

# **Great Yarmouth Third River Crossing**

## **Application for Development Consent Order**

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### **Document 6.2: Environmental Statement Volume II: Technical Appendix 16D: Piling Works Risk Assessment**

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**Planning Act 2008**

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

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# 1 Introduction

## 1.1 Authorisation

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- 1.1.1 This PWRA has been produced to support the design and Development Consent Order (DCO) process for the construction of a third river crossing over the River Yare at Great Yarmouth ("the Scheme").

## 1.2 Site Information

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- 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 underpass for existing businesses, enabling the new dual carriageway road to rise westwards towards the crest of the new crossing.

- 1.2.2 If constructed, the Scheme would comprise the following principal elements:

- a new dual carriageway road, crossing the River Yare in an east-west orientation, comprising of:
  - A new double-leaf bascule bridge providing an opening span to facilitate vessel movement within the river. This would include structures to support and accommodate the operational requirements of the bridge-opening mechanism, including counterweights below the level of the bridge deck. The bridge would be supported on driven piles;
  - New substructures, supported by driven piles, to support the double leaf bascule bridge within the existing quays either side of the river and within the river itself, requiring new permanent "knuckle" walls, creating cofferdams in the waterway to accommodate their construction;
  - A new five-arm roundabout connecting the new dual carriageway road with Suffolk Road, William Adams Way and the western end of Queen Anne's Road. Sections of the new five arm roundabout

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would be supported on driven piles where deep soft ground is encountered;

- A single-span bridge over Southtown Road, with reinforced earth embankments joining that bridge to the new roundabout at William Adams Way. Southtown Road bridge and the reinforced earth embankments would be supported on driven piles;
  - A single-span bridge to provide an underpass on the eastern side of the river, with reinforced earth embankments joining that single span bridge to South Denes Road. The underpass and reinforced earth embankments would be supported on driven piles; and
  - A new signalised junction connecting the new road with A1243 South Denes Road.
- The closure of Queen Anne's Road, at its junction with Suffolk Road, and the opening of a new junction onto Southtown Road providing vehicular and pedestrian access to residential properties and the MIND Centre and Grounds at the eastern end of Queen Anne's Road;
  - Revised access arrangements for existing businesses onto the local highway network;
  - Dedicated provision for cyclists and pedestrians which ties into existing networks;
  - Implementation of part of a flood defence scheme along Bollard Quay that is proposed to be promoted by the Environment Agency, and works to integrate with the remainder of the flood defence scheme;
  - A control tower structure located immediately south of the crossing on the western side of the river. The control tower would facilitate the 24/7 operation of the opening span of the new double-leaf bascule bridge;
  - A plant room located on the eastern side of the river for the operation of the opening span of the new double-leaf bascule bridge;
  - The demolition of an existing footbridge on William Adams Way;
  - Associated changes, modifications and/or improvements to the existing local highway network;
  - Additional signage, including Variable Message Signs (VMS) at discrete locations, to assist the movement of traffic in response to network conditions and the openings / closings of the double-leaf bascule bridge;
  - The relocation of existing allotments to compensate for an area to be lost as a result of the Scheme and other works, including those at the MIND Centre and Grounds; and
  - New public realm, landscape, ecology and sustainable drainage measures.

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### 1.2.3 The Scheme also includes works to facilitate the construction, operation and maintenance of the above elements including:

- Creation of temporary construction sites and accesses from the public highway;
- Provision of new utilities and services and the diversion of existing utilities;
- Provision of drainage infrastructure, lighting and landscaping;
- Demolition of a number of existing residential and commercial / business properties; and
- Provision of vessel waiting facilities to the north and south of the new crossing, either as floating pontoons or additional fendering to the existing berths, including any dredging and quay strengthening works that may be required.

## 1.3 Objectives

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### 1.3.1 The objective of this PWRA is to assess the potential risks to human health and controlled waters associated with piling through the Made Ground into the underlying natural strata and Principal Aquifer. This report also provides a brief summary of the ground and groundwater conditions encountered during the recent ground investigation works, as reported in:

- WSP Interpretative Environmental Ground Investigation Report, Great Yarmouth Third River Crossing prepared by WSP UK Ltd dated March 2019 (Appendix 16C of the Environmental Statement).

## 1.4 Previous Reports

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### 1.4.1 The Principal Application Site has been the subject of a ground investigation (GI) undertaken between September 2017 and July 2018 by Norfolk Partnership Laboratory (NPL) who are the Applicant's appointed Sub-Contractor. Piling will only be occurring within the Principal Application Site. No piling is to be carried out within the Satellite Application Sites.

### 1.4.2 The following reports have been produced by WSP UK Ltd in relation to the contaminated land aspects of the Scheme:

- 
- Interpretative Environmental Desk Study Report, ref. 70046035-EGS-0001 dated March 2019 (Appendix 16B of the Environmental Statement)
  - Interpretative Environmental Ground Investigation Report, ref. 70046035-EGS-0002 dated March 2019 (Appendix 16C of the Environmental Statement)

**1.4.3** Information provided in Sections 2 and 3 of this report has been reproduced from the above reports.

## **1.5 Assessment**

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**1.5.1** The Applicants Construction Contractor has tendered a design that has identified that the following piling techniques will be adopted for the Scheme:

- Combi piles comprising driven open toe steel tube and interconnecting driven steel sheet piles to form the bridge abutment cofferdam. These will transfer the bridge load through the made ground and superficial deposits into the underlying Crag Formation.
- Pre-cast concrete driven piles for the highway embankment approaches to the bascule bridge. These will transfer the embankment load through the made ground into the underlying superficial deposits.

**1.5.2** The PWRA has been carried out with consideration to the guidance and information provided in the following documents:

- Piling in layered ground: risks to groundwater and archaeology. Environment Agency (October 2006) (Ref 16D.1);
- Piling into contaminated sites. Environment Agency National Groundwater and Contaminated Land Centres (February 2002) (Ref 16D.2); and
- Piling and penetrative ground improvement methods on land affected by contamination: guidance on pollution prevention. Environment Agency (May 2001) (Ref 16D.3).



