Hampshire Water Transfer and Water Recycling Project

Outline Foundation Works Risk Assessment – 1 of 3 documents

Tunnels and Shafts

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from Southern Water

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Executive summary

Southern Water Services Limited (the Applicant) has commissioned this Outline Foundation Works Risk Assessment (FWRA) to support the application for a Development Consent Order for the proposed construction, operation and maintenance of a new water recycling plant and water supply infrastructure to address the sustainability objectives of reduced abstractions on Hampshire's two main rivers - the Test and Itchen and ensure a resilient water supply for the Applicant's customers.

The purpose of this Outline FWRA is to demonstrate that the construction of the shafts and tunnels required for the Project would not have an adverse environmental impact by creating new pathways for the migration of contamination, considering the protection of water resources, ecological receptors and human health. This Outline FWRA has been produced in accordance with guidance published by CL:AIRE in March 2025 on 'Piling and Penetrative Ground Improvement Methods on Land Affected by Contamination: Guidance on Pollution Prevention'. The assessment is not intended to prescribe a definitive foundation design, nor to preclude alternative technical solutions. Instead, it demonstrates that a viable engineering solution is achievable in principle, subject to detailed design development and appropriate specification at the construction stage.

This Outline FWRA considers the Bedhampton, Purbrook and Otterbourne tunnels including Mill Lane East Shaft, Mill Lane West Shaft, Portsdown Hill Shaft, Purbrook Shaft and launch and reception shafts for the Otterbourne tunnel. The purpose of the shafts is to provide access at the required depth to construct the tunnels, with the shafts providing maintenance access in the future. Once the shafts have been completed, tunnel boring will commence with the required infrastructure installed in the tunnels.

Ground investigations have been undertaken at each shaft location to determine the geological succession and to characterise the ground conditions at each site. There are a number of potential sources of contamination present associated with previous land uses.

The risk assessment process considers seven scenarios:

- Creation of preferential pathways, through a low permeability layer, to cause contamination of groundwater in an aquifer.
- The driving of solid contaminants down into an aquifer during pile driving.
- Contamination of groundwater and subsequently surface waters by turbidity, support fluids such as bentonite, concrete, cement paste or grout.
- Direct contact with contaminated soil or leachate causing degradation of pile materials.
- Creation of preferential pathways to allow migration of landfill gas or contaminant vapours to surface.
- Causing off-site migration of ground gas or increased vertical emissions as a result of vibration or other effects from the pile installation process.
- Direct contact with contaminated soil arisings that have been brought to the surface.

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Shafts

The results of the risk assessment for the shafts are summarised below.

Pollution Scenarios / Shaft Name	PS1	PS2	PS3	PS4	PS5	PS6 (highest risk assessed)	PS7
Mill Lane East	Moderate/ Low	Not applicable	Moderate	Low	Not applicable	Not applicable	Not applicable
Mill Lane West	Low	Not applicable	Moderate/ Low	Low	Very Low	Not applicable	Not applicable
Portsdown Hill Shaft	Moderate/ Low	Not applicable	Moderate/ Low	Low	Very Low	Not applicable	Moderate/ Low
Purbrook Shaft	Not applicable	Not applicable	Moderate/ Low	Low	Moderate/ Low	Not applicable	Not applicable
Otterbourne Shafts	Not applicable	Not applicable	Moderate/ Low	Low	Low	Not applicable	Not applicable

Most Pollution Scenarios either do not apply to shaft construction, or shaft construction poses a 'Low' or 'Very low' risk of pollution. 'Moderate/Low' risk was assessed for Pollution Scenarios 1, 3, 5 and 7.

The greatest risk, with ratings of 'Moderate' or 'Moderate/Low' across the six shafts, is suggested to be Pollution Scenario 3, i.e. *the contamination of groundwater … by wet concrete, cement paste, or grout.* Bentonite, additives and turbidity were also included in this assessment. These ratings assume that the construction Contractor would adopt the correct mitigation measures to limit the likelihood of a contamination linkage being created. It should be noted that the risk level relates to likelihood of *any* level of contamination. However, any flux of contaminants by these means is expected to be small and short-lived, while the construction is ongoing up to the point of the grout and concrete fully hardening. Measurable levels of contamination would be expected to be in close proximity to the shaft only and certainly not at any abstraction points.

For Pollution Scenario 1, the Moderate/Low risk resulted from conservative assumptions around possible contaminant sources, given the absence of some critical ground investigation data. They may therefore be reduced after further sampling/ testing in future. For all shafts it should be noted that the construction of the shaft will remove any potential source of contamination. For Pollution Scenario 5 regarding ground gas migration, presence of moderate flow rates and methane gas above lower explosive limits are cause for concern and this risk should be further investigated. Any construction activity will be considered to fall under the Confined Spaces Regulations which mandates procedures are adopted to control risks from gases. For Pollution Scenario 7, the 'Moderate/ Low' risk rating could also be subject to reduction with further investigation/ testing. For Portsdown Hill Shaft, the assessment was only carried out because of a lack of ground investigation data. This could also result in a reduction of risk should it become available.

Tunnels

The results of the risk assessment for the tunnels are summarised below.

Pollution Scenarios / Tunnel Name	PS1	PS2	PS3	PS4	PS5	PS6 (highest risk assessed)	PS7
Purbrook	Not applicable	Not applicable	Moderate	Low	Not applicable	Not applicable	Not applicable
Bedhampton	Not applicable	Not applicable	Moderate	Low	Not applicable	Not applicable	Not applicable
Otterbourne	Not applicable	Not applicable	Moderate	Low	Not applicable	Not applicable	Not applicable

The only Pollution Scenarios considered relevant to the tunnels are Pollution Scenarios 3 and 4. The maximum risk of Pollution Scenario 3 being realised is moderate in all three tunnels due to a turbidity source, which would be likely to affect the aquifer, despite engineering good practice. Pollution Scenario 4 only brings about a low risk, provided that concrete is designed to the correct specification given the ground conditions.

Risk Mitigation

Standard industry good practice measures to prevent pollution are assumed to be adopted by the Contractor which will be set out in their Construction Environmental Management Plan. The assessment for shafts under Pollution Scenarios 1 and 7 may be refined during detailed design through acquisition of location specific ground investigation data.

1 Introduction

1.1 Preamble

1.1.1 Southern Water Services Limited (the Applicant) has commissioned this Outline Foundation Works Risk Assessment (FWRA) to support the application for a Development Consent Order (DCO) for the proposed construction, operation and maintenance of a new water recycling plant and water supply infrastructure to address the sustainability objectives of reduced abstractions on Hampshire's two main rivers - the Test and Itchen - and ensure a resilient water supply for the Applicant's customers.

1.2 Assessment context

1.2.1 The purpose of this Outline FWRA is to demonstrate that the proposed foundation method would not have an adverse impact by creating new pathways for the migration of contamination, considering the protection of both water resources and human health.

1.2.2 This Outline FWRA version has been produced in light of guidance published by CL:AIRE in March 2025, "Piling and Penetrative Ground Improvement Methods on Land Affected by Contamination: Guidance on Pollution Prevention" [1]

1.2.3 The assessment is not intended to prescribe a definitive foundation design, nor to preclude alternative technical solutions. Instead, it demonstrates that a viable engineering solution is achievable in principle, subject to detailed design development and appropriate specification at the construction stage.

1.2.4 The information presented within this document is based upon an iterative design process, integrating available ground investigation data, conceptual site model development, and engineering judgement at the time of reporting.

1.2.5 It is acknowledged that foundation type, depth, geometry, and construction methodology would be dependent upon the detailed structural design chosen by the Contractor.

1.2.6 This Outline FWRA is a dynamic documenting process which, following additional site investigation data and detailed foundation design, would be revised through the various stages of the Project.

1.3 Description of the project

1.3.1 The Project comprises the construction, operation and maintenance of the following components:

- Water Recycling Plant (WRP) and associated pumping stations.
- Pipelines between Budds Farm Wastewater Treatment Works (WTW) and the WRP site.

- Pipelines between the WRP site and Bedhampton Springs, connecting to pipelines being delivered by Portsmouth Water between Bedhampton Springs and Havant Thicket Reservoir.
- Pipeline between the WRP site and Otterbourne Water Supply Works (WSW).
- Above Ground Plant (AGP) comprising Intermediate Pumping Stations (IPS) and Break Pressure Tanks (BPT) located along the Pipeline between the WRP site and Otterbourne WSW.

1.3.2 The Project would also comprise the use of the following infrastructure:

- Havant Thicket Reservoir (which has been consented separately by Portsmouth Water and is currently under construction) for the storage of recycled water.
- The existing Eastney Long Sea Outfall (LSO), Eastney Pumping Station, and associated Eastney Transfer Tunnel for the release of reject water from the WRP site.
- Pipelines and other related works (which have been consented separately by Portsmouth Water) for the transfer of recycled water and source water between Bedhampton Springs and Havant Thicket Reservoir.

1.3.3 The construction and operation of the Project would be supported by other temporary and permanent works.

1.3.4 The Project will require the demolition, disassembly and/or temporary relocation of a number of small structures.

1.3.5 A detailed description of the Project can be found in Environmental Statement (ES) Chapter 3 Description of the Proposed Development, Volume I (Document reference 6.1, DCO Volume 6). The Application Glossary (Document reference 1.7, DCO Volume 1) sets out the abbreviations and definitions used in the DCO application for the Project.

1.4 Scope of work

1.4.1 The purpose of this Outline FWRA is to demonstrate that the proposed construction of tunnels and shafts can be undertaken without causing an adverse impact by creating new pathways for the migration of contamination during construction or operational phases. It considers the protection of both water resources and human health.

1.4.2 To achieve this, the Outline FWRA report first presents a summary description of the ground conditions and geoenvironmental conditions across the Site, which should be read in conjunction with the Hampshire Water Transfer and Water Recycling Project Geotechnical and Geo-Environmental Desk Study and the Hampshire Water Transfer and Water Recycling Project Geo-Environmental Interpretative Report for Phase 1 and 3A Ground Investigation (Shafts and Tunnels), which are both contained within ES Appendix 11.2 Geotechnical and geo-environmental reports, Volume II (Document Reference 6.2, DCO Volume 6). It then describes the potential construction methods for the proposed tunnels and shafts. These would ultimately be decided by the Contractor and are not final. Finally, a preliminary risk assessment is carried out in accordance with the Pollution Scenarios contained within published guidance [1].

1.4.3 This Outline FWRA relates solely to the following tunnels and shafts:

- Bedhampton Pipe-Jack and associated shafts (outside the WRP):
  - Mill Lane East Shaft
  - Mill Lane West Shaft
- Purbrook Tunnel and associated shafts (outside the WRP):
  - Portsdown Hill Shaft
  - Purbrook Shaft
- Otterbourne Pipe Jack including launch and reception shafts

1.4.4 This Outline FWRA does not include:

- new piled foundations at the WRP;
- Budds Farm tunnel and associated shafts;
- launch shafts for Bedhampton Pipe-Jack, Purbrook Tunnel located within the WRP (WRP East Shaft and WRP West Shaft); and
- Additional Above Ground Plant (AGP) and the trenchless crossings required for the pipelines.

1.4.5 Outline FWRAs for the elements listed above are provided under separate cover (Document Reference 7.4, DCO Volume 7).

1.4.6 At the time of writing, the exact shaft and tunnel construction methodology is unknown and will be decided by the Contractor. Further, the risk assessment has been carried out according to the tunnel alignments and shaft locations shown in Appendix A and included in the Shafts and Tunnels GIR within ES Appendix 11.2 Geotechnical and geo-environmental reports, Volume II (Document reference 6.2, DCO Volume 6). The tunnels and shafts may change location within the set Limits of Deviation. This Outline FWRA will be used by the Contractor as a framework to develop their own FWRA during detailed design.

1.5 Limitations

1.5.1 This assessment is based upon information available at the DCO submission stage. Detailed design will be undertaken post-DCO consent, and this assessment should therefore be updated at such a time that more detailed information is available.

1.5.2 This report draws upon information presented in other studies prepared as part of submissions to support the ES submitted as part of the DCO. Where referenced, the reports presenting this information should be read in conjunction with this report.

1.5.3 This document should be read as part of the wider ground risk and design information package and is not a substitute for detailed structural design, Contractor-led method statements, or project-specific risk assessments required at later stages post-DCO consent.

2 Proposed structures

2.1.1 This Section presents details of the proposed shafts and tunnel routes considered in this Outline FWRA and the possible construction methodology that will be adopted by the Contractor for each.

2.1.2 Shaft and tunnel locations are shown on the exploratory hole plans in Appendix A and Potential Sources of Contamination (PSC) plans, which have been extracted from the Hampshire Water Transfer and Water Recycling Project Geotechnical and Geo-Environmental Desk Study contained within ES Appendix 11.2 Geotechnical and geo-environmental reports, Volume II (Document reference 6.2, DCO Volume 6), are presented in Appendix B.

2.2 Shafts

2.2.1 Basic shaft details are described from paragraph 2.2.2 and further details provided from paragraph 2.2.5. The outline construction methodologies for shaft options are described from paragraph 2.2.16.

Shaft details

2.2.2 The shafts considered as part of this Outline FWRA include the intervention and reception shafts associated with Bedhampton and Purbrook Tunnels. The exception is Mill Lane West shaft which may be used as a secondary launch shaft to facilitate the change in direction of the Bedhampton tunnel. The launch shafts for the tunnels, which are from within the WRP, are included in the Outline Foundations Works Risk Assessment – Proposed Water Recycling Plant and Trenchless Crossing to Budds Farm WTW Shaft Site (Document Reference 7.4, DCO Volume 7).

2.2.3 Current proposed shaft details are shown in Table 2-1 below. The construction type is not prescriptive and will be decided by the appointed construction Contractor. At this stage, it is assumed that the deeper shafts, which will be subject to significant water and earth pressures, will be constructed using diaphragm walls and not precast segmental lining.

Table 2-1 Details of proposed shafts

Shaft Name	Associated tunnel	Purpose	Likely Construction type	Internal diameter (m)	Tunnel invert level (mbgl)
Mill Lane East	Bedhampton	Reception	Precast segmental lining	8.2	~9.5
Mill Lane West	Bedhampton	Launch / Intervention	Precast segmental lining	10.5	~11.0
Portsdown Hill Shaft	Purbrook Tunnel	Intervention	Diaphragm Wall	12.5	64.5
Purbrook Shaft	Purbrook Tunnel	TBM Reception	Diaphragm Wall	12.5	64.8
Otterbourne (Reception)	Otterbourne	Launch	Precast segmental lining	10.5	~13

Highbridge (Launch)	Otterbourne	Reception	Precast segmental lining	12.5	~15

Notes:
Launch shaft – a shaft sunk to provide an access point for the tunnel boring equipment to commence tunnelling.
Intervention shaft – a shaft sunk part way along the proposed tunnel alignment to provide access to the tunnel during construction
Reception shaft – a shaft sunk at the point the tunnel is complete to recover the tunnel boring equipment.

2.2.4 Illustrative sections through a shaft with precast segmental lining and a shaft with diaphragm walls are provided in Figure 2-1, Figure 2-2, Figure 2-3 and Figure 2-4.

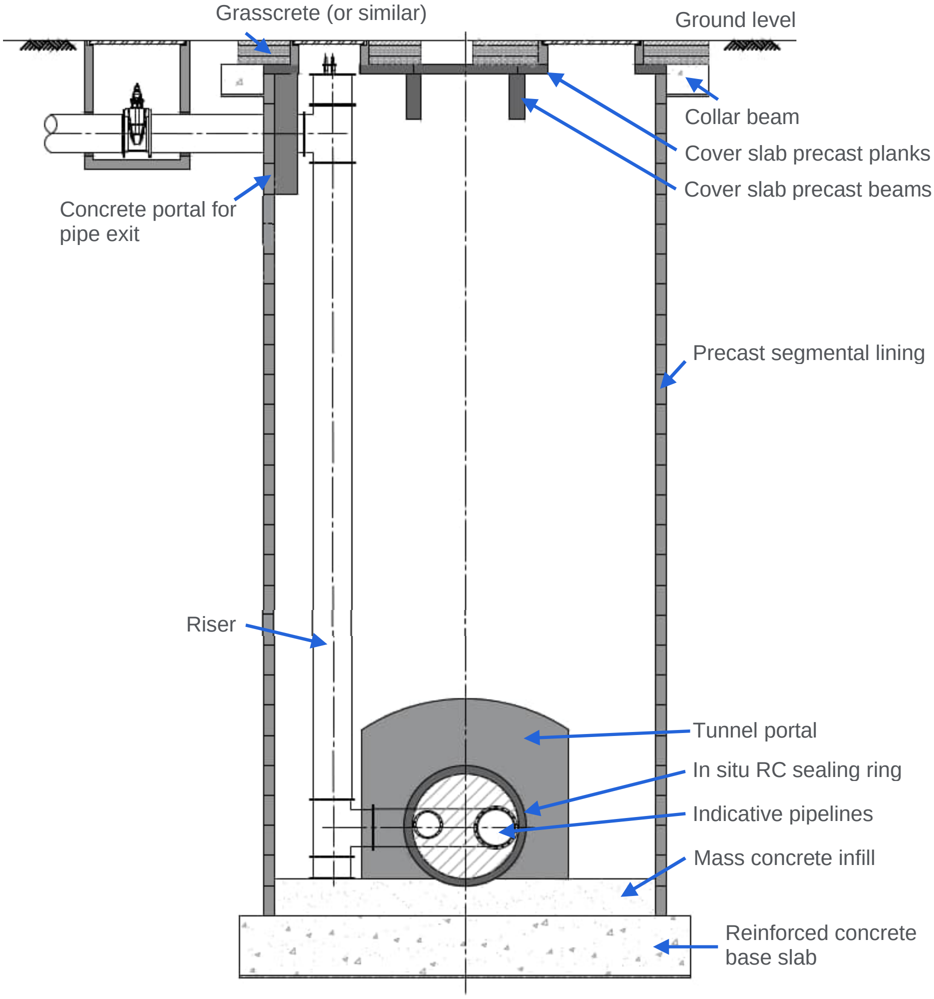

Figure 2-1 Typical shaft with precast concrete segmental lining

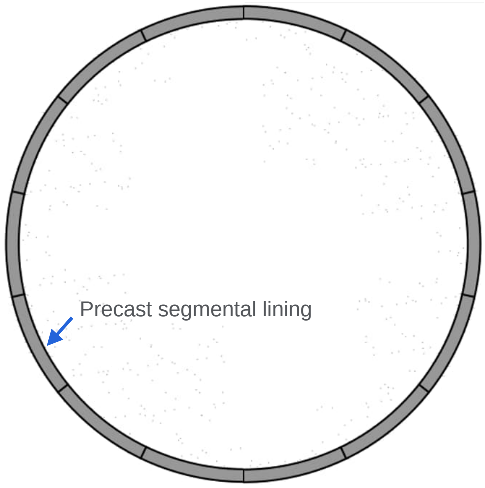

Figure 2-2 Schematic plan view of completed shaft with precast concrete segmental lining

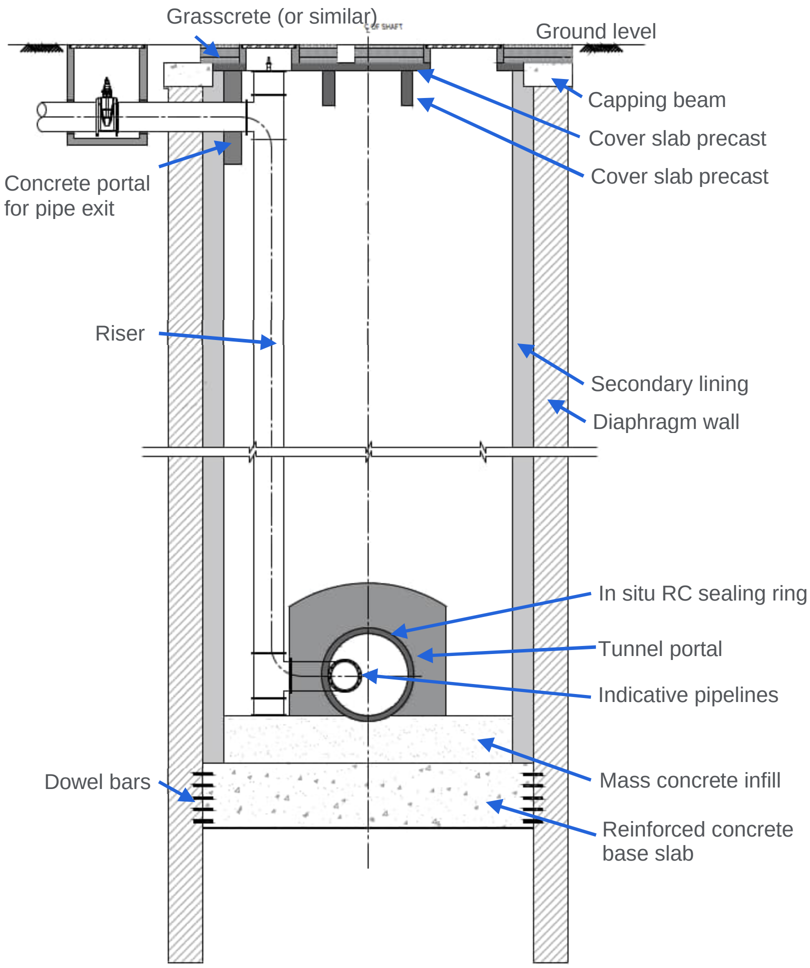

Figure 2-3 Typical shaft with diaphragm wall lining

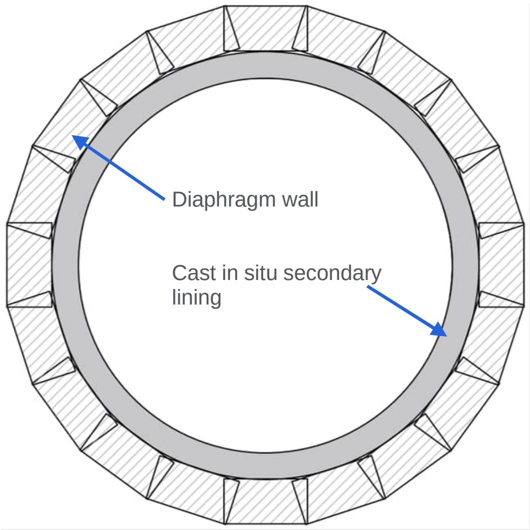

Figure 2-4 Schematic plan view of completed shaft with diaphragm walls

Main shaft elements

2.2.5 Elements are labelled in the figures above and described below.

Shaft cover slab

2.2.6 The shaft cover slab will consist of precast concrete slabs with openings for water main entry/exit, access staircase, ventilation, and crane access. Access covers with a water-tight seal will be provided over the openings.

Shaft capping beam/collar beam

2.2.7 A circular reinforced concrete capping beam will be provided at the top of diaphragm walls and a collar beam at the top of segmentally lined shafts. They act to provide structural continuity between wall sections, evenly distribute load above the wall, ensure verticality of the shaft and control displacements of the lining during construction.

Shaft primary lining

Precast segmental lining

2.2.8 Shallower shafts in predominantly cohesive soils or Chalk will likely be formed using rings of precast, traditionally reinforced or steel fibre reinforced concrete standard segments. A gasket system integrated into the segments will ensure the watertightness of the structure. Segmental linings will be designed to withstand the ground, groundwater, construction and surcharge loads in the temporary and the permanent case.

Diaphragm wall

2.2.9 Diaphragm walls will be based on a series of overlapping panels poured in situ. and will be designed to withstand the ground, groundwater and surcharge loads in the temporary case. In the permanent case, the diaphragm wall will be designed to withstand a share of the ground and surcharge loads, based on the relative stiffness of the primary and secondary linings.

2.2.10 All panels will be provided with traditional steel reinforcement bars. Glass fibre reinforced polymer bars may be required at the portal opening location in intervention and reception shafts to enable TBM breakthrough into the shaft.

Shaft secondary lining

2.2.11 Diaphragm walls are not considered to be water-tight structures due to the existence of the joints between the panels, through which water can flow. Therefore, diaphragm wall shafts will be provided with a cast in-situ reinforced concrete secondary lining to ensure watertightness. The secondary lining will be designed to withstand 100 % of the groundwater pressure loading in the permanent case. A secondary lining is not required for a shaft with precast segmental lining, for which a gasket system ensures watertightness.

Tunnel-to-shaft portals

2.2.12 Reinforced concrete tunnel portals in the shafts will provide the required support for the tunnel penetration. For shafts with a secondary lining, the portal will be integrated into the secondary lining. In segmentally lined shafts (without a secondary lining), an alternative means of temporary support will be required. This may include, for example, steel needle beams bolted to the precast segments adjacent to the portal opening prior to forming the opening.

2.2.13 In all shafts, a cast in-situ concrete finishing ring, incorporating re-injectable grout tubes, should be provided to ensure a watertight seal between the precast tunnel segments and the main part of the portal.

