Great Yarmouth Third River Crossing

Application for Development Consent Order

Document 6.2: Environmental Statement Volume II: Technical Appendix 16C: Interpretative Environmental Ground Investigation Report

Planning Act 2008

The Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009 (as amended) ("APFP")

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1 Introduction

1.1.1 An assessment of contaminated land including associated risks, constraints and liabilities has been undertaken to support a DCO application and design of the Great Yarmouth Third River Crossing ('the Scheme').

1.1.2 This report has been prepared with the factual ground investigation information available at the time of reporting. The groundwater assessments in Sections 5 and 6, and the gas assessment in Section 6, are based on data collected during monitoring visits between 1st June and 20th December 2018.

1.2 Scheme Description

1.2.1 The Scheme involves the construction, operation and maintenance of a new crossing of the River Yare in Great Yarmouth. The Scheme consists of a new dual carriageway road, including a road bridge across the river, linking the A47 at Harfrey's Roundabout on the western side of the river to the A1243 South Denes Road on the eastern side. The Scheme would feature an opening span double leaf bascule (lifting) bridge across the river, involving the construction of two new 'knuckles' extending the quay wall into the river to support the bridge. The Scheme would include a bridge span over the existing Southtown Road on the western side of the river, and a bridge span on the eastern side of the river to provide an accommodation underpass for existing businesses, enabling the new dual carriageway road to rise westwards towards the crest of the new crossing.

1.3 Project Scope

1.3.1 To assist in meeting the terms of reference at stated in Section 1.1, the scope of the study in this report comprises:

- Generic quantitative risk assessment (GQRA) of potentially sensitive receptors with respect to ground and groundwater contamination.
- Refinement of the preliminary conceptual site model (CSM) that was developed in the WSP Ltd Interpretative Environmental Desk Study Report (presented as Appendix 16B to the Environmental Statement).
- Piling Works Risk Assessment (presented as Appendix 16D to the Environmental Statement).
- Provision of recommendations with respect to the management and mitigation of potential ground contamination constraints or liabilities which are identified.

1.3.2 A geotechnical assessment has also been undertaken for outline pile foundation and highway design purposes which will be reported separately.

1.4 Legislative Context and Guidance

1.4.1 The project was undertaken in the legislative and policy context of:

- The Planning Act 2008 (Ref 16C.1)
- National Policy Statement for National Networks (Ref 16C.2)
- National Policy Statement for Ports (Ref 16C.3)
- The National Planning Policy Framework (Ref 16C.14)

1.4.2 The following good practice and statutory guidance was considered and the contaminated land assessment was undertaken in general accordance with:

- Environment Agency 'Model Procedures for the Management of Land Contamination', CLR11 (2004) (Ref 16C.5);
- British Standard 'Investigation of Potentially Contaminated Sites – Code of Practice', BS EN 10175:2011 (Ref 16C.6);
- British Standard 'Code of Practice for Ground Investigations', BS 5930:2015 (Ref 16C.7);
- CIRIA 'Contaminated Land Risk Assessment. A guide to good practice', C552 (2001) (Ref 16C.8);
- Defra 'Environmental Protection Act 1990: Part 2A Contaminated Land Statutory Guidance', PB13735 (2012) (Ref 16C.9); and
- CIRIA 'Assessing Risks Posed by Hazardous Ground Gases to Buildings', C665 (2007) (Ref 16C.10).

1.5 Sources of information

1.5.1 The following sources of information were used in the production of this report.

Table 1.1: Sources of Information

Source	Report
Reports	Factual Report October 2007 prepared by Norfolk Partnership Laboratory. Interpretative Environmental Desk Study Report dated March 2019 (presented as Appendix 16B to the Environmental Statement)
Public Information	British Geological Survey BGS 'Geology of Britain' online viewer. Environment Agency website
Notes:	The report contains British Geological Survey materials ©NERC 2018 and Environment Agency information ©Environment Agency and database right.

2 Site Description and Current Use

2.1 Site Description and Current Use

2.1.1 For the purposes of this report, the term Study Area is used to define the area within the Principal Application Site within which the ground investigation was undertaken. No site investigation works were undertaken within the Satellite Application Sites as no significant excavation / construction works are proposed in these areas that would interact / affect soils, geology or contamination.

2.1.2 The Principal Application Site is currently occupied by highways, vacant land, residential properties, public space, commercial / industrial businesses and the River Yare. Further details are provided in the Interpretative Environmental Desk Study Report (presented as Appendix 16B of the Environmental Statement).

2.1.3 Table 2.1 below summarises the details presented in the WSP Interpretative Environmental Desk Study Report dated March 2019 (Appendix 16B) that are relevant to the contamination assessment. Further details are presented in the Chapter 2: Description of the Scheme in the Environmental Statement (document reference 6.1).

Table 2.1: Summary of Site Details

Detail	Comment
Principal Application Site Description and Current Use	The flat site is split into two parts by the River Yare which flows from north to south through the Principal Application Site. The eastern part of the Principal Application Site is densely developed, predominantly with commercial / industrial properties including oil / gas storage sites, an operating port facility with associated hard standing and warehouses / depots. Other uses include residential properties (predominantly in the northern part of the area), a petrol filling station and car dealership. The western part of the Principal Application Site includes a hard

Detail	Comment
	standing quayside, the major A12 dual carriageway, William Adams Way highway, residential properties, commercial properties including car and caravan sales, a petrol station, oil and gas storage facilities, docks and port facilities; military properties (air training corps), community facilities and public open space and allotments.
Setting and Surrounding Area	North; Predominantly commercial / industrial with some residential properties on the west side of the river and predominantly residential properties with a few commercial properties on the east side of the river. East; Predominantly residential properties with occasional commercial properties and a community centre. South; Commercial / industrial properties on the east side of the river and residential properties, commercial properties and a recreation ground on the west side of the river. West; Commercial / industrial properties.
Topography and Ground Cover	The Principal Application Site is generally flat and is largely hard standing predominantly associated with quayside in the eastern areas and roads and properties in the western area.
Drainage & Flooding	The River Yare is recorded as a Primary River. Much of the Principal Application Site is within the Zone 3 floodplains. Away from the River Yare the risk of flooding from the

Detail	Comment
	river and the sea is generally low and then very low at the western end of the Principal Application Site.
Embankments & Slopes	None of any significance.
Trees & Vegetation (including invasive species)	The only vegetation recorded during the walkover were landscaping hedges and bushes / scrubs. No invasive species were confirmed during the walkover, although due to access restrictions at some locations, not all of the Principal Application Site was accessible. Ecological surveys have been undertaken and are reported in Chapter 8: Nature Conservation within the Environmental Statement (document reference 6.1).
Foundations, Retaining Walls & Basements	There is the significant possibility of foundations, retaining walls and basements being present due to current and former buildings.
Visual Observations of Contamination or Ground Subsidence	No visual signs of contamination were noted during the walkover although petrol stations and oil / gas storage facilities were observed and could include contamination.
Geology	The regional BGS 1:50,000 geological map and information available on the BGS on-line Geology of Britain Viewer (www.bgs.ac.uk) indicates the Superficial Geology immediately underlying the Principal Application Site within the Order Limits boundary varies as follows:

Detail	Comment
	• South west of the River Yare - peat of the Breydon Formation, • North west of the River Yare – clay and silt of the Breydon Formation, • East of the River Yare – sand and gravel of the North Denes Formation. • Within the River Yare - clay and silt Tidal River or Creek Deposits. The BGS 1:50,000 geological map indicates that the Crag Group (sand and gravel) comprises the underlying geology across the Principal Application Site.
Hydrogeology and Hydrology	The River Yare splits the Order Limits in two and is recorded as a Primary River. At this point it is estuarine and is not separated from the sea by any locks. No other surface water features are present. No surface water or potable surface water abstractions are present within 2km of the Order Limits. The North Denes Formation superficial deposits underlying the Principal Application Site to the east of the River are classified as a Secondary (A) Aquifer with permeable layers. These are defined by the Environment Agency as permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers.

Detail	Comment
	The peat and clay / silt superficial deposits underlying the Principal Application Site to the west of the River Yare are classified as unproductive. The underlying bedrock is classified as a Principal Aquifer. These are defined by the Environment Agency as layers of rock or drift deposits that have high intergranular and/or fracture permeability - meaning they usually provide a high level of water storage. They may support water supply and/or river base flow on a strategic scale. The nearest active groundwater abstraction is approximately 71m to the north west of the Principal Application Site and is for laundry use.

2.2 Site History

2.2.1 The following site history summary has been taken from the Interpretative Environmental Desk Study Report (Appendix 16.B of this Environmental Statement) which includes a more detailed site history.

2.2.2 For simplicity, for the purposes of this report, the Principal Application Site has been split into two areas – east of the River Yare and west of the River Yare.

Eastern Area

2.2.3 The earliest map provided by GroundSure dated 1883 indicates the eastern area of the Principal Application Site to be densely developed predominantly with commercial / industrial properties including a gasworks, boat building yard and an icehouse. Some residential properties were present but generally the area is dominated by industry. This eastern area of the Principal Application Site has generally remained a commercial / industrial area up to the present day. Various industries have been present including fish canning, oilskin production, chemical factory and unspecified depots, warehouses and factories.

Western Area

2.2.4 The earliest map provided by GroundSure dated 1883 indicates the western area of the Principal Application Site to be less developed than the eastern area. The majority of the development was present adjacent to the River Yare and comprised a mix of residential properties and commercial / industrial sites such as an iron works, rope walk, gas works and malthouses. Beyond, towards the western boundary of the study area.

2.2.5 By 1906, a railway line running north south was constructed towards the western boundary and by 1926 / 1927, formal gardens and allotments are present towards the centre of the Principal Application Site. A shoe factory is marked adjacent to Queen Anne's Road in 1949 and by 1966 is relabelled as a printing works.

2.2.6 By 1978, the railway line had been dismantled and commercial / industrial units had started to be developed in the far west of the Principal Application Site and beyond. By 1988, the former rail route had started to be redeveloped as a dual carriageway and by 2002 the current major highway routes had been established.

2.3 Surrounding Land Uses

2.3.1 Surrounding land uses as detailed in the Interpretative Environmental Desk Study Report (Appendix 16B of this Environmental Statement) are as follows:

- North - Predominantly commercial / industrial with some residential properties on the west side of the river and predominantly residential properties with a few commercial properties on the east side of the river.
- East - Predominantly residential properties with occasional commercial properties and a community centre.
- South - Commercial / industrial properties on the east side of the river and residential properties, commercial properties and a recreation ground on the west side of the river.
- West - Commercial / industrial properties.