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## 2 Site Setting

### 2.1 Site History

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- 2.1.1** Piling is only occurring within the Principal Application Site. For the purposes of this piling report to enhance clarity when discussing the ground conditions and historical uses, the Principal Application Site has been split in two, bisected by the River Yare – referred to as the eastern area and western area.

### 2.2 Eastern Area

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- 2.2.1** 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.

### 2.3 Western Area

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- 2.3.1** 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 malhouses. Beyond, towards the western boundary of the study area was agricultural land.
- 2.3.2** 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.
- 2.3.3** 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.

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## 2.4 Surrounding Land Uses

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2.4.1 Immediate neighbouring land uses were as follows at the time of the Environmental Desk Study Report dated March 2019 (Appendix 16B of the Environmental Statement):

- North – Predominantly commercial / industrial with some residential properties on the west side of the river and predominantly residential with a few commercial / industrial 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 / industrial properties and a recreation ground on the west side of the river.
- West – Commercial / industrial properties.

## 2.5 Environmental Setting

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### Published Geology

2.5.1 The regional BGS 1:50,000 geological map and information available on the BGS on-line Geology of Britain Viewer ([www.bgs.ac.uk](http://www.bgs.ac.uk)) indicates the Superficial Geology immediately underlying the Principal Application Site within the Order Limits varies as follows:

- 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.

2.5.2 Bedrock geology is indicated to be the Crag Group (sand and gravel) across the Principal Application Site.

### Hydrogeology

2.5.3 The North Denes Formation superficial deposits underlying the red-line boundary 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.

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- 2.5.4 The peat and clay / silt superficial deposits underlying the Principal Application Site to the west of the River Yare are classified as unproductive.
  - 2.5.5 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.
  - 2.5.6 The nearest active groundwater abstraction is approximately 71m to the north west of the red-line boundary and is for laundry use.
  - 2.5.7 The Principal Application Site is not within a Source Protection Zone.

### Hydrology

- 2.5.8 The River Yare splits the red-line boundary 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.
- 2.5.9 No surface water or potable water abstractions are present within 2km of the Order Limits.

## 2.6 Ground Investigation

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- 2.6.1 The ground investigation undertaken in 2017/2018 by Norfolk Partnership Laboratory (NPL) generally confirmed the anticipated geological sequence above and is summarised below. Full details of the ground investigation works undertaken and the ground conditions encountered are presented in the WSP Interpretative Environmental Ground Investigation Report (Appendix 16C of the Environmental Statement).
- 2.6.2 Exploratory hole locations are indicated on the drawing entitled Exploratory Hole Locations Figure 16.1 reference GYTRC-WSP-EGN-XX-DR-EN-0047 presented in Volume 3 of the Environmental Statement.

### Made Ground Eastern Area

- 2.6.3 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.
- 2.6.4 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**

- 2.6.5 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.
- 2.6.6 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.
- 2.6.7 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.
- 2.6.8 WS4 at 2.3m and WS5 at 1.85m recorded a geogrid structure.

### **Concrete and Underground Structures**

- 2.6.9 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.
- 2.6.10 Tarmac up to 0.2m thick was recorded at a few locations in the western area but was absent from the eastern area.
- 2.6.11 No pipes or underground structures were recorded on the Engineer's logs.

### **Natural Strata**

#### Tidal River or Creek Deposits

- 2.6.12 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.
- 2.6.13 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.

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### North Denes Formation

- 2.6.14 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.
- 2.6.15 The Formation was recorded at a maximum depth of 5.6m below ground level (bgl) 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

- 2.6.16 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.
- 2.6.17 The Breydon Formation can be recognised as separate interbedded substrata and these are described below.

### Breydon Peat

- 2.6.18 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.
- 2.6.19 The Peat was found to a maximum depth of 11.9m bgl in BH2, with thickness ranging between 0.25m to 3.66m.
- 2.6.20 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

- 2.6.21 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

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vary from 0.1m to 1.0m in the eastern area and from 0.1m to a maximum of 5.1m in the western area.

- 2.6.22 The silts and clays were encountered between 0.3m and 4.0m bgl in the western area, and between 2.60m and 4.50m bgl in the eastern area.

#### Breydon Sand and Gravel

- 2.6.23 The granular component of the Breydon Formation 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.
- 2.6.24 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 and to a maximum depth of 6.50m bgl
- 2.6.25 The granular material in the western area was encountered in layers ranging between 0.10m and 4.00m thick, the top of which was found at depths of 0.85m bgl to 11.40m bgl. The base of the strata was found up to a maximum depth of 13.00m bgl

#### Breydon Formation (Stratum A)

- 2.6.26 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 and gravel, where the gravels are fine to medium, angular to rounded flint and quartz with some rare limestone gravels and shells.
- 2.6.27 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 and in the eastern area at depths of between 3.20m bgl to 11.70m bgl
- 2.6.28 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

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

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- 2.6.30** 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.
- 2.6.31** The formation was encountered in the western area at depths ranging between 5.00m bgl to 13.00m bgl 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 ranging in thickness between 3.00m and 12.00m.

#### Crag Group

- 2.6.32** 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.
- 2.6.33** This stratum was encountered at depths ranging between 15.85m bgl and 22.80m bgl 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

- 2.6.34** 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.
- 2.6.35** The London Clay was encountered at depths ranging between 44.00m bgl to 46.50m bgl and the base was not confirmed in any boreholes.

#### **Visual and Olfactory Evidence of Contamination**

- 2.6.36** 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 of the Interpretative Ground Investigation Report (Appendix 16C of the Environmental Statement).



