

# DETAILED QUANTITATIVE RISK ASSESSMENT

South Bank Area A  
Former Steel Works  
Redcar  
TS10 5QW

MAY 2021



Detailed Quantitative Risk Assessment  
South Bank Area A, Redcar  
10035117-AUK-XX-XX-RP-ZZ-0270-01-SBA\_DQRA

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## Site Investigation and Detailed Quantitative Risk Assessment

### South Bank Area A, Dormer Steel Works, Redcar TS10 5QW

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## VERSION CONTROL

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01	May 2021	Hebah Abdel-Hady	N/A – First Issue

This report dated 21 May 2021 has been prepared for South Tees Development Corporation (the “Client”) in accordance with the terms and conditions of appointment (the “Appointment”) between the Client and **Arcadis (UK) Limited** (“Arcadis”) for the purposes specified in the Appointment. For avoidance of doubt, no other person(s) may use or rely upon this report or its contents, and Arcadis accepts no responsibility for any such use or reliance thereon by any other third party.

**Executive Summary**

<p>Background</p>	<p>Arcadis (UK) Limited (Arcadis) was commissioned by South Tees Development Corporation to undertake a Detailed Quantitative Risk Assessment (DQRA) for a parcel of land known as South Bank Area A ('SBA', the 'Site') which sits within the wider Former Redcar Steek Works site in Redcar, TS10 5QW (indicative postcode). The DQRA follows on from an Environmental Site Assessment (ESA) comprising an intrusive site investigation and a Generic Quantitative Risk Assessment (GQRA) reported in Arcadis, March 2021.</p> <p>The site is currently part of a wider masterplan for the regeneration of the Former Redcar Steelworks site and SBA makes up approximately 11ha of the wider site.</p> <p>Arcadis have been commissioned to develop a better understanding of the current environmental conditions underlying the site and to refine the Conceptual Site Model (CSM) developed within the GQRA.</p> <p>It is understood that the end use for the wider site will be industrial in nature, comprising warehouses, depots, and offices. A specific end design with final site levels is not present for the SBA site.</p>
<p>Objectives</p>	<p>The aim of this DQRA is to further assess the risk posed by contaminants of concern (CoC) which were measured in exceedance of the environmental quality standards (EQS) adopted in the GQRA.</p> <p>To do this, the assessment draws on data gathered for the Arcadis March 2021 ESA, as well as data reported in Royal Haskoning (April, 2021) as part of an intrusive investigation along the northern border to inform the design of a quay wall.</p>
<p><b>Potentially active Pollutant Linkages</b></p>	<p><b><u>Sources</u></b></p> <p>A number of on-site sources were identified within the GQRA. Assessment of contaminant distribution indicates that on site Made Ground is likely to be the most significant on-site source. Contaminants primarily associated with Made Ground are found dispersed throughout the site in varying concentrations. Diffuse contaminants found throughout the site associated with Made Ground include metals, hydrocarbons including polyaromatic hydrocarbons (PAH), inorganics including cyanide, ammonia and sulphate, asbestos and limited amounts of other organic compounds such as phenolics.</p> <p>A number of off-site sources were also identified in the GQRA. Assessment of groundwater flow direction and on-site contaminant distribution indicated that the South Bank Coke Ovens and Biproducts Plant (SBCO) to the south of the site is the most significant in terms of its effect on on-site groundwater quality. Associated contaminants of concern (CoC) with the potential to affect groundwater quality include metals, hydrocarbons (including tars), PAH, inorganics including cyanide, ammonia and sulphate and other volatile and semi-volatile organic compounds.</p> <p><b><u>Receptors</u></b></p> <p><i>Human Health</i></p> <p>Due to the absence of an end use design and final site level, it is considered most appropriate to consider the human health risk assessment on a generic basis. Further assessment may potentially be undertaken as necessary at a later stage and factored into the design when this information is available. The assessment of pollutant linkages relating to human health are presented in the Arcadis GQRA (2021).</p> <p><i>Water Resources</i></p> <p>The primary water resource receptor associated with the site is considered to be The River Tees estuary, although a theoretical compliance point with the aquifer has also been considered in line with the EA guidance for hazardous substances. Groundwater within the underlying Tidal Flat Deposits and the Mercia Mudstone are designated as a Secondary A and Secondary B Aquifers, respectively. However, the resource potential for these aquifers</p>

## Executive Summary

is considered to be very low. Furthermore, the evidence from contaminant distribution data indicates that migration into these units is limited.

### Water Resource Pathways

The following pathways are considered potentially active;

- Leaching of CoC from soil into groundwater
- Migration in groundwater towards the surface water receptor (River Tees Estuary) and subsequent dilution within the receptor
- Vertical migration of impacts down relic foundation piles is also considered potentially active.

The monitoring wells installed as part of the quayside investigation (Royal Haskoning, 2021) intersect site groundwater prior to its potential discharge into the River Tees. These wells are therefore considered as sentinel wells and assist in evaluating the risk from the groundwater to surface water pathway.

## Detailed Quantitative Risk Assessment

### Method

The DQRA was undertaken for the potentially active pollutant linkage present to the water resources (excluding risk from future piles which was considered qualitatively). Remedial Targets Worksheet (RTW) was used to derive Site Specific Assessment Criteria (SSAC) for groundwater using site-specific information, where available. Dilution with the River Tees was also calculated in line with the Remedial Targets Methodology (RTM) guidance.

Two sources were assessed:

- **Made Ground** from across the site – considered to comprise a single diffuse soil source associated with Made Ground and slag.
- **Groundwater** in the vicinity of BH110 – considered to represent impacts associated with an off-site source to the south of the site (SBCO).

The assessment considered three separate compliance points, for which SSAC were derived:

- On-site 50m compliance point, protective of aquifers and surface water (groundwater source only)
- Prior to the River Tees (at sentinel wells and 360m down gradient from Groundwater Source); and
- Within the River Tees (dilution in the receptor)

### DQRA Findings

#### *50m Compliance Point (Groundwater Source only)*

The 50m compliance point was modelled for the groundwater source as a first stage of assessment in line with EA guidance for hazardous substances. This compliance point is located on site (down gradient boundary approximately 310m beyond). Aquifers underlying the site are considered of limited resource potential. Furthermore, the evidence from site data indicates that contamination is not migrating downwards significantly into the underlying aquifers and is generally limited to the overlying Made Ground (reclaimed land). As such, although a number of hydrocarbons and cyanide exceed the 50m SSAC derived, measured concentrations are not considered to present a significant risk to water resources on this basis. Assessment of a more distant compliance point protective of the River Tees provides a more accurate appraisal of the risk to water resources.

#### *Compliance Point Prior to the River Tees (at Sentinel Wells and 360m down gradient from Groundwater Source)*

From the groundwater source, cyanide, naphthalene and benzene were the only CoC compounds to exceed. Naphthalene and benzene exceeded by less than an order of magnitude. Given the conservatism in the assessment (as demonstrated in the model

## Executive Summary

validation), and assumptions in modelling cyanide, the risk presented by these CoC within the groundwater source is considered to be low.

Measured groundwater concentrations in sentinel wells exceeded EQS for a number of CoC including TPH, metals, inorganics and PAH. This is not unexpected given that some of the sentinel wells are installed directly screening the Made Ground. As Made Ground forms the boundary with the River Tees, concentrations are likely to be similar immediately adjacent to the River. The presence of structures such as sheet piled walls (potentially installed as part of future redevelopment works) would go some way to limit the amount of groundwater discharge from the site into the River Tees.

### *Compliance Point within The River Tees (dilution in the receptor)*

None of the measured concentrations from either the on-site groundwater source wells (BH110 and BH105; location of the highest measured groundwater concentrations of hydrocarbons and the majority of other contaminants) or the sentinel wells (located along the hydraulically down gradient northern site boundary) exceeded their respective SSAC when dilution within the River Tees was considered.

The dilution assessment is based on RTM guidance and only allows for a limited amount of dilution (actual dilution occurring likely much higher). 10% of compliance concentrations (saline EQS) have been taken in line with guidance to add further conservatism. Given the margin by which concentrations fall below the criteria, contaminant concentrations in the River Tees are considered unlikely to exceed measurable concentrations due to inputs from on-site sources.

Surface water monitoring data from the River Tees is provided in Royal Haskoning 2021. The findings of the surface water sampling are considered to support the above conclusions.

### *Other Considerations*

It is understood the SBCO plant to the south is likely to be demolished with a ground investigation and remedial works to be undertaken at the site. It is likely that, once this has been carried out, contaminant concentrations at SBA are likely to decrease, particularly within BH110 and the groundwater source area, from where the highest measured groundwater concentrations were sampled.

The modelling shows that sufficient time may not have yet elapsed for contaminants to have reached a steady state equilibrium with groundwater (in relation to the groundwater source). A timeframe assessment for the groundwater source predicated that measured concentrations may increase by around an order of magnitude from present day (assumed around the 50yr timeframe modelled) to steady state (approximately 190yrs or greater). Given this and the current measured concentrations in the sentinel wells, measured sentinel well concentrations will still remain well below their SSAC (considering dilution in the River Tees).

DNAPL has been measured on site. This may require consideration as part of remediation works. However, dissolved phase concentrations indicate that DNAPL is not presenting a risk to water resources, although does have potential to act as an ongoing source of contamination.

A potential pathway due to piled foundations was identified under the pollutant linkages. Based on the findings of the contaminant distribution and underlying ground conditions, it is considered unlikely that this pathway could represent a significant risk to water resources. Although contamination may locally be able to enter the underlying natural deposits around piles, lateral migration within the unit is unlikely to be significant.

# CONTENTS

<b>1</b>	<b>INTRODUCTION .....</b>	<b>1</b>
1.1	Objectives.....	1
1.2	Previous Environmental Works .....	1
1.3	Scope of Works.....	2
1.4	Reliability of Information / Limitations .....	2
1.5	Reliance .....	2
<b>2</b>	<b>SUMMARY OF GQRA FINDINGS.....</b>	<b>3</b>
2.1	Summary of Scope .....	3
2.2	Summary of Site History .....	3
2.3	Summary of Ground Conditions .....	4
2.4	GQRA Conclusions and CSM .....	5
2.4.1	Human Health.....	5
2.4.2	Water Resources .....	5
<b>3</b>	<b>POTENTIALLY ACTIVE POLLUTANT LINKAGES.....</b>	<b>1</b>
3.1	Human Health.....	1
3.2	Water Resources .....	1
<b>4</b>	<b>SITE CHARACTERISATION.....</b>	<b>2</b>
4.1	Environmental Setting.....	2
4.2	Sources.....	2
4.2.1	On-Site Sources .....	2
4.2.2	Off-Site Sources .....	2
4.2.3	Contaminant Distribution .....	3
4.2.4	Modelled Source Area .....	5
4.2.5	Selected Compounds for Modelling.....	6
4.2.6	Chemical Characterisation.....	7
4.3	Receptors .....	7
4.3.1	Water Resources .....	7
4.4	Pathways .....	7
4.4.1	Modelled Pathways.....	7
4.4.2	Environmental Fate and Transport Pathways .....	8

<b>5</b>	<b>DETAILED QUANTITATIVE RISK ASSESSMENT .....</b>	<b>9</b>
<b>5.1</b>	<b>Selection of the Assessment Tools .....</b>	<b>9</b>
<b>5.2</b>	<b>Water Resources .....</b>	<b>9</b>
5.2.1	Methodology .....	9
5.2.2	Model Run Parameters .....	9
5.2.3	Model Validation .....	10
5.2.4	Modelled Timeframe Assessment .....	10
5.2.5	Evaluation of Potential Dilution Effects .....	11
5.2.6	Development of Water Resource SSAC.....	12
5.2.7	Water Resource Risk Estimation .....	12
5.2.8	Water Resource Risk Evaluation .....	13
<b>5.3</b>	<b>Assumptions, Limitations and Data Gaps .....</b>	<b>14</b>

## FIGURES

Figure 1 – Site Location Plan and Environmental Setting

Figure 2 – Conceptual Site Model – Cross Section

Figure 3a-x – Contaminant Distribution Plots

Figure 4 – Modelled Source Area and Investigation Location Plan

## TABLES

Table 1 – Comparison of Measured Concentrations of CoC in Groundwater ( $\mu\text{g/l}$ ) with Environmental Quality Standards (EQS)

Table 2 - Site Specific Assessment Criteria (SSAC) for Groundwater Source ( $\mu\text{g/l}$ )

Table 3 - Comparison of CoC Concentrations to Site Specific Assessment Criteria (SSAC) for Groundwater Source ( $\mu\text{g/l}$ )

Table 4 - Comparison of Sentinel Wells to Site Specific Assessment Criteria (SSAC) for Groundwater ( $\mu\text{g/l}$ )

## APPENDICES

### APPENDIX A

Study Limitations

### APPENDIX B

Chemical Input Parameters

## **APPENDIX C**

### **Sensitivity Testing**

## **APPENDIX D**

### **Physical Input Parameters**

## **APPENDIX E**

### **Risk Assessment Methodology**

## **APPENDIX F**

### **Compliance Criteria Selection**

## **APPENDIX G**

### **TPH Breakthrough Times**

## **APPENDIX H**

### **Example RTW Output Sheet for Benzene**

## ACRONYMS THAT MAY HAVE BEEN USED IN THIS REPORT

<b>Acronym</b>	<b>Acronym Definition</b>
Arcadis	Arcadis Consulting (UK) Limited
BTEX	Benzene, Toluene, Ethylbenzene, total Xylenes
CDM	Construction (Design and Management) Regulations 2015
CLEA	Contaminated Land Exposure Assessment
CLR	Contaminated Land Report
CoC	Contaminants of Concern
DEFRA	Department for Environment, Food and Rural Affairs
DQRA	Detailed Quantitative Risk Assessment
EA	Environment Agency
EQS	Environmental Quality Standard
GAC	Generic Assessment Criteria
GC-FID	Gas Chromatography-Flame Ionisation Detector
GC-MS	Gas Chromatography Mass Spectrometry
GSV	Gas Screening Value
HDPE	High-Density Polyethylene
ICP-OES	Inductively Coupled Plasma – Optical Emission Spectroscopy
m bgl	Metres Below Ground Level
MCertS	Monitoring Certification Scheme
MDL	Method Detection Limit
MTBE	Methyl-Tertiary-Butyl-Ether
NAPL	Non-Aqueous Phase Liquids
PAH	Polycyclic Aromatic Hydrocarbon
PID	Photo-Ionisation Detector
RTM	Remedial Targets Methodology
RTW	Remedial Targets Worksheet
TPH	Total Petroleum Hydrocarbons (EC5-EC35)
TPH CWG	Total Petroleum Hydrocarbons Criteria Working Group
UKAS	United Kingdom Accreditation Service
US EPA	United States Environmental Protection Agency
UV	Ultraviolet



## 1 Introduction

Arcadis Consulting (UK) Limited (Arcadis) was commissioned by South Tees Development Corporation to undertake a Detailed Quantitative Risk Assessment (DQRA) at South Bank Area A (SBA, “the site”), a land parcel approximately 11.2 ha in size, situated at the Former Redcar Steelworks, located within the industrial area generally known as ‘South Tees’, TS10 5QW (indicative postcode). This report follows on from an Environmental Site Assessment (ESA) report comprising a Generic Quantitative Risk Assessment (GQRA) undertaken by Arcadis as part of the intrusive site investigation reporting (Arcadis, March 2021) and the Ground Investigation and GQRA Report undertaken by Royal Haskoning (Royal Haskoning, 2021). This report should therefore be read in conjunction with the ESA report (Ref: 10035117-AUK-XX-XX-RP-ZZ-0192-01-SBA\_ESA Review) and Royal Haskoning Report (Ref: PC1084-RHD-ZZ-XX-RP-Z-0001).

This DQRA further assesses the potential risk to water resource receptors from contaminants of concern (CoC) identified in the GQRA that have exceeded the relevant Environment Quality Standard (EQS). The potential risk to human health is discussed but is not further assessed based on the findings of the GQRA and project status.

The South Tees Regeneration Masterplan has been developed detailing the industrial-led regeneration of the Former Redcar Steelworks into a world class employment-generating zone and economic growth enabler for the Tees Valley.

The Masterplan has identified SBA (also formerly known as Cleveland North) as being located within the Southern Industrial Zone. The site is a priority development area and Arcadis understands outline planning has been submitted for “*demolition of existing structures on site and the development of up to 418,000 sqm (gross) of general industry (use class B2) and storage or distribution facilities (use class B8) with office accommodation (use class B1), HGV and car parking and associated infrastructure works all matters reserved other than access*” Ref. R/2020/0357/OOM.

Planning has also been granted for “*Demolition of structures and engineering operations associated with ground preparation and temporary storage of soils and its final use in the remediation and preparation of land for regeneration and development*” (R/2019/0427/FFM).

This report is to be used to support the ongoing planning process at the site.

All works have been carried out in reference to English legislation and regulatory guidance for the assessment of land contamination.

### 1.1 Objectives

The objective of this DQRA is to further assess the CoC identified as exceeding the relevant EQS in the GQRA. The DQRA focuses on water resources, specifically, the River Tees which forms the northern border of the site. This report will help refine the present conceptual site model (CSM) and define any potential risks posed to the River Tees by the measured concentration of CoC in groundwater. This should in turn inform any remedial strategy that may be required based on the outcome of the DQRA and the planning process.

### 1.2 Previous Environmental Works

Previous reports issued by Arcadis in relation to the site:

- Environmental Site Assessment, March 2021 (Ref: 10035117-AUK-XX-XX-RP-ZZ-0192-01-SBA\_ESA Review)

Arcadis was provided with the following third-party reports:

- South Bank Quay – Ground Investigation and Generic Quantitative Risk Assessment Report, dated 16th April 2021, Report Ref: PC1084-RHD-ZZ-XX-RP-Z-0001, [Royal Haskoning, 2021].
- TS4 South Bank – Phase 1 Geo-Environmental Desk Study, prepared by CH2M Hill for the Homes and Communities Agency, report ref. 678079\_TS4\_002 dated August 2017 and marked Final [CH2M 2017].
- Former Steelworks Land, South Tees Outline Remedial Strategy, Prepared for South Tees Development Corporation by Wood, ref 41825-wood-XX-XX-RP-OC-0001\_S0\_P01 dated 25th June 2019 [Wood 2019]

- Soil and Groundwater Baseline Characterisation Study, Teesside Works, prepared by Enviro for Corus UK Ltd [Enviro 2004], Comprising:
  - Volume 1 – Factual Report, Ref. Rlp250604corusteessidefactual.Doc dated 25th June 2004 and marked Final;
  - Volume 2 – Interpretive Report Ref. Mwicorusdraftinterpretivemmdv#2.Doc dated 25<sup>th</sup> June 2004 and marked Final; and,
  - Volume 3 – Summary Report dated June 2004.
- South Tees Industrial Area – Site C – Ground Investigation, prepared by Allied Exploration and Geotechnics Ltd. for English Partnerships, ref 1715H dated 12th July 1999 and marked Draft [AEG 1999].

The site is also considered in:

- South Industrial Zone ES - Vol 2 - Chapter H (Ground Conditions and Remediation), prepared by Arcadis for STDC and dated July 2020.

### 1.3 Scope of Works

The scope of works to meet the objectives comprised the below undertakings.