Base slabs and mass concrete infill

2.2.14 A cast in-situ circular reinforced concrete slab will be formed at the bottom of each shaft. During the construction case, it is envisaged that a temporary sump may be required in the base slab in order to collect water ingress into the shaft that may occur during construction.

2.2.15 Mass concrete infill will be provided above the base slab in the permanent case to raise the shaft invert levels to the required finished levels. The mass concrete infill can incorporate a permanent sump to collect any water ingress into the shaft and also serves as a reservoir into which the water mains can be drained when carrying out maintenance or replacement works. The sumps extend from the top of the mass concrete to the top of the reinforced concrete base slab.

Construction methodology

2.2.16 The following provides a likely construction sequence for the shafts. Shafts with precast segmental lining may be constructed by underpinning or by caisson method or by a combination of both depending on ground conditions. Caisson is more appropriate for non-cohesive soils or where there is high groundwater. Underpinning is better suited in self-supporting soil where the ground is more resistant and jacking the shaft is not feasible. A combination of the two methods can be employed where soil conditions vary. For instance, a shift from caisson to underpinning can occur at depth where soil/ rock becomes too resistant to jacking.

Precast segmental lining (underpinned)

- Excavate to formation level of temporary concrete collar beam.
- Construct first shaft segmental lining ring at formation level and install dowel bars to strengthen the circumferential joint connections.
- Cast temporary reinforced concrete collar to support the first shaft segmental lining ring.
- Activate dewatering wells where required. This may be preceded by injection of fissure grout around the excavation and/ or below base slab formation level within the Chalk. Pumping tests can be carried out to monitor the hydrogeological regime before excavation and determine the measures necessary for groundwater control.
- Mechanically excavate and install subsequent segmental lining rings by underpinning. Excavators can be at the surface or within the excavation depending on ground conditions. Accurate excavation to avoid overbreak and excess grout use is essential and can be achieved from either position.
- Grout annulus between ground and segments immediately after installing each ring. Rings are installed and grout is injected through the walls via a grout gun inserted into a threaded socket.
- Excavate base slab to formation level, fix reinforcement and cast base slab.

Tunnel portal details

2.2.17 Permanent Support Method:

- Fix reinforcement and cast reinforced concrete permanent portal to provide long-term support.
- Cut/ remove shaft precast segments at tunnel eye.
- Receive TBM/ Pipe-Jack and remove from shaft or TBM/ Pipe-Jack pass through (intervention shaft).

2.2.18 Temporary Support Method:

- Construct temporary support around tunnel eye opening
- Cut/ remove shaft precast segments at tunnel eye.
- Install temporary tunnel eye support/ soft eye.
- Receive TBM/ Pipe-Jack and remove from shaft or TBM/ Pipe-Jack pass through (intervention shaft).
- Fix reinforcement and cast reinforced concrete permanent portal to provide long-term support and encapsulate any temporary works.
- Install the shaft portal opening and high-level chambers.
- Cast finishing concrete to provide a seal between the permanent portal and segmental tunnel rings. Re-injectable grout tubes to be provided within the sealing concrete to ensure watertightness.
- Deactivate dewatering wells.
- Cast mass concrete infill up to finished invert levels, including a drainage sump.
- Install the shaft cover slab with access openings.

Precast segmental lining (caisson method)

- Collar beam is constructed, providing a counterweight to enable jacking forces to be applied to the top ring.
- Hydraulic jacks are installed around the collar.
- Construct first one or two rings at ground level with a special cutting ring at the leading edge.
- Cutting edge provides an overcut so that an annulus is formed around the rings, into which bentonite slurry/ thixotropic lubricant can be introduced to reduce friction and support the surrounding ground.
- A ‘choker ring’ provides a seal diameter between the shaft and excavated ground, to retain fluid in the annulus above the ring.
- Mechanical excavation proceeds and the caisson is sunk by letting the shaft sink in a controlled manner, usually by use of vertical hydraulic jacks positioned around the collar.
- ‘Dry’ excavation: ground is naturally stable or has been stabilised by dewatering. Therefore, excavation can be carried out from the surface or from within the shaft akin to the methods used for underpinning. Where required in Chalk, dewatering may be preceded by injection of fissure grout. Pumping tests can be carried out beforehand to monitor the hydrogeological regime and determine the measures necessary for groundwater control before excavation proceeds.
- ‘Wet’ excavation: This may be necessary where ground conditions are poor, ground is waterlogged or there is risk of the base ‘blowing’. In this case the shaft excavation must be flooded to the prevailing hydrostatic level and excavation carried out by excavator-mounted pole grab/ rope-operated digging grab mounted on a crawler crane.
- As the shaft sinks further, rings are added at the surface.
- Constant checks on verticality and square of the shaft. Jacks can be corrected to keep within tolerance.
- When caisson has been sunk the lubricant (bentonite slurry or otherwise) is replaced with cementitious grout to lock the caisson into position and reduce settlement.
- Fix reinforcement and cast base slab.
- Replace thixotropic material in annulus with cementitious grout in one operation to fix caisson reduce settlement.

Tunnel portal details

2.2.19 Permanent support method:

- Fix reinforcement and cast reinforced concrete permanent portal to provide long-term support.
- Cut/ remove shaft precast segments at tunnel eye.
- Receive TBM/ Pipe-Jack and remove from shaft or TBM/ Pipe-Jack pass through (intervention shaft).

2.2.20 Temporary support method:

- Construct temporary support around tunnel eye opening

- Cut/ remove shaft precast segments at tunnel eye.
- Install temporary tunnel eye support/ soft eye.
- Receive TBM/ Pipe-Jack and remove from shaft or TBM/ Pipe-Jack pass through (intervention shaft).
- Fix reinforcement and cast reinforced concrete permanent portal to provide long-term support and encapsulate any temporary works.
- Install the shaft portal opening and chambers.
- Cast finishing concrete to provide a seal between the permanent portal and segmental tunnel rings. Re-injectable grout tubes to be provided within the sealing concrete to ensure watertightness.
- Deactivate dewatering wells.
- Cast mass concrete infill up to finished invert levels, including a drainage sump.
- Install the shaft cover slab with access openings.

Diaphragm wall

- Prepare working platform at ground surface level.
- Excavate, fix reinforcement and pour concrete guide wall (typically up to 1.5m depth).
- A grab excavator (or hydrofraise/hydromill cutter in more competent ground) will be used to form the excavation for each wall 'panel', with a bentonite slurry used to keep the excavation open, ensuring smooth-sided diaphragm walls and good contact of the poured concrete with surrounding soil.
- Once a panel has been excavated, reinforcement cages are lowered into the excavation, after which concrete for that panel is poured.
- After completion of the diaphragm wall panels, fix reinforcement and pour concrete for the capping beam.
- Activate dewatering wells in Chalk strata and/or fissure grout below base slab formation level where appropriate.
- Once diaphragm wall and capping beam concrete reach 28-day strength, excavate to base slab formation level. Groundwater inflow to be reduced by embedding diaphragm walls into competent Chalk and fissure grouting (if required) the Chalk beneath the final excavation level. Pumping tests can be carried out to monitor the hydrogeological regime and determine the measures necessary for groundwater control.
- Drill dowels into the diaphragm wall panels (or use pre-fix couplers) to provide a connection with the base slab.
- Fix reinforcement and temporary pressure relief wells, then cast base slab.
- Fix reinforcement and cast temporary/permanent concrete portal ('picture frame') around tunnel eye opening, which will later form part of the secondary lining.
- Cast secondary shaft lining by slip forming (continuous concrete pouring behind moving formwork to create 'flawless' concrete) to provide additional watertightness. Diaphragm wall panels will be cut later at the tunnel eye as tunnelling proceeds.
- TBM pass through / reception
- Install the shaft portal opening

- Cast finishing concrete to provide a seal between the permanent portal and segmental tunnel rings.
- Deactivate dewatering wells (if used).
- Cast mass concrete infill from the top of the base slab up to finished invert levels.
- Install the shaft cover slab with access opening

2.3 Tunnels

2.3.1 Basic tunnel details are described from paragraph 2.3.2 below and the construction methodologies for tunnelling options are described from paragraph 2.3.7.

Tunnel details

2.3.2 The tunnels considered as part of this Outline FWRA are:

Bedhampton tunnel

2.3.3 An approximately 0.5km long pipe-jack is proposed to connect the planned WRP (WRP East Shaft) with Bedhampton Springs. This route will then be connected to the planned Havant Thicket Reservoir via Portsmouth Water assets. Associated shafts (outside WRP):

- Mill Lane East Shaft
- Mill Lane West Shaft

Purbrook tunnel

2.3.4 An approximately 3.9km long tunnel is proposed to connect the pumping station at the WRP site to pump source water to Otterbourne WSW, and arable farmland located approximately 200m north of B2177 / Portsdown Hill Road. Associated shafts (outside the WRP):

- Portsdown Hill Shaft
- Purbrook Shaft

Otterbourne tunnel

2.3.5 An approximately 1.1km long tunnel is proposed between Highbridge and Otterbourne.

2.3.6 Current proposed tunnel details are shown in Table 2-2 below. Whilst the construction type is not prescriptive and will be decided by the Contractor, the Outline FWRA is on the basis that the Bedhampton and Otterbourne tunnels will be constructed by pipe jacking and the Purbrook tunnel by tunnel boring machine.

Table 2-2 Current proposed design details for tunnels

Tunnel Name	Internal diameter tunnel (m)	External diameter tunnel (m)	Invert level at start (mbgl)	Invert level at end (mbgl)	Pipeline details.

Bedhampton	2.4	2.83	~19.5	~9.5	One 1200mm ID gravity main and one 800mm ID rising main
Purbrook Tunnel	3.5	4.00	24.6	64.8	One 1200mm ID rising main
Otterbourne	1.2	2.83	7.63	5.50	One 1200mm ID rising main

Construction methodology

2.3.7 The tunnels will be excavated below groundwater either by TBM or pipe-jacking methods, both of which are non-displacement excavation methods and produce tunnels lined with precast, segmental concrete rings with sealing gaskets for watertightness.

2.3.8 The construction methods for each tunnel type are as follows:

Generic TBM tunnelling methodology

2.3.9 A TBM operates in a cyclical process of excavation, spoil removal and construction of the tunnel lining:

- TBM assembled within launch shaft.
- TBM excavates the tunnel using its rotating cutter head pushed by hydraulic cylinders, to break through the soil/ rock.
- Spoil/ slurry is excavated away from the face to the surface.
- Excavation halts while precast concrete segments are transported into tunnel and assembled behind the shield to form complete rings, with sealing gaskets to provide a watertight connection. Excavation then resumes.
- Tail-skin grouting creates a seal between the rings and surrounding soil. This adds watertightness and stability to the tunnel and surrounding ground.
- Constant monitoring and adjustments are made throughout the tunnelling process, to ensure alignment and suitable face pressure. Careful control of face pressures also limits the spread of construction fluids into surrounding ground.
- TBM breakthrough at reception shaft followed by disassembly.

2.3.10 There are two alternative TBM machines/ techniques:

Earth pressure balance (EPB) TBM

2.3.11 Earth Pressure Balance (EPB) TBM, which utilises a pressurised ‘plug’ inside the cutting head chamber to counteract the external earth and hydrostatic pressures. Spoil is transported from the cutting face through a screw conveyor and guillotine valve for onward transfer out of the tunnel by conveyor/wagons. Key considerations of this technique include:

- Mobilisation of Chalk ‘flour’ from the TBM operation is limited and face stability can be more easily maintained.
- EPB TBMs can also condition the chalk with additives, if necessary (and subject to the approval of the Environment Agency), to improve its consistency and ensure smooth excavation. This is particularly useful if the chalk is moist and cohesive.

- Since EPB TBMs can reuse much of the excavated chalk for face support, they may produce less waste and present less of a potential hazard of groundwater contamination compared to Slurry TBMs (see below).
- EPB TBMs may be less effective in dry, non-cohesive chalk where stability issues may arise. This is not anticipated to be a problem at the Site where all tunnels are to be constructed within the saturated chalk.

Slurry TBM

2.3.12 Slurry TBM utilises a compressed air cushion/ bubble to fine tune the slurry support pressure. A slurry of excavated material, water and drilling fluids is transported through a discharge pipe to a treatment plant at surface for segregation. Cleaned slurry is returned to the TBM via a slurry feed pipe. Key considerations of this technique include:

- Better resilience against flint wear and reduced requirement for maintenance interventions.
- Effective in high-pressure water conditions.
- However, there can be more downtime and operational challenges due to the complexity of the slurry handling system and Slurry TBMs will generate significant waste which requires proper management.

2.3.13 The ultimate choice of TBM technique will depend on the ground conditions including groundwater pressures as determined from the GI and geotechnical testing, as well as operational requirements.

Pipe-jack methodology

2.3.14 Pipe-jacking is a trenchless technique for installing small-diameter utility tunnels by hydraulically pushing a series of jacking pipes behind a tunnelling shield undertaking a controlled excavation at the advancing face. The tunnelling shield and jacking pipes are pushed/jacked from a launch shaft to a reception shaft. An outline methodology is as follows:

- Jacking frame is installed at the base of the launch shaft. The frame will provide the structural support during the jacking operation. The jacking force will require a thrust block wall to provide structural support for the hydraulic system used to push the pipes. The thrust block will be integrated into the base slab or shaft wall.
- Precast concrete jacking pipe is positioned in the launch shaft. Jacking pipes are typically 2-2.5m length with joints incorporating elastomeric gaskets to provide a watertight connection.
- Mechanical excavation tool (likely to be EPB or Slurry TBM) to break through the soil/ rock in front of jacking pipe and excavated soil removed from the pipe using conveyor belts/slurry pipeline.
- First jacking pipe is fixed to the excavation tool.
- Hydraulic jacks used to push pipe forward into the soil.
- As each pipe is pushed forward, the next pipe is added and jacked into place, continuing the process until the pipes reach the reception shaft.

- A low permeability lubricant (for example, bentonite) can be injected into the annulus around the jacking pipes during installation to aid advancement of the pipe jack and support the surrounding soil.
- Annulus grouting upon completion of pipe jacked tunnel to fill any voids and stabilise the tunnel.

3 Site setting

3.1.1 The text within this section is summarised from the Hampshire Water Transfer and Water Recycling Project, Geo-Environmental Interpretative Report for Phase 1 and 3A Ground Investigation (Shafts and Tunnels) and the Desk Study Report, which should be read in conjunction with this Outline FWRA. Shaft and tunnel locations are shown on the exploratory hole plans in Appendix A and Potential Sources of Contamination (PSC) plans, which have been extracted from the Desk Study are presented in Appendix B.

3.2 Site history

3.2.1 A summary of the site history for each tunnel route, based on the 1:10,560 and 1:10,000 historical maps, is provided below for each tunnel Potential contaminant sources have been highlighted in bold text.

Bedhampton tunnel

- The 1866 map shows south of the tunnel route at WRP east / west shaft as marshland (Broad Marsh). Bedhampton is developed with structures including the present-day railway, Bedhampton Mill (corn) Upper Mill (corn), a manor house, The Old Poorhouse, Bidbury Springs and Mill Dam.
- The 1930-31 maps show a sewage works (Havant Borough District Council) on the Bedhampton route approximately 200 m north of the WRP east shaft.
- By 1938 there has been further development in Bedhampton with a water works (Bedhampton Springs).
- According to historical maps and information from the EA, between 1969 and 1987 the area south of the tunnel route within the WRP at WRP east shaft, was part of a landfill accepting household, commercial and industrial waste. The EA stated that "*the site is also recorded as being a dilute and disperse facility, so any engineering is likely to be minimal*".
- By 1975 the sewage works is no longer shown, apart from the outline of the premises and a tank in the northwest of the works. Bedhampton and Upper Mill are no longer shown. Broad Marsh is no longer shown on the map.
- The 1991 map shows the WRP east shaft area as a playing field. Planning application information indicates this area underwent earthworks to raise the ground by approximately one metre beforehand. Hermitage stream has been diverted around the proposed WRP. There are no other significant changes.
- During the mid-2000s the area south of the tunnel route within the WRP at WRP east shaft appears to have been used as a stockpiling and construction compound during Harts Farm Way/A27 road works.
- From 2010s onwards, this area appears to have been restored to its existing condition.

Purbrook tunnel

- The 1866 map shows WRP shaft west in Broad Marsh. The South Coast Railway crosses the tunnel route approximately 275 m northwest of WRP shaft east in a northeast to southwest orientation. The route passes through an area called Camp Down, with old or current chalk pits shown on or greater than 50 m from the tunnel route. The route also passes under an old quarry north the present day Gillman Road. Additional chalk pits surround the tunnel route around the current A3 and B2177 (Portsdown Hill Road), east of New Down Lane, Purbrook.
- The 1895 map has the tunnel route under a reservoir owned by the Borough of Portsmouth Water Company, south of Boundary Way, Purbook.
- Upper Reservoir is on the 1898 map, approximately 80 m south of the B2177 and north of Grant Road.
- There are no significant changes until the 1930 - 1931 map where Fort Purbrook and Farlington Redoubt appear approximately 80 m north. Although these may have been present before this time but not shown on historical maps. Chalk pits at the junction of the A3 and B2177 are either disused, or the land redeveloped. Additional buildings (likely residential housing) are present in the wider Purbrook area.
- The 1938 map shows Upper Reservoir has expanded and is also a filtration works. Air vents / shafts are present approximately 20 m south and 80 m north of the tunnel route. The chalk pits at Camp Down are vegetated on the map.
- The 1963 and 1966 maps show additional development (likely residential) south of Portsdown Hill Road between Bedhampton and Purbrook and around Purbrook / Widley.
- Redevelopment of the A27 has occurred between 1966 and 1980. Harts Farm Way (road) is shown going south and west round the former Broad Marsh which has been infilled.
- According to historical maps and information from the EA, between 1969 and 1987 the Broad Marsh area was a landfill accepting household, commercial and industrial waste. The EA stated that "*the site is also recorded as being a dilute and disperse facility, so any engineering is likely to be minimal*".
- The 1991 map shows the WRP west shaft area as a playing field. Planning application information indicates this area underwent earthworks to raise the ground by approximately one metre beforehand. Hermitage stream has been diverted around the proposed WRP. There are no other significant changes.
- During the mid-2000s the area south of the tunnel route within the WRP at WRP west shaft appears to have been used as a stockpiling and construction compound during harts Farm Way/ A27 road works.
- From 2010s onwards, this area appears to have been restored to its existing condition.

Otterbourne tunnel

- The 1868 map shows the London and Southwestern Railway, Itchen Navigation (canal) and River Itchen crossing the tunnel route from northeast to southwest. The River Itchen flows southeast south of the tunnel route. Otterbourne Park Wood is approximately 60 m east of the Otterbourne Shaft. The town of Bambridge is approximately 200 m east of Highbridge Shaft. Bugle Farm (buildings) are approximately 130 m north of the tunnel route along the current B3335. The River Itchen is approximately 250 m south of the tunnel route at the B3335. The area is largely rural.

- The 1931 map (partial) has a gravel pit approximately 120 m southwest of the tunnel alignment. The 1957 map shows the same gravel pit immediately south of Bugle Farm and, therefore, on the tunnel route. There has been additional development around Bambridge with additional buildings, likely to be residential housing.
- The 1968 map no longer shows the main gravel pit at Bugle Farm. Smaller gravel pits cross the tunnel route approximately 200 m west of B3335 (Brambridge Road). Gravel pits are also shown approximately 138 m south and 230 m north of the tunnel route. The 1980 map labels the former gravel pit at Bugle Farm as 'Pit (disused)'. Smaller gravel pits shown on the tunnel alignment in 1968 are still present on the map. The gravel pit to the north has largely been infilled with only a smaller area of gravel pit approximately 45 m north of Bugle Farm. The gravel pit to the south is still shown. A works is approximately 70 m south of the tunnel route in the area of the gravel pits.

Shafts

3.2.2 Table 3-1 provides site history information for each individual shaft and is based on Appendix H from the Desk Study Report. Further details regarding military sites can also be found in the Desk Study Report.

Table 3-1 Site history summary for shafts (summarised from desk study report)

Shaft Name	Current Site Use	Site History (summary)
Mill Lane East Shaft (Bedhampton Tunnel)	Open land (grass and trees present)	• **1840-1920s:** The Site appears undeveloped. The land appears to be part of Upper Mill / Bedhampton Mill. Upper Mill is approximately 100m northeast and Bedhampton Mill is approximately 125m south. Both processed corn. Mill Dam is approximately 30m southeast. A railway is approximately 30m northwest. The 1869 map shows a railway siding approximately 10m west of the shaft from the main railway, heading southwest to an unidentified building 60m southwest. A building with a railway siding from the mainline past the shaft is approximately 40m north. By 1909 Upper Mill and Bedhampton Mill are shown as 'disused' The railway siding has been removed from Bedhampton Mill but remains adjacent to the shaft. • **1920s -1960s:** By 1932 Upper Mill has been replaced by a Portsmouth Water pumping station. Bedhampton Mill is no longer shown, and Mill House is present. The 1939 map shows tanks approximately 90m northeast at the pumping station. • **1961 to present day:** The 1999 aerial map no longer shows the railway siding adjacent to the Site. No other significant changes.
Mill Lane West Shaft (Bedhampton Tunnel)	Open land (grass covered field)	• **1840-1920s:** The Site is shown as a field/ [1], open land. Bedhampton Corn Mill is shown approximately 20m east with railway sidings. A watercourse (now known as Hermitage Stream) flows through the mill. A railway line is approximately 25m northwest (in present day location). Bedhampton Mills is shown as disused on 1909 maps. • **1930s-1970s:** Allotment gardens (1930s-C.1960) are shown on-site otherwise no further changes. A wastewater treatment works is now present approximately 120m south. • **1970s to present day:** No change on-site. Off-site, a residential development is in progress to the north of the railway line (2022-23).
Portsdown Hill Shaft (Purbrook Tunnel)	Land within Farlington Water Treatment Works (WTW) (Portsmouth Water)	• **1840s-1920s:** The Site comprises open land to the north of Portsdown Hill reservoirs. An old quarry is located approximately 50m east. • **1930s-1950s:** Increased expansion of the water works to the south and southeast of the Site (Portsmouth Water Co.). Farlington Redoubt and Fort Purbrook are located approximately 430m east and 200m west of the Site, respectively.
Purbrook Shaft (Purbrook Tunnel)	Agricultural Land	• **c.1840s-present day:** Agricultural land on-site. • **1840s-1920s:** Land surrounding the Site includes rural land, Dell Garden (approximately 65m east) associated with Portsdown Lodge property, possible pits 100m and 170m northwest, reservoir 180m southeast and large chalk pits (greater than 200m) to the south. • **1920s-1970s:** residential expansion to the northeast and southeast of the Site. • **1970s to present day:** continued residential development surrounding the Site and a new reservoir site approximately 100m south of the Site.
Otterbourne Launch	Agricultural Land	• **c.1840s-present day:** Agricultural land on-site. • **1960s** Bugle Farm landfill infilled
Otterbourne Reception	Agricultural Land	• **c.1840s-present day:** Agricultural land on-site.

3.3 Geology

3.3.1 The geological ground conditions, as encountered during the various phases of ground investigation that have been undertaken in the shaft and tunnel locations, are summarised in Table 3-2 below. Further detail is provided in the Geo-Environmental Interpretative Report for Phase 1 and 3A Ground Investigation (Shafts and Tunnels) contained within ES Appendix 11.2 Geotechnical and geo-environmental reports, Volume II (Document reference 6.2, DCO Volume 6). With reference to the shafts, this includes the most relevant (closest) exploratory holes only. Geological descriptions have been summarised to include factors most relevant to the Outline FWRA. For instance, colour is excluded unless it is relevant to the contamination state. Where Chalk is described as 'possibly unstructured', the log recorded 'Unable to determine CIRIA Grade' or 'No Core Recovery'. Where no description is provided for London Clay Formation, it can be assumed to comprise stiff silty clay.