*Table 2.1: Summary of Visual and Olfactory Evidence of Contamination*

	Exploratory Hole reference	Comment	Strata Type (identified on Engineer's logs)	Impacted Strata Depth (m bgl)
<b>Eastern Area</b>	WS21	Hydrocarbon odour	Alluvium	1.4m – 2.0m
	WS21	Hydrocarbon odour	Alluvium	2.5m – 2.95m
	BH14	Diesel odour	Alluvium	2.6m
	BH14	Slight diesel odour	North Denes Formation	7.6m – 8.0m
<b>Western Area</b>	BH6	Slight hydrocarbon odour	Made ground	0.4m – 1.2m
	BH4BU	Hydrogen sulphide odour	Breydon Formation	2.65m – 2.85m

### Marine Sediments

**2.6.37** The Engineer's logs for the marine boreholes presented in Annex C of the Interpretative Environmental Ground Investigation Report (Appendix 16C of the Environmental Statement) 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.



## 3 Contamination Assessment

- 3.1.1 This Section summarises the findings of human health, controlled waters and ground gas risk assessments. Full details are presented in the WSP Interpretative Environmental Ground Investigation Report (ref. 70046035-EGS-0002) dated March 2019 (Appendix 16C of the Environmental Statement).

### 3.2 Human Health Risk Assessment

- 3.2.1 The chemical test results were screened against both a public open space and a commercial / industrial end use. Whilst both are considered to be conservative these are the two closest standard scenarios for the type of site ie highway with landscaping areas accessible by the general public.

#### Assessment of Results – Public Open Space End Use Scenario

- 3.2.2 Evidence of hydrocarbons (diesel) was identified at three locations during the ground investigation as detailed in Table 2.1 above. Two of these three locations were targeted for chemical testing and none of the results exceeded the Generic Assessment Criteria (GAC) derived for hydrocarbons using a Public Open Space (POS) scenario. 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)

- 3.2.3 The following Contaminants of Concern (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)

- 3.2.4 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)

- 3.2.5 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)

**3.2.6** 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,
- 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.
- 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.

#### **Assessment of Results – Commercial / Industrial End Use Scenario**

**3.2.7** Evidence of hydrocarbons (diesel) was identified at three locations during the ground investigation as detailed in Table 2.1 above. Two of these three locations were targeted for chemical testing and none of the results exceeded the GAC derived for hydrocarbons using a Commercial / Industrial end use scenario. 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)

**3.2.8** 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)

**3.2.9** 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)

3.2.10 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)

3.2.11 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.

### **Discussion**

3.2.12 Asbestos has been identified at four shallow locations and is therefore likely to be encountered during the earthworks. Most of the other exceedances will 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 may need further assessment if this material is likely to be disturbed during construction.

## **3.3 Controlled Waters Risk Assessment**

### **Risks to Aquifer**

#### Soil Leachability Testing

3.3.1 Generic screening of 31 soil leachate test results from the ground investigation was undertaken against Water Quality Standards (WQS). The exceedances are summarised in the table below.

*Table 3.1: Summary of Potential Leachate Risks to the Aquifer*

Determinand	WQS	Number of Exceedences	Range of Values Recorded
<b>Alkaline pH</b>	>10	1	11.18
<b>Acid pH</b>	<6.5	1	6.22
<b>Ammoniacal Nitrogen</b>	0.389mg/l	11	0.39mg/l to 5.08mg/l
<b>Total Cyanide</b>	0.005mg/l	6	0.006mg/l to 0.021mg/l
<b>Arsenic</b>	10µg/l	6	13µg/l to 37µg/l
<b>Lead</b>	10µg/l	12	14µg/l to 145µg/l
<b>Nickel</b>	20µg/l	1	61µg/
<b>Selenium</b>	10µg/l	1	20µg/l
<b>Benzo(a)pyrene</b>	0.01µg/l	3	0.03µg/l to 0.13µg/l
<b>Sum of four polyaromatic hydrocarbons</b>	0.1µg/l	2	0.23µg/l to 0.34µg/l

**3.3.2** 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 Sampling

**3.3.3** Generic screening of groundwater test results from the fourteen monitoring visits identified WQS exceedences for the following determinands but not from every sample on every monitoring visit.

- pH
- Ammoniacal nitrogen
- Sulphate
- Free cyanide
- Total cyanide
- Arsenic
- Boron
- Benzo(a)pyrene

- Sum of four speciated Polyaromatic Hydrocarbons
- Aromatic C10-C12
- Aromatic C12-C16
- Aromatic C16-C21

3.3.4 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.

3.3.5 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:

- 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.
- Sulphate exceeds the WQS by one order of magnitude in a few samples; BH7, BH4D (deep), BH11, BH13 and BH4.
- Arsenic exceedances are no more than one order of magnitude higher than the WQS and are generally recorded in BH7, BH4D (shallow), BH15, but also in BH4D (deep), BH13, BH11, WS20, WS21 and WS22 on occasions.
- 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.
- 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.
- 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.

### Risks to River Yare Surface Water

#### Soil Leachability Testing

- 3.3.6** Generic screening of 31 soil leachate test results from the ground investigation was undertaken against Water Quality Standards (WQS). The table below summarises the exceedences.

*Table 3.2: Summary of Potential Leachate Risks to Surface Waters*

Determinand	WQS	Number of Exceedences	Range of Values Recorded
<b>Cyanide</b>	0.001mg/l	6	0.006mg/l to 0.021mg/l
<b>Arsenic</b>	25µg/l	1	37µg/l
<b>Copper</b>	3.76µg/l	18	4µg/l to 80µg/l
<b>Nickel</b>	8.6µg/l	1	11µg/l
<b>Mercury</b>	0.07µg/l	1	0.1µg/l
<b>Lead</b>	1.3µg/l	23	2µg/l to 145µg/l
<b>Zinc</b>	6.8µg/l	21	7µg/l to 644µg/l
<b>Anthracene</b>	0.1µg/l	1	0.13µg/l
<b>Benzo(a)pyrene</b>	0.00017µg/l	3	0.03µg/l to 0.13µg/l
<b>Fluoranthene</b>	0.0063µg/l	21	0.02µg/l to 0.2µg/l
<b>Naphthalene</b>	2µg/l	1	3.75µg/l
<b>Bis(2-ethylhexyl)phthalate</b>	1.3µg/l	1	4µg/l
<b>Phenol</b>	7.7µg/l	1	11µg/l
<b>Aromatic hydrocarbons C<sub>8</sub>-C<sub>10</sub></b>	20µg/l	1	21µg/l
<b>Aromatic hydrocarbons C<sub>12</sub>-C<sub>16</sub></b>	2µg/l	1	11µg/l