#### Production of a DQRA:

- Assessment of the potential risk posed to water resources using a source-pathway-receptor approach to refine the existing conceptual site model (CSM); and,
- Evaluation of the need for remediation works to be undertaken.

### 1.4 Reliability of Information / Limitations

The following scenarios are not considered in the derivation of site-specific assessment criteria (SSAC):

- Risks to Construction Workers – any redevelopment and construction work should be conducted in full recognition of HS(G)66 (no longer current but has not been updated and is cited in The Building Regulations, 2010) and with reference to CIRIA Report 132; and,
- Nuisance health effects – the Statutory Nuisance Act considers olfactory impacts from odours and allows comparison of enclosed space air concentrations with odour threshold concentrations.

Arcadis' liability, pursuant to the terms of the appointment of Arcadis by South Tees Development Corporation, is strictly limited to the work undertaken and the matters contained and specifically referred to in this report.

A copy of Arcadis' Study Limitations is presented in Appendix A.

### 1.5 Reliance

It is understood that the current report has been prepared for the use of South Tees Development Corporation in their planning process. The contents of this report may not be used or relied upon by any person other than this party without the express written consent and authorisation of Arcadis.

## 2 Summary of GQRA Findings

### 2.1 Summary of Scope

The ESA report prepared by Arcadis, March 2021 (Ref: 10035117-AUK-XX-XX-RP-ZZ-0192-01-SBA\_ESA Review) encompassed the majority of the site footprint and reported an intrusive ground investigation (GI) comprising the following scope:

- 49no. trial pits to 4.5m below ground level (bgl);
- 9.no boreholes advanced by rota-sonic rig to depths between 10m – 20m bgl, 3no. of these were advanced 5m into the underlying bedrock;
- Soil logging and sampling;
- Installation of 15no. groundwater monitoring wells (6no. dual installations);
- Groundwater monitoring and sampling (3no. rounds) as well as aquifer permeability testing and tidal monitoring; and;
- Permanent ground gas monitoring.

The Ground Investigation and GQRA Report prepared by Royal Haskoning (Royal Haskoning, 2021) encompassed the quayside area in the north of the site, along with the quayside area extending east from the site. The report included an intrusive GI comprising the following scope:

- 25no. boreholes advanced by rota-sonic rig to a maximum depth of 41m bgl (16no. of which were located with the site boundary)
- Soil logging and sampling;
- Installation of 17no. groundwater monitoring wells (13no. of which were located with the site boundary); and;
- Groundwater and surface water monitoring and sampling (2no. rounds).

### 2.2 Summary of Site History

The report outlines the history of the site and its immediate surroundings to form a CSM. The below table summarises the history of the site:

Date	Description
1856	The site was predominantly mud, sand and marshes associated with the Tees Estuary and below the high tide limit. The railway line is present to the south of the site.
1893	The site is still shown as estuarine mud with two jetties crossing to the river in the west. South Bank Iron Works and Phosphate Manure Works have been constructed to the south of the site.
1913 - 1938	The site appears to have been reclaimed from the Tees Estuary by the placement of materials from the steelmaking process. Various structures are shown on site including railways, cranes, a pumping station, brine wells / salt works, blast furnaces, galvanising works, and tanks later labelled as containing benzol. Two large reservoirs are shown between 1913 and 1927.
1955	The site is primarily comprised of stocking areas with sidings and travelling cranes present. The benzol tanks are still shown on site. There has been development to the south of the site with a concrete plant, and basic slag works.
1965	The South Bank Coke Ovens and Biproducts Plant (SBCO) has been built immediately to the south of the site in its present-day format with tanks.

1970	Sidings are present down much of the west of the site and the large building currently being demolished is labelled as a ferro-manganese crushing plant.
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The industrial history of the site and its surroundings highlights the potential for contaminant sources to be present from the Made Ground material used to build up the land when it was reclaimed from the estuary, as well as from other specific sources relating to on-site and off-site industrial operations.

## 2.3 Summary of Ground Conditions

The below table summarises the ground conditions encountered during the 2020 investigation reported in Arcadis, 2020 which encompasses the majority of the site footprint. Ground conditions encountered in the quayside area, reported in Royal Haskoning, 2021, we found to be in line with the below:

Unit	Minimum Basal Depth (m bgl)	Maximum Basal Depth (m bgl)	Comment
Made Ground	2.6	8.6	<p>Site surfacing comprised either soft standing of gravel, sand, or slag.</p> <p>The Made Ground encountered during the investigation predominantly comprised granular material with a fine-grained component and medium to high cobble/boulder content which included slag, brick, concrete and occasionally clinker, coke, coal and/or metal. Rare to frequent refractory materials were identified in a number of trial pits across the site. Based on visual assessment slag was found to be the dominant component of Made Ground in 42 of 49 trial pits.</p> <p>In one location (SBA_AUK_TP156) a concrete slab was identified at 1.1m bgl in the north east of the site.</p>
Tidal Flat Deposits (Secondary A Aquifer)	6.8	11.7	<p>Encountered in all 9 boreholes. Generally comprised soft sandy silt (often shelly) frequently underlain by a silty sand. Identified to be widely distributed across the site below the Made Ground.</p>
Glaciolacustrine Deposits (unproductive strata)	7.3 (base not proven)	11.7	<p>Glaciolacustrine Deposits were recorded in 7 boreholes below the Tidal Flat Deposits. The deposit was noted to be less than 1m thick in SBA_AUK_BH103 and SBA_AUK_BH107.</p> <p>The deposits were generally described as a soft to firm brown laminated clay often with sand partings along laminations.</p> <p>In one location SBA_AUK_BH105 two units of Glaciolacustrine deposits were noted with Glacial Till in between.</p>
Glacial Till (unproductive strata)	14.7 (base not proven)	22.0	<p>Glacial Till was identified in 8 boreholes below the Glaciolacustrine Deposits (if present) or Tidal Flat Deposits. Glacial Till was described as a firm to very stiff red brown slightly sandy slightly gravelly clay, with gravel composed of mixed lithologies, including sandstone, mudstone, and limestone. Glacial till is distributed widely across the site overlying the bedrock.</p> <p>In one location SBA_AUK_BH105 two units of Glacial Till was present the upper layer interbedded between Glaciolacustrine deposits.</p>

Unit	Minimum Basal Depth (m bgl)	Maximum Basal Depth (m bgl)	Comment
Sand and Gravel (suspected to be a granular lense at the base of the Glacial Till)	19	22.4	Sand and Gravel was identified in 2 boreholes. In SBA_AUK_BH105 it was noted below the lower band of Glaciolacustrine Deposits and below the Glacial Till Deposits, and in SBA_AUK_BH102 it was noted below the Glacial Till.  The Sand and Gravel was described as a clayey Sand and Gravel with gravel composed of mixed lithologies, including sandstone, limestone, flint and chert.
Mercia Mudstone (Secondary B Aquifer)	16.5	31.2	An extremely weak to weak red brown mudstone partially to highly weathered with numerous bands of white gypsum and locally green grey glauconite, recorded in six boreholes. The Mercia Mudstone was noted to become interbedded mudstone, sandstone and siltstone from 23.7m bgl to 25.2m bgl within three boreholes.

Two types of Made Ground were noted:

- **Slag-dominant material (>50% slag):** Generally ranging from gravel to cobble and occasional boulder size fragments. The slag material was generally vesicular and grey-green-white in colour. Slag dominant made ground was identified to comprise the primary made ground in 42 of the 49 trial pits.
- **Granular Made Ground:** Identified widely across the site of varying composition, most frequently a sandy gravel with varying cobble content. Gravel and cobbles include brick (including refractory), concrete, ash and clinker, slag was not the dominant constituent although often still present within the soil matrix.

## 2.4 GQRA Conclusions and CSM

### 2.4.1 Human Health

The GQRA concluded that concentrations of lead, benzene, dibenzofuran, and PAHs were measured exceeding the GAC in soil. Concentrations of contaminants were not measured above the GAC derived for the protection of human health in groundwater. NAPL and tar were identified primarily within the Made Ground in a couple of locations. Asbestos was recorded in 7no. of the Made Ground samples and this poses a potential chronic risk to human health and has implications for remedial costs. Permanent ground gas monitoring showed the risk from ground gases to be very low. The report concluded that Human health risk could be reassessed further when a redevelopment scenario and proposed site levels have been fully defined.

The Royal Haskoning April 2021 report highlighted elevated levels of arsenic exceeding human health GAC in the wells drilled along the northern edge of the site as part of a ground investigation to inform the design of a sheet pile wall. Their report concluded that soils in those wells do not pose an unacceptable risk to future commercial users, however have highlighted some areas of concern where elevations were recorded.

The findings of the GQRAs currently provide an appropriate level of assessment based on what is known of the planned redevelopment scenario. Further human health assessment has therefore not been undertaken at this stage.

### 2.4.2 Water Resources

Several exceedances of Water Quality Standards (WQS) were measured on site relating to the Made Ground and the Tidal Flat Deposits. The GQRA recommends further assessment in relation to controlled waters and ecological receptors (River Tees and Teesmouth and Cleveland Coast SSSI) and noted the limited resource value of the underlying aquifer. Consideration of contaminant dilution with surface water and the Quay Wall GI findings should also be considered.

Dense Non-Aqueous Phase Liquid (DNAPL) was measured in BH110 in two of the three groundwater monitoring visits. This, along with other CoC could not be fully delineated as part of the ESA due to the presence of an exclusion zone on site relating to the instability of the ammonia scrubbers on the SBCO site to the south.

The proximity of the site to the River Tees (approximately 20m north of the site boundary) has resulted in a tidal influence in some of the monitoring wells and this should also be considered.

The Royal Haskoning April 2021 report also shows detections of the same CoC highlighted within the Arcadis March 2021 report within the groundwater in the wells running along the northern site boundary. They also highlight a potential for DNAPL to be present within BH2025, although this was not measured or sampled during the works but rather based on observations during drilling and contaminant concentrations within the soil and groundwater. The source of the impacts in BH2025 is not known as is speculated to perhaps be an off-site source.

## 3 Potentially Active Pollutant Linkages

### 3.1 Human Health

Based on the intended industrial / commercial end use of the site, future on-site commercial workers and construction workers are considered as the primary human health receptor. A human health GQRA has been undertaken and is considered to provide an appropriate level of assessment based on what is known of the planned redevelopment scenario. Therefore, human health will not be assessed further within the DQRA, as discussed in Section 2 above. It is recommended that risks to human health are considered at the design stage of any proposed redevelopment with regards to dermal, ingestion and inhalation pathways.

### 3.2 Water Resources

The site overlies Tidal Flat Deposits and the Mercia Mudstone, both of which are designated as Secondary A and Secondary B aquifers, respectively. The pathway of leaching of CoC from impacted soils and migration into the groundwater is active for both of these receptors. This is due to the absence of hardstanding on the site and active process of infiltration from rainwater.

The River Tees is present approximately 20m to the north of the site boundary. The Teesmouth and Cleveland Coast is also a designated Ramsar site, Site of Special Scientific Interest (SSSI) and a Special Protection Area (SPA).

Due to the limited resource value of the underlying aquifers based on the industrial site setting, low permeability of the Tidal Flat Deposits & the Mercia Mudstone and the brackish nature of the water, it is considered unlikely that groundwater would be abstracted for drinking purposes. As such, the use of environmental quality standards (EQS) as opposed to drinking water standards (DWS) are considered most appropriate for assessing the risk to water resources, based on protection of surface water as of primary concern.

The groundwater underlying the site was found to be consistently resting within the lower 1.2m – 1.7m of the Slag Made Ground (4.03m – 7.18m bgl). Soil impacts from the lower end of the Made Ground and the Tidal Flat Deposits are therefore saturated and considered to be best assessed using groundwater contaminant concentrations.

Lateral migration of CoC within the groundwater towards the River Tees Estuary is also considered an active pathway due to the proximity of the River. Groundwater flow direction has been mapped to flow towards the north (towards the River), as would be expected.

A tidal influence measured in some of the on-site wells, and the lack of a sheet pile wall or physical barrier between the site and River Tees, means the groundwater migration pathway to the River and Estuary is also likely to be active. A maximum tidal influence range of 4cm was measured in Tidal Flat Deposits. Tidal influence in Made Ground was not measured but is anticipated to be greater.

A DNAPL source within the groundwater has been measured in BH110 towards the southern boundary of the site. While the DNAPL has not been measured downstream, a dissolved phase plume located north towards the River Tees from the BH110 area is present. The DNAPL was found resting on the boundary between the Slag Made Ground and the Tidal Flat deposits. Due to the granular nature of the Made Ground and groundwater levels underlying the site, a migration pathway from this groundwater source to the River and estuary is also considered potentially active.

To summarise, the following pollutant linkages are considered potentially active;

- Leaching of CoC from soil into groundwater
- Migration in groundwater towards the surface water receptor (River Tees Estuary)
- Vertical migration of impacts down relic foundation piles is also considered potentially active.



## 4 Site Characterisation

### 4.1 Environmental Setting

The environmental setting of the site is summarised on Figure 1 and 2. Figure 1 identifies potentially sensitive land uses in the vicinity of the site, alongside identified environmental receptors located hydraulically down-gradient. Figure 2 includes a simplified profile of the geological conditions, alongside a conceptual cross-section identifying potentially active pollutant linkages.

### 4.2 Sources

#### 4.2.1 On-Site Sources

Arcadis 2021 identified the following as potential on-site sources of contamination:

- Made Ground including slag
- Benzol plant
- Iron / Galvanizing works
- Ferro-manganese plant
- Stocking area, railways and sidings
- Above ground storage tanks (various) and Heavy Fuel Oil (HFO) line
- Transformers and substations
- Infilled reservoir

#### Made Ground

The entirety of SBA is reclaimed land from the River Tees Estuary. The Made Ground used for the land reclamation is primarily composed of by-products from surrounding industrial processes, including slag. The Made Ground has therefore been considered as a single diffuse source of CoC across the entire site.

Contaminants primarily associated with Made Ground are found dispersed throughout the site in varying concentrations. Diffuse contaminants found throughout the site associated with Made Ground include metals, hydrocarbons including polyaromatic hydrocarbons (PAH), inorganics including cyanide, ammonia and sulphate, asbestos and limited amounts of other organic compounds such as phenolics.

#### Other Potential On-Site Sources

The other potential sources, identified in addition to Made Ground, represent more localised potential sources of historical contamination. The Benzol plant and Ferro-manganese plant were located in the eastern portion of the site. The coal stocking area was located in the southwest of the site and Iron / Galvanising works in the northwest of the site. Two substations were identified in the centre and northeast of the site and the decommissioned HFO line runs along the eastern boundary of the site. Two large reservoirs were present historically on site which were infilled.

Contaminants associated with the above include metals, hydrocarbons (including tars), PAH, inorganics including cyanide, ammonia and sulphate, polychlorinated biphenyls (PCB), asbestos and other volatile and semi-volatile organic compounds.

#### 4.2.2 Off-Site Sources

A number of potential off-site sources are identified in Arcadis 2021. The report concluded that those most likely to affect on-site groundwater was SBCO. Heavy Fuel Oil (HFO) tanks and High Tip Landfill were also considered to have potential to affect on-site groundwater.

#### SBCO

It is known that there is a contaminant source located off-site associated within the SBCO facility boundary, thought to be affecting groundwater quality beneath the site. The SBCO is shown on historical maps to have been built around 1965 and is known to have soil and groundwater impacts from the facility operation and associated tanks and infrastructure. The site's southern boundary separates the site from the SBCO facility immediately to the south.



Associated contaminants with the potential to affect groundwater quality include metals, hydrocarbons (including tars), PAH, inorganics including cyanide, ammonia and sulphate and other volatile and semi-volatile organic compounds.

#### **Other Potential Off-Site Sources**

The High Tip and HFO tanks are located immediately to the east of the site. Associated contaminants with the potential to affect groundwater quality include metals, hydrocarbons, PAH, inorganics including cyanide, ammonia and sulphate and other volatile and semi-volatile organic compounds.

### **4.2.3 Contaminant Distribution**

Based on the results of the two recent site investigations reported in Arcadis (2021) and Royal Haskoning (2021), the contaminant distribution is summarised below for key CoC. Contaminant distribution plots are also provided for key CoC exceeding EQS in unsaturated soil and groundwater as Figures 3a-3x (for the purpose of drawings, unsaturated soils have been defined as those above 6m bgl based on an average of site data).

The 13no. Royal Haskoning wells along the northern boundary of the site have been referred to as sentinel wells to indicate contaminant flow off-site from SBA. Saturated soil and leachate samples are considered useful for assessing where contaminant mass is stored, but potential risks are considered best represented by concentrations of CoC in groundwater. As such, saturated soil and leachate samples have not been included in the discussion below.

It is noted that investigations were also completed in 2004 and 1999 by Enviros and AEG respectively. Given the age of these investigations, and the coverage of the recent 2021 investigations, findings of the 2004 and 1999 investigations have not been discussed in detail below. However, where pertinent information was identified, this has been referenced.

#### **4.2.3.1 Non-Aqueous Phase Liquid (NAPL)**

Dense Non-Aqueous Phase Liquid (DNAPL) was identified resting at the base of the Made Ground on the Tidal Flats deposits in BH110 at the southern boundary of the site. DNAPL thickness was measured on two occasions in October 2020 resting between 7.44 and 7.50m bgl (6cm thickness), and 7.16m and 7.50m bgl (34cm thickness).

NAPL was not identified in the Royal Haskoning April 2021. Hydrocarbon odours were noted in BH2025 and BH2021 (in the northwest and northeast of the site respectively) which the Royal Haskoning report states may be due to the presence of DNAPL.

Investigations undertaken by Enviros in 2004 (Enviros, 2004) also identified NAPL in two locations in the south of the site, approximately 30m from the SBCO boundary.

#### **4.2.3.2 Soil**

##### **Metals and Inorganics**

Metals and inorganic species such as cyanide are found throughout the site. As discussed above, this is likely due to the imported Made Ground and slag from which the site is formed. There are some locations which show higher concentrations than others, however no discernible correlation with on-site sources has been identified. The highest cyanide concentration was measured in TP113 at 3m bgl, located in the west of the site (775mg/kg total cyanide, 7.69mg/kg free cyanide). The highest metal concentrations were generally measured in TP136, located in the east of the site (28,000mg/kg zinc and 3,350mg/kg lead).

As such, the presence of metals and inorganics is considered to predominately be a diffuse source associated with Made Ground.

##### **Organic Compounds**

Similarly to metals, PAH and TPH are found throughout the site and are also likely to be associated with the imported Made Ground and slag from which the site is formed. Again, no discernible correlation with on-site sources has been identified across the majority of the site. The highest concentrations were measured in TP154, located in the northeast of the site, with a maximum sum TPH of 7,970mg/kg at 0.6m bgl and maximum benzene of 23.2mg/kg. The next highest sum TPH was from TP113, located in the west of the site, with a

maximum of 1,883mg/kg at 3m bgl. Outside of these two locations, the majority of samples had TPH concentrations of less than 100mg/kg with most reported less than MDL. It is noted that phenolic compounds (maximum phenol 2,260mg/kg) were also measured at relatively high concentrations in TP154, when compared with other samples from the site (majority of site phenol was less than MDL). Higher sum TPH concentrations were measured in BH110, but these were saturated so are best represented by groundwater and discussed below.