2.4 Potential Sources of Contamination

On-Site Contamination Sources

2.4.1 The following potential historical on-site sources of contamination have been identified with anticipated contaminants derived in accordance with site-specific interpretation of Department of Environment Industry Profiles:

Table 2.2: Areas of Potential Contamination (APC)

APC No.	APC Type	Anticipated Contaminants in Soil & / or Groundwater
APC1	Former railway lines, sidings and depots	Metals and metalloids, cyanides, ammonia, nitrates, sulphates and sulphides involved in a range of chemical processes formerly taking place on site. It is likely these contaminants are present within the soil although some compounds are soluble and therefore may also be present within the groundwater and soil leachate samples. Petroleum hydrocarbons (TPH), PCBs, benzene, toluene, ethylbenzene, xylene (BTEX), polyaromatic hydrocarbons (PAH), Volatile Organic Compounds (VOC) and semi-VOC (SVOC), phenolic compounds, resins arising from fuel spillages and former onsite chemical processes. It is likely these compounds if present will be found within groundwater and leachate samples. Some of the volatile compounds such as solvents may be present as mobile gases. Made ground associated with the development of the Principal Application Site for its former industrial uses resulting in potential ground gas contaminants (methane and carbon dioxide). Ground gases are considered likely in the former landfill areas. Made ground also has the potential to contain asbestos. The presence of buried former structures and foundations may also be a source of contaminants.
APC2	Former gasworks	
APC3	Former boat building yards, quayside and travelling crane	
APC4	Former iron works	
APC5	Former icehouse	
APC6	Former allotments	
APC7	Former rope walk	
APC8	Former depots	
APC9	Potentially contaminated silts	
APC10	Former oilskin works	
APC11	Former fish canning factories	
APC12	Former tanks on unlabelled sites	
APC13	Various former factories: chemical, shoe, printing and publishing works,	
APC14	Concrete works	

Off-Site Contamination Sources

2.4.2 Within the surrounding area, the following potential sources of contamination are identified in the GroundSure report (Annex B of the Interpretative Environmental Desk Study Report) and has the potential to migrate onto the Principal Application Site:

- Former and current shipbuilding and dock works surrounding the River Yare
- Former saw mills, timber yard, boat building, icehouse and malthouse immediately adjacent to the river
- Former military barracks
- Former rope walk
- Former oilskin works
- Former barrel and box making factories
- Former electricity works
- Former oil pipeline construction depot
- Commercial / industrial buildings including tanks
- Contaminated silts within the River Yare
- Hospital

2.5 2006 Ground Investigation

2.5.1 The Applicant undertook an intrusive ground investigation partly within the Principal Application Site in 2006 and prepared a Factual Report dated October 2007. A copy of the 2007 report is presented in Annex B.3.

2.5.2 Where data from the 2006 ground investigation has been used in the assessments in Sections 5 to 8 of this interpretative report it is referenced where necessary to distinguish it from data from the 2017/2018 ground investigation.

2.5.3 The fieldwork was undertaken between the 7 August and 19 September 2006 and comprised the following:

- Nineteen cable percussion boreholes were carried out to a maximum depth of 40m.
- Eight window sample holes were carried out to a maximum depth of 5m.
- Three trial pits were carried out to a maximum depth of 3.5m.

2.5.4 In addition, samples were taken for both geotechnical and environmental testing. Standard Penetration Tests were also carried out within the boreholes and piezometers and combined water / gas monitoring installations were installed in seventeen cable percussion holes.

2.5.5 These locations were within the Principal Application Site - BH101, BH102, BH103, BH105, BH106, BH108, BH109, TP101, TP104, WS107 and WS108.

2.5.6 The following locations are immediately adjacent to the Principal Application Site and are therefore also considered - BH104, BH107 and BH110.

2.5.7 The following are sufficiently far from the Principal Application Site that they are unlikely to provide anything other than useful background information and are generally not considered further in this summary - BH111, BH111A, BH111B, BH112, BH113, BH114, BH115, BH116, BH117, WS103, WS104, WS105, WS106, WS110, WS111 and TP109.

Ground Conditions Encountered

2.5.8 The following ground conditions were noted from the Engineers logs presented in the October 2007 Factual Report.

Made Ground

2.5.9 Asphalt and concrete (often reinforced with steel) were recorded at the surface at a number of locations up to 0.35m thick. Made ground was recorded at all locations from 0.3m thick (BH109) to 3m thick (WS108) and was heterogenous across the Principal Application Site but generally comprised a sand matrix with cobbles and man-made inclusions of concrete, brick, ash, metal and plastic.

Tidal River or Creek Deposits

2.5.10 Tidal River and Creek deposits were recorded underlying made ground in the eastern area up to 3.9m thick (BH105) as clay, silt or sand. It was not recorded in the western area.

Breydon Formation

2.5.11 Peat, silt clay or sand of the Breydon Formation underlies made ground in the eastern area in the absence of the Tidal or River Creek Deposits and was not recorded in the western area. The Breydon peat was recorded as a soft dark grey amorphous peat up to 1.1m thick (BH101). The silts, clay and sand strata were recorded up to 5m thick (BH110) and always overlying the North Denes Formation.

North Denes Formation

2.5.12 The North Denes Formation was recorded across most of the site as a sand with varying proportions of gravel. Thickness ranges from 3.95m on BH106 to 14m in BH107. Densities varied from loose to very dense.

Corton Formation

2.5.13 The 2007 Factual Report discusses Corton Sand (recorded in the western area only) separately from the Corton Formation but does not include an explanation to clarify this.

2.5.14 The Corton Formation was only encountered in the western area where it was recorded as fine and medium sand between 0.3m thick (TP109) to 6.7m thick (BH110) and was underlain by the Crag Formation. Densities varied between medium dense and dense.

2.5.15 The Corton Sand was also only recorded in the western area between 6.9m thick (BH102) and 9.2m thick (BH104) and was underlain by the Crag Formation. Densities varied from medium dense up to very dense.

Kesgrave Sand and Gravel

2.5.16 The 2007 Factual Report recorded the Kesgrave Sand and Gravel between the North Denes Formation and the Crag Formation. It was recorded as a loose, fine, medium and coarse sand and as a silty sandy clay.

Crag Formation

2.5.17 Crag Formation was recorded in all cable percussion boreholes within the Principal Application Site but the trial pits and window samples did not progress to sufficient depth to encounter the formation.

2.5.18 The formation was generally encountered as a fine and medium sand with densities ranging from medium dense to very dense. Laminae, lenses and layers of silty clay and silt were recorded in this strata.

Visual and Olfactory Evidence of Contamination

2.5.19 Man-made detritus was recorded in made ground and comprised concrete, brick, metal, plastic.

2.5.20 In addition, the following evidence of contamination was also recorded.

- TP101 – 1.5m to 1.7m. Base of made ground / top of Breydon Formation. Hydrocarbon and chemical odour – possible spent oxide.
- TP104 – 0.1m to 2.0m. Made ground. Sheets of asbestos
- BH104 – 0.7m to 1.9m. Made ground. Slight oil odour.
- BH110 – 0.1m to 0.2m. Made ground. Chemical odour.
- BH110 – 1.7m to 2.3m. Breydon Formation. Very heavily stained and spent oxide odour.

Monitoring Wells

2.5.21 Gas and groundwater monitoring wells are recorded in a number of boreholes and are summarised in the table below. Exact details of each installation are shown on the Engineer's logs in Annex B.3.

Table 2.3: Summary of Monitoring Wells

Borehole ID	BH Depth (m bgl)	Installation Type	Standpipe Depth (m bgl)	Standpipe Response Zone (mbgl)	Target Strata
BH101	20.45	50mm	2.80	1.00-2.80	Made ground / Breydon
		19mm	9.00	6.00-9.00	Corton Sand
BH102	35.00	50mm	3.10	0.50-3.00	Made ground / Breydon
		50mm	28.00	22.00-28.00	Crag
BH103	35.00	50mm	1.50	1.00-1.50	Made ground / Tidal and River Creek Deposits
		19mm	35.00	32.00-35.00	Crag
BH104	30.45	50mm	5.00	0.50-5.00	Made ground / Breydon

Borehole ID	BH Depth (m bgl)	Installation Type	Standpipe Depth (m bgl)	Standpipe Response Zone (mbgl)	Target Strata
		50mm	30.00	27.00-30.00	Crag
BH105	40.00	50mm	3.00	1.00-3.00	Made Ground / Tidal and River Creek Deposits
		19mm	29.00	26.00-29.00	Crag
		19mm	37.00	34.00-37.00	Crag
BH106	30.45	50mm	3.50	0.50-3.50	Made ground / Tidal and River Creek Deposits / North Denes
		19mm	12.00	9.00-12.00	Kesgrave
BH107	30.00	50mm	2.50	0.50-2.50	Made ground / North Denes
		19mm	10.0	10.00-9.00	North Denes
		19mm	20.00	19.00-20.00	Crag
BH108	20.00	50mm	2.20	1.50-2.20	Breydon Peat
		19mm	20.00	17.00-20.00	Crag
BH109	40.00	50mm	1.60	1.00-1.60	Tidal and River Creek Deposits
		19mm	39.00	36.00-39.00	Crag
BH110	31.00	50mm	3.00	0.50-3.00	Made ground / Breydon
		50mm	31.00	28.00-31.00	Crag

Gas Monitoring

2.5.22 Gas monitoring was undertaken on five occasions from dual and triple installations within BH101 to BH110. The maximum concentration of carbon dioxide recorded was 6.4% (BH107) and the maximum methane

concentration recorded was 0.1%. Maximum flow rate was 0.2 litres per hour (BH101).

2.5.23 Significantly depleted oxygen was recorded in BH101, BH102, BH104, BH105, BH108, BH109 and BH110.

Groundwater Monitoring

2.5.24 Groundwater monitoring was undertaken on five occasions (26th September 2007, 5th October 2007, 12th October 2007, 19th October 2007 and 22nd October 2007). The results are presented in the Factual Report in Annex B.3.

2.5.25 Water levels monitored appear to be generally consistent across all wells indicating a degree of hydraulic continuity between the shallow strata and the deeper Crag Formation.

Contamination Testing

2.5.26 For the exploratory holes within or immediately adjacent to the Principal Application Site, chemical testing was undertaken on 40 samples from 13 exploratory hole locations for the following determinands, although not all samples were tested for all determinands:

- total sulphate;
- boron;
- arsenic;
- barium;
- beryllium;
- cadmium;
- chromium;
- copper;
- lead;
- mercury;
- nickel;
- selenium;

- vanadium;
- zinc;
- ammonium as NH4;
- nitrate;
- sulphide;
- total cyanide;
- free cyanide;
- complex cyanide;
- asbestos;
- speciated petroleum hydrocarbons including MTBE; and
- speciated polyaromatic hydrocarbons.

2.5.27 Water samples were taken on one occasion from six exploratory holes within or immediately adjacent to the Principal Application Site and tested for the following determinands, although not all samples were tested for all determinands:

- arsenic;
- barium;
- beryllium;
- boron;
- cadmium;
- chromium;
- copper;
- lead;
- nickel;
- selenium;
- vanadium;
- zinc;
- mercury;
- nitrate;

- sulphate;
- sulphide;
- total cyanide;
- free cyanide;
- complex cyanide;
- sulphur;
- pH;
- extractable petroleum hydrocarbons (EPH); and
- speciated polyaromatic hydrocarbons.