- 3.3.7 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 Sampling

- 3.3.8 Generic screening of groundwater test results from the 14 monitoring visits identified WQS exceedances for the following determinands but not from every sample on every monitoring visit.
- Free cyanide
  - Total cyanide
  - Arsenic
  - Copper
  - Mercury
  - Zinc
  - Anthracene
  - Benzo(a)pyrene
  - Fluoranthene
  - Phenol
  - Trichloroethene
  - Aromatic C9-C10
  - Aromatic C10-C12
  - Aromatic C12-C16
  - Aromatic C21-C35
- 3.3.9 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, as detailed below:
- 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.

- 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).
- 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.
- 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 visits generally did not.
- 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.
- 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).

### Discussion

- 3.3.10 The ground investigation recorded some olfactory evidence of hydrocarbons in WS21, BH14 and BH6.
- 3.3.11 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.



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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.

- 3.3.12** 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.
- 3.3.13** 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.
- 3.3.14** 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.
- 3.3.15** 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.

## **3.4 Groundwater Levels**

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- 3.4.1** Monitoring of groundwater levels in relation to Ordnance Datum was undertaken on eight occasions following the completion of the intrusive ground investigation works and the data is summarised in Tables 3.3 and 3.4 below.
- 3.4.2** The tables 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 ground water cannot be confirmed.

*Table 3.3: Summary of Ground Water Level Monitoring in the Eastern Study Area*

Stratum	Minimum (mOD)	Maximum (mOD)	Observations
<b>Made Ground</b>	-	-	No standalone monitoring wells within the made ground
<b>Natural Ground</b>	-0.18	0.77	-

*Table 3.4: Summary of Ground Water Level Monitoring in the Western Study Area*

Stratum	Minimum (mOD)	Maximum (mOD)	Observations
<b>Made Ground</b>	-1.66	0.09	-
<b>Natural Ground</b>	-0.33	0.19	-

### Hydraulic Gradient

- 3.4.3 The groundwater 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

- 3.4.4 The superficial deposits are likely to be in hydraulic continuity with the Crag Group due to the absence of any continuous low permeable strata separating these aquifers.
- 3.4.5 Similar groundwater quality characteristics across the Principal Application Site and the proximity to the tidally influenced River Yare also indicate that the mixing of groundwater between the superficial deposits and the Crag Group is likely to be occurring.
- 3.4.6 The regional Chalk Group aquifer is essentially 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.

### Assessment of Saline Intrusion

- 3.4.7 The two most recent sets (14th November and 29th November 2018) 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. It is noted that pile materials should take into account the potential presence of saline water.

### 3.5 Ground Gas Risk Assessment

**3.5.1** 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,
- 20th December 2018 – only BH7 was monitored on this occasion.

**3.5.2** A control building and a plant room will be constructed as part of the bridge and therefore this gas assessment will inform the design of those buildings.

**3.5.3** Atmospheric pressure varied as summarised in Table 3.5 below during the monitoring period:

*Table 3.5: Summary of Atmospheric Pressure Recorded during Gas Monitoring Visits*

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

**3.5.4** The results of the gas monitoring are presented in Annex B.1 of the Interpretative Environmental Ground Investigation Report (Appendix 16C of the Environmental Statement). The table below presents Gas Screening

Values (GSV) which have been calculated in accordance with C665 for each gas monitoring well.

*Table 3.6: 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
<b>BH4</b>	0.1	0	4.8	0	0.000048	1
<b>BH4A</b>	0	0	5.1	0	0	1
<b>BH4D Shallow</b>	1.1	0	10.6	0	0.1166	2
<b>BH4D Deep</b>	1.0	0	10.1	0	0.101	2
<b>BH6</b>	0.1	0	0.9	0	0.0009	1
<b>BH7</b>	0	0	4.7	0	0	1
<b>BH10</b>	0.1	0	1.5	0	0.0015	1
<b>BH11</b>	1.1	1.1	6.1	0.0121	0.0671	1
<b>BH12B</b>	0.1	0	3.6	0	0.0036	1
<b>BH13</b>	0.1	0.8	0.3	0.0008	0.0003	1
<b>BH15</b>	0	0	0.5	0	0	1
<b>WS20</b>	0	0	0.1	0	0	1
<b>WS21</b>	0	0	0.1	0	0	1
<b>WS22</b>	0	0	0.2	0	0	1

**3.5.5** 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.

**3.5.6** No gas protection measures above and beyond standard construction are required for the areas classified as Characteristic Situation 1 whereas areas classified as Characteristic Situation 2 are likely to require gas protection measures. However, the only buildings to be constructed on the Principal Application Site (control room and the plant room) are both located on the bridge abutments above ground level, cantilevered from the sides of the abutments. It is therefore considered that no pathway exists for ground gas to migrate into either of these proposed buildings and hence no gas protection measures are required for the design.

## 4 Conceptual Site Model

### 4.1 Introduction

- 4.1.1** This Section summarises the Conceptual Site Model (CSM) from the WSP Interpretative Environmental Ground Investigation Report (Appendix 16C of the Environmental Statement). Plausible source-pathway-receptor contaminant linkages have been refined in line with industry good practice (principally CLR11 (Ref 16D.4)).
- 4.1.2** Table 4.1 provides the potential contaminant linkages that are considered to be plausible for the future use of the Principal Application Site. Where mitigation measures are proposed in the table below, these are detailed in the outline CoCP (document reference 6.16) and secured via a requirement in the DCO.