As such, the presence of PAH and TPH in soil is considered to predominately be a diffuse source associated with Made Ground, although some potential localised areas of higher concentrations may be present.

#### 4.2.3.3 Groundwater

##### **TPH**

Sum TPH (C5-C35) was measured above the laboratory method detection limit (MDL) in eight of the ten groundwater monitoring wells reported in Arcadis (2021). The only locations with no measurable concentration of TPH on all three visits are BH106D and BH108D, which are located to the west of the site, outside of the general groundwater flow direction from the SBCO to the south.

The highest concentration of sum TPH were measured in BH110, located in the south of the site and screening the Made Ground, and ranged between 3,900ug/l – 14,000ug/l across the three visits. TPH was also measured in wells screening Made Ground hydraulically downgradient and ranged from 5,900ug/l to 2,900ug/l.

The highest measured groundwater concentrations were generally encountered in wells screening the Made Ground, indicating that this is the main pathway for lateral migration of dissolved phase contaminants.

Concentrations measured in wells screening the bedrock aquifer (Mercia Mudstone) ranged from less than MDL to 2700ug/l in BH104D and BH101D to the east and north, respectively.

Sum TPH was measured above the MDL in BH2010 (141ug/l) and BH2025, both of which screen the Tidal Flat Deposits. Concentrations associated with BH2010 (1,430ug/l) are interpreted to be linked to the oil depot immediately to the northeast of the site due its location immediately on the border between the two sites. In BH2025 concentrations could perhaps be linked to concentrations observed in BH107D (less than MDL – 1000ug/l), or off-site sources as it is located along the western boundary of the site. BH107D screens the top of the Tidal Flat Deposits. It should be noted that the Tidal Flat Deposits in these locations have a granular component underlying the Made Ground, and therefore, contamination from Made Ground could mix into the top of the more granular Tidal Flat Deposits, although it is considered unlikely to travel further given the cohesive nature of the majority of this unit.

##### **BTEX Compounds**

Benzene was measured above the MDL in seven of the ten monitored groundwater wells. The highest concentrations were measure in BH110, located in the south of the site, and ranged between 24,000 ug/l and 47,000 ug/l across the three visits. The next highest benzene concentration of 1,400µg/l was measured in BH104 in the east of the site and screening the Mudstone, although benzene was measured below the MDL of 1µg/l in the other two monitoring visits. After this location, the next highest benzene concentrations were measured in BH103 and BH105, located in the vicinity of BH110 and screening the Made Ground.

Within the sentinel wells benzene was only measured in two locations BH2015 at 1ug/l and in BH2025 at 70ug/l.

Toluene and xylenes were measured above the MDL in six of the ten monitored wells. Highest concentrations were again measured in BH110, with toluene ranging between 2,600ug/l – 4,500ug/l and sum xylenes measured at 468ug/l – 920ug/l across the three visits.

##### **PAH**

Total PAH was detected above the laboratory MDL in all monitored locations reported in Arcadis (2021), as well as in the 13no. sentinel wells along the northern border. Again, the highest concentrations from Arcadis (2021) were measured in BH110, with sum PAH ranging from 26.9ug/l to 528ug/l across the three visits. The sentinel wells showed the highest total PAH concentrations measured in BH2010 and BH2025, with

naphthalene making up the bulk of the concentrations. Naphthalene was measured at 91ug/l and 500ug/l in BH210 and BH2025, respectively.

## VOC

VOCs detected above the MDL in Arcadis (2021) were 1,2-dichloroethane and chloroform. Chloroform was only detected in two locations, BH105 (26ug/l) and BH108D (10ug/l). Concentrations of 1,2-dichloroethane were detected in 5no. locations and ranged between 6ug/l and 85ug/l, with the highest concentration detected in BH104D to the southeast of the site. Within the Sentinel wells there was only one detection of 1,2-dichloroethane and this was in BH2025 (4ug/l), and no detections of chloroform.

## Cyanide

Cyanide was measured above the laboratory MDL in five of the ten monitored wells in Arcadis (2021). It should be noted that the MDL for the analysis was higher (40ug/l) than that for the sentinel wells (0.1µg/l), in which measured concentrations of cyanide above the MDL were recorded in all 13no. wells. Therefore, cyanide may be present in lower concentrations throughout the rest of the site.

Notwithstanding this, the highest concentrations were distinctly present in BH110 which ranged from <40ug/l to 690ug/l. Whilst background concentrations of cyanide are evidently present due to the Made Ground, there is potentially also a separate source relating concentrations in BH110, likely from the SBCO.

### 4.2.3.4 Surface Water

Surface water samples from the River Tees were obtained and reported in Royal Haskoning 2021. Samples were taken from locations during two rounds of monitoring.

Measured concentrations of TPH, phenolics VOC and SVOC were below the laboratory MDL. Concentrations of metals and inorganics were measured above the MDL, along with a number of PAH compounds. Measured concentrations were similar for the majority of CoC from all three sampling locations, suggesting no trends related to groundwater discharges from the site.

### 4.2.4 Modelled Source Area

In unsaturated soil, in most cases, no significant spatial distribution trends have been identified, suggesting Made Ground is of a similar composition across the site and should be considered as a single source. As such, contaminants measured in Made Ground are not generally due to primary contaminant sources associated with infrastructure and historical industrial processes on-site.

The highest hydrocarbon concentrations measured in soils are associated with saturated soils (also from BH110), suggesting that they relate to a groundwater source rather than the Made Ground. Due to the location of the soil impacts being within saturated strata, groundwater data is considered better representative of the contaminant risk beneath the site.

In groundwater, a more distinct plume is evident and does not appear to be associated with concentrations in unsaturated soils. The highest groundwater contaminant concentrations were measured in BH110 adjacent to the southern boundary, which separates the site from the SBCO facility (predominantly hydrocarbons and phenolics, and also cyanide). Relatively high hydrocarbon concentrations, particularly benzene, were measured in nearby location BH105 and downgradient BH103. BH110 also had a measured thickness of DNAPL on two of the three groundwater monitoring visits undertaken in October and November 2020 resting at the base of the Slag Made Ground above the Tidal Flat Deposits.

Based on the above, two distinct sources have been considered:

- **Made Ground** from across the site – considered to comprise a single diffuse soil source associated with Made Ground and slag.
- **Groundwater** in the vicinity of BH110 – considered to represent impacts associated with an off-site source to the south of the site (SBCO).

The groundwater source area modelled is defined to include BH110 and extends to the west to the edge of SBCO along the southern boundary. There is an absence of ground investigation data to fully delineate the CoC extent because of the exclusion zone around SBCO. The source area modelled extends along the southern boundary with the SBCO given that groundwater flow direction is to the north and CoC are likely to be travelling on site in this area.

Figure 4 shows the modelled groundwater source area defined as well as the groundwater monitoring wells present on site.

Assessment of the risk to water resources from the Made Ground source has been undertaken using the 13no. sentinel wells along the site's northern boundary. Based on the northerly flow direction (towards the River Tees) these wells are considered to intersect the pathway between the source (Made Ground) and primary receptor (River Tees). As such, a modelled source area has not been defined given that the assessment is based on pathway rather than source concentrations.

## 4.2.5 Selected Compounds for Modelling

### 4.2.5.1 Groundwater Source

Table 1 shows the maximum concentration of contaminants measured within the Arcadis ESA (March, 2021) report. These concentrations have been screened against the EQS for coastal and estuarine waters given that the River Tees is considered the primary water resource receptor associated with the site.

Compounds from the list were then selected for the modelling with the reasoning also displayed within the table. Consideration was given as to whether the compound was present in the groundwater source area (define as monitoring wells BH105 and BH110) and whether or not they were likely attributable to the groundwater or Made Ground source. The Arcadis, 2021 data from across the site has been used to represent potential groundwater source concentrations. Albeit groundwater data from across the site will include a contribution from on-site Made Ground leaching, as well as the groundwater source originating off-site from SBCO.

Impacts associated with fuel were assessed following the English guidance on the assessment of petroleum hydrocarbon contamination, (EA, 2005) which recommends the use of speciated TPH combined with selected indicator compounds. A selection of polyaromatic hydrocarbons (PAH) and volatile organic compounds (VOC), which were also measured exceeding the EQS for coastal and estuarine waters in the GQRA, have also been selected for modelling.

The table below summarises the compounds adopted in the groundwater risk assessment:

Speciated TPH	Indicator Compounds	PAH	VOC	Others
Aliphatic C5-C6	Benzene (Aromatic >EC6-EC7)	Anthracene	1,2-dichloroethane	Phenol
Aliphatic >C6-C8		Fluoranthene	Chloroform	Cyanide
Aliphatic >C8-C10	Benzo(a)pyrene*	Benzo(b)fluoranthene		
Aliphatic >C10-C12	Ethylbenzene	Benzo(k)fluoranthene		
Aliphatic >C12-C16	Naphthalene	Benzo(g,h,i)perylene		
Aliphatic >C16-C35	Toluene (Aromatic >EC7-EC8)			
Aromatic >EC8-EC10	Xylenes			
Aromatic >EC10-EC12				
Aromatic >EC12-EC16				
Aromatic >EC16-EC21				
Aromatic >EC21-EC35				

Key indicator compounds were selected based on the following criteria:

- The indicator compound represents a relatively high proportion of the likely source contaminant, i.e., a petroleum hydrocarbon substance.
- The properties of the indicator compound are well understood and documented both in terms of toxicology and fate and transport capabilities.

#### 4.2.5.2 Made Ground Source

As discussed in 4.2.4 above, assessment of the risk to water resources from the Made Ground source has been undertaken using the 13no. sentinel wells along the site's northern boundary. The assessment has been undertaken for contaminants measured above the laboratory MDL in the 13no. sentinel wells.

#### 4.2.6 Chemical Characterisation

The chemical data from EA (2008a) has been adopted where provided. A range of literature sources have been reviewed and chemical properties applicable at 10°C have been adopted where possible.

Key chemical properties for the CoC are presented in Appendix B.

### 4.3 Receptors

#### 4.3.1 Water Resources

The primary water resource receptor associated with the site is considered to be The River Tees estuary, although a theoretical compliance point with the aquifer has also been considered in line with the EA guidance for hazardous substances (EA, 2017).

Surface water features present are the River Tees and the Teesmouth and Cleveland Estuary. There are both considered to be receptors, with the Teesmouth and Cleveland also being a designated Ramsar site, SPA and a SSSI.

Groundwater within the Tidal Flat Deposits and the Mercia Mudstone are designated as a Secondary A and Secondary B Aquifers, respectively. However, as discussed in Section 3, due to the aquifer characteristics, the industrial history of the site and its surroundings, as well as the brackish nature of the groundwater due to proximity to the estuary, groundwater abstraction for potable water is unlikely to be considered in the future. The resource potential for these aquifers is therefore considered to be very low.

Furthermore, assessment of the contaminant distribution indicates that the majority of contamination is restricted to the Made Ground. Impacts in the underlying Tidal Flat Deposits and Mudstone are limited and localised, indicating that vertical migration into these units is limited. Given that the Made Ground represents reclaimed land, it is unlikely to be considered as a receptor under the aquifer classifications and would instead represent a pathway towards surface water.

### 4.4 Pathways

#### 4.4.1 Modelled Pathways

To assess the level of risk presented to the identified receptors, the pathways defined as potentially active within the pollutant linkages need to be considered further. Site-specific information is used where possible to assign parameter values for:

- the physical characterisation of the geological and hydrogeological setting of the site.

Based on the results of the environmental investigations completed at the site, the unsaturated zone, source zone and aquifer have been conceptualised as presented in Figure 2.

Assessment of the contaminant distribution indicates that the majority of contamination is within the Made Ground. Impacts in the underlying Tidal Flat Deposits and Mudstone are limited and localised, indicating that vertical migration into these units is limited. The permeability of the Made Ground is likely much higher than that for the underlying natural geology, based on the soil log descriptions from the site. Evidence from tidal loggers also showed limited variation (maximum 4cm) within the natural deposits, indicating that the potential for lateral migration within these units is likely also limited. As such, Made Ground has been modelled as the primary pathway within which the lateral migration of contamination occurs.

A sensitivity analysis has been carried out using the Remedial Targets Worksheet (RTW) model, in line with the methodology outlined in the Remedial Targets Methodology (RTM) Guidance (EA, 2006), to assist with selection of parameter values required for the key fate and transport pathways. The results of sensitivity testing

are presented in Appendix C. Sensitivity testing was completed for benzene. A full listing of the physical parameter values, used in the risk assessment is presented in Appendix D.

#### **4.4.2 Environmental Fate and Transport Pathways**

The environmental fate and transport pathways modelled within the DQRA are:

- **Groundwater Source:** Lateral migration of potentially impacted groundwater towards the identified water resource receptors and subsequent dilution with the receptor.
- **Made Ground Source:** Dilution with the receptor.

## 5 Detailed Quantitative Risk Assessment

### 5.1 Selection of the Assessment Tools

The DQRA has been undertaken using site-specific information, where available, to derive risk-based assessment criteria, which can be used to assess whether the measured concentrations of CoC on site present potentially unacceptable risks to the identified receptors.

The following modelling tools were selected for the assessment water resources:

Receptor	Media	Selected Modelling Tool
Water Resources	Groundwater	RTW v3.2

### 5.2 Water Resources

#### 5.2.1 Methodology

The water resources risk assessment has been undertaken using Remedial Targets Worksheet (RTW) to back-calculate evaluation criteria, or water resource SSAC, as outlined in Appendix E. Further to this, SSAC taking into account a dilution factor within the River Tees has also been calculated based on one of the selected compliance point distances. This is discussed further in Section 5.2.3.

#### 5.2.2 Model Run Parameters

The model run parameters are presented in the table below:

Parameter	Value	Comment
Compliance Point Distance	<p><b>Groundwater Source</b></p> <p>Three compliance point distances (in hydraulically down gradient direction) were used for the derivation of groundwater source SSAC;</p> <ul style="list-style-type: none"> <li>50m (EA guidance (EA, 2017) for hazardous substances)</li> <li>360m (downgradient sentinel well, representing a point of compliance prior to the River Tees); and</li> <li>Within the River Tees</li> </ul>	In line with RTM methodology
	<p><b>Made Ground Source</b></p> <p>For Made Ground source SSAC, a compliance point immediately prior to the River Tees (sentinel wells) and within the River Tees was considered given that Made Ground is present up to the boundary of the site.</p>	
Compliance Criteria	CoC Specific	Tables 1 & 4 and Appendices F & G
Degradation*	CoC Specific	Appendix B (Chemical Input Parameters)

Parameter	Value	Comment
Time Frame	Ogata-Banks solution	In line with RTM methodology
Dispersivity	Longitudinal, transverse and vertical dispersivities have been calculated within the RTW model as 10%, 1% and 0.1% of the compliance point distance respectively.	In line with RTM methodology

\*There is a wealth of literature which provides evidence for the ready degradation of petroleum hydrocarbons in aerobic conditions (e.g. Potter & Simmons, 1998; EA, 2009c; Noble & Morgan, 2002; Howard et al 1991; CCME, 2000). Degradation has conservatively been modelled in the dissolved phase only although it is likely that at least some degradation is also occurring in the sorbed phase.

### 5.2.3 Model Validation

A model validation exercise was undertaken for the RTW model by comparing forward predicted concentrations at a hydraulically down-gradient well, with measured concentrations in groundwater, whilst considering the time that measured CoC have likely been in the subsurface.

The model set-up was as per the parameters defined in Appendix D. For the purpose of validation, a forward prediction to monitoring wells BH103S and BH2017 were undertaken based on measured benzene concentrations. BH103S is located approximately 90m from the modelled source area and BH2017 is located approximately 360m from the modelled source area near the northern boundary of the site (sentinel well). BH110, BH103S and BH2017 all screen the Made Ground. Longitudinal and transverse dispersivity were set to 10% and 1% of the distance modelled (in line with RTM guidance).

For the forward prediction, the average concentration of benzene in BH110 was selected as the source concentration, and the average concentration in BH103S and BH2017 were used as the downgradient concentration for comparison. Timeframes of 20 to 60yrs were used on the basis that the SBCO has been in operation since approximately 1965 and that contaminant releases are not thought to be recent. The results of the forward prediction are presented below.

Timeframe	BH110 Average Measured Benzene Concentration (µg/l)	BH103S Average Measured Benzene Concentration (µg/l)	BH103S RTW Model predicted Benzene Concentration (µg/l)	BH2017 Average Measured Benzene Concentration (µg/l)	BH2017 RTW Model predicted Benzene Concentration (µg/l)
20	34,000	127	253	<1	<1
30			1,260		<1
40			1,950		<1
50			2,180		1.06
60			23,400		3.17

The results of the model validation indicate that the model is likely over predicting down gradient concentrations by around an order of magnitude for BH103S and potentially also overpredicting for BH2017. As such, the model set up is considered reasonable, whilst providing a level of conservatism in the assessment.

### 5.2.4 Modelled Timeframe Assessment

An assessment of modelled timeframes was undertaken in order to ascertain whether conditions on site have likely reached steady state. The assessment looks at the travel time from the modelled groundwater source to the sentinel wells (approximately 360m to BH2017). The purpose of this timeframe assessment was to confirm whether or not current concentrations in the sentinel wells could be considered to represent the risk from the modelled groundwater source to the River Tees.



For the Made Ground source, such an assessment is not considered necessary as a number of the sentinel wells are directly installed within the Made Ground. Given the diffuse nature of contamination in the Made Ground from across the site, the relatively permeable nature of the Made Ground and the significant length of time the Made Ground has been present, concentrations in sentinel wells are considered unlikely to increase further over time and to be at steady state in relation to Made Ground.

For benzene, the model indicates a contaminant flow velocity of 5.14m/day. This corresponds with a travel time of approximately 190yrs from the modelled groundwater source to the sentinel wells. Based on this, after 190yrs, concentrations 360m downgradient are expected to be at or close to steady state.

This suggests the concentrations observed in downgradient sentinel wells due to the groundwater source may continue increasing over time as less than 190yrs has elapsed. On this basis, current concentrations in sentinel wells may not represent the risk to water resource from the groundwater source. It is therefore considered appropriate to derive SSAC (at steady state conditions) to assess the risk.

When a forward prediction is undertaken for a 190yr timeframe or longer (360m, from modelled source to BH2017 sentinel well using average benzene concentrations as defined in 5.2.3 above), a concentration of 16µg/l benzene is predicted 360m downgradient. This is in excess of the benzene saline EQS (8µg/l) and indicates that SSAC derived based on the RTM modelling alone (at 360m compliance point) will be exceeded. As such, dilution in the receiving surface water body (River Tees) is considered further below.

