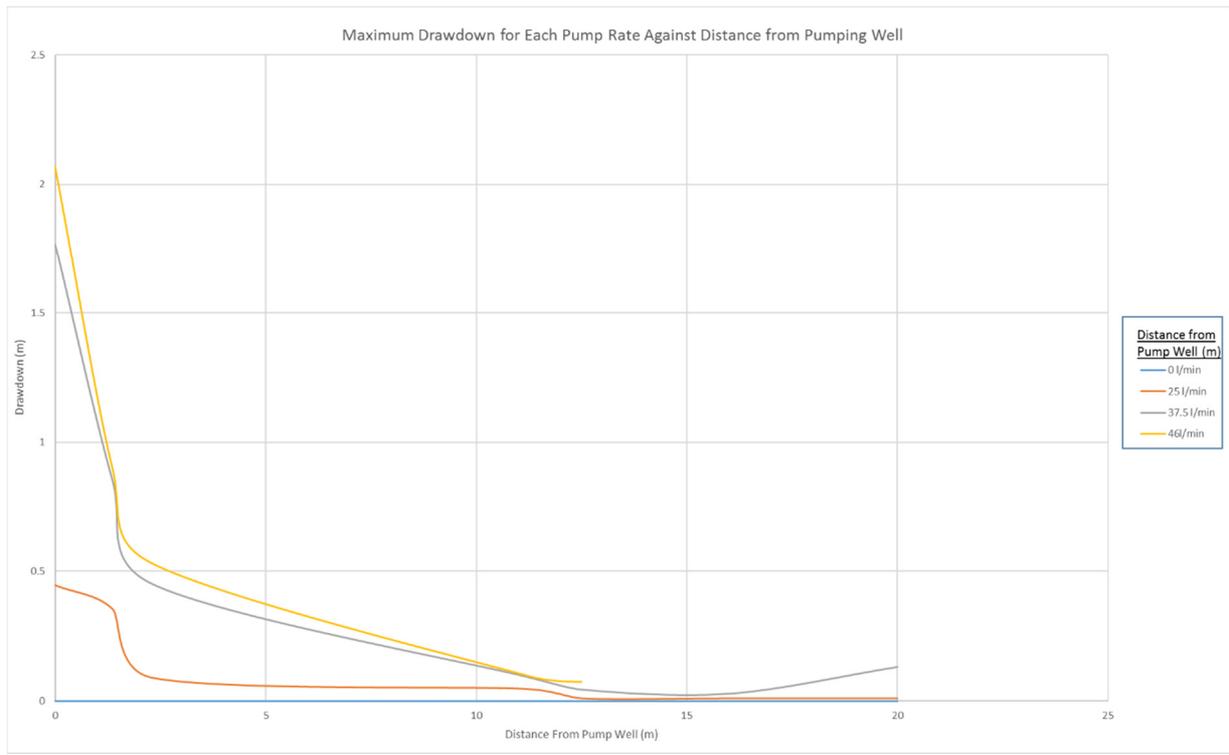


Graph 7 - Graph showing relationship between distance from pumping well, drawdown and pumping speed from the pumping well and surrounding boreholes during the step test carried out in the Rectifier Yard area

As illustrated in Graph 7 there is a clear relationship between drawdown of hydraulic head and distance from pumping well. The maximum drawdown achieved for the test was 2.06m in WS301. This influence is shown to decrease rapidly with distance from the pumping well with maximum drawdown at 46l/min less than half of that 1.3m away in WS318. The drop in hydraulic head was again found to be around half as high as that found in WS318 at the same rate at 2.3m distance from WS301. The relationship was found to follow broadly the same pattern at lower pumping rates, however data obtained from WS318 (1.3m distant) was not found to ascribe to this trend below 30l/min. The graph shows a limited increase in effective drawdown for increase in pump rate at all distances beyond 37.5l/min.

The pump used for this test was not capable of higher rates. As such, projecting drawdown for WS301 (pumping well) to below the base of the well (a further metre of drawdown) it is estimated it would take a further two to three hours to dewater WS301. The drawdown likely to be achieved from 0l/min – 46l/min from a well installed at distances up to 20m can be estimated from this.

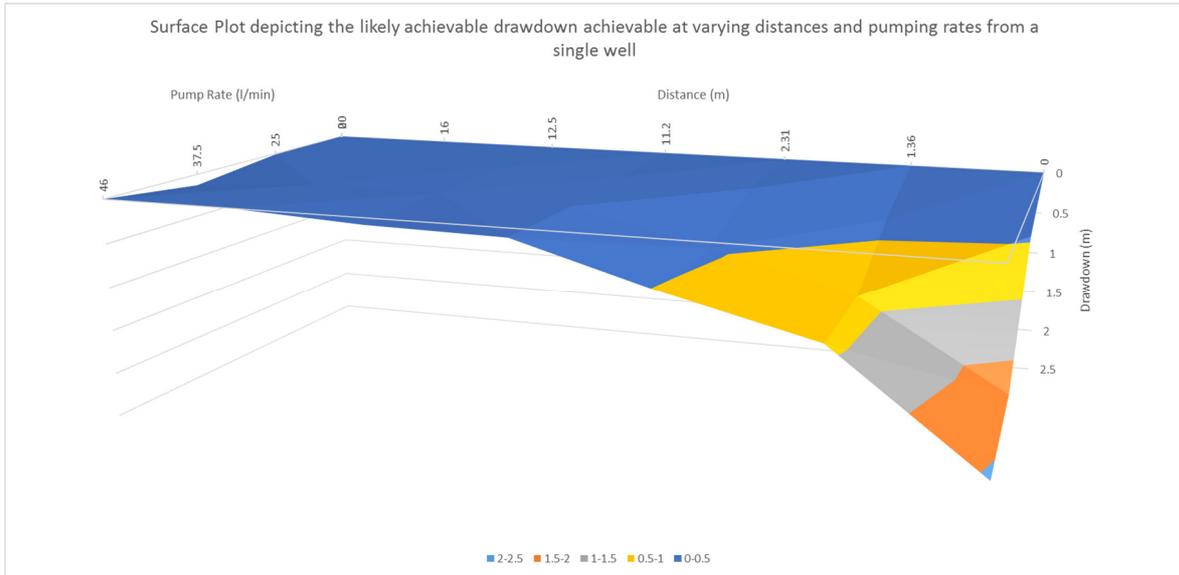
If the data is plotted as shown in Graph 8, overleaf, with drawdown plotted against distance from the pumping well, the maximum drawdown at an approximate distance can be estimated.



Graph 8 - Graph showing relationship between distance from pumping well, drawdown and pumping speed from the pumping well and surrounding boreholes during the step test carried out in the Rectifier Yard area

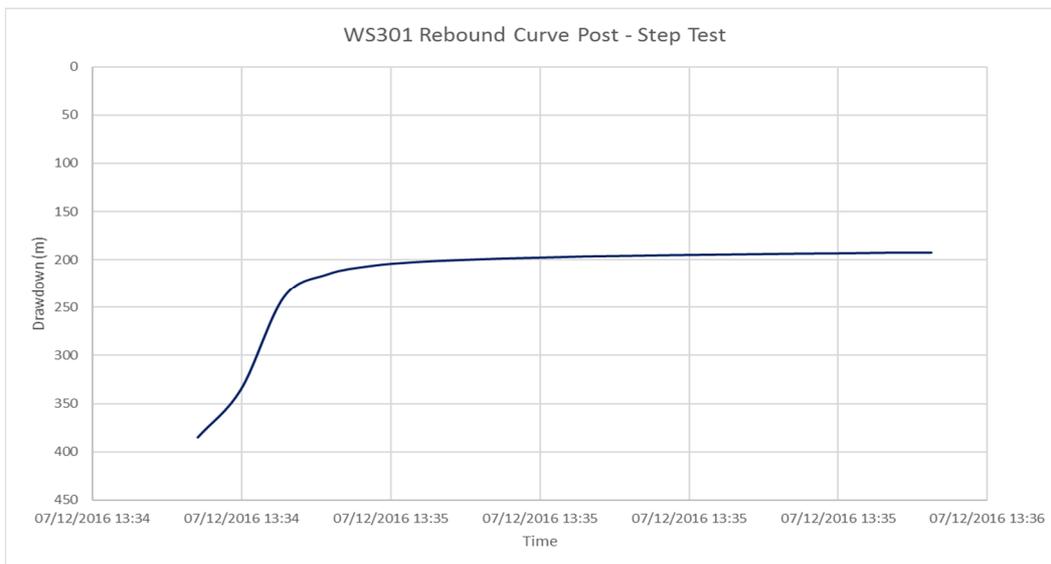
Additionally, this graph better illustrates the rapid decrease in hydraulic influence with distance that occurs at each pump rate.

With three variables, a surface plot can be drawn depicting measured changes in drawdown, distance and pumping rate which is useful for graphically illustrating these variables. This is displayed overleaf in Graph 9.

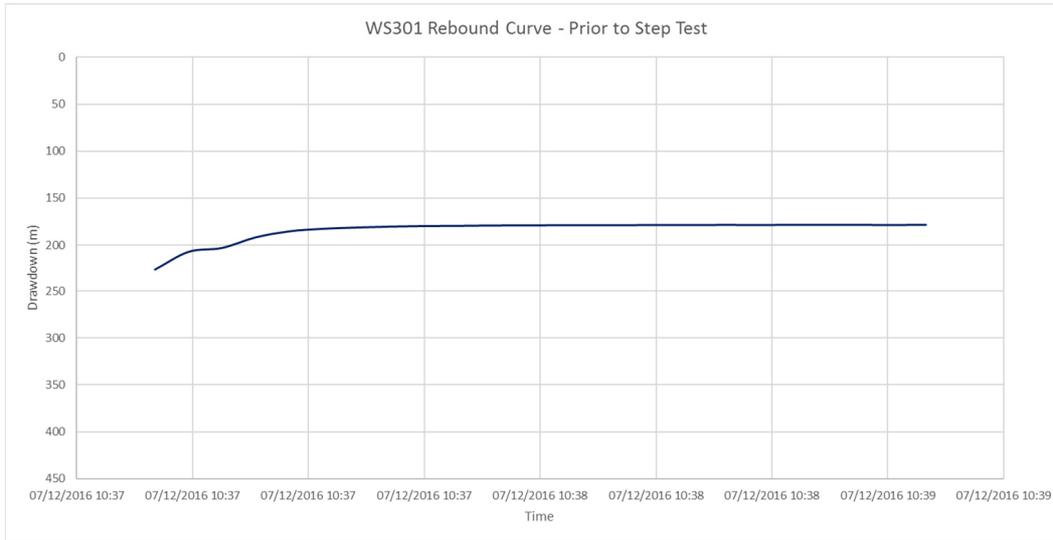


Graph 9 - Surface plot graphically illustrating changes in drawdown at varying pump speeds and distances

Graphs 10 and 11, plotted from data from which hydraulic conductivities were obtained, are displayed below. Type curve fitting charts from which hydraulic conductivities were calculated are displayed in Appendix D. Table 8, overleaf, displays the results of this analysis.



Graph 10 - Graph displaying changes in hydraulic head in WS301 during a rebound phase following pumping out of water prior to the step test



Graph 11 - Graph displaying changes in hydraulic head in WS301 during a rebound phase following the step test

Well	Hydraulic Conductivity WS301 (Obtained prior to step test)	Hydraulic Conductivity WS301 (Obtained following step test)
Hydraulic Conductivity (m/d)	12.722	28.584
Initial Displacement (m)	0.476	0.366

Table 8 - Table detailing calculated hydraulic conductivity and initial displacement calculated from rebound curves taken from data obtained before and after the Rectifier Yard step tests

Calculated hydraulic conductivity prior to the step test conducted on WS301 was found to be 12.722m/day. This increased to 28.584m/day following the completion of the step test.

4.4 Summary of Hydraulic Conditions

Hydraulic Conductivity

The collated results of the hydraulic testing in the Rectifier Yard are shown below in Table 9.

Well	Hydraulic conductivity - Rectifier Yard						
	Supplementary information			Hydraulic conductivity (m/d)			
	Soil Type	Data source	Measuring Device	Test 1	Test 2	Test 3	Average
WS306a	Clayey	Slug Test	Diver	1.50797	3.28885	3.99928	2.932033
WS303	Clayey	Slug Test	Diver	0.0469535	N/A	N/A	0.046954
RB219	Gravelly	Slug Test	Diver	21.6992	19.5373	N/A	20.61825
WS318	Clayey	Step Test	Dip Meter	0.280872	N/A	N/A	0.280872
WS301	Gravelly	Step Test	Diver	12.7084	28.5839	N/A	20.64615
Overall Conductivity Average (m/day)	10.18						
Average in clayier/siltier weathered schist gravels (m/day)	1.83						
Average in less clayey/silty weathered schist gravels (m/day)	20.63						

Table 9 - Table detailing overall hydraulic conductivities calculated in the Rectifier Yard area for all tests

Two area averages have been given, with significantly lower hydraulic conductivities assigned to 'Average in clayier/siltier gravels' and higher hydraulic conductivities assigned to 'Average in less clayey/silty weathered schist gravels'.

Transmissivity

Table 12 detailing the hydraulic conductivity encountered in the Rectifier Yard area is displayed below.

Well	Hydraulic Transmissivity – Rectifier Yard			
	Data source	Measuring Device	Transmissivity	Storage Coefficient
WS301	Falling Head Test	Diver	447.27	8.45x10 ⁻¹⁰

Table 10 - Table detailing calculated hydraulic transmissivity calculated in the Rectifier Yard area during the falling head test

Data was obtained from WS301 on hydraulic transmissivity that indicating the schist gravel aquifer found underlying the site is capable of accepting a large quantity of water.

5.0 Vacuum Testing



A vacuum test was undertaken in the Rectifier Yard. Here the water table was found to be close to the top of the screened section of standpipe. As a consequence applied vacuum was liable to draw water up the pipe in ground conditions with lower soil pore space air transmissivity. Despite reducing the vacuum applied to the vacuum well in this area and attempting to draw from multiple locations, water was found to be drawn up the well, blocking the available pore space and as a consequence no measurable vacuum or useful data could be recorded in nearby wells.

6.0 Treatability Trials

In order to determine the suitability of a chemical oxidation solution to treat the identified dissolved phase and soil sorbed residual contamination in areas where the LNAPL has been recovered by physical means, or where no LNAPL has been present, a programme of lab scale treatability trials have been undertaken.

A full report from the laboratory is included in Appendix F, this should be read in detail when undertaking any remediation design. What follows is a summary of the works undertaken and findings.

6.1 Model Development

To ensure bench scale trials represented site conditions as accurately as possible samples of materials from the site were recovered including:

- Intact cores of the aquifer material;
- Bulk disturbed samples of the aquifer matrix;
- Bulk samples of the most significantly impacted groundwater, composited from across the plume area.

A conceptual model was devised for each treatment area, based on typical logs, depth to water and rock head (considered impermeable in this assessment) in each area. This model has been advanced using the findings of the depth profiling assessment, sampling of soil and groundwater (source term determination) and matrix oxidant demand testing and derivation of oxidant half-lives based on first order decay.

The findings of these tests were used in contaminant destruction profiling for selected oxidant activator systems also detailing effects of daughter products and rebound potential.

6.2 Technologies Assessed

A series of oxidant and activator designs were tested following an initial screening. The following mixes were trialled in reactor cells based upon the aquifer conditions of each area:

- Persulphate at total oxidant requirement;
- Persulphate at 2 x total oxidant requirement;
- Peroxide activated Persulphate at total oxidant requirement;
- Peroxide activated Persulphate at 2 x total oxidant requirement;
- Peroxide at 2%;
- Peroxide at 5%.

Chemical oxidation reactors were sampled at regular intervals over a period of 672 hours for persulphate based systems and over 96 hours for peroxide based systems (a more rapidly acting oxidant).

Total oxidant requirement is derived from the stoichiometric oxidant demand based on contaminant loading plus the matrix oxidant demand.

6.3 Treatability Results

Based upon the results of the chemical oxidation reactors, peroxide appears to have the greatest level of contaminant destruction. Coupled with the high permeability of the aquifer this also allows efficient delivery of oxidant mass into the subsurface and high groundwater flow zones.

Persulphate based systems showed significantly lower destruction efficiencies at both low and high injection concentrations. Additionally, use of this approach would cause mobilisation of trace metals whereas Peroxide systems do not require subsequent aquifer rehabilitation or pH adjustment in order to prevent mobilisation of trace metals.

Contaminant destruction in both aquifer systems showed similar responses to specific oxidation systems. The similarities in the modelled aquifer parameters for each of the three target areas are such that a single treatment strategy may be applied to all areas.

A 2% oxidant application is considered to be suitable for the site, this will achieve NAPL dissolution from within the matrix in early stages of treatment preventing rebound. The peroxide based oxidant will have completed its treatment by the end of 96 hours after which stepped application of the oxidant is recommended in key areas.

It should be noted that this approach will not treat measurable thicknesses of LNAPL where encountered.

7.0 Conclusions

A remediation pilot study programme was commissioned by The LK Group to aid in design of a remediation system to treat the three known impacts in the Escrow areas of the Anglesey Aluminium Site, Holyhead.

This report details the known impact in the Rectifier Yard area, which was targeted with further drilling and depth profiling works to aid vertical delineation of the impact through the soil column. Additionally, hydraulic and vacuum testing was undertaken to assess the hydraulic conductivity and radius of influence of pumped treatment systems within the target formations. Subsequent laboratory scale testing enables the most suitable oxidant system to be determined for use in each of the key areas.

Depth profiling indicates the bulk of the impacts in all areas to be predominantly based within the groundwater within the more permeable gravel fractions. The matrix itself does not typically exhibit high concentrations of sorbed contamination. These cores do suggest areas of lower permeability and variability within the Rectifier Yard, with lower permeability areas displaying limited soils impact around the periphery of the main aquifer body.

Hydraulic testing of the Rectifier Yard suggests that all areas have a very high primary permeability within the aquifer, with a significant radius of influence within the aquifer achieved under pumping. Although it should be noted that there is evidence of high variability within the aquifer with low permeability zones present within the subsoils in each of these areas.

This high permeability indicates that a pumped solution as a means of recovering LNAPL and dissolved phase hydrocarbons is considered to be a suitable method for use in the Rectifier Yard.

Chemical oxidation trials have demonstrated that a peroxide based oxidant represents a highly effective means of treating the dissolved phase hydrocarbon impacts in all three Escrow Areas. The high permeability of the subsurface should ensure rapid oxidant transfer and minimal risk of rebound from the soil matrix.

8.0 Limitations

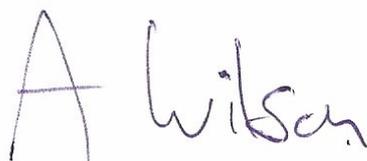
Geo²'s conclusions, recommendations and opinions are based on information gathered at the time of the investigation from a variety of third party sources and from observations made during site reconnaissance and ground conditions encountered during the field work and on the results of laboratory and field tests performed during the investigation. However, there may be conditions at the site that have not been taken into account, such as unpredictable soil strata and water conditions between or below intrusive locations. It should also be noted that groundwater levels may vary due to seasonal or other effects and may at times differ to those measured during the investigation.

A portion of this report is based solely upon information provided by third parties. The information has not been independently verified by Geo². Whilst this report and the opinions given in it are accurate to the best knowledge of Geo², Geo² cannot guarantee the completeness or accuracy of any descriptions, opinions or conclusions based solely upon information that has not been independently verified.

The recommendations contained within this report represent our professional opinions. These opinions were arrived at in accordance with currently accepted industry practices and hydrological and engineering practices at this time. As such they are not a guarantee that the site is free of hazardous materials or conditions.

Geo² prepared this report for our Client; any third parties using this report do so entirely at their risk. Geo² makes no warranty or representation whatsoever, express or implied, with respect to the use by a third party of any information contained in this report or its suitability for any purpose. Geo² assumes no responsibility for any costs, claims, damages or expenses (including any consequential damages) resulting from the use of this report or any information contained in this report by a third party.

This report was prepared by



Adam Wilson

06/04/17

Date

This report was reviewed by



Paul Stapleton

06/04/17

Date

9.0 References

The LK Group

Escrow Sites: Scope of Works. May 2016

Site Condition Report: January 2014

LK Review of Previous Work.

Unpublished laboratory analysis and logs from 2016 works

CE Geochem

ANGLESEY: Lab Bench Scale Oxidation Study. March 2017. A161201

British Standards Institute

BS10175:2011 “Investigation of potentially contaminated land sites – code of practice”

Environment Agency

CLR 11- Model procedures for the management of contaminated land.

Ciria

C552 Contaminated Land Risk Assessment: A guide to good practice.