3 2017 Ground Investigation

3.1 Preliminary Conceptual Site Model

3.1.1 The preliminary conceptual site model (CSM) from the Interpretative Environmental Desk Study Report identified a number of potential contaminant sources which are summarised in Section 2.4. The preliminary CSM also identified a number of plausible contaminant linkages (PCLs) that, without necessary protection and/or remediation, could put the following identified receptors at risk of significant exposure:

- Site users - Future site users, visitors and maintenance workers,
- Adjacent site users - Residents and users of nearby properties,
- Controlled waters - Principal and Secondary (A) aquifers and surface watercourses,
- On site infrastructure - Buildings, foundations and buried services,
- Marine Ecology - Vertebrates and invertebrates within the River Yare.

3.2 Rationale and Scope

3.2.1 The rationale for the site investigation scope was to provide geotechnical and geo-environmental information for design and to inform the DCO application. The scope was developed to also provide information to refine the preliminary Conceptual Site Model outlined in the Interpretative Environmental Desk Study Report presented as Appendix 16B to the Environmental Statement.

3.2.2 The main ground investigation works were land based but ten boreholes were also drilled in the River Yare itself and for distinction are referred to as marine investigation works.

3.2.3 Further details on the scope of works are presented in Annex A and Annex B.1.

Land Based Ground Investigation

3.2.4 The land based ground investigation was undertaken by the Applicants appointed Contractor, Norfolk Partnership Laboratory (NPL) between 18th September 2017 and 27th March 2018 and comprised the following:

- 25 Cable percussion boreholes;
- 16 Window Samples;
- Installation of gas and groundwater monitoring wells in 14 selected boreholes;
- Soil sampling from the boreholes and window samples for the purpose of chemical testing;
- Gas and groundwater monitoring and groundwater sampling and chemical testing following completion of the intrusive works; and
- It had been proposed to undertake machine excavated trial pits but these were changed to window samples due to access restrictions.

3.2.5 In addition to the above, static cone penetration tests (CPT), dynamic cone penetrometer tests (DCP) and standard penetration tests (SPT) were also undertaken for the purposes of geotechnical assessment and will be reported separately by the WSP Ltd Geotechnical team.

3.2.6 The as-built exploratory hole locations are presented on Drawing GYTRC-WSP-HGT-DR-GE-0001(AB) within the WSP Factual Report presented in Annex B.1. Exploratory hole locations are also presented on Drawing GYTRC-WSP-EGN-XX-DR-EN-0047 Figure 16.2 Exploratory Hole Locations (Regulation 5(2)(a)).

3.2.7 Table 3.1 presents the scope of geo-environmental intrusive works undertaken.

Table 3.1: Summary of Ground Investigation Intrusive Works

Exploratory Hole Type	Depth	Purpose
25 Cable Percussion Boreholes	5m – 50.45m	General site conditions and also targeting deeper ground conditions.
16 Window Samples plus.	1.1m – 6.0m	General site conditions where deep ground condition information is not required. Three additional window samples targeting previously identified hydrocarbon odour.

3.2.8 The scope of the field works and chemical testing suites are discussed in further detail in Annex A. Factual information provided by NPL comprising chemical test results and Engineer's logs is presented in the WSP Factual Report presented in Annex B.1.

3.2.9 The findings of the ground investigation are discussed in Sections 4 to 7 and inform the refined CSM which is presented in Section 8.

Marine Based Sampling

3.2.10 The marine based sampling was carried out by NPL between 11th June 2018 and 14th July 2018. This work was primarily to inform the bridge abutment design but was also used to facilitate sampling of the river bed sediments to ascertain the contamination status in order to inform potential disposal routes for any excavated sediments. The marine sampling comprised the following:

- Six cable percussion boreholes to a nominal 25m depth (three on each side of the river) located close to the quayside
- Four cable percussion boreholes to a nominal 40m depth (two on each side of the river) located away from the quayside at the outer edge of the proposed abutments.

3.2.11 Two locations were terminated at shallow depth and moved. MB01 was terminated due possible Unexploded Ordnance and MB04 was terminated due to a concrete obstruction.

3.2.12 The as-built exploratory hole locations are presented on Drawing GYTRC-WSP-HGT-DR-GE-0006, within the WSP Factual Report presented in Annex C.

3.2.13 In addition to the above, standard penetration tests (SPT) and pressure meter testing were also undertaken for the purposes of geotechnical assessment and will be reported separately by the WSP Ltd Geotechnical team.

3.2.14 The scope of the marine based sampling works and chemical testing suites are discussed in further detail in Annex A. Factual information provided by NPL comprising chemical test results and Engineer's logs is presented in the WSP Factual Report presented in Annex C.

3.2.15 The findings of the ground investigation are discussed in Sections 4 to 7 and inform the refined CSM which is presented in Section 8.

4 Ground Conditions Assessment

4.1 Ground Conditions Encountered On-Site

4.1.1 The findings summarised below generally confirm the anticipated strata identified in the Interpretative Environmental Desk Study Report (presented as Appendix 16B to the Environmental Statement). The findings are also similar to the findings from the 2006 ground investigation detailed in Section 2.5 above.

Made Ground Eastern Area

4.1.2 Made ground was recorded at almost all exploratory hole locations (absent from BH15) and varied in thickness from 0.55m to 4.8m. The thickness of made ground varied across the Principal Application Site with the thicker made ground generally recorded close to the quay wall.

4.1.3 The made ground was generally granular and heterogeneous in nature and included detritus comprising brick, wood, concrete, porcelain, asphalt, ceramics and metal. However, BH12A and BH13A both recorded brick / concrete within natural strata at depth (5.9m and 3.5m respectively) indicating this material may be reworked rather than being in-situ natural strata.

Made Ground Western Area

4.1.4 Made ground was recorded at almost all exploratory hole locations (absent from WS8) and varied in thickness from 0.4m to at least 4.2m, although the base of the made ground was not encountered in WS2 at 2m depth and therefore may be deeper.

4.1.5 The thickness of made ground varied across the western area and although thick made ground was recorded close to the quay wall, the thickest made ground was not recorded in this area.

4.1.6 The made ground was generally granular and heterogeneous in nature and included detritus comprising; concrete, asphalt, tile, brick, ceramic, pottery, wood, ash, leather, metal, glass, plastic, mortar and slag. BH5A at 2.0m recorded brick gravel within the Breydon Formation indicating this layer is likely to be made ground rather than in-situ natural strata.

4.1.7 WS4 at 2.3m and WS5 at 1.85m recorded a geogrid structure.

Concrete and Underground Structures

4.1.8 Solid concrete was recorded at most locations in the eastern area and was recorded up to 0.65m thick. However, only a few locations in the western area recorded concrete up to 0.5m thick.

4.1.9 Bitumen up to 0.2m thick was recorded at a few locations in the western area but was absent from the eastern area.

4.1.10 No pipes or underground structures were recorded on the Engineer's logs.

Natural Strata

Tidal River or Creek Deposits

4.1.11 Tidal River or Creek deposits were generally indistinguishable from the underlying Breydon Formation. The Tidal River or Creek Deposits encountered that can be differentiated are located in the eastern area overlying the sand deposits of the North Denes formation. Here, they generally comprised a dark grey to black, silty, variably organic Clay, and a sandy, clayey Silt interbedded with light brown to black, fine to coarse Sand with occasional flint gravel and pockets of organic material.

4.1.12 The deposit was generally encountered underlying Made Ground, to the maximum depth of 5.6m in BH14. The thickness of this deposit varied from 0.5m in BH13 to 3.80m in borehole BH14.

North Denes Formation

4.1.13 The North Denes Formation was only encountered in the eastern area where it was found underlying made ground. The Formation was typically described as a very loose to dense yellowish-brown fine to coarse sand with some rare gravels and some rare thin silt and clay bands.

4.1.14 The Formation was recorded at a maximum depth of 5.6m below ground level (bgl) (-3.64m above Ordnance Datum (aOD)) in BH14 and was not recorded in the four boreholes undertaken along the edge of the eastern quay wall (BH12, BH12A, BH13, BH13A), where Tidal River or Creek Deposits and the Breydon Formation were encountered within the depth range that the sands of the North Denes Formation were found towards the east.

Breydon Formation

4.1.15 The Breydon Formation was encountered in most boreholes in both the western and eastern areas of the Principal Application Site. In the west the Formation was encountered as either granular, cohesive or peat material.

The Breydon Peat was encountered predominantly towards the west, but was also found in thinner layers close to the river. The cohesive and granular materials were encountered as interbedded layers of varying thicknesses across the Principal Application Site.

4.1.16 The Breydon Formation can be recognised as separate interbedded sub-strata and these are described below.

Breydon Peat

4.1.17 The Breydon Peat was encountered solely in the western area as soft, dark brown and black, variably fibrous, sometimes clayey amorphous Peat. Occasional wood and reed fragments were observed.

4.1.18 The Peat is found to a maximum depth of 11.9m bgl (-10.34m aOD) in BH2, with thickness ranging between 0.25m to 3.66m.

4.1.19 Towards the west the Peat was encountered in thicker layers often underlying made ground and overlaying the granular and cohesive Breydon Formation strata.

Breydon Clay and Silt

4.1.20 The clay component of the Breydon Formation was generally encountered as very soft to soft, dark grey to brown and variably silty, sandy and organic Clay, containing occasional shell fragments, gravel, pockets of peat and rootlets. The silt component contains occasional traces of gravel, organic debris, rootlets and shell fragments. The thickness of the cohesive bands varies from 0.1m to 1.0m in the eastern area and from 0.1m to a maximum of 5.1m in the western area.

4.1.21 The silts and clays were encountered between 0.3m and 4.0m bgl (1.19m aOD and -2.44m aOD) in the western area, and between 2.60m and 4.50m bgl (-0.32m aOD and -2.13m aOD) in the eastern area.

Breydon Sand and Gravel

4.1.22 The granular component comprises predominantly loose to very loose, with some locally dense areas, grey and brown grey silty clayey fine to medium Sand, with some angular to rounded gravels of flint and occasional quartz.

4.1.23 The thickness of the sand and gravel varies from 0.15m to 2.0m in the eastern area, with the top being encountered between 4m bgl and 4.95m bgl (-1.72m aOD to -2.58m aOD), and to a maximum depth of 6.50m bgl (-4.22m aOD).

4.1.24 The granular material in the western area was encountered in layers ranging between 0.10m and 4.00m thick, the top of which is found at depths of 0.85m bgl to 11.40m bgl (1.19m aOD to -9.70m aOD). The base of the strata is found up to a maximum depth of 13.00m bgl (-11.30m aOD).