### 5.2.5 Evaluation of Potential Dilution Effects

The potential dilution occurring within surface water is calculated by considering both the flow rate of groundwater into surface water and the flow rate of the surface water. Surface water rates have been based on data provided by the Centre for Hydrology and Ecology National River Flow Archive ([www.nrfa.ceh.ac.uk](http://www.nrfa.ceh.ac.uk)), for the River Tees (recorded at Leven Bridge, reference: 25005 and at Low Moor, reference 25009) and are presented in the table below. The 95th percentile (minimum monthly flow) has been adopted to undertake the dilution calculation:

River Tees (Leven Bridge & Low Moor)	Flow rate (m3/s)	Flow Rate (m3/day)
Mean flow	22.389	1,934,410
Minimum monthly flow	3.329	287,626

The rate of groundwater flow into the river is estimated using the following algorithm, based on Darcy's Law:

$$Q_{gw} = k \cdot i \cdot A$$

Where:

- $Q_{gw}$  = Groundwater rate of discharge into surface water (m<sup>3</sup>/day)
- $k$  = Hydraulic conductivity (m/day)
- $i$  = Hydraulic gradient
- $A$  = Area of impacted groundwater entering river (m<sup>2</sup>)

The values used for the above parameters and their justification are presented in Appendix D. In line with the methodology presented in the RTM, a sensitivity of parameters is also discussed in Appendix C.

The dilution factor, DF, is calculated as:

$$DF_{\text{River}} = \frac{Q_u + Q_{\text{gw}}}{Q_{\text{gw}}}$$

- $DF_{\text{River}}$  = Dilution factor within the river  
 $Q_u$  = Surface water flow upstream of discharge point under low flow conditions (m<sup>3</sup>/day) – minimum flow rate  
 $Q_{\text{gw}}$  = Groundwater rate of discharge into surface water (m<sup>3</sup>/day)

As such, using the input parameters in Appendix D, the dilution factor at the 95th percentile is calculated as:

$$DF_{\text{River}} = 21,100$$

## 5.2.6 Development of Water Resource SSAC

SSAC defined for the protection of the identified water resource receptors have been derived and are presented as follows:

**Groundwater Source** – Presented in Table 2

- 50m compliance point (aquifer compliance point)
- 360m compliance point (prior to entering River Tees)
- Within the River Tees (360m lateral migration and dilution in the river)

**Made Ground Source** – Presented in Table 4

- Prior to entering the River Tees (sentinel wells comparison with EQS)
- Within the River Tees (EQS incorporating dilution in the river)

For the groundwater source, 10% of the 360m compliant point SSAC was multiplied by the dilution factor when considering dilution in the River Tees. For the Made Ground source, 10% of the EQS was multiplied by the dilution factor, as per EA guidance.

Example RTW output sheets for benzene are presented in Appendix G.

The RTM states:

*“A simple check that should be undertaken is that the calculated remedial target does not exceed the solubility limit for the contaminant. In this case remediation of the soil would be unnecessary to protect water resources...”*

For groundwater, the SSAC have been compared to the theoretical solubility. Where the SSAC exceeds the theoretical solubility, this is indicated by “>SOL” in the SSAC columns in the tables, and these CoC are not considered to pose unacceptable risks to the identified water resources receptors.

In addition, the RTM also states:

*“For contaminants which are characterised by a high partition coefficient (e.g., some PAH compounds), the rates of contaminant movement can be slow (centimetres per year). Thus, there may be a considerable delay (tens of thousands of years) before the contaminant reaches the compliance point. In these cases, it may be acceptable for no action to be taken even if the remedial target is exceeded.”*

## 5.2.7 Water Resource Risk Estimation

### Groundwater Source

The measured concentrations of CoC in groundwater reported in Arcadis (2021) from wells within the modelled groundwater source area (BH105 and BH110; as discussed in Section 4, generally the locations of the highest measured groundwater concentrations) have been compared to the SSAC protective of water resources in Table 3.

Concentrations of several TPH fraction were measured exceeding the 50m SSAC and no fractions exceed the 360m SSAC. Benzene, naphthalene and cyanide were found to exceed the 360m compliance point SSAC.

None of the measured concentrations exceeded the SSAC incorporating dilution within the River Tees.

### **Made Ground Source**

Measured concentrations of CoC in groundwater reported in Royal Haskoning (2021) from the 13no. sentinel wells have been compared to the SSAC protective of water resources in Table 4.

Measured groundwater concentrations for a number of metals, cyanide, petroleum hydrocarbons, PAH phenolics and other organic compounds exceeded the EQS. When comparing against SSAC incorporating dilution within the River Tees, none of the measured concentrations exceed the SSAC.

## **5.2.8 Water Resource Risk Evaluation**

The assessment considered multiple compliance points including; within the River Tees, a compliance point prior to the River Tees and an on-site compliance point (groundwater source only, 50m compliance point).

### **50m Compliance Point (Groundwater Source only)**

The 50m compliance point was modelled for the groundwater source as a first stage of assessment in line with EA guidance for hazardous substances. This compliance point is located on site (down gradient boundary approximately 310m beyond) and is protective of aquifers. As discussed in Section 4, the aquifers underlying the site are considered of limited resource potential. Furthermore, the evidence from site data indicates that contamination is not migrating downwards significantly into the underlying aquifers and is generally limited to the overlying Made Ground (reclaimed land). As such, although a number of hydrocarbons and cyanide exceed the 50m SSAC derived, measured concentrations are not considered to present a significant risk to water resources on this basis. Assessment of a more distant compliance point protective of the River Tees provides a more accurate appraisal of the risk to water resources.

### **Compliance Point Prior to the River Tees (at Sentinel Wells and 360m down gradient from Groundwater Source)**

From the groundwater source, naphthalene and benzene were the only hydrocarbon compounds to exceed based on a compliance point prior to the River Tees (360m compliance point). Concentrations exceeded by less than an order of magnitude. Given the conservatism in the assessment (as demonstrated in the model validation), the risk presented by these CoC within the groundwater source to a compliance point prior to the River Tees (360m compliance point) is considered to be low.

From the groundwater source, cyanide exceeds based on compliance point prior to the River Tees by a greater margin. Cyanide is an inorganic species which may be present in a variety of forms including complexes, salts and as free cyanide (hydrogen cyanide). It is hydrogen cyanide which is of greatest concern due to its toxicity and mobility. EQS and the RTM modelling undertaken are based on free cyanide. Some cyanide complexes may convert to free cyanide, but many are strongly bound and will remain in complex form. Analysis from the site indicates that total and complex cyanide concentrations are higher than free cyanide (representing compounds which can be readily converted to free cyanide) and that free cyanide is not above measurable concentrations in the majority of locations. As such, the risk from cyanide is likely to be overestimated and is not considered significant based on the dilution assessment.

Measured groundwater concentrations in sentinel wells (considered to represent the risk from the Made Ground source) exceeded EQS for a number of CoC including TPH, metals, inorganics and PAH. This is not unexpected given that some of the sentinel wells are installed directly screening the Made Ground. As Made Ground forms the boundary with the River Tees, concentrations are likely to be similar immediately adjacent to the River. The presence of structures such as sheet piled walls (potentially installed as part of future redevelopment works) would go some way to limit the amount of groundwater discharge from the site into the River Tees.

### **Compliance Point within The River Tees (dilution in the receptor)**

None of the measured concentrations from either the on-site groundwater source wells (BH110 and BH105; location of the highest measured groundwater concentrations of hydrocarbons and the majority of other

contaminants) or the sentinel wells (located along the hydraulically down gradient northern site boundary) exceeded their respective SSAC when dilution within the River Tees was considered.

The dilution assessment is based on upstream gauging stations, prior to the point that the River Tees becomes estuarine. Therefore, the dilution assessment is conservative and actual dilution effects are likely to be much greater. Furthermore, in line with the RTM guidance, dilution is based on 10% of EQS and on low flow conditions. The modelling undertaken demonstrates that concentrations in the River Tees will remain below 10% of the EQS based on inputs from on site sources. Given the margin by which concentrations fall below the criteria, contaminant concentrations in the River Tees are considered unlikely to exceed measurable concentrations due to inputs from on-site sources.

Surface water monitoring data from the River Tees is provided in Royal Haskoning 2021. Measured concentrations were generally below the EQS, with the exception of fluoranthene (maximum measured 0.05µg/l versus EQS of 0.0063µg/l). Measured concentrations were similar from the three sampling locations, suggesting no trends related to groundwater discharges from the site. Given the potential for other contributions into the river from upstream land uses, and that fluoranthene was not identified on site of particular concern (higher concentrations of other more mobile contaminants were measured), the findings of the surface water sampling are considered to support the above conclusions.

### **Other Considerations**

The modelling shows that sufficient time may not have yet elapsed for contaminants to have reached a steady state equilibrium with groundwater (in relation to the groundwater source). However, it is understood the SBCO plant to the south is likely to be demolished with a ground investigation and remedial works to be undertaken at the site. This will allow for better delineation of the source and the full extent of the CoC impacts to be documented. It is likely that once this has been carried out, contaminant concentrations at SBA are likely to decrease, particularly within BH110, where the greatest impacts are observed.

Whilst the timeframe assessment for the groundwater source indicated that steady state may not yet have been reached, it predicted that measured concentrations may increase by around an order of magnitude from present day (assumed around the 50yr timeframe modelled) to steady state (approximately 190yrs or greater). Given this and the current measured concentrations in the sentinel wells, although the model predicts an increase in measured concentrations in sentinel wells due to the groundwater source, it is considered that measured sentinel well concentrations will still remain well below their SSAC (considering dilution in the River Tees).

DNAPL has been measured on site. This may require consideration as part of remediation works however, dissolved phase concentrations indicate that DNAPL is not presenting a risk to water resources, although it does have potential to act as an ongoing source of contamination.

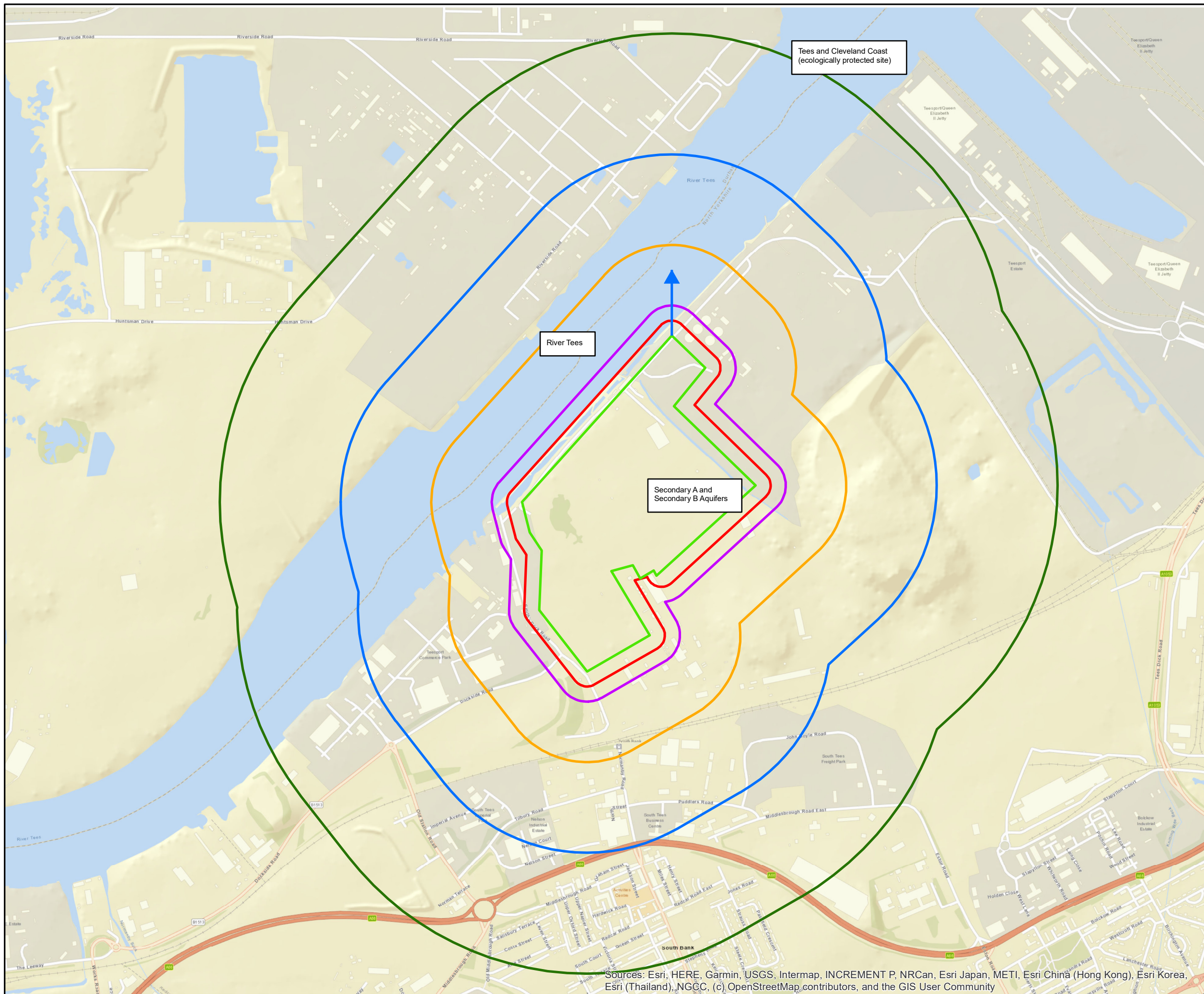
A potential pathway due to piled foundations was identified under the pollutant linkages. Based on the findings of the contaminant distribution and underlying ground conditions, it is considered unlikely that this pathway could represent a significant risk to water resources. Although contamination may locally be able to enter the underlying natural deposits around piles, lateral migration within the unit is unlikely to be significant.

## **5.3 Assumptions, Limitations and Data Gaps**

The SSAC defined to offer protection to the identified water resource receptors are based on current best practice and are defined using the site investigation data available at the present time. Modifications to the conceptual model, such as the collection of additional site data, may result in changes to the SSAC defined here.

## Figures



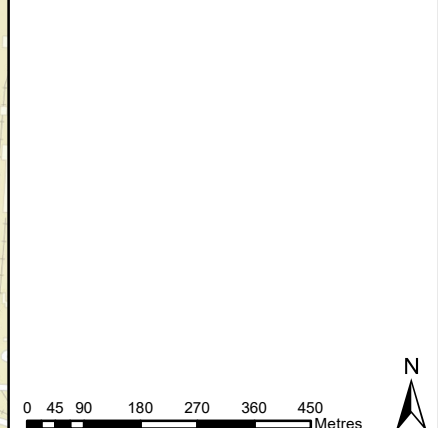


### LEGEND

- SITE BOUNDARY
- BUFFER**
- 50m
- 100m
- 300m
- 600m
- 1000m
- ➔ INFERRED GROUNDWATER FLOW DIRECTION

### NOTES

SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE.



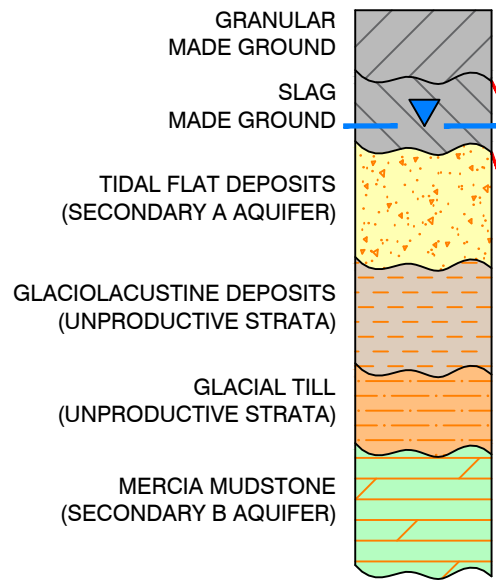
TITLE: <b>SITE LOCATION AND ENVIRONMENTAL SETTING</b>	
SITE: <b>REDCAR SOUTH BANK AREA A</b>	
CLIENT: <b>SOUTH TEES DEVELOPMENT CORPORATION</b>	
PROJECT: <b>10035117</b>	<b>FIGURE 1</b>
DATE: 21/05/21	DRAWN BY: AP
DRG No.: 10035117-AUK-XX-XX-DR-ZZ-008-P1 GIS	
SCALE: <b>1 : 12,000</b>	PRINT: <b>A3</b>

Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

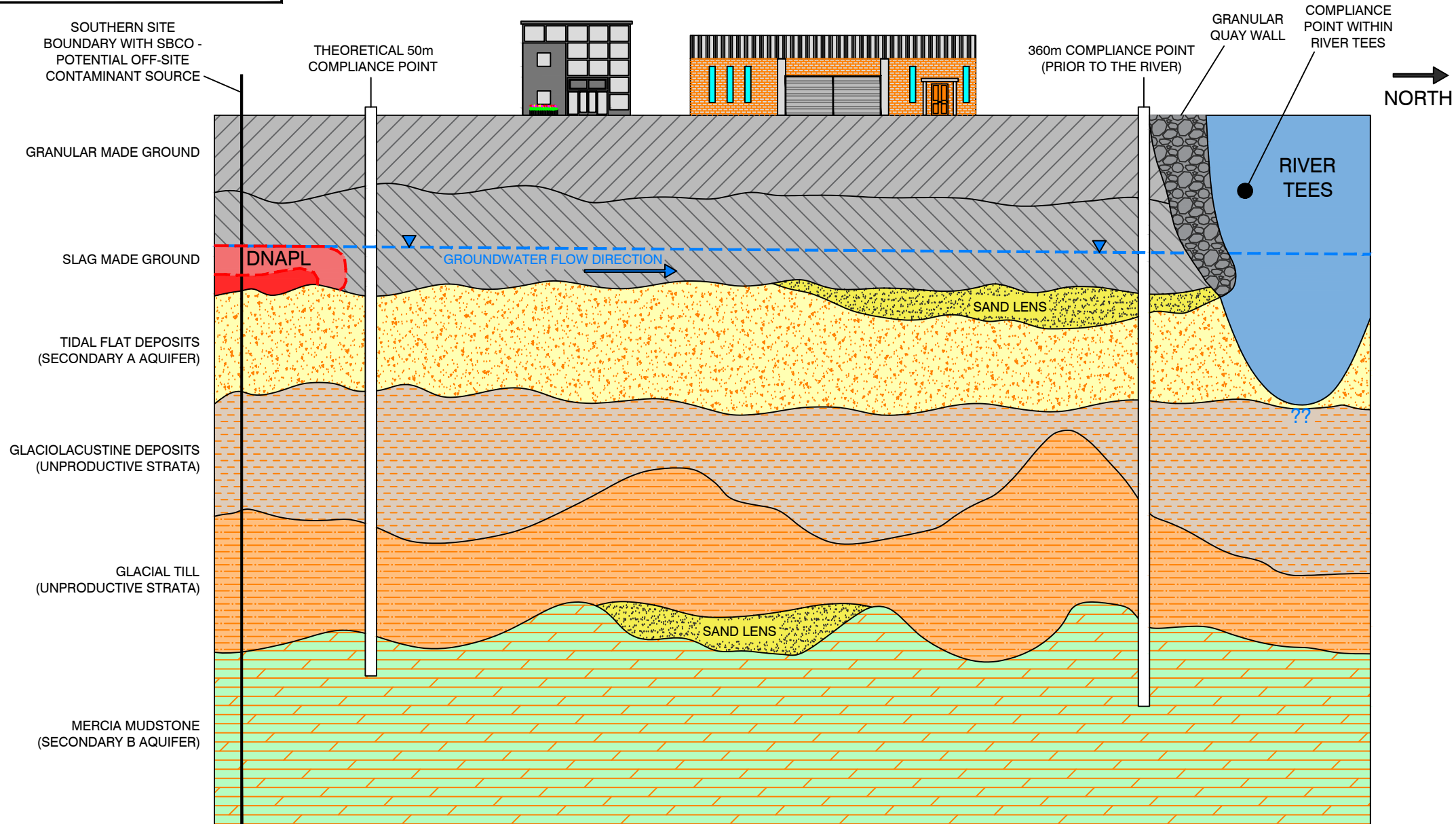




**COMMERCIAL / INDUSTRIAL END USE CSM**



CONCEPTUAL ZONE	PHYSICAL CHARACTERISTICS	JUSTIFICATION
UNSATURATED ZONE	GRANULAR MADE GROUND - SANDY GRAVEL WITH VARYING COBBLE CONTENT	REPRESENTATIVE OF DEPOSITS IMMEDIATELY ABOVE THE SOURCE ZONE
SOURCE ZONE	SLAG MADE GROUND - SANDY GRAVEL & COBBLES (>50% SLAG)	REPRESENTATIVE OF DEPOSITS WITHIN WHICH THE MAJORITY OF IMPACTS ARE LOCATED
AQUIFER	SLAG MADE GROUND - SANDY GRAVEL & COBBLES (>50% SLAG)	REPRESENTATIVE OF THE DEPOSITS ENCOUNTERED BENEATH THE SITE, THROUGH WHICH OFF-SITE MIGRATION OF GROUNDWATER IS ANTICIPATED TO TAKE PLACE



KEY

NOTES

INDICATIVE - NOT TO SCALE  
 SBCO - SOUTH BANK COKE OVEN  
 DNAPL - DENSE NON-AQUEOUS PHASE LIQUID  
 MADE GROUND IS ALSO CONSIDERED A SOURCE OF DIFFUSE CONTAMINANTS - NOT DEPICTED FOR SIMPLICITY.