*Table 4.1: Summary of Plausible Contaminant Linkages*

Potential Contaminants	Potential Pathways	Potential Receptors	Comments
<b>Free asbestos fibres in made ground soil</b>	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

Potential Contaminants	Potential Pathways	Potential Receptors	Comments
			from inhalation of fibres.
<b>Contaminants in soil</b>	Dermal contact, ingestion and inhalation of contaminated made ground, soil particles and fugitive dust.	Future site users Future maintenance workers	<p>Detected potential contaminants limited to benzo-a-pyrene (2 locations), pH (ten locations) and lead (one location).</p> <p>Extensive hard standing will restrict exposure at most locations except where landscaping is proposed where an inert capping will be required.</p>
<b>Leachable contaminants and contaminants in groundwater</b>	Vertical leaching from impacted soil and lateral migration of impacted groundwater derived from on-site sources.	<p>Superficial Secondary (A) aquifers and bedrock Principal Aquifer.</p> <p>River Yare surface water</p>	<p>Groundwater appears to have been impacted slightly by inorganic determinands and at a few locations (principally WS22) by hydrocarbons.</p> <p>There is a theoretical risk to surface waters from leachable contaminants in soil including minor hydrocarbon exceedances.</p> <p>Extensive hard standing will limit rainfall percolation and leachate potential and the identified exceedances of the</p>



Potential Contaminants	Potential Pathways	Potential Receptors	Comments
			<p>WQS criteria are generally not significantly elevated.</p> <p>Whilst a potential contaminant linkage has been identified, an unacceptable risk to controlled waters is considered unlikely to occur due to the limited contamination identified.</p>

## 5 Piling Risk Assessment

### 5.1 Pile Type and Method

- 5.1.1 Due to the inherently variable nature of the Made Ground, the soft compressible nature of the Superficial deposits including Breydon Peat and Tidal River and Creek Deposits and the high loads required to support the structures, piled foundations are considered the most appropriate technique for the Scheme.
- 5.1.2 The Applicant's construction Contractor's tender design has identified that the following techniques will be adopted at the Scheme:
- Combi piles comprising driven open toe steel tube and interconnecting driven steel sheet piles to form the bridge abutment cofferdam. These will transfer the bridge load through the made ground and superficial deposits into the underlying Crag Formation.
  - Pre-cast concrete driven piles for the highway embankment approaches to the bascule bridge. These will transfer the embankment load through the made ground into the underlying superficial deposits.
- 5.1.3 Driven piles provide the most effective solution for the ground conditions present on the Applicant Site (ie. predominantly granular soils). Bored piles would not be as suited to the ground conditions present due to the risk of 'blowing sands' and disturbance of the sands at the pile toe which could compromise the integrity of the bridge foundations. Driven piles also avoid the need for disposal of pile arisings and the use of drillings fluids such as bentonite hence eliminating the risk of pile arisings and spillages entering the River Yare. Noise and vibration from driven piles present a nuisance risk due to the proximity of residential properties and businesses and will need to be adequately mitigated by selection of appropriate driving heads and vibratory plant.
- 5.1.4 Driven piles can introduce preferential migration pathways due to the smooth surface of the piles (in the case of the proposed precast concrete and steel tubes). However, due to the limited contamination (i.e no significant plumes of hydrocarbons, solvents or other mobile / leachable contaminants) identified at the proposed piling locations (highway embankments and bridge abutments), it is considered that an unacceptable risk to groundwater is unlikely to occur. It is also noted that vertical hydraulic continuity is likely to exist between the superficial deposits and the underlying Crag Group and hence piling will not introduce any new migration pathways.
- 5.1.5 Driven piles can also allow potentially contaminated soils to be dragged along the shaft of the pile or be pushed ahead of the pile toe while driving.



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However, this is not considered to represent an unacceptable risk due to the limited contamination identified at the piling locations.

### Design Responsibility

- 5.1.6 Specific pile design is the responsibility of the specialist contractor who will complete the detailed design of the Scheme based on the available ground information, the loads to be carried, the preferred construction sequence and their own proprietary techniques.
- 5.1.7 As detailed in the outline CoCP (document reference 6.16) and secured via CoCP Requirements, the detailed piling design will follow regulatory guidance and take full cognisance of any contaminated soils and groundwater identified on the Principal Application Site. Appropriate site management and pile installation quality control measures will be in place during pile installation.

## 5.2 Pollution Scenarios and Mitigation Measures

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- 5.2.1 Environment Agency guidance document 'Piling and Penetrative Ground Improvement Methods on Land Affected by Contamination: Guidance on Pollution Prevention' (2001) (Ref 16D.3) presents guidance on the potential environmental and human health risks associated with different piling techniques. Six possible pollution scenarios are identified and described, representing situations where there is concern that piling or penetrative ground improvement operations have potential to cause a risk to receptors:

**Scenario 1** - Creation of preferential pathways, through a low permeability layer (an aquitard), to allow potential contamination of an underlying aquifer;

**Scenario 2** - Creation of preferential pathways, through a low permeability surface layer, to allow upward migration of landfill gas, soil gas, or contaminant vapours to the surface;

**Scenario 3** - Direct contact of site workers and others with contaminated soil arisings which have been brought to the surface;

**Scenario 4** - Direct contact of the piles or engineered structures with contaminated soil or leachate causing degradation of pile materials (where the secondary effects are to increase the potential for contaminant migration);

**Scenario 5** - The driving of solid contaminants down into an aquifer during pile driving; and

**Scenario 6** - Contamination of groundwater and, subsequently, surface water by concrete, cement paste, or grout.

**5.2.2** Where potential contaminant linkages have been identified, mitigation measures have been outlined and these are detailed in the outline CoCP (document reference 6.16) which is secured by a requirement in the DCO. A summary of each pollution scenario is shown in Table 5.1 below. The identification of potential “contaminant linkages” is a key aspect of the evaluation of potentially contaminated land. An approach based on the UK CIRIA report C552 (Ref 16D.5) has been adopted within this table and the matrices used to generate the risk level are presented in Annex A.