Table 3-2 Summary of encountered ground conditions

Structure	Relevant exploratory holes	Typical description thickness of strata encountered
Mill Lane East Shaft	BHP06 (8.5m from shaft centre)	• 0.8m of Made Ground (CLAY with chalk, chert and brick gravel) over 0.7m of Head Deposits (sandy, gravelly CLAY), overlying • 5.4m River Terrace Deposits (sandy GRAVEL with ~1m thick SAND layer at 2.6mbgl), overlying • Chalk (possibly unstructured NEWHAVEN CHALK FORMATION) at base shaft/ tunnel depth. Log reads 'Unable to determine CIRIA Grade'. Material consists of orange-stained gravel-sized fragments of chalk to 13.5mbgl, after which staining is mainly absence and chalk pieces are recovered with less disturbance.
Mill Lane West Shaft	BHP02 (~11m from shaft centre)	• 3.4m River Terrace Deposits (gravelly clayey SILT/ sandy CLAY), overlying • Chalk (unstructured NEWHAVEN CHALK FORMATION) at base shaft/tunnel depth noting that SPTs have been performed which leads to more damage to the chalk.
Bedhampton Tunnel	numerous	• All Chainages: Chalk (unstructured NEWHAVEN CHALK FORMATION / WHITE CHALK SUBGROUP)
Portsdown Hill Shaft	BH301 (40m from shaft centre)	• ~0.75m Head Deposits (gravelly SAND/sandy GRAVEL), overlying • Chalk (~5m unstructured CULVER CHALK FORMATION, ~10m structured CULVER CHALK FORMATION, ~30m structured NEWHAVEN CHALK FORMATION, structured SEAFORD CHALK FORMATION to base shaft/tunnel depth).
Purbrook Shaft	BH303-D (16m from shaft centre)	• ~3m Head Deposits (silty CLAY), overlying • Chalk (~2m unstructured CULVER CHALK FORMATION, ~55m structured PORTSDOWN / CULVER CHALK FORMATION, over structured NEWHAVEN CHALK FORMATION to base shaft/tunnel depth). • Trial pits TP304-306 which were all within 10m of the shaft recorded similar results, although Head deposits were thin/absent overlying the Chalk.
Purbrook Tunnel	numerous	• Unstructured NEWHAVEN CHALK FORMATION at Chainage 0 at WRP shaft, • becoming Structured NEWHAVEN CHALK FORMATION between Chainage 150 and 650, • becoming Structured SEAHAVEN CHALK FORMATION between Chainage 650 and 2900, • becoming Structured CULVER CHALK FORMATION between Chainage 2900 and 3450, • becoming Structured NEWHAVEN CHALK FORMATION between Chainage 3450 and Purbrook Shaft.
Highbridge Launch	BH501	• 0.4 Topsoil bgl • River Terrace Deposits to 3.5mbgl

		• London Clay Formation to 13m • Lambeth Group to 29m l • Structured CULVER CHALK FORMATION unproven
Otterbourne Tunnel		• London Clay Formation • Probably in a Lambeth Sand channel from Ch 100-0600 • Passing into London Clay at approx. Chainage 600-1+060m
Otterbourne Reception	BH506	• 0.4m Topsoil over HEAD deposits to 1.0m • River Terrace Deposits 1.6m • London Clay 228m • Structured CULVER CHALK FORMATION unproven

3.4 Hydrogeology

3.4.1 A summary of the groundwater levels recorded during post-investigation monitoring at each of the shaft locations and for the three tunnels is provided in Table 3-3, as well as other information pertinent to the Outline FWRA. Further detail is provided in the Geo-Environmental Interpretative Report for Phase 1 and 3A Ground Investigation (Shafts and Tunnels) contained within ES Appendix 11.2 Geotechnical and geo-environmental reports, Volume II (Document reference 6.2, DCO Volume 6).

3.4.2 Generally, groundwater is consistently shallow and water pressures at tunnel depth high along Bedhampton Tunnel. Groundwater is much deeper along Purbrook Tunnel, although it varies significantly along the route and seasonally within boreholes. Groundwater is at 21m depth along the Otterbourne Tunnel.

3.4.3 In addition to the information provided in Table 3-3, it is notable that the Mill Lane East shaft is located some 30m from the edge of a groundwater Source Protection Zone (SPZ) and Bedhampton and Havant Springs Groundwater Drinking Water Safeguard Zone.

Table 3-3 Summary of hydrogeological setting

Structure	Aquifer Designations	Groundwater Vulnerability (based on BGS 1:50,000 geological maps)	In groundwater SPZ and abstractions within 250 m?	Spot Monitoring of Groundwater Levels Post GI and Commentary Relating to Abstractions / SPZs
Mill Lane East Shaft	Secondary Undifferentiated and Secondary A Aquifers (Head and River Terrace Deposits) Principal Aquifer (Chalk)	Medium to High	**No**. (50m buffer zone, 250m buffer for potentially infilled land). A SPZ 1 is approximately 35m north. **Groundwater Abstractions**: 1 No. approximately 155m northeast of the shaft.	Relevant exploratory boreholes: BHP06 (shaft location) and BHP05 (~80m from shaft centre) Groundwater monitoring installation at BHP06 within Chalk at 7.0 to 12.6 mbgl recorded groundwater at 3.91 mAOD at ground level. Similarly, an installation in the Chalk nearby in BHP05 (response zone at 5.0 to 10.6 mbgl) recorded groundwater between 3.73 and 2.69 mAOD ().56 to 1.60 mbgl). Groundwater in the Chalk may be confined, at least locally, by the Alluvium overlying it at BHP05 and possibly by the Head at BHP06. The abstraction is operated by Portsmouth Water. The permit for this abstraction (11/42/36.2/1) permits the abstraction of up to 137,000m^3 of groundwater per day for public drinking water supply from the chalk aquifer.
Mill Lane West Shaft	Secondary A Aquifer (River Terrace Deposits) Principal Aquifer (Chalk)	Medium to High	**No** Groundwater abstractions not identified within 250 m.	Relevant exploratory boreholes: BHP02 (shaft location) and BHP05 (~45m from shaft centre – details provided above) Groundwater monitoring installations at BHP02 within River Terrace Gravel (silt/clay recorded and the response zone at 1.2 to 3.0 mbgl) and in the Chalk (response zone at 6.0 to 11.6 mbgl) recorded groundwater as shallow as 3.1 mAOD (0.74 mbgl) in the former and as shallow as 2.68 mAOD (1.24 mbgl) in the latter. The difference in readings indicates the strata aren't fully hydraulically connected, which may be due to the fines content in the RTG.
Bedhampton Tunnel	Principal Aquifer (Chalk)	Medium to High	**No** **Groundwater Abstractions**: 1 No. approximately 155m northeast of Mill Lane East shaft.	Relevant exploratory boreholes: BHRP01, BHP01, BHP02, BHP05, BHP06 Groundwater monitoring installations along the length of the tunnel in both the Chalk and the overlying River Terrace Deposits (RTG) record shallow groundwater, between 1.93 and 4.62 mAOD which is between 0.19 and 2.87 mbgl from ~Ch.60 to Ch.497 and within the landfill at WRP_72 some 10 mbgl at BHRP01. The readings are very similar between the Chalk and overlying deposits, suggesting at least partial hydraulic connectivity, likely explained by the fines content of the RTG, Alluvium and Head. The abstraction is operated by Portsmouth Water. The permit for this abstraction (11/42/36.2/1) permits the abstraction of up to 137,000m^3 of groundwater per day for public drinking water supply from the chalk aquifer.
Portsdown Hill Shaft	Secondary Undifferentiated Aquifer (Head Deposits) Principal Aquifer (Chalk)	High	**No** Groundwater abstractions not identified within 250 m.	Relevant exploratory boreholes: BH301 (40m from shaft centre) A groundwater monitoring installation within Chalk at the tunnel level (^1.0 to 66.0 mbgl) recorded very low water pressures, within or slightly above the response zone. Another installation much higher in the Chalk (response zone at 34.50 to 41.10) was dry.

Purbrook Shaft	Secondary Undifferentiated Aquifer (Head Deposits) Principal Aquifer (Chalk)	High	**No** Groundwater abstractions not identified within 250 m.	Relevant exploratory boreholes: BH303 (46m from shaft centre) A groundwater monitoring installation within Chalk at the tunnel level (response zone at 62.50 to 68.00) recorded relatively high water pressures with a head of 20m to 40m above the response zone, at 26.64 mbgl to 42.48 mbgl. Another installation at much shallower depths in the Chalk (response zone at 36.00 to 46.60), gave very similar readings (24.88 mbgl to 42.40 mbgl), suggesting hydraulic continuity.
Purbrook Tunnel	Principal Aquifer (Chalk)	Medium to High becoming High at ~Ch. 950	**No** Groundwater abstractions not identified within 250 m.	Relevant exploratory boreholes: RO102, BHRP02, BH202, BH301, BH302 and BH303 Installations in the Chalk at tunnel depth along the tunnel length reveal highly variable water pressures. At BHRP02 in WRP_72, a water head of circa 20m was recorded, reducing to some 10m at BH202, a few metres at BH301, a few metres at BH302, and as much as ~20m at BH303. At BH303, water pressures varied by 15m in response to wet/ dry seasons.
Otterbourne Shafts and Tunnel	Secondary Undifferentiated Aquifer (Head Deposits and River Terrace Deposits) Principal Aquifer (Lambeth Group and Chalk)	High for Secondary aquifers	**YES** SPZ 1c along alignment but associated with deeper underlying strata (greater than 25m below shaft formation level) Groundwater abstractions not identified within 250m	Relevant exploratory boreholes: BH502, BH503, BH505, BH50, BH507 Groundwater levels are close to surface within the Head and River Terrace Deposits. Confined conditions in London Clay Formation with groundwater rising to 3mbgl from a strike depth of 10m

3.5 Geoenvironmental conditions

3.5.1 A summary of the geoenvironmental conditions encountered at each shaft is presented from paragraph 3.5.3 and a summary for the tunnels is provided from paragraph 3.5.55 (including Otterbourne shafts). It includes a summary of PSCs relevant to each site, ground investigation and its relation to these, potential hazards to human health and potential hazards to controlled waters. Further detail is provided in the GIR which should be read in conjunction with this report. Reference tables for the presence and location of relevant PSCs are provided in Table 3-4 and Table 3-5.

3.5.2 A buffer zone of 50m for potential solid contaminant sources, leachate and groundwater, and 250m for potential ground gas sources, has been used in the first instance to capture potential PSCs. These radii may be reduced depending on the pathways addressed by each Pollution Scenario.

Geoenvironmental summary for Mill Lane east shaft

PSCs

3.5.3 As shown in Table 3-4 and

3.5.4 Table 3-5, Mill Lane East Shaft is located within PSC No. 387 (Former Bedhampton Corn Mill. Two additional potential solid contaminant sources are within 50m of the shaft: PSC No. 391 some 10 to 25m from the shaft centre (railway, embankment and siding) and PSC No. 383 circa 45m from the shaft centre (building and potential siding).

3.5.5 All these PSCs are also a potential ground gas source with an additional 4 potential sources between 125 and 215m from the shaft centre. They include infilled ponds and watercourses, marshland and Bedhampton Waterworks landfill (185m away).

Ground investigation

3.5.6 BHP06 is located approximately 8.5m from the proposed shaft centre and within PSC No. 387.

3.5.7 TPP05-DS is also within 50m of the shaft although not within a PSC.

3.5.8 Between 50m and 250m from the shaft centre BHP05, BHP02 and BH101 were excavated. Only BHP05 was located within a PSC (No. 387).

Potential hazards to human health within the on-site soils (50m buffer)

3.5.9 Soil samples in BHP06 and TPP05-DS were tested and assessed against generic assessment criteria (GACs) protective of human health [2] [3] at multiple depths and strata in each hole. There were no soil contaminant concentrations in excess of human health GACs.

Potential hazards to human health from contaminated leachate and groundwater (drinking water standards) (50m buffer)

3.5.10 Regarding potential hazards to human health from contaminated leachate, no soil leachate tests were carried out in either exploratory hole within 50m of the shaft centre.

3.5.11 Regarding potential hazards to human health from contaminated groundwater, it was sampled and tested in BHP06 at 0.85m in Head deposits and at 5.0m depth in River Terrace Gravel. Drinking water exceedances were found in BHP06 at 5.0m depth for **manganese** (120 µg/l compared to GAC of 50 µg/l).

Potential hazards to controlled waters receptors (EQS) from contaminated leachate and groundwater

3.5.12 Regarding potential hazards to controlled waters receptors from contaminated leachate, no soil leachate tests were carried out in either exploratory hole within 50m of the shaft centre.

3.5.13 Regarding potential hazards to controlled waters receptors from contaminated groundwater, Environmental Quality Standards exceedances were found in both BHP06 samples. For the sample from 0.85m depth, exceedances were identified for c**opper** (2 µg/l compared to a GAC of 1 µg/l) and z**inc** (18 µg/l compared to a GAC of 10.9 µg/l). For the sample at 5.0m depth exceedances were identified for n**ickel** (5 µg/l compared to a GAC of 4 µg/l).

3.5.14 Note, there are two surface water bodies relatively close to the shaft, at a distance of approximately 25m and 35m.

Potential hazards to human health from contaminated ground gas (250m buffer for potentially infilled land)

3.5.15 The closest borehole fitted with ground gas monitoring equipment was BHP02, which is some 135m from the shaft centre and not within any PSCs. The deeper response zone (6.0 to 11.6mbgl) was always flooded at the time of monitoring. British Standard 8485:2015 +A1:2019 states "*the response zone of the gas monitoring standpipe should be wholly or partly above groundwater level to provide valid data" and "if water is present above the top of the slotted section of the gas standpipe, any peak flow recorded is likely to be due to a build-up of pressure caused by rising water trapping the gas within the solid section of pipe; in this case, the initial peak flow is not representative of the rate of gas generation within the ground*". Similarly, a negative peak flow can be caused by water levels falling within a sealed standpipe. On this basis, the results of the ground gas monitoring undertaken at this depth is not considered to be representative of the gas regime.

3.5.16 The shallower installation (response zone between 1.2 and 3 mbgl) was often dry and recorded elevated CO_2 (up to 3.6 % vol.) and depleted O_2 (7.6 to 15.5 %vol.), beyond exceedance thresholds. However, the gas flow rates were negligible (less than 0.1 l/hr).

3.5.17 In the absence of significant ground gas flow (greater than ±3 l/hr), or methane concentrations in excess of 0.1 %vol it is considered that ground gases from this area are not migrating to the shaft area and a hazard to human health is not present.

3.5.18 According to the Site History, the Mills associated with PSC 387 were decommissioned by 1932 and the railway associated with PSC 391 and 383 was constructed more than 100 years ago. In all cases, it is considered that the potential for these sources to still be generating landfill gases is negligible. Further, there is no evidence of deeply infilled ground within these PSCs, that could have caused migrating ground gas to accumulate under the site within the River Terrace Deposits and trapped by the Head above, not able to vent to the surface. These PSCs are therefore not considered to present a credible ground gas hazard to human health.

Geoenvironmental summary for Mill Lane west shaft

PSCs

3.5.19 As shown in Table 3-4 and

3.5.20 Table 3-5, Mill Lane West Shaft is located some 20m and 25m from a former corn mill (No. 387) and a railway line in a cutting (No. 391), respectively. Both are potential solid and gas contaminant sources.

3.5.21 There are three additional potential gas contaminant sources located between 75m and 230m from the proposed shaft centre, that is PSC No. 417, 429 and 372 which include a potentially infilled watercourse and marshland.

Ground investigation

3.5.22 BHP02 is located approximately 11m from the proposed shaft centre but not within a PSC. BHP05 is circa 45m from the shaft centre within PSC No. 387.

3.5.23 Between 50m and 250m from the shaft centre, 2B1500SA, BHP06, TPP05-DS and TPP02 were excavated. However, none were located within any of the potential sources of gas contamination.

Potential hazards to human health within the on-site soils (50m buffer)

3.5.24 Soils were sampled at four depths in BHP02, from between 0.1 and 4.6mbgl. In BHP05 they were sampled from five depths, from between 0.3 and 6.5mbgl. There were no soil contaminant concentrations found to be in excess of human health GACs.

Potential hazards to human health from contaminated leachate and groundwater (drinking water standards) (50m buffer)

3.5.25 Regarding potential hazards to human health from contaminated leachate, no soil leachate tests were carried out in either exploratory hole within 50m of the shaft centre.

3.5.26 Regarding potential hazards to human health from contaminated groundwater, it was sampled and tested in BHP02 at 1.36mbgl in River Terrace Deposits, and at 6.0 and 6.3 mbgl in Newhaven Chalk Formation.

3.5.27 Drinking water exceedances were found in the samples from 1.36 and 6.3 mbgl, for various species of **aliphatic and aromatic hydrocarbons** (ranging between 50 to 580 µg/l per species compared to GAC of 10 µg/l per species).

Potential hazards to controlled waters receptors (EQS) from contaminated leachate and groundwater

3.5.28 Regarding potential hazards to controlled waters receptors from contaminated leachate, no soil leachate tests were carried out in either exploratory hole within 50m of the shaft centre.

3.5.29 Regarding potential hazards to controlled waters receptors from contaminated groundwater, no Environmental Quality Standards exceedances were identified in the samples tested.

Potential hazards to human health from contaminated ground gas (250m buffer for potentially infilled land)

3.5.30 The closest borehole fitted with ground gas monitoring equipment was BHP02, which is approximately 11m from the shaft centre and not within any PSCs. The deeper response zone (6.0 to 11.6mbgl) was always flooded at the time of monitoring and the monitoring is therefore not valid. The shallower installation (response zone between 1.2 and 3 mbgl) was often dry and recorded elevated CO_2 (up to 3.6 % vol) and depleted O_2 (7.6 to 15.5 %vol), beyond exceedance thresholds. Gas flow rates were negligible (less than 0.1 l/hr).

3.5.31 According to the Site History, the Mills associated with PSC 387 were decommissioned by 1932 and the railway associated with PSC 391 was constructed more than 100 years ago. In both cases, it is considered that the potential for these sources to still be generating landfill gases is negligible. Further, there is no evidence of deeply infilled ground within these PSCs, that could have caused migrating ground gas to accumulate under the site within the Chalk and trapped by the cohesive River Terrace Deposits above, not able to vent to the surface. These PSCs are therefore not considered to present a credible ground gas hazard to human health.

3.5.32 At 2B1500SA circa 190m from the proposed shaft centre, ground gas monitoring took place for a response zone between 1 and 7mbgl in Alluvium, Head cand River Terrace Deposits. Both exceeded allowable thresholds. CO_2 was recorded at between less than 0.1 to 4.3% and O_2 measured between 12.7 and 20.9%. However, the flow rate of -0.1 l/hr was negligible and in the absence of significant ground gas flow (greater than ±3 l/hr), or methane concentrations in excess of 0.1 %vol it is considered that ground gases from this area are not migrating to the shaft area and a hazard to human health is not present from this source.

Geoenvironmental summary for Portsdown Hill shaft

PSCs

3.5.33 As shown in Table 3-4 and

3.5.34 Table 3-5, Portsdown Hill Shaft is located within PSC No. 308 (land north of reservoirs) and circa 35m from PSC No. 306 (an old chalk quarry and pit), which are both a potential solid contamination sources.

3.5.35 These two PSCs are also a potential ground gas source, with two additional potential sources within 250m of the shaft centre, some 50m and 180m away. The former is a Filtration Works and the latter is a reservoir.

Ground investigation

3.5.36 The closest exploratory holes to the shaft are BH301 and 301A which were excavated 35m from the shaft centre and not within any PSC. There is only one borehole, 2D2500SA (175m from the shaft centre), between 50m and 250m from the shaft centre, located within PSC Nos. 306 and 361.

3.5.37 There are no exploratory holes within PSC No. 308 within which the shaft is located.

Potential hazards to human health within the on-site soils (50m buffer)

3.5.38 Soil samples from 0.3, 0.65 and 2.8 mbgl in BH301 were tested and assessed against GACs.

3.5.39 Regarding potential hazards to human health within the on-site soils, there were no soil contaminant concentrations in excess of human health GACs.

Potential hazards to human health from contaminated leachate and groundwater (drinking water standards)

3.5.40 Regarding potential hazards to human health from contaminated leachate, soil leachate tests were carried out at 0.65m depth in Head deposits. No exceedances of GACs were identified.

3.5.41 Regarding potential hazards to human health from contaminated groundwater, it was sampled and tested three times between 62 and 62.36 mbgl. Drinking Water Standards exceedances were found in all three samples. They included **chloride** (373000 µg/l compared to a GAC of 250000 µg/l), **sodium** (276000 compared to a GAC of 200000 µg/l), and various species of **aliphatic and aromatic hydrocarbons** (ranging between 50 and 550 µg/l per species compared to GAC of 10 µg/l per species).

Potential hazards to controlled waters receptors (EQS) from contaminated leachate and groundwater

3.5.42 Regarding potential hazards to controlled waters receptors from contaminated leachate, Environmental Quality Standards exceedances were found for **copper** (9 µg/l compared to a GAC of 1 µg/l).

3.5.43 Regarding potential hazards to controlled waters receptors from contaminated groundwater, Environmental Quality Standards exceedances were found in all three samples. They included **cadmium** (0.1 µg/l compared to a GAC of 0.08 µg/l), **copper** (between 4 and 5 µg/l compared to a GAC of 1 µg/l), **lead** (2 µg/l compared to a GAC of 1.2 µg/l), **nickel** (7 µg/l compared to a GAC of 4 µg/l), Zinc (37 and 157 µg/l compared to a GAC of 10.9 µg/l) and **fluoranthene** (0.01 and 0.05 µg/l compared to a GAC of 0.0063 µg/l).

3.5.44 Note, there are no surface water bodies in close proximity to the shaft, therefore no credible pathway for contaminants at 0.65m depth to reach and harm such environments.

Potential hazards to human health from contaminated ground gas (250m buffer for potentially infilled land)

3.5.45 BH301A was fitted with gas monitoring equipment at some 35m and 60 mbgl in the chalk aquifer. These response zones were not flooded, and gas monitoring data is valid. The shallower response zone recorded exceedances **for CO_2 and O_2, with CO_2** measurements as high as 2.1 %vol and O_2 as low as 13.4 %. However, flow rates were negligible at 0.1 l/hr.

3.5.46 At 2D2500SA circa 175m from the proposed shaft centre, ground gas monitoring took place for a response zone between 1 and 10 mbgl in Chalk, which was dry on every groundwater monitoring occasion. **CO_2** exceedances of up to 2.3 %vol and **O_2** exceedances of as low as 14.6 %vol were recorded. However, flow rates were negligible at 0.1 l/hr.

3.5.47 No gas monitoring has been carried out at PSC 308 (land north of reservoirs) but no infilling is expected based on the Site History. Source is potential Made Ground from during construction of water works i.e. over 70 years ago. Sources are shallow and likelihood of gases still being created is low.

Geoenvironmental summary for Purbrook shaft

PSCs

3.5.48 As shown in Table 3-4 and

3.5.49 Table 3-5, there are no potential solid or gaseous contaminant sources within 50m of the proposed Purbrook shaft. There are eight potential sources of gas contamination (PSCs) between 50m and 250m from the shaft centre, including reservoirs (former and active), pits and potentially infilled land.

Ground investigation

3.5.50 There are three trial pits (TP304 to 306) within 10m of the shaft centre while borehole BH303 is some 15m from the shaft centre. There are 9 additional exploratory holes between 50m and 250m from the shaft centre (3E3100DS, 3E3101TP, 2E3001RC, 3E7508IT, 3E7504IT, 3E7503IT, 3E7502IT, 2E3002RC and 3E7505IT). None are located within PSCs.

Potential hazards to human health within the on-site soils (50m buffer)

3.5.51 Soil samples from 0.1, 0.5, 0.9, 63.5 and 65.1 mbgl in BH303 were tested and assessed against GACs. Samples between 0 and 1m depth in trial pits 304 to 306 were also tested.

3.5.52 Regarding potential hazards to human health within the on-site soils, there were no soil contaminant concentrations in excess of human health GACs.

Potential hazards to human health from contaminated leachate and groundwater (drinking water standards)

3.5.53 Regarding potential hazards to human health from contaminated leachate, soil leachate tests were carried out at 1.0m depth in TP304, TP305 and TP306 in Chalk. One exceedance of **naphthalene** was identified in TP305 at 1 mbgl (8.03 µg/l compared to a GAC of 2 µg/l).

3.5.54 Regarding potential hazards to human health from contaminated groundwater, BH303 was sampled and tested three times between 44.0 and 57.5 mbgl in Chalk. Multiple exceedances of Drinking Water Standards were recorded, including **arsenic** (21-23 µg/l compared to a GAC of 10 µg/l), **Iron** (640-1440 µg/l compared to a GAC of 200 µg/l), **manganese** (1680-1900 µg/l compared to a GAC of 50 µg/l), **ammoniacal nitrogen** as NH_4 (769-2048 µg/l compared to a GAC of 500 µg/l) and various species of **aliphatic and aromatic hydrocarbons** (ranging between 21 and 550 µg/l per species compared to GAC of 10 µg/l per species).

Potential hazards to controlled waters receptors (EQS) from contaminated leachate and groundwater

3.5.55 Regarding potential hazards to controlled waters receptors from contaminated leachate, Environmental Quality Standards exceedances were found in TP305 and TP306 for Copper (2 µg/l compared to a GAC of 1) and in TP305 an exceedance for naphthalene was also recorded (8.03 µg/l compared to a GAC of 2 µg/l).

3.5.56 Regarding potential hazards to controlled waters receptors from contaminated groundwater, Environmental Quality Standards exceedances were found in all three samples. They included Iron (1420 and 1400 µg/l compared to a GAC of 1000 µg/l), Manganese (between 1680 and 1900 µg/l compared to a GAC of 123 µg/l) and Nickel (6 and 18 µg/l compared to a GAC of 4 µg/l).