REV	DATE	COMMENT	CAD

TITLE: WATER RESOURCES CONCEPTUAL SITE MODEL  
 SITE: REDCAR SOUTH BANK AREA A  
 CLIENT: SOUTH TEES DEVELOPMENT CORPORATION  
 PROJECT: 10035117 FIGURE 2  
 DATE: 06/05/21 DRAWN: BNB REV: -  
 DRG.No.: 10035117-AUK-XX-XX-DR-ZZ-0010-P1 PRINT: A3





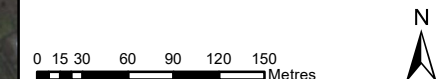


**LEGEND**

- SITE BOUNDARY
- <MDL
- <MDL - 10 mg/kg
- 10 - 100 mg/kg
- 100 - 1,000 mg/kg
- 1,000 - 10,000
- >10,000

**NOTES**

SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE.



TITLE: **MEASURED TOTAL PETROLEUM HYDROCARBON CONCENTRATIONS IN SOIL (mg/kg)**

SITE: **REDCAR SOUTH BANK AREA A**

CLIENT: **SOUTH TEES DEVELOPMENT CORPORATION**

PROJECT: **10035117** **FIGURE 3a**

DATE: 01/06/21 DRAWN BY: AP

DRG No.: 10035117-AUK-XX-XX-DR-ZZ-0011-P1 GIS

SCALE: 1 : 5,000 PRINT: A3

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community





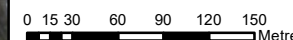


**LEGEND**

- SITE BOUNDARY
- <MDL
- <MDL - 10 mg/kg
- 10 - 100 mg/kg
- 100 - 1,000 mg/kg
- 1,000 - 10,000
- >10,000

**NOTES**

SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE.



TITLE: **MEASURED COPPER CONCENTRATIONS IN SOIL (mg/kg)**

SITE: **REDCAR SOUTH BANK AREA A**

CLIENT: **SOUTH TEES DEVELOPMENT CORPORATION**

PROJECT: **10035117** **FIGURE 3b**

DATE: 03/06/21 DRAWN BY: AP

DRG No.: 10035117-AUK-XX-DR-ZZ-0012-P1 GIS

SCALE: **1 : 5,000** PRINT: **A3**

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community





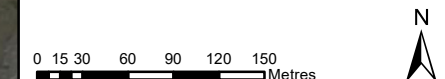


**LEGEND**

- <MDL
- <MDL - 10 mg/kg
- 10 - 100 mg/kg
- 100 - 1,000 mg/kg
- 1,000 - 10,000
- >10,000
- SITE BOUNDARY

**NOTES**

SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE.



<b>TITLE:</b> MEASURED LEAD CONCENTRATIONS IN SOIL (mg/kg)	
<b>SITE:</b> REDCAR SOUTH BANK AREA A	
<b>CLIENT:</b> SOUTH TEES DEVELOPMENT CORPORATION	
<b>PROJECT:</b> 10035117	<b>FIGURE 3c</b>
<b>DATE:</b> 03/06/21	<b>DRAWN BY:</b> AP
<b>DRG No.:</b> 10035117-AUK-XX-DR-ZZ-0013-P1 GIS	
<b>SCALE:</b> 1 : 5,000	<b>PRINT:</b> A3

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community





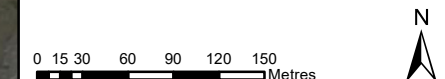


**LEGEND**

- <MDL
- <MDL - 10 mg/kg
- 10 - 100 mg/kg
- 100 - 1,000 mg/kg
- 1,000 - 10,000
- >10,000
- SITE BOUNDARY

**NOTES**

SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE.

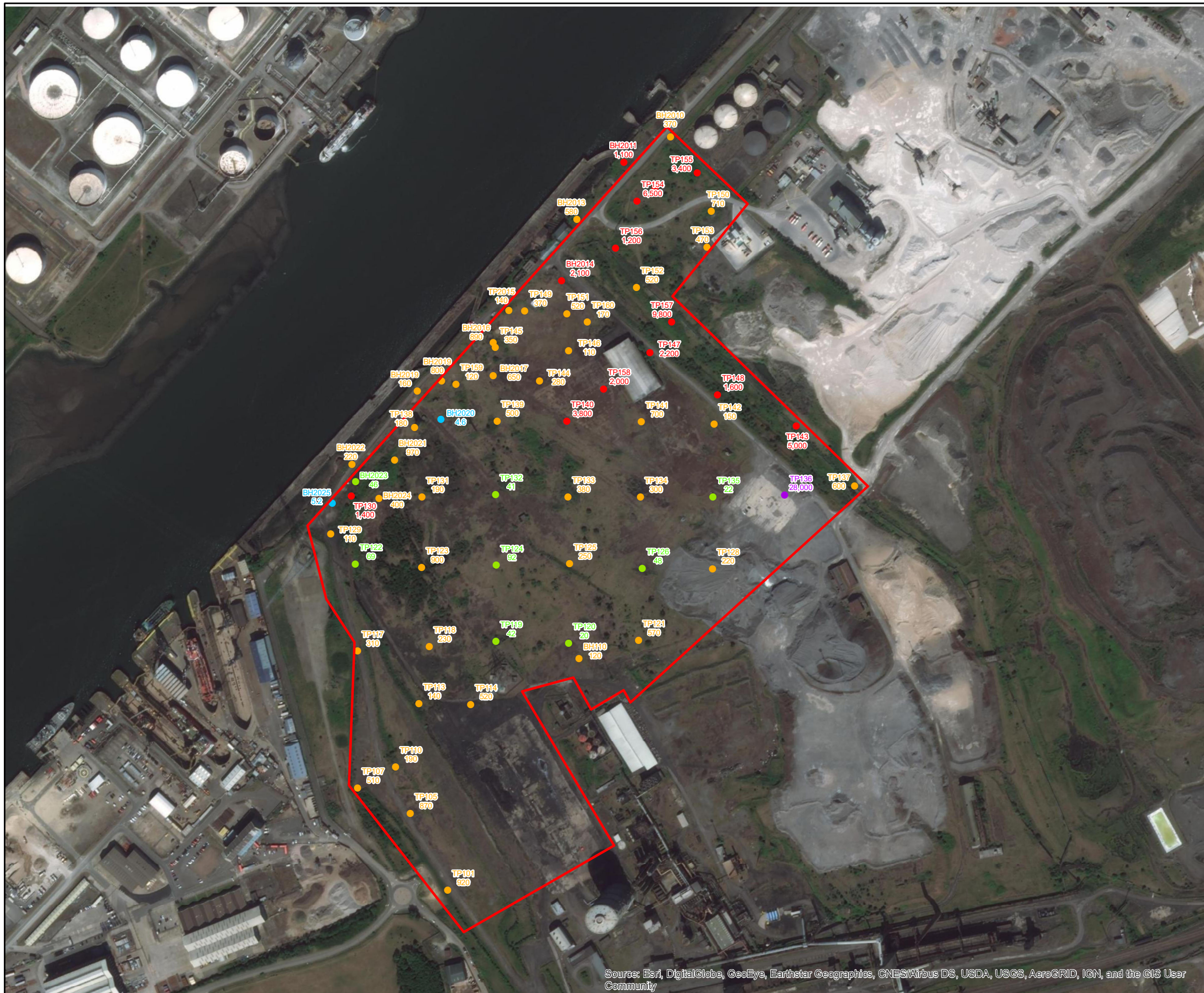


TITLE: <b>MEASURED NICKEL CONCENTRATIONS IN SOIL (mg/kg)</b>	
SITE: <b>REDCAR SOUTH BANK AREA A</b>	
CLIENT: <b>SOUTH TEES DEVELOPMENT CORPORATION</b>	
PROJECT: <b>10035117</b>	<b>FIGURE 3d</b>
DATE: 03/06/21	DRAWN BY: AP
DRG No.: 10035117-AUK-XX-DR-ZZ-0014-P1 GIS	
SCALE: 1 : 5,000	PRINT: A3

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community





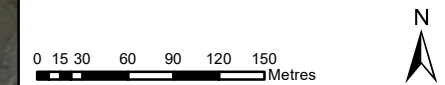


**LEGEND**

- SITE BOUNDARY
- <MDL
- <MDL - 10 mg/kg
- 10 - 100 mg/kg
- 100 - 1,000 mg/kg
- 1,000 - 10,000
- >10,000

**NOTES**

SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE.



TITLE: <b>MEASURED ZINC CONCENTRATIONS IN SOIL (mg/kg)</b>	
SITE: <b>REDCAR SOUTH BANK AREA A</b>	
CLIENT: <b>SOUTH TEES DEVELOPMENT CORPORATION</b>	
PROJECT: <b>10035117</b>	<b>FIGURE 3e</b>
DATE: 03/06/21	DRAWN BY: AP
DRG No.: 10035117-AUK-XX-DR-ZZ-0015-P1 GIS	
SCALE: 1 : 5,000	PRINT: A3

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community





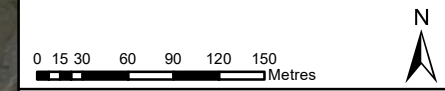


**LEGEND**

- SITE BOUNDARY
- <MDL
- <MDL - 10 mg/kg
- 10 - 100 mg/kg
- 100 - 1,000 mg/kg
- 1,000 - 10,000
- >10,000

**NOTES**

SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE.



TITLE: <b>MEASURED TOTAL CYANIDE CONCENTRATIONS IN SOIL (mg/kg)</b>	
SITE: <b>REDCAR SOUTH BANK AREA A</b>	
CLIENT: <b>SOUTH TEES DEVELOPMENT CORPORATION</b>	
PROJECT: <b>10035117</b>	<b>FIGURE 3f</b>
DATE: <b>02/06/21</b>	DRAWN BY: <b>AP</b>
DRG No.: <b>10035117-AUK-XX-DR-ZZ-0016-P1 GIS</b>	
SCALE: <b>1 : 5,000</b>	PRINT: <b>A3</b>

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community







LEGEND	
●	<MDL
●	MDL - 0.5mg/kg
●	0.5 - 1mg/kg
●	1 - 5mg/kg
●	5 - 10mg/kg
●	>10
□	SITE BOUNDARY

NOTES	
SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE.	

0 15 30 60 90 120 150 Metres

N

<b>TITLE:</b> MEASURED FREE CYANIDE CONCENTRATIONS IN SOIL (mg/kg)	
<b>SITE:</b> REDCAR SOUTH BANK AREA A	
<b>CLIENT:</b> SOUTH TEES DEVELOPMENT CORPORATION	
<b>PROJECT:</b> 10035117	<b>FIGURE</b> 3g
<b>DATE:</b> 02/06/21	<b>DRAWN BY:</b> AP
<b>DRG No.:</b> 10035117-AUK-XX-DR-ZZ-0017-P1 GIS	
<b>SCALE:</b> 1 : 5,000	<b>PRINT:</b> A3

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community





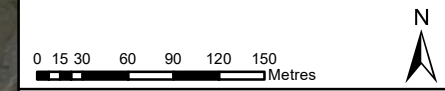


**LEGEND**

- SITE BOUNDARY
- <MDL
- MDL - 0.5mg/kg
- 0.5 - 1mg/kg
- 1 - 5mg/kg
- 5 - 10mg/kg
- >10

**NOTES**

SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE.



TITLE: <b>MEASURED BENZENE CONCENTRATIONS IN SOIL (mg/kg)</b>	
SITE: <b>REDCAR SOUTH BANK AREA A</b>	
CLIENT: <b>SOUTH TEES DEVELOPMENT CORPORATION</b>	
PROJECT: <b>10035117</b>	<b>FIGURE 3h</b>
DATE: <b>02/06/21</b>	DRAWN BY: <b>AP</b>
DRG No.: <b>10035117-AUK-XX-DR-ZZ-0018-P1 GIS</b>	
SCALE: <b>1 : 5,000</b>	PRINT: <b>A3</b>

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community





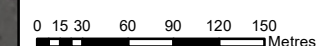


**LEGEND**

- SITE BOUNDARY
- <MDL
- <MDL - 10 mg/kg
- 10 - 100 mg/kg
- 100 - 1,000 mg/kg
- 1,000 - 10,000
- >10,000

**NOTES**

SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE.



TITLE: MEASURED TOTAL PETROLEUM HYDROCARBON CONCENTRATIONS IN GROUNDWATER: WELLS SCREENING MADE GROUND (µg/l)

SITE: REDCAR SOUTH BANK AREA A

CLIENT: SOUTH TEES DEVELOPMENT CORPORATION

PROJECT: 10035117      FIGURE 3i

DATE: 02/06/21      DRAWN BY: AP

DRG No.: 10035117-AUK-XX-DR-ZZ-0019-P1 GIS

SCALE: 1 : 5,000      PRINT: A3

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community





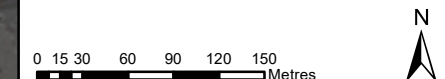


**LEGEND**

- SITE BOUNDARY
- <MDL
- <MDL - 10 mg/kg
- 10 - 100 mg/kg
- 100 - 1,000 mg/kg
- 1,000 - 10,000
- >10,000

**NOTES**

SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE.



TITLE: <b>MEASURED TOTAL PETROLEUM HYDROCARBON CONCENTRATIONS IN GROUNDWATER: WELLS SCREENING NATURAL STRATA (µg/l)</b>	
SITE: <b>REDCAR SOUTH BANK AREA A</b>	
CLIENT: <b>SOUTH TEES DEVELOPMENT CORPORATION</b>	
PROJECT: <b>10035117</b>	<b>FIGURE 3j</b>
DATE: <b>02/06/21</b>	DRAWN BY: <b>AP</b>
DRG No.: <b>10035117-AUK-XX-XX-DR-ZZ-0020-P1 GIS</b>	
SCALE: <b>1 : 5,000</b>	PRINT: <b>A3</b>

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community





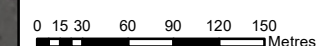


**LEGEND**

- SITE BOUNDARY
- <MDL
- MDL - 0.5mg/kg
- 0.5 - 1mg/kg
- 1 - 5mg/kg
- 5 - 10mg/kg
- >10

**NOTES**

SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE.



TITLE:  
**MEASURED COPPER CONCENTRATIONS  
IN GROUNDWATER: WELLS SCREENING  
MADE GROUND (µg/l)**

SITE:  
**REDCAR SOUTH BANK AREA A**

CLIENT:  
**SOUTH TEES  
DEVELOPMENT CORPORATION**

PROJECT: **10035117**      **FIGURE 3k**

DATE: 03/06/21      DRAWN BY: AP

DRG No.: 10035117-AUK-XX-XX-DR-ZZ-0021-P1 GIS

SCALE: **1 : 5,000**      PRINT: **A3**

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community





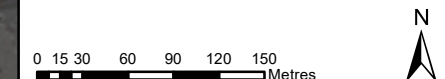


**LEGEND**

- <MDL
- MDL - 0.5mg/kg
- 0.5 - 1mg/kg
- 1 - 5mg/kg
- 5 - 10mg/kg
- >10
- SITE BOUNDARY

**NOTES**

SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE.



TITLE: **MEASURED COPPER CONCENTRATIONS IN GROUNDWATER: WELLS SCREENING NATURAL STRATA (µg/l)**

SITE: **REDCAR SOUTH BANK AREA A**

CLIENT: **SOUTH TEES DEVELOPMENT CORPORATION**

PROJECT: **10035117** **FIGURE 3I**

DATE: 03/06/21 DRAWN BY: AP

DRG No.: 10035117-AUK-XX-XX-DR-ZZ-0023-P1 GIS

SCALE: 1 : 5,000 PRINT: A3

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community





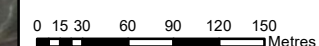


**LEGEND**

- <MDL
- MDL - 0.5mg/kg
- 0.5 - 1mg/kg
- 1 - 5mg/kg
- 5 - 10mg/kg
- >10
- SITE BOUNDARY

**NOTES**

SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE.



TITLE: **MEASURED LEAD CONCENTRATIONS IN GROUNDWATER: WELLS SCREENING MADE GROUND (µg/l)**

SITE: **REDCAR SOUTH BANK AREA A**

CLIENT: **SOUTH TEES DEVELOPMENT CORPORATION**

PROJECT: **10035117** **FIGURE 3m**

DATE: 03/06/21 DRAWN BY: AP

DRG No.: 10035117-AUK-XX-DR-ZZ-0024-P1 GIS

SCALE: 1 : 5,000 PRINT: A3

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community





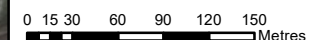


**LEGEND**

- SITE BOUNDARY
- <MDL
- MDL - 0.5mg/kg
- 0.5 - 1mg/kg
- 1 - 5mg/kg
- 5 - 10mg/kg
- >10

**NOTES**

SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE.



TITLE: **MEASURED LEAD CONCENTRATIONS IN GROUNDWATER: WELLS SCREENING NATURAL STRATA (µg/l)**

SITE: **REDCAR SOUTH BANK AREA A**

CLIENT: **SOUTH TEES DEVELOPMENT CORPORATION**

PROJECT: **10035117** **FIGURE 3n**

DATE: **02/06/21** DRAWN BY: **AP**

DRG No.: **10035117-AUK-XX-DR-ZZ-0025-P1 GIS**

SCALE: **1 : 5,000** PRINT: **A3**

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community





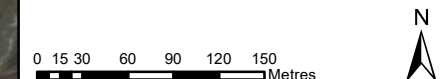


**LEGEND**

- SITE BOUNDARY
- <MDL
- MDL - 0.5mg/kg
- 0.5 - 1mg/kg
- 1 - 5mg/kg
- 5 - 10mg/kg
- >10

**NOTES**

SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE.