Breydon Formation (Stratum A)

4.1.25 A stratum within the Breydon Formation was encountered as quartz and quartzite gravels within a granular matrix. This material was encountered across both the eastern and western areas and was typically described as a loose to medium dense, grey, slightly silty sand and gravel, where the gravels are fine to medium, angular to rounded flint and quartz with some rare limestone gravels and shells.

4.1.26 It was encountered across both the western and eastern areas at thicknesses ranging between 1.6m to 9.4m. The thickness decreases towards the west away from the river but remains relatively consistent in the eastern area. The top of the strata in the western area was encountered at depths of between 3.00m bgl to 6.00m bgl (-0.49m aOD to -4.23m aOD) and in the eastern area at depths of between 3.20m bgl to 11.70m bgl (-0.82m aOD to -8.50m aOD).

4.1.27 To differentiate it from the other strata within the Breydon Formation, the WSP Geotechnical assessment has labelled this material as Breydon Formation (Stratum A).

Happisburgh Glacigenic Formation

4.1.28 The Happisburgh Glacigenic Formation was encountered below the Breydon Formation Stratum A in the east. In the western area, it is partly replaced by the granular and cohesive layers of the Breydon Formation.

4.1.29 The Happisburgh Glaciogenic Formation was typically described as a loose to medium dense, light brown to orange-brown, fine to coarse though predominantly medium, variably silty sand with rare fine gravels. The sand contains variable amounts of angular to rounded, fine to coarse flint gravel. Some cohesive deposits were encountered within the strata as firm to stiff orange-brown laminated sandy silt and clay, with olive grey clay banding.

4.1.30 The formation was encountered in the western area at depths ranging between 5.00m bgl to 13.00m bgl (-3.97m aOD to -12.44m aOD) and ranged in thickness between 4.30m to 14.70m. On the eastern area, the formation was encountered deeper than in the west at depths ranging from 10.00m bgl to 18.00m bgl (-7.63m aOD to -16.00m aOD), ranging in thickness between 3.00m and 12.00m.

Crag Group

4.1.31 The Crag Group was encountered across the entire Principal Application Site underlying the Happisburgh Glacigenic Formation as dense to very dense, grey to dark grey, fine to medium grained silty sand with frequent white shell fragments, with some fine gravel and occasional soft to firm silty clay layers.

4.1.32 This stratum was encountered at depths ranging between 15.85m bgl and 22.80m bgl (-14.64m aOD to -20.30m aOD) and with thicknesses ranging from 22.30m to 25.65m. Generally, the top of the strata indicated a relatively uniform horizon in both the west and east of the Principal Application Site.

London Clay

4.1.33 London Clay was encountered at depth underlying the Crag Formation as a stiff to very stiff, brown grey, sometimes laminated silty clay. Some rare flint gravels and gypsum crystals were encountered.

4.1.34 The London Clay was encountered at depths ranging between 44.00m bgl to 46.50m bgl (-41.63m aOD to -44.00m aOD) and the base was not confirmed in any boreholes.

Visual and Olfactory Evidence of Contamination

4.1.35 Other than the man-made detritus recorded within the made ground, visual and olfactory evidence of contamination was recorded by NPL at the following locations. Further detail is provided on the Engineer's logs presented in Annex B.1.

Table 4.1: Summary of Visual and Olfactory Evidence of Contamination

Exploratory Hole Reference	Comment	Strata Type	Impacted Strata Depth (m bgl)
WS21	Hydrocarbon odour	Alluvium (Engineer's Log states Alluvium but is likely to be either Tidal River or Creek Deposits or Breydon Formation)	1.4m – 2.0m
WS21	Hydrocarbon odour		2.5m – 2.95m
BH14	Diesel odour		2.6m
BH14	Slight diesel odour	North Denes Formation	7.6m – 8.0m

Exploratory Hole Reference	Comment	Strata Type	Impacted Strata Depth (m bgl)
BH6	Slight hydrocarbon odour	Made ground	0.4m – 1.2m
BH4BU	Hydrogen sulphide odour	Breydon Formation	2.65m – 2.85m

4.2 Marine Sediment

4.2.1 The Engineer's logs for the marine boreholes presented in Annex C indicate that the shallow sediments within the River Yare comprise gravel, sand, silt and clay and are classified as Tidal River or Creek Deposits. These vary in thickness from 0.8m up to 5.3m. Underlying these sediments are the Happisburg Glacigenic Formation and the Crag Formation, both predominantly comprising sand but layers of silt and clay are also present. London Clay was encountered at depth beneath the Crag Formation at a few locations.

5 Hydrological and Hydrogeological Conditions

5.1 Local Hydrology

Surface Water Features

5.1.1 The River Yare splits the Principal Application Site in two and is recorded as a Primary River. Other than the sea, no other surface water features are present within 500m of the Principal Application Site.

5.1.2 Assessment of surface water is presented in more detail in Chapter 11: Road Drainage and the Water Environment within the Environmental Statement (document reference 6.1).

Surface Water Abstractions & Discharges

5.1.3 No surface water or potable water abstractions are present within 2km of the Principal Application Site.

5.2 Hydrogeology

Geology and Aquifer Status

5.2.1 Various superficial deposits were recorded during the ground investigation. Assessment of hydrogeology is presented in more detail in Chapter 11: Road Drainage and the Water Environment within the Environmental Statement (document reference 6.1).

5.2.2 The Happisburgh Formation, Breydon Formation and North Denes Formation are classified as Secondary (A) Aquifers which are defined by the Environment Agency as permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers.

5.2.3 The Crag Group bedrock (comprising sand with occasional gravel and clay layers) is designated by the Environment Agency as a Principal Aquifer. However, according to the British Geological Survey the Crag Group in the area of Great Yarmouth is recorded as a Secondary (A) Aquifer. For the purposes of this report and Environmental Statement, the worst case scenario is assumed and the Crag Group is considered a Principal Aquifer.

5.2.4 The deeper London Clay is classified as classified as unproductive. These are defined by the Environment Agency as rock layers or drift deposits with low permeability that have negligible significance for water supply or river base flow.

Groundwater Abstractions

5.2.5 The nearest active groundwater abstraction point is approximately 71m to the north west of the Principal Application Site for laundry use.

Groundwater Encountered During Investigation

5.2.6 Groundwater was recorded at a number of locations during the 2017/2018 ground investigation. The details are summarised in the table below. Groundwater strikes during the 2006 ground investigation are presented in the factual report in Annex B.3.

Table 5.1: Summary of Groundwater Strikes during the 2017/2018 Ground Investigation

Exploratory Hole Location	Groundwater Level at Strike (mOD)	Strata Type
BH1	-1.1	Sand (Made Ground)
BH1	-9.7	Sand (Breydon Formation)
BH2	-1.54	Sand (Made Ground)
BH4	-1.23	Sand and Gravel (Made Ground)
BH4	-3.73	Peat (Breydon Formation)
BH4A	-1.95	Peat (Breydon Formation)
BH4D	-0.72	Sand (Made Ground)
BH5A	-2.69	Sand (Made Ground)
BH5A	-0.19	Clay (Breydon Formation)
BH6	-1.17	Sand (Breydon Formation)
BH7	-2.67	Sand (Breydon Formation)
BH8	1.09	Sand (Made Ground)
BH9	0.53	Clay (Breydon Formation)
BH10	-1.55	Sand (Breydon Formation)
BH10A	1.15	Sand (either Tidal or River Creek Deposits or Breydon Formation)
BH11	0.06	Gravel (Made Ground)
BH11A	1.20	Sand (Made Ground)
BH12	-0.92	Silt (Alluvium either Tidal or River Creek Deposits or Breydon Formation)

Exploratory Hole Location	Groundwater Level at Strike (mOD)	Strata Type
BH13	0.57	Clay (Made Ground)
BH13A	0.48	Gravel (Breydon Formation)
BH14	0.56	Gravel (Made Ground)
BH15	-0.08	Sand (North Denes Formation)
BH16	0.00	Clay (Alluvium either Tidal or River Creek Deposits or Breydon Formation)
BH17	-0.45	Silt (Alluvium either Tidal or River Creek Deposits or Breydon Formation)
BH18	-0.70	Sand (Alluvium either Tidal or River Creek Deposits or Breydon Formation)
BH4ASU	0.13	Sand and Gravel (Marine Beach Deposits)
BH4ASU	-2.87	Sand (Breydon Formation)
TP1	-4.28	Silt (Breydon Formation)
TP1B	-0.18	Clay (Breydon Formation)
WS1	-0.45	Sand (Marine Beach Deposits)
WS2	-1.15	Sand and Gravel (Made Ground)
WS3	-0.62	Silt (Breydon Formation)
WS4	-0.41	Sand and Gravel (Breydon Formation)
WS6	-1.86	Clay and Silt (Breydon Formation)
WS7	-1.30	Sand (Breydon Formation)
WS9	-0.23	Sand (Made Ground)
WS20	-2.51	Sand (Alluvium either Tidal or River Creek Deposits or Breydon Formation)
WS21	0.96	Sand (Alluvium either Tidal or River Creek Deposits or Breydon Formation)
WS22	-1.00	Sand (Alluvium either Tidal or River Creek Deposits or Breydon Formation)

Monitored Groundwater Levels

5.2.7 Monitoring of groundwater levels in relation to Ordnance Datum was undertaken on 8 occasion's to-date following the completion of the

2017/2018 intrusive ground investigation works. The details are provided in Annex B.1 and are summarised in the tables below.

5.2.8 The tables below do not include the data for BH4A, BH10 or BH12B. The response zones in these wells cross the made ground / natural ground boundary and therefore the exact source of the groundwater cannot be confirmed.

Table 5.2: Summary of Groundwater Level Monitoring in the Eastern Study Area

Stratum	Monitoring Well	Minimum (mOD)	Maximum (mOD)	Strata
Made Ground	No standalone monitoring wells within the made ground.			
Natural Ground	BH11	-0.3	0.19	Breydon, North Denes and Crag Formations.
	BH13	0.31	0.66	Breydon and Crag Formations.
	BH15	-0.18	0.66	North Denes Formation.
	WS20	0.23	0.29	Alluvium
	WS21	0.67	0.86	Alluvium
	WS22	1.05	1.14	Alluvium

Table 5.3: Summary of Groundwater Level Monitoring in the Western Study Area

Stratum	Monitoring Well	Minimum (mOD)	Maximum (mOD)	Strata
Made Ground	BH4D Shallow	-1.12	-0.12	Made ground
Natural Ground	BH4	-0.33	0.62	Breydon and Crag Formations
	BH4D Deep	-1.13	-0.01	Crag Formation
	BH6	-1.17	-0.21	Crag Formation

5.2.9 It should be noted that a monitoring well was also installed in BH7 but an oversight by the Contractor resulted in no monitoring at BH7 until the final visit on 20th December 2018. This does not effect the validity of the assessment undertaken and reported in this Environmental Statement.

5.2.10 The water levels recorded during the 2006 ground investigation are broadly similar to those in Tables 5.2 and 5.3 above.