Appendix A

Figures



Figure 1 - Site Situation

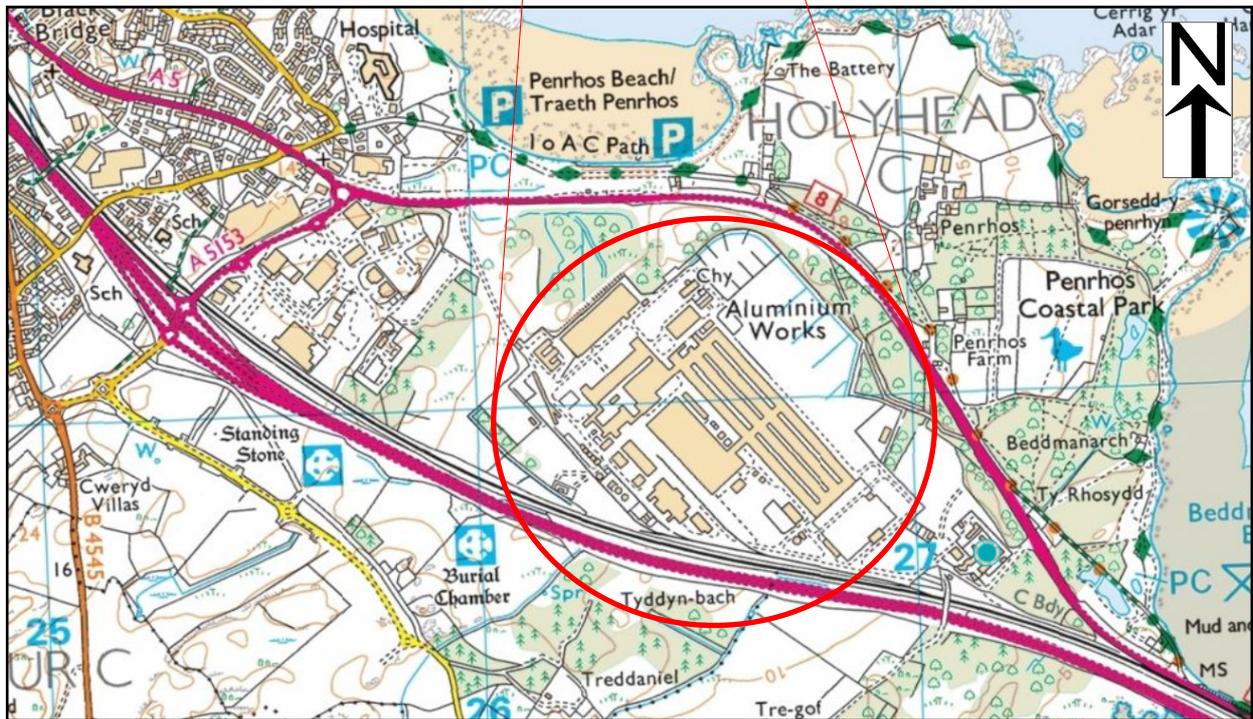


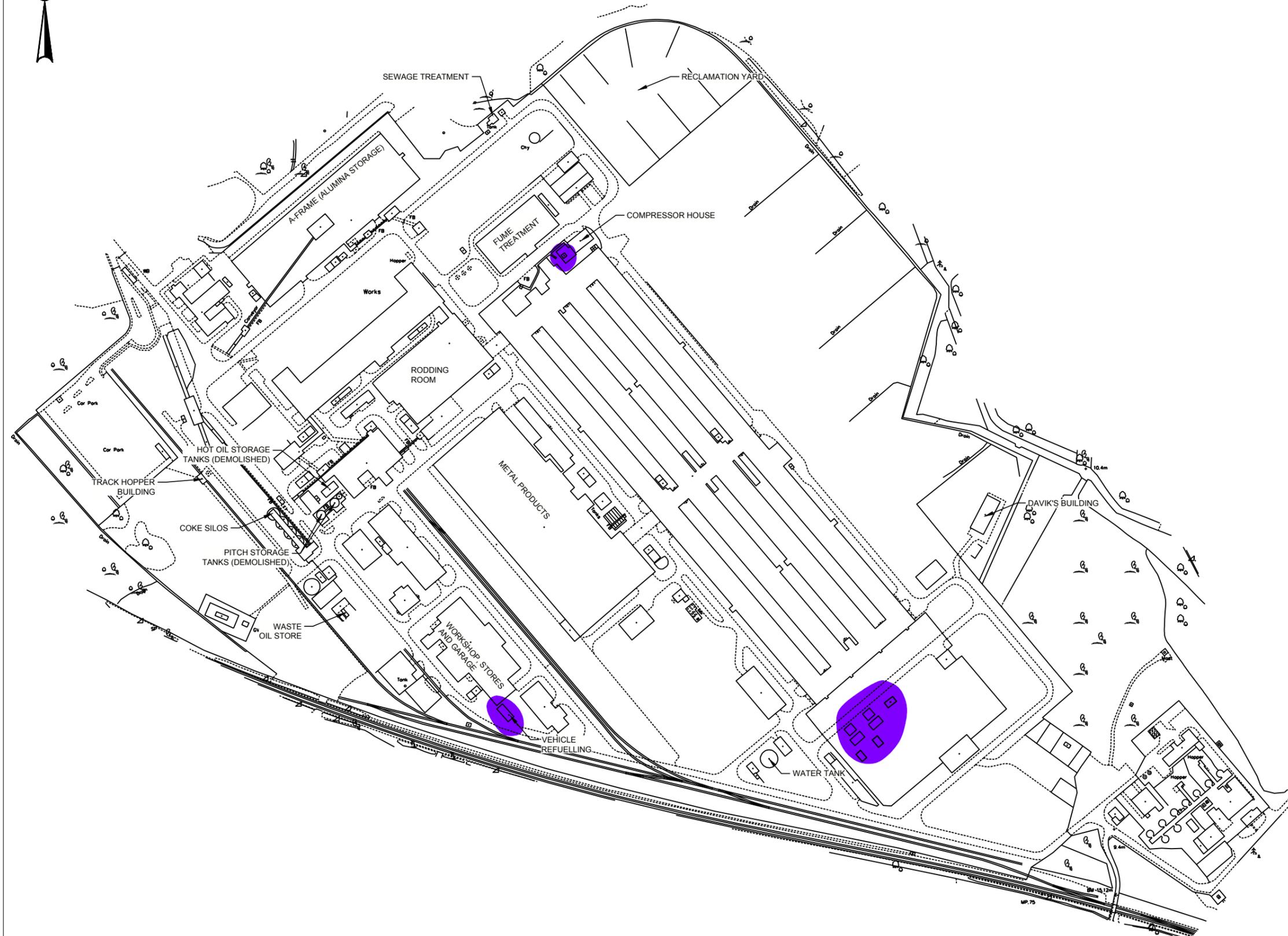
Figure 2 - Site Location

Ref: Envirocheck Report



Figures 1 & 2 Site Situation and Location -
Escrow Areas, Anglesey Aluminium, Penrhos Works, Holyhead

Geo² Remediation Limited, 11 The Mending Rooms, Sunny Bank Mills, Town Street, Farsley, Leeds, LS28 5UJ



LEGEND
 Area of identified light Non-Aqueous Phase Liquid (LNAPL)

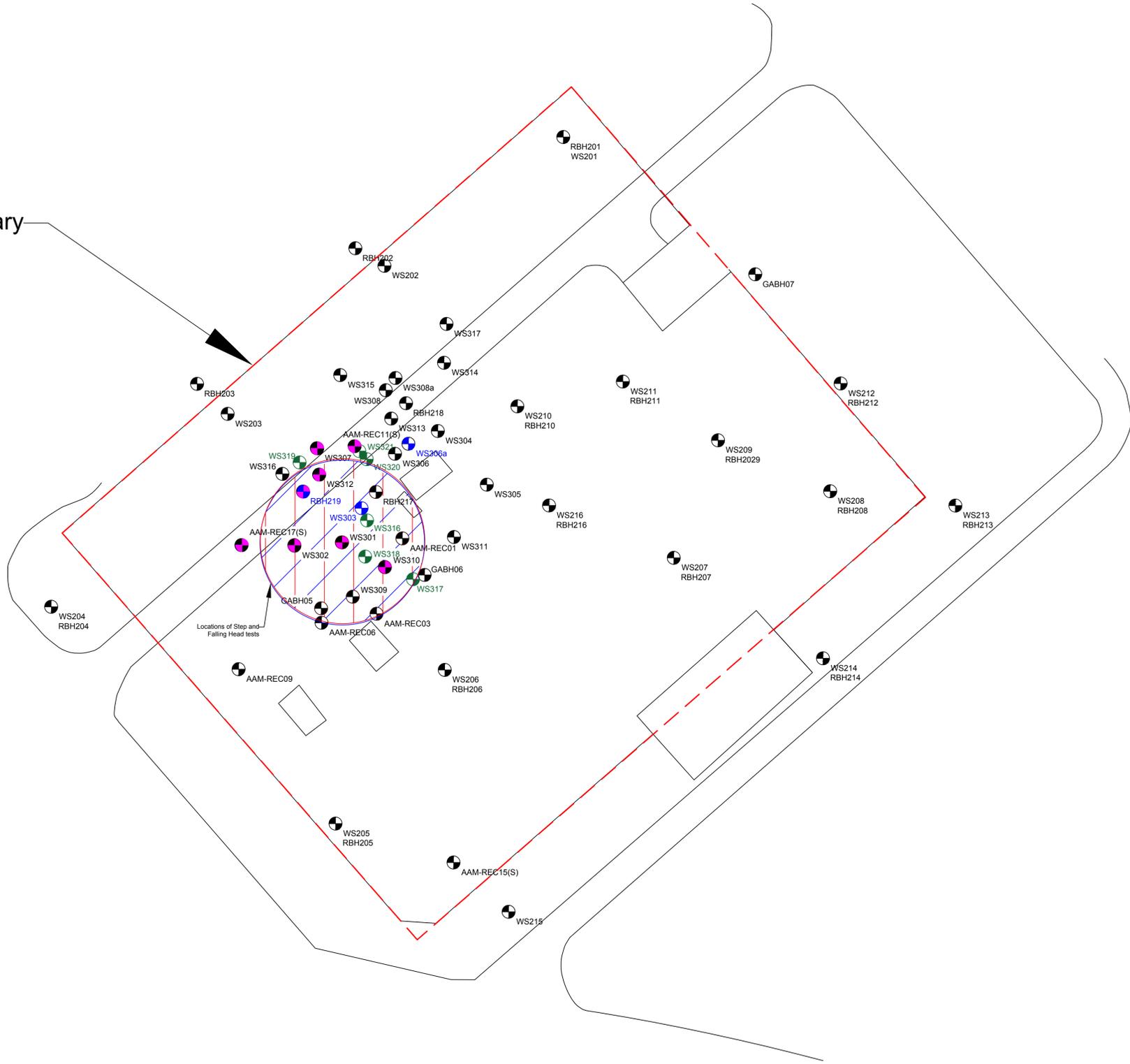
NOTES
 REFERENCES
 DRAWING BASED ON INFORMATION PROVIDED BY: ANGLESEY ALUMINIUM

Rev	Description	PM	Review	Date
Client ANGLESEY ALUMINIUM				
Project SITE SALE				
Title AREAS OF LNAPL				
Created by	Requested by	Proj Manager	Reviewer	Date
AD	HD	HD	HD	14/07/15
File No. 0001-X-0001		Project No. 1419735		
Size A3	Scale 1:4,000	Status REPORT ISSUE		
Drawing No. 1				Rev -




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Rectifier Yard Boundary



LEGEND

- Borehole
- Borehole used for slug testing
- Borehole constructed for frozen core sampling
- Boreholes monitored during attempted vacuum testing
- Location of Falling Head Test
- Location of Step Test

General Notes:
Building proportions and borehole locations based on previous survey conducted by LK

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 Tel: 0113 257 5397
 E-Mail: info@geo2.co.uk
 Website: www.geo2.co.uk

Client
LK

Site Location
**Rectifier Yard
Anglesey Aluminium**

Drawn by	LHD	Approved by	
Scale	Not to scale	Revision	-
Date	24/01/2017	Sheet No.	1 of 1

Appendix B

Borehole Logs



11 The Mending Rooms
Sunny Bank Mills
Town St., Farsley, LS28 5UJ
0113 257 5397

Borehole Log

Borehole No.

WS 316

Sheet 1 of 1

Project Name: Anglesea Aluminium, Anglesea		Project No. 0626	Co-ords:	Hole Type WS
Location: Anglesea Aluminium - Anglesea		Level:		Scale 1:50
Client: LK		Dates: 06/03/2017		Logged By L. Hanson Diamond

Well	Water Strikes	Sample and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description	
		Depth (m)	Type	Results					
					0.10			MADE GROUND - Blue, sub-angular, medium sized granite, GRAVEL.	
					0.30			GRAVEL - Weathered, schist GRAVEL in a silty clayey matrix.	
					0.60			GRAVEL - Weathered, slightly clayey, schist GRAVEL.	
					1.00			GRAVEL - Weathered, clayey, medium to large schist GRAVEL.	1
					1.00			GRAVEL - Weathered, clayey, medium to large schist GRAVEL. Wet from 1.7m	
					2.00			GRAVEL - Blue/grey, angular, silty GRAVEL of fractured shale.	2
					2.75			Zone of core loss.	
					3.00			End of Borehole at 3.00m	3
									4
									5
									6
									7
									8
									9
									10

Remarks
Core frozen at 2-3m and logged by third party C E Geochem. Terminated at 3m.



11 The Mending Rooms
Sunny Bank Mills
Town St., Farsley, LS28 5UJ
0113 257 5397

Borehole Log

Borehole No.

WS 317

Sheet 1 of 1

Project Name: Anglesea Aluminium, Anglesea		Project No. 0626	Co-ords:	Hole Type WS
Location: Anglesea Aluminium - Anglesea		Level:		Scale 1:50
Client: LK		Dates: 06/03/2017		Logged By L. Hanson Diamond

Well	Water Strikes	Sample and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description	
		Depth (m)	Type	Results					
					0.10		MADE GROUND - Blue, sub-angular, medium sized granite, GRAVEL. In a clayey matrix from 0.05m.		
					1.00		CLAY - Blue/stained red, wet, friable, stiff CLAY with frequent weathered schist.	1	
					1.30		GRAVEL - Large and occasionally small, weathered, schist GRAVEL in stiff dry clay matrix.		
					2.00		Zone of core loss.	2	
					2.40		GRAVEL - Blue/grey, dense, clayey GRAVEL of tabular shale fragments.		
					2.50		Zone of core loss.		
					2.70		SAND - Yellow/grey, dense, silty SAND with some angular cobbles.	3	
					3.00		GRAVEL - Medium sized weathered gravels in a dry friable clay matrix. Damp at 3.5m and becomes more clayey with depth.		
					4.00		End of Borehole at 4.00m	4	
								5	
								6	
								7	
								8	
								9	
								10	

Remarks
Core frozen at 2-3m and logged by third party C E Geochem. Refused at 4m.



11 The Mending Rooms
Sunny Bank Mills
Town St., Farsley, LS28 5UJ
0113 257 5397

Borehole Log

Borehole No.

WS 318

Sheet 1 of 1

Project Name: Anglesea Aluminium, Anglesea		Project No. 0626	Co-ords:	Hole Type WS
Location: Anglesea Aluminium - Anglesea		Level:		Scale 1:50
Client: LK		Dates: 06/03/2017		Logged By L. Hanson Diamond

Well	Water Strikes	Sample and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description	
		Depth (m)	Type	Results					
					0.10		MADE GROUND - Blue, sub-angular, medium sized granite GRAVEL.		
					0.40		GRAVEL - Schist GRAVEL.		
					0.80		CLAY - Blue, stiff, friable, possibly reworked, CLAY with frequent weathered, schist gravels.		
					1.60		CLAY - Brown/red, stiff CLAY, with occasional blue/grey, small, weathered gravels.		1
					2.00		GRAVEL - Red/grey GRAVEL in a weak clayey matrix.		
					2.10		Zone of core loss.		2
					2.40		SILT - Light grey/green, gravelly SILT, with clasts of quartz and shale. Patches of iron staining.		
					2.60		SILT - Light grey/green gravelly SILT with patches of iron staining. Gravel coarsening with depth.		
					3.00		SILT - Shattered, dark grey/green, fine sandy SILT with shale and quartzite clasts.		3
					4.00		GRAVEL - Blue GRAVEL in a weak clayey matrix.		
							End of Borehole at 4.00m		4
									5
									6
									7
									8
									9
									10

Remarks
Core frozen at 2-3m and logged by third party C E Geochem.



11 The Mending Rooms
Sunny Bank Mills
Town St., Farsley, LS28 5UJ
0113 257 5397

Borehole Log

Borehole No.

WS 319

Sheet 1 of 1

Project Name: Anglesea Aluminium, Anglesea		Project No. 0626	Co-ords:	Hole Type WS
Location: Anglesea Aluminium - Anglesea		Level:		Scale 1:50
Client: LK		Dates: 06/03/2017		Logged By L. Hanson Diamond

Well	Water Strikes	Sample and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description	
		Depth (m)	Type	Results					
					0.05			GRAVEL - Weathered schist GRAVEL in a clayey matrix.	
					0.60			GRAVEL - crush of clayey, weathered. schist GRAVEL.	
					0.70			GRAVEL - Large sandy, concrete and schist GRAVEL.	
					1.00			GRAVEL - Clayey crush of small to medium schist GRAVEL.	1
					1.20			GRAVEL - Light grey, graded, silty, sandy GRAVEL.	
					1.50			SHALE - Dark grey/blue SHALE.	
								End of Borehole at 1.50m	2
									3
									4
									5
									6
									7
									8
									9
									10

Remarks
Core frozen at 1-1.5m and logged by third party Geochem.



11 The Mending Rooms
Sunny Bank Mills
Town St., Farsley, LS28 5UJ
0113 257 5397

Borehole Log

Borehole No.

WS 320

Sheet 1 of 1

Project Name: Anglesea Aluminium, Anglesea		Project No. 0626	Co-ords:	Hole Type WS
Location: Anglesea Aluminium - Anglesea		Level:		Scale 1:50
Client: LK		Dates: 06/03/2017		Logged By L. Hanson Diamond

Well	Water Strikes	Sample and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description	
		Depth (m)	Type	Results					
					0.15		TARMAC		
					0.80		MADE GROUND - White/blue concrete and gravel crush fill.		
					1.00		GRAVEL - Brown, firm, small to medium GRAVEL in a clayey matrix.		1
					1.50		GRAVEL - Blue, weathered, schist GRAVEL in a slightly clayey/sandy matrix.		
					2.00		CLAY - Brown, stiff, plastic CLAY.		2
					2.40		SAND - Light grey, fine, silty SAND. Increasingly more silty with depth.		
					3.00		SILT - Orange/brown, clayey, sandy SILT. Planar inclusion at 2.9-3.0m depth.		3
					4.00		SAND - Dark grey/blue, fine to coarse, SAND. Sand is wet and coarsens with depth. Hydrocarbons at top, fading with depth. Last 10cm become green/blue weathered schist.		4
							End of Borehole at 4.00m		5
									6
									7
									8
									9
									10

Remarks
Core frozen at 2-3m and logged by third party C E Geochem.



11 The Mending Rooms
Sunny Bank Mills
Town St., Farsley, LS28 5UJ
0113 257 5397

Borehole Log

Borehole No.

WS 321

Sheet 1 of 1

Project Name: Anglesea Aluminium, Anglesea		Project No. 0626	Co-ords:	Hole Type WS
Location: Anglesea Aluminium - Anglesea		Level:		Scale 1:50
Client: LK		Dates: 07/12/2016		Logged By L. Hanson Diamond

Well	Water Strikes	Sample and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description
		Depth (m)	Type	Results				
					0.10		TARMAC POOR RETURNS	
					2.20		GRAVEL - Grey, weathered, clayey, sandy, schist GRAVELS.	
					2.30		CLAY - Brown, stiff, plastic, slightly friable CLAY, with iron oxide spots.	
					2.50		SILT - Grey, fine, sandy SILT.	
					2.60		SILT - Dark grey, slightly sandy SILT.	
					2.80		SILT - Dark grey SILT with odour of hydrogen sulphide.	
					2.90		SILT - Light brown, fine, sand and SILT.	
					3.25		SILT - Light grey/green SILT with fine to medium clasts of shale.	
					3.50		End of Borehole at 3.50m	

Remarks
Core frozen at 2.5-3.5m and logged by third party C E Geochem. Ended at 3.5m



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 Tel: 0161 763 7200 web: www.thelkgroup.com

Site
 Anglesey Aluminium REP

Number
WS301

Excavation Method Drive-in Window Sampler	Dimensions	Ground Level (mOD)	Client Orthios Ecoparks (Anglesey) Ltd	Job Number LKC 14 1181
	Location	Dates 10/05/2016	Engineer LKC	Sheet 1/1

Depth (m)	Sample / Tests	Water Depth (m)	Field Records	Level (mOD)	Depth (m) (Thickness)	Description	Legend	Water
0.60-1.00	D1 PID= <0.1ppm		Water strike(1) at 1.00m.		(0.50)	MADE GROUND: Grey slightly sandy gravel (sub-base). Sand is fine to medium. Gravel is fine to coarse, angular to subrounded.		
					0.50 (0.50)	MADE GROUND: Dark blackish brown slightly gravelly slightly sandy organic clay with rare coal, brick and concrete fragments. Sand is fine to medium. Gravel is fine to coarse, angular to subrounded.		
					1.00	Orangish brown slightly gravelly very clayey SAND with occasional iron staining, rare coal fragments. Sand is fine to medium. Gravel is fine to coarse, angular to subrounded mica schist.		▽1
					(1.50)	Borehole collapsing to 1.50mbgl.		
					2.50 (0.50)	Greenish grey weathered mica SCHIST. Recovered as very silty gravel. Gravel is fine to coarse, angular to subrounded. Little recovery between 2.50-3.0mbgl due to mica schist cobble.		
					3.00	Complete at 3.00m		

Remarks Sampler refused at 3.0mbgl on mica schist bedrock.	Scale (approx)	Logged By
	1:25	AF
	Figure No. LKC 14 1181.WS301	



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Site
 Anglesey Aluminium REP

Number
WS302

Excavation Method Drive-in Window Sampler	Dimensions	Ground Level (mOD)	Client Orthosis Ecoparks (Anglesey) Ltd	Job Number LKC 14 1181
	Location	Dates 10/05/2016	Engineer LKC	Sheet 1/1

Depth (m)	Sample / Tests	Water Depth (m)	Field Records	Level (mOD)	Depth (m) (Thickness)	Description	Legend	Water
0.40-1.00	D1 PID= <0.1ppm				0.40	MADE GROUND: Grey slightly sandy gravel (sub-base). Sand is fine to medium. Gravel is fine to coarse, angular to subrounded.		
					1.40	Firm consistency orangish brown mottled grey slightly gravelly slightly sandy CLAY with rare fine coal fragments. Sand is fine to medium. Gravel is fine to coarse, angular to subrounded mica schist.		
2.00-2.50	D2 PID= <0.1ppm		Water strike(1) at 1.80m.		1.80	Reddish brown SAND and GRAVEL. Sand is fine to medium. Gravel is fine to medium, angular to subrounded. Soft consistency noted at 1.80mbgl and strata becomes slightly silty.		▽1
					3.00	Borehole collapsing between 1.80-4.80mbgl.		
					4.80	Greenish grey weathered mica SCHIST. Recovered as very silty gravel. Gravel is fine to coarse, angular to subrounded.		
					5.00			

Remarks Sampler refused at 5.0mbgl on mica schist bedrock.	Scale (approx)	Logged By
	1:25	AF
	Figure No. LKC 14 1181.WS302	



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Site
 Anglesey Aluminium REP

Number
WS303

Excavation Method Drive-in Window Sampler	Dimensions	Ground Level (mOD)	Client Orthios Ecoparks (Anglesey) Ltd	Job Number LKC 14 1181
	Location	Dates 10/05/2016	Engineer LKC	Sheet 1/1

Depth (m)	Sample / Tests	Water Depth (m)	Field Records	Level (mOD)	Depth (m) (Thickness)	Description	Legend	Water
0.40-1.00	D1 PID = <0.1ppm				0.40	MADE GROUND: Grey slightly sandy gravel (sub-base). Sand is fine to medium. Gravel is fine to coarse, angular to subrounded schist.		
					(1.00)	Greenish grey mottled brown very gravelly very clayey organic SAND with rare coal fragments. Sand is fine to medium. Gravel is fine to coarse, angular to subrounded.		
1.40-2.00	D2 PID = <0.1ppm		Water strike(1) at 1.40m.		1.40	Grey slightly sandy very clayey GRAVEL. Sand is fine to medium. Gravel is fine to coarse, angular to subrounded mica schist.		▽1
					(0.80)	WEAK FUEL/OIL ODOUR NOTED BETWEEN 1.40-2.20mbgl. Sheen noted on strata.		
					2.20	Soft to firm consistency grey slightly gravelly slightly sandy CLAY with rare coal fragments. Sand is fine to medium. Gravel is fine to medium, angular to subrounded.		
2.50-3.00	D3 PID = <0.1ppm				2.50	Greenish grey mottled orangish brown slightly gravelly SAND. Sand is fine to medium. Gravel is fine to medium, angular to subrounded.		
					(0.50)			
					3.00	Complete at 3.00m		