Potential hazards to human health from contaminated ground gas (250m buffer for potentially infilled land)

3.5.57 BH303D was fitted with gas monitoring equipment measuring a response zone between approximately 63m and 68m in Chalk. BH303S was fitted with gas monitoring equipment measuring a response zone between circa 36m and 46m also in Chalk. The deep borehole was always flooded when gas monitoring was undertaken so the results are not reliable. For the shallower response zone, the response zone was at least partially dry on most occasions and it recorded exceedances for **CH_4, CO_2 and O_2**, with CH_4 measurements of up to 4.8 %vol. (which exceeds the Lower Explosive Limit of 4.4 %vol.), CO_2 measurements of less than 0.1 to 6.7 %vol. and O_2 of 10 to 22.0%vol were recorded and flow rates were moderate at 2.2 l/hr.

3.5.58 These results indicate a potential ground gas hazard at the shaft. The risk shall be mitigated through adopted ventilation measures.

Geoenvironmental Summary for Bedhampton pipe-jack and Purbrook tunnel

3.5.59 This section only details the factors relevant to the Pollution Scenarios to be assessed. An assessment of their relevance is presented in Section 4.7.

PSCs

3.5.60 Given the depth of the tunnels, PSCs are not relevant to the seven Pollution Scenarios assessed in this report, with the exception of PSC No. 466 – Harts Farm Landfill at the WRP which is a significantly sized, unlined landfill. The details of this potential contamination source are discussed at length in the Havant Water Recycling Plant - Land Parcel 72, Geo-Environmental Interpretative Report contained within ES Appendix 11.2 Geotechnical and geo-environmental reports, Volume II (Document reference 6.2, DCO Volume 6) and Outline FWRA. These details are of limited relevance to the Pollution Scenarios assessed in this report, except for the potentially aggressive ground conditions brought about by the landfill.

Ground investigation

3.5.61 Exploratory holes are located along the length of all three tunnels as shown in Appendix A. Samples from tunnel depth were taken and tested.

Contaminants

3.5.62 The relevance of each Pollution Scenario to the tunnels assessed in this report, is described in Section 4.7. For the Pollution Scenarios that are to be assessed, only the potential hazard from soil contaminants is relevant.

3.5.63 As detailed in the GIR, there are no exceedances of GAC for soils along any of the tunnel routes.

Geoenvironmental summary for Otterbourne tunnel and shafts

3.5.64 This section only details the factors relevant to the Pollution Scenarios to be assessed. An assessment of their relevance is presented in Section 4.7.

PSCs

3.5.65 Given the depth of the tunnel, PSCs are not relevant to the seven Pollution Scenarios assessed in this report, with the exception of Bugle Farm Landfill which is a small sized, unlined landfill. The details of this potential contamination source are discussed at length in the Geo-environmental Interpretative Report for the Phase 0 Ground Investigation (Tunnels and Shafts) contained within ES Appendix 11.2 Geotechnical and geo-environmental reports, Volume II (Document reference 6.2, DCO Volume 6). These details are of limited relevance to the pollution scenarios assessed in this report, except for the potentially aggressive ground conditions brought about by the landfill.

Ground investigation

3.5.66 Exploratory holes are located along the length of the tunnel as shown in Appendix A.

Potential hazards to human health within the on-site soils (50m buffer)

3.5.67 Regarding potential hazards to human health within the on-site soils, there were no soil contaminant concentrations in excess of human health GACs.

Potential hazards to human health from contaminated leachate and groundwater (drinking water standards)

3.5.68 Regarding potential hazards to human health from contaminated leachate, soil leachate tests were carried out at in TP504, TP505, TP506, TP507, TP508, TP509, BH503, BH5054 and BH506. Exceedance of thresholds for **fluoride** were identified in TP507 at 0.5 mbgl and BH504 at 31m depth.

3.5.69 Regarding potential hazards to human health from contaminated groundwater, BH504 recorded exceedance of the drinking water standard for **petroleum hydrocarbons** at 31m depth.

Potential hazards to controlled waters receptors (EQS) from contaminated leachate and groundwater

3.5.70 No exceedances of environmental quality standards were noted.

Potential contaminant sources

3.5.71 Table 3-4 provides a summary of the potential solid contaminant sources affecting each shaft, for which a 50m buffer zone has been allowed for the assessment.

3.5.72 Table 3-5 provides a summary of the potential ground gas sources affecting each shaft, for which a 250m buffer zone has been allowed for the assessment.

Table 3-4 Potential solid contaminant source (up to 50m from shaft)

Shaft Name	Solid Contaminant Sources ≤50m	Approx. dist. from shaft /m	Potential Contaminants
Mill Lane East	PSC 387: Former Bedhampton Corn Mill.	0	Metals, inorganics, asbestos, petroleum hydrocarbons, PAHs, benzene, toluene, ethylbenzene (BTEX).
	PSC 391: Railway Land with embankment and siding.	10-25	Petroleum hydrocarbons, metals, polycyclic aromatic hydrocarbons (PAHs), asbestos, pesticides/herbicides.
	PSC 383: Building with railway siding - potential Made Ground/Fill.	45	
Mill Lane West	PSC No. 387: Former Bedhampton Corn Mill.	20	Metals, inorganics, asbestos, petroleum hydrocarbons, PAHs, benzene, toluene, ethylbenzene, xylenes (BTEX).
	PSC No. 391: Railway Line in cutting. Potential for Made Ground/Fill.	25	Petroleum hydrocarbons, metals, polycyclic aromatic hydrocarbons (PAHs), asbestos, pesticides/ herbicides.

Portsdown Hill Shaft	PSC No. 308: Land north of reservoirs - potential Made Ground/Fill.	0	Metals, inorganics, petroleum hydrocarbons, asbestos, polycyclic aromatic hydrocarbons (PAHs), benzene, toluene, ethylbenzene (BTEX) and total phenols.
	PSC Nos.306 and 361: Old chalk quarry and pit - potential for Made Ground/Fill.	32	Same as PSC 308.
Purbrook Shaft	none	NA	NA
Otterbourne Shafts	Infilled gravel pit at Bugle Farm	10m	Metals, inorganics, petroleum hydrocarbons, asbestos, polycyclic aromatic hydrocarbons (PAHs), benzene, toluene, ethylbenzene (BTEX) and total phenols.

Table 3-5 Potential ground gas sources (up to 250m from shaft)

Shaft Name	Ground gas sources ≤250m	Approx. dist. from shaft /m
Mill Lane East	PSC 387: Corn Mills	0
	PSC 391: Railway Land with embankment and siding	10-25
	PSC 383: Building with railway siding. Potential for Made Ground/Fill during construction.	45
	PSC 417: Infilled Watercourse	170
	PSC 416: Bedhampton Waterworks Landfill	185
	PSC 384: Infilled Pond/Watercourse	125
	PSC 429: Marshland	200
	PSC 393: Infilled Pond	180
	PSC 386: Infilled Watercourse	215
Mill Lane West	PSC No. 387: Former Bedhampton Corn Mill - potential for Made Ground/Fill.	20
	PSC No. 391: Railway Line in cutting - potential for Made Ground/Fill during construction.	25
	PSC No. 417: Possible infilled watercourse	75
	PSC No. 429: Marshland	140
	PSC No. 372: Marshland - potential for Made Ground/Fill.	230

Portsdown Hill Shaft	PSC No. 308: Land north of reservoirs (Portsmouth Water). Potential for Made Ground/Fill material during construction.	0
	PSC No. 307: Reservoirs (Portsmouth Water) - potential for Made Ground/Fill. Likely storage of chemical and bulk fuels.	180
	PSC No. 309: Filtration works (Portsmouth Water) - potential for Made Ground/Fill. Likely storage of chemical and bulk fuels.	50
	PSC Nos.306 and 361: Old chalk quarry and chalk pit - potential for Made Ground/Fill.	35
Purbrook Shaft	PSC No. 358: Active Reservoir (covered)	100
	PSC No. 319: Former Reservoir	140
	PSC No. 314: The Dell Pit	65
	PSC No. 499: Infilled Land	100
	PSC No. 262: Pit potentially infilled	165
	PSC No. 315: Infilled Pond	195
	PSC No. 313: Chalk Pit	240
	PSC No.367: Chalk Pit	160
Otterbourne Shafts	Infilled gravel pit at Bugle Farm	10m

4 Outline foundation works risk assessment

4.1 Purpose

4.1.1 The purpose of this Outline FWRA is to ensure that the construction of the shafts and tunnels would not have an adverse impact on the environment by creating new pathways for the migration of contamination, considering the protection of both water resources and human health. The need for a Foundation Works Risk Assessment is set out in ES Chapter 11 Land quality and ground conditions, Volume I (Document reference 6.1, DCO Volume 6) as a risk reduction measure.

4.2 Proposed development

4.2.1 At the time of writing, the exact shaft and tunnel construction methodology is unknown and will be developed by the Contractor during detailed design. Further, the tunnels and therefore the shafts may also alter their location within the set Limits of Deviation. This Outline FWRA has assessed a "worst case" design envelope and any changes to the design are expected to result in more significant effects. This assessment will be updated by the Contractor during their development of the shaft design, any changes to the location of these structures, changes to proposed construction methodology and any additional ground investigation and laboratory testing that becomes available.

4.3 Climate change

4.3.1 The EA's Land Contamination Risk Management guidance (Environment Agency, 2023) [5] recommends the incorporation of climate change considerations into land contamination risk assessment and the options appraisal process to ensure Site works and any long-term remediation are sustainably robust and endure future climate change events.

4.3.2 Climate change requires the design and implementation of land contamination risk management reduction measures to account for Extreme Weather Events (EWE). EWE considers not just the general increase in magnitude such as temperature but also the intensity such as increasingly intense precipitation causing run-off or short-term groundwater level rise or surface flooding.

4.3.3 In relation to this Outline FWRA, the existing baseline conditions could evolve through changes to long term groundwater levels, increased tidal variability due to rising sea levels, and increased seasonal variations of groundwater levels potentially affecting structures and other elements of the project that interact with the ground. EWEs leading to more frequent and higher intensity precipitation, or hotter drier conditions could lead to increased erosion/deterioration of unprotected natural surfaces.

4.3.4 Consideration of the potential effects of climate change have been conducted during the design of the project, and suitable design parameters have been adopted to account for any potential adverse impacts from climate change.

4.4 Methodology

4.4.1 The adopted methodology follows the recommendations of the National Groundwater and Contaminated Land Centre report NC/99/73: 'Piling and penetrative ground improvement methods on land affected by contamination: Guidance on pollution prevention' [4].

4.4.2 Table 4-1 presents the methodology for assessment of source significance. A value between 1 (Very Low) and 5 (Very High) is assigned, based upon professional judgement taking account of factors such as historical land use, gas generation potential, and the results of any ground investigation.

Table 4-1 Criteria for classifying source significance

Classification/Score	Potential for generating contamination/gas based on land use
Very Low 1	Land Use: Residential, retail or office use, agriculture Contamination: Limited. Gas generation potential: Soils with low organic content
Low 2	Land Use: Recent small scale industrial and light industry Contamination: locally slightly elevated concentrations. Gas generation potential: Soils with high organic content (limited thickness)
Moderate 3	Land Use: Railway yards, collieries, scrap yards, engineering works. Contamination: Possible widespread slightly elevated concentrations and locally elevated concentrations. Gas generation potential: Dock silt and substantial thickness of organic alluvium/peat
High 4	Land Use: Heavy industry, non-hazardous landfills. Contamination: Possible widespread elevated concentrations. Gas generation potential: Shallow mine workings Pre 1960s landfill
Very High 5	Land Use: Hazardous waste landfills, gas works, chemical works, Contamination: Likely widespread elevated concentrations. Gas generation potential: Landfill post 1960

4.4.3 Table 4-2 presents the criteria for assessment of receptor sensitivity, showing how for various receptors, a sensitivity value between 1 (Very Low) to 5 (Very High) is assigned using professional judgement.

Table 4-2 Criteria for classifying receptor sensitivity

Classification	Definition
Very Low 1	Receptor of limited importance • Groundwater: Unproductive strata (Strata with negligible significance for water supply or river baseflow) (previously Non-aquifer), Secondary B (water-bearing parts of non-aquifers), Secondary undifferentiated (previously minor or non-aquifer, but information insufficient to classify as secondary A or B) • Surface water: Water Framework Directive (WFD) Surface Water status Bad • Ecology: No local designation • Buildings: Replaceable • Human health: Unoccupied/limited access
Low 2	Receptor of local or county importance with potential for replacement • Groundwater: Secondary A aquifer • Surface water: WFD Surface Water status Poor

	• Ecology: local habitat resources • Buildings: Local value • Human health: Minimum score 4 where human health identified as potential receptor
Moderate 3	Receptor of local or county importance with potential for replacement • Groundwater: Principal aquifer • Surface water: WFD Surface Water status Moderate • Ecology: County wildlife sites, Areas of Outstanding Natural Beauty (AONB) • Buildings: Area of Historic Character • Human health: Minimum score 4 where human health identified as potential receptor
High 4	Receptor of county or regional importance with limited potential for replacement • Groundwater: Source Protection Zone (SPZ) 2 or 3 • Surface water: WFD Surface Water status Good • Ecology: SSSI, National or Marine Nature Reserve (NNR or MNR) • Buildings: Conservation Area • Human health: Minimum score 4 where human health identified as potential receptor
Very High 5	Receptor of national or international importance • Groundwater: SPZ 1 • Surface water: WFD Surface Water status High • Ecology: Special Areas of Conservation (SAC and candidates), Special Protection Areas (SPA and potentials) or wetlands of international importance (RAMSAR) • Buildings: World Heritage site • Human health: Residential, open spaces and uses where children are present

4.4.4 The assigned numerical values for source significance and receptor sensitivity are multiplied together to give a classification of consequence, as summarised below:

- Minor – 1 to 4
- Mild – 5 to 9
- Medium – 10 to 16
- Severe – 17 to 25

4.4.5 Probability is assigned a value between 'Unlikely' and 'High Likelihood' as defined in Table 4-3 [5].

Table 4-3 Classification of probability

Classification	Definition
High Likelihood	There is a contaminant linkage and an event that appears either very likely in the shortterm and almost inevitable over the long term, or there is evidence at the receptor of harm or pollution.
Likely	There is a contaminant linkage, and all the elements are present and in the right place,which means that it is probable that an event will occur. Circumstances are such that an event is not inevitable, but possible in the short term,and likely over the long term.
Low Likelihood	There is a contaminant linkage and circumstances are possible under which an eventcould occur. However, it is by no means certain that even over a longer period such event would takeplace and is less likely in the shorter term.
Unlikely	There is contaminant linkage, but circumstances are such that it is improbable that anevent would occur even in the long term.

4.4.6 The matrix below is then used to combine the assessed values for probability and consequence.

Table 4-4 Matrix for classifying risk (combination of probability and consequence)

Probability	Consequence			
	Severe	***Medium***	***Mild***	***Minor***
High likelihood	Very high	High	Moderate	Moderate/Low
Likely	High	Moderate	Moderate/Low	Low
Low likelihood	Moderate	Moderate/Low	Low	Very low
Unlikely	Moderate/Low	Low	Very low	Very low

4.4.7 The Outline FWRA has been conducted for the shaft and tunnel construction methods described in Section 2 above.

4.5 Pollution scenarios

4.5.1 The guidance (CL:AIRE, 2025) considers seven pollution scenarios with respect to piling and penetrative ground improvement methods:

1. Creation of preferential pathways, through a low permeability layer, to cause contamination of groundwater in an aquifer.
2. The driving of solid contaminants down into an aquifer during pile driving.
3. Contamination of groundwater and subsequently surface waters by turbidity, support fluids such as bentonite, concrete, cement paste or grout.
4. Direct contact with contaminated soil or leachate causing degradation of pile materials.
5. Creation of preferential pathways to allow migration of landfill gas or contaminant vapours to surface.
6. Causing off-site migration of ground gas or increased vertical emissions as a result of vibration or other effects from the pile installation process.
7. Direct contact with contaminated soil arisings that have been bought to the surface.

4.5.2 The assessed risks associated with each pollution scenario are presented in the following sections.

4.6 Outline FWRA for shafts

Pollution scenario 1

4.6.1 Pollution scenario 1 considers the creation of preferential pathways, through a low permeability layer (an aquitard), to allow potential contamination to migrate into an underlying aquifer.

4.6.2 Assessment of this pollution scenario has been provided when the following conditions are met:

- The proposed structure will encounter groundwater, and the construction of the structure involves elements that will extend through a low permeability layer between a shallow and a deep aquifer. *And*,
- The ground investigation has identified contamination that could migrate to a deeper aquifer if an aquiclude were punctured. *or,*
- A credible potential source of contamination has been identified but was not investigated during the recent ground investigations.

4.6.3 Table 4-5 presents the screening process for shafts which are to be carried forward for assessment under this pollution scenario.

Table 4-5 Summary of proposed structures to be assessed under pollution scenario 1

Shaft	Structure will encounter groundwater and extend through an aquitard to a lower aquifer	Contamination has been identified that could migrate to a deeper aquifer if an aquiclude were punctured?	A credible PSC has been identified but was not investigated during the recent ground investigations.	Carry forward to assessment?
Mill Lane East	Yes – Groundwater is shallow and structure will penetrate shallow, cohesive Head/Alluvium (aquiclude)) before entering the granular River Terrace Deposits and Chalk aquifer below.	Yes – Copper and Zinc contamination of groundwater at 0.85m depth (according to EQS GACs only). Small probability of entering watercourses nearby from River Terrace Deposits	Yes – PSC Nos. 383 and 391 are within 50m of the shaft and were not investigated.	**Yes**
Mill Lane West	Yes – Groundwater is shallow and structure will penetrate cohesive River Terrace Deposits (aquiclude) before entering the Chalk aquifer below.	Yes – Significant hydrocarbon contamination of groundwater at 1.36m depth in cohesive River Terrace Deposits (according to DWS GACs).	Yes – PSC No. 391 is within 50m of the shaft and was not investigated.	**Yes**
Portsdown Hill Shaft	Yes – Groundwater is shallow and structure will penetrate cohesive Head deposits (aquiclude) before entering the Chalk aquifer below.	Yes – Copper contamination of leachate at 0.65m depth in Head deposits. However, exceedance of EQS GACs only. No surface water bodies nearby therefore not a credible hazard.	Yes – PSC Nos. 343 and 308 are within 50m of the shaft and were not investigated.	**Yes**
Purbrook Shaft	No - groundwater is very deep, much deeper than aquiclude and only slightly above tunnel level	No – No contaminants identified within or shallower than the aquiclude (Head deposits)	No – No PSC Nos. within 50m of shaft.	No

Shaft	Structure will encounter groundwater and extend through an aquitard to a lower aquifer	Contamination has been identified that could migrate to a deeper aquifer if an aquiclude were punctured?	A credible PSC has been identified but was not investigated during the recent ground investigations.	Carry forward to assessment?
Otterbourne Shafts	No – groundwater within shallow Head and Terrace Deposits but shafts and tunnel will not penetrate London Clay Formation	Minor leachate exceedance for Fluoride	Bugle Farm Landfill is likely to be greater than 50m from the shaft	No

4.6.4 Based on the screening process, Mill Lane East and West shafts and Portsdown Hill Shaft are conservatively taken forward for risk assessment under Pollution Scenario 1. It should be noted that Mill Lane East and Portsdown Hill Shaft have been assessed based on environmental quality standard (EQS) exceedances only and a lack of sampling and testing within credible PSCs.

4.6.5 The risk assessment has been carried out in accordance with the guidance set out in Section 4.4.

Source significance

4.6.6 The significance of identified or potential contaminants at each shaft location has been rated and is shown in Table 4-6. A conservative assessment has been made where ground investigation data is not available.

4.6.7 Relevant contamination results from the GI are summarised in Section 3.5 and potential contaminants associated with each PSC are detailed in Table 3-4.

Table 4-6 Summary of contaminant sources at each shaft and their significance rating

Shaft name	Mill Lane east	Mill Lane west	Portsdown Hill
Land Use (50m radius from shaft)	On-site: former Corn Mill (now green open space) Off-site: railway, embankment siding and related building	On-site: green open space Off-site: former Corn Mill and a railway in cutting	On-site: land within Farlington Water Treatment Works Off-site: old chalk quarry and pit (potential Made Ground/fill)
Contamination	Locally slightly elevated concentrations (GI). Not all potential sources tested.	Possible widespread slightly elevated concentrations and locally elevated concentrations. Not all potential sources tested.	Unknown. Ground investigation not carried out at/ close to shaft location and not within any PSCs.
Significance	**Low to Moderate**	**Moderate**	**Moderate to Very High**
Comment	Conservative assessment based on lack of GI data.	-	The shaft is close to an old pit which may contain landfill. GI data is not sufficient to confirm absence of hazardous landfill ('Very High' significance).

Pathway summary

4.6.8 For all shafts taken through to assessment for Pollution Scenario 1, construction would involve penetration of an aquiclude down into an aquifer below. Therefore, there is theoretically potential for preferential flow pathways to be created at the interface between the shaft and the surrounding soils, allowing contaminants to migrate into aquifers. The likelihood of this pathway forming depends on the quality of contact between the shaft and the surrounding soils. Table 4-7 summarises the likely construction methods for each shaft and the quality of contact that can be achieved.

Table 4-7 Potential pathway assessment for each shaft

Shaft name	Mill Lane east	Mill Lane west	Portsdown Hill
Pathway	Shaft/ soil interface		
Likely shaft construction method	Precast segmental lining	Precast segmental lining	Diaphragm Wall
Expected quality of contact between shaft and surrounding soils	High	High	Very high – 'intimate'

4.6.9 Details of the proposed shaft construction method are included from paragraph 2.2.16. The best contact can be expected with the diaphragm wall method, because the wall is poured into a trench and the stability of that trench and integrity of the trench wall is maintained through the use of cut-off walls and bentonite slurry. A high level of contact can still be achieved with precast segmental lining because grout is injected into the space between the segments and the surrounding soil.

Receptor summary

4.6.10 Table 4-8 shows the potential receptors at each shaft and their Sensitivity rating. All penetrate a Principal Aquifer or Secondary A Aquifer. Three are within or very close to a Source Protection Zone and have therefore been assigned a 'Very high' Sensitivity rating, with the remaining two assigned 'Moderate'.

Table 4-8 Summary of potential receptors at each shaft and their sensitivity rating

Shaft name	Mill Lane east	Mill Lane west	Portsdown Hill
Upper aquifer designation	Secondary A Aquifer (RTDs)	Secondary A Aquifer (RTDs)	Principal Aquifer (Chalk)
Lower aquifer designation (where applicable)	Principal Aquifer (Chalk) A Zone 1 Source Protection Zone is approximately 35m to the north.	Principal Aquifer (Chalk)	-
Groundwater abstractions	One located ~155m NE	None within 250m of shaft	None within 250m of shaft
Surface Water bodies / Watercourses	Hermitage Stream and Brookside Road Streams located circa 25m and 35m from shaft centre	Hermitage Stream and Brookside Road Streams located circa 75m and 85m from shaft centre	✘
Sensitivity	**Very high**	**Moderate**	**Moderate**
Comment	Conservative because just outside a SPZ 1 and 155m from abstraction	Based on Principal Aquifer. More than 150m from SPZ	

Shaft name	Mill Lane east	Mill Lane west	Portsdown Hill
	point		

Risk assessment summary

4.6.11 Finally, the overall risk of the pollution event has been assessed and is presented in Table 4-9. Risk is based on the Consequence classification (derived from Source Significance and Receptor Sensitivity) and the Likelihood of the pollution 'event' occurring.

4.6.12 On the basis of the proposed outline construction methodology, a likelihood of 'Low' has been assigned for all cases of shaft construction, i.e. *'Circumstances are such that it is by no means certain than an event would occur even over a longer period, and it is less likely in the short-term'.* The final risk assessed for all shafts is either 'Low' or 'Moderate/ Low'.

Table 4-9 Risk assessment summary for each shaft

Shaft Name	Mill Lane east	Mill Lane west	Portsdown Hill
Source Significance	2 to 3 (Low to Moderate)	3 (Moderate)	3 to 5 (Moderate to Very High)
Receptor Sensitivity	5 (Very high)	3 (Moderate)	3 (Moderate)
Consequence classification	10 to 15 (Medium)	9 (Mild)	9 to 15 (Mild to Medium)
Likelihood	Low	Low	Low
Risk of Pollution Scenario being realised	**Moderate/ low**	**Low**	**Moderate/ low**
Comments	-	-	Worst case consequence assumed

4.6.13 It should be noted that Mill Lane East and Portsdown Hill Shaft have been carried forward for assessment based on EQS exceedances only and a lack of sampling and testing within credible PSCs. These shafts have also been given the highest risk ratings. However, it may be possible to reduce this risk rating in future should more GI and testing data become available.

4.6.14 It is suggested that in any case this assessment is revised following development of the shaft construction methodology.