**5.2.3** In view of the controlled waters contamination assessment and the absence of any significant soil based contamination summarised in Section 3 above, the potential for contamination of groundwater from the proposed piling activities is considered to be LOW.

**Pollution Scenario 1 – Creation of Preferential Pathways through an Aquitard, to Allow Potential Contamination of an Underlying Aquifer**

**5.2.4** It is assumed that piles would penetrate through made ground and be founded in either the superficial deposits (Secondary A aquifer) in the case of the precast driven piles supporting the embankment approaches or in the Crag Group in the case of the combi piles for the bridge support foundations. The soils encountered on site are predominantly granular with no continuous low permeability surface layers being identified and hence are likely to be in hydraulic continuity. Therefore, the proposed piling technique (ie. driven) is not considered to create new preferential pathways for any contamination present. It is also noted that only limited contamination has been identified at the proposed piling locations. Scenario 1 is considered to represent a low risk.

**Pollution Scenario 2 – Creation of Preferential Pathways through a Low Permeability Surface Layer, to Allow Upward Migration of Soil, Gas or Contaminant Vapours to the Surface**

**5.2.5** Piles have the potential to create a pathway for any soil gas or contaminant vapours to migrate to the surface. Gas monitoring undertaken and reported in the Interpretative Environmental Ground Investigation report (Appendix 16C of the Environmental Statement) identified that concentrations of methane and carbon dioxide are generally below threshold values (1.0% v/v and 5.0% v/v, respectively) with associated low flow rates once steady state has been reached. Based on the monitoring data, most monitoring locations are classified as Characteristic Situation 1 (Very low risk) with two locations being Characteristic Situation 2 (Low risk). Scenario 2 is considered to represent a low risk for the Principal Application Site due to the proposed end-use (bridge structure/ highway/ landscaping) and the absence of any significant concentrations of ground gas. The only proposed buildings (control room and plant room) are to be founded above ground level and

cantilevered off the side of the bridge abutments and therefore no gas pathway exists.

### **Pollution Scenario 3 – Direct Contact of Site Workers and others with Contaminated Soil Arisings that have been brought to the Surface**

- 5.2.6 WSP's Interpretative Environmental Ground Investigation report (Appendix 16C of the Environmental Statement) has identified only limited contamination present, mainly in the made ground deposits. All made ground was tested for the presence of asbestos and chrysotile fibres were identified in four soil samples (from BH6 and CPT3) located to the west of any proposed bridge supports. It is possible that asbestos fibres could be present in made ground in other areas of the Principal Application Site and hence shallow soils could pose a potential risk to construction workers and third parties.
- 5.2.7 On the basis that appropriate health and safety training, planning and monitoring will be in place for the works the risks are anticipated to be low and contractors will be made aware of the potential issues associated with coming into contact with potentially contaminated material. There will be no pile arisings due to the piling technique adopted by the Contractor.
- 5.2.8 The Contractor should ensure that all construction workers wear appropriate PPE/RPE and the application of mitigation measures such as the dust suppression are implemented in any areas where excavations are undertaken. It is considered that employing appropriate measures, wearing suitable PPE/RPE and the fact that site workers will have limited exposure to excavated soils will prevent Scenario 3 from being a significant concern and the risk is considered to be very low.

### **Pollution Scenario 4 – Direct Contact of the Piles or Engineered Structures with Contaminated Soil or Leachate Causing Degradation of Pile Materials (where the Secondary Effects are to Increase the Potential for Contaminant Migration)**

- 5.2.9 With regard to the potential for contaminated soil or leachate causing degradation of pile materials, appropriate chemical resistant concrete / steel should be employed for the piles in accordance with guidance provided in 'BRE Special Digest 1 Concrete in Aggressive Ground' (Ref 16.D.6) for all strata encountered. This is considered not to be a significant issue and should not pose lasting impact to the Principal Application Site or the wider environment. The pile type adopted by the Contractor (ie. driven steel tubes and precast concrete piles) will be fabricated off-site and result in improved quality control compared with cast in-situ concrete piles.
- 5.2.10 No Non-Aqueous Phase Liquid (NAPL) has been identified and as such the opportunity for degradation of piles is limited. However, consideration of pile material should be given during design and an appropriate material selected

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for use. The potential for degradation of materials under Scenario 4 is therefore considered to be low.

#### **Pollution Scenario 5 – The Driving of Solid Contaminants down into an Aquifer during Pile Driving**

- 5.2.11 There is a risk that potentially contaminated soils could be dragged along the shaft of the pile or be pushed ahead of the pile toe during pile driving due to the piling techniques adopted by the Contractor. However, Scenario 5 is considered to represent a low risk due to the limited contamination present.

#### **Pollution Scenario 6 – Contamination of Groundwater and Subsequently, Surface Waters by Concrete, Cement, Paste or Grout**

- 5.2.12 The driven piles selected by the Contractor (precast concrete and steel tubes) are fabricated off site and hence the risk of pollution by spillages of concrete or arisings during pile installation does not require further consideration. Good site practices should be employed to prevent escape of concrete, cement paste and grout, particularly with regard to spillages of such materials into the River Yare if any in-situ concreting is undertaken. Scenario 6 is therefore considered to represent a low risk assuming good site management practices.

### **5.3 Existing Infrastructure**

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- 5.3.1 Consideration will be given to the safeguarding of existing buried services, pursuant to the relevant draft protective provisions contained within the DCO (document reference 3.1).

### **5.4 Risk Matrix and Pollution Scenarios**

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- 5.4.1 Table 5.1 presents the risk matrix and pollution scenarios. Reference should be made to Annex A for a description of the methodology and risk descriptors.