Remarks	Scale (approx)	Logged By
	1:25	AF
	Figure No. LKC 14 1181.WS303	



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Site
 Anglesey Aluminium REP

Number
WS306A

Excavation Method Drive-in Window Sampler	Dimensions		Ground Level (mOD)	Client Orthios Ecoparks (Anglesey) Ltd	Job Number LKC 14 1181
	Location		Dates 12/05/2016	Engineer LKC	Sheet 1/1

Depth (m)	Sample / Tests	Water Depth (m)	Field Records	Level (mOD)	Depth (m) (Thickness)	Description	Legend	Water
0.30-0.50	D1 PID = <0.1ppm				0.30	MADE GROUND: Grey slightly sandy gravel (sub-base). Sand is fine to medium. Gravel is fine to coarse, angular to subrounded schist.		
					0.30	Orangish brown very gravelly slightly sandy CLAY with rare coal fragments. Sand is fine to medium. Gravel is fine to coarse, angular to subrounded mica schist.		
					(1.00)			
					1.30	Greenish grey slightly sandy very clayey GRAVEL (weathered mica schist). Sand is fine to medium. Gravel is fine to coarse, angular to subrounded mica schist and quartz.		
			Water strike(1) at 1.80m.		(0.30)	Grey slightly sandy very clayey slightly silty GRAVEL (weathered mica schist). Sand is fine to medium. Gravel is fine to coarse, angular to subrounded.		∇1
2.00-2.50	D2 PID = 4.9ppm				1.60	WEAK FUEL ODOUR NOTED BETWEEN 1.30-4.0mbgl.		
					(1.40)	Sand content increased from 2.70mbgl.		
					3.00	Grey slightly silty SAND and GRAVEL. Sand is fine to medium. Gravel is fine to coarse, angular to subrounded.		
					(1.00)	Sand content increases and gravel content decreases from 3.50mbgl.		
4.00-4.50	D3 PID = <0.1ppm				4.00	Grey weathered mica SCHIST. Recovered as very gravelly slightly sandy silt. Sand is fine to medium. Gravel is fine to coarse, angular to subrounded.		
					(0.50)			
					4.50	Complete at 4.50m		

Remarks Sampler refused at 4.50mbgl on mica schist bedrock.	Scale (approx)	Logged By
	1:25	AF
	Figure No. LKC 14 1181.WS306A	



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Site
 Anglesey Aluminium REP

Number
WS310

Excavation Method Drive-in Window Sampler	Dimensions	Ground Level (mOD)	Client Orthios Ecoparks (Anglesey) Ltd	Job Number LKC 14 1181
	Location	Dates 12/05/2016	Engineer LKC	Sheet 1/1

Depth (m)	Sample / Tests	Water Depth (m)	Field Records	Level (mOD)	Depth (m) (Thickness)	Description	Legend	Water
0.30-0.60	D1 PID = 0.0ppm				(0.30)	MADE GROUND: Grey slightly sandy gravel (sub-base). Sand is fine to medium. Gravel is fine to coarse, angular to subrounded mica schist.		
					0.30	Grey very gravelly slightly sandy organic CLAY with rare coal fragments. Sand is fine to medium. Gravel is fine to coarse, angular to subrounded mica schist.		
					0.60	Orangish brown very gravelly very clayey SAND with rare coal fragments. Sand is fine to medium. Gravel is fine to coarse, angular to subrounded mica schist.		
2.00-2.50	D2 PID = 0.0ppm				(1.00)			
					1.60	Greenish grey mottled brown weathered mica SCHIST. Recovered as very gravelly slightly sandy silt. Sand is fine to medium. Gravel is fine to coarse, angular to subrounded mica schist.		
					2.50	Complete at 2.50m		

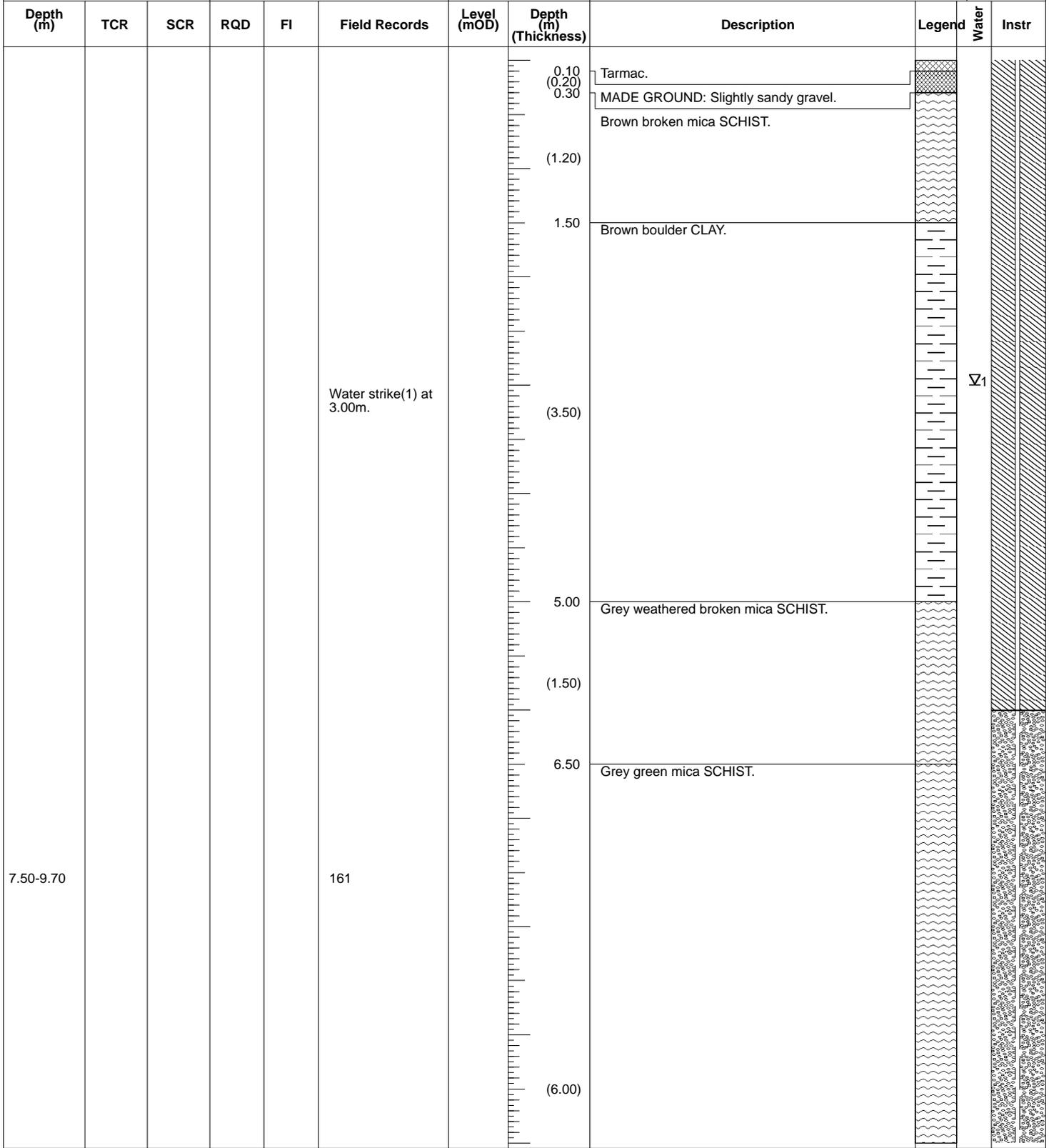
Remarks Borehole dry. Sampler refused at 2.50mblg on weathered mica schist bedrock.	Scale (approx)	Logged By
	1:25	AF
	Figure No. LKC 14 1181.WS310	



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Site
 Anglesey Aluminium REP
Borehole Number
RBH219

Machine : Flush : Core Dia: mm Method : Rotary Cored	Casing Diameter	Ground Level (mOD)	Client Orthios Ecoparks (Anglesey) Ltd	Job Number LKC 14 1181
	Location	Dates 17/05/2016- 18/05/2016	Engineer LKC	Sheet 1/2



Remarks
 5 x 1.5m (7.5m) of casing left in the borehole.
 No visual or olfactory evidence of hydrocarbon contamination identified.
 Water strike at 3.0mbgl.
 Rotary open hole log based on driller's description & observations.

Scale (approx)
1:50

Logged By

Figure No.
LKC 14 1181.RBH219



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Site
 Anglesey Aluminium REP

Borehole Number
RBH219

Machine : Flush : Core Dia: mm Method : Rotary Cored	Casing Diameter	Ground Level (mOD)	Client Orthios Ecoparks (Anglesey) Ltd	Job Number LKC 14 1181
	Location	Dates 17/05/2016- 18/05/2016	Engineer LKC	Sheet 2/2

Depth (m)	TCR	SCR	RQD	FI	Field Records	Level (mOD)	Depth (m) (Thickness)	Description	Legend	Water	Instr
							12.50	Complete at 12.50m			

Remarks	Scale (approx) 1:50	Logged By
	Figure No. LKC 14 1181.RBH219	

Appendix C

Photographic Appendix

Photo Appendix



Figure 1 - Rectifier Yard Area of frozen core collection. Photograph taken during pumping operations.



Figure 2 - Example of subsoils extracted during drilling works in the Rectifier Yard area. Blue, silty weathered schist can be seen in the lower third of the photograph. These cores had been removed from plastic sleeves. Cores to be frozen were left intact.



Figure 3 - Cores selected for freezing were sealed at the base using a plastic cap before further sealing with plastic film and tape to prevent water loss

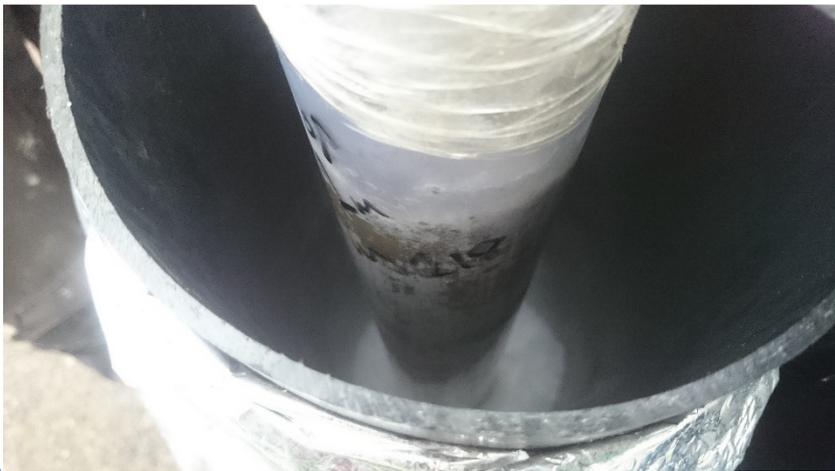


Figure 4- Cores were subsequently placed into insulated HDPE rapid preservation tubes before being surrounded with frozen pellets of CO². Once processed, these tubes were removed for longer-term storage in prepared insulated caskets.



Figure 5- Insulated caskets prepared for the storage of dry ice were also used to store frozen cores.

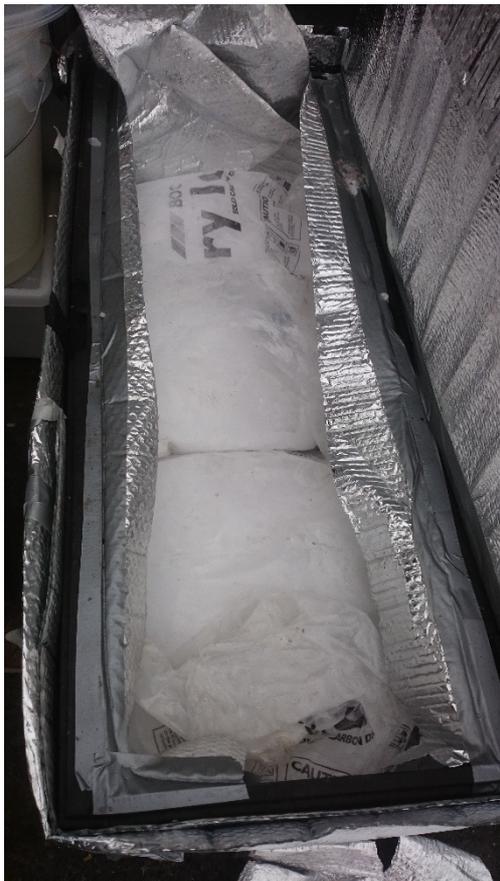


Figure 6- Storage of dry ice in insulated caskets..

Hydraulic Testing



Figure 7 - Ideal locations for hydraulic testing were identified prior to arrival onsite, monitoring using an interface probe was undertaken during the works to confirm these locations or to select alternative areas for study. The wells in the above photograph were located in the Rectifier Yard area.



Figure 8 – Once identified and investigated, hydraulic testing was undertaken on selected boreholes to determine aquifer properties. Here, a falling head test is in progress in the Rectifier Yard. Pressure transducers have been placed in the injection well and in wells in the surrounding area to monitor changes in hydraulic head.

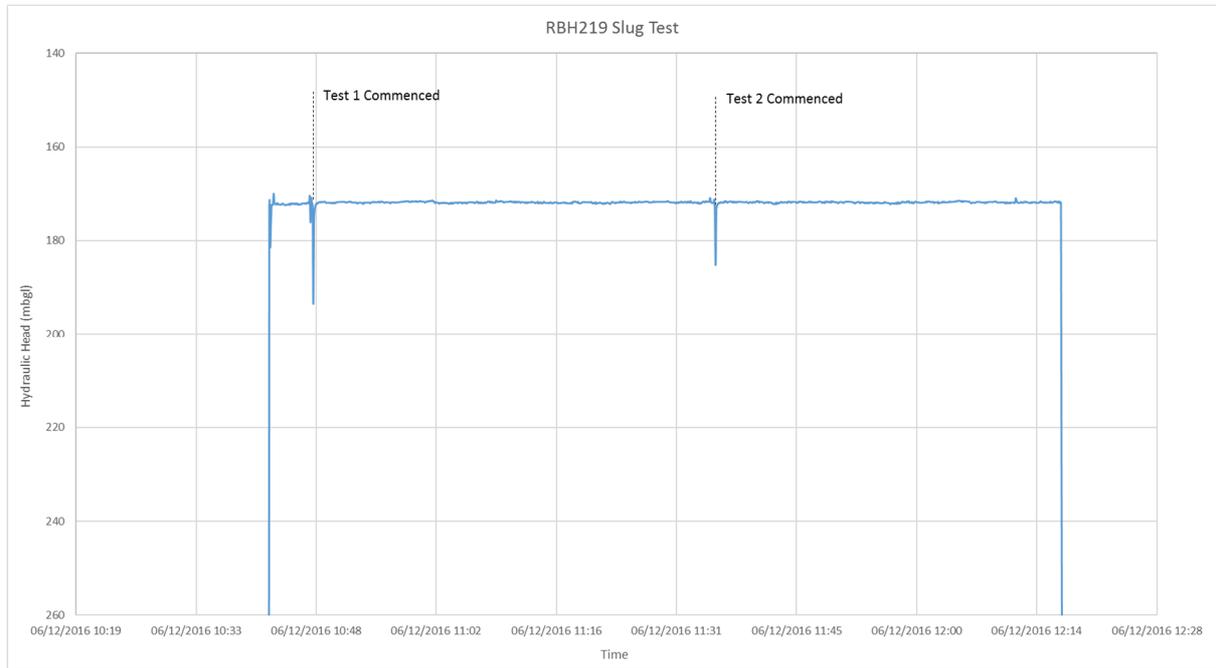
Appendix D

Hydraulic Testing

Rectifier Yard

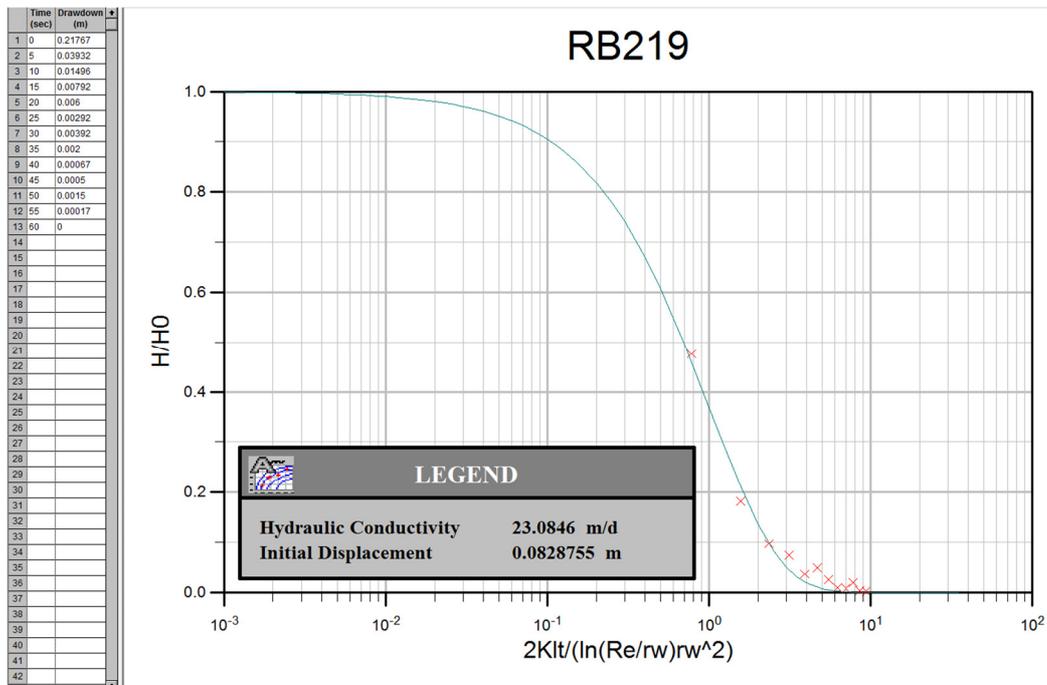
Slug Tests

RBH219



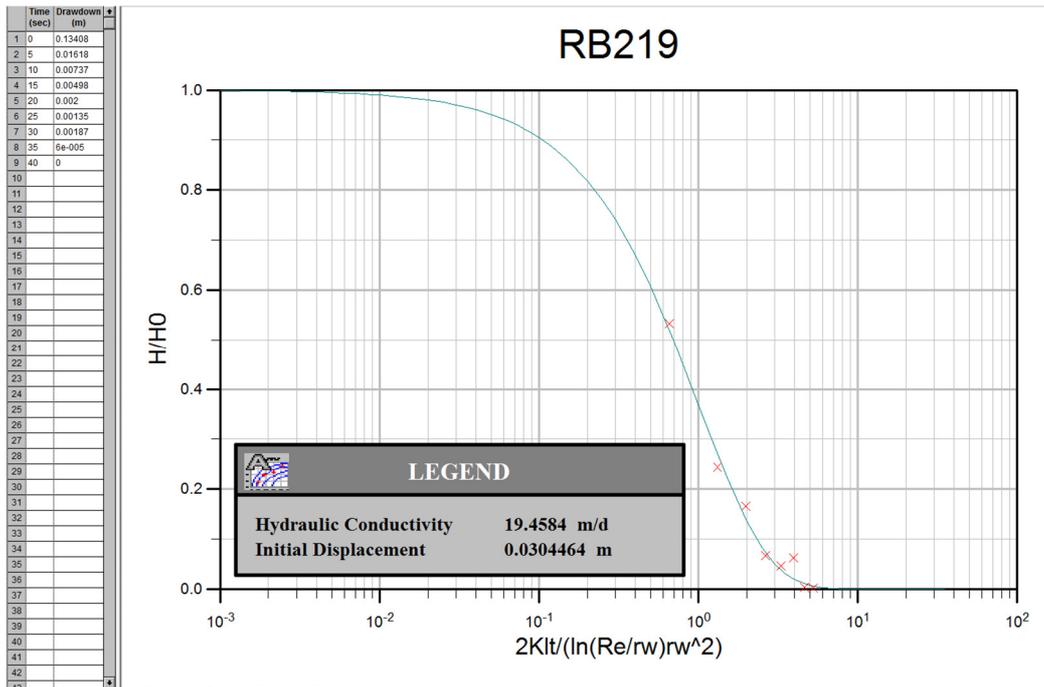
Graph 11 – Contextual graph detailing changes in hydraulic head in RBH219 during Slug testing

Test 1



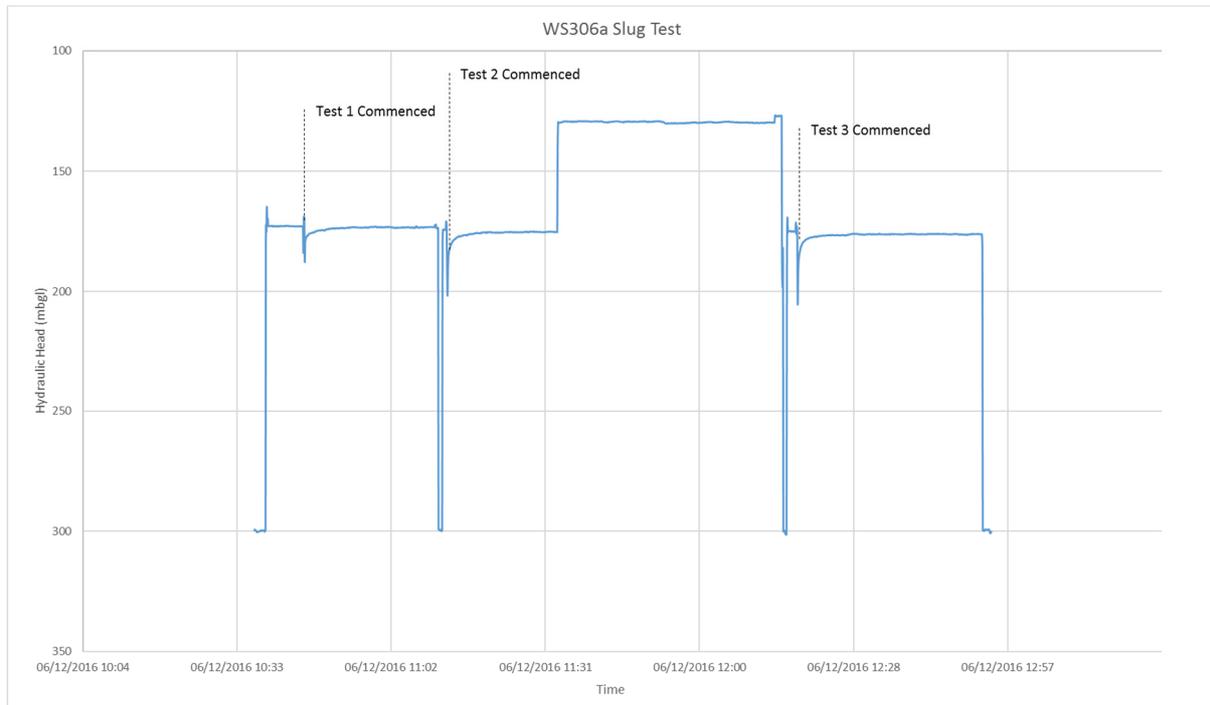
Graph 12 - Hydraulic conductivity type-fit curve for Test 1 of 2 slug tests undertaken on RBH219