Hydraulic Gradient

5.2.11 The monitoring data obtained to date appears to indicate the hydraulic gradient is towards the River Yare from both the western area and the eastern area as would be expected. However, it should be noted that the groundwater monitoring data may be subject to tidal fluctuations which could affect the recorded levels.

Hydraulic Continuity

5.2.12 The superficial deposits are likely to be in hydraulic continuity with the Crag Group due to the absence of any continuous low permeability strata separating these aquifers.

5.2.13 Similar groundwater quality characteristics across the Principal Application Site and the proximity to the River Yare also indicate the mixing of groundwater within the superficial deposits and the Crag Group is likely to be occurring.

5.2.14 The regional Chalk Group aquifer is considered to be protected by the overlying London Clay Formation, which is considered to significantly reduce the potential risks of any groundwater pollution present migrating to the Chalk within the study area. The superficial deposits are considered to be in hydraulic continuity with the Crag Group because no low permeable geologies segregate these aquifers. The mixing of groundwater and similar groundwater quality characteristics, dominated by the proximity to the River Yare, is therefore likely between the two hydrogeological units.

6 Qualitative Risk Assessment

6.1 Introduction

6.1.1 In the United Kingdom, the presence of contamination within soil or groundwater at a site is generally only of concern if an actual or potentially unacceptable risk to a sensitive receptor exists.

6.1.2 The risk assessment process begins with screening chemical concentrations in soil or groundwater against conservative screening values, a process called Generic Qualitative Risk Assessment (GQRA). GQRA's are performed to assess the potential risks to human health and controlled waters and to identify the presence of contaminants of concern (CoC), which may require further, more detailed assessment.

6.1.3 Annex B.1 and Annex B.3 presents the chemical test data and Annex E presents the screening spreadsheets.

6.2 Human Health Risk Assessment

6.2.1 Following the tiered approach which is described in Model Procedures for the Management of Land Contamination (Ref 16C.5) published by DEFRA and the Environment Agency, this section provides a GQRA of those contaminant linkages that were determined to be plausible in the refined CSM.

6.2.2 DEFRA and the Environment Agency have published a limited number of Soil Guideline Values (SGVs) for a series of generic land use scenarios which follow the Contaminated Land Exposure Assessment (CLEA) methodology. Where SGV's are not available, WSP has derived a set of Generic Assessment Criteria (GAC) for the CLEA generic land use scenarios using the CLEA Workbook v1.071 Excel modelling tool. The CLEA workbook does not currently have the capacity to derive criteria to assess risks from the inhalation of vapours derived from contaminants dissolved in groundwater. Therefore, a set of groundwater GAC's has also been derived using the Johnson & Ettinger (1991, Ref 16C.11) (J&E) approach.

6.2.3 The chemical test results have been assessed against screening values for both commercial / industrial and public open space land use scenarios. Further details in the methodologies adopted by WSP Ltd are provided in Annex D. These land use scenarios are also defined in the Environment Agency document 'Updated Technical Background to the CLEA Model' Report SC050021/SR3, January 2009 (Ref 16C.12).

6.2.4 These two scenarios are most appropriate for the proposed highway and landscaping end uses, although both are considered to be reasonably conservative as it is unlikely anyone will be on-site for the duration that either scenario assumes. In the case of public open space this is up to 2hours per day, up to 170 days per year for a 1-6 year old child. In the case of commercial / industrial, this is 0.7 hours per day up to 230 days per year.

6.2.5 The soil chemical data has been compared against end use GAC's for a conservative 1% soil organic matter (SOM) content. The average SOM concentration is 2.07% and therefore the nearest conservative concentration is 1%. Samples that exceed the screen are identified as CoC and are carried forward for further discussion.

6.2.6 For an initial assessment, the data has been split into made ground and natural ground averaging areas and then split again into eastern area and western area.

6.2.7 For some CoC, direct contact will be the dominant pathway for exposure. Due to the unknown nature of soil excavation and reuse at this stage of the design, it is possible that materials from any depth could be excavated and placed at or near the surface in the final design. In order to advise the development options, human exposure to all unsaturated soils, irrespective of depth, was assumed possible for the purpose of this assessment. This will maximise the information available to the design team on the suitability of all unsaturated material and can support with their materials management options.

6.2.8 Potential risks to human health from soil gases are assessed in Section 6.4.

Assessment of Results – Public Open Space Land Use Scenario

6.2.9 Evidence of hydrocarbons (diesel) was identified at three locations during the ground investigation as detailed in Table 4.1 above. Two of these three locations were targeted for chemical testing and none of the results exceed the hydrocarbon GAC's. It should be noted that the diesel odour in BH14 was not scheduled for chemical testing by NPL but the area was targeted subsequently at the request of WSP with the three additional window samples WS20, WS21 and WS22. None of the additional samples tested recorded results in excess of the hydrocarbon GAC's.

Natural Ground (Eastern Area)

6.2.10 The following CoC have been identified from the screening of natural ground in the eastern area:

- Alkaline pH at two locations – BH13A and WS20 – 9.78 and 10.31 respectively compared to a screening value of 9.5.

Natural Ground (Western Area)

6.2.11 The following CoC have been identified from the screening of natural ground in the western area:

- Acid pH at one location – TP01 – 5.4 compared to a screening value of 5.5.

Made Ground (Eastern Area)

6.2.12 The following CoC have been identified from the screening of made ground in the eastern area:

- Alkaline pH at five locations – BH12A (9.62), BH17 (12.49), BH16 (11.41), BH14 (10.15) and WS21 (11.01) exceeded the GAC of 9.5.

Made Ground (Western Area)

6.2.13 The following COC have been identified from the screening of made ground in the western area:

- Asbestos was recorded by the chemical testing laboratory in four samples:
  - BH6 at 0.5m as chrysotile loose fibres;
  - BH6 at 1.0m as chrysotile loose fibres;
  - CPT3 at 0.5m as chrysotile loose fibres; and
  - CPT3 at 1.0m as chrysotile loose fibres.
- Lead at one location – BH5A at 0.5m depth (878mg/kg) compared to a GAC of 808mg/kg;
- Alkaline pH at two locations – BH11A (9.84) and BH10A (11.62) values exceeded the GAC of 9.5; and
- Benzo(a)pyrene at two locations – BH7 at 0.8m depth (510mg/kg) and BH4 at 2.0m depth (13.9mg/kg) compared to a GAC of 11mg/kg.

2006 Ground Investigation Data

6.2.14 The 2006 ground investigation data was also screened against the public open space screening values and only one exceedance was recorded:

- BH110 total cyanide 36mg/kg compared to a screening value of 15mg/kg. This location also recorded evidence of spent oxide on the Engineers log

and this cyanide exceedance is likely to be further evidence of spent oxide waste.

Assessment of Results - Commercial / Industrial Land Use Scenario

6.2.15 Evidence of hydrocarbons (diesel) was identified at three locations during the 2017 ground investigation as detailed in Table 4.1 above. Two of these three locations were targeted for chemical testing and none of the results exceed the hydrocarbon GAC's. It should be noted that the diesel odour in BH14 was not scheduled for chemical testing by NPL but the area was targeted subsequently at the request of WSP with the three additional window samples WS20, WS21 and WS22. None of the additional samples tested recorded results in excess of the hydrocarbon GAC's.

Natural Ground (Eastern Area)

6.2.16 The following CoC have been identified from the screening of natural ground in the eastern area:

- Alkaline pH at two locations – BH13A and WS20 – 9.78 and 10.31 respectively compared to a screening value of 9.5.

Natural Ground (Western Area)

6.2.17 The following CoC have been identified from the screening of natural ground in the western area:

- Acid pH at one location – WS TP01 – 5.4 compared to a screening value of 5.5.

Made Ground (Eastern Area)

6.2.18 The following CoC have been identified from the screening of made ground in the eastern area:

- Alkaline pH at five locations – BH12A (9.62), BH17 (12.49), BH16 (11.41), BH14 (10.15) and WS21 (11.01) exceeded the GAC of 9.5.

Made Ground (Western Area)

6.2.19 The following CoC have been identified from the screening of made ground in the western area:

- Asbestos was recorded by the chemical testing laboratory in four samples:
  - BH6 at 0.5m as chrysotile loose fibres,
  - BH6 at 1.0m as chrysotile loose fibres,
  - CPT3 at 0.5m as chrysotile loose fibres,
  - CPT3 at 1.0m as chrysotile loose fibres,
- Alkaline pH at two locations – BH11A (9.84) and BH10A (11.62) values exceeded the GAC of 9.5.
- Benzo(a)pyrene at one location – BH7 (510mg/kg) compared to a GAC of 38mg/kg.

2006 Ground Investigation Data

6.2.20 The 2006 ground investigation data was also screened against the commercial industrial screening values and no exceedances were recorded.

Discussion

6.2.21 Asbestos has been identified at five shallow locations and is therefore likely to be encountered during the earthworks. Most of the other exceedances are likely to be mitigated from a human health perspective through the presence of hard standing or landscaping inert cover. However, the benzo(a)pyrene exceedance of 510mg/kg in BH7 at 0.8m depth may need further assessment or removal if this material is likely to be disturbed during construction.

6.2.22 The area around BH110 from the 2006 ground investigation which recorded elevated cyanide is just outside the Principal Application Site. However, it is approximately 200m to the south of the western bridge abutment and similar made ground could be encountered during excavation of the bascule pit.

6.2.23 The MIND charity site will include an area of green space and allotments close to the A47 / William Adams Way junction. In the absence of any suitable topsoil / subsoil identified across the Principal Application Site during the ground investigations, it is considered that construction of the new green space and allotment area will require an appropriate thickness of inert sub-soil and topsoil to be imported to encourage plant growth.

6.2.24 Depending upon the final Principal Application Site levels, excavation and placement of material may be required. If, following excavation, made ground remains, a geotextile break layer is likely to be required to separate the made ground from imported subsoil and topsoil.

6.3 Controlled Waters Risk Assessment

6.3.1 The generic controlled waters risk assessment was conducted in accordance with the principles of the Environment Agency publication 'Remedial Targets Methodology: Hydrogeological Risk Assessment for Land Contamination' 2006 (Ref 16C.13) and the 'prevent and limit' approach of the Water Framework Directive (2000/60.EC). Generic controlled waters risk assessments compare directly measured concentrations with standard assessment criteria. In this case the following assessments were undertaken:

- Level 1 - evaluates the concentrations of chemicals within the pore water in the unsaturated zone of source area soil, in this case soil leachate analysis/using theoretical calculations.
- Level 2 - evaluates the concentrations of chemicals within the saturated zone immediately underlying a source area i.e. taking dilution and attenuation into account, in this case groundwater analysis.