TITLE:  
**MEASURED NICKEL CONCENTRATIONS  
IN GROUNDWATER: WELLS SCREENING  
MADE GROUND (µg/l)**

SITE:  
**REDCAR SOUTH BANK AREA A**

CLIENT:  
**SOUTH TEES  
DEVELOPMENT CORPORATION**

PROJECT: **10035117**      **FIGURE 3o**

DATE: 02/06/21      DRAWN BY: AP

DRG No.: 10035117-AUK-XX-DR-ZZ-0026-P1 GIS

SCALE: 1 : 5,000      PRINT: A3

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community





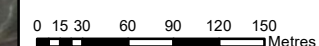


**LEGEND**

- <MDL
- MDL - 0.5mg/kg
- 0.5 - 1mg/kg
- 1 - 5mg/kg
- 5 - 10mg/kg
- >10
- SITE BOUNDARY

**NOTES**

SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE.



TITLE: <b>MEASURED NICKEL CONCENTRATIONS IN GROUNDWATER: WELLS SCREENING NATURAL STRATA (µg/l)</b>	
SITE: <b>REDCAR SOUTH BANK AREA A</b>	
CLIENT: <b>SOUTH TEES DEVELOPMENT CORPORATION</b>	
PROJECT: <b>10035117</b>	<b>FIGURE 3p</b>
DATE: 02/06/21	DRAWN BY: AP
DRG No.: 10035117-AUK-XX-DR-ZZ-0027-P1 GIS	
SCALE: 1 : 5,000	PRINT: A3

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community





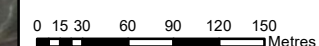


**LEGEND**

- SITE BOUNDARY
- <MDL
- MDL - 0.5mg/kg
- 0.5 - 1mg/kg
- 1 - 5mg/kg
- 5 - 10mg/kg
- >10

**NOTES**

SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE.



TITLE: **MEASURED ZINC CONCENTRATIONS IN GROUNDWATER: WELLS SCREENING MADE GROUND (µg/l)**

SITE: **REDCAR SOUTH BANK AREA A**

CLIENT: **SOUTH TEES DEVELOPMENT CORPORATION**

PROJECT: **10035117** **FIGURE 3q**

DATE: 02/06/21 DRAWN BY: AP

DRG No.: 10035117-AUK-XX-DR-ZZ-0028-P1 GIS

SCALE: 1 : 5,000 PRINT: A3

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community





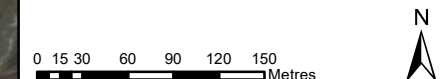


**LEGEND**

- <math>< 0.5</math> mg/kg
- MDL - 0.5mg/kg
- 0.5 - 1mg/kg
- 1 - 5mg/kg
- 5 - 10mg/kg
- >10
- SITE BOUNDARY

**NOTES**

SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE.



TITLE: <b>MEASURED ZINC CONCENTRATIONS IN GROUNDWATER: WELLS SCREENING NATURAL STRATA (µg/l)</b>	
SITE: <b>REDCAR SOUTH BANK AREA A</b>	
CLIENT: <b>SOUTH TEES DEVELOPMENT CORPORATION</b>	
PROJECT: <b>10035117</b>	<b>FIGURE 3r</b>
DATE: 02/06/21	DRAWN BY: AP
DRG No.: 10035117-AUK-XX-DR-ZZ-0029-P1 GIS	
SCALE: 1 : 5,000	PRINT: A3

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community





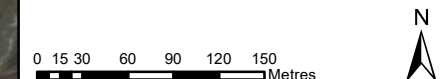


**LEGEND**

- SITE BOUNDARY
- <MDL
- MDL - 10ug/l
- 10 - 100ug/l
- 100 - 1,000ug/l
- 1,000 - 10,000ug/l
- >10,000ug/l

**NOTES**

SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE.



TITLE: **MEASURED TOTAL CYANIDE CONCENTRATIONS IN GROUNDWATER: WELLS SCREENING MADE GROUND (µg/l)**

SITE: **REDCAR SOUTH BANK AREA A**

CLIENT: **SOUTH TEES DEVELOPMENT CORPORATION**

PROJECT: **10035117** **FIGURE 3s**

DATE: 02/06/21 DRAWN BY: AP

DRG No.: 10035117-AUK-XX-DR-ZZ-0030-P1 GIS

SCALE: 1 : 5,000 PRINT: A3

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community





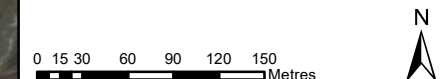


**LEGEND**

- SITE BOUNDARY
- <MDL
- MDL - 10ug/l
- 10 - 100ug/l
- 100 - 1,000ug/l
- 1,000 - 10,000ug/l
- >10,000ug/l

**NOTES**

SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE.



TITLE: **MEASURED TOTAL CYANIDE CONCENTRATIONS IN GROUNDWATER: WELLS SCREENING NATURAL STRATA (µg/l)**

SITE: **REDCAR SOUTH BANK AREA A**

CLIENT: **SOUTH TEES DEVELOPMENT CORPORATION**

PROJECT: **10035117**      **FIGURE 3t**

DATE: 02/06/21      DRAWN BY: AP

DRG No.: 10035117-AUK-XX-DR-ZZ-0031-P1 GIS

SCALE: 1 : 5,000      PRINT: A3

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community





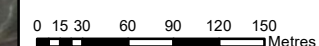


**LEGEND**

- SITE BOUNDARY
- <MDL
- MDL - 0.5mg/kg
- 0.5 - 1mg/kg
- 1 - 5mg/kg
- 5 - 10mg/kg
- >10

**NOTES**

SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE.



TITLE: **MEASURED FREE CYANIDE CONCENTRATIONS IN GROUNDWATER: WELLS SCREENING MADE GROUND (µg/l)**

SITE: **REDCAR SOUTH BANK AREA A**

CLIENT: **SOUTH TEES DEVELOPMENT CORPORATION**

PROJECT: **10035117** **FIGURE 3u**

DATE: 02/06/21 DRAWN BY: AP

DRG No.: 10035117-AUK-XX-DR-ZZ-0032-P1 GIS

SCALE: 1 : 5,000 PRINT: A3

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community





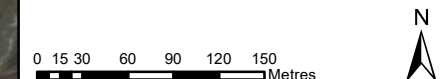


**LEGEND**

- SITE BOUNDARY
- <MDL
- MDL - 0.5mg/kg
- 0.5 - 1mg/kg
- 1 - 5mg/kg
- 5 - 10mg/kg
- >10

**NOTES**

SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE.



TITLE: **MEASURED FREE CYANIDE CONCENTRATIONS IN GROUNDWATER: WELLS SCREENING NATURAL STRATA (µg/l)**

SITE: **REDCAR SOUTH BANK AREA A**

CLIENT: **SOUTH TEES DEVELOPMENT CORPORATION**

PROJECT: **10035117**      **FIGURE 3v**

DATE: 02/06/21      DRAWN BY: AP

DRG No.: 10035117-AUK-XX-DR-ZZ-0033-P1 GIS

SCALE: 1 : 5,000      PRINT: A3

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community





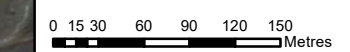


**LEGEND**

- SITE BOUNDARY
- <MDL
- <MDL - 10 mg/kg
- 10 - 100 mg/kg
- 100 - 1,000 mg/kg
- 1,000 - 10,000
- >10,000

**NOTES**

SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE.



TITLE: <b>MEASURED BENZENE CONCENTRATIONS IN GROUNDWATER: WELLS SCREENING MADE GROUND (µg/l)</b>	
SITE: <b>REDCAR SOUTH BANK AREA A</b>	
CLIENT: <b>SOUTH TEES DEVELOPMENT CORPORATION</b>	
PROJECT: <b>10035117</b>	<b>FIGURE 3w</b>
DATE: 02/06/21	DRAWN BY: AP
DRG No.: 10035117-AUK-XX-DR-ZZ-0034-P1 GIS	
SCALE: 1 : 5,000	PRINT: A3

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community





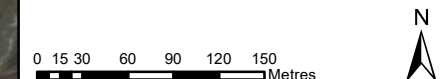


**LEGEND**

- SITE BOUNDARY
- <MDL
- <MDL - 10 mg/kg
- 10 - 100 mg/kg
- 100 - 1,000 mg/kg
- 1,000 - 10,000
- >10,000

**NOTES**

SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE.



TITLE:  
**MEASURED BENZENE CONCENTRATIONS  
 IN GROUNDWATER: WELLS SCREENING  
 NATURAL STRATA (µg/l)**

SITE:  
**REDCAR SOUTH BANK AREA A**

CLIENT:  
**SOUTH TEES  
 DEVELOPMENT CORPORATION**

PROJECT: **10035117**      **FIGURE 3x**

DATE: 02/06/21      DRAWN BY: AP

DRG No.: 10035117-AUK-XX-XX-DR-ZZ-0034-P1 GIS

SCALE: **1 : 5,000**      PRINT: **A3**

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community





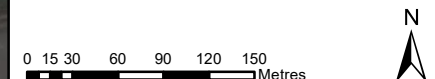


**LEGEND**

- SITE BOUNDARY
- SOURCE
- ◆ 'SENTINEL' MONITORING WELLS
- + MONITORING WELL LOCATION
- + TRIAL PIT LOCATION

**NOTES**

SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE.



TITLE: <b>SOURCE ZONE AND INVESTIGATION LOCATION PLAN</b>	
SITE: <b>REDCAR SOUTH BANK AREA A</b>	
CLIENT: <b>SOUTH TEES DEVELOPMENT CORPORATION</b>	
PROJECT: <b>10035117</b>	<b>FIGURE 4</b>
DATE: 21/05/21	DRAWN BY: AP
DRG No.: 10035117-AUK-XX-DR-ZZ-009-P1 GIS	
SCALE: <b>1 : 5,000</b>	PRINT: <b>A3</b>

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community





Detailed Quantitative Risk Assessment  
South Bank Area A, Redcar  
10035117-AUK-XX-XX-RP-ZZ-0270-01-SBA\_DQRA

## Tables

South Bank A, Redcar

Table 1: Comparison of Measured Concentrations of CoC in Groundwater (µg/l) with Environmental Quality Standards (EQS)

Contaminant of Concern	EQS (Estuaries & Coastal Waters)*	Maximum Measured Concentration (µg/l)	Location of Detection	Further Consideration required in relation to water resources?
<b>Aliphatics</b>				
Aliphatic C5-C6	#	<MDL	<MDL	Yes <sup>1</sup>
Aliphatic C6-C8	#	1400	BH104	Yes <sup>1</sup>
Aliphatic C10-C12	#	16	BH101D	Yes <sup>1</sup>
Aliphatic C12-C16	#	120	BH103S	Yes <sup>1</sup>
Aliphatic C16-C21	#	140	BH101 D	Yes <sup>1</sup>
Aliphatic C21-C35	#	78	BH101D	Yes <sup>1</sup>
<b>Aromatics</b>				
Aromatic C5-C7	8	1200	BH104	Yes <sup>1</sup>
Aromatic C7-C8	74	5900	BH110	Yes <sup>1</sup>
Aromatic C10-C12	#	<MDL	<MDL	Yes <sup>1</sup>
Aromatic C12-C16	#	1600	<MDL	Yes <sup>1</sup>
Aromatic C16-C21	#	210	BH110	Yes <sup>1</sup>
Aromatic C21-C35	#	27	BH101D	Yes <sup>1</sup>
TPH	50**	14000	BH110	Yes
<b>Indicator Compounds</b>				
Benzene	8	47000	BH110	Yes
Toluene	74	4500	BH110	Yes
Ethylbenzene	20	37	BH110	Yes
Xylenes	30	920	BH110	Yes
<b>PAH</b>				
Naphthalene	2	11000	BH110	Yes
Acenaphthylene	-	270	BH110	No <sup>2</sup>
Acenaphthene	-	630	BH105	No <sup>2</sup>
Fluorene	-	190	BH110	No <sup>2</sup>
Phenanthrene	-	310	BH110	No <sup>2</sup>
Anthracene	0.1	52	BH110	Yes
Fluoranthene	0.0063	260	BH110	Yes
Pyrene	-	190	BH110	No <sup>2</sup>
Benzo(a)anthracene	-	100	BH110	No <sup>2</sup>
Chrysene	-	84	BH110	No <sup>2</sup>
Benzo(b)fluoranthene	0.0000425***	110	BH110	Yes
Benzo(k)fluoranthene	0.0000425***	61	BH110	Yes
Benzo(a)pyrene	0.0000425***	100	BH110	Yes
Indeno(1,2,3-c,d)pyrene	0.0000425***	74	BH110	Yes
Dibenzo(a,h)anthracene	-	15	BH110	No <sup>2</sup>
Benzo(g,h,i)perylene	0.0000425***	45	BH110	Yes
<b>VOC</b>				
Bromochloromethane	-	4	BH105	No <sup>3</sup>
Chloroform	2.5	26	BH105	Yes
1,2-dichloroethane	10	85	BH104	Yes
Bromodichloromethane	-	5	BH105	No <sup>3</sup>
Styrene	-	43	BH110	No <sup>3</sup>
Isopropylbenzene	-	5	BH103S	No <sup>4</sup>
2-chlorotoluene	-	2	BH110	No <sup>3</sup>
1,3,5-trimethylbenzene	-	36	BH110	No <sup>3</sup>
4-chlorotoluene	-	1	BH103S	No <sup>3</sup>
Tert-butylbenzene	-	8	BH110	No <sup>3</sup>
1,2,4-trimethylbenzene	-	55	BH110	No <sup>3</sup>
p-isopropyltoluene	-	8	BH110	No <sup>3</sup>

South Bank A, Redcar				
Table 1: Comparison of Measured Concentrations of CoC in Groundwater (µg/l) with Environmental Quality Standards (EQS)				
Contaminant of Concern	EQS (Estuaries & Coastal Waters)*	Maximum Measured Concentration (µg/l)	Location of Detection	Further Consideration required in relation to water resources?
<b>SVOC</b>				
Aniline	-	20	BH105	No <sup>3</sup>
Benzyl Alcohol	-	5.9	BH102	No <sup>4</sup>
2-Methylphenol	-	950	BH110	No <sup>3</sup>
3&4-Methylphenol	-	2500	BH110	No <sup>3</sup>
2,4-Dimethylphenol	-	880	BH110	No <sup>3</sup>
2-Methylnaphthalene	-	26	BH107D	No <sup>4</sup>
4-Nitrophenol	-	19	BH107D	No <sup>3</sup>
Dibenzofuran	-	110	BH105	No <sup>3</sup>
Bis(2-ethylhexyl)phthalate	-	2.7	BH103S	No <sup>4</sup>
1,4-Dinitrobenzene	-	4.1	BH103S	No <sup>3</sup>
Carbazole	-	4.9	BH103S	No <sup>4</sup>
1-Methylnaphthalene	-	96	BH103S	No <sup>4</sup>
<b>Phenolics</b>				
Phenol	7.7	1300	BH110	Yes
<b>Inorganics</b>				
Cyanide	1	690	BH110	Yes

**Notes:**

*	UK Estuaries and Coastal EQS Annual Average (AA)
**	Surface Waters (Abstraction for Drinking Water) Regulations 1989. Further discussion on TPH criteria is provided in Appendix F.
***	Criteria of 0.00017 split between the sum of 5 PAH
1	No GAC available. Speciated TPH selected for further assessment.
2	Indicator approach adopted for PAH inline with UK guidance. PAH with published
3	For these compounds, no GAC was readily available for comparison. Review of the detections indicated that the remaining petroleum hydrocarbons assessed were considered appropriate indicators for the assessment of these compounds.
4	Compound not present in source wells and may relate to Made Ground rather than a groundwater source.
-	No water quality standard identified as suitable for deriving generic assessment criteria
#	No GAC for individual TPH fractions given that the compliance criteria is for sum TPH
9.99	Measured concentration exceeds the criteria defined for the protection of water resources
Yes	Further assessment required
No	No further assessment required

**South Bank A, Redcar**

**Table 2: Site Specific Assessment Criteria (SSAC) for Groundwater Source (µg/l)**

Contaminant of Concern	Theoretical Solubility Concentrations (µg/l)	Water Resources SSAC (µg/l)		
		50m Compliance Point	360m Compliance Point	Dilution Factor applied to 360m SSAC
<b>Aliphatics</b>				
>C <sub>5</sub> -C <sub>6</sub>	36,000	119	ND	ND
>C <sub>6</sub> -C <sub>8</sub>	5,400	59.6	ND	ND
>C <sub>8</sub> -C <sub>10</sub>	430	#	#	#
>C <sub>10</sub> -C <sub>12</sub>	34	#	#	#
>C <sub>12</sub> -C <sub>16</sub>	1	#	#	#
>C <sub>16</sub> -C <sub>35</sub>	0	#	#	#
<b>Aromatics</b>				
>EC <sub>8</sub> -EC <sub>10</sub>	65,000	331	ND	ND
>EC <sub>10</sub> -EC <sub>12</sub>	25,000	78	ND	ND
>EC <sub>12</sub> -EC <sub>16</sub>	5,800	159	#	ND
>EC <sub>16</sub> -EC <sub>21</sub>	510	23.1	#	ND
>EC <sub>21</sub> -EC <sub>35</sub>	7	#	#	#
<b>Indicator Compounds</b>				
Benzene	1,780,000	39.6	17000	ND
Ethylbenzene	180,000	265	ND	ND
Toluene	590,000	979	ND	ND
Xylenes	191,000	397	ND	ND
<b>PAH</b>				
Naphthalene	19,000	12.5	9990	ND
Anthracene	70	0.194	#	#
Fluoranthene	230	0.0126	#	#
Benzo(b)fluoranthene	2.00	#	#	#
Benzo(k)fluoranthene	0.80	#	#	#
Benzo(a)pyrene	4	#	#	#
Indeno(1,2,3-c,d)pyrene	0.20	#	#	#
Benzo(g,h,i)perylene	0.26	#	#	#
<b>Volatile Organic Compounds</b>				
Chloroform	8,950,000	3.54	22.7	47,897
1, 2-dichloroethane	8,680,000	47.7	18300	ND
<b>Phenolics</b>				
Phenol	84,100,000	ND	ND	ND
<b>Inorganics</b>				
Cyanide	1,000,000,000	1	1.07	2,258

**Notes:**

SSAC  
ND

#

Site Specific Assessment Criteria  
Results of risk assessment demonstrate pathway does not present significant level of risk.  
Target acceptable risk not exceeded at theoretical solubility concentration  
Modelling shows no breakthrough of contaminant within 1000 years at a 50m compliance point.