Test 2



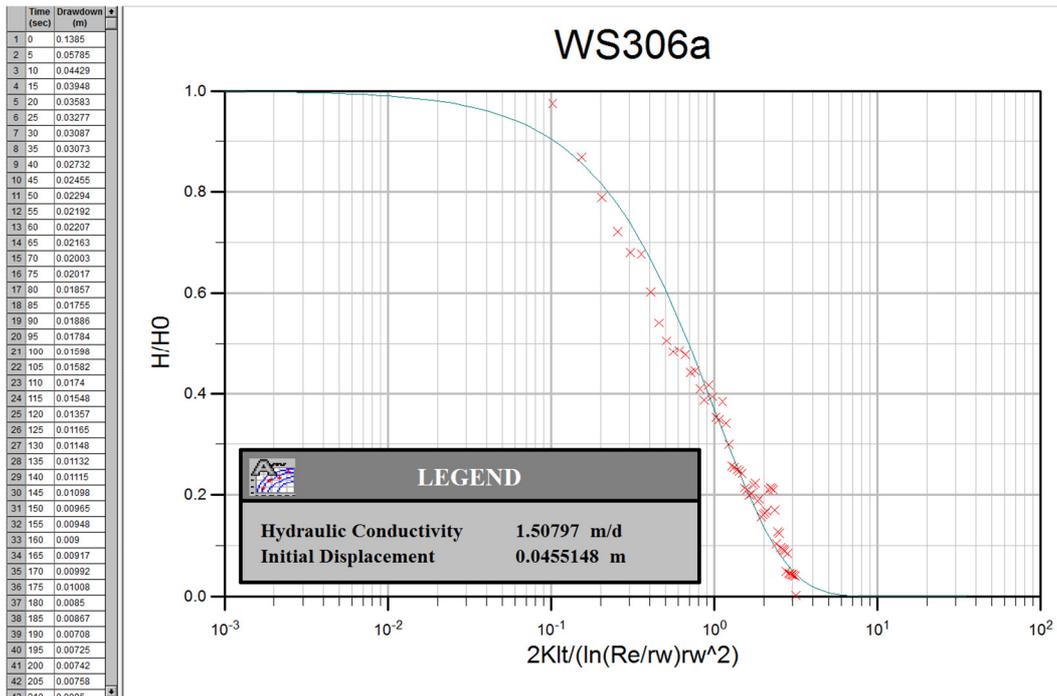
Graph 13 - Hydraulic conductivity type-fit curve for Test 2 of 2 slug tests undertaken on RB219

WS306a



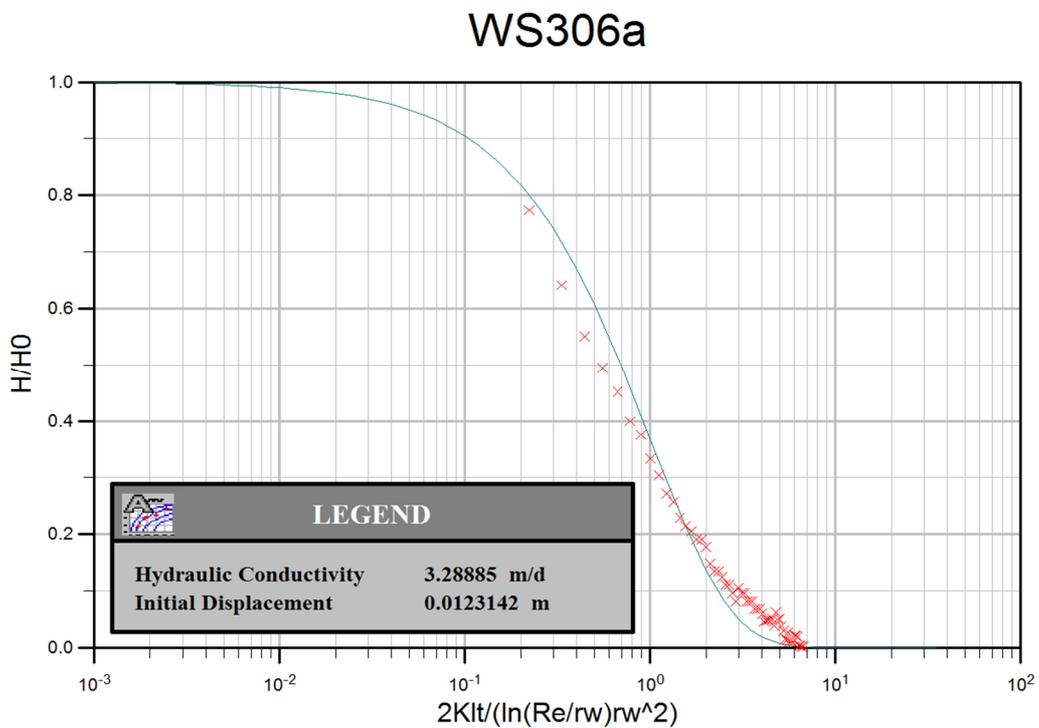
Graph 14 - Contextual graph detailing changes in hydraulic head during Slug Testing undertaken on WS306a

Test 1



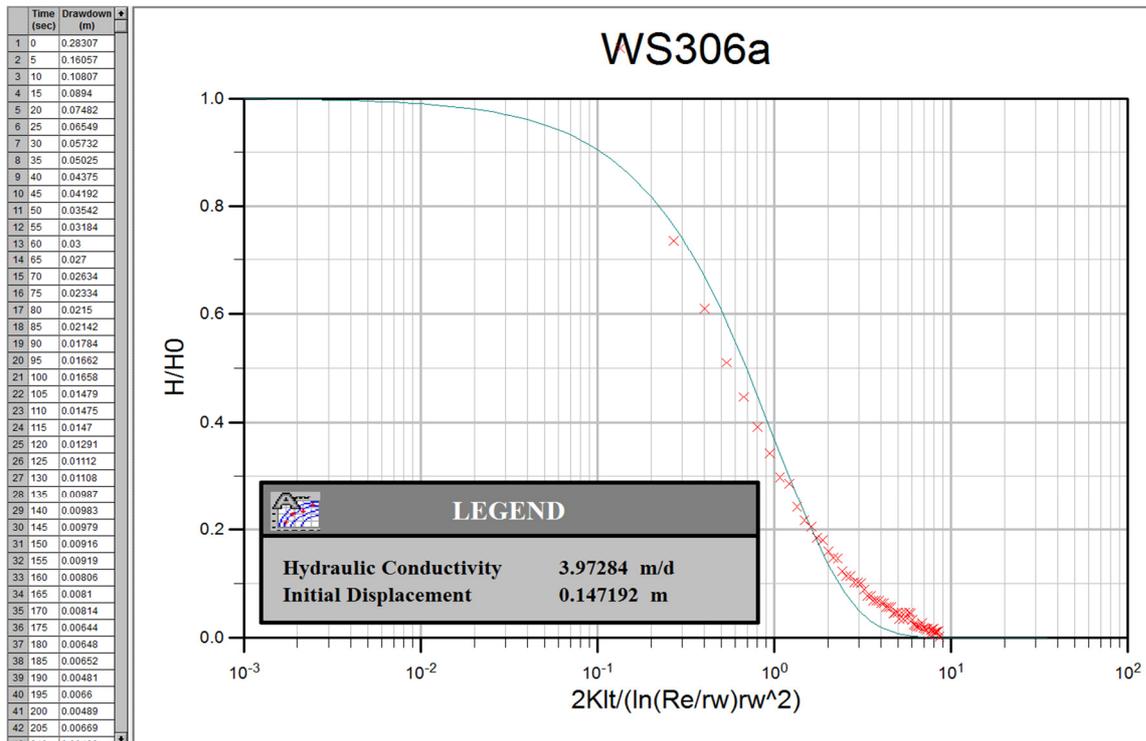
Graph 15 - Hydraulic conductivity type-fit curve for Slug Test 1 of 3 undertaken in WS306a

Test 2



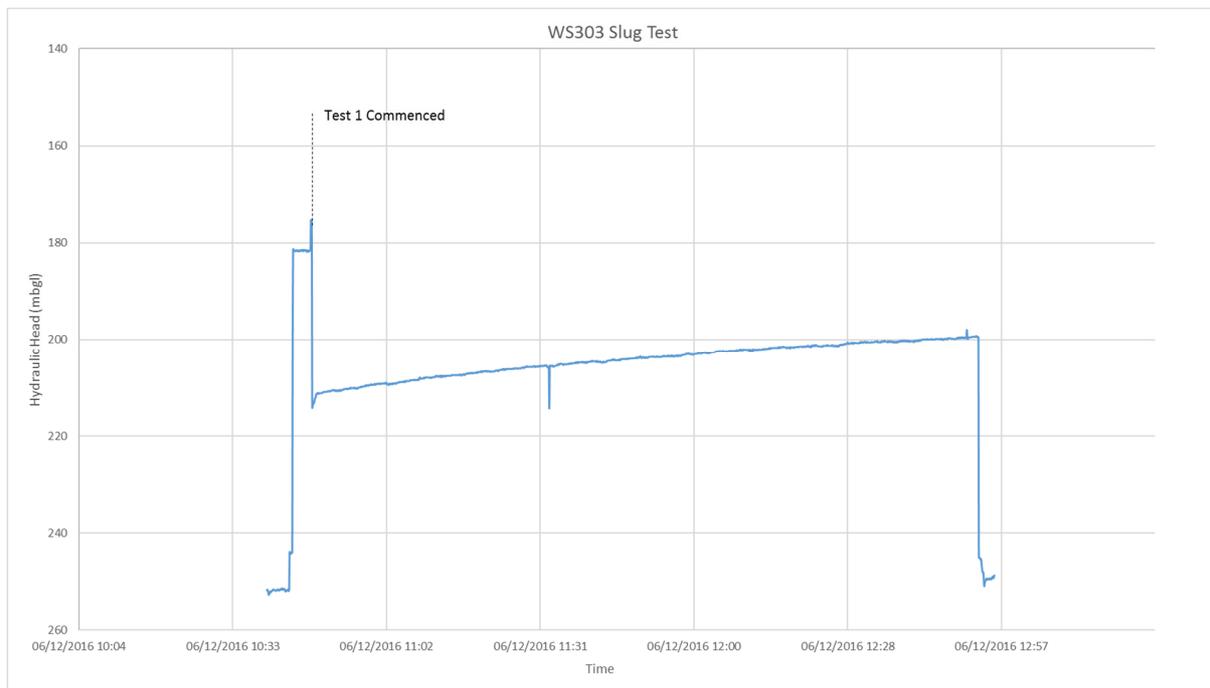
Graph 16 - Hydraulic conductivity type-fit curve for Slug Test 2 of 3 undertaken in WS306a

Test 3



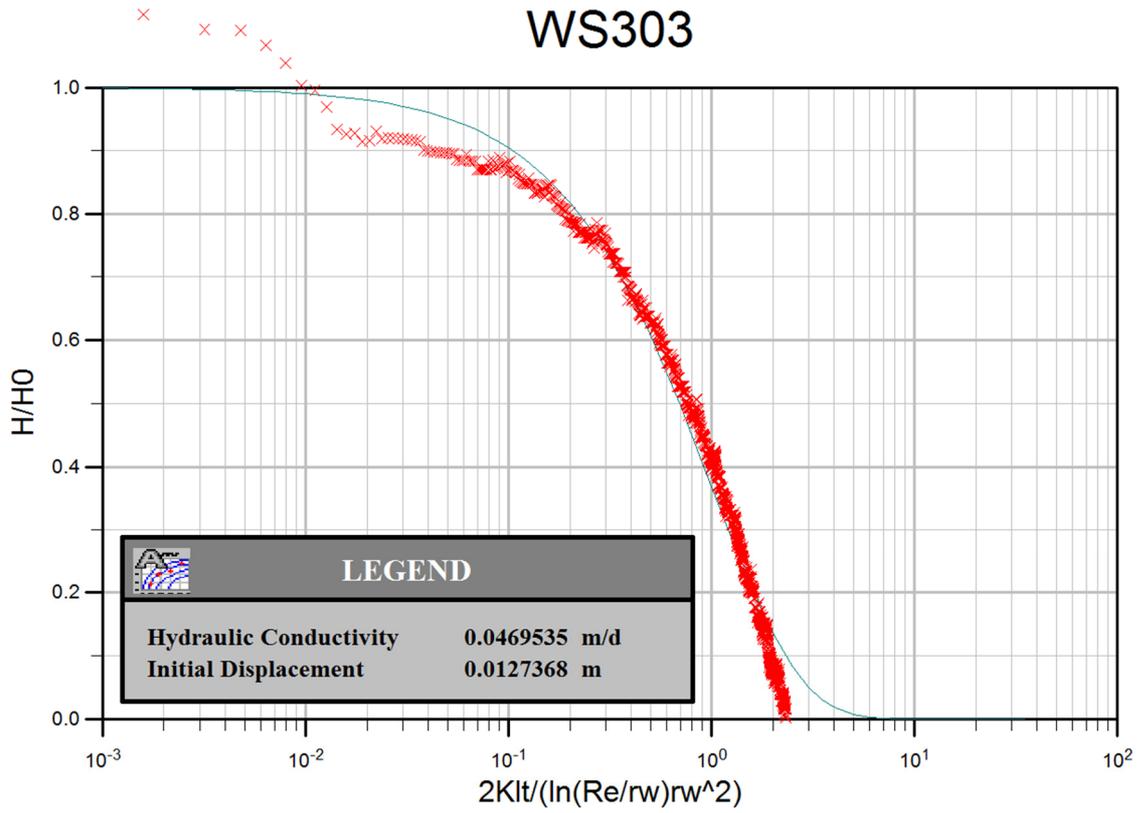
Graph 17 - Hydraulic conductivity type-fit curve for Slug Test 3 of 3 undertaken in WS306a

WS303



Graph 18 - Contextual graph detailing changes in hydraulic head during Slug Testing undertaken on WS303

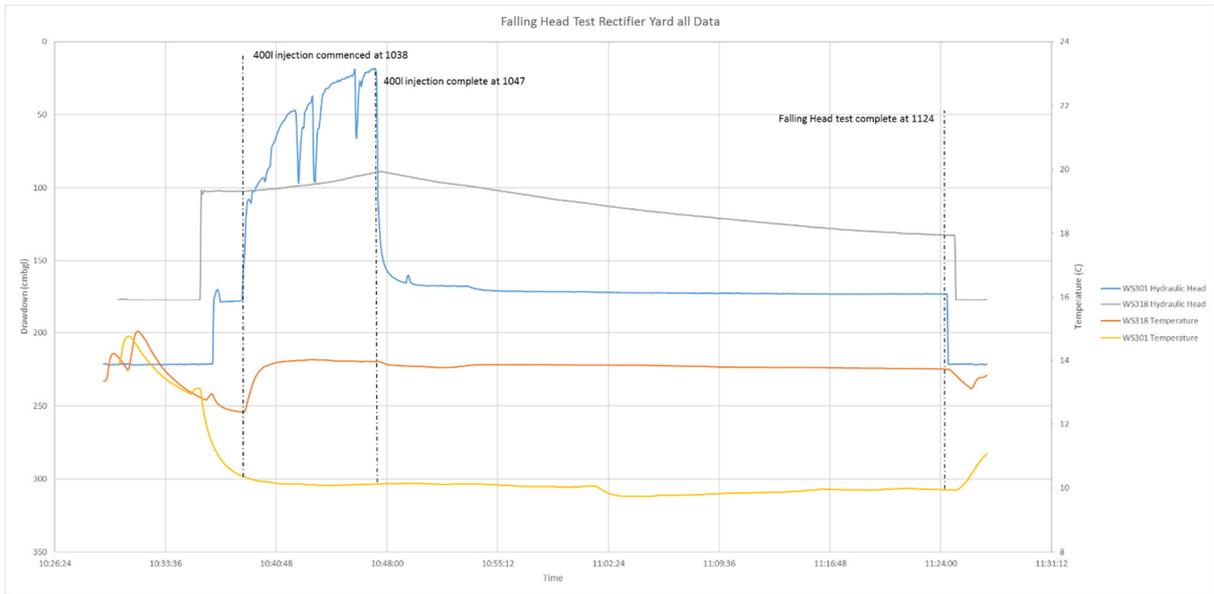
WS303



Graph 19 - Hydraulic conductivity type-fit curve for Slug Testing undertaken on WS303

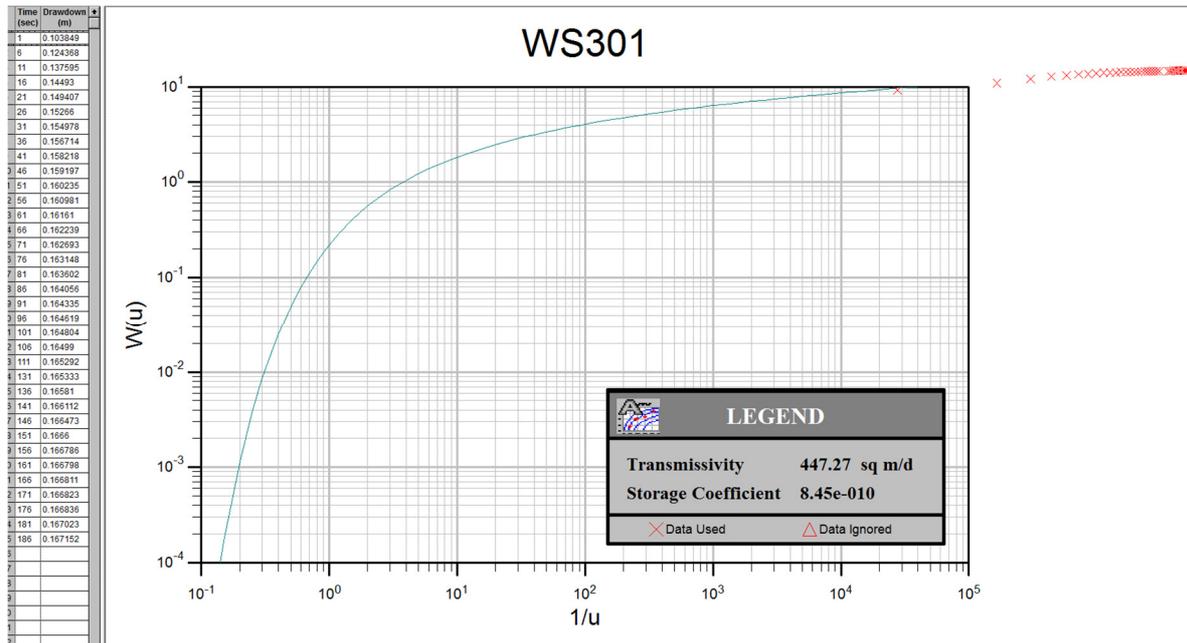
Falling Head Test

WS301



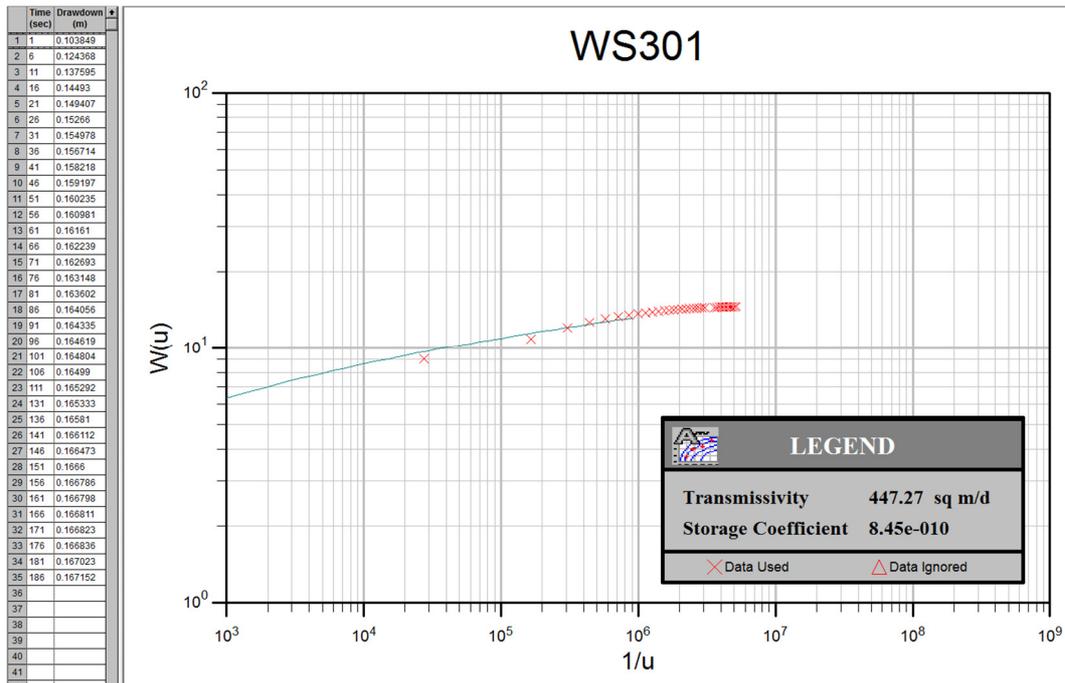
Graph 20 - Contextual graph detailing changes in hydraulic head during the Falling Head Test undertaken on WS301

First run of data:



Graph 21 - Hydraulic Transmissivity type-fit curve constructed using data taken from a Falling Head Test conducted on WS301