Pollution scenario 2

4.6.15 Pollution scenario 2 considers the driving on of solid contaminants down into an aquifer.

4.6.16 Contaminated solid waste has not been identified at any shaft location. Additional GI is recommended at Bedhampton Springs and Portsdown Hill shafts and could confirm the absence of contaminated solid waste. However, such waste is not expected given their historical land use as green space, a recreation ground and undeveloped land on the fringes of a water works, respectively. Therefore, this

Pollution Scenario has not been assessed further. Should such waste be discovered then this pollution scenario should be re-assessed.

4.6.17 It is noted that it is unlikely that solid contaminated waste encountered within any on-site soils during shaft excavation would be driven downwards into an aquifer and not brought to the surface as arisings for disposal off-site, given the outline proposed construction methods.

Pollution scenario 3

4.6.18 Pollution scenario 3 considers the contamination of groundwater and, subsequently, surface waters by wet concrete, cement paste, or grout. For completeness, bentonite and additives and turbidity caused by disturbance of natural ground have also been considered.

4.6.19 Assessment of this pollution scenario has been provided when the following conditions are met:

- The proposed structure will encounter groundwater and,
- A receptor that could be impacted has been identified, e.g., an aquifer that is being abstracted from, or a watercourse that is anticipated to be in hydraulic continuity with the surrounding groundwater

4.6.20 The first condition is detailed in pollution scenario 1 from paragraph 4.6.1. All shafts will be regarded as fulfilling this condition and encountering groundwater, including Portsdown Hill Shaft which only had a small head of water above tunnel level, but nonetheless was not dry. Table 4-8 presents data regarding critical receptors, which are present at all shaft locations. Therefore, all shafts will be taken forward for risk assessment under pollution scenario 3.

Source summary

4.6.21 There are three theoretical mechanisms by which shaft construction could contaminate groundwater under this scenario. Note, any flux of contaminants by these means is expected to be small and short-lived, while the construction is ongoing up to the point of the grout and concrete fully hardening.

4.6.22 A description of each, its relevance and design considerations are presented below:

Turbidity

4.6.23 This includes particulates from disturbance of natural ground and concrete/ grout particulates washed into groundwater through ground disturbance. Finer particles will migrate further in an aquifer as they are held in suspension at lower velocities and migrate through smaller pore sizes.

4.6.24 Disturbance of ground will occur during excavation, concrete casting and jacking processes are detailed from paragraph 2.2.16. However, disturbance should be relatively localised around the edges of the excavation.

Design Considerations

4.6.25 The Contractor undertaking the excavation works will update the Outline Water Monitoring Plan which forms ES Appendix 19.9, Volume II (Document Reference 6.2, DCO Volume 6). The aim of this plan is to identify significant changes to groundwater / contamination levels in key locations during construction and establish appropriate responses and actions in the event adverse impacts are identified.

4.6.26 When pouring concrete water with high pH and chloride content may bleed into the surrounding ground, as the fresh concrete is subject to high head pressures (particularly in diaphragm walls) resulting in high pore-water pressures inside the fresh concrete matrix. This can be much higher than the pore-water pressures in the surrounding soil and thus cause water to be forced out of the fresh concrete matrix into the soil matrix (Martin D. Larisch, September 2019) with the area of bleed often located at the bottom of the shaft. All shaft construction methods detailed from paragraph 2.2.16 require some concrete pouring, however the diaphragm wall will create the greatest head pressures because of the volume and height of poured concrete.

4.6.27 Additives can be added to concrete to reduce the amount of water used in the mix and thereby reduce the amount of concrete loss and bleed. The concrete mix is to be designed according to appropriate technical guidance by the Contractor and with the agreement of the EA.

4.6.28 The concrete mix composition has not yet been designed, however Clause 1604.7 of the Specification for Highway Works [6] requires that "*the concrete shall be designed so that segregation does not occur during the placing process, and bleeding of the concrete shall be minimised*". There are currently no specific requirements in the specification to control bleed but Clause B21.5.4 of the Institution of Civil Engineers (ICE) Pile Specification allows for determination of bleed in accordance with the test recommended by the Concrete Institute of Australia (CIA). The CIA recommended practice [7] gives an acceptance criterion of 15 l/m^3. [8] indicates that a suitable specification of the fine/ medium sand content, water/ cement ratio and admixtures will effectively restrict bleeding.

4.6.29 The Contractor will be required to specify the concrete mix to prevent bleed as far as is reasonably practicable. It is anticipated that this would be done by default as the Contractor would (for cost reasons) wish to reduce concrete loss.

Excess dispersal of grout and leaching of contaminants into groundwater

4.6.30 Grout would be used in considerable volumes for all shaft construction methodologies as detailed from paragraph 2.2.16. Grout is injected into the ground at relatively high pressure which can cause it to disperse widely, especially in the area of open fissures or particularly weak rock. Grout contains some potential contaminants that can leach into the groundwater so volumes injected should be kept to a minimum by avoiding wide dispersal beyond the target area.

4.6.31 Where required, a high-density grout mix (cement, gravel and bentonite) will be utilised to prevent dispersal through the rock. Grout volume should be reduced with careful preparation and methodology, including injection pressure control. The methodology for this will be agreed with the EA following detailed design.

4.6.32 Dispersal of grout can be reduced in a number of ways, for instance by altering its consistency with additives that make it more resistant to washout. A thixotropic grout can be selected, i.e. one that is fluidised upon action by vibration and pumping, and becomes stiff as pressure releases, and would prevent wide dispersal of grout into the surrounding Chalk. Grout should be properly mixed and injection pressures can be carefully administered and monitored, to ensure suitability for the ground conditions.

Bentonite breakout

4.6.33 Bentonite is a dense and viscous, thixotropic material, which stabilises excavation walls, and in the case of caisson shafts, also provides some lubrication. It is not expected to be used for underpinned segmentally lined shafts.

4.6.34 When poured the bentonite lines the excavation with a low permeability layer (or ‘filter cake’). These properties prevent it from dispersing widely beyond the excavation walls. Bentonite mud is formed from inert, non-toxic clays, that are not damaging to land surfaces and quickly break down in salt water. Breakout of bentonite mud occurs when the mud pressure in the trench exceeds the strength of the overlying/ surrounding ground resulting in mud being forced out into the surrounding formation.

4.6.35 The Contractor will develop their construction methodology to mitigate and remediate breakouts during excavation. This is likely to include the following measures.

- Limiting the volume of the breakout. The Contractor will be monitoring fluid pressure and the volume of fluid returns to allow losses to be quickly identified if they occur. When fluid losses are identified the Contractor will cease excavation and investigate if the losses are visible at surface and, if so, the location of the breakout. During the excavation a watching brief will be maintained for any signs of breakout.
- Containing the breakout. When a surface breakout has been identified, it will be contained with appropriate methods. The most appropriate methods will depend on the location of the breakout. Sandbags arranged to form a bund around the breakout are the most common method.
- Removing the breakout fluid. Typically, hand carried pumps and hoses are used to pump the fluid from the breakout location to either the entry or exit pits, or a holding tank or bowser for transfer back to the excavation.
- Sealing the breakout. Most breakouts seal themselves after either a period of time to allow the bentonite mud to gel in the fracture, or when the excavation advances, reducing the pressure of the fluid passing the fracture. In some cases, environmentally friendly additives, termed Lost Circulation Materials (LCM) are added to the drilling fluid to assist in sealing the fracture.

- Remediating the breakout. When the breakout is deemed to have been sealed, any remaining bentonite mud will be removed as far as possible, with the proviso that the cleaning process does not cause more harm or damage to the environment than leaving the fluid to dissipate and break down naturally.
- Slurry/ concrete/ grout additives.

4.6.36 Additives may be used to enhance the performance of the bentonite slurry, concrete or grout and may include polymers, clay, cement, foaming agents, thickening agents, etc. These contaminants may have potential to leach into groundwater and disperse through the aquifer.

Design considerations

4.6.37 Additives and conditioning agents should be appropriately selected with the exclusion of substances that could be hazardous to the environment. The EA should be consulted by the Contractor should any potentially hazardous additives be proposed for use.

Risk assessment summary

4.6.38 Based on these factors, a risk assessment has been undertaken for each shaft and is presented in Table 4-10 to Table 4.13. They include ratings for source Significance, receptor Sensitivity, Consequence, Likelihood and a final Risk level. The criteria for classifying source Significance is provided in Table 4-1, for receptor Sensitivity in Table 4-2, for Likelihood in Table 4-3 and for overall Risk in Table 4-4. The hydrogeology and Sensitivity factors at each location are summarised in Table 3-3 and should be referenced. Explanations and justifications are provided in the 'Comments' rows.

4.6.39 The risk assessment assumes that the 'Design Considerations' above would have been properly implemented by the Contractor during detailed design. For further construction details refer to paragraph 2.2.16 onwards.

Table 4-10 Risk assessment summary for Mill Lane east shaft[1]

Source	Turbidity	Concrete bleeding	Grout dispersal and contamination	Bentonite breakout	Additives
Source Significance	2 Low	2 Low	2 Low	2 Low	2 Low
Comment	Mechanical excavation (Very low) and jacking of caissons (Low)	Poured concrete for base slab, mass infill and finishing concrete.	Grout injected into void between segments and surrounding soil. Fissure grout may be used to assist dewatering in Chalk. Discontinuities in Chalk most susceptible.	Bentonite used in annulus during Caisson excavation. Relatively small volumes.	Could be added to concrete/ grout or bentonite. Significance limited by ratings for other sources.

Source	Turbidity	Concrete bleeding	Grout dispersal and contamination	Bentonite breakout	Additives
Receptor Sensitivity	5 Very High (conservative as not in an SPZ) (See Table 4-8: Principal Aquifer – Chalk; Hermitage and Brookside Road streams 25m to 35m from shaft flow into Langstone Harbour; Zone 1 SPZ approximately 35m to the north; and 155m from abstraction point)				
Consequence classification	**10 (Medium)**	**10 (Medium)**	**10 (Medium)**	**10 (Medium)**	**10 (Medium)**
Likelihood of reaching streams	**Unlikely**	**Unlikely**	**Unlikely**	**Unlikely**	**Unlikely**
Comments	Streams are 20 to 30m from perimeter of shaft and at a similar elevation to the ground surface in the shaft footprint. Contaminants travelling laterally in high enough concentrations to be measurable in the streams is improbable.				
Likelihood of reaching aquifer	**Likely**	**Likely**	**Unlikely**	**Low likelihood**	**Unlikely**
Comments	Assumes mitigation measures are taken to reduce the likelihood, as suggested in the Design Considerations sections/ Contaminants would be released directly into aquifer.				
Risk of Pollution Scenario being realised in streams	**Low**	**Low**	**Low**	**Low**	**Low**
Risk of Pollution Scenario being realised in aquifer	**Moderate**	**Moderate**	**Low**	**Moderate/ Low**	**Low**

Notes: Precast segmental lining expected

4.6.40 In summary, the risk of pollution scenario 3 being realised in the streams adjacent to Mill Lane east is deemed to be 'Low' and being realised in the aquifer is 'Low' to 'Moderate'.

4.6.41 It should also be noted that the receptor Sensitivity is rated very conservatively as it is only close to and not within an SPZ. A reduced Sensitivity rating from 'Very high' to 'High' would result in a consequence of 8 ('Mild'), reducing the Risk to 'Moderate/ Low' to 'Very low'.

4.6.42 Considering the small and temporary flux of contaminants expected, groundwater contamination is not expected to be measurable in the aquifer except for in the immediate vicinity of the shaft and certainly not at the abstraction wells some 155m away. Nonetheless, appropriate monitoring should be carried out should works go ahead as detailed in Section 5.2.

Table 4-11 Risk assessment summary for Mill Lane west shaft[1]

Source	Turbidity	Concrete bleeding	Grout dispersal and contamination	Bentonite breakout	Additives
Source Significance	2 Low	2 Low	2 Low	2 Low	2 Low
Comment	Mechanical excavation (Very low) and jacking of caissons (Low)	Poured concrete for base slab, mass infill and finishing concrete.	Grout injected into void between segments and surrounding soil. Fissure grout may	Bentonite used in annulus during Caisson excavation. Relatively small	Could be added to concrete/ grout or bentonite. Significance limited by ratings for other

Source	Turbidity	Concrete bleeding	Grout dispersal and contamination	Bentonite breakout	Additives
			be used to assist dewatering in Chalk. Discontinuities in Chalk most susceptible.	volumes.	sources.
Pathway	Stream receptor: **No credible pathway** – streams are 70 to 80m from shaft perimeter and available ground investigation indicates shaft surrounded by aquiclude (clay) Aquifer receptor: Migration directly into surrounding Chalk below ~3.5m depth (cohesive aquiclude above). Or along the shaft/ soil interface and into aquifer.				
Receptor Sensitivity	3 Moderate (See Table 4-8: Principal Aquifer – Chalk; Hermitage and Brookside Road streams 75m to 85m from shaft; and greater than 150m from abstraction point)				
Consequence classification	**6 (Mild)**	**6 (Mild)**	**6 (Mild)**	**6 (Mild)**	**6 (Mild)**
Likelihood of reaching aquifer	**Likely**	**Likely**	**Unlikely**	**Low likelihood**	**Unlikely**
Comments	Assumes mitigation measures are taken to reduce the likelihood, as suggested in the Design Considerations sections/ Contaminants would be released directly into aquifer.				
Risk of Pollution Scenario being realised in aquifer	**Moderate/ Low**	**Moderate/ Low**	**Very low**	**Low**	**Very low**
Comments	-	-	-	-	-

Notes: Precast segmental lining expected

4.6.43 In summary, there is a 'Very Low' to 'Moderate/ Low' risk of pollution scenario 6 being realised in the Chalk aquifer at Mill Lane west.

4.6.44 Considering the small and temporary flux of contaminants expected, groundwater contamination is not expected to be measurable in the aquifer except for in the immediate vicinity of the shaft and certainly not at the abstraction wells over 150m away. Nonetheless, appropriate monitoring should be carried out should works go ahead, as detailed in Section 5.2.

Table 4-12 Risk assessment summary for Portsdown Hill and Purbrook shafts[1]

Source	Turbidity	Concrete bleeding	Grout dispersal and contamination	Bentonite breakout	Additives
Source Significance	2 Low	2 Low	2 Low	2 Low	2 Low
Comment	Physical disturbance of soils during the vertical grab excavation process.	Poured concrete wall under high pressures but within structured Chalk rock predominantly	Grout may be used at the base of the shaft prior to dewatering. Structured Chalk expected.	Bentonite used to support wall excavation prior to concrete pouring. Under relatively high pressure but within (mostly structured) Chalk	Could be added to concrete/ grout or bentonite. Significance limited by ratings for other sources.
Pathway	Aquifer receptor: Directly into surrounding Principal Aquifer (Chalk) However, at Purbrook Shaft dry conditions are expected along most of the shaft and any contaminants at these depths will not be carried down into the aquifer/ carried down at negligible rates.				
Receptor Sensitivity	3 Moderate (See Table 4-8: Principal Aquifer (Chalk)				
Consequence classification	**6 (Mild)**	**6 (Mild)**	**6 (Mild)**	**6 (Mild)**	**6 (Mild)**
Likelihood of reaching aquifer	**Likely**	**Likely**	**Low likelihood**	**Low likelihood**	**Unlikely**
Comments	Assumes mitigation measures are taken to reduce the likelihood, as suggested in the Design Considerations sections/ Notes, at Purbrook Shaft release into the aquifer is only expected to occur near the depth of the tunnel as groundwater is very deep (See hydrogeology in Table 4-8).				
Risk of Pollution Scenario being realised in aquifer	**Moderate/ Low**	**Moderate/ Low**	**Low**	**Low**	**Very low**

Notes: Diaphragm wall expected

4.6.45 In summary at Portsdown Hill and Purbrook shafts, the risk of pollution scenario 3 being realised in the aquifer is 'Very Low' to 'Moderate/ Low'.

4.6.46 Considering the small and temporary flux of contaminants expected, groundwater contamination is not expected to be measurable in the aquifer except for in the immediate vicinity of the shaft and certainly not at abstraction wells over 250m away. This is especially the case at Purbrook shaft where groundwater is expected to be very deep.

Table 4-13 Risk assessment summary for Otterbourne shafts[1]

Source	Turbidity	Concrete bleeding	Grout dispersal and contamination	Bentonite breakout	Additives
Source Significance	2 Low	2 Low	2 Low	2 Low	2 Low
Comment	Mechanical excavation (Very low) and jacking of caissons (Low)	Poured concrete for base slab, mass infill and finishing concrete.	Grout injected into void between segments and surrounding soil.	Bentonite used in annulus during Caisson excavation. Relatively small volumes.	Could be added to concrete/ grout or bentonite. Significance limited by ratings for other sources.
Pathway	Aquifer receptor: Directly into surrounding Secondary Aquifer (Gravels) However, groundwater expected to be sealed once shafts penetrate London Clay, gravel aquifer is of limited thickness.				
Receptor Sensitivity	2 Low Secondary A Aquifer Ecological receptors in nearby River Itchen not considered at risk due to limited groundwater within shallow gravels which will be quickly sealed once shaft penetrates underlying London Clay Fm				
Consequence classification	**4 (Minor)**	**4 (Minor)**	**4 (Minor)**	**4 (Minor)**	**4 (Minor)**
Likelihood of reaching aquifer	**Likely**	**Unlikely**	**Unlikely**	**Low likelihood**	**Unlikely**
Comments	Assumes mitigation measures are taken to reduce the likelihood, as suggested in the Design Considerations sections/				
Risk of Pollution Scenario being realised in aquifer	**Moderate/ Low**	**Very Low**	**Very Low**	**Very Low**	**Very low**

Notes: Precast segmental lining expected

4.6.47 In summary at Otterbourne Shafts, the risk of Pollution Scenario 3 being realised in the aquifer is 'Very Low' to 'Moderate/ Low'.

4.6.48 Considering the small and temporary flux of contaminants expected, groundwater contamination is not expected to be measurable in the aquifer except for in the immediate vicinity of the shaft and certainly not at abstraction wells over 250m away.

Conclusion

4.6.49 The maximum risk of Pollution Scenario 3 being realised at each shaft location is either 'Moderate' or 'Moderate/Low'. This assumes good mitigation practices are implemented, which will require careful management and proper liaising with the EA. The construction Contractor should employ good practice at all stages of shaft installation, as outlined in the opening paragraphs of this Section, in order to keep the pollutant linkage Likelihood ratings to a minimum.

Pollution scenario 4

4.6.50 Pollution Scenario 4 considers the direct contact between engineered structures and contaminated soil or leachate causing degradation of structural materials (where the secondary effects are to increase the potential for contaminant migration).

4.6.51 The pollution linkage assessed, and the assessed significance of the potential source, pathway and receptor are summarised in the following table.

Table 4-14 Pollution Scenario 4 - Significance of potential pollution linkage

Link	Description	Comment	Significance
Source	Sulphate in soils and groundwater	The results of the pH and sulphate tests undertaken on the Head deposits and Culver Chalk Formation indicate a preliminary worst-case design sulphate class of DS-1 and a worst case aggressive chemical environment for concrete (ACEC) class of AC-1. For London Clay Formation and Bognor Sand Member it is indicated to be DS-2 and AC-2, respectively. There is insufficient data to determine the design sulphate class or ACEC class for Alluvium, River Terrace Deposits, Lambeth Group Reading Beds, Newhaven Chalk Formation or White Chalk Subgroup from testing along these tunnel alignments alone. When combined with data from the Outline FWRA report which covers AGP and trenchless crossings for the project, appropriate preliminary ratings are DS-1 and AC-1 for Alluvium and River Terrace Deposits, DS-4 and AC-4 for Lambeth Group Reading Beds and DS-2 and AC-2 for the Newhaven Chalk Formation and White Chalk Subgroup. Made Ground classifications will be location-specific and may be highly variable. There is currently insufficient data for Made Ground in shaft locations to provide classifications. Soil contamination with the potential to impact structures has not been identified. Free phase hydrocarbons were not encountered.	High (4)
Pathway	Structure/ soil interface	Direct contact with surrounding soils and groundwater.	-
Receptor	In-ground structural elements	To be designed using an appropriate concrete class for the geochemical environments encountered in each proposed shaft location.	High (4)

4.6.52 Concrete in contact with aggressive or contaminated soils or groundwater may be subject to chemical attack, resulting in degradation of the concrete. Such degradation could reduce the effectiveness of the seal between the structure and surrounding ground resulting in pathways to open along the soil/ structure interface, increasing the risk of pollution scenario 1. In particularly aggressive scenarios, degradation of concrete can cause structural weakness leading to long term settlement or eventual collapse of structures.

4.6.53 Laboratory testing on soil and groundwater samples taken along the three tunnel alignments and in shaft locations (but not within the WRP site) has been used to calculate preliminary classifications as provided in Table 4-7. Additional testing should be carried out on all geological materials to confirm appropriate classifications. The recommendations of [9] should then be followed in the design of mixes for buried concrete for the classifications given.

4.6.54 The degree of harm, given the nature of the source (High - 4) and Significance of the receptor (High - 4) is assessed as 'Medium'. Assuming the use of an appropriate concrete mix, the probability of degradation of in-ground concrete due to attack by aggressive chemicals or naturally occurring sulphates and acids is assessed to be 'Unlikely'.

4.6.55 By combining a 'Medium' consequence and 'Unlikely' probability, as per Table 4-4, the associated risk of degradation of concrete and the associated creation of new pathways is assessed to be **Low**.

Pollution scenario 5

4.6.56 Pollution scenario 5 considers the potential for 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.

4.6.57 This relates specifically to the creation of preferential pathways for upward gas migration as a result of constructing the shaft. Assessment of this pollution scenario has been provided when the following conditions are met:

- A ground gas hazard has been identified through gas monitoring within or in close proximity to the shaft footprint, or
- A ground gas hazard has been identified through gas monitoring of a PSC that crosses the Site, despite the monitoring location not being within or in close proximity to the shaft footprint, or
- A potential gas contaminant source (PSC) has been identified on or in close proximity to the Site and has not been monitored.

4.6.58 Table 4-15 presents the screening process for shafts which are to be carried forward for assessment under this pollution scenario. Details regarding gas monitoring and assessment of credible hazards are provided in Section 3.5.

Table 4-15 Summary of proposed structures to be assessed under pollution scenario 5

Shaft	Monitoring confirms a ground gas hazard within/ close to shaft footprint?	Monitoring confirms ground gas hazard within a PSC that falls within or close to the shaft footprint?	Monitoring of a credible potential gas contaminant source (PSC) within/ in close proximity to the shaft footprint has not yet been undertaken?	Carry forward to assessment?
Mill Lane East	No - no gas monitoring was carried out at this distance.	No	No – ground gas hazard is not credible	**No**
Mill Lane West	Yes – gas monitoring in BHP02, 11m from shaft centre, recorded depleted O_2 and elevated CO_2	No	No – ground gas hazard is not credible	**Yes**

Shaft	Monitoring confirms a ground gas hazard within/ close to shaft footprint?	Monitoring confirms ground gas hazard within a PSC that falls within or close to the shaft footprint?	Monitoring of a credible potential gas contaminant source (PSC) within/ in close proximity to the shaft footprint has not yet been undertaken?	Carry forward to assessment?
	levels. Negligible flow rates.			
Portsdown Hill Shaft	Yes – gas monitoring in BH301, ~35m from shaft centre, recorded depleted O_2 and elevated CO_2 levels. Negligible flow rates.	Yes – gas monitoring in 2D2500SA within PSC 306 and 361 recorded depleted O_2 and elevated CO_2 levels. Negligible flow rates.	Yes – gas monitoring has not been undertaken within PSC No. 308	**Yes**
Purbrook Shaft	Yes – gas monitoring in BH303, ~15m from shaft centre, recorded depleted O_2 and elevated CO_2 and CH_4 levels as well as moderate flow rates (2.2 l/hr).	No	No	**Yes**
Otterbourne Shafts	Partial monitoring undertaken but no monitoring at the launch shaft	Yes – gas monitoring recorded elevated CO_2 levels. Low flow rates.	Yes – gas monitoring has not been undertaken close to Bugle Farm landfill (Launch shaft)	**Yes**

4.6.59 Based on the screening process, Mill Lane West Shaft, Portsdown Hill Shaft and the Purbrook and Otterbourne Shafts are taken forward for risk assessment under Pollution Scenario 5. The risk assessment has been carried out in accordance with the guidance set out in Section 4.4.

Source significance

4.6.60 The Significance of identified or potential gas contaminants at each shaft location has been rated and is shown in Table 4-16. The ground gas regime has been assigned a characteristic situation to assist with this, based predominantly on the flow rates measured.