*Table 5.1: Piling Works Risk Matrix with Pollution Scenarios*

Risk Scenario	Severity of Risk	Probability of Risk Occurring	Comments	Does the Pile Design Sufficiently Mitigate Risk?	Risk Level CIRIA 552
<b>1. Creation of preferential pathways through an aquitard.</b>	<b>Medium</b> - Pollution of sensitive controlled waters (surface waters or aquifers).	<b>Unlikely</b> – Proposed piles will likely be founded in the Crag Group but new preferential pathways are unlikely to be created as no continuous low permeable strata exist above the Crag Group. Also, it is noted that only limited contamination has been identified at the piling locations.	The shallow groundwater is already likely to be in hydraulic continuity with the Crag Deposits and hence the piles will not create an additional pathway	Yes	Low Risk
<b>2. Creation of preferential pathways through a low permeability surface layer allowing migration of soil gas or</b>	<b>Medium</b> - Chronic (long-term) risk to human health.	<b>Unlikely</b> - Gas monitoring undertaken identified that all levels of methane and carbon dioxide are generally below threshold values (1.0% v/v and 5.0% v/v, respectively) with associated negligible	Limited ground gas identified. No pathway exists as the only buildings proposed are not founded on the ground.	Yes	Low Risk

Risk Scenario	Severity of Risk	Probability of Risk Occurring	Comments	Does the Pile Design Sufficiently Mitigate Risk?	Risk Level CIRIA 552
contaminant vapours to the surface		flow rates once steady state has been reached.			
<b>3. Direct contact of site workers and others with contaminated soil arisings</b>	<b>Minor</b> - Requirement for protective equipment during site works to mitigate health effect.	<b>Unlikely</b> – Limited contamination of near surface soils identified; asbestos identified at 4 locations. There will be no soil arisings from the piling techniques adopted by the Contractor (ie. driven). Based on control measures, any contact with potential contaminated soils will be mitigated.	Appropriate control measures and correct selection of PPE/ RPE and training for staff will mitigate any risks from any contaminated soil encountered including asbestos.	Yes	Very Low Risk
<b>4. Direct contact of the piles or engineered structures with contaminated soil</b>	<b>Medium</b> – degradation of piles and structures.	<b>Unlikely</b> – No NAPL was identified. Appropriate chemical resistant concrete / steel will need to be employed for the piles in	Appropriate pile material selection required. The driven piles adopted by the Contractor will be	Yes	Low Risk

Risk Scenario	Severity of Risk	Probability of Risk Occurring	Comments	Does the Pile Design Sufficiently Mitigate Risk?	Risk Level CIRIA 552
or leachate causing degradation of materials		accordance with BRE Special Digest 1.	fabricated off-site under stringent quality control measures.		
<b>5. The pushing of solid contaminants down into an aquifer during pile driving</b>	<b>Medium</b> - Pollution of sensitive controlled waters (surface waters or aquifers).	<b>Unlikely</b> – Potential risk of any near surface contamination present being dragged along the pile shaft or being pushed ahead of the pile toe while driving. However, pollution is not considered likely due to limited contamination identified at piling locations.	Limited contamination identified at piling locations.	Yes	Low Risk
<b>6. Contamination of groundwater and subsequently, surface waters by wet concrete,</b>	<b>Medium</b> - Pollution of sensitive controlled waters (surface	<b>Unlikely</b> – The driven piles adopted by the Contractor will be fabricated off-site and hence spillages of concrete or arisings into the River Yare	If wet concrete, cement paste or grout is proposed, good site practice should be employed to avoid	Yes	Low Risk

Risk Scenario	Severity of Risk	Probability of Risk Occurring	Comments	Does the Pile Design Sufficiently Mitigate Risk?	Risk Level CIRIA 552
<b>cement paste or grout</b>	waters or aquifers).	during pile construction do not require further consideration.	spillages into the River Yare or impacting the aquifer.		



## 6 Conclusions and Requirements

### 6.1 Conclusions

- 6.1.1** Due to the inherently variable nature of the Made Ground and the soft, compressible, near surface soils, piles founded in the superficial deposits or Crag Group are considered the most appropriate solution for the proposed bascule bridge and the approach embankments. The Contractor has adopted driven piles; combi piles comprising steel tubes with interconnecting sheet piles for the bascule bridge foundations and precast concrete piles for the embankments. Limited contamination has been identified from analysis of soils, leachate and groundwater results (mainly in the near surface soils) but it is noted that the near surface soils are likely to be in hydraulic continuity with the Principal Aquifer (Crag Group) at depth so the use of piles will not create additional pathways for migration of any contamination present.
- 6.1.2** A detailed review of the groundwater levels and also the chemical composition of groundwater (including electrical conductivity) within the Superficial Deposits (Tidal River or Creek Deposits, North Denes Formation, Breydon Formation and Happisburgh Glacigenic Formation) and underlying Principal Aquifer (Crag Formation) identifies that the strata are in hydraulic continuity and that there is saline intrusion in both shallow and deep groundwater samples retrieved from borehole installations. This is as expected due to the lack of any continuous low permeable strata separating the Superficial Deposits and the Crag Formation. It is also considered that the groundwater will be in hydraulic continuity with the River Yare although it is noted that the river is subject to tidal influence at this location.
- 6.1.3** The proposed driven pile solution provides the most effective solution for the ground conditions present on the Site (ie. predominantly granular soils). Driven piles also avoid the need for disposal of pile arisings and the use of drillings fluids such as bentonite hence eliminating the risk of pile arisings and spillages entering the River Yare. Driven piles can introduce preferential migration pathways due to the smooth surface of the piles (in the case of the proposed precast concrete and steel tubes). However, due to the limited contamination identified at the proposed piling locations, it is considered that an unacceptable risk to groundwater is unlikely to occur and no additional pathways will be created as a result of using driven piles as the Superficial Deposits and underlying Crag Deposits are already in hydraulic continuity.
- 6.1.4** Mitigation measures will be required if construction workers come into contact with excavated soils, including (but not limited to) dust suppression and the wearing of appropriate PPE/RPE. This will be the responsibility of the piling contractor and managed accordingly. Details are given in the outline CoCP (document reference 6.16).