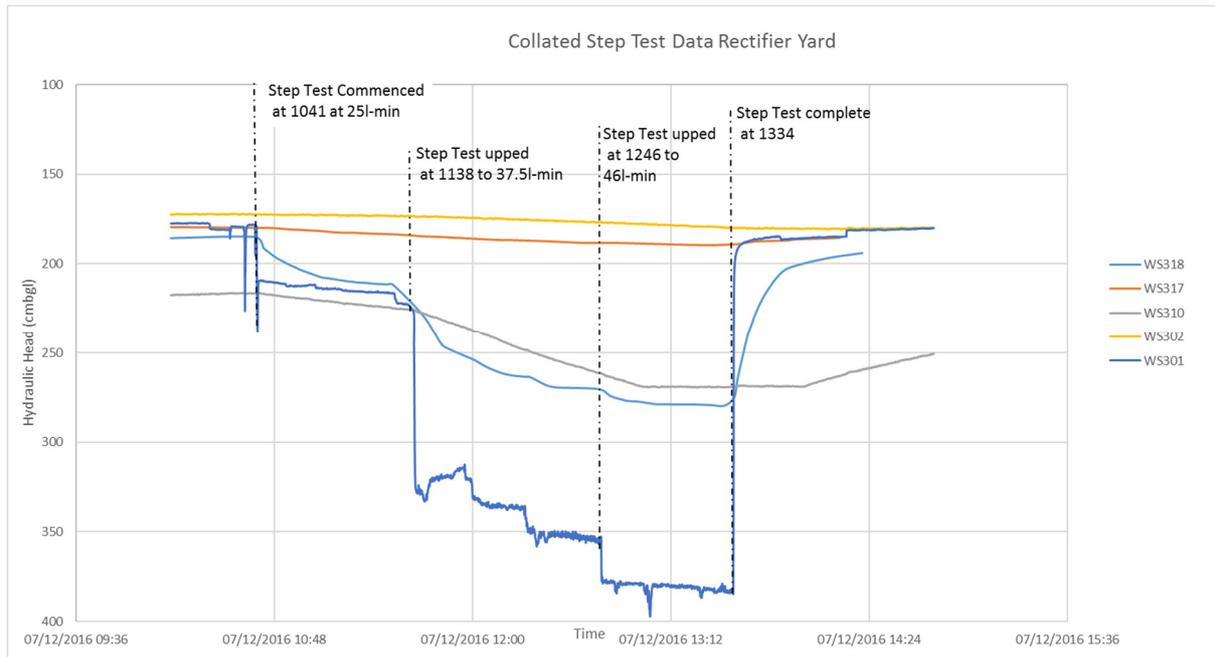
Data further optimised to fit curve:



Graph 22 - Hydraulic Transmissivity type-fit curve constructed using data taken from a Falling Head Test conducted on WS301

Step Test

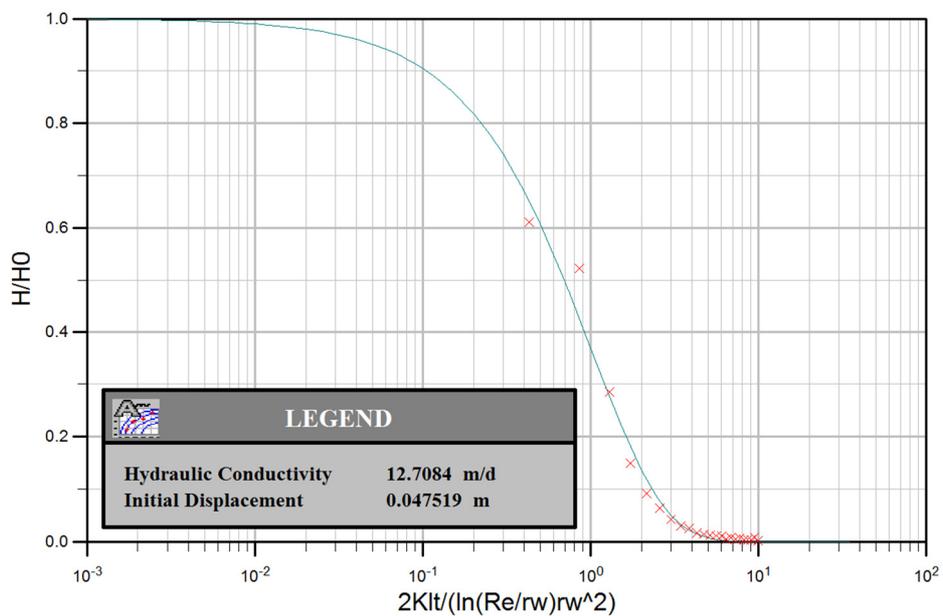
WS301



Graph 23 - Contextual graph detailing changes in hydraulic head during a Step Test undertaken on WS301

Prior to Step Test

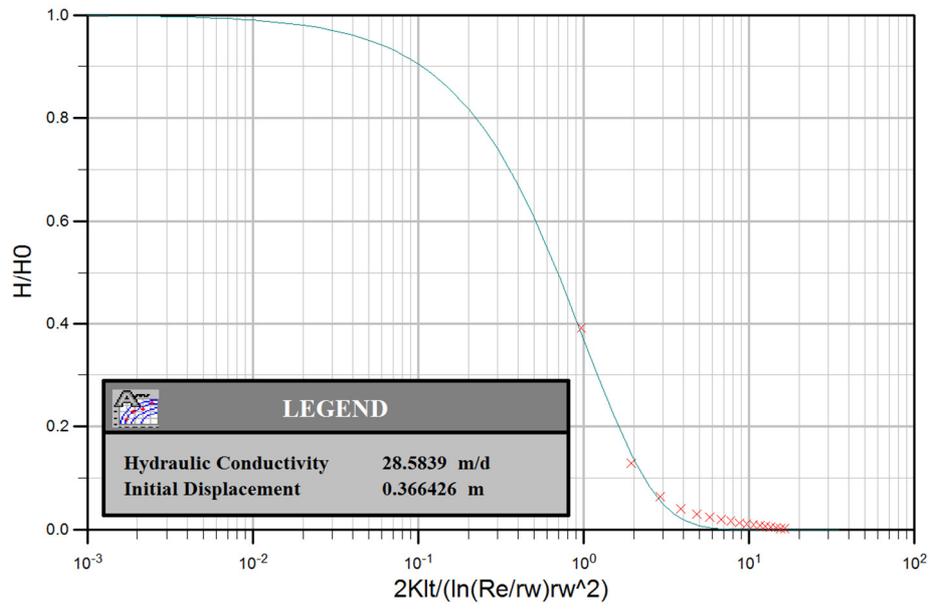
WS301



Graph 24 - Hydraulic Conductivity type-fit curve constructed using data taken prior to the commencement of a Step Test conducted on WS301

Post Step Test

WS301



Graph 25 - Hydraulic Conductivity type-fit curve constructed using data taken at the end of a Step Test conducted on WS301

Appendix F

Treatability Trial

Interactive logs detailing chemical testing results and logging Cores retrieved for the Treatability Trial are available in digital spreadsheet form.

APPENDIX B

CHEMICAL OXIDANT LABORATORY TRIALS REPORT

Anglesey

Laboratory Bench Scale Chemical Oxidation Study

Report A161201
March 2017



Prepared for



Revision Schedule

March 2017

Rev	Date	Details	Prepared by	Reviewed by	Approved by
01	03/2017	Draft	Dr Jamie Cutting	Dr Vanesa Appleby	Dr Jamie Cutting

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The methodology adopted and the sources of information used by CE Geochem in providing its services are outlined in the original Proposal [P161201]. The description of work packages described in this Proposal are based on the information available during the offer period. The scope of the original Proposal and offered services are accordingly factually limited by the availability of factual data and clarifications provided by the client to CE Geochem during the Proposal process.

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Unless otherwise stated in this Report, the assessments made assume that the sites and facilities will continue to be used for their current purpose without significant changes.

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Table of Contents

1	Executive Summary.....	5
2	Introduction	6
2.1	Project Appreciation	6
2.2	Geochemical Test Work Programme.....	6
2.3	Nominated Third-Party Analytical Laboratory Accreditation and Quality Assurance	7
3	Conceptual Technology Design Model	8
4	Experimental Methodology	9
4.1	Sample Selection, Characterisation and Preparation	9
4.2	Matrix Oxidant Demand & Chemical Oxidation Kinetics	9
4.3	Treatability Trials.....	10
5	Preliminary Investigations	12
5.1	Groundwater Characterisation & Aquifer Depth Profiling Studies	12
6	Oxidant Kinetics & Subsurface Travel	15
6.2	Derivation of Oxidant Kinetics	15
6.3	2D Oxidant Travel and Decay Simulations	17
7	Treatability Assessment	24
7.2	Contaminant Destruction.....	24
7.3	C5-C8 TPH	25
7.4	C8-C10 TPH	26
7.5	C10-C12 TPH	26
7.6	C12-C16 TPH	27
7.7	C16-C21 & C21-C35 TPH	27
7.8	Residual Sorbed Phase Mass	33
7.9	Chemical Oxidation Performance Summary.....	33
8	Trace Element Leaching Assessment.....	35
9	Conclusions & Recommendations.....	37
	Appendix A <i>Certificates of Analysis</i>	38
	Appendix B <i>Data Interpretations</i>.....	39

1 Executive Summary

CE Geochem have been commissioned by Geo2 to undertake a laboratory study and prepare an interpretive laboratory report for bench scale treatability trials to assess the feasibility of, and optimise where possible, the deployment of In Situ Chemical Oxidation (ISCO) groundwater treatment technology for an undisclosed site on Anglesey, Wales, UK.

3 No. candidate oxidant-activator systems were assessed for 2 No. different aquifer matrices. Candidate oxidants included persulphate, both with and without peroxide as an activator, and hydrogen peroxide alone as a single oxidant system.

Kinetic studies were used to derive pseudo-first order rate constants for oxidant utilisation in the presence of the target aquifer matrix under a suite of potential oxidant loading concentrations and during treatability trials. Site specific half-lives for oxidant decomposition were computed from the experimentally derived rate constants. The relatively high groundwater travel velocities present within the target aquifers favour the application of high energy oxidants demonstrating rapid decomposition kinetics. The use of peroxide based chemical oxidation techniques will ensure source zones are not bypassed due to the low residence times that may be encountered.

6 No. candidate oxidant systems were investigated for contaminant destruction profiling in order to assess the extent of target contaminant destruction. Persulphate was added at the respective Total Oxidant Requirement (TOR) with, and without peroxide as an activator and also at 2 x TOR, with and without peroxide as an activator. In addition, peroxide trialled at application rates of 2% and 5%. Chemical oxidation systems were investigated for 2 No. aquifer matrices; composited Garage and Compressor samples (GC) and also an aquifer matrix composed of the Rectifier (R) area.

Treatability study datasets showed that greatest oxidant efficacy was achieved for peroxide systems. Both low (2%) and high-range (5%) peroxide systems demonstrated similar destruction efficacies across the full range of TPH fractions present. Dissolved phase contaminant destruction profiles suggest that peroxide systems may enhance the dissolution of free phase NAPL components where present at the subject site, enable contaminant mass mineralisation in the dissolved phase. No rebound was observed for peroxide system, a feature that was encountered over extended time, for both of the trialled persulphate oxidant systems.

In contrast to peroxide activated persulphate, single oxidant peroxide applications provided circum-neutral reaction conditions, effectively limiting any trace metal release that may be associated with low pH ISCO technologies such as the dual oxidant, peroxide activated persulphate system investigated in this study.

Based on available datasets, and in particular the predicted rapid sub-surface reactivity of peroxide, CE Geochem recommend that 2% peroxide be considered the optimum oxidant system for the subject site.

Because peroxide is relatively short-lived in the sub-surface, multiple injections may be administered, based on the residual TPH concentrations following oxidant consumption (circa. 96 hours after injection). This approach should enable specific areas of elevated source mass to be treated sequentially without significant impact on the proposed site works injection programme.

2 Introduction

2.1 Project Appreciation

2.1.1 Geo2 have commissioned CE Geochem to undertake a bench-scale chemical oxidation study to assess the feasibility of deploying optimised oxidant-activator systems for achieving remedial betterment at the subject site (undisclosed). This chemical oxidation study has been completed in order to develop a detailed design for the treatment of groundwater contaminants.

2.2 Geochemical Test Work Programme

2.2.1 The geochemical test work programme has included the following core components;

- Groundwater and aquifer characterisation
 - Depth profiling study to assess subsurface contaminant distribution and identify target aquifer compartments for this study
 - Matrix Oxidant Demand (MOD) testing and the derivation of oxidant half-lives from pseudo-first order rate laws
 - Contaminant destruction profiling for selected oxidant-activator systems with assessment of transition products, daughter products and rebound potential
- 2.2.2 Persulphate decomposition / utilisation rates under hydrogen peroxide activated and native (unactivated) conditions, in addition to peroxide decomposition / utilisation rates, were assessed through initial MOD investigations.
- 2.2.3 The two aquifer matrices investigated, were designated as GC, which comprised representative aquifer matrix and groundwater samples from both the Garage and Compressor area, and R, which relates to the Rectifier area.
- 2.2.4 Test work samples used in this study may be regarded as; weathered schist comprising horizons of gravel, sand and silt.
- 2.2.5 The selection of trial oxidant-activator stoichiometries was based on providing appropriate oxidant mass to destroy the source contaminant mass, persulphate based oxidant chemistries selected to promote greater oxidant longevity if required in lower permeability strata. The chemical oxidation studies were replicated for the both GC and R materials.

I. Persulphate at TOR

II. Persulphate at 2 x TOR

III. Peroxide activated Persulphate at TOR

IV. Peroxide activated Persulphate at 2 x TOR

V.Peroxide at 2%

VI.Peroxide at 5%

2.3 Nominated Third-Party Analytical Laboratory Accreditation and Quality Assurance

- 2.3.1 Chemtest is accredited to the ISO17025 International Standard *General Requirements for the Competence of Testing and Calibration Laboratories* (Lab Ref. 2183), for those tests that are so identified and listed on our current UKAS schedule. ISO17025 accreditation also demonstrates that our Quality Management System operates in accordance with the principles of ISO9001.
- 2.3.2 In addition to ISO17025, the laboratory is accredited to the EA MCERTS *Performance Standard for Laboratories Undertaking Chemical Testing of Soil* and MCERTS *Performance Standard for Organisations Undertaking Sampling and Chemical Testing of Water*. MCERTS accredited tests are also detailed on our UKAS schedule, available from the UKAS website.
- 2.3.3 Quality Control in the laboratory is ensured by a comprehensive system of internal and external QC measures. This includes the use of Certified Reference Materials (CRMs) in method validation and routine Analytical Quality Control (AQC) by means of in-house QC samples, independent AQC standards and blanks, as appropriate to the method and to satisfy the requirements of the accreditation held.
- 2.3.4 Inter-laboratory Proficiency Testing (PT) studies, notably the LGC CONTEST, LGC Aquacheck and DEFRA LEAP schemes, are participated in for a wide range of determinands and the resulting proficiency scores scrutinised by means of internal quality system procedures, in order to affirm fitness for purpose of the relevant tests.
- 2.3.5 Analytical results are controlled by means of AQC data subject to statistically derived limits and plotted on Shewhart control charts. These charts are reviewed regularly to monitor on-going method performance and are, where applicable, subject to the QC limits for bias and precision specified by the MCERTS standard.

3 Conceptual Technology Design Model

- 3.1.1 For the purpose of assessing the potential deployment of In Situ Chemical Oxidation (ISCO) techniques at the subject site, CE Geochem have conceptualised the hydrogeological system as an unconfined superficial aquifer, composed primarily of drift deposits.
- 3.1.2 The underlying geology schist, a medium grained metamorphic bedrock, overlain by variable thicknesses of unconsolidated superficial deposits.
- 3.1.3 The conceptual design model considers rockhead will act as the impermeable base of the superficial aquifer systems to be targeted for treatment. Hydrogeological site investigations undertaken by Geo2 during 2016, have characterised the unconsolidated drift deposits as relatively high permeability groundwater systems, which may be locally variable.
- 3.1.4 The saturate thickness of superficial deposits is taken as defining the mixing zone depth of site injection protocols. Table 3.1 provides information used to determine the saturated zone thickness for relevant areas of the subject site.
- 3.1.5 The main hydrogeological compartments are presented in Table 3.1 below.

Hydrogeological Unit	Depth to groundwater (m)	Depth to rockhead (m)
Rectifier Area	1.7-1.8	2-2.5
Compressor Area	2.8-3.3	2.3-5.8

Table 3.1 Data used for computation of mixing zone depths.

- 3.1.6 It is important to note that the underlying schists have been identified as a physical barrier to the vertical component of contaminant migration, with an assumed low vertical permeability. This defines the only treatment zone as the overlying drift.
- 3.1.7 Based on the maximum saturated thickness above rockhead we calculate mix zone depths of 0.8m in the Rectifier area and 3.0m in the Compressor area.
- 3.1.8 Average hydraulic conductivities for the compressor area were determined to be 180m/day (n=3 locations), whilst the average for the Rectifier area was determined to be 10m/day (n=5 locations).
- 3.1.9 Due to the relatively high groundwater travel velocity in the target aquifer, the selection of short-lived, high energy peroxygenic compounds may be favoured as an ISCO groundwater treatment technique at the subject site.
- 3.1.10 Please see Appendix B for interactive depth profiling logs which provide litho-geochemical details for sub-surface contaminant mass distribution.

4 Experimental Methodology

4.1 Sample Selection, Characterisation and Preparation

- 4.1.1 All samples used in this study were provided by Geo2. An initial test work composite was formed from the Garage, Compressor, and Rectifier area for Matrix Oxidant Demand studies. Separate homogenised test work composites were produced for the Garage and Compressor (GC) areas, and the Rectifier (R) area, for use in Treatability Trials.
- 4.1.2 3 No. discrete 20L Groundwater samples from the Garage, Compressor and Rectifier areas, respectively, were received from Geo2 and composites of Garage and Compressor samples were prepared for GC Treatability Trials. GW samples from the Rectifier area were used exclusively for R treatability trials.
- 4.1.3 Source characterisation studies were undertaken on frozen intact cores, sampled at 100mm depth intervals throughout the full depth of recovered cores. All core samples were stored at -20°C prior to sectioning, logging and sampling. Source term characterisation certificates of analysis are presented in Appendix A with Interactive Depth Profiling Logs provided in Appendix B.
- 4.1.4 Soil source characterisation was undertaken on the homogenised composite test work sample produced from the Garage and Compressor areas, and the discrete sample from the Rectifier area. Certificates of Analysis are presented in Appendix A.
- 4.1.5 Groundwater characterisation datasets were undertaken on unfiltered groundwater samples from all three areas. Certificates of analysis are presented in Appendix A.
- 4.1.6 Mineralogical and major elemental composition determined by X-Ray Diffraction (XRD) and X-Ray Fluorescence Spectrometry (XRF), respectively. Analyses were carried out on a dried and ground sub-sample recovered from the composited GC test work sample. Results are presented in Appendix C. This sample was selected to represent geological materials of greatest interest to this study in terms of the host mineralogy likely to be provide subsurface reactivity within the aquifer matrix.

4.2 Matrix Oxidant Demand & Chemical Oxidation Kinetics

- 4.2.1 Aquifer Matrix Oxidant Demand (MOD) curves were generated using a derivative method of ASTM D7262-07 at slurry densities of 50 w/w % for oxidant loadings of 0, 5, 10, 20, 35 and 50 g/l in deionised water (ASTM Type II – 15 MΩ),
- 4.2.2 Oxidant demand testing was conducted under ambient temperature and pressure with continual agitation on a Gyro-rocker platform at 40 rpm. All MOD testing was performed in 250 ml glass erlenmyeyer flasks with supernatant recovery by centrifugation for sub-samples collected at time (t) = 24, 96, 168, 240, & 336 hours for persulphate oxidant systems and (t) = 6, 24, 48 hours for peroxide oxidant systems. Residual oxidant concentrations were determined using the iodometric spectrophotometric method of Liang, 2008.

- 4.2.3 pH, Eh, and EC were also determined for each time point.
- 4.2.4 The experimental matrix employed is shown in Table 4.1.
- 4.2.5 Datasets were used to derive first order rate constants and absolute MOD in g/kg and mol/kg. MOD datasets are presented in Appendix B

Oxidant – Activator System	Activator	Oxidant Mass (g/l)				
<i>Persulphate</i>	-	5	10	20	35	50
<i>Peroxide Activated Persulphate</i>	5g/L Peroxide	5	10	20	35	50
<i>Peroxide</i>		5	10	20	35	50

Table 4.1 MOD and oxidant kinetics experimental matrix

4.3 Treatability Trials

- 4.3.1 Chemical Oxidation (Chemox) treatability trials were conducted in continuous batch mode at room temperature under sealed headspace conditions. All chemox investigations employed a 20 w/w % aquifer matrix slurry density.
- 4.3.2 Chemox experiments were conducted for each of the identified hydrogeological systems (GC or R), employing 2000 ml glass reactors for assessing the destruction of 8-band TPH. Residual dissolved phase metals were analysed in each reactor system at the final time point. All reactors were hermetically sealed using PTFE bound threads to prevent gaseous exchange with atmosphere.
- 4.3.3 Residual oxidant concentrations, pH, Eh and EC were also monitored at each sampling point.
- 4.3.4 Residual aquifer matrices were recovered by centrifugation at time (t) = 672 hours for persulphate oxidant systems and (t) = 96 hours for peroxide oxidant systems, to allow residual source mass determination.
- 4.3.5 The chemox experimental matrix is shown in Table 4.2.

Chemox System	Chemox Reactor	Oxidant (g/l)	Activator Chemistry
<i>Control</i>	1(9)		
<i>Duplicate Persulphate TOR</i>	2(10)	3.81	
<i>Persulphate TOR</i>	3(11)	3.81 (12.63)	
<i>Persulphate 2 x TOR</i>	4(12)	7.62 (25.26)	
<i>Persulphate TOR / Peroxide</i>	5(13)	17.41 (26.23)	5g/L H ₂ O ₂
<i>Persulphate 2 x TOR/ Peroxide</i>	6(14)	34.82 (52.46)	5g/L H ₂ O ₂
<i>Peroxide 2%</i>	7(15)	20	
<i>Peroxide 5%</i>	8(16)	50	

Table 4.2 Chemox Experimental Matrix. Chemox Reactors and Oxidants in ()'s relate to Rectifier matrix and groundwater whereas non-bracketed reactor ID's relate to the Garage/Compressor composite matrix and groundwater.

- 4.3.6 Oxidant masses employed were calculated as Total Oxidant Requirements (TOR) based on the Stoichiometric Oxidant Demand (SOD) for dissolved phase & sorbed phase TPH + Matrix Oxidant Demand (MOD) from MOD determinations.
- 4.3.7 Chemox reactors were sampled at time (t) = 0, 24, 96, 168, 336 & 672 hours for persulphate oxidant systems, and (t) = 0, 6, 24, 48 & 96 hours for peroxide oxidant systems.
- 4.3.8 Sub samples were collected from below the aqueous phase surface, to ensure analytical datasets relate exclusively to dissolved phase concentrations. TPH extractions were undertaken immediately following sampling using a 40:1 liquid-liquid pentane extraction technique to immediately quench chemical oxidation samples. All certificates of analysis are presented in Appendix A.

5 Preliminary Investigations

5.1 Groundwater Characterisation & Aquifer Depth Profiling Studies

5.1.1 Source term characterisation was conducted on bulk samples recovered by Geo2 from intrusive locations representative of the Garage, Compressor and Rectifier areas. Source characterisation data for the Garage and Compressor area relate to the homogenised composite test work sample. Datasets for the composited Garage & Compressor (GC) and Rectifier (R) are presented in Table 5.1. No VOC components were detected in either test work sample.