Table 4-16 Summary of contaminant sources at each shaft and their significance rating

Shaft name	Mill Lane West	Portsdown Hill	Purbrook	Otterbourne
Characteristic Situation	CS2 Low	CS1 Very low	CS3 Moderate	CS2 Low
Significance	**Very Low**	**Very Low**	**Moderate**	**Low**
Comment	Negligible flow rates. May be 'Very low' CS, but less than 0.07 l/hr is less than the limit of detection (0.1 l/hr) for monitoring apparatus. No other credible sources of ground gas hazards.	PSC 308 not monitored. However, the potential source is from Made Ground/Fill during construction (i.e. at least 60 yrs ago) and not infilled land. Therefore only small volumes of gas would be expected, at shallow depth, with very low chance of still being created.	Flow rate moderate and presence of CH4 above Lower Explosive Limit.	Reasonable flow rates and presence of high CO_2 concentrations

4.6.61 The gas contaminant sources have been assigned a 'Very Low Significance at Mill Lane West and Portsdown Hill but a 'Moderate' Significance at Purbrook Shaft due to the moderate flow rates and presence of Methane above the lower explosive limit. The source has been assigned a Low significance at Otterbourne due to moderate flow and presence of carbon dioxide.

Pathway summary

4.6.62 For all shafts taken through to assessment for Pollution Scenario 5, construction would involve penetration of an aquiclude down into an aquifer below, as discussed in Pollution Scenario 1. The aquiclude would currently be providing a ‘cap’ to any ground gases below, preventing them from venting at the surface. Therefore, there is theoretically potential for preferential flow pathways to be created at the interface between the shaft and the surrounding soils, allowing gas contaminants up through the aquiclude and venting to the surface. The likelihood of this pathway forming depends on the quality of contact between the shaft and the surrounding soils. Table 4-17 summarises the likely construction methods for each shaft and the quality of contact that can be achieved, as is summarised in Pollution Scenario 1. Details of the proposed shaft construction method are included from paragraph 2.2.16.

Table 4-17 Potential pathway assessment for each shaft (long term)

Shaft name	Mill Lane West	Portsdown Hill	Purbrook	Otterbourne
Pathway	Shaft/ soil interface			
Likely shaft construction method	Precast segmental lining	Diaphragm Wall	Diaphragm Wall	Precast segmental lining
Expected quality of contact between shaft and surrounding soils	High	Very high – ‘intimate’	Very high – ‘intimate’	High

4.6.63 During construction of diaphragm walls, shallow excavations will be made to 1.5m depth to pour the concrete guide wall. For Portsdown and Purbrook shafts, the potential gas contamination is located at some 40m depth and this excavation would therefore not be expected to create a short-term pathway. The main wall excavation is filled with bentonite slurry prior to concrete being poured, which would prevent short term pathways forming.

4.6.64 For precast segmental linings, as may be the construction method used to form Mill Lane West shaft and the Otterbourne Shafts, dry excavation is used above the water table and there is therefore an opportunity for gas migration pathways to form prior to the completion of the shaft.

Receptor summary

4.6.65 The critical receptor is workers constructing (short term) or working at (long term) the proposed shafts. This is given a High Sensitivity rating.

Risk assessment summary

4.6.66 Finally, the overall risk of the pollution event has been assessed and is presented in Table 4-18. Risk is based on the Consequence classification (derived from

Source Significance and Receptor Sensitivity) and the Likelihood of the pollution 'event' occurring.

4.6.67 On the basis of the proposed outline construction methodology and the Characteristic Situations designated, a Likelihood rating of 'Unlikely' has been assigned for Mill Lane West and Portsdown Hill Shafts i.e. *'Circumstances are such that it is improbable than an event would occur even in the very long term'*. A Likelihood rating of 'Low' has been assigned to the Purbrook and Otterbourne Shafts i.e. *'Circumstances are such that it is by no means certain than an event would occur even over a longer period, and it is less likely in the short-term'.* Additional justification is provided in the table.

Table 4-18 Risk assessment summary for each shaft

Shaft Name	Mill Lane West	Portsdown Hill	Purbrook	Otterbourne
Source Significance	1 (Very low)	1 (Very low)	3 (Moderate)	2 (Low)
Receptor Sensitivity	4 (High)	4 (High)	4 (High)	4 (High)
Consequence classification	4 (Minor)	4 (Minor)	12 (Medium)	8 (Mild)
Likelihood (short and long term)	Unlikely	Unlikely	Low	Low
Risk of Pollution Scenario being realised (short and long term)	**Very low**	**Very low**	**Moderate/ Low**	**Low**
Comments	Likelihood based on negligible flow rates despite soil exposure during construction.	Likelihood based on negligible flow rates and 'wet' construction	Likelihood based on moderate flow rates but 'wet' construction and good seal between shaft and soil	Whilst ground gas is present the shafts will quickly penetrate through permeable strata into London Clay

4.6.68 The final short and long term risk to workers from exposure to upwardly migrating gases is 'Very low' at Mill Lane West and Portsdown Hill shafts; Low at Otterbourne and 'Moderate/ Low' at Purbrook shaft.

4.6.69 It is suggested that this assessment is revised following development of the shaft construction methodology.

4.6.70 The Contractor's risk assessment and method statement will need to address all issues in relation to potential exposure to ground gases during construction.

Pollution scenario 6

4.6.71 Pollution Scenario 6 considers causing of off-site migration of ground gas or increased vertical emissions as a result of vibration or other effects from the pile installation process.

4.6.72 None of the shafts will require piling, shaft construction for all shafts is anticipated to be by non-percussive excavation for the purposes of this Outline FWRA. Any changes in construction methodology will be assessed by the Contractor during detailed design.

4.6.73 On this basis, no further assessment of Pollution Scenario 6 is required.

Pollution scenario 7

4.6.74 Pollution Scenario 7 considers direct contact of site workers and others with contaminated soil arisings which have been brought to the surface.

4.6.75 Assessment of this pollution scenario has been provided when the following conditions are met:

- A soil contamination hazard has been identified through soil testing within or in close proximity to the shaft footprint, or
- A soil contamination hazard has been identified through soil testing of a PSC that crosses the shaft footprint, despite the testing location not being within or in close proximity to the shaft footprint, or
- A potential soil contaminant source (PSC) has been identified within the shaft footprint and has not yet been tested.

4.6.76 Table 4-19 presents the screening process for shafts which are to be carried forward for assessment under this Pollution Scenario.

Table 4-19 Summary of proposed structures to be assessed under pollution scenario 7

Shaft	Testing confirms a soil contamination hazard within/ close to shaft footprint?	Testing confirms a soil contamination hazard within a PSC that falls within the shaft footprint?	Testing of a credible soil contaminant source (PSC) within the shaft footprint has not yet been undertaken?	Carry forward to assessment?
Mill Lane East	No – testing showed no soil contamination	No – testing of the PSC confirmed no soil contamination	No – testing has been undertaken	**No**
Mill Lane West	No – testing showed no soil contamination	No – no PSC within the shaft footprint	No – no PSC within the shaft footprint	**No**
Portsdown Hill Shaft	No testing carried out	No	Yes – testing of the PSC within the shaft footprint has not been carried out	**Yes**
Purbrook Shaft	No – testing showed no soil contamination	No – no PSC within the shaft footprint	No – no PSC within the shaft footprint	**No**
Otterbourne Shafts	No – testing showed no soil contamination	No – no PSC within the shaft footprint	No – no PSC within the shaft footprint	**No**

4.6.77 Based on the screening process, potential hazards to human health within the on-site soils have only been identified at Portsdown Hill Shaft, which is taken forward for risk assessment under Pollution Scenario 7. The risk assessment has been carried out in accordance with the guidance set out in Section 4.4.

Source significance

4.6.78 The Significance of identified or potential gas contaminants at each shaft location has been rated and is shown in Table 4-20.

Table 4-20 Summary of contaminant sources Portsdown Hill shaft and their significance rating

Shaft name	Portsdown Hill
Source	No testing has been carried out within PSC which represents 'Land north of reservoirs (Portsmouth Water) – potential for Made Ground / Fill material during construction.
Significance	**Low**
Comment	Conservative because testing has not been carried out and the waterworks is located just to the south i.e. 'small scale industrial'.

4.6.79 The soil contaminant sources have been assigned a 'Low' Significance at Portsdown Hill Shaft. Justification is provided in the table.

4.6.80 It should be noted that the GAC used to define these hazards relate to a commercial/ industrial end use scenario. These criteria are used to assess chronic risk to a worker's health over a period of multiple years and are not strictly applicable to the acute, short-term risk associated with exposure to excavation arisings over a period of weeks. Significance may therefore be conservative.

Pathway summary

4.6.81 For all shafts taken through to assessment for Pollution Scenario 7, the pathway could be through direct dermal contact, ingestion, and inhalation of dusts, gases and vapours with excavated arisings during excavation works and stockpiling during shaft construction.

Receptor summary

4.6.82 The critical receptor is construction workers undertaking the shaft construction works. This is therefore given a High Sensitivity rating.

Risk assessment summary

4.6.83 Finally, the overall risk of the pollution event has been assessed and is presented in Table 4-21. Risk is based on the Consequence classification (derived from Source Significance and Receptor Sensitivity) and the Likelihood of the pollution 'event' occurring.

4.6.84 On the basis of the proposed outline construction methodology, which involves excavating arisings which may be contaminated, the Likelihood of realising the linkage between source and receptor (in the absence of mitigation) is designated 'Likely' i.e. *'Circumstances are such that such an event is not inevitable, but is possible in the short-term and is likely over the long-term'.*

Table 4-21 Risk assessment summary for each shaft

Shaft Name	Portsdown Hill
Source Significance	2 (Low)
Receptor Sensitivity	4 (High)
Consequence classification	8 (Mild)
Likelihood	Likely
Risk of Pollution Scenario being realised	**Moderate/ Low**
Comments	-

4.6.85 By combining a 'Minor' or 'Mild' Consequence with a 'Likely' probability as per Table 4-4, the associated risk is assessed to be 'Moderate/ Low' at Portsdown Hill.

4.6.86 However, it should be noted that further GI (recommended in the GIR – see ES Appendix 11.2 Geotechnical and geo-environmental reports, Volume II (Document reference 6.2, DCO Volume 6)) may conclude that a contaminated soil hazard is not present at this site, in which case the risk will be eliminated.

4.6.87 It is noted that this risk is assessed in the absence of any mitigation measures. It will be the responsibility of the Contractor undertaking the construction works to prepare suitable RAMS for excavating contaminated soil to prevent harm occurring to their staff.

4.6.88 In addition, in line with current regulations (such as the Construction (Design and Management) Regulations, 2015) and good practice, appropriate protective clothing and equipment will be worn by site workers; and good standards of hygiene adopted to prevent prolonged skin contact, inhalation and ingestion of soils during construction, whilst appropriate methods of working will be selected to limit the potential for air-borne dust to arise associated with the excavation and disturbance of the soils present on the Site.

4.6.89 The inclusion of mitigation measures does not alter the Sensitivity of the receptor or the magnitude of the hazard (i.e., the Consequence) which remains as Medium. However, it does reduce the Likelihood of the risk being realised to 'Unlikely'. By combining a 'Minor' or 'Mild' consequence with an 'Unlikely' (including mitigation) probability as per Table 4-4, the associated risk would be revised to assessed to be Very low.

4.7 Outline FWRA for tunnels

Pollution scenario 1

4.7.1 Pollution Scenario 1 considers the creation of preferential pathways, through a low permeability layer (an aquitard), to allow potential contamination to migrate into an underlying aquifer.

4.7.2 On the basis that the three tunnels are to be constructed sub-horizontally, entirely within the natural geology at depth, i.e., the tunnel construction does not create a linkage between surface and an underlying aquifer, an assessment of this Pollution Scenario is not required. Additionally the annulus around the tunnels is sealed in the permanent case, reducing the risk of migration of contamination along the line of the tunnel.

Pollution scenario 2

4.7.3 Pollution Scenario 2 considers the driving of solid contaminants down into an aquifer during construction.

4.7.4 On the basis that the three tunnels are to be constructed at depths entirely within the natural geology, and therefore will not encounter solid contaminants, an assessment of this Pollution Scenario is not required.

Pollution scenario 3

4.7.5 Pollution Scenario 3 considers the contamination of groundwater and, subsequently, surface waters by wet concrete, cement paste, or grout.

4.7.6 For completeness, bentonite and additives and turbidity caused by disturbance of natural ground have also been considered.

4.7.7 Assessment of this pollution scenario has been provided when the following conditions are met:

- The proposed tunnel will encounter groundwater; and
- A receptor that could be impacted has been identified, e.g., an aquifer that is being abstracted from, or a watercourse that is anticipated to be in hydraulic continuity with the surrounding groundwater.

4.7.8 According to the hydrogeological regimes described in Section 3.4, all tunnels will be under the water table and the first condition is therefore met. All the tunnels pass through a Principal/ Secondary A Aquifer, therefore meeting the second condition. Additionally, watercourses in the vicinity of Bedhampton are understood to be partially fed by artesian springs emanating from the Chalk aquifer. It is assumed where a tunnel interacts with the SPZ associated with the public water supplies at Bedhampton Springs, the tunnel would also have the potential to interact with watercourses via the same springs.

Source summary

4.7.9 There are three theoretical mechanisms by which tunnel construction could contaminate groundwater under this Scenario. Note, the flux of contaminants is expected to be temporary while the construction is ongoing up to the point of the grout and concrete fully hardening. Full details of construction methodology are provided from paragraph 2.3.7.

4.7.10 A description of each, its relevance and design considerations are presented below:

Turbidity

4.7.11 Turbidity is described from paragraph 2.6.23.

4.7.12 Turbidity could potentially be caused during tunnel construction during the activities described from paragraph 2.3.7. They include:

- The pressure and rotation of cutter heads against the tunnel face.
- Force of the pressurised ‘plug’ (Earth Pressure Balance (EPB) TBM) or compressed air cushion/ bubble and slurry (Slurry TBM) inside the excavation chamber, especially if not properly controlled. This includes any loss of slurry at the drill head should pressures get too high.
- The force of tail skin grouting (TBM tunnelling).
- Injection of any bentonite mud around the annulus, and annulus grouting at the end of excavation (Pipe-jacking).
- General vibrations.
- Pressure at the face should be carefully controlled and slightly negative within Chalk to encourage consistent inward movement of excavated materials. This technique reduces mobilisation of chalk ‘flour’, which would otherwise contribute to increases in turbidity within the aquifer.

<u>Design considerations</u>

4.7.13 For both TBM methods, turbidity in the aquifer can be reduced through careful control of pressures in the excavation chamber. Ideally the pressure should be maintained at a slightly lower pressure than groundwater pressure, to maintain consistent inward movement of excavated material/ slurry.

Excess dispersal of grout and leaching of contaminants into groundwater

4.7.14 For Purbrook tunnel, which is most likely to be constructed using a TBM, tail skin grouting will be used to continuously seal the void between the tunnel and the surrounding soil.

4.7.15 In the case of Bedhampton Pipe-Jack, annulus grouting is completed at the end of construction, filling the void between the tunnel and the surrounding soil that is kept open with bentonite mud during excavation.

4.7.16 Dispersal can be reduced with the use of a high-density grout mix (cement, aggregate and bentonite) or additives that make it more resistant to washout. A thixotropic grout can also be selected, i.e. one that is fluidised upon action by vibration and pumping, and becomes stiff as pressure releases, and would prevent wide dispersal into the surrounding ground.

4.7.17 Grout volume should be reduced with careful preparation and methodology to ensure suitability for the ground condition and careful injection pressure control.

Bentonite breakout

4.7.18 Bentonite mud is formed from inert, non-toxic clays, that are not damaging to land surfaces and quickly break down in salt water. Breakout of bentonite mud occurs when the mud pressure exceeds the strength of the surrounding ground resulting in mud being forced out into the surrounding formation.

4.7.19 Bentonite mud would not be used for excavation by EPB TBM.

4.7.20 Bentonite is a dense, viscous, thixotropic material, which in the use of a slurry TBM will be injected into the excavation chamber at pressure. The slurry penetrates the ground a short distance ahead of the cutter head to form a low permeability layer (or 'filter cake'). These properties prevent it from dispersing widely beyond the excavation walls.

4.7.21 A bentonite mud may also be injected around the precast concrete linings during pipe-jacking to provide lubrication for the tunnel lining against the surrounding rock and to seal any annulus between the tunnel lining and the surrounding rock in the temporary case.

Design considerations

4.7.22 The tunnel excavation contractor should have a Breakout Management Plan to mitigate and remediate breakouts during tunnelling and should contain the mitigation and responses outlined in the following points.

- Limiting the volume of the breakout. The Contractor will be monitoring fluid pressure and the volume of fluid returns to allow losses to be quickly identified if they occur. When fluid losses are identified the Contractor will cease excavation and investigate if the losses are visible at surface and, if so, the location of the breakout. During the tunnelling a watching brief will be maintained for any signs of breakout.
- Removing the breakout fluid. Typically, hand carried pumps and hoses are used to pump the fluid from the breakout location to either the entry or exit pits, or a holding tank or bowser for transfer back to the excavation.
- Sealing the breakout. Most breakouts seal themselves after either a period of time to allow the bentonite mud to gel in the fracture, or when the excavation advances, reducing the pressure of the fluid passing the fracture. In some cases, environmentally friendly additives, termed Lost Circulation Materials (LCM) are added to the drilling fluid to assist in sealing the fracture.
- Remediating the breakout. When the breakout is deemed to have been sealed, any remaining bentonite mud will be removed as far as possible, with the proviso that the cleaning process does not cause more harm or damage to the environment than leaving the fluid to dissipate and break down naturally.
- Slurry/ concrete/ grout additives**.** Additives may be used to enhance the performance of the bentonite slurry, concrete or grout and may include polymers, clay, cement, foaming agents, thickening agents, etc. These contaminants may have potential to leach into groundwater and disperse through the aquifer.

4.7.23 Additives and conditioning agents should be appropriately selected with the exclusion of substances that could be hazardous to the environment. The EA should be consulted by the Contractor should any potentially hazardous additives be proposed for use.

Risk assessment summary

4.7.24 Based on these factors, a risk assessment has been undertaken for each tunnel and is presented in Table 4-22 for the Bedhampton Pipe-Jack and Purbrook Tunnel. The table include ratings for source Significance, receptor Sensitivity, Consequence, Likelihood and a final Risk level. The criteria for classifying source Significance is provided in Table 4-1, for receptor Sensitivity in Table 4-2, for Likelihood in Table 4-3 and for overall Risk in Table 4-4. The hydrogeology and Sensitivity factors at each location are summarised in Table 3-3 and should be referenced. Explanations and justifications are provided where necessary in the 'Comments' rows.

4.7.25 The risk assessment assumes that the 'Design Considerations' above would have been properly implemented. Conservative assumptions were made throughout the assessment, especially where data was unavailable/ information unknown (such as construction methodology). For example, an EPB TBM or Slurry TBM may be used so the one that would be 'worst case' is assumed for the assessment of each potential Source. For further construction details refer to paragraph 2.3.7 onwards.

Table 4-22 Risk assessment summary for Bedhampton, Purbrook and Otterbourne tunnels

Source	Turbidity	Excess grout dispersal and contamination	Bentonite breakout	Additives
Source Significance	4 High	2 Low	4 High	4 High
Comment	Excavation activities are significant and would cause turbidity	Volumes are relatively small	Bentonite breakout from tunnel either at cutting face, or from annulus, and leaching of contaminants into groundwater.	Could be added to concrete, grout or bentonite. Significance limited by ratings for other sources.
Pathway	Aquifer receptor: Directly into surrounding Principal Aquifer (Chalk) (excluding Otterbourne Pipe-Jack which is within London Clay) Watercourse receptor: No pathways to watercourses			
Receptor Sensitivity	3 (Moderate) - Principal Aquifer outside SPZ (Otterbourne Pipe-Jack will be driven through the overlying London Clay Formation so would not affect the underlying SPZ within the Chalk)			
Consequence classification	12 (Medium)	6 (Mild)	12 (Medium)	12 (Medium)
Likelihood of reaching aquifer	Likely	Unlikely	Low likelihood	Unlikely
Comments	Based on adoption of engineering measures to reduce effects.			
Risk of Pollution Scenario being realised in aquifer	**Moderate**	**Very low**	**Moderate/ Low**	**Low**

Source	Turbidity	Excess grout dispersal and contamination	Bentonite breakout	Additives
Comments	-	-	-	-

4.7.26 In summary, the risk of Pollution Scenario 3 being realised in the aquifer around Bedhampton Pipe-Jack, Purbrook Tunnel and Otterbourne Pipe-Jack is assessed as 'Very low' to 'Moderate'.

4.7.27 Turbidity poses the greatest risk to the aquifer, being rated 'Moderate' risk although this risk is unlikely to be realised for the Otterbourne Pipe-Jack which is driven through the London Clay.

4.7.28 It should be noted that towards the end of Bedhampton Pipe-Jack at Mill Lane East, the SPZ is very close (circa 35m from the shaft) and some 155m from a groundwater abstraction point. For additional conservatism, the risk assessment carried out for Ch. 500 to 1100 of Havant Tunnel could be assumed locally along this end section of the tunnel, which would increase the risk to 'Low' to 'High'.

4.7.29 ES Chapter 8 Terrestrial and freshwater biodiversity, Volume I (Document reference 6.1, DCO Volume 6) assesses the impact of vibrations caused during tunnelling on sensitive aquatic species. This assessment has determined a minor adverse effect which is not significant.

Conclusion

4.7.30 The maximum risk of Pollution Scenario 3 being realised is 'Moderate'. The highest risk is due to turbidity effects which are 'Likely' despite engineering good practice.

4.7.31 The risk ratings assume good mitigation practices are implemented, which will require careful management and proper liaising with the EA by the construction Contractor during detailed design. The construction Contractor will develop appropriate mitigation strategies during detailed design and will employ good practice at all stages of tunnel installation, as outlined in the opening paragraphs of this Section, in order to keep the pollutant linkage Likelihood ratings to a minimum.

Pollution scenario 4

4.7.32 Pollution Scenario 4 considers the direct contact of engineered structures with aggressive or contaminated soil or leachate causing degradation of construction materials (where the secondary effects are to increase the potential for contaminant migration).

4.7.33 The assessment of geochemical environments along each tunnel alignment outside the WRP site is covered from paragraph 4.6.50, where the risk is assessed to be 'Low'.

4.7.34 As the tunnels enter the vicinity of the WRP, the assessment of geochemical environments there applies instead, as is discussed in the Outline FWRA for the WRP. While these tunnel sections are to be constructed entirely within the natural geology at depth beneath the WRP and therefore will not encounter contaminated soil, the presence of two separate overlying landfills that operate on the 'dilute and disperse' principle, means that there is potential that landfill leachate could be encountered (albeit diluted by groundwater within the Chalk).

4.7.35 However, data from Chalk at the WRP indicates a preliminary concrete design classification of DS-1 and ACEC-1. Free phase hydrocarbons were not encountered. The consequence of contamination, given the nature of the source (High - 4) and significance of the receptor (High - 4) is assessed as 'Medium'. Assuming the use of an appropriate concrete mix, the probability of degradation of in-ground concrete due to attack by aggressive chemicals or naturally occurring sulphates and acids is assessed to be 'Unlikely'.

4.7.36 By combining a 'Medium' consequence and 'Unlikely' probability, as per Table 4-4, the associated risk of degradation of concrete and the associated creation of new pathways for the tunnel sections within the WRP is assessed to be 'Low'.

Pollution scenario 5

4.7.37 Pollution Scenario 5 considers the potential for 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.

4.7.38 On the basis that the three tunnels are to be constructed entirely within the natural geology at depth, i.e., the construction does not penetrate a low permeability surface layer, an assessment of this Pollution Scenario is not required.

Pollution scenario 6

4.7.39 Pollution Scenario 6 considers causing of off-site migration of ground gas or increased vertical emissions as a result of vibration or other effects from the pile installation process.

4.7.40 None of the tunnels will require piling.

4.7.41 On this basis, no further assessment of Pollution Scenario 6 is required.

Pollution scenario 7

4.7.42 Pollution Scenario 7 considers direct contact of site workers and others with contaminated soil arisings which have been brought to the surface.

4.7.43 According to the GIR for Phase 1 and 3A Ground Investigation (Shafts and Tunnels), there is no potential risk to human health from soil contaminants at tunnel depth in any of the tunnels, which is unsurprising given that all are to be constructed at depths entirely within the natural geology. An assessment of this Pollution Scenario is therefore not required.

5 Conclusions and Recommended Mitigation Measures

5.1 Conclusions

Pollution scenarios

5.1.1 This Outline FWRA has followed the approach recommended in the CL:AIRE guidance [10]. The following Pollution Scenarios have been considered as part of this outline foundation works risk assessment.

1. Creation of preferential pathways, through a low permeability layer, to cause contamination of groundwater in an aquifer.
2. The driving of solid contaminants down into an aquifer during pile driving.
3. Contamination of groundwater and subsequently surface waters by turbidity, support fluids, concrete, cement paste or grout.
4. Direct contact with contaminated soil or leachate causing degradation of pile materials.
5. Creation of preferential pathways to allow migration of landfill gas or contaminant vapours to surface.
6. Causing off-site migration of ground gas or increased vertical emissions as a result of vibration or other effects from the pile installation process.
7. Direct contact with contaminated soil arisings that have been brought to the surface.