**South Bank A, Redcar**

**Table 3: Comparison of CoC Concentrations to Site Specific Assessment**

Contaminant of Concern	SSAC at 50m Compliance Point (µg/l)	SSAC at 360m Compliance Point (µg/l)	Dilution Factor applied to 360m SSAC (µg/l)
<b>Aliphatics</b>			
Aliphatic C5-C6	119	ND	ND
Aliphatic C6-C8	59.6	ND	ND
Aliphatic C8-C10	#	#	#
Aliphatic C10-C12	#	#	#
Aliphatic C12-C16	#	#	#
Aliphatic C16-C35	#	#	#
<b>Aromatics</b>			
Aromatic C8-C10	331	ND	ND
Aromatic C10-C12	78	ND	ND
Aromatic C12-C16	159	#	ND
Aromatic C16-C21	23.1	#	ND
Aromatic C21-C35	#	#	#
<b>Indicator Compounds</b>			
Benzene	39.6	17000	ND
Ethylbenzene	265	ND	ND
Toluene	979	ND	ND
Xylenes	397	ND	ND
<b>PAH</b>			
Naphthalene	12.5	9990	ND
Anthracene	0.194	#	#
Fluoranthene	0.0126	#	#
Benzo(b)fluoranthene	#	#	#
Benzo(k)fluoranthene	#	#	#
Benzo(a)pyrene	#	#	#
Indeno(1,2,3-c,d)pyrene	#	#	#
Benzo(g,h,i)perylene	#	#	#
<b>Volatile Organic Compounds</b>			
1,2-dichloroethane	47.7	18300	ND
Chloroform	3.54	22.7	47897
<b>Phenolics</b>			
Phenol	ND	ND	ND
<b>Inorganics</b>			
Cyanide	1	1.07	2258

**Notes**

- Concentration exceeding compliance SSAC at 50m C
- Concentration exceeding compliance SSAC at 360m
- ND Target acceptable risk not exceeded at theoretical sol
- # Modelling shows no breakthrough of contaminant within 1000 years at a 50m compliance point
- <123 Below laboratory Method Detection Limit (MDL)

South Bank A, Redcar

Table 3: Comparison of CoC Concentrations to Site Specific Assessment Criteria (SSAC) for Groundwater (

Contaminant of Concern	SSAC at 50m Compliance Point (µg/l)	SSAC at 360m Compliance Point (µg/l)	Dilution Factor applied to 360m SSAC (µg/l)	SBA_AUK_BH105	SBA_AUK_BH105	SBA_AUK_BH105
				Visit 1	Visit 2	Visit 3
				08/10/202	20/10/202	09/11/2020
<b>Aliphatics</b>						
Aliphatic C5-C6	119	ND	ND	<0.1	<0.1	<0.1
Aliphatic C6-C8	59.6	ND	ND	530	<0.1	<0.1
Aliphatic C8-C10	#	#	#	72	<0.1	<0.1
Aliphatic C10-C12	#	#	#	<1.0	<1.0	<1.0
Aliphatic C12-C16	#	#	#	<1.0	<1.0	<1.0
Aliphatic C16-C35	#	#	#	14	<1.0	<1.0
<b>Aromatics</b>						
Aromatic C8-C10	331	ND	ND	<0.1	<0.1	<0.1
Aromatic C10-C12	78	ND	ND	870	<1.0	1000
Aromatic C12-C16	159	#	ND	920	<1.0	1600
Aromatic C16-C21	23.1	#	ND	3.5	<1.0	13
Aromatic C21-C35	#	#	#	1.4	<1.0	<1.0
<b>Indicator Compounds</b>						
Benzene	39.6	17000	ND	330	<1	<1
Ethylbenzene	265	ND	ND	<1	<1	<1
Toluene	979	ND	ND	45	<1	<1
Xylenes	397	ND	ND	94	<2	<2
<b>PAH</b>						
Naphthalene	12.5	9990	ND	1900	0.85	850
Anthracene	0.194	#	#	1.1	2	0.98
Fluoranthene	0.0126	#	#	0.2	0.47	0.21
Benzo(b)fluoranthene	#	#	#	<0.01	0.04	0.01
Benzo(k)fluoranthene	#	#	#	<0.01	0.02	<0.01
Benzo(a)pyrene	#	#	#	<0.01	0.03	<0.01
Indeno(1,2,3-c,d)pyrene	#	#	#	<0.01	0.02	<0.01
Benzo(g,h,i)perylene	#	#	#	<0.01	0.02	<0.01
<b>Volatile Organic Compounds</b>						
1,2-dichloroethane	47.7	18300	ND	21	<1	<1
Chloroform	3.54	22.7	47897	<1	<1	26
<b>Phenolics</b>						
Phenol	ND	ND	ND	230	<100	110
<b>Inorganics</b>						
Cyanide	1	1.07	2258	60	300	190

Notes

- Concentration exceeding compliance SSAC at 50m Compliance Point
- Concentration exceeding compliance SSAC at 360m Compliance Point
- ND Target acceptable risk not exceeded at theoretical solubility concentration
- # Modelling shows no breakthrough of contaminant within 1000 years at a 50m compliance point
- <123 Below laboratory Method Detection Limit (MDL)



South Bank A, Redcar						
Table 3: Comparison of CoC Concentrations to Site Specific Assessment (µg/l)						
Contaminant of Concern	SSAC at 50m Compliance Point (µg/l)	SSAC at 360m Compliance Point (µg/l)	Dilution Factor applied to 360m SSAC (µg/l)	SBA_AUK_BH110	SBA_AUK_BH110	SBA_AUK_BH110
				Visit 1	Visit 2	Visit 3
				08/10/2020	20/10/2020	09/11/2020
<b>Aliphatics</b>						
Aliphatic C5-C6	119	ND	ND	<0.1	<0.1	<0.1
Aliphatic C6-C8	59.6	ND	ND	640	<0.1	<0.1
Aliphatic C8-C10	#	#	#	5	410	490
Aliphatic C10-C12	#	#	#	<1.0	<1.0	<1.0
Aliphatic C12-C16	#	#	#	<1.0	<1.0	<1.0
Aliphatic C16-C35	#	#	#	<1.0	<1.0	<1.0
<b>Aromatics</b>						
Aromatic C8-C10	331	ND	ND	<0.1	<0.1	<0.1
Aromatic C10-C12	78	ND	ND	2300	<1.0	5800
Aromatic C12-C16	159	#	ND	340	<1.0	1200
Aromatic C16-C21	23.1	#	ND	45	<1.0	210
Aromatic C21-C35	#	#	#	<1.0	<1.0	3.5
<b>Indicator Compounds</b>						
Benzene	39.6	17000	ND	47000	24000	31000
Ethylbenzene	265	ND	ND	<1	<1	37
Toluene	979	ND	ND	4500	2600	3300
Xylenes	397	ND	ND	890	468	920
<b>PAH</b>						
Naphthalene	12.5	9990	ND	6100	5500	11000
Anthracene	0.194	#	#	52	13	45
Fluoranthene	0.0126	#	#	260	11	25
Benzo(b)fluoranthene	#	#	#	110	1.7	2.4
Benzo(k)fluoranthene	#	#	#	61	0.62	1.2
Benzo(a)pyrene	#	#	#	100	1.5	2.2
Indeno(1,2,3-c,d)pyrene	#	#	#	74	0.86	1.5
Benzo(g,h,i)perylene	#	#	#	45	0.61	0.83
<b>Volatile Organic Compounds</b>						
1,2-dichloroethane	47.7	18300	ND	<1	<1	<1
Chloroform	3.54	22.7	47897	<1	<1	<1
<b>Phenolics</b>						
Phenol	ND	ND	ND	16000	14000	14000
<b>Inorganics</b>						
Cyanide	1	1.07	2258	570	690	<40

Notes

Concentration exceeding compliance SSAC at 50m C

Concentration exceeding compliance SSAC at 360m C

ND Target acceptable risk not exceeded at theoretical sol

# Modelling shows no breakthrough of contaminant within 1000 years at a 50m compliance point

<123 Below laboratory Method Detection Limit (MDL)

**South Bank A, Redcar**

**Table 4: Comparison of Sentinel Wells to Site Specific Assessment Criteria (SSAC) for Groundwater Source (µg/l)**

Contaminant of Concern	MDL (µg/l)	EQS (Estuaries & Coastal Waters)* (µg/l)	SSAC based on EQS** (µg/l)	BH-2010	BH-2011	BH-2013	BH-2014	BH-2015	BH-2016	BH-2017	BH-2019	BH-2020	BH-2021	BH-2022	BH-2024	BH-2025
				09/03/2021	16/02/2021	16/02/2021	16/02/2021	15/02/2021	15/02/2021	15/02/2021	15/02/2021	15/02/2021	15/02/2021	15/02/2021	15/02/2021	15/02/2021
<b>Aromatics</b>																
Aromatic C8-C10	0.1	12.5***	>SOL	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Aromatic C10-C12	0.1	12.5***	>SOL	42	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	8.9
Aromatic C12-C16	0.1	12.5***	>SOL	73	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	630
Aromatic C16-C21	0.1	12.5***	>SOL	26	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	770
<b>Metals</b>																
Arsenic, Dissolved	0.16	25	52750	3.3	1.8	2.8	3	2.5	2.1	2	1.1	1.6	1.7	2.1	1.3	0.94
Barium, Dissolved	0.26	-	-	84	25	45	46	40	32	46	30	19	70	61	33	27
Beryllium, Dissolved	0.1	-	-	< 0.1	< 0.1	< 0.1	0.2	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Boron, Dissolved	12	7000	14770000	1500	4700	2000	1500	1600	3500	4100	3300	2100	1500	1400	1400	690
Cadmium, Dissolved	0.03	0.2	422	< 0.03	0.12	< 0.03	0.12	< 0.03	< 0.03	0.06	< 0.03	< 0.03	0.05	0.03	< 0.03	< 0.03
Chromium III, Dissolved	1	-	-	< 1.0	< 1.0	< 1.0	5	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Chromium, Hexavalent	7	0.6	1266	< 7.0	< 7.0	< 7.0	< 7.0	< 7.0	< 7.0	< 7.0	< 7.0	< 7.0	< 7.0	< 7.0	< 7.0	< 7.0
Copper, Dissolved	0.4	3.76	7934	< 0.4	0.9	1.2	6.1	< 0.4	0.8	1	0.9	0.8	2.3	2	< 0.4	0.7
Lead, Dissolved	0.09	1.3	2743	< 0.09	0.16	0.54	11	0.17	0.23	0.4	0.16	< 0.09	0.45	0.3	< 0.09	0.18
Mercury, Dissolved	0.01	0.7	>SOL	0.01	< 0.01	< 0.01	0.05	0.08	< 0.01	< 0.01	< 0.01	0.01	< 0.01	0.02	< 0.01	< 0.01
Nickel, Dissolved	0.5	8.6	18146	0.9	11	3.1	3.4	0.6	0.8	2.5	0.8	< 0.5	2.8	2.3	< 0.5	0.8
Selenium, Dissolved	0.25	-	-	3.3	1.4	0.65	12	1.3	4.1	4.4	5	10	2.9	2.3	0.39	9.1
Vanadium, Dissolved	0.6	-	-	< 0.6	0.8	1.3	7.8	0.6	1.3	1.7	1.9	2.8	1.4	1.6	< 0.6	1.3
Zinc, Dissolved	1.3	7.9	16669	< 1.3	66	17	17	2.1	5.2	9	4.2	1.6	4.9	7.4	1.4	3.7
<b>Inorganics</b>																
Cyanide, Total Low Level	0.1	1	2110	110	32	9.6	4.5	8.3	21	33	46	20	8.8	11	32	71
<b>Indicator Compounds</b>																
Benzene	1	8	>SOL	NA	NA	NA	NA	1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	70
Ethylbenzene	1	-	-	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	NA	3	< 1
Total Xylenes	< 2	30	-	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	NA	< 2	2
<b>PAH</b>																
Naphthalene	0.05	2	>SOL	91	1	0.07	0.11	0.83	0.1	< 0.05	< 0.05	< 0.05	< 0.05	0.05	< 0.05	500
Acenaphthylene	0.01	-	-	0.58	0.02	< 0.01	< 0.01	0.11	0.02	0.03	0.04	0.21	0.03	0.07	< 0.01	7.7
Acenaphthene	0.01	-	-	59	0.85	0.06	0.05	0.32	0.05	0.06	0.09	7.4	0.1	0.58	0.03	220
Fluorene	0.01	-	-	17	0.21	0.02	0.02	0.31	0.03	0.02	0.02	0.05	0.01	0.13	0.01	58
Phenanthrene	0.01	-	-	4	0.03	0.03	0.01	0.46	0.02	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.01	5.9
Anthracene	0.01	0.1	>SOL	0.1	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.02	0.02	0.02	< 0.01	0.02	< 0.01	6.4
Fluoranthene	0.01	0.0063	>SOL	0.06	< 0.01	0.02	0.01	0.04	0.01	0.01	0.01	0.03	0.01	0.02	< 0.01	0.22
Pyrene	0.01	-	-	0.04	< 0.01	0.01	0.01	0.05	0.01	0.01	0.01	0.02	0.01	0.02	< 0.01	0.13
Chrysene	0.01	-	-	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.02
<b>Phenolics</b>																
Xylenols & Ethylphenols	0.1	-	-	< 0.01	< 0.01	< 0.01	< 0.01	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	0.33
<b>VOC</b>																
1,2-dichloroethane	1	10	21100	< 1	< 1	NA	NA	< 1	< 1	< 1	< 1	< 1	< 1	NA	< 1	4
Trichloroethylene	1	10	21100	1	< 1	NA	NA	< 1	< 1	< 1	< 1	< 1	< 1	NA	< 1	< 1
1,2-dichloropropane	1	-	-	< 1	< 1	NA	NA	< 1	7	< 1	< 1	7	< 1	NA	< 1	< 1
<b>SVOC</b>																
2-Methylnaphthalene	1	-	-	6.5	< 1	NA	NA	< 1	< 1	< 1	< 1	< 1	< 1	NA	< 1	< 1
Dibenzofuran	1	-	-	6.7	< 1	NA	NA	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	NA	< 1.0	16
4-Nitroaniline	1	-	-	< 1	< 1	NA	NA	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	NA	< 1.0	1
Carbazole	1	-	-	< 1	< 1	NA	NA	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	NA	< 1.0	1.9
1-Methylnaphthalene	1	-	-	4.9	< 1	NA	NA	1.8	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	NA	< 1.0	14

**Notes**

- No water quality standard identified as suitable for deriving assessment criteria
- NA Not Analysed
- Measured concentration exceeds EQS
- Measured concentration exceeds SSAC and EQS
- <123 Below laboratory Method Detection Limit (MDL)
- \* UK Estuaries and Coastal EQS Annual Average (AA) except for TPH
- \*\* Calculated as 10% of relevant EQS based on EA guidance
- \*\*\* TPH Criteria of 50µg/l split between the 4 fractions measured above MDL (see Appendix F)

Detailed Quantitative Risk Assessment  
South Bank Area A, Redcar  
10035117-AUK-XX-XX-RP-ZZ-0270-01-SBA\_DQRA

## **APPENDIX A**

### **Study Limitations**

**IMPORTANT.** This appendix should be read before reliance is placed on any of the information, opinions, advice, recommendations or conclusions contained in this report.

1 This report has been prepared by Arcadis (UK) Limited ('Arcadis'), with all reasonable skill, care and diligence within the terms of the Appointment and with the resources and manpower agreed with South Tees Development Corporation (UK) Limited (the 'Client'). Arcadis does not accept responsibility for any matters outside the agreed scope.

2 This report has been prepared for the sole benefit of the Client unless agreed otherwise in writing. otherwise in writing. The contents of this report may not be used or relied upon by any person other than this party without the express written consent and authorisation of Arcadis.

3 Unless stated otherwise, no consultations with authorities or funders or other interested third parties have been carried out. Arcadis is unable to give categorical assurance that the findings will be accepted by these third parties as such bodies may have unpublished, more stringent objectives. Further work may be required by these parties.

4 All work carried out in preparing this report has used, and is based on, Arcadis' professional knowledge and understanding of current relevant legislation. Changes in legislation or regulatory guidance may cause the opinion or advice contained in this report to become inappropriate or incorrect. In giving opinions and advice, pending changes in legislation, of which Arcadis is aware, have been considered. Following delivery of the report, Arcadis has no obligation to advise the Client or any other party of such changes or their repercussions.

5 This report is only valid when used in its entirety. Any information or advice included in the report should not be relied upon until considered in the context of the whole report.

6 Whilst this report and the opinions made are correct to the best of Arcadis' belief, Arcadis cannot guarantee the accuracy or completeness of any information provided by third parties. provided by third parties. Arcadis has taken reasonable steps to ensure that the information sources used for this assessment provided accurate information, and has therefore assumed this to be the case.

7 This report has been prepared based on the information reasonably available during the project programme. All information relevant to the scope may not have been received.

8 This report refers, within the limitations stated, to the condition of the site at the time of the inspection. No warranty is given as to the possibility of changes in the condition of the site since the time of the investigation.

9 The content of this report represents the professional opinion of experienced environmental consultants. Arcadis does not provide specialist legal or other professional advice. The advice of other professionals may be required.

10 Where intrusive investigation techniques have been employed they have been designed to provide a reasonable level of assurance on the conditions. Given the discrete nature of sampling, no investigation technique is capable of identifying all conditions present in all areas. In some cases the investigation is further limited by site operations, underground obstructions and above ground structures. Unless otherwise stated, areas beyond the boundary of the site have not been investigated.

11 If below ground intrusive investigations have been conducted as part of the scope, safe location of exploratory holes has been carried out with reference to the Arcadis ground disturbances procedure. No guarantee can be given that all services have been identified. Additional services, structures or other below ground obstructions, not indicated on the drawing, may be present on site.

12 Unless otherwise stated the report provides no comment on the nature of building materials, operational integrity of the facility or on any regulatory compliance issues.

13 Unless otherwise stated, an inspection of the site has not been undertaken and there may be conditions present at the site which have not been identified within the scope of this assessment.

14 Unless otherwise stated, samples from the site (soil, groundwater, building fabric or other samples) have not been obtained.

15 Arcadis has relied upon the accuracy of documents, oral information and other material and information provided by the Client and others, and Arcadis assumes no liability for the accuracy of such data, although in the event of apparent conflicts in information, Arcadis would highlight this and seek to resolve.

16 Unless otherwise stated, the scope of works has not included an environmental compliance review, health and safety compliance review, hazardous building materials assessment, interviews or contacting Local Authority, requests for information to the petroleum officer, sampling or analyses of soil, ground water, surface water, air or hazardous building materials or a chain of title review.

17 Unless otherwise stated, this assessment has considered the ongoing use of the site and has not been prepared for the purposes of redevelopment which may act as a trigger for site investigation and remediation works not needed for ongoing use.