5.1.2 Depth profiling investigations are presented in Appendix B as interactive Excel™ files.

Determinand	Units	LOD	GC	R
Moisture	%	0.020	11	8.9
Acid Neutralisation Capacity	mol/kg	0.0020	0.071	0.069
Calcium	mg/l	20	2300	1500
Sodium	mg/l	2.0	70	31
Iron (Total)	mg/kg	100	20000	21000
Arsenic	mg/kg	1.0	5.6	4.0
Cadmium	mg/kg	0.10	< 0.10	< 0.10
Chromium	mg/kg	1.0	26	22
Copper	mg/kg	0.50	35	160
Mercury	mg/kg	0.10	< 0.10	< 0.10
Manganese	mg/kg	5.0	710	640
Nickel	mg/kg	0.50	34	31
Lead	mg/kg	0.50	6.9	5.7
Selenium	mg/kg	0.20	< 0.20	< 0.20
Vanadium	mg/kg	5.0	23	19
Zinc	mg/kg	0.50	71	67
Total Organic Carbon	%	0.20	0.46	0.22
TPH >C5-C6	mg/kg	1.0	< 1.0	< 1.0
TPH >C6-C7	mg/kg	1.0	< 1.0	< 1.0
TPH >C7-C8	mg/kg	1.0	< 1.0	< 1.0
TPH >C8-C10	mg/kg	1.0	< 1.0	< 1.0
TPH >C10-C12	mg/kg	1.0	< 1.0	< 1.0
TPH >C12-C16	mg/kg	1.0	< 1.0	25
TPH >C16-C21	mg/kg	1.0	< 1.0	280
TPH >C21-C35	mg/kg	1.0	< 1.0	150
Total TPH >C5-C35	mg/kg	10	< 10	450

Table 5.1. Source term concentrations for target contaminants identified within the test work sample composites. All data presented to 2 significant figures. VOC data not presented.

5.1.3 As can be seen by inspection of Table 5.1, target contaminants are identified as TPH in the area R only. The inorganic composition of both test work matrices was fairly consistent,

with circa. 2 wt.% Fe and an ANC of circa. 0.07 mol/kg. Due to the similarity between both areas, MOD testing was undertaken on a composite test work sample formed from the Garage, Rectifier and Compressor bulk samples.

- 5.1.4 TPH source term mass in the R test work matrix was predominately composed of large chain hydrocarbons spanning C12-C35, with a Total TPH concentration of 450 mg/kg. No TPH was detected in the GC composite test work matrix.
- 5.1.5 Groundwater source characterisation datasets for the 3 No. areas under investigation are presented in Table 5.2 below.
- 5.1.6 Dissolved phase TPH, predominately C12-C21 is present within G and R groundwaters, however TPH was below analytical detection limits for Area C. Low levels of benzene and toluene were detected in area G. Due to the limited dissolved phase source term mass of VOCs, these compounds were excluded from treatability studies.
- 5.1.7 Ground water test work composites were formed by compositing G and C samples at 50:50 ratio, whereas trials conducted on area R were taken from the homogenised groundwater bulk sample as received.

Determinand	Units	LOD	C	G	R
pH		N/A	8.4	8.4	7.8
Electrical Conductivity	µS/cm	1.0	640	630	450
Chemical Oxygen Demand	mg O2/l	10	29	78	180
Alkalinity (Total)	mg CaCO3/l	10	210	290	190
Chloride	mg/l	1.0	44	34	27
Sulphate	mg/l	1.0	46	24	7.8
Calcium	mg/l	5.0	28	50	72
Sodium	mg/l	0.50	100	49	14
Arsenic (Dissolved)	µg/l	1.0	1.0	1.9	< 1.0
Cadmium (Dissolved)	µg/l	0.080	< 0.080	0.082	< 0.080
Chromium (Dissolved)	µg/l	1.0	< 1.0	< 1.0	< 1.0
Copper (Dissolved)	µg/l	1.0	11	4.4	< 1.0
Iron (Dissolved)	µg/l	20	83	160	230
Mercury (Dissolved)	µg/l	0.50	< 0.50	< 0.50	< 0.50
Manganese (Dissolved)	µg/l	1.0	49	1600	3500
Nickel (Dissolved)	µg/l	1.0	1.0	2.5	< 1.0
Lead (Dissolved)	µg/l	1.0	< 1.0	< 1.0	< 1.0
Selenium (Dissolved)	µg/l	1.0	1.3	2.2	< 1.0
Vanadium (Dissolved)	µg/l	1.0	< 1.0	< 1.0	< 1.0
Zinc (Dissolved)	µg/l	1.0	3.6	4.0	8.0
Manganese [II]	µg/l	1.0	62	1400	4200
Iron [II]	µg/l	20	< 20	< 20	310
Dissolved Organic Carbon	mg/l	2.0	11	23	68
TPH >C5-C6	µg/l	0.10	< 0.10	< 0.10	< 0.10
TPH >C6-C7	µg/l	0.10	< 0.10	< 0.10	< 0.10
TPH >C7-C8	µg/l	0.10	< 0.10	< 0.10	< 0.10
TPH >C8-C10	µg/l	0.10	< 0.10	10	2.8
TPH >C10-C12	µg/l	0.10	< 0.10	140	33

Determinand	Units	LOD	C	G	R
TPH >C12-C16	µg/l	0.10	< 0.10	870	280
TPH >C16-C21	µg/l	0.10	< 0.10	940	660
TPH >C21-C35	µg/l	0.10	< 0.10	190	320
Total TPH >C5-C35	µg/l	10	< 10	2100	1300
Benzene	µg/l	1.0	< 1.0	13	< 1.0
Toluene	µg/l	1.0	< 1.0	52	< 1.0

Table 5.2. Groundwater characterisation data for areas G, C and R. All VOC compounds with the exception of benzene and toluene were reported below LOD and are not presented.

- 5.1.8 As presented in Table 5.2, groundwater's are circum-neutral with a a relatively low COD, consistent with the low DOC levels reported. Elevated concentrations of dissolved divalent iron and manganese, likely generated through dissolution of iron and manganese aquifer minerals may provide the basis for in situ activation chemistries in G and R areas. Corresponding dissolved phase trace metal concentrations are relatively low, all within expected natural background geochemical baseline concentrations.
- 5.1.9 X-Ray Diffraction (XRD) data revealed that the aquifer matrix is predominantly composed of quartz and ferroan clinochlore with minor components of albite muscovite. We assume that Fe groundwater concentrations are linked to the dissolution of ferroan clinochlore.
- 5.1.10 X-Ray Fluorescence (XRF) data confirms the predominance of silicon and aluminosilicate-iron based phases. XRF data is presented for both major and trace elements in Appendix A.
- 5.1.11 Based on the available data presented above we would generally not anticipate that matrix derived rebound effects from sorbed phase contaminant mass would liberate significant dissolved phase mass.
- 5.1.12 Transient rebound during field applications may however occur when oxidants and/or groundwater pH profiles directly influence the mobilisation of contaminant mass. This may give rise to elevated aqueous phase concentrations both during the onset of ISCO treatment, particularly where peroxide chemistries are used, that provide a potential for gas induced liberation (scrubbing) of TPH from the matrix through decomposition to molecular oxygen. Any dissolved phase rebound is considered to be short-lived due to the low sorbed phase TPH mass present within the target aquifer.

6 Oxidant Kinetics & Subsurface Travel

- 6.1.1 CE Geochem believe the most appropriate treatment of oxidant kinetics is through the derivation of pseudo-first order rate constants to allow the estimation of half-lives that can subsequently be used for analytical fate and transport simulations. This approach provides a consistent framework for comparing different oxidant travel times and provides an insight into the likely local oxidation potential provided at distance from the injection well, assuming a homogeneous isotropic aquifer model.
- 6.1.2 The use of single value Matrix Oxidant Demand (MOD) parameters, although convenient, is limited to only providing a single point estimate of oxidant utilisation over a known time period. These empirical values cannot easily or robustly be extrapolated and provide no basis for assessing oxidant utilisation v travel velocities. The use of the MOD approach is typically best suited to kinetically slow oxidants such as persulphate. Peroxide systems undergo complete decomposition, hence the total oxidant mass utilised needs to be reconciled with kinetic rates in order to provide a benchmark for assessing matrix oxidant demand across multiple oxidant systems.

6.2 Derivation of Oxidant Kinetics

- 6.2.1 A summary of rate constants and half-lives derived from MOD tests are provided in Table 6.1 below.
- 6.2.2 Half-lives have been generated from pseudo-first order rate constants from linearization of $\ln(A)$ over t plots, where A is residual oxidant mass.
- 6.2.3 Both persulphate and peroxide activated persulphate datasets demonstrate reasonable regression statistics for the aforementioned kinetic rate laws. Both systems demonstrated initial oxidant concentration dependence on the experimentally derived rate constant, as can be seen from inspection of Table 6.1. It is noteworthy that persulphate in the absence of activation showed a plateau in oxidant utilisation rates after time (t) = 96 hours.
- 6.2.4 Persulphate utilisation in peroxide activated systems is significantly faster than persulphate alone, particularly at low persulphate loading where the peroxide : persulphate ratio is higher. All peroxide activated persulphate systems exhibit a persulphate dependant pH reduction which appears to recover to circum-neutral conditions following the complete consumption of persulphate as shown by 10g/l persulphate systems. Higher persulphate loadings do also show a general recovery of pH over extended time, however all systems with Co persulphate concentrations >10 g/l remained net acidic.
- 6.2.5 Peroxide MOD test systems showed no acidification. Oxidant consumption rates provide an excellent fit to pseudo-first order reaction kinetics, which are both rapid and complete within 96 hours. Typical half-lives are estimated to range from 4.7-5.8 hours.
- 6.2.6 MOD datasets with pseudo-first order kinetic plots are presented in Appendix B.

	Persulphate				
	5g/l	10g/l	20g/l	35g/l	50g/l
Matrix Oxidant Demand (g/kg)	3.8	5	8.5	14	17.65
Matrix Oxidant Demand (mol/kg)	0.0160	0.0210	0.0357	0.0588	0.0742
1st Order Rate Constant (k)	4.09E-04	3.09E-04	2.35E-04	1.95E-04	1.63E-04
Regression Stat for k (R2)	0.877	0.870	0.835	0.706	0.716
Persulphate Half-life (hours)	1693.8	2243.2	2944.1	3558.5	4251.6
Persulphate Half-life (days)	70.6	93.5	122.7	148.3	177.1
	Peroxide				
	5g/l	10g/l	20g/l	35g/l	50g/l
Matrix Oxidant Demand (g/kg)	25	50	100	175	250
Matrix Oxidant Demand (mol/kg)	0.1050	0.2101	0.4202	0.7353	1.0504
1st Order Rate Constant (k)	N.A.	1.49E-01	1.19E-01	1.25E-01	1.56E-01
Regression Stat for k (R2)	N.A.	0.999	0.994	0.999	0.991
Peroxide Half-life (hours)	N.A.	4.7	5.8	5.5	4.4
Peroxide Half-life (days)	N.A.	0.2	0.2	0.2	0.2
	Peroxide activated Persulphate				
	5g/l	10g/l	20g/l	35g/l	50g/l
Matrix Oxidant Demand (g/kg)	25	50	85.65	121.5	119.7
Matrix Oxidant Demand (mol/kg)	0.1050	0.2101	0.3599	0.5105	0.5029
1st Order Rate Constant (k)	2.20E-02	3.17E-02	1.81E-03	7.61E-04	5.50E-04
Regression Stat for k (R2)	1.000	0.760	0.625	0.920	0.855
Persulphate Half-life (hours)	31.5	21.8	383.2	911.1	1260.2
Persulphate Half-life (days)	1.3	0.9	16.0	38.0	52.5

Table 6.1. Derived Oxidant half-lives for persulphate, peroxide and peroxide activated persulphate decomposition using a mixed G,C and R aquifer matrix..

- 6.2.7 The derivation of oxidant-activator-matrix specific rate constants has enabled scoping calculations for estimating the Radius of Influence (RoI) for different candidate oxidant systems. This approach allows visualisation of sub surface oxidant distribution for specific oxidant application rates.
- 6.2.8 It should be recognised that MOD testing is undertaken using a deionised water matrix rather than groundwater. This approach is employed to specifically investigate matrix mediated oxidant decomposition rates. Due to the elevated dissolved Fe(II) load in native groundwater at the subject site, kinetic rates may be higher than those reported here.
- 6.2.9 Due to the high permeability of the target aquifer, the favoured oxidant systems should ideally undergo relatively rapid decomposition kinetics in order that the oxidant delivers treatment within the affected source zone. Slower decomposition rates for oxidants such as persulphate, may lead to the oxidant by-passing the target aquifer compartment as residence times may be unsuitable.
- 6.2.10 Trial oxidant selection is based on the observed lithological characteristics of the target aquifer compartment, which showed little evidence of sorbed phase contaminant mass. This suggests that the majority of mass destruction should be possible through aqueous phase reactions and that the slower long term diffusion of oxidants into low permeability lithologies is not required or desirable at the subject site.
- 6.2.11 Optimum oxidant systems for the subject site are considered to be those displaying higher energy rapid kinetics, specifically peroxide or peroxide activated persulphate. Peroxide is considered for immediate source mass destruction through the delivery of high energy oxidation potentials. The high oxidation potentials created by peroxide will influence direct redox coupling and contaminant mineralisation, whilst also delivering relatively short lived free radical attack species in close proximity to the injection wells. This approach also includes peroxide activated persulphate as a dual oxidant system (Caros acid type) which, by reference to Table 6.1, demonstrated accelerated oxidant kinetics relative to persulphate alone.

6.3 2D Oxidant Travel and Decay Simulations

- 6.3.1 2D oxidant travel and decomposition has been modelled using the following analytical governing equation to visualise the radius of influence for peroxide and persulphate under the assumption of an isotropic aquifer system. These simulations assume 10 % dispersivity along the primary flow axis (α_x) and 1% dispersivity perpendicular to primary flow (α_y).
- 6.3.2 Simulations for the Rectifier and Compressor areas are based on site specific hydraulic conductivity data provided by Geo2 of 10 m/day and 180 m/day respectively. Modelling is based on the assumptions of an isotropic aquifer system comprising porous media with 40 % effective porosity. The simulations are based on an instantaneous mass injection as a line source at the injection well. Please note that these simulations have been undertaken to model absolute mass injections required to produce oxidant concentrations at distance (x,y), after (t) hours following injection.

6.3.3 For comparative purposes we present visualisation of oxidant travel at time (t) = 1, 6, 12, 24 for the Rectifier and, 1, 3, 6, 9 hours for the compressor area.

6.3.4 Rectifier area simulations are based on delivering a total oxidant mass equivalent to 1 pore volume of 5% peroxide or 5% persulphate over a 10 m Rol which equates to 160 kg.

$$c_s(x, y, t) = \frac{\Delta M}{4\pi n_e m \sqrt{\alpha_x \alpha_y} t} \exp\left(-\frac{(x - \bar{v}t/R)^2}{4\alpha_x \bar{v}t/R} - \frac{y^2}{4\alpha_y \bar{v}t/R}\right) \exp(-\lambda t)$$

Equation 1. Governing equation for 2D simulations.

6.3.5 Mixing zone depths are assumed to be constrained by rock head and hence provide a barrier preventing the vertical migration of groundwater contaminants. Under this site model we characterise drift deposits as the target aquifer with a maximum saturated thickness of 0.8m in the Rectifier area and 3.0m in the Compressor area.

6.3.6 Figures 6.1 & 6.2 presents Rol simulations for peroxide and peroxide activated persulphate injections in the Rectifier area, assuming an absolute mass injection of 160kg to achieve one pore volume of 5% oxidant, considering a target 10m Rol at 40% effective porosity(n_e).

6.3.7 These simulations are repeated for the higher groundwater conductance zone in the Compressor area, whilst maintaining all other parameters consistent with the Rectifier area simulations; $n_e = 0.4$, $\alpha_x = 2.5m$, $\alpha_y = 0.25m$, $R=1$ (no retardation) and Oxidant Mass =160 Kg. Although 1 pore volume at 5% would require 600 Kg of oxidant for the 3m mixing zone in this area. Preliminary simulations demonstrated that the higher injection mass is unlikely to be beneficial, as the target oxidant concentrations are achieved within the treatment zone by utilising a 160 kg injection. Note the influence of dispersion perpendicular to the flow pathway, which limits the extent of oxidant destruction in the y-axis.

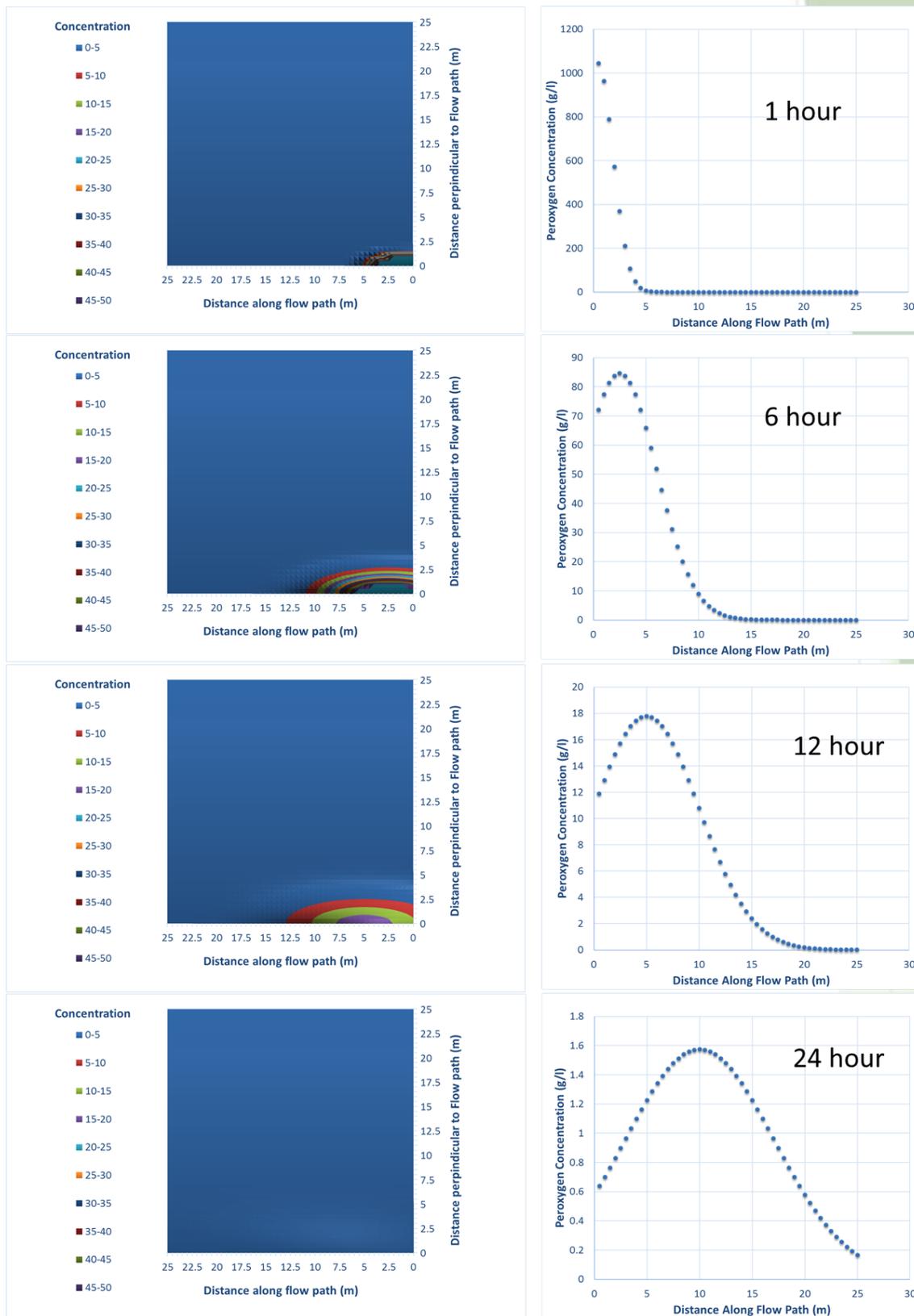


Figure 6.1 Radius of influence for peroxide injections (without activator) within the Rectifier area ($\lambda = 0.2$).

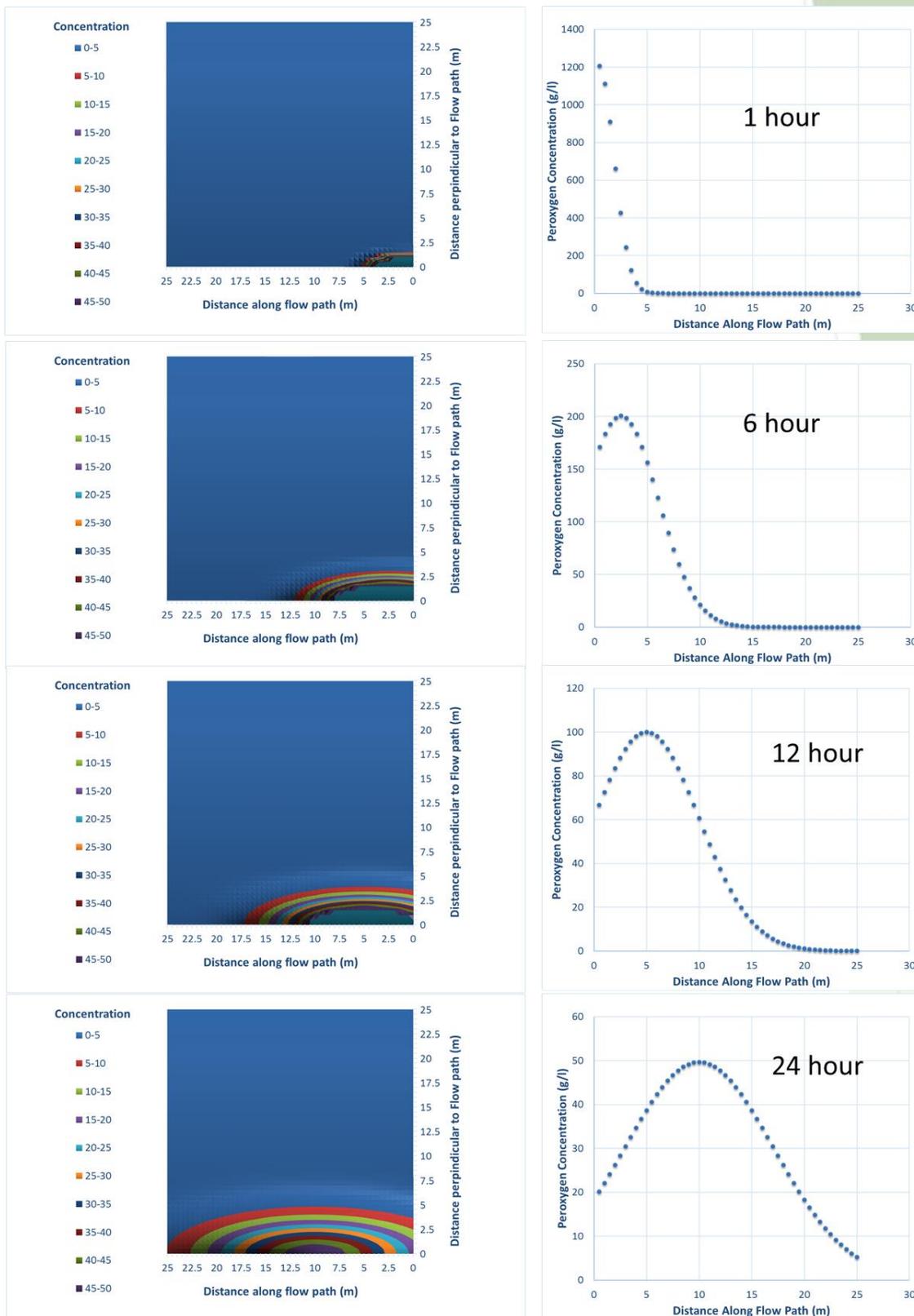


Figure 6.2 Radius of influence for peroxide activated persulphate injections within the Rectifier area ($\lambda = 52.5$).