6.3.2 Appropriate Water Quality Standards (WQS) are selected based on both a hierarchy of relevance to England and Wales and the receptor. In this case, the controlled water receptors identified in the CSM are:

- River Yare surface watercourse;
- The underlying Secondary (A) and Principal Aquifers within the superficial and bedrock strata;

6.3.3 The following hierarchies of WQS were therefore considered to be appropriate:

<u>Aquifers</u>

- UK Drinking Water Quality Standards (DWS) from The Water Supply (Water Quality) Regulations 2000 (amended 2016) (UK DWS) (Ref 16C.14);
- World Health Organisation Drinking Water Guidelines 2017 (WHO DWG 2017) (Ref 16C.15);
- World Health Organisation Petroleum Products in Drinking Water (2008) (WHO 2008) (Ref 16C.16)

Surface Waters

- Environmental Quality Standards (EQS) from The Water Framework Directive (Standards and Classification) Directions (England and Wales) 2015 (WFD 2015) (Ref 16C.17)
- CL:AIRE Petroleum in Groundwater Guidance 2017 (CL:AIRE 2017) (Ref 16C.18),
- R&D Technical Report P2-115/TR4 2002 (Ref 16C.19).

6.3.4 The following Sections detailing the determinands recording test results in excess of the WQS screening values should be read in conjunction with the screening tables presented in Appendix E.

6.3.5 It should be noted that two versions of the groundwater screening tables are presented in Annex E. One presented the data per monitoring visit and the other presents the data per geological strata so that a comparison between the different strata can be made.

6.3.6 NPL undertook water sampling visits to extract water from the monitoring wells for chemical testing on the following occasions. It should be noted that not all monitoring wells were sampled on each visit:

- 1st June 2018
- 21st June 2018
- 3rd July 2018
- 19th July 2018
- 2nd August 2018
- 17th August 2018
- 30th August 2018
- 4th October 2018
- 18th October 2018
- 1st November 2018
- 14th November 2018
- 29th November 2018
- 11th December 2018
- 20th December 2018

Risks to Aquifer

Soil Leachability Testing

6.3.7 Generic screening of 24 soil leachate test results from the 2017/2018 ground investigation identified exceedances of the WQS screening values for the following determinands:

Table 6.1: Summary of Soil Leachate Exceedances (Risks to Aquifer)

Determinand	Exceedance	Screening Value	Source of Screening Value*	Number of Exceedances	Soil Concentrations at Exceedances
Alkaline pH	11.18	10	UK DWS	1	10.31
Acid pH	6.22	6.5	UK DWS	1	8.38
Ammoniacal Nitrogen	5.08mg/l to 0.39mg/l	0.389mg/l	UK DWS	10	71.2mg/kg to 8.6mg/kg
Total cyanide	0.021mg/l to 0.006mg/l	0.005 mg/l	UK DWS	6	2mg/kg to <1mg/kg
Arsenic	23µg/l to 13µg/l	10µg/l	UK DWS	5	12mg/kg to 4mg/kg
Lead	145µg/l to 14µg/l	10µg/l	UK DWS	9	752mg/kg to 14mg/kg
Benzo(a)pyrene	0.13µg/l to 0.03µg/l	0.01µg/l	UK DWS	3	13.9mg/kg to 0.37mg/kg
Sum of four PAH	0.34µg/l to 0.23µg/l	0.1µg/l	UK DWS	2	34.67mg/kg to 1.34mg/kg

6.3.8 It should be noted that the limits of detection for benzo(a)pyrene, bis(2-ethylhexyl)phthalate and hexachlorobutadiene are in excess of the screening values.

Groundwater Testing

6.3.9 Generic screening of groundwater test results from the fourteen monitoring visits (from the 2017/2018 ground investigation) identified WQS exceedances for the following determinands but not from every sample on every monitoring visit. Discussion of the exceedances is presented in the following sections.

Table 6.2: Summary of Groundwater Exceedances (Risks to Aquifer)

Determinand	Exceedance	Screening Value	Source of Screening Value*	Number of Exceedances
Alkaline pH	10.34 to 11.9	10	UK DWS	5
Ammoniacal Nitrogen	0.42mg/l to 12.9mg/l	0.389mg/l	UK DWS	102
Sulphate	282mg/l to 2,720mg/l	250mg/l	UK DWS	54
Free Cyanide	0.006mg/l to 0.033mg/l	0.005mg/l	UK DWS	15
Total Cyanide	0.016mg/l to 0.231mg/l	0.005mg/l	UK DWS	39
Arsenic	11µg/l to 75µg/l	10µg/l	UK DWS	48
Boron	1,010µg/l to 4,920µg/l	1,000µg/l	UK DWS	37
Benzo(a)pyrene	0.02µg/l to 1.87µg/l	0.01µg/l	UK DWS	16
Sum of four PAH	0.11µg/l to 5.46µg/l	0.1µg/l	UK DWS	9
Aromatic C_{10}-C_{12}	97µg/l	90µg/l	WHO 2008	1
Aromatic C_{12}-C_{16}	121µg/l to 163µg/l	90µg/l	WHO 2008	2
Aromatic C_{16}-C_{21}	110µg/l	90µg/l	WHO 2008	1

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6.3.10 It should be noted that the limits of detection for bis(2-ethylhexyl)phthalate, vinyl chloride, 1,2-dibromoethane, 1,2-dibromo-3-chloropropane, hexachlorobutadiene are in excess of the screening values.

6.3.11 Most of the exceedances are marginal (less than one order of magnitude) and are unlikely to pose an unacceptable risk to drinking water. However, there are a few exceedances that are one or more orders of magnitude higher than the screening values and these are highlighted below.

6.3.12 Ammoniacal nitrogen exceeds the WQS in most samples by one order of magnitude although occasional samples from BH13, WS20, WS21 and WS22 recorded concentrations two orders of magnitude higher.

6.3.13 Sulphate exceeds the WQS by one order of magnitude in a few samples; BH6, BH4D (deep), BH11, BH13 and BH4.

6.3.14 Arsenic exceedances are no more than one order of magnitude higher than the WQS and are generally recorded in BH6, BH4D (shallow), BH15, but also in BH4D (deep), BH13, BH11, WS20, WS21 and WS22 on occasions.

6.3.15 Exceedances of benzo(a)pyrene were recorded in BH4D, BH4, WS20, WS21, WS22 and are generally less than one order of magnitude higher than the screening value. However, a maximum concentration of 1.87µg/l was recorded in WS22 during visit eight on 4th October 2018.

6.3.16 Total PAH exceeded the WQS on only nine occasions and were generally less than one order of magnitude higher than the WQS. However, two samples recorded concentrations greater than one order of magnitude – WS22 – 5.46µg/l on 4th October and WS20 – 1.54µg/l on 29th November.

6.3.17 Petroleum hydrocarbons are generally below the screening values apart from WS21 and BH13 in the last two monitoring visits where aromatic C12-C16 hydrocarbons were recorded up to 163µg/l. Test results above the limit of detection were also recorded for aromatic C10-C35 hydrocarbons indicating the possible presence of diesel.

Groundwater Testing – 2006 Ground Investigation

6.3.18 Generic screening of groundwater test results from the single monitoring visit from the 2006 ground investigation identified WQS exceedances for the following determinands. Discussion of the exceedances is presented in Sections 6.3.35 to 6.3.43.

Table 6.3: Summary of Groundwater Exceedances 2006 GI (Risks to Aquifer)

Determinand	Exceedance	Screening Value	Source of Screening Value*	Number of Exceedances
Arsenic	20µg/l to 35µg/l	10µg/l	UK DWS	4
Boron	1.4mg/l to 3.0mg/l	1mg/l/l	UK DWS	3
Nickel	26µg/l to 47µg/l	20µg/l	UK DWS	3
Selenium	53µg/l to 130µg/l	10µg/l	UK DWS	4

Determinand	Exceedance	Screening Value	Source of Screening Value*	Number of Exceedances
Sulphate	330mg/l to 1600mg/l	250mg/l	UK DWS	5
Total cyanide	0.18mg/l to 3.5mg/l	0.005mg/l	UK DWS	2
Free cyanide	0.94mg/l	0.005mg/l	UK DWS	1
Benzo(a)pyrene	34ng/l	10ng/l	UK DWS	1

6.3.19 Most exceedances are less than one order of magnitude greater than the screening value. However, selenium and sulphate both exceed by one order of magnitude. The cyanide and benzo(a)pyrene exceedances are recorded in BH110 and TP104 in the southern part of the western area and may be indicative of gasworks waste and / or ash fill.

Risks to River Yare Surface Water

Soil Leachability Testing

6.3.20 Generic screening of 24 soil leachate test results from the 2017/2018 ground investigation identified the following WQS exceedances:

Table 6.4: Summary of Soil Leachability Exceedances (Risks to River Yare)

Determinand	Exceedance	Screening Value	Source of Screening Value*	Number of Exceedances	Soil Concentrations at Exceedances
Cyanide	0.021mg/l to 0.006mg/l	0.001mg/l	WFD 2015	6	2mg/kg to <1mg/kg
Copper	38µg/l to 4µg/l	3.76µg/l	WFD 2015	14	157mg/kg to 3mg/kg
Nickel	11µg/l	8.6µg/l	WFD 2015	1	17mg/kg
Mercury	0.1µg/l	0.07µg/l	WFD 2015	1	<0.17mg/kg
Lead	145µg/l to 2µg/l	1.3µg/l	WFD 2015	19	752mg/kg to 7mg/kg

Determinand	Exceedance	Screening Value	Source of Screening Value*	Number of Exceedances	Soil Concentrations at Exceedances
Zinc	644µg/l to 7µg/l	6.8µg/l	WFD 2015	15	1,900mg/kg to 16mg/kg
Anthracene	0.13µg/l	0.1µg/l	WFD 2015	1	0.02mg/kg
Benzo(a)pyrene	0.13µg/l to 0.03µg/l	0.00017µg/l	WFD 2015	3	13.9mg/kg to 0.37mg/kg
Fluoranthene	0.2µg/l to 0.02µg/l	0.0063µg/l	WFD 2015	16	9.18mg/kg to <0.08mg/kg
Naphthalene	3.75µg/l	2µg/l	WFD 2015	1	0.18mg/kg
Bis(2-ethylhexyl)phthalate	4µg/l	1.3µg/l	WFD 2015	1	<500µg/kg
Aromatic C_{12}-C_{16}	11µg/l	2µg/l	CL:AIRE 2017	1	15.8µg/kg

6.3.21 It should be noted that the limits of detection for cyanide, phenols, cadmium, hexavalent chromium, mercury, benzo(a)pyrene, fluoranthene, 1,2,4-trichlorobenzene, 2,4-dichlorophenol, bis(2-ethylhexyl)phthalate, butylbenzyl phthalate, phenol and aromatic C5-C7, C10-C12, C12-C16, C16-C21 and C21-C35 hydrocarbons are in excess of the screening values.

Groundwater Testing

6.3.22 Generic screening of groundwater test results from the 14 monitoring visits (from the 2017/2018 ground investigation) identified WQS exceedances for the following determinands but not from every sample on every monitoring visit.