5.1.2 This assessment has been expanded to include bentonite slurry and any additives used.

Risk assessment results for the shafts

5.1.3 Table 5-1 provides a results summary of the seven Pollution Scenario risk assessments carried out for the five shafts included in the study. Conservative assumptions were made throughout the assessment, especially where data was unavailable/ information unknown (such as construction methodology). For instance, the ‘worst-case’ segmental lining method (caisson versus underpinning) was assumed for each Source. The shafts are to be designed to be sealed and grouted to reduce the likelihood of leachate or gas entering the shafts. It is expected the shafts will be managed under confined space entry during the operational phase.

Table 5-1 Summary of assessed risk ratings for each pollution scenario (PS)

Pollution Scenarios / Shaft Name	PS1	PS2	PS3	PS4	PS5	PS6 (highest risk assessed)	PS7
Mill Lane East	Moderate/ Low	NA	Moderate	Low	NA	NA	NA
Mill Lane West	Low	NA	Moderate/ Low	Low	Very Low	NA	NA
Portsdown Hill Shaft	Moderate/ Low	NA	Moderate/ Low	Low	Very Low	NA	Moderate/ Low
Purbrook Shaft	NA	NA	Moderate/ Low	Low	Moderate/ Low	NA	NA
Otterbourne Shafts	NA	NA	Moderate/ Low	Low	Low	NA	NA

5.1.4 Most Pollution Scenarios either do not apply to shaft construction, or shaft construction poses a 'Low' or 'Very low' Risk of pollution. 'Moderate/Low' risk was assessed for Pollution Scenarios 1, 3, 5 and 7.

5.1.5 The greatest risk, with ratings of 'Moderate' or 'Moderate/ Low' across the six shafts, is suggested to be Pollution Scenario 3, i.e. *the contamination of groundwater … by wet concrete, cement paste, or grout.* Bentonite, additives and turbidity were also included in this assessment. These ratings assume that the construction Contractor would adopt the correct mitigation measures to limit the likelihood of contamination linkage.

5.1.6 It should be noted that for these contaminants, the risk level relates to likelihood of *any* level of contamination. However, any flux of contaminants by these means is expected to be small and short-lived, while the construction is ongoing up to the point of the grout and concrete fully hardening. Measurable levels of contamination would be expected to be in close proximity to the shaft only and certainly not at any abstraction points.

5.1.7 For Pollution Scenario 1, these high scores resulted from conservative assumptions around possible contaminant sources, given the absence of some critical ground investigation data. They may therefore be reduced after further sampling/ testing in future. For all shafts it should be noted that the construction of the shaft will remove any potential source of contamination.

5.1.8 For Pollution Scenario 5 regarding ground gas migration, presence of moderate flow rates and methane gas above lower explosive limits are cause for concern and this risk should be further investigated. Any construction activity will be considered to fall under the Confined Spaces Regulations which mandates procedures are adopted to control risks from gases.

5.1.9 For Pollution Scenario 7, the 'Moderate/ Low' risk rating could also be subject to reduction with further investigation/ testing. For Portsdown Hill Shaft, the assessment was only carried out because of a lack of GI data. This could also result in a reduction of risk should it become available.

Risk assessment results for the tunnels

5.1.10 Table 5-2 provides a results summary of the seven Pollution Scenario risk assessments carried out for the three tunnels included in the study. Again, conservative assumptions were made throughout the assessment, especially where data was unavailable/ information unknown (such as construction methodology). For instance, an EPB TBM or Slurry TBM may be used, so the one that would be 'worst case' is assumed for the assessment of each potential Source.

Table 5-2 Summary of assessed risk ratings for each pollution scenario (PS)

Pollution Scenarios / Tunnel Name	PS1	PS2	PS3	PS4	PS5	PS6 (highest risk assessed)	PS7
Purbrook	NA	NA	Moderate	Low	NA	NA	NA
Bedhampton	NA	NA	Moderate	Low	NA	NA	NA
Otterbourne	NA	NA	Moderate	Low	NA	NA	NA

5.1.11 The only Pollution Scenarios considered relevant to the tunnels are Pollution Scenarios 3 and 4.

5.1.12 The maximum risk of Pollution Scenario 3 being realised is 'Moderate' in all three tunnels. These ratings are due to a turbidity Source, which would be 'Likely' to affect the aquifer, despite engineering good practice.

5.1.13 Pollution Scenario 4 only brings about a 'Low' risk, provided that concrete is designed to the correct specification given the ground conditions.

5.2 Mitigation measures

5.2.1 The following general mitigation measures are assumed as part of this assessment:

- A Construction Environmental Management Plan (CEMP) presenting construction and operational good practice measures (prevention of the creation of new pollution, personal protective equipment, safe methods of work).
- Assurance of a high standard of work by selecting a competent contractor(s) to carry out the shaft and trenchless crossing construction works, ideally with prior experience in similar conditions.
- Appropriate risk assessment and method statements (RAMS) will be prepared as required by the Construction (Design and Management) Regulations 2015.
- Cleaning down equipment if any obvious smearing or contaminated materials is observed to be adhering to machinery, with any contaminated water resulting from this contained and disposed of appropriately as per the method statement.
- Appropriate personal protection and dust control measures during site works to reduce exposure to construction workers.
- Collection and appropriate disposal of waste concrete and other arisings.
- A protocol for dealing with unexpected contamination will be in operation.

- Appropriate concrete mix/metal selection and appropriate design life of the development.
- A watching brief on the Hermitage Stream, Langstone Harbour, the River Itchen and any other surface watercourses should be put in place to identify any visual indication of increased turbidity, and should this occur a stop placed on the works until visual impact has dispersed.

5.2.2 In addition to the above, the storage of materials e.g., cement, grout, additives, diesel, cleaning chemicals etc. will all require control. Controls for materials storage will be provided within the CEMP.

5.3 Further work

5.3.1 Further GI is recommended specifically for geo-environmental purposes:

- Additional ground investigation should be undertaken by the Contractor during detailed design at the Portsdown Hill shaft, once the locations are confirmed, to provide site specific ground investigation data as the information currently assessed is approximately 30m (BH301 / BH301A) away from the shaft location. Different conditions may be encountered from those assessed which may impact the soil, leachate, groundwater and waste classification requirements.

5.3.2 Following completion of the detailed design a Detailed FWRA will be prepared by the Contractor, replacing this Outline FWRA.

5.3.3 Engagement and consultation with the EA, Havant Borough Council, Portsmouth Water and other relevant consultees will be continued in order to address relevant concerns and clarify regulatory requirements for the works as above including any required licences, permits and 3.4.5, e.g., for dewatering, and treatment of contaminated waters pumped from the excavations.

Glossary

Term	Definition
Above Ground Plant (AGP)	This collectively refers to the Intermediate Pumping Stations and Break Pressure Tanks.
Anthropogenic	Caused by humans or their activities.
Applicant	Southern Water Services Limited.
Aquitard	Geological formations that have low permeability and restrict the flow of water. They are often made up of clay, shale, or other fine-grained materials, and can act as barriers that prevent or restrict the movement of water between aquifers or between groundwater and surface water.
Baseline	The current environmental and social conditions within the Order Limits or within a study area. This provides a benchmark against which changes arising from the Proposed Development are assessed for each relevant assessment.
Break Pressure Tank (BPT)	BPT are anticipated to be required at high points along the pipeline route. Water is pumped to BPTs, where it then flows onwards using gravity from the tank. This reduces the amount of energy required to transfer water. BPTs reduce the overall maximum pressure in the pipeline system associated with changes in flow rate as a result of topography.
Budds Farm Wastewater Treatment Works (WTW)	An existing Southern Water site that treats wastewater from the Applicant's customers prior to release into the Solent from the Eastney Long Sea Outfall. The Proposed Development would utilise highly treated wastewater from the Budds Farm WTW to produce recycled water at the Water Recycling Plant site. Reject water would be transferred from the Water Recycling Plant back to Budds Farm WTW where a connection would be made for onwards transfer to the existing Eastney Transfer Tunnel, Eastney Pumping Station and Eastney Long Sea Outfall for discharge into the Solent. Chemical filter washing at the Water Recycling Plant site would generate process waste that would be discharged via the foul sewer network to Budds Farm WTW for treatment.
Carbon dioxide (CO_2)	A naturally occurring gas, also a by-product of burning fossil fuels from fossil carbon deposits, such as oil, gas and coal, of burning biomass, of land use changes and of industrial processes (e.g. cement production). It is the principal anthropogenic greenhouse gas that affects the earth's radiative balance.
Climate	The general weather conditions prevailing over a long period of time. Climate change will see trends in the climate conditions changing (seasonal averages and extremes).
Contractor	The Applicant or a person appointed by the Applicant or by anyone else having the benefit of part or all of the Development Consent Order to carry out any construction element of the Proposed Development or to operate the Proposed Development.
Development Consent Order (DCO)	A statutory order which provides consent for a project and means that a range of other consents, such as planning permission and listed building consent, will not be required. A DCO can also include powers authorising the compulsory acquisition and temporary possession of land and rights over land which is the

Term	Definition
	subject of an application. A draft DCO (Document reference 3.1, DCO Volume 3) is submitted by the applicant as part of its application (Planning Inspectorate, 2025).
Drinking water	Water that has been treated to strict regulatory standards, ready for supply to domestic and non-domestic customers as drinking water.
Eastney Long Sea Outfall (LSO)	An existing Southern Water infrastructure component used to release treated wastewater from Budds Farm Wastewater Treatment Works. No works to the Eastney LSO are proposed as part of the Proposed Development; however, reject water produced from the Water Recycling Plant will be released from the Eastney LSO using the Eastney Transfer Tunnel and Eastney Pumping Station.
Environmental Statement (ES) (DCO Volume 7.4)	A document reporting the findings of the Environmental Impact Assessment which describes the likely significant effects arising from the Proposed Development on the environment and measures proposed to mitigate likely significant effects.
Hampshire Water Transfer and Water Recycling Project	This is the name of the Proposed Development, that is the Strategic Resource Option being delivered as part of the Water For Life Hampshire programme. A water supply scheme comprising a combination of both water transfer and water recycling technology that would play a major role in making up the shortfall in water supply across the Hampshire supply area, especially in a drought.
Hazardous waste	Waste, or the material or substances it contains, which is harmful to humans or the environment, and is classified as hazardous in The Hazardous Waste (England and Wales) Regulations 2005 (SI 2005/894).
Made Ground	Areas where natural deposits have been replaced or altered by the introduction of artificial deposits and/or imported natural materials.
Main River	Watercourses designated under the Water Resources Act 1991 as 'main' are usually larger rivers and streams that are shown on the Environment Agency's Statutory Main River map. The Environment Agency has permissive powers, but not a duty, to carry out maintenance, improvement or construction work on designated Main Rivers to manage flood risk.
Mitigation	Measures intended to avoid, prevent, reduce and, where possible, offset likely significant adverse environmental effects. Measures follow the mitigation hierarchy as described in section 5.3 of Environmental Statement Chapter 5 EIA approach and methodology, Volume I (Document reference 6.1, DCO Volume 6).
Monitoring	Measures to ensure the systematic and ongoing collection, analysis and evaluation of data related to the implementation and performance of a development. Monitoring can be undertaken to monitor conditions in the future to verify any environmental effects identified by the Environmental Impact Assessment, the effectiveness of mitigation or enhancement measures or ensure remedial action are taken should adverse effects above a set threshold occur. All monitoring measures adopted by the Proposed Development are reflected in Environmental Statement

Term	Definition
	Appendix 5.5 Commitments Register, Volume II (Document reference 6.2, DCO Volume 6).
Otterbourne Water Supply Works (WSW)	An existing Southern Water site which abstracts water from river Itchen and ground sources and will continue to do in certain circumstances after the Proposed Development. The Proposed Development would transfer source water from Havant Thicket Reservoir to Otterbourne WSW. The source water would be treated to strict regulatory standards at Otterbourne WSW prior to being supplied to customers.
Outline Construction Environmental Management Plan (CEMP) (Document reference 7.1, DCO Volume 7)	Contains identified topic specific mitigation measures to be adopted during construction and specifies plans and method statements to be produced by the Contractor to avoid and reduce environmental effects. Mitigation measures are generally tertiary mitigation, although some secondary mitigation measures are also included. The measures contained in the Outline CEMP are secured by a requirement in Schedule 2 to the Development Consent Order. Detailed CEMP(s) will be produced and submitted for approval in accordance with the corresponding requirement in Schedule 2 to the draft Development Consent Order (Document reference 3.1, DCO Volume 3).
Outline Foundation Works Risk Assessment (FWRA) (Document reference 7.4, DCO Volume 7)	A preliminary assessment prepared during the design phase that identifies potential risks associated with foundation works, such as piling or ground improvement, particularly in areas of contamination or sensitive ground conditions. It sets out initial mitigation measures and informs the development of detailed risk assessments post-consent.
Principal Aquifer	Rocks or soils that provide significant quantities of water and can support water supply and/or baseflow to rivers, lakes and wetlands on a strategic scale. They typically have a high intergranular and/or fracture permeability, meaning they usually provide a high level of water storage.
Project	This refers to the Hampshire Water Transfer and Water Recycling Project, as described in Environmental Statement Chapter 3 Description of the Proposed Development, Volume I (Document reference 6.1, DCO Volume 6).
Receptor	An individual, group or asset that receives an impact of effect.
Recycled water	Purified water that has been produced by taking treated wastewater and removing remaining impurities using advanced treatment techniques.
Reject water	During the water recycling process, reject water is produced. Reject water is water containing impurities removed from the treated wastewater and released using the existing Eastney Transfer Tunnel and Eastney Long Sea Outfall.
Release from the Eastney Long Sea Outfall (LSO)	The existing Eastney LSO releases treated wastewater from Budds Farm Wastewater Treatment Works via the existing Eastney Transfer Tunnel and Eastney Pumping Station. The Proposed Development would utilise the Eastney LSO for the release of reject water produced by the Water Recycling Plant site. During maximum operation approximately 22 Mega litres per day (Ml/d) of reject water would be released from the Eastney

Term	Definition
	LSO. During minimum flow operation approximately 4Ml/d of reject water would be released from the Eastney LSO.
Remediation	An action taken to break or modify the source-pathway-receptor (contaminant) linkage so that the risks are removed or reduced to an acceptable level for the land use under consideration (from CIRIA).
Secondary A aquifer	These are 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. These are generally aquifers formerly classified as minor aquifers.
Secondary B aquifer	These are mainly lower permeability layers that may store and yield limited amounts of groundwater through characteristics like thin cracks (called fissures) and openings or eroded layers.
Secondary undifferentiated aquifer	This has been assigned in cases where it has not been possible to attribute either a Secondary A or B aquifer to the soil type due to the variable characteristics. In most cases, this means that the layer in question has previously been designated as both minor and non-aquifer in different locations due to the variable characteristics of the rock type.
Source water	Water that is used as a source for drinking water. For the Proposed Development, this water is treated to strict regulatory standards at the Otterbourne Water Supply Works before being supplied to customers.
Source-pathway-receptor linkage	For a risk to arise there must be hazard that consists of a 'source' (e.g. high rainfall); a 'receptor' (e.g. people, environment); and a pathway between the source and the receptor (e.g. flooding).
Special Area of Conservation (SAC)	Area(s) of protected habitat(s) and species as defined in the European Union Habitats Directive (92/43/EEC).
Special Protection Area (SPA)	A designated area for birds under the European Union Directive on the Conservation of Wild Birds (2009/147/EC).
waterTrenchless crossings	Crossings where trenchless installation techniques will be used during construction of the Proposed Development.
Unproductive strata	These are predominantly rock layers or drift deposits with low permeability that have negligible significance for water supply or river base flow.
Waste	Any substance or object which the holder discards or intends to or is required to discard – unusable or unwanted.
Wastewater	A combination of water from kitchens, bathrooms, sinks and taps (in domestic and non-domestic properties) and rainwater from roads and roofs, that is transported to, and cleaned at, a wastewater treatment works.
Water for Life Hampshire	This is the programme being progressed by the Applicant to address the sustainability objectives of to meet demand following a reduction in abstractions on Hampshire's two main rivers - The Test and Itchen - and ensuring a resilient water supply for the Applicant's customers, especially during times of drought.
Water Recycling Plant (WRP)	The WRP would receive a total maximum volume of approximately 82 Mega litres per day (Ml/d) of treated wastewater from Budds Farm Wastewater Treatment Works. This would provide a maximum output of approximately 60Ml/d of recycled

Term	Definition
	water. Approximately 22Ml/d of reject water is produced from the water recycling process and would be combined with the existing Budds Farm Wastewater Treatment Works treated wastewater flows (that are generated by the existing operation of Budds Farm Wastewater Treatment Works), and released via the existing Eastney Transfer Tunnel, Eastney Pumping Station, and Eastney Long Sea Outfall operated by the Applicant.
Water Recycling Plant (WRP) site	The site containing the WRP, three pumping stations, a main process building, kiosks, administrative buildings and parking facilities. Located at a site north-west of Budds Farm Wastewater Treatment Works.
The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017 (WER)	The WER transpose the European Water Framework Directive 2000/60/EC into law in England and Wales.
The Water Framework Directive (Standards and Classification) Directions (England and Wales) 2015 (WFD Direction)	The WFD Direction establish a series of thresholds that are used in the classification of water body status under the Water Environment (Water Framework Directive) England and Wales) Regulation 2017.

Abbreviations

Abbreviation	Meaning
AGP	Above Ground Plant
AGS	Association of Geotechnical and Geoenvironmental Specialists
ACEC	Aggressive Chemical Environment for Concrete
BPT	Break Pressure Tank
CIA	Concrete Institute of Australia
CIRIA	Construction Industry Research and Information Association
CL:AIRE	Contaminated Land in Real Environments
DCO	Development Consent Order
EA	Environment Agency
EIC	Environment Industries Commission
EPB	Earth Pressure Balance
EWE	Extreme Weather Events
FWRA	Foundation Works Risk Assessment
GAC	Generic Assessment Criteria
ICE	Institution of Civil Engineers
IPS	Intermediate Pumping Station
LSO	Long Sea Outfall
LQM	Land Quality Management
PSC	Potential Source of Contamination
SPZ	Source Protection Zone
TBM	Tunnel Boring Machine
WFD	Water Framework Directive
WRP	Water Recycling Plant
WTW	Wastewater Treatment Works
WSW	Water Supply Works

References

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[3] EIC/AGS/CL:AIRE, Soil Generic Assessment Criteria for Human Health Risk Assessment, 2010.

[4] EA, “ Piling and penetrative ground improvement methods on land affected by contamination: Guidance on pollution prevention,” Environment Agency National Groundwater & Contaminated Land Centre., 2001.

[5] CIRIA, “C552- Contaminated land risk assessment. A guide to good practice,” CIRIA, 2001.

[6] National Highways, “Specification for Highway Works - Series 1600, Piling and Embedded Retaining Walls,” 2005.

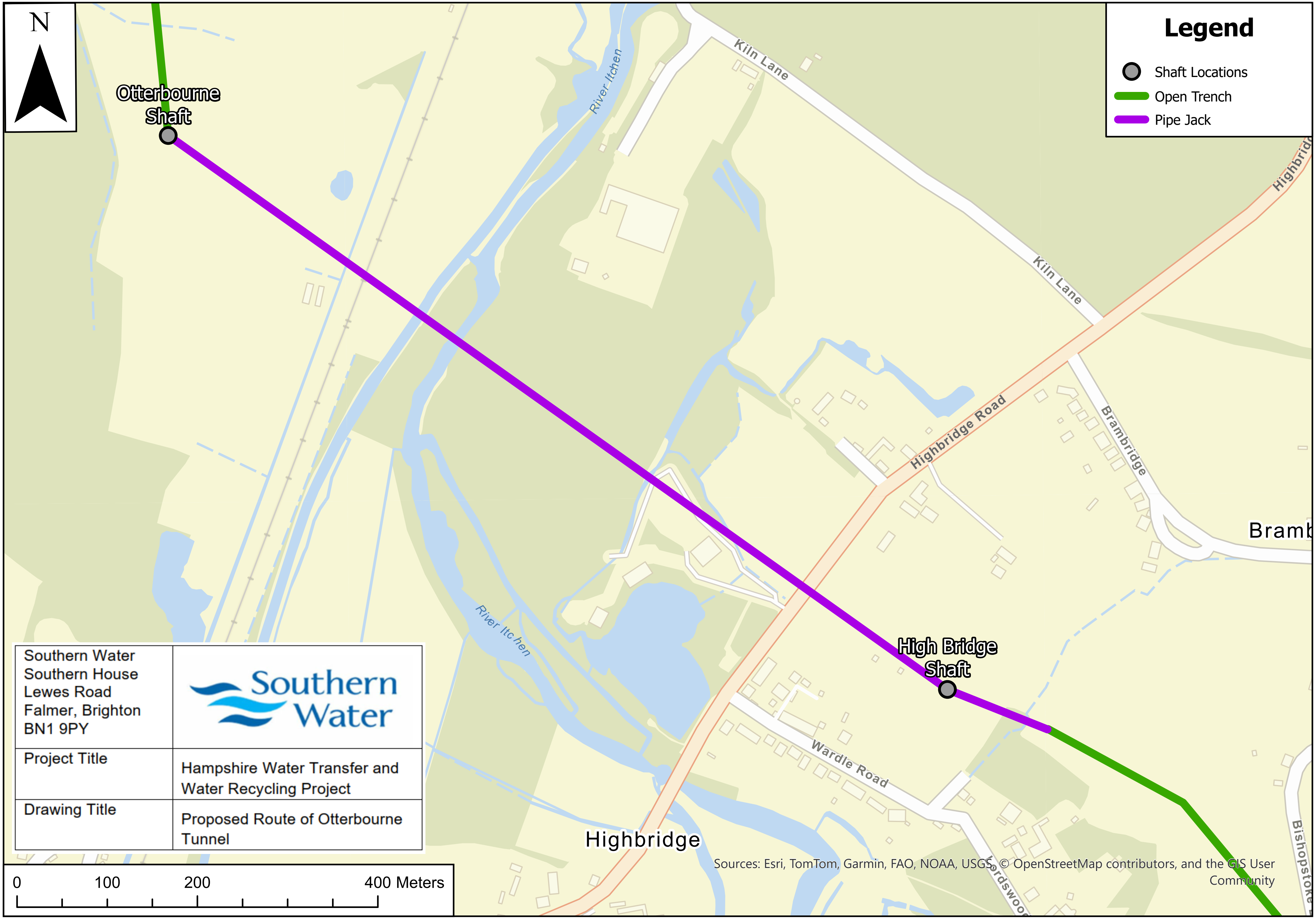
[7] CIA, “Z17 - Tremie Concrete for Deep Foundations,” Concrete Institute of Australia, 2012.

[8] M. Larisch, “Fundemental Mechanisms of Concrete Bleeding in Bored Piles,” 2019.

[9] BRE, “Special Digest 1 Concrete in aggressive ground. 3rd edition (Includes February 2017 amendments),” IHS BRE Press, Bracknell, 2017.

[10] CL:AIRE, Piling and Penetrative Ground Improvement Methods on Land Affected by, Reading: CL:AIRE, 2025.