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- 6.1.5** The driven piles should be constructed of suitable materials taking into consideration the chemical composition of the soil encountered on the Principal Application Site including the potential presence of saline water.
- 6.1.6** On review of the ground investigation data, the proposed piling works are not considered to represent a significant risk to local controlled waters or human health receptors. A risk assessment adopting the approach in UK CIRIA Report C552 (Ref 16D.5) assesses the risk to be LOW.
- 6.1.7** Specific pile design will remain the responsibility of a specialist contractor who will complete the detailed design of the Scheme based on the available ground information, the loads to be carried, the preferred construction sequence and their own proprietary techniques.
- 6.1.8** The detailed piling design will follow regulatory guidance and take full cognisance of any contaminated soils and groundwater identified on the Principal Application Site. Appropriate site management and pile installation quality control measures will be in place during pile installation.

## **6.2 Requirements**

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- 6.2.1** On the basis of this assessment, the following will be detailed in the outline CoCP (document reference 6.16) and secured via full CoCP Requirements.
- Use of appropriate pile materials to be resistant to the chemical composition of soil encountered on the Application Site including the potential presence of saline water.
  - Due to limited soil contamination (predominantly in the near surface soils and groundwater), appropriate dust suppression measures should be undertaken and site workers should wear suitable PPE/ RPE.
  - Quality Assurance and Quality Control (QA/QC) measures should be identified and adopted prior to piling works being undertaken. These are primarily for construction quality and structural performance. However, they are also equally relevant to mitigate environmental risk, for example spillages of oil/hydrocarbons during the construction process (re-fuelling). The relevant measures should ensure that the foundation pile solution techniques are carried out correctly and in an appropriate manner so that the risk assessment and conclusions remain valid. Such QA/QC procedures will normally be agreed between the contractor, client, and relevant regulators.

## Annex A: Risk Descriptors

**A.1.1.1** The identification of potential “pollutant linkages” is a key aspect of the evaluation of potentially contaminated land. An approach based on the UK CIRIA report C552 (Contaminated Land Risk Assessment: A Guide to Good Practice, 2001) has been adopted within this report. For each of the pollutant linkages, an estimate is made of:

- The potential severity of the risk; and
- The likelihood of the risk occurring.

**A1.1.2** Table A-1 presents the classification of the severity of the risk:

**Table A-1: Severity of Risk**

Severe	Acute risks to human health; Major pollution of controlled waters (watercourses or groundwater)
Medium	Chronic (long-term) risk to human health; Pollution of sensitive controlled waters (surface waters or aquifers)
Mild	Pollution of non-sensitive water resources.
Minor	Requirement for protective equipment during site works to mitigate health effects; Damage to non-sensitive ecosystems or species

**A1.1.3** The probability of the risk occurring is classified by criteria given in Table A-2.

**Table A-2: Probability of Risk Occurring**

High Likelihood	Pollutant linkage may be present, and risk is almost certain to occur in the long term, or there is evidence of harm to the receptor.
Likely	Pollutant linkage may be present, and it is probable that the risk will occur over the long term.
Low Likelihood	Pollutant linkage may be present and there is a possibility of the risk occurring, although there is no certainty that it will do so.
Unlikely	Pollutant linkage may be present but the circumstances under which harm would occur are improbable.

**A1.1.4** An overall evaluation of the level of risk is gained from a comparison of the severity and probability as presented in Table A-3.

**Table A-3: Comparison of Severity and Probability**

		Severity			
		Severe	Medium	Mild	Minor
Probability	High Likelihood	Very high risk	High risk	Moderate risk	Moderate / low risk
	Likely	High risk	Moderate risk	Moderate/ low risk	Low risk
	Low Likelihood	Moderate risk	Moderate/ low risk	Low risk	Very low risk
	Unlikely	Moderate / low risk	Low risk	Very low risk	Very low risk

**A1.1.5** Table A-4 then provides a description of the typical consequences and potential actions required following each risk definition.

**Table A-4: Qualitative Risk Assessment - Classification of Consequence**

Classification	Definition
Very High Risk	Severe harm to a receptor may already be occurring, or a high likelihood severe harm will arise to a receptor, unless immediate remedial works / mitigation measures are undertaken.
High Risk	Harm is likely to arise to a receptor, and is likely to be severe, unless appropriate remedial actions / mitigation measures are undertaken. Remedial works may be required in the short-term, but likely to be required over the long-term.
Moderate Risk	Possible that harm could arise to a receptor, but low likelihood that such harm would be severe. Harm is likely to be mild. Some remedial works may be required in the long-term.
Moderate / Low Risk	Possible that harm could arise to a receptor, but where a combination of likelihood and consequence results in a risk that is above low, but is not of sufficient concern to be classified as mild.  Limited further investigation may be required to clarify the risk. If necessary, remediation works are likely to be limited in extent.
Low Risk	Possible that harm could arise to a receptor. Such harm, at worst, would normally be mild.



Very Low Risk

Low likelihood that harm could arise to a receptor. Such harm is unlikely to be any worse than mild.

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## References

Ref 16D.1: Environment Agency (2006). Piling in layered ground: risks to groundwater and archaeology. Science Report SC020074/SR.

Ref 16D.2: Environment Agency National Groundwater and Contaminated Land Centres (2002). Piling into contaminated sites.

Ref 16D.3: Environment Agency (2001). Piling and penetrative ground improvement methods on land affected by contamination: guidance on pollution prevention.

Ref 16D.4: The Environment Agency (2004). Model Procedures for the Management of Land Contamination. Contaminated Land Report 11.

Ref 16D.5 CIRIA (2001). Contaminated Land Risk Assessment – A guide to good practice. C552.

Ref 16D.6: BRE (2005). BRE Special Digest 1: 2005 Concrete in aggressive ground.