Table 6.5: Summary of Groundwater Exceedances (Risks to River Yare)

Determinand	Exceedance	Screening Value	Source of Screening Value*	Number of Exceedances
Free cyanide	0.006µg/l to 0.033µg/l	0.001mg/l	WFD 2015	15

Determinand	Exceedance	Screening Value	Source of Screening Value*	Number of Exceedances
Total cyanide	0.016µg/l to 0.231µg/l	0.001mg/l	WFD 2015	39
Arsenic	53µg/l to 75µg/l	25µg/l	WFD 2015	12
Copper	4µg/l to 74µg/l	3.76µg/l	WFD 2015	50
Mercury	0.1µg/l to 0.2µg/l	0.07µg/l	WFD 2015	2
Zinc	7µg/l to 60µg/l	6.8µg/l	WFD 2015	29
Anthracene	0.24µg/l to 0.25µg/l	0.1µg/l	WFD 2015	2
Benzo(a)pyrene	0.01µg/l to 1.87µg/l	0.00017µg/l	WFD 2015	22
Fluoranthene	0.01µg/l to 2.33µg/l	0.0063µg/l	WFD 2015	77
Phenol	13µg/l	7.7µg/l	WFD 2015	1
Trichloroethene	14µg/l to 20µg/l	10µg/l	WFD 2015	5
Aromatic C9-C10	5µg/l to 97µg/l	2µg/l	CL:AIRE 2017	13
Aromatic C10-C12	6µg/l to 163µg/l	2µg/l	CL:AIRE 2017	13
Aromatic C12-C16	6µg/l to 110µg/l	0.1µg/l	CL:AIRE 2017	23
Aromatic C21-C35	16µg/l to 45µg/l	0.00017µg/l	CL:AIRE 2017	5

6.3.23 Most of the exceedances are marginal (less than one order of magnitude) and are unlikely to pose an unacceptable risk to surface waters. However, there are a few possible patterns that may indicate an impact has previously occurred.

6.3.24 Trichloroethene and 1,2-dichloroethene are recorded above the limit of detection in BH4 (shallow and deep wells) in most of the monitoring visits. Trichloroethene is recorded above the screening value of 10µg/l in BH4D

(deep) during each of the first five monitoring visits. The concentrations recorded range from 14µg/l to 20µg/l. 1,2-dichloroethene concentrations only vary from 1µg/l to 12µg/l (compared to a WQS of 50µg/l). This would suggest an impact has occurred in the past but in the absence of significantly elevated concentrations of any other VOC's a significant risk is not considered to exist. This location is on the western side of the river.

6.3.25 Hydrocarbons were not recorded above the limit of detection during the first six visits. However, aromatic hydrocarbons were recorded above the limit of detection in wells on the eastern side of the river from visit seven (30th August 2018), particularly BH13, WS20, WS21 and WS22. Until the final two monitoring visits, the concentrations did not exceed 53µg/l. However, the last two monitoring visits recorded an increase in the number of locations recording concentrations above the limit of detection, particularly for aromatic C16 to C21 (up to 97µg/l). WS21 recorded aromatic hydrocarbons up to 163µg/l (C12 to C16).

6.3.26 Aliphatic hydrocarbons were generally less than the limit of detection except for a few occasions when BH4D, BH10, WS21 and WS22 recorded speciations above the limit of detection up to 80µg/l.

6.3.27 Hydrocarbon odours were recorded in BH14 and WS21 on the eastern side of the river during the drilling works. Elevated hydrocarbon concentrations within the groundwater have also been recorded in a similar area but only during the final two sampling visits. The elevated concentrations are for the aromatic C9 to C35 fractions and have a maximum concentration of 163µg/l and exceed the WQS for these fractions. An impact appears to have occurred but it is unclear why the last two sampling visits recorded exceedances and the previous visit generally did not.

6.3.28 Elevated arsenic was recorded in BH15 only up to a maximum concentration of 75µg/l and elevated cyanide was commonly recorded in BH15 and BH4D up to 0.227µg/l.

6.3.29 Fluoranthene was recorded in most samples during most visits and the results are generally in the range of 0.01µg/l to 0.05µg/l. However, occasional results for WS20, WS21, WS22, BH12B and BH4D (shallow) are recorded an order of magnitude higher, up to 0.48µg/l. WS22 also recorded a maximum concentration of 2.33µg/l. This same sample from WS22 (4th October 2018) also recorded elevated benzo(a)pyrene (1.87µg/l), the highest recorded during the monitoring as well as the only phenol exceedance and one of two anthracene exceedances (the other being WS20).

Groundwater Testing – 2006 Ground Investigation

6.3.30 Generic screening of groundwater test results from the single monitoring visit from the 2006 ground investigation identified WQS exceedances for the following determinands but not from every sample on every monitoring visit.

Table 6.6: Summary of Groundwater Exceedances 2006 GI (Risks to River Yare)

Determinand	Exceedance	Screening Value	Source of Screening Value*	Number of Exceedances
Arsenic	33µg/l to 35µg/l	25µg/l	WFD 2015	3
Cadmium	µg/l to µg/l	0.2µg/l	WFD 2015	1
Nickel	µg/l to µg/l	8.6µg/l	WFD 2015	4
Zinc	µg/l to µg/l	µg/l	WFD 2015	4
Total cyanide	µg/l to µg/l	µg/l	WFD 2015	2
Free cyanide	µg/l to µg/l	µg/l	WFD 2015	1
Naphthalene	67µg/l	2µg/l	WFD 2015	1
Anthracene	1.3µg/l	0.1µg/l	WFD 2015	1
Fluoranthene	0.019µg/l to 3.6µg/l	0.0063µg/l	WFD 2015	2
Benzo(a)pyrene	0.034µg/l	0.00017µg/l	WFD 2015	1

6.3.31 Some exceedances are less than one order of magnitude greater than the screening value. However, zinc, total cyanide, free cyanide, naphthalene, anthracene, fluoranthene and benzo(a)pyrene exceedances are recorded at concentrations one or two orders of magnitude higher than the screening values. BH110 in particular records the most exceedances and may be indicative of gasworks waste and / or ash fill.

Discussion

6.3.32 The ground investigation recorded some olfactory evidence of hydrocarbons in WS21, BH14 and BH6 from the 2017 ground investigation and in TP101, BH104 and BH110 from the 2006 ground investigation.

6.3.33 Sampling of groundwater from monitoring well installations (adopting best practice of purging) identified some exceedances of the conservative generic groundwater screening values for metals, inorganics and hydrocarbons. Most of these exceedances are less than one order of magnitude greater

than the screening values and are therefore not considered to be indicative of significant contamination.

6.3.34 However, there is some evidence of organic contamination (polyaromatic hydrocarbons, volatile organic compounds and petroleum hydrocarbons) and to a lesser extent metals and non-metals in the groundwater across the Principal Application Site indicating the groundwater has been impacted previously and has the potential to impact the surface water of the River Yare.

6.3.35 The soil leachate WQS exceedances are generally less than one order of magnitude above the screening values and indicate that there is a theoretical potential for an impact to occur. However, the Principal Application Site will be generally hard standing, thus limiting the degree of rainfall percolation through the made ground and hence the concentrations recorded suggest the made ground would not pose a significant risk to Controlled Waters.

6.3.36 In view of the above it is considered that the absence of test results that consistently exceed the screening values at each monitoring visit indicates that there is unlikely to be an unacceptable risk to the identified receptors and hence specific remediation to target existing groundwater exceedances is not considered necessary.

6.3.37 The groundwater monitoring test data has also been assessed on a strata by strata basis. This has not identified any significant difference in the exceedances between the different strata or from one side of the river to the other. This would suggest there is hydraulic continuity between the different strata.

Assessment of Saline Intrusion

6.3.38 The two most recent sets of groundwater testing included results for electrical conductivity in order to make an assessment of saline intrusion. The results indicate that there is some influence from seawater across the Principal Application Site in both shallow and deep groundwater monitoring wells.

6.4 Ground Gas Assessment

Results

6.4.1 To date, nine rounds of ground gas monitoring have been undertaken by NPL on the following dates:

- 17th August 2018 – excludes BH7 and window sample locations WS20-WS22;
- 30th August 2018 - excludes BH7 and window sample locations WS20-WS22;
- 4th October 2018 – excludes BH7;
- 18th October 2018 - excludes BH7;
- 1st November 2018 - excludes BH7;
- 14th November 2018 - excludes BH7;
- 29th November 2018 - excludes BH7;
- 11th December 2018 - excludes BH7; and
- 20th December 2018 – only BH7 was monitored on this occasion.

6.4.2 It is likely that a control building will be constructed adjacent to the eastern abutment and therefore this gas assessment will inform the design of that building.

6.4.3 Atmospheric pressure varied as set out in Table 6.7 during the monitoring period.

Table 6.7: Summary of Atmospheric Pressure Recorded during Gas Monitoring Visits

Date	Atmospheric Pressure	Trend
17/8/18	1010	Steady
30/8/18	1020	Steady
4/10/18	1022	Steady
18/10/18	1024	Steady
1/11/18	1001	Steady
14/11/18	1022-1021	Falling
29/11/18	1002	Steady
11/12/18	1026	Steady
20/12/18	1003	Steady

6.4.4 The results of the 2018 gas monitoring are presented in Annex B.2. The table below presents Gas Screening Values (GSV) and the subsequent Characteristic Situation which have been calculated in accordance with CIRIA Guidance C665 (Ref 16C.10) for each gas monitoring well.

Table 6.8: Summary of Ground Gas Monitoring Results

Exploratory Hole	Max Flow Rate (l/hr)	Max Methane (% v/v)	Max Carbon Dioxide (% v/v)	Methane GSV	Carbon Dioxide GSV	Characteristic Situation
BH4	0.1	0	4.8	0	0.000048	1
BH4A	0	0	5.1	0	0	1
BH4D Shallow	1.1	0	10.6	0	0.1166	2
BH4D Deep	1.0	0	10.1	0	0.101	2
BH6	0.1	0	0.9	0	0.0009	1
BH7	0	0	4.1	0	0	1
BH10	0.1	0	1.5	0	0.0015	1
BH11	1.1	1.1	6.1	0.0121	0.0671	1
BH12B	0.1	0	3.6	0	0.0036	1
BH13	0.1	0.8	0.3	0.0008	0.0003	1
BH15	0	0	0.5	0	0	1
WS20	0	0	0.1	0	0	1
WS21	0	0	0.1	0	0	1
WS22	0	0	0.2	0	0	1

6.4.5 The above GSV's range between zero and 0.1166 and indicate most monitoring wells are classified as Characteristic Situation 1, with two locations (BH4D deep and BH4D shallow) being Characteristic Situation 2. However, BH4A, BH11 and possibly also BH4, BH7 and BH13 exhibit gas concentrations that could classify these as Characteristic Situation 2 should gas flow increase at these locations.

6.4.6 No gas protection measures above and beyond standard construction are required for the areas classified as Characteristic Situation 1. However, areas classified as Characteristic Situation 2 may require gas protection measures.