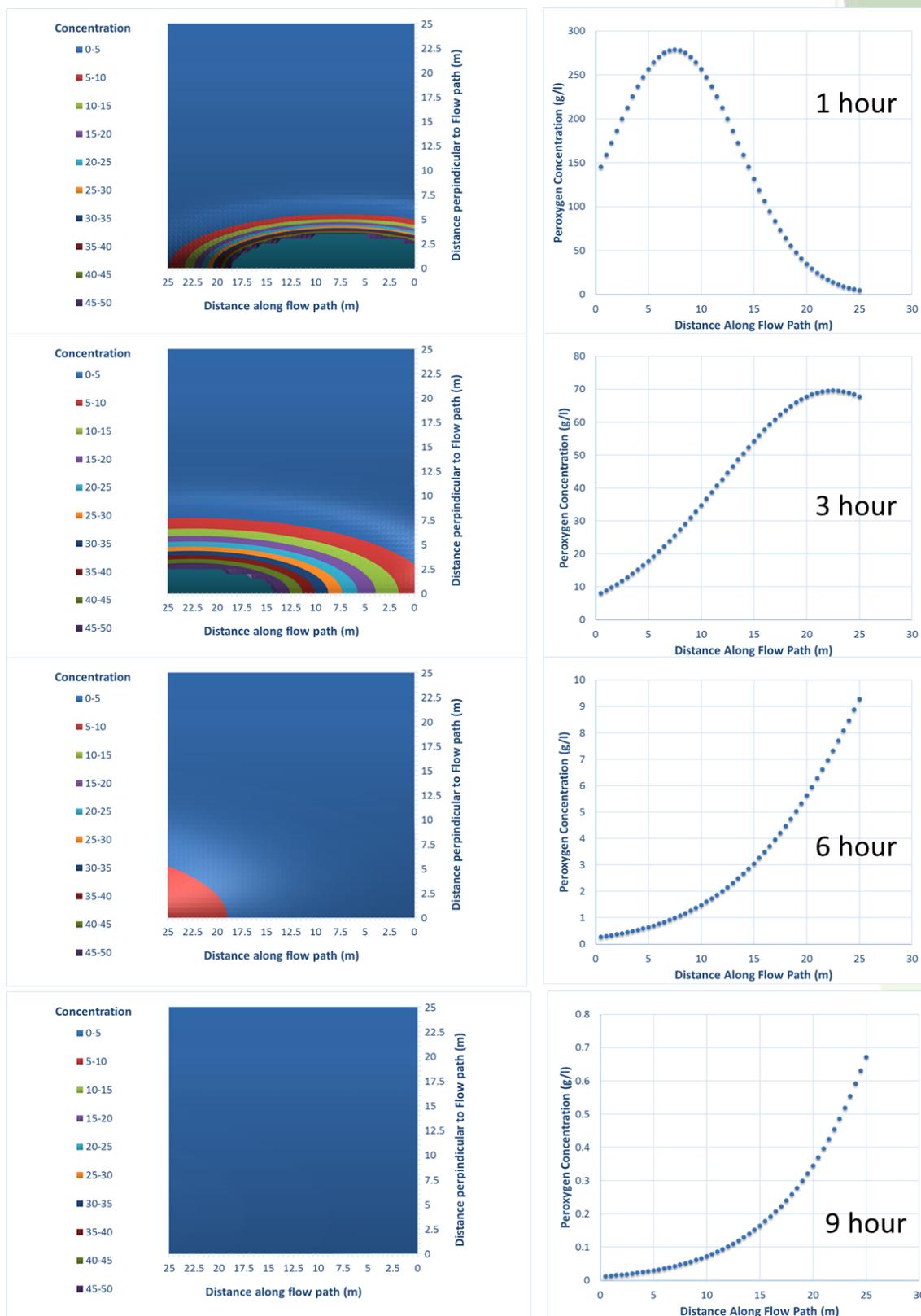


Figure 6.3 Radius of influence for peroxide injections (without activator) within the Compressor area ($\lambda = 0.2$).

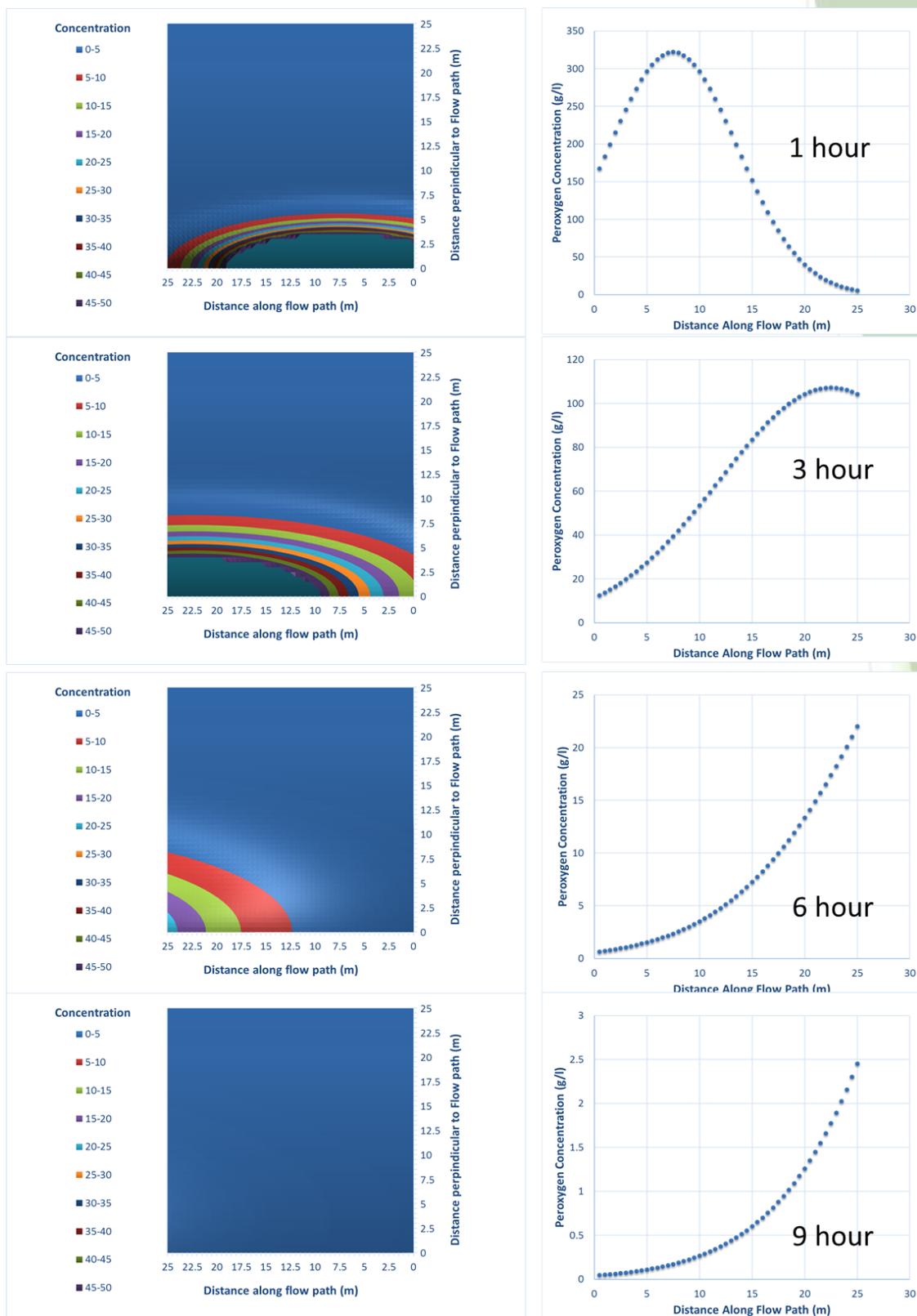


Figure 6.4 Radius of influence for peroxide activated persulphate injections within the Compressor area. ($\lambda = 52.5$).

- 6.3.8 As can be seen from comparison of simulated time slices, based on the experimentally derived half-lives, oxidant systems are expected to remain active within the target groundwater treatment zone of the Rectifier for up to 24 hours, with residence times dictated by decomposition rates rather than groundwater velocity.
- 6.3.9 Peroxyen residence times within the Compressor area however are likely to be dictated by groundwater flow velocity, allow up to circa. 6 hours contact time.
- 6.3.10 It is of interest to note that the radius of influence achieved by peroxide may be up to 45m at 6 hours following injection, whilst still achieving slightly in excess of 2% (22.52 g/l) groundwater peroxide concentrations.

7 Treatability Assessment

- 7.1.1 Treatability investigations are discussed below for the main contaminants of concern; 8-band TPH.
- 7.1.2 Please note that section 8 is dedicated to the interpretation of trace element mobility post chemical oxidation.
- 7.1.3 Details of chemox reactor systems are presented in Table 4.2
- 7.1.4 All experimental chemox reactor systems have been operated to provide bench marking, optimisation and validation for the trialled oxidant system's performance at the subject site. Chemox Reactors 2, 3, 4, 5, 6, 7 and 8 were trialled for persulphate, peroxide activated persulphate and peroxide chemistries on Garage/Compressor composite systems. Reactors 10, 11, 12, 13, 14, 15 and 16 were trialled for persulphate, peroxide activated persulphate and peroxide chemistries for Rectifier systems. Reactor 2 is a duplicate system of chemox reactor 3 and Reactor 10 is a duplicate system of chemox reactor 11. Reactors 1 and 9 act as controls for the Garage /Compressor and for the Rectifier areas respectively.

7.2 Contaminant Destruction

- 7.2.1 An interactive Excel™ workbook presenting contaminant destruction profiles is provided in Appendix B. Only data for the key contaminants previously identified in section 5 are discussed within this section.
- 7.2.2 Please note that dissolved phase sampling was undertaken by inserting a Teflon sampling tube below the surface to avoid any inadvertent inclusion of free phase TPH that may be present within the source groundwater.
- 7.2.3 Although no visual identification of a discrete free phase NAPL was identified during these investigations, a hydrophobic coating of the sampling tube was noted during removal of samples, indicating some NAPL may be present within the groundwater / aquifer slurry matrix.
- 7.2.4 Results are discussed below for each TPH fraction, with an assessment of performance for each of the candidate chemical oxidation systems under investigation for each of the target aquifer types. It should be noted that contaminant destruction in both aquifer systems showed similar responses to specific oxidation systems. We conclude that for the purpose of future ISCO design, both aquifer groundwater systems may be considered under a single groundwater treatment strategy with respect to the selected oxidant.
- 7.2.5 As with the interpretation of any time-variant geochemical process, it must be recognised that analytical datasets from chemical oxidation studies represent a “snap-shot” of transient system conditions at a single point in time. In particular, the influence of chemical oxidation reagents may encourage desorption of target compounds from the test matrix, including the diffusion controlled release of organic contaminants from high surface area substrates such as clays or, particularly in this case, may influence free phase dissolution kinetics.

- 7.2.6 Dissolved phase rebound can occur during chemical oxidation treatment, especially in high surface area (high sorbed mass) matrices or where components occur as a free phase product. This is due to the competing effects of mass transfer (desorption / dissolution) and chemical destruction in the dissolved phase. These processes are most conveniently conceptualised as forward and reverse kinetic reactions. At low oxidant mass, rebound is observed when the forward reaction controlling contaminant destruction in the dissolved phase (chemical oxidation), is exceeded by the rate of production from desorption or dissolution (increasing dissolved mass).
- 7.2.7 Where contaminant mass is present in the sorbed phase, these competing processes are often observed as an initial reduction in dissolved phase mass whilst peroxygen concentrations within the system exceed the required activation energy for target contaminant mass destruction. As reaction times proceed however, peroxygen concentrations become depleted through both direct redox coupling and natural decomposition reactions, and the chemical oxidation potential of the systems declines. Rebound is hence observed as the effects of cumulative contaminant mass transfer into the dissolved phase overcome the systems chemical oxidation capacity (system run-down) over extended time frames.
- 7.2.8 Where contaminants may be present as in a separate non-aqueous phase liquid (NAPL), the influence on dissolved phase mass will be a function of dissolution kinetics, whereby a reduction in dissolved phase mass would only be observed when the rate of contaminant destruction exceeds the rate of NAPL dissolution. A sustained plateau in dissolved phase mass following complete oxidant utilisation would tend to indicate complete dissolution of free phase mass.
- 7.2.9 The Total Oxidant Requirement (TOR) for Chemox Reactors (CR) was calculated from the Matrix Oxidant Demand (MOD) discussed in section 6, plus the Stoichiometric Oxidant Demand (SOD) calculated from redox coupling equations for complete mineralisation of Diesel Range Organics (DRO) based on a stoichiometric co-factor of 50.015 for persulphate. It must be noted that oxidant mass is based on observed dissolved and sorbed phase mass only, as NAPL was not quantified during the source term characterisation.
- 7.2.10 As per Table 4.2, reactors for all persulphate trials were operated at TOR or TOR x2, whilst peroxide reactors were operated at 2% and 5%.

7.3 C5-C8 TPH

- 7.3.1 Only a single detection was reported within the C7-C8 band for CR13 at 672 hours (48 µg/l). It is noteworthy that this reactor showed complete consumption of oxidant (peroxide activated persulphate at TOR) following 24 hours, hence we tentatively ascribe the appearance of C7-C8 TPH over extended time points to free phase dissolution / matrix desorption phenomena in the absence of adequate oxidant mass that may have otherwise maintained TPH mass below the analytical limits of detection.

7.4 C8-C10 TPH

- 7.4.1 All reactors show an initial spiking in dissolved phase C8-C10 TPH. This may relate to the production of lower molecular weight hydrocarbons from the cleavage of larger TPH molecules, or may be as a result of free phase dissolution. Both of these processes are indistinguishable, when interpretations are based on macroscopic observations relating to changes in dissolved phase concentrations.
- 7.4.2 As can be seen from inspection of Figure 7.1, peroxide systems demonstrate rapid and complete destruction of C8-C10 TPH compounds in the Rectifier area (R), whereas the initial increase in dissolved phase mass for Garage / Compressor (GC) peroxide systems was not observed. We assume this may be due to the complete destruction of this determinand prior to the first 3 hour sampling point, or limited non-aqueous phase source.
- 7.4.3 Later stage rebounding of dissolved phase concentrations is observed at time (t) = 672 hours for both persulphate and peroxide activated persulphate systems trialled for the GC area, which based on the initial source characterisation datasets contained no sorbed phase contamination. This later stage increase in dissolved phase C8-C10 is considered likely to be due to dissolution of free phase NAPL acting as a TPH pool, becoming evident over time as the dissolved phase concentration exceeds the oxidant activity. From the available peroxide treatability datasets, it is assumed that peroxide has effectively removed any free phase source.
- 7.4.4 Area R shows no evidence of dissolved phase rebound for C8-10.
- 7.4.5 Peroxide activated persulphate and peroxide ISCO formulations are observed to provide the greatest treatment efficacy against dissolved phase C8-C10 TPH.

7.5 C10-C12 TPH

- 7.5.1 All candidate ISCO systems demonstrated satisfactory performance over the time course of this chemical oxidation study for Area R, which showed the anticipated trend in destruction kinetics from fastest to slowest: peroxide>peroxide activated persulphate>>persulphate.
- 7.5.2 Duplicate reactors CR10 and CR11 show good agreement in dissolved contaminant concentrations, suggesting reasonable reproducibility. In addition, as may be expected, contaminant destruction profiles show oxidant mass dependant rates for C10-C12 TPH mineralisation.
- 7.5.3 As with C8-C10 fractions, no rebound in dissolved phase contaminant mass was identified for Area R.
- 7.5.4 Contaminant destruction profiles for Area GC suggest near complete mineralisation of C10-C12 for peroxide systems, again supporting the notion of oxidant concentration dependant rates of treatments. Again, there is strong evidence for peroxide induced NAPL dissolution with a notable spiking in dissolved phase concentrations at t=6 hours.

- 7.5.5 Both persulphate based oxidant systems show evidence for possible groundwater dissolved phase rebound over extended time periods, particularly at the lower TOR application rate.
- 7.5.6 Peroxide based oxidant systems are identified as providing superior performance over persulphate systems for both source areas, with evidence from CR7, 8, 15 and 16 providing indirect evidence for enhanced NAPL dissolution and subsequent C10-12 TPH destruction in the aqueous phase.

7.6 C12-C16 TPH

- 7.6.1 Significant liberation of C12-C16 mass was observed in Area GC peroxide reactors, generating 5,800 µg/l dissolved phase concentrations for the 5% peroxide treatment. As previously discussed, we infer from the matrix characterisation datasets that aqueous TPH concentrations are generated through NAPL dissolution rather than matrix desorption. There was no observable increase in dissolved phase C12-C16 TPH from Area R peroxide reactors.
- 7.6.2 Peroxide activated persulphate systems were seen to out-perform persulphate only treatments, with no rebounding effects identified for Area R in either system. Good reproducibility was seen again between duplicates, with ISCO chemistries again showing an oxidant concentration dependant response in residual dissolved phase contaminant mass over time.
- 7.6.3 Both Area GC persulphate based chemox systems demonstrated later stage rebound in dissolved phase C12-C16 components, consistent with observations from C10-C12 and C8-C10 TPH analysis.
- 7.6.4 Both peroxide activated persulphate and peroxide treatments produced similar treatment efficacies for C12-C16, out-performing systems that employed just persulphate for Area R, however peroxide provided superior performance in Area GC reactors.

7.7 C16-C21 & C21-C35 TPH

- 7.7.1 Changes in dissolved phase C16-C21 and C21-C35 fractions are discussed together given their similar response to oxidants over the time course of the chemox study discussed herein.
- 7.7.2 As can be observed from inspection of Figures 7.4 and 7.5, persulphate systems for Area R and GC show an initial drop in dissolved phases TPH concentrations for the C16-C35 band, followed by a plateauing or gradual increase.

A similar response is seen for peroxide activate persulphate systems, however the magnitude of dissolved phase rebound is notably higher for Area GC.

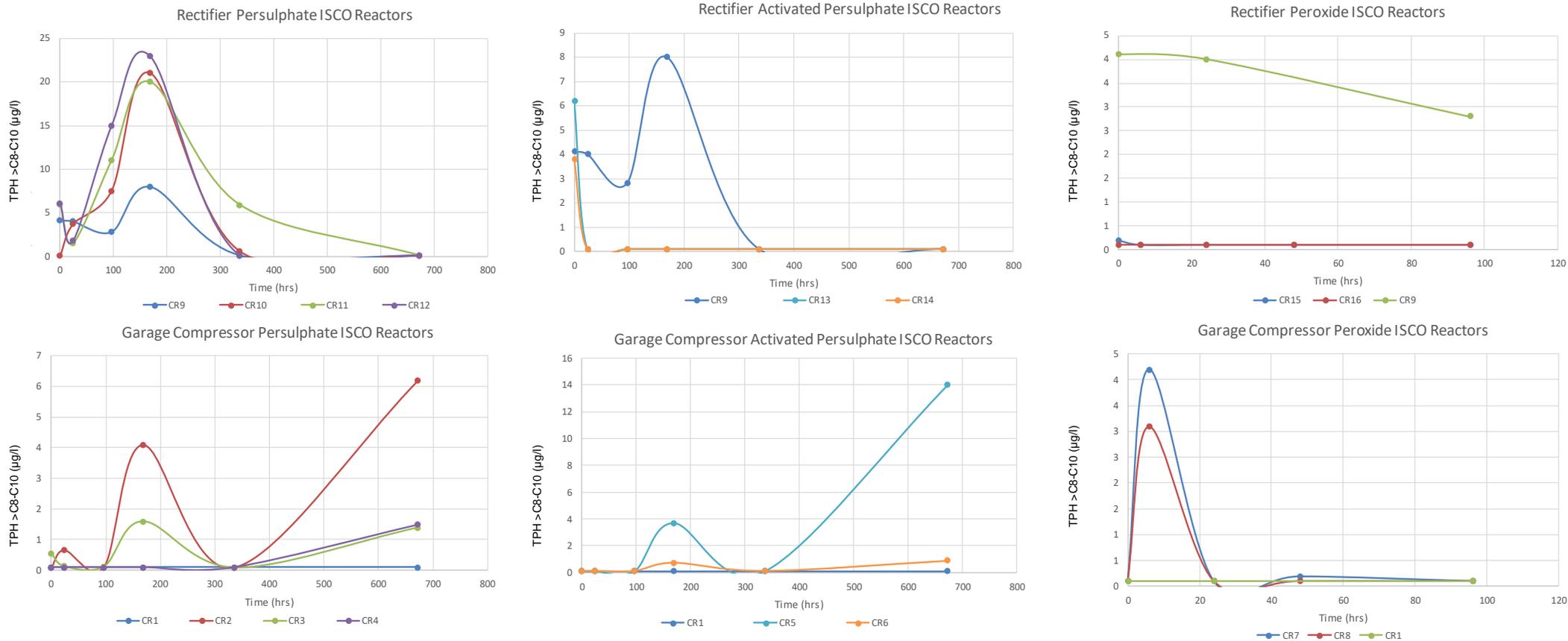


Figure 7.1 C8-C10 TPH dissolved phase concentrations during chemical oxidation studies. Note different sampling times employed for peroxide and persulphate systems.