Detailed Quantitative Risk Assessment  
South Bank Area A, Redcar  
10035117-AUK-XX-XX-RP-ZZ-0270-01-SBA\_DQRA

## **APPENDIX B**

### **Chemical Input Parameters**

South Bank A, Redcar		
Appendix B: Chemical Input Parameter Values		
Contaminant	Half Life*	Degradation Coefficient
Symbol	$t_{1/2}$	I
Units	days	days <sup>-1</sup>
<b>Total Petroleum Hydrocarbons</b>		
Aliphatic >C <sub>5</sub> -C <sub>6</sub>	360	1.93 x 10 <sup>-3</sup> [2]
Aliphatic >C <sub>6</sub> -C <sub>8</sub>	360	1.93 x 10 <sup>-3</sup> [2]
Aliphatic >C <sub>8</sub> -C <sub>10</sub>	712	9.74 x 10 <sup>-4</sup> [3]
Aliphatic >C <sub>10</sub> -C <sub>12</sub>	1750	3.96 x 10 <sup>-4</sup> [3]
Aliphatic >C <sub>12</sub> -C <sub>16</sub>	1750	3.96 x 10 <sup>-4</sup> [3]
Aliphatic >C <sub>16</sub> -C <sub>35</sub>	1750	3.96 x 10 <sup>-4</sup> [3]
Aromatic >C <sub>8</sub> -C <sub>10</sub>	200	3.47 x 10 <sup>-3</sup> [1]
Aromatic >C <sub>10</sub> -C <sub>12</sub>	300	2.31 x 10 <sup>-3</sup> [2]
Aromatic >C <sub>12</sub> -C <sub>16</sub>	204	3.40 x 10 <sup>-3</sup> [2]
Aromatic >C <sub>16</sub> -C <sub>21</sub>	1000	6.93 x 10 <sup>-4</sup> [2]
Aromatic >C <sub>21</sub> -C <sub>35</sub>	2000	3.47 x 10 <sup>-4</sup> [2]
<b>Indicator Compounds</b>		
Benzene	350	1.98 x 10 <sup>-3</sup> [1]
Ethylbenzene	200	3.47 x 10 <sup>-3</sup> [1]
Toluene	200	3.47 x 10 <sup>-3</sup> [1]
Xylenes	200	3.47 x 10 <sup>-3</sup> [1]
<b>Polycyclic Aromatic Hydrocarbons</b>		
Naphthalene	300	2.31 x 10 <sup>-3</sup> [1]
Anthracene	920	7.53 x 10 <sup>-4</sup> [2]
Fluoranthene	880	7.88 x 10 <sup>-4</sup> [2]
Benzo[b]fluoranthene	1220	5.68 x 10 <sup>-4</sup> [2]
Benzo[k]fluoranthene	4280	1.62 x 10 <sup>-4</sup> [2]
Benzo(a)pyrene	1060	6.54 x 10 <sup>-4</sup> [2]
Indeno[123-cd]pyrene	1460	4.75 x 10 <sup>-4</sup> [2]
Benzo(g,h,i)perylene	1300	5.33 x 10 <sup>-4</sup> [2]
<b>Organic Compounds</b>		
Chloroform	1800	3.85 x 10 <sup>-4</sup> [2]
1,1-dichloroethane	360	1.93 x 10 <sup>-3</sup> [2]
Phenol	7	9.90 x 10 <sup>-2</sup> [2]
<b>Inorganics</b>		
Cyanide	9E+99	- [4]

**Notes**

\*

Where possible, half life data for compounds within TPH fractions was used, adopted from Howard et al, 1991 and Noble and Morgan 2003. Where no half life data for compounds within the fractions was available, reference was made to CCME<sup>[3]</sup>, December 2000, which details conservative half lives for a range of fractions.

**Sources:**

[1]

Noble and Morgan, 2002. The Effects of Contaminant Concentration on the Potential for Natural Attenuation.

[2]

Howard et al. Handbook of Environmental Degradation Rates, Lewis Publishers Inc. Chelsea, MI (1991).

[3]

Canadian Council of Ministers of the Environment, December 2000.

[4]

Assumed no degradation



Detailed Quantitative Risk Assessment  
South Bank Area A, Redcar  
10035117-AUK-XX-XX-RP-ZZ-0270-01-SBA\_DQRA

## **APPENDIX C**

### **Sensitivity Testing**

## **Appendix C** **Sensitivity Testing**

To account for the inherent uncertainty present when simplifying the environment for modelling purposes, a range of values was specified for each parameter adopted within the assessment. The RTW model is set up using a value from each of the ranges; this value is not necessarily the final chosen value.

Each parameter is modified, one at a time, whilst maintaining the remaining parameters at the starting values to identify which parameters have the greatest effect on the site model.

The process is repeated to ensure the site model is appropriate for the site conditions. The RTW model was setup with the chemical parameters for benzene and a 50m compliance point. The physical input value selection and sensitivity of each parameter are presented on the following sheets.



Appendix C: Sensitivity Testing

Parameter	Range	Data Source
<b>Aquifer Bulk Density (g/cm<sup>3</sup>)</b>	1.6 - 2.0	A range of values for bulk density were defined based on values reported by ConSim (2002) for a gravel (1.36 to 2.19 g/cm <sup>3</sup> ) and 1.6 to 2.0 g/cm <sup>3</sup> report by Tomlinson (1995) for a gravel. As such, a range of values between 1.6 g/cm <sup>3</sup> and 2.0 g/cm <sup>3</sup> was adopted for sensitivity testing.

Aquifer Bulk Density (g/cm <sup>3</sup> ) Soil	Level 3 Soil SSAC (mg/kg)

Aquifer Bulk Density (g/cm <sup>3</sup> ) Groundwater	Level 3 Groundwater SSAC (µg/l)
1.6	39.65
1.7	39.65
1.8	39.65
1.9	39.65
2.0	39.65

Selected value highlighted green	1.6
----------------------------------	-----

Parameter	Range	Data Source
<b>Saturated Aquifer Thickness (m)</b>	0.6 - 1.7	Groundwater was encountered resting in the bottom half of the Slag Made Ground beneath the site. Most commonly, it was found to be saturating the bottom 1.5m of this unit, however, the saturated thickness of the unit ranged from 0.6 to 1.7m. As such, this range was adopted for the sensitivity testing.

Saturated Aquifer Thickness (m) Soil	Level 3 Soil SSAC (mg/kg)

Saturated Aquifer Thickness (m) Groundwater	Level 3 Groundwater SSAC (µg/l)
0.6	39.65
0.9	39.65
1.2	39.65
1.4	39.65
1.7	39.65

Selected value highlighted green	1.2
----------------------------------	-----

Detailed Quantitative Risk Assessment  
South Bank Area A, Redcar  
10035117-AUK-XX-XX-RP-ZZ-0270-01-SBA\_DQRA

## **APPENDIX D**

### **Physical Input Parameters**

South Bank A, Redcar		
Appendix D: Physical Parameter Values		
Parameter	Value	Source
Width of groundwater source area (m)	190	Site data
Length of Site perpendicular with river (m)	710	Site data
Aquifer Lithology	Sandy gravel and cobbles	Site data
Effective porosity (cm <sup>3</sup> /cm <sup>3</sup> )	0.30	
Hydraulic conductivity (m/day)	20.00	
Hydraulic gradient (m/m)	0.0008	
Saturated Aquifer Thickness (m)	1.2	See Appendix C (sensitivity testing)
Fraction of organic carbon (g oc/g soil)	0.026	
Soil bulk density (g/cm <sup>3</sup> )	2	
Plume thickness	1.20	

Detailed Quantitative Risk Assessment  
South Bank Area A, Redcar  
10035117-AUK-XX-XX-RP-ZZ-0270-01-SBA\_DQRA

## **APPENDIX E**

### **Risk Assessment Methodology**



## Appendix E Risk Assessment Methodology

### Non-statutory Regulatory Technical Guidance

The following documents, which have been consulted in undertaking this DQRA, present guiding principles in assessing potentially contaminated land:

General	<ul style="list-style-type: none"> <li>Model Procedures for the Management of Land Contamination, DEFRA &amp; EA (R&amp;D Publication CLR 11).</li> </ul>
Water Resources	<ul style="list-style-type: none"> <li>Remedial Targets Methodology (RTM): Hydrogeological Risk Assessment for Land Contamination (EA, 2006).</li> </ul>

### Calculating Evaluation Criteria

#### Water Resources

In order to estimate the risk to water resource receptors, fate and transport algorithms are used to predict a concentration at a defined receptor point, which is then compared to an appropriate water quality standard. A predicted concentration in excess of the water quality standard suggests the need to undertake a further level of investigation or action. Water resources SSAC are defined using a water quality standard at the point of compliance, then back-calculating to determine the contaminant level which is acceptable beneath the site in soils and/or groundwater.

The SSAC can be compared to the measured concentrations of the CoC to evaluate whether unacceptable risks are present, and with which pollutant linkage or linkages the unacceptable risks are associated.

#### Modelling Tools

Modelling tools are developed to enable the calculations associated with fate and transport, exposure modelling and risk evaluation to be undertaken by risk assessors in a time-efficient manner, and producing defensible and consistent outputs.

#### **Water Resources**

There are two commonly used modelling tools that have been developed to implement the guidance presented within the EA's Remedial Targets Methodology. These are:

RTW v.3.2	The Remedial Target Worksheet (RTW) version 3.2 is an excel-based model tool produced by the EA to implement the guidance presented in the hydrogeological risk assessment methodology. RTW assesses the potential risk to a defined receptor point using a tiered analysis process (Level 1 soils – partitioning, Level 2 soils – dilution, Level 3 soils and groundwater – attenuation). RTW is a deterministic model.
ConSim v.2.5	Contamination Impact on Groundwater: Simulation by Monte Carlo Method, version 2.5 (ConSim), was developed by Golder Associates in association with the EA. ConSim is a probabilistic modelling tool, which implements the hydrogeological risk assessment guidance in a similar manner to RTW. However, ConSim allows a more detailed assessment of vertical migration pathways in the unsaturated zone, and, as such, is a useful tool for sites where groundwater is present at a considerable depth.

Detailed Quantitative Risk Assessment  
South Bank Area A, Redcar  
10035117-AUK-XX-XX-RP-ZZ-0270-01-SBA\_DQRA

## **APPENDIX F**

### **Compliance Criteria Selection**

## Appendix F Compliance Criteria Selection

The selection of compliance criteria in land contamination assessments in England and Wales is not clearly defined within Environment Agency guidance, as the changes introduced as a result of the Water Framework Directive have led to a number of water quality standards historically used in land contamination risk assessments (e.g. taken from the Dangerous Substance Directive 1975) are in the process of being superseded by new standards introduced under the Water Framework Directive. Further, guidance released by the Environment Agency in 2009 (Fretwell et al., 2009) which identified a number of potential compliance criteria now needs revision as some of the sources quoted for the criteria are no longer valid. As such, consideration has to be given on a case by case as to what is appropriate as a compliance criterion, taking into account the high level guidance on selection of compliance criteria in the Remedial Targets Worksheet.

Arcadis' approach is to adopt Drinking Water Standards (DWS), where available, unless the site under evaluation is located in close proximity to a surface watercourse, at which point Environmental Quality Standards (EQS) are instead considered. Where the DWS is higher than the EQS, typically the EQS will be used as a substitute DWS.

### **Total Petroleum Hydrocarbons**

There is no quantitative criterion for total petroleum hydrocarbons (TPH), or speciated TPH fractions. Historically, standards provided for petroleum hydrocarbons ranges from 10µg/l (Private Water Supply Regulations 1991, removed from the 2009 regulations) to 50µg/l-1000µg/l (Surface Waters (Abstraction for Drinking Water) Regulations 1989) which related to the degree of treatment of water prior to use as drinking water. Over time, the legislative standards have been rescinded and no alternative standard provided, although the Environment Agency planned to release speciated TPH criteria (Fretwell et al., 2009). In the absence of suitable criteria, Arcadis adopts a value of 10 µg/l split between the TPH fractions for the more sensitive locations (e.g. Principal Aquifer, drinking water abstraction), and a value of 50µg/l split between the TPH fractions for locations considered less sensitive (e.g. low permeability aquifers) or where a site is located in close proximity to a surface watercourse.

Detailed Quantitative Risk Assessment  
South Bank Area A, Redcar  
10035117-AUK-XX-XX-RP-ZZ-0270-01-SBA\_DQRA

## **APPENDIX G**

### **TPH Breakthrough Times**

South Bank A, Redcar			
Appendix G: TPH Breakthrough Times			
Contaminant of Concern	Breakthrough Time (years) at 50m Compliance Point	Group	Adopted Compliance Criteria (µg/l)
<b>TPH Aliphatic</b>			
Aliphatic C5-C6	33	A	25.00
Aliphatic >C6-C8	170	B	12.50
Aliphatic >C8-C10	>1000		
Aliphatic >C10-C12	>1000		
Aliphatic >C12-C16	>1000		
Aliphatic >C16-C35	>1000		
<b>TPH Aromatic</b>			
Aromatic >EC8-EC10	63	A	25.00
Aromatic >EC10-EC12	110	B	12.50
Aromatic >EC12-EC16	200	B	12.50
Aromatic >EC16-EC21	680	B	12.50
Aromatic >EC21-EC35	>1000		

**Notes:**

The environmental quality standard for sum TPH of 50 µg/l (see Appendix F). This standard has been split between the number of TPH fractions that reach the defined compliance point (50m) within a set time period (100 to 999 years for example). These groups are defined as follows:

- A <100 years
- B 100 - 1000 years

The guidance presented within the RTM (2006) indicates that no remediation is considered necessary where a compound is not predicted to reach the defined compliance point within 1,000 years. Therefore, for the TPH fractions which are predicted to reach the compliance point after 1,000 years, no significant risk is considered to be present and no criteria is adopted.

Detailed Quantitative Risk Assessment  
South Bank Area A, Redcar  
10035117-AUK-XX-XX-RP-ZZ-0270-01-SBA\_DQRA

## **APPENDIX H**

### **Example RTW Output Sheet for Benzene**

R&D Publication 20 Remedial Targets Worksheet, Release 3.2



Level 3 - Groundwater See Note

Input Parameters (using pull down menu)	Variable	Value	Unit	Source
Contaminant		Benzene		from Level 1
Target Concentration	$C_T$	8.00E-03	mg/l	from Level 1

Select analytical solution (click on brown cell below, then on pull-down menu)

**Ogata Banks** Equations in HRA publication

Approach for simulating vertical dispersion: **Simulate vertical dispersion in 1 direction**

Select nature of decay rate (click on brown cell below, then on pull-down menu)

Approach for simulating degradation of pollutants: **Apply degradation rate to dissolved pollutants only**

	Variable	Value	Unit	Source of parameter value
Initial contaminant concentration in groundwater at plume core	$C_0$	1.00E+00	mg/l	
Half life for degradation of contaminant in water	$t_{1/2}$	3.50E+02	days	
Calculated decay rate	$\lambda$	1.98E-03	days <sup>-1</sup>	
Width of plume in aquifer at source (perpendicular to flow)	Sz	1.90E+02	m	
Plume thickness at source	Sy	1.20E+00	m	
Saturated aquifer thickness	da	1.20E+00	m	
Bulk density of aquifer materials	$\rho$	1.60E+00	g/cm <sup>3</sup>	
Effective porosity of aquifer	n	3.00E-01	fraction	
Hydraulic gradient	i	8.00E-04	fraction	
Hydraulic conductivity of aquifer	K	2.00E+01	m/d	
Distance to compliance point	x	5.00E+01	m	
Distance (lateral) to compliance point perpendicular to flow direction	z	0.00E+00	m	
Distance (depth) to compliance point perpendicular to flow direction	y	0.00E+00	m	
Time since pollutant entered groundwater	t	9.00E+99	days	time variant options only
<i>Parameters values determined from options</i>				
Partition coefficient	Kd	1.76E+00	l/kg	see options
Longitudinal dispersivity	ax	5.00E+00	m	see options
Transverse dispersivity	az	5.00E-01	m	see options
Vertical dispersivity	ay	1.00E-99	m	see options

Calculated Parameters Variable

Groundwater flow velocity	v	5.33E-02	m/d
Retardation factor	Rf	1.04E+01	fraction
Decay rate used	$\lambda$	1.91E-04	d <sup>-1</sup>
Rate of contaminant flow due to retardation	u	5.14E-03	m/d
Contaminant concentration at distance x, assuming one-way vertical dispersion	$C_{ED}$	2.02E-01	mg/l
Attenuation factor (one way vertical dispersion, CO/CED)	AF	4.96E+00	

Remedial Targets

Remedial Target	Value	Unit	Notes
Remedial Target	3.96E-02	mg/l	For comparison with measured groundwater concentration.
Ogata Banks			
Distance to compliance point	50	m	
Concentration of contaminant at compliance point after	$C_{ED}/C_0$	2.02E-01	mg/l
		9.0E+99	days
			Ogata Banks

Care should be used when calculating remedial targets using the time variant options as this may result in an overestimate of the remedial target. The recommended value for time when calculating the remedial target is 9.9E+99.

Select Method for deriving Partition Co-efficient (using pull down menu)

**Calculate for non-polar organic chemicals**

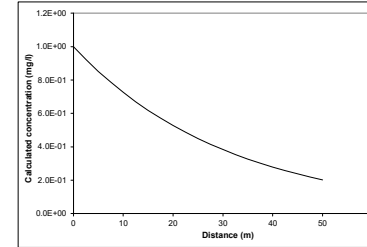
Entry if specify partition coefficient (option)			
Soil water partition coefficient	Kd		l/kg
Entry for non-polar organic chemicals (option)			
Fraction of organic carbon in aquifer	foc	2.60E-02	fraction
Organic carbon partition coefficient	Koc	6.76E+01	l/kg
Entry for ionic organic chemicals (option)			
Sorption coefficient for related species	$K_{oc,n}$		l/kg
Sorption coefficient for ionised species	$K_{oc,i}$		l/kg
pH value	pH		
acid dissociation constant	pKa		fraction
Fraction of organic carbon in aquifer	foc		
Soil water partition coefficient	Kd	1.76E+00	l/kg

Define dispersivity (click brown cell and use pull down list)

**User defined values for dispersivity**

	Enter value	Calc value Xu & Eckstein	Unit
Longitudinal dispersivity	ax	5.00E+00	m
Transverse dispersivity	az	5.00E-01	m
Vertical dispersivity	ay	1.00E-99	m

Note values of dispersivity must be > 0  
For calculated value, assumes ax = 0.1 \* x, az = 0.01 \* x, ay = 0.001 \* x  
Xu & Eckstein (1995) report ax = 0.83(log<sub>10</sub>X)<sup>-2.14</sup>; az = ax/10, ay = ax/100 are assumed



Note graph assumes plume disperses vertically in one direction only. An alternative solution assuming the centre of the plume is located at the mid-depth of the aquifer is presented in the calculation sheets.

Note

This sheet calculates the Level 3 remedial target for groundwater, based on the distance to the receptor or compliance located down hydraulic gradient of the source. Three solution methods are included, the preferred option is Ogata Banks.

By setting a long travel time it will give the steady state solution, which should be used to calculate remedial targets.

The measured groundwater concentration should be compared with the Level 3 remedial target to determine the need for further action.

Note if contaminant is not subject to first order degradation, then set half life as 9.0E+99.

This worksheet should be used if pollutant transport and degradation is best described by a first order reaction. If degradation is best described by an electron limited degradation such as oxidation by O<sub>2</sub>, NO<sub>3</sub>, SO<sub>4</sub> etc than an alternative solution should be used.

Site being assessed: Redcar SBA  
Completed by: Hebah Abdel-Hady  
Date: #####  
Version: 1

Calculated concentrations for distance-concentration graph

Distance	Concentration
	mg/l
0	1.0E+00
2.5	9.23E-01
5.0	8.52E-01
7.5	7.87E-01
10.0	7.26E-01
12.5	6.70E-01
15.0	6.19E-01
17.5	5.71E-01
20.0	5.27E-01
22.5	4.87E-01
25.0	4.49E-01
27.5	4.15E-01
30.0	3.83E-01
32.5	3.53E-01
35.0	3.26E-01
37.5	3.01E-01
40.0	2.78E-01
42.5	2.57E-01
45.0	2.37E-01
47.5	2.19E-01
50.0	2.02E-01