6.4.7 The results of the gas monitoring from the 2006 ground investigation (presented in Annex B.3) do not change this assessment of the Characteristic Situation.

6.4.8 The control room and plant room are located at an elevated position on the side of the bridge abutments. They will not have any direct contact with the ground and therefore are considered to not require gas protection measures.

6.5 Piling Risk Assessment

6.5.1 A Piling Works Risk Assessment has been prepared in accordance with the following Environmental Agency guidance and will be presented as Appendix 16D to the Environmental Statement (document reference 6.3);

- Piling in layered ground: risks to groundwater and archaeology. Environment Agency Science Report SC020074/SR (Ref 16C.20);
- Piling into contaminated sites. Environment Agency National Groundwater and Contaminated Land Centres (Ref 16C.21); and
- Piling and penetrative ground improvement methods on land affected by contamination: guidance on pollution prevention. Environment Agency (Ref 16C.22).

7 Waste Assessment

7.1 Hazardous Properties Assessment

7.1.1 A waste classification hazardous properties assessment has been carried out in accordance with the WM3 Technical Guidance (Ref 16C.23), to determine if the site soils contain any hazardous properties.

7.1.2 The soil chemical test results from the 2017/2018 ground investigation have been assessed and identified hazardous properties in six samples;

- BH6 at 0.5m bgl,
- BH7 at 0.8m bgl,
- WS3 at 0.3m bgl,
- BH4D at 3.9m bgl,
- BH10A at 2.9m bgl,
- BH17 at 0.5m bgl,

7.1.3 All of the above are in made ground and exhibit hazardous properties due to elevated either zinc, petroleum hydrocarbons, pH or speciated polyaromatic hydrocarbons or a combination of these.

7.1.4 A further 42 samples were highlighted as potentially hazardous due to the petroleum hydrocarbons.

7.1.5 Four samples recorded asbestos as loose fibres of chrysotile. Two of these samples underwent quantification testing, recording 0.016% (BH6 at 0.5m bgl) and <0.001% (BH6 at 1.0m bgl). BH6 at 0.5m may therefore also be classified as hazardous waste based on the asbestos content.

7.1.6 It may not be possible for material classified as hazardous to be reused in the Order Limits, Waste Catalogue (EWC) as ’17 05 03’ soil and stones containing dangerous substances.

7.1.7 Material classified as not containing hazardous properties is likely to be classified under the EWC as ’17 05 04’ soil and stones other than those mentioned in ‘17 05 03’.

7.1.8 Further testing will need to be carried out to confirm the waste classification of the material classified as potentially hazardous. No significant effects will occur as the material will have been earmarked for removal from site. The further testing is required to identify the appropriate disposal route.

Waste Acceptance Criteria Testing

7.1.9 Waste acceptance criteria (WAC) analysis has been carried out on a number of samples in order to assess the acceptability to landfill should offsite disposal be required. Two samples (WS9 at 1.4m and BH4D at 3.9m) recording hazardous or potentially hazardous properties and subjected to WAC testing failed the hazardous waste criteria for loss on ignition (LOI) and total organic carbon (TOC).

7.1.10 Seven samples subjected to WAC testing recorded no hazardous properties. Six of these pass the inert waste criteria, but one sample (BH4A at 2.1m) fails the inert waste criteria for sulphate and total dissolved solids (TDS) and may require disposal as non-hazardous waste if the material is surplus to the scheme.

7.1.11 In addition, five samples were subjected to WAC testing but without a hazardous properties assessment. Of these, one (BH8 at 1.0m) fails the hazardous waste criteria for total organic carbon and one (WS20 at 3.1m) fails the inert waste criteria for chloride.

7.1.12 The construction Contractor will need to make their own assessment of the waste classifications.

8 Refined Conceptual Site Model

8.1 Introduction

8.1.1 This section provides a refinement of the preliminary CSM from the Interpretative Environmental Desk Study Report (presented as Appendix 16B within the Environmental Statement). From the information identified during the ground investigation and the risk assessments detailed in Section 6 above, plausible source-pathway-receptor contaminant linkages have been refined in line with industry good practice (principally CLR11 (Ref 16C.5)).

8.1.2 The refined CSM provides an updated understanding of the Principal Application Site based on the findings of the site investigation and analytical results and draws on the ground, hydrogeological and contamination models which are presented in Sections 4, 5 and 6. It has been used to inform the quantitative risk assessments undertaken in Section 6 in the context of a future land use comprising a new highway layout, bridge and associated landscaping and hard standing.

8.2 Plausible Contaminant Linkages

8.2.1 Table 8.1 provides a revised evaluation of the potential contaminant linkages that were considered to be plausible for the future use of the Principal Application Site. It uses the current site investigation findings to refine the Phase 1 assessment.

Table 8.1: Summary of Plausible Contaminant Linkages

Potential Contaminants	Potential Pathways	Potential Receptors	Comments
Free asbestos fibres in made ground soil	Inhalation of asbestos fibres.	Future site users Future maintenance workers	Extensive hard standing will restrict exposure following construction but exposure during construction and during maintenance works cannot be discounted. The presence of asbestos elsewhere within the made ground cannot be discounted therefore if made ground materials are placed in landscaping areas, a capping layer will also need to be considered to minimise the risk to site users and adjacent site users from inhalation of fibres.
Contaminants in soil	Dermal contact, ingestions and inhalation of contaminated made ground, soil particles and fugitive dust.	Future site users Future maintenance workers	Detected potential contaminants limited to benzo-a-pyrene (2 locations), pH (ten locations) and lead (one location).

Potential Contaminants	Potential Pathways	Potential Receptors	Comments
			Extensive hard standing will restrict exposure at most locations except where landscaping is proposed.
Leachable contaminants and contaminants in groundwater	Vertical leaching from impacted soil and lateral migration of impacted groundwater derived from on-site sources.	Superficial Secondary (A) aquifers and bedrock Principal Aquifer. River Yare surface water	Groundwater appears to have been impacted slightly by inorganic determinands and at a few locations (principally WS22) by hydrocarbons. There is a theoretical risk to surface waters from leachable contaminants in soil including limited hydrocarbon exceedances. Extensive hard standing will limit rainfall percolation and leachate potential and the identified exceedances of the WQS criteria are generally not significantly elevated. Whilst a potential contaminant linkage has been identified, an unacceptable risk to

Potential Contaminants	Potential Pathways	Potential Receptors	Comments
			controlled waters is considered unlikely. However, the hydrocarbons identified in WS22 will need to be assessed once all the groundwater monitoring visits are complete.

9 Conclusions

9.1 Ground Conditions

9.1.1 The ground investigation encountered made ground across most locations. The encountered underlying Superficial geology comprised clay and silt of the Tidal River or Creek Deposits, sand of the North Denes Formation, granular, cohesive or peat material of the Breydon Formation, sand of the Happisburg Formation. Bedrock geology was encountered at depth and comprised sand of the Crag Group and below that, clay of the London Clay.

9.1.2 Made ground was recorded at almost all exploratory locations, varied in proven thickness from 0.4m to 4.8m and was generally granular and heterogeneous in nature.

9.1.3 Solid concrete was encountered at most locations in the eastern area and was recorded up to 0.65m thick. However, only a few locations in the western area encountered concrete up to 0.5m thick.

9.1.4 Other than the man-made detritus recorded within the made ground, olfactory evidence of contamination was recorded at only a few locations as hydrocarbon odour or sulphurous odour. No hydrocarbon sheen or free phase product was recorded on the Engineer's logs.

9.1.5 The ground investigation confirmed the presence of shallow groundwater which is likely to be in hydraulic continuity with the River Yare.

9.2 Environmental / Contamination Assessment

9.2.1 The following contamination issues have been identified:

- Asbestos was recorded by the chemical testing laboratory at four locations as loose fibres of chrysotile. The potential for more asbestos containing materials to be present within made ground materials cannot be discounted and the construction Contractor should take necessary precautions to protect their staff, site users and adjacent site users as set out in the Outline Code of Construction Practice (Outline CoCP) (document reference 6.16).
- Natural ground has recorded exceedances of the human health GAC values for pH.
- Made ground has recorded exceedances of the human health GAC values for pH benzo(a)pyrene and lead.

- There have been several exceedances (for a number of determinants) of the conservative generic WQS screening values in the groundwater and soil leachate samples tested. The groundwater test results indicate that some impact to controlled waters has already occurred but it is considered unlikely that the proposed scheme will have an adverse impact on controlled waters. The soil leachability results indicate the soils have the theoretical potential to generate leachate but the impact is unlikely to be significant.
- Gas monitoring data indicates ground gas has been recorded at concentrations that may require specific gas protection measures up to Characteristic Situation 2, depending upon the location and design of any control buildings or structures. The control room and plant room are at an elevated location on the side of the bridge abutments and therefore do not have any direct contact with the ground. Gas protection measures are therefore not considered to be necessary for these two spaces.

9.3 Outline Remedial Measures

9.3.1 Potential risks to future site users from asbestos within made ground have been identified and the possibility of made ground at the Principal Application Site containing further asbestos cannot be ruled out. If the known asbestos locations are to be exposed / disturbed during construction or will be exposed at the surface in final landscaping areas, further sampling and assessment at these locations will need to be undertaken by the construction Contractor and if necessary, consideration should be given to excavating and removing this material from the Principal Application Site. The same will apply if further presence of asbestos is observed during the construction works. Measures are set out in the interim Outline CoCP (document reference 6.16) and will form part of the full CoCP.

9.3.2 Other potential human health risks were identified. These are mitigated to acceptable levels where construction of the road will break the pathway. However, in areas where landscaping or the MIND site allotments are proposed, it is considered that placement of an inert subsoil and topsoil capping underlain by a geotextile (to delineate the made ground / capping interface and to minimise mixing of the soils) may be necessary (in particular in the proposed allotment area). Discussion with the Regulators at detailed design stage will be required to agree the scope of any capping. Measures are set out in the interim Outline CoCP (document reference 6.16) and will form part of the full CoCP.

9.3.3 Groundwater extracted from excavations during construction is likely to require treatment prior to discharge and the exact details of this will need to be confirmed by the Contractor depending upon their chosen disposal route.

Measures are set out in the Outline CoCP (document reference 6.16) and will form part of the full CoCP.

9.4 Construction Considerations

9.4.1 Protection of construction workers, site users and adjacent site users from airborne dust generated from made ground during construction will be required and measures are set out in the Outline CoCP (document reference 6.16) and will form part of the full CoCP.

9.4.2 The construction Contractor will need to keep a 'watching brief' for unforeseen contamination including hydrocarbons and asbestos. Hydrocarbon odours were identified during the ground investigation, but chemical testing did not record any elevated concentrations at those locations.

9.5 Operation Considerations

9.5.1 Long term risks associated with contamination are dealt with in the outline remedial measures sub-section above. No additional remedial measures are therefore necessary during operation of the Scheme.

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