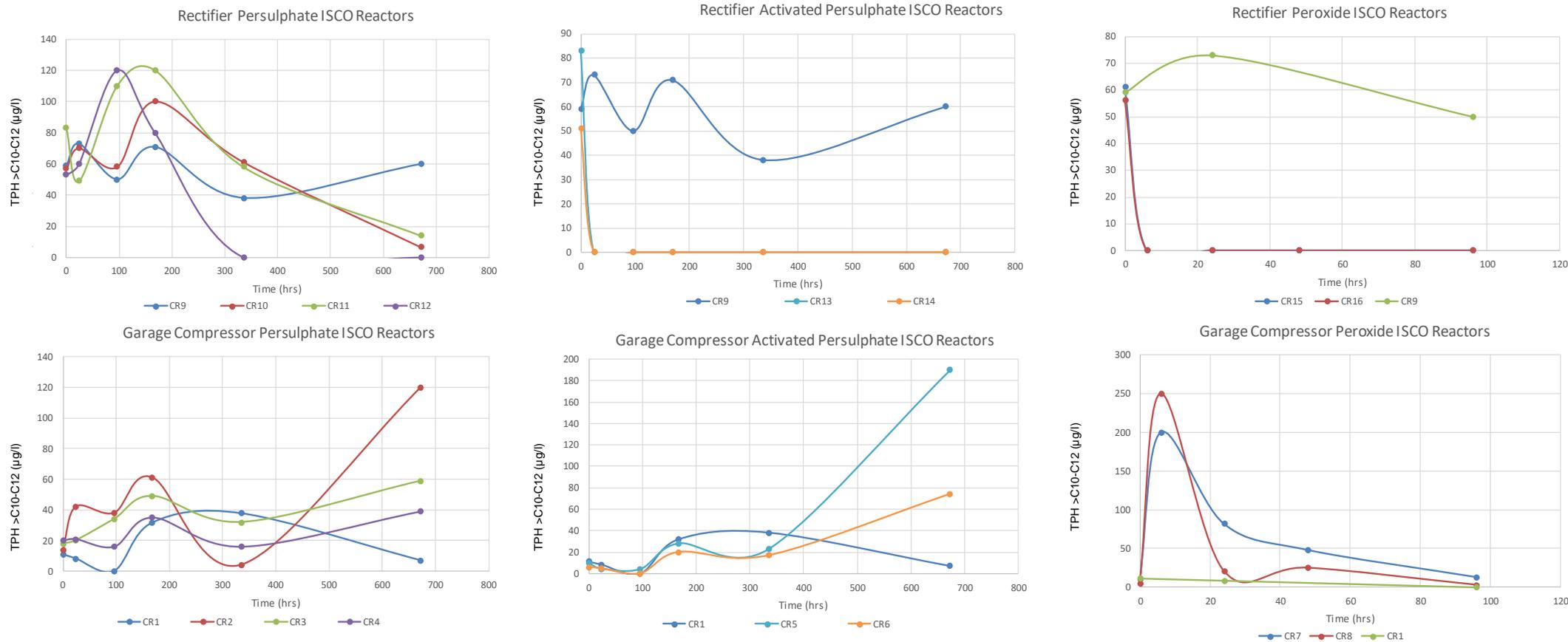


Figure 7.2 C10-C12 TPH dissolved phase concentrations during chemical oxidation studies. Note different sampling times employed for peroxide and persulphate systems.

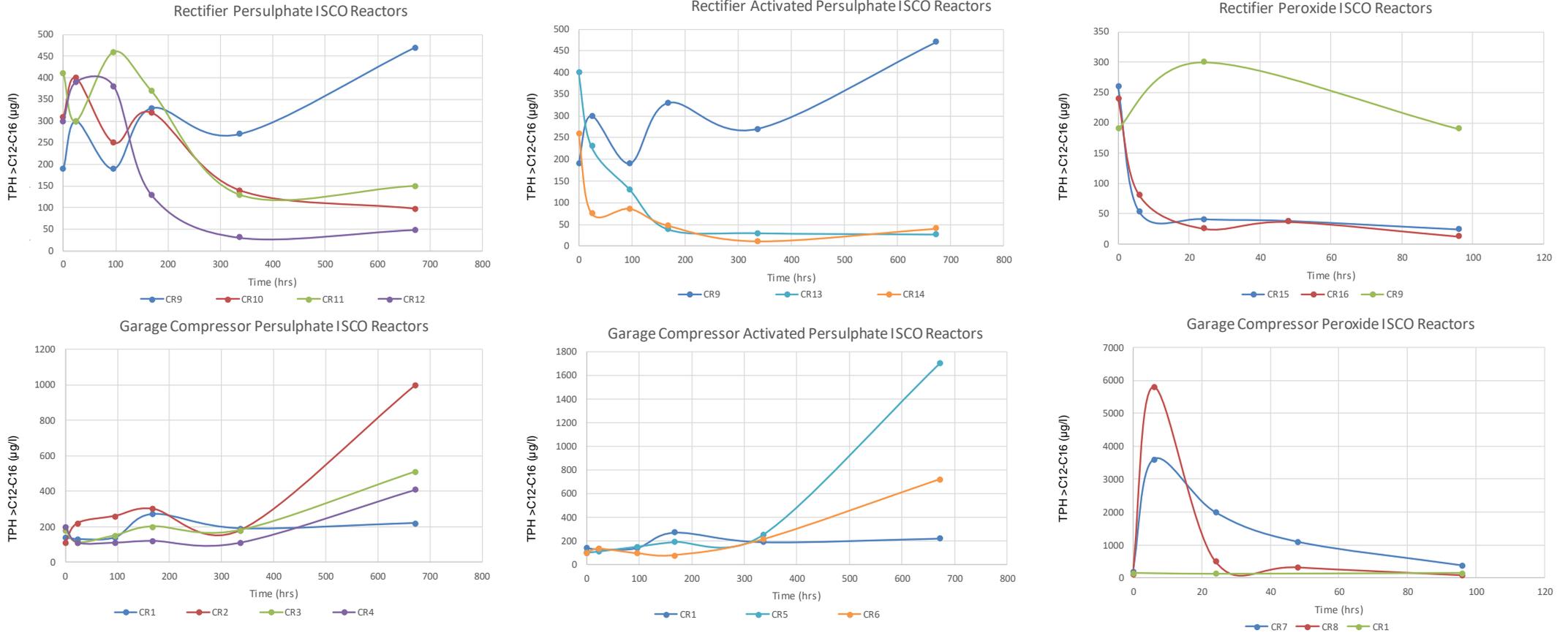


Figure 7.3 C12-C16 TPH dissolved phase concentrations during chemical oxidation studies. Note different sampling times employed for peroxide and persulphate systems.

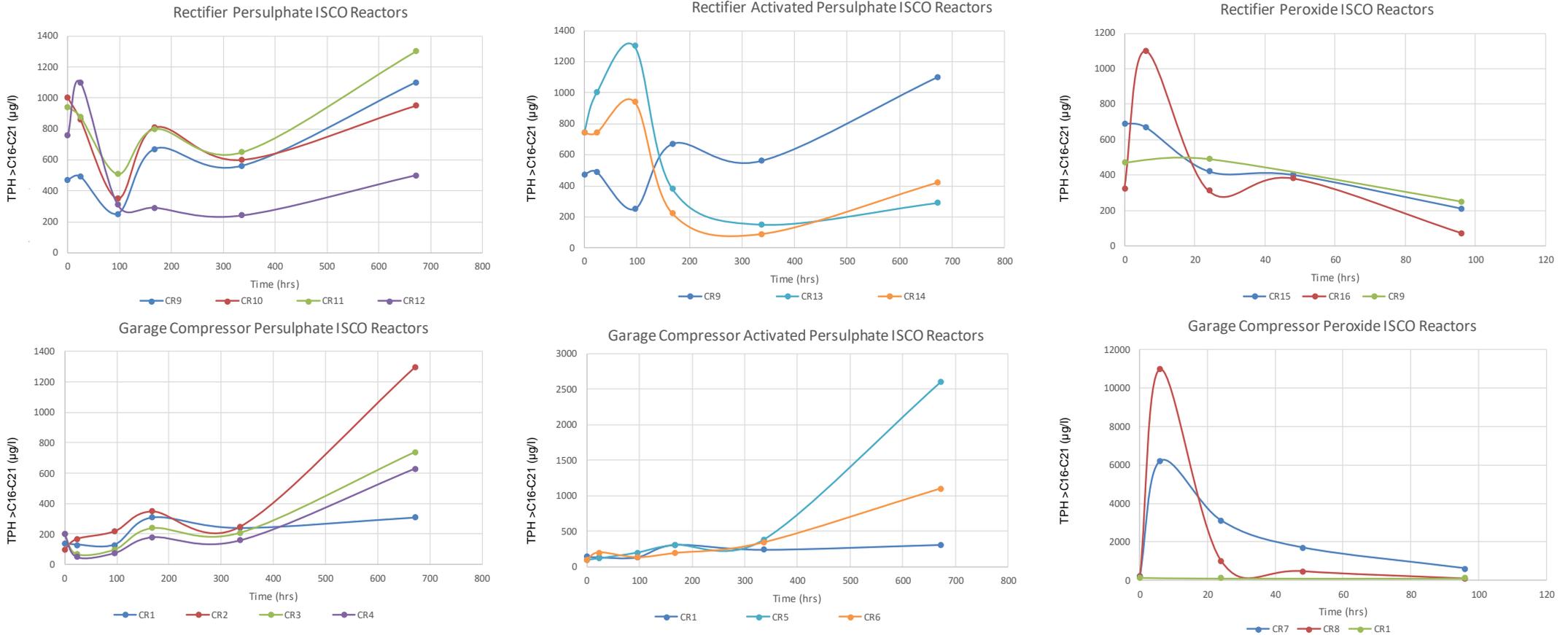


Figure 7.4 C16-C21 TPH dissolved phase concentrations during chemical oxidation studies. Note different sampling times employed for peroxide and persulphate systems

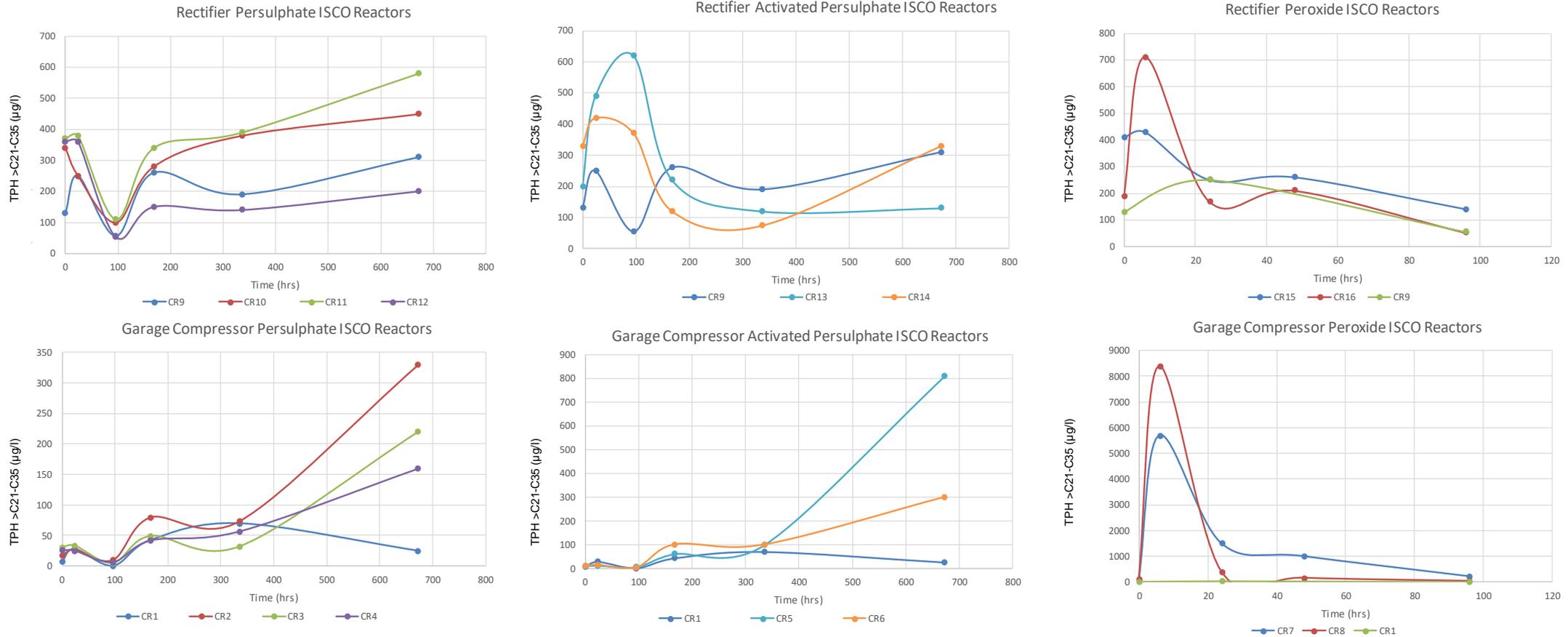


Figure 7.5 C21-C35 TPH dissolved phase concentrations during chemical oxidation studies. Note different sampling times employed for peroxide and persulphate systems.

- 7.7.3 Peroxide systems show the previously described early increase in dissolved phase C16-C35 TPH, which is possibly associated with oxidant mediated NAPL dissolution in Area GC, followed by a sustained reduction in aqueous concentrations. Peroxide systems demonstrate good remedial efficacy over the initial 24 hours, consistent with the high decomposition kinetics of peroxide, followed by lower rates of TPH destruction and oxidant mass becomes depleted.
- 7.7.4 Based on the available datasets generated from this chemical oxidation study, peroxide appears to provide the greatest treatment efficacy for C16-C35 TPH compounds, suggesting this oxidant may also be actively enhancing free phase dissolution, enabling destruction to proceed via direct redox coupling and / or free radical attack in the dissolved phase.

7.8 Residual Sorbed Phase Mass

- 7.8.1 Certificates of analysis for residual sorbed phase mass are presented in Appendix A.
- 7.8.2 Initial source characterisation datasets revealed that test work aquifer matrix composites for the Garage / Compressor (GC) area contained no detectable levels of TPH, whereas the Rectifier (R) area matrix contained only C12-C35 fractions, with a total TPH concentration of 450 mg/kg.
- 7.8.3 Consistent with initial source characterisation datasets, no TPH compounds were detected above analytical detection limits in any of the matrix samples recovered from chemox reactors at the final time point for any of the GC systems investigated.
- 7.8.4 Low residual TPH source mass (C12-C35) was detected in all persulphate based chemox reactors except CR12 (persulphate @ 2 x TOR). No residual TPH was detected in any of the peroxide treatment systems for area G.

7.9 Chemical Oxidation Performance Summary

- 7.9.1 Due to the observed influence of candidate peroxygenic compounds on desorption / dissolution of sorbed or free phase TPH mass, direct quantification of performance ranking has not been possible for this study.
- 7.9.2 Qualitatively, if we consider the trajectories for dissolved phase TPH fractions, peroxide based systems clearly demonstrate the highest rate of contaminant mass destruction.
- 7.9.3 In addition, the strongest oxidant studied in these investigations, peroxide, also appears to have facilitated rapid and complete NAPL dissolution with no evidence for dissolved phase rebound. The action of peroxide, leads to an initial rise in dissolved phase TPH, followed by sustained degradation in the dissolved phase.
- 7.9.4 All persulphate based systems appear to result in slower dissolution / desorption of TPH in the systems tested, leading to increasing dissolved phase TPH over time as the oxidant pool becomes depleted. This phenomena suggests that if deployed at the subject site,

persulphate based ISCO strategies may lead to longer term rebounding of groundwater
TPH concentrations

8 Trace Element Leaching Assessment

- 8.1.1 The potential for trace metal mobilisation following ISCO applications has been assessed through the analysis of residual groundwater samples for persulphate chemox systems at t=672 hours and peroxide chemox systems at t=96 under final equilibrium Eh and pH conditions.
- 8.1.2 As would typically be anticipated, trace metals (Cu, Cd, Cr, Ni and Zn) show enhanced solubility at low pH. We would generally ascribe this trace metal solubility in acidic conditions to be related to dissolution and desorption from the aquifer matrix materials. This particularly effects peroxide activated persulphate systems, which produce extremely acidic groundwater conditions, as low as pH 1.4 in the rectifier area reactors at 2 x TOR.
- 8.1.3 Neither peroxide or persulphate single oxidant systems produced significant changes to the native pH. Complete decomposition of peroxide leads to the generation of water and molecular oxygen as terminal end products, whereas persulphate results in significantly elevated levels of residual dissolved sulphate. This is apparent from EC data which shows peroxide treatments remained circum-neutral with EC of circa 600-700 μS , not dissimilar to pre-treatment conditions.
- 8.1.4 Elevated Fe and Mn concentrations are also reported for all peroxide activated persulphate reactors trialled. The increase in Fe and Mn solubility observed for both aquifer matrices in contact with low and high persulphate loadings is likely due to the associated reduction in pH causing matrix dissolution of Mn (and Fe) from accessory aquifer mineral phases.
- 8.1.5 Trace metal datasets are presented in Tables 8.1 for area R and area GC chemox reactor systems.
- 8.1.6 As discussed above, high residual sulphate loadings are to be anticipated for all persulphate systems under investigation.
- 8.1.7 We strongly recommend that should peroxide ISCO systems should be considered optimum for deployment at the subject site. From the datasets generated in this study, peroxide based ISCO should not require any post treatment rehabilitation of groundwater to re-adjust pH or amend high sulphate loading.

Determinand	Units	LOD	Garage Compressor								Rectifier							
			Control	PS@TOR	PS@TOR	PS@2xTOR	APS@TOR	APS@2xTOR	2% PO	5% PO	Control	PS@TOR	PS@TOR	PS@2xTOR	APS@TOR	APS@2xTOR	2% PO	5% PO
			CR1	CR2	CR3	CR4	CR5	CR6	CR7	CR8	CR9	CR10	CR11	CR12	CR13	CR14	CR15	CR16
pH			7.41	7.309	7.325	7.173	2.879	1.809	7.398	7.534	7.132	6.09	6.15	3.865	1.71	1.44	6.977	7.23
Eh	mV		281.8	486.4	514.6	522.2	370.7	658.9	215.2	209.3	304.9	566.7	559.8	661.1	381.7	812.9	232.5	217.5
EC	mS		0.7	4.499	4.468	7.909	15.87	35.56	0.64	0.64	0.64	12.15	12.26	22.22	32.41	58.9	0.57	0.55
Oxidant	g/l	0.01	0	3.78	3.77	7.83	0.01	1.08	0.637	0.325	0.01	13	13.2	27.3	0.17	18.44	0.802	1.254
Calcium	mg/l	5.0	76	180	170	250	520	610	110	74	95	290	310	390	500	630	110	110
Sodium	mg/l	0.50	54	800	770	1600	3400	8600	130	75	53	2700	2700	4800	5800	100000	15	15
Arsenic (Dissolved)	µg/l	1.0	910	28	8.1	10	17	220	3	2.9	12	2.9	130	1.2	150	240	1.8	1.8
Boron (Dissolved)	µg/l	20	170	120	120	120	150	1400	110	99	53	45	3500	23	23	27	42	37
Cadmium (Dissolved)	µg/l	0.080	0.08	0.08	0.08	0.08	8.4	42	0.08	0.08	0.77	0.14	5.9	0.72	9.9	7.3	0.28	0.2
Chromium (Dissolved)	µg/l	1.0	1.3	12	10	17	320	1100	40	51	35	9.9	760	1.3	830	1100	18	31
Copper (Dissolved)	µg/l	1.0	2	11	14	24	2300	4100	32	27	110	77	4500	260	4700	5600	120	77
Mercury (Dissolved)	µg/l	0.50	0.5	0.5	0.55	0.99	0.66	31	0.58	0.5	0.5	2.9	72	7.1	2.8	1.2	0.5	0.5
Manganese (Dissolved)	µg/l	1.0	1100	26	3	1.5	36000	42000	1100	670	4200	140	690	200	34000	38000	4000	3000
Molybdenum (Dissolved)	µg/l	1.0	13	6.6	6.7	6.9	1	68	13	12	6.9	1.4	90	1	1.4	4.7	11	14
Nickel (Dissolved)	µg/l	1.0	2.3	1.6	1.2	1.6	420	1400	4.3	2.8	56	5.4	220	14	1100	1400	12	8.3
Lead (Dissolved)	µg/l	1.0	1	1	1	1	57	270	1	1	6.2	7	2.5	1	370	310	1	1
Selenium (Dissolved)	µg/l	1.0	4.6	5.3	5.3	7	26	150	7.7	7.5	5	21	1500	22	15	1	16	16
Vanadium (Dissolved)	µg/l	1.0	3.5	3.1	3.1	3.2	210	440	98	100	16	1.4	140	1	780	590	91	100
Zinc (Dissolved)	µg/l	1.0	9.8	55	63	110	2200	4200	5.6	4.1	130	240	19000	570	4000	4200	14	5.4
Iron (Total)	µg/l	20	310	530	520	760	190000	910000	200	180	13000	740	69000	320	6000000	770000	300	280

Table 8.1 Trace element mobilisation in chemox reactors at t= 672 hours for persulphate reactors and t=96 hours for peroxide reactors.

9 Conclusions & Recommendations

- 9.1.1 The information and interpretations presented in this report are provided to support the assessment of In Situ Chemical Oxidation (ISCO) as a viable groundwater treatment technology for the destruction of target contaminants discussed in section 7.
- 9.1.2 The candidate chemical oxidation systems trialled have allowed assessment of oxidant kinetics, derivation of half-lives and the estimation of Matrix Oxidant Demand (MOD). In addition, treatability level investigations have been used to establish the efficacy of treatment systems for contaminant destruction.
- 9.1.3 Through the assessment of target contaminant destruction profiles and oxidant depletion rates, CE Geochem conclude that peroxide based chemox systems provide the greatest level of contaminant destruction, and are expected to exhibit efficient delivery of reactive oxidant mass into the high groundwater flow velocity source zone.
- 9.1.4 Persulphate chemistries showed relatively poor treatment efficacies in general at both low and high-range application rates. We ascribe this to the milder oxidising potential of the persulphate ion relative to the peroxy species. The generation of acidic groundwater conditions by peroxide activate persulphate would also limit the applicability of this technique at the subject site due to the observed magnitude of trace metal release.
- 9.1.5 Taking into consideration the relatively high hydraulic conductivities of superficial drift deposits at the subject site, and the nature of the key remedial drivers, considered to be TPH, we recommend that 2% peroxide be considered as an optimum solution (cost v performance) for ISCO at the subject site. As observed in treatability trials, oxidant induced NAPL dissolution is likely to be observed in the target aquifer during early stages of treatment, however treatability datasets support significant mass reduction of dissolved phase TPH over the time course of 96 hours.
- 9.1.6 CE Geochem strongly recommend that the ISCO injection strategy is based on step-wise applications to achieve 2% peroxide within the target groundwater compartment. The use of sequential injection protocols should allow oxidant delivery to be optimised for the most heavily impacted aquifer compartment through monitoring of residual dissolved phase TPH. Based on the results of this study, peroxide is considered capable of treating residual NAPL sources through enhanced dissolution followed by dissolved phase destruction.
- 9.1.7 Field injection trials should be undertaken prior to full scale injection works to confirm that equivalent subsurface peroxygen travel and reactivity can be achieved as demonstrated during these trials.

Appendix A *Certificates of Analysis*

Appendix B *Data Interpretations*

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