Appendix A Tunnel, shaft and exploratory hole location plans



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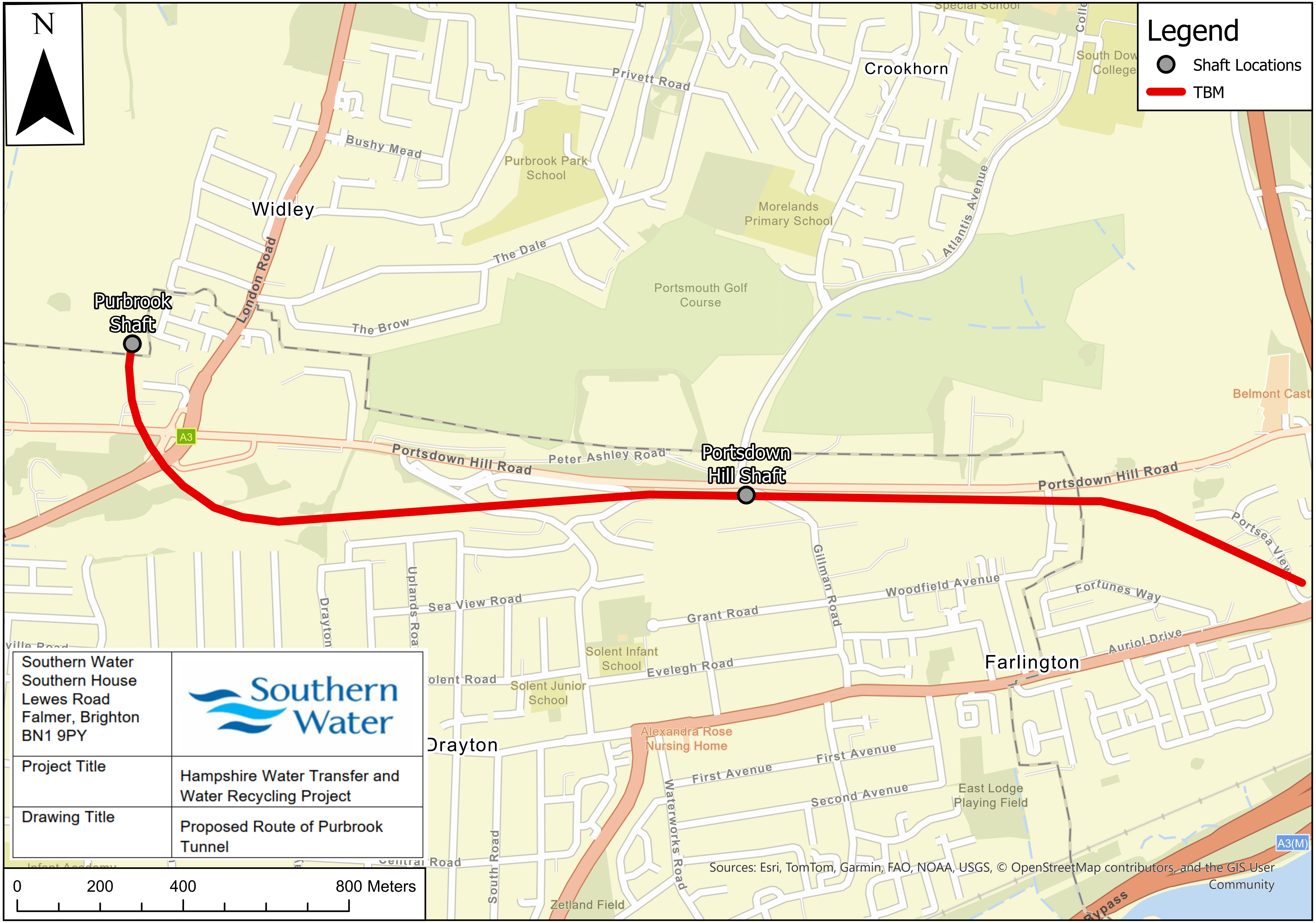
Project Title	Hampshire Water Transfer and Water Recycling Project
Drawing Title	Proposed Route of Otterbourne Tunnel



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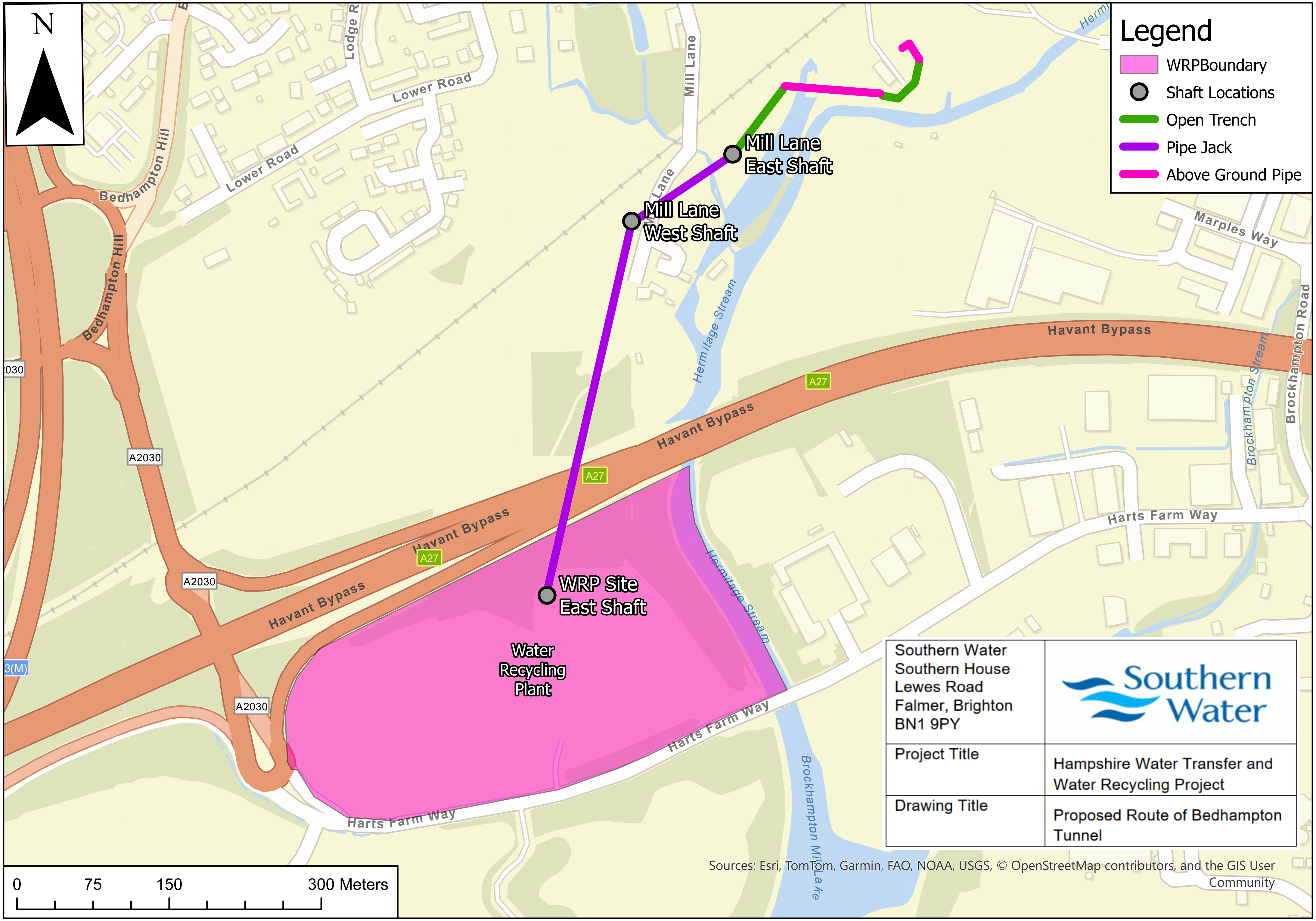
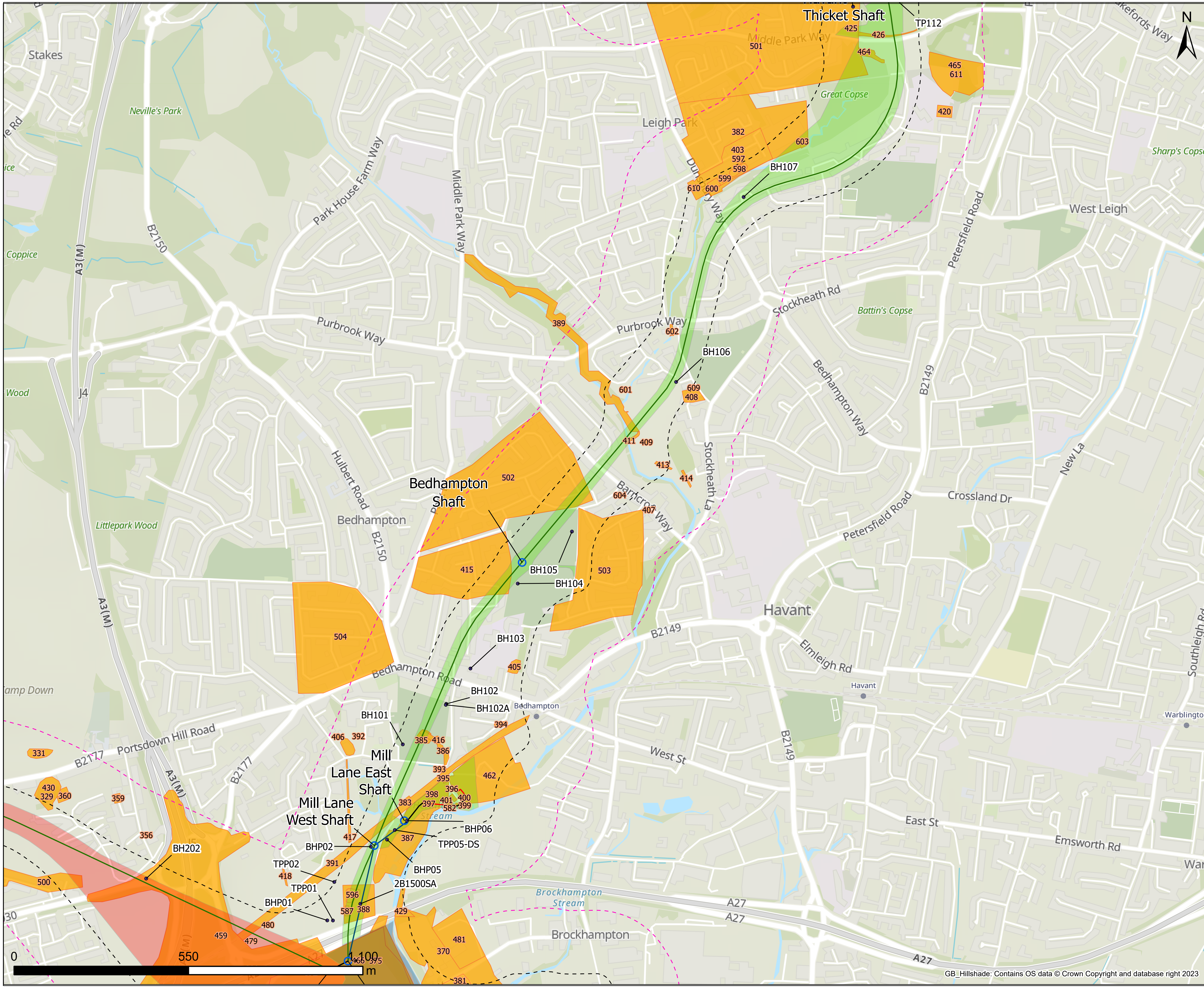
Drawing Title	Proposed Route of Purbrook Tunnel


N
Legend
WRPBoundary
Shaft Locations
Open Trench
Pipe Jack
Above Ground Pipe
Mill Lane East Shaft
Mill Lane West Shaft
WRP Site East Shaft
Water Recycling Plant
Lower Road
Bedhampton Hill
Mill Lane
Lodge R
Marples Way
Brockhampton Road
Havant Bypass
A27
A2030
Harts Farm Way
Hermitage Stream
Brockhampton Stream
Brockhampton Mill Lake
Southern Water
Southern House
Lewes Road
Falmer, Brighton
BN1 9PY
Southern Water
Project Title
Hampshire Water Transfer and Water Recycling Project
Drawing Title
Proposed Route of Bedhampton Tunnel
Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community
0
75
150
300 Meters

Appendix B PSC location plans



Legend

- Ground Investigations
- Shafts
- Draft Order Limits 50m buffer
- Draft Order Limits 250m buffer

GI Scoping Route

- Above Ground - Subject to Change
- Open cut
- Trenchless
- Tunnel

Draft Order Limits Sections

- A
- B
- C
- D
- E
- F
- G
- H
- J
- K
- L
- M
- Potential Sources of Contamination

Contains Southern Water preliminary data - All site locations and routes shown are preliminary only and subject to further site selection assessment and stakeholder consultation.

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Project Title: Hampshire Water Transfer and Water Recycling Project

Drawing Title: Section B Ground Investigation Locations with PSCs

Scale	Date Drawn	Page	Sheet Size
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Originator	Checker	Reviewer	Approver
SB	GS	AC	JH
Project No.			Revision
710166-SWS-XX-XX-SK-GE-00001			A

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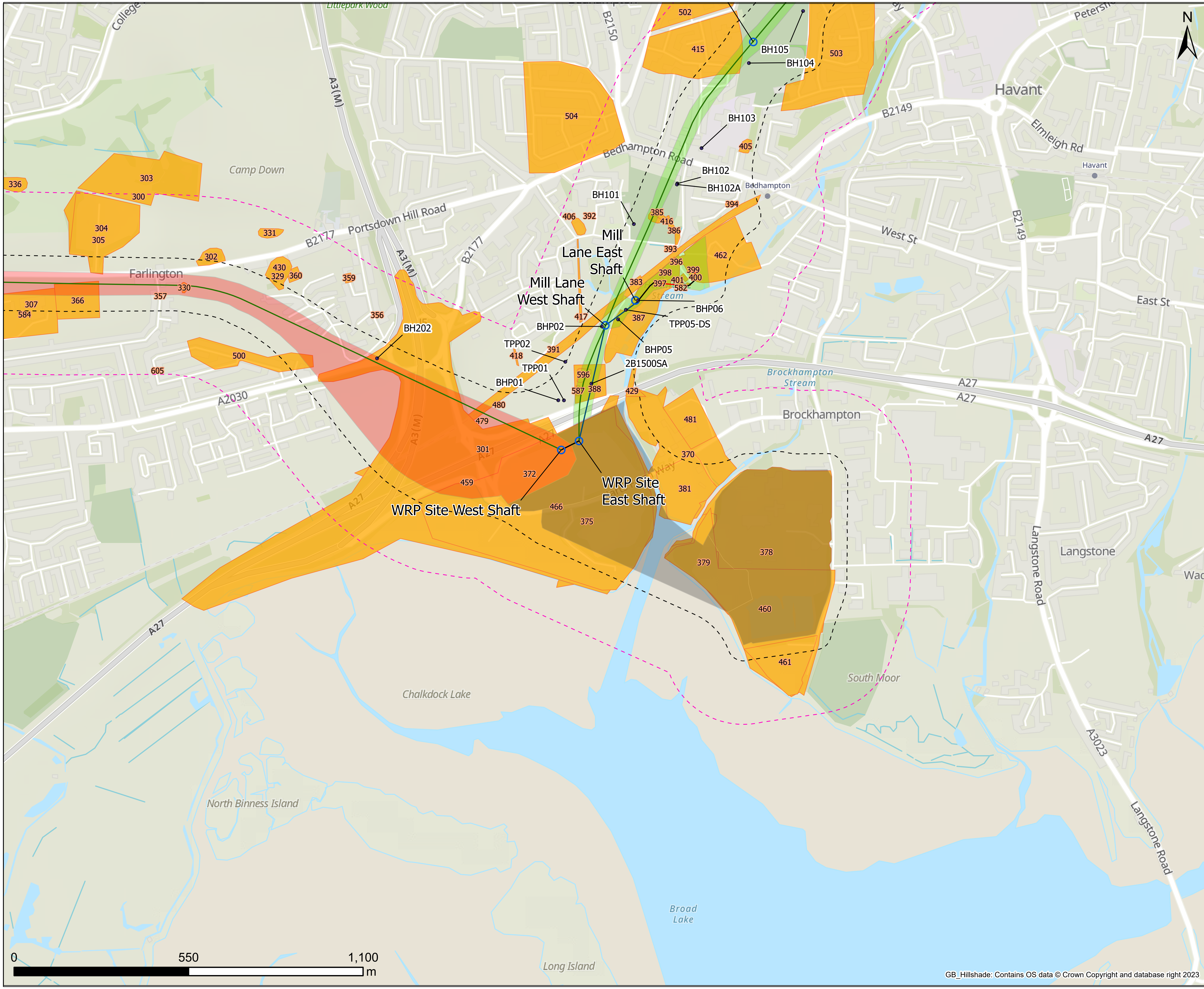

Legend

- Ground Investigations
- Shafts
- Draft Order Limits 50m buffer
- Draft Order Limits 250m buffer

GI Scoping Route

- Above Ground - Subject to Change
- Open cut
- Trenchless
- Tunnel

Draft Order Limits Sections

- A
- B
- C
- D
- E
- F
- G
- H
- J
- K
- L
- M
- Potential Sources of Contamination

Contains Southern Water preliminary data - All site locations and routes shown are preliminary only and subject to further site selection assessment and stakeholder consultation.

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Project Title	Hampshire Water Transfer and Water Recycling Project		
Drawing Title	Section C Ground Investigation Locations with PSCs		
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Originator SB	Checker GS	Reviewer AC	Approver JH
Project No. 710166-SWS-XX-XX-SK-GE-00001			Revision A

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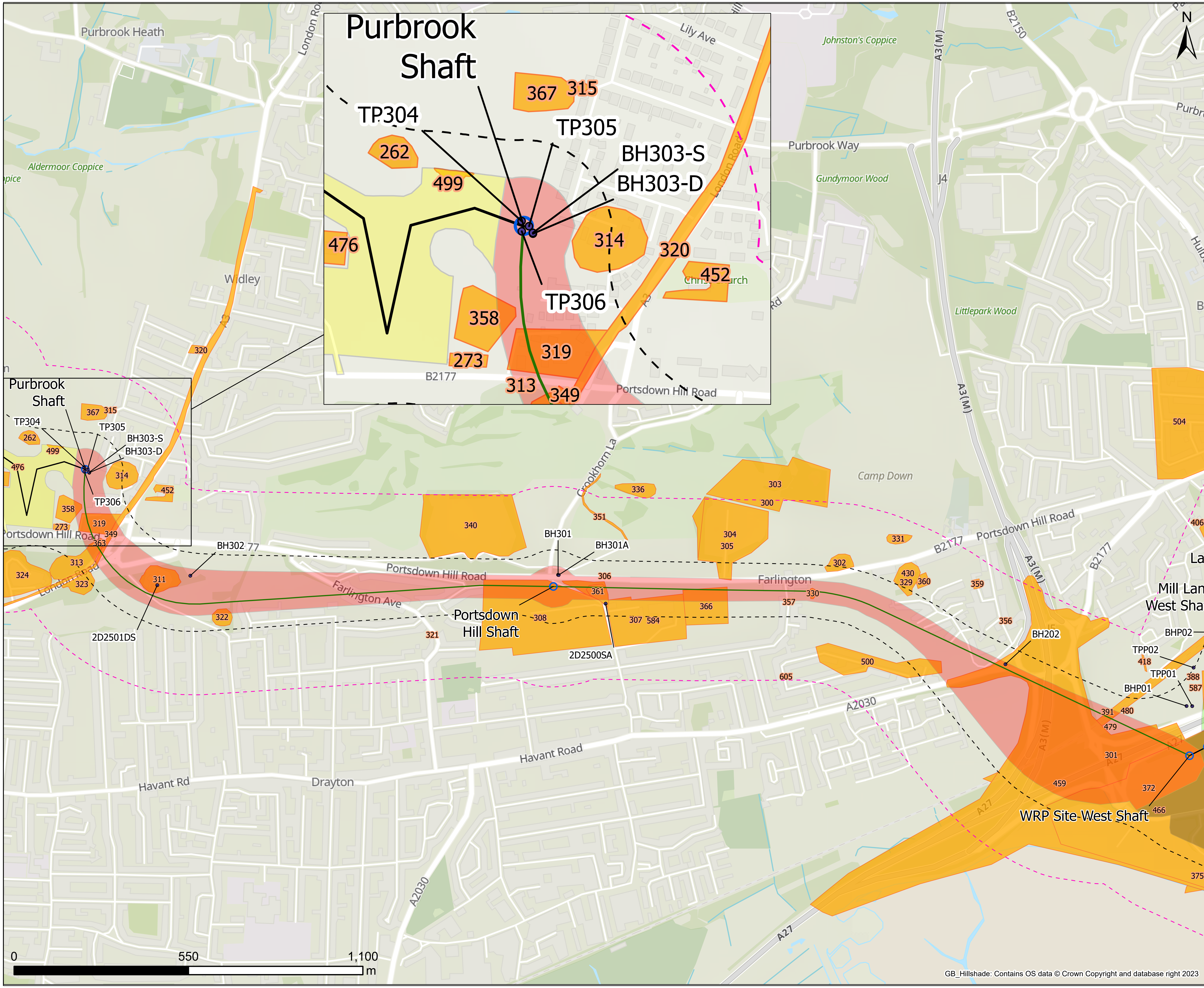

Legend

- Ground Investigations
- Shafts
- Draft Order Limits 50m buffer
- Draft Order Limits 250m buffer

GI Scoping Route

- Open cut
- Tunnel

Draft Order Limits Sections

- A
- B
- C
- D
- E
- F
- G
- H
- J
- K
- L
- M
- Potential Sources of Contamination

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Project Title: Hampshire Water Transfer and Water Recycling Project

Drawing Title: Section D
Ground Investigation Locations with PSCs

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Originator	Checker	Reviewer	Approver
SB	GS	AC	JH
Project No.			Revision
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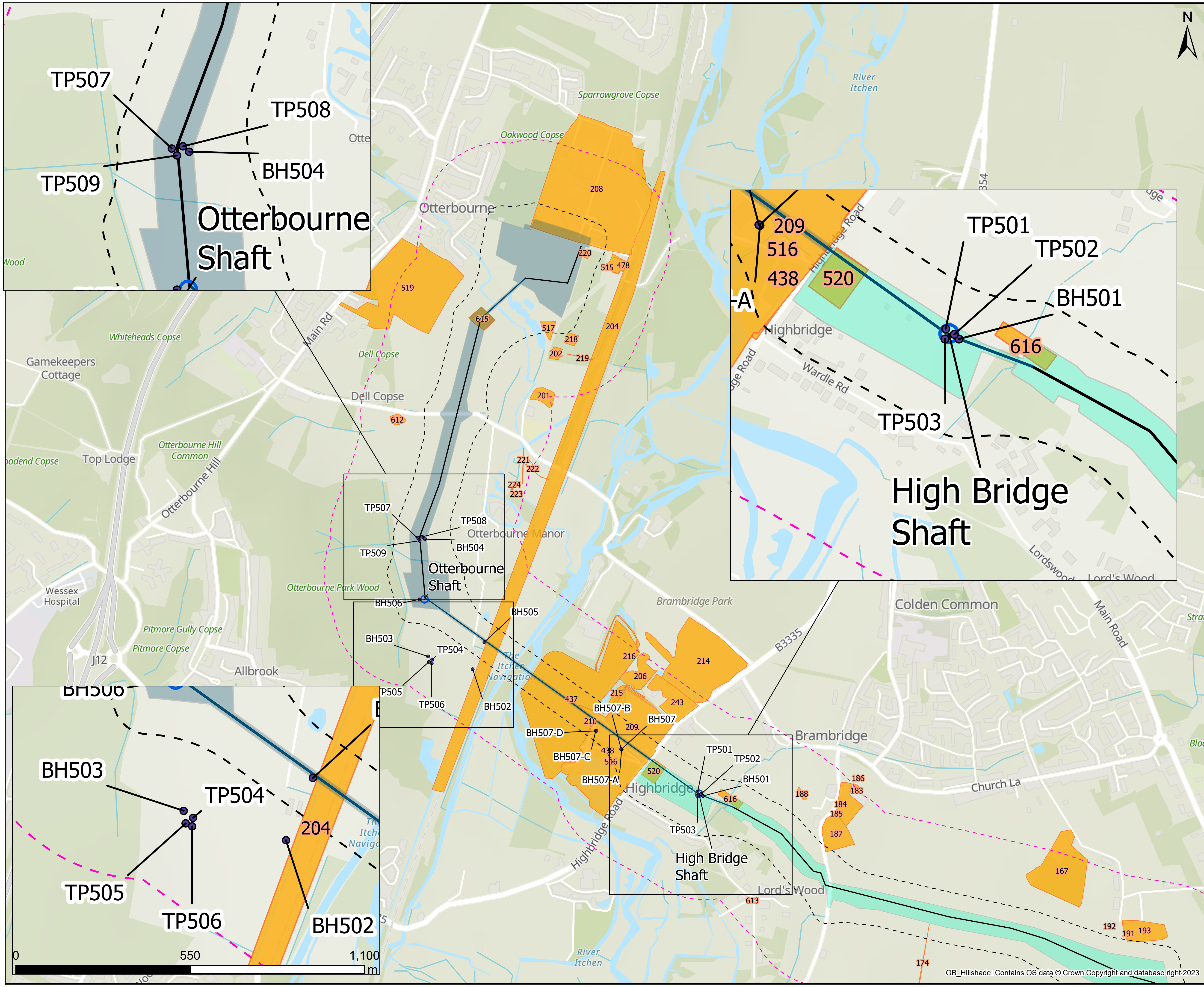

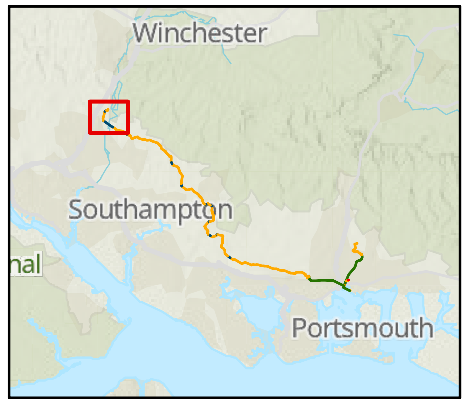

Legend

- Ground Investigations
- Shafts
- Draft Order Limits 50m buffer
- Draft Order Limits 250m buffer

GI Scoping Route

- Open cut
- Trenchless

Draft Order Limits Sections

- A
- B
- C
- D
- E
- F
- G
- H
- J
- K
- L
- M
- Potential Sources of Contamination

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Project Title: Hampshire Water Transfer and Water Recycling Project

Drawing Title: Section M
Ground Investigation Locations with PSCs

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