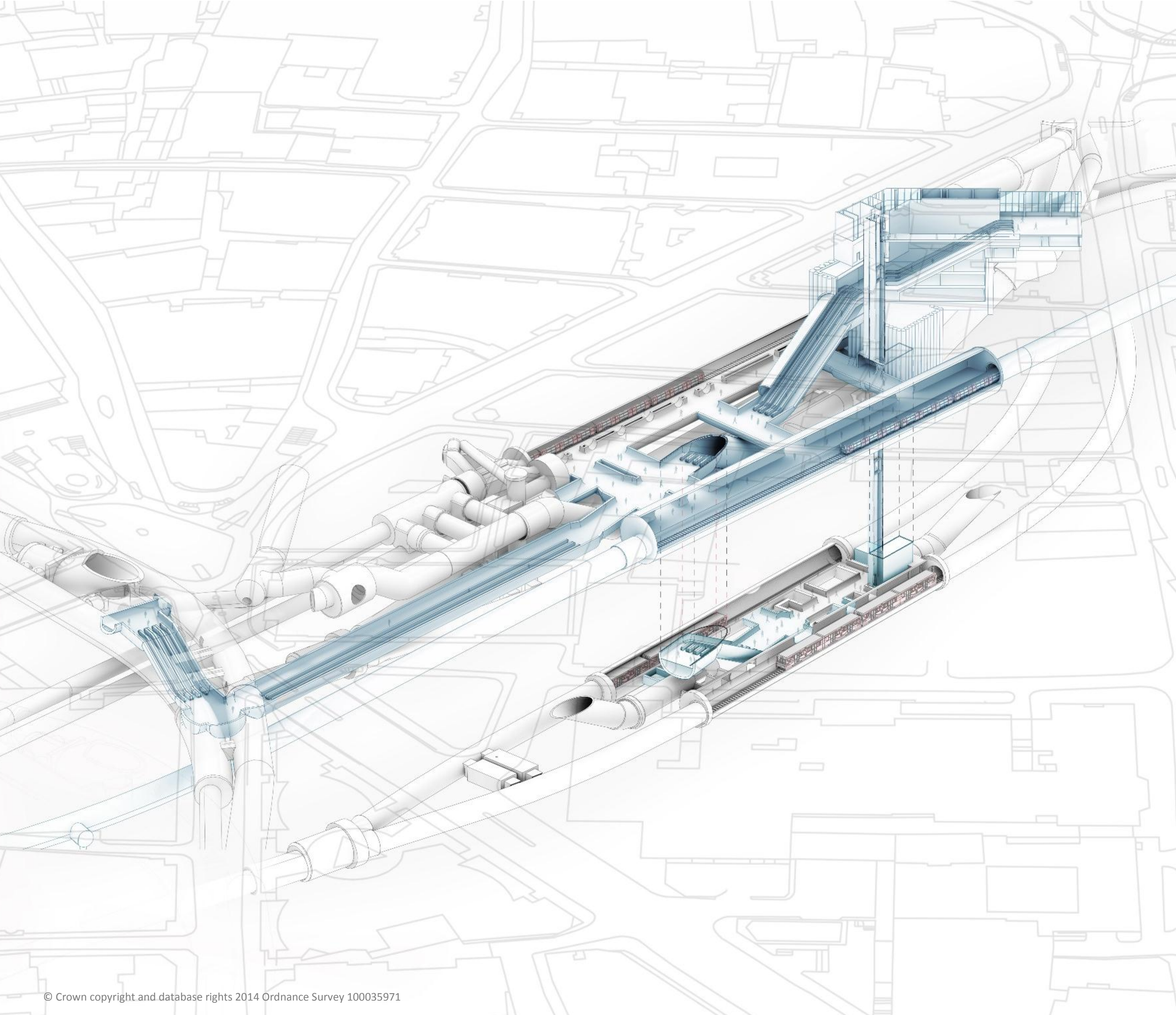
A13 – Water Resources and Flood Risk

A13.1 – Flood Risk Assessment

A13.2 – Water Resources Baseline Report (Mott MacDonald)

A13.1 – Flood Risk Assessment



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Transport and Works Act 1992

London Underground (Bank Station Capacity Upgrade) Order

Flood Risk Assessment

September 2014

MAYOR OF LONDON

TRANSPORT FOR LONDON
EVERY JOURNEY MATTERS

Transport and Works Act 1992

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Flood Risk Assessment

September 2014

Bank Station Capacity Upgrade Project
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List of Abbreviations

Acronym	Definition
AEP	Annual Exceedance Probability
ALV	Alluvium deposits
AOD	Above Ordnance Datum
BGS	British Geological Survey
BSCU	Bank Station Capacity Upgrade
CDA	Critical Drainage Areas
CDS	Conceptual Design Statement
CIRIA	Construction Industry Research and Information Association
DCLG	Department of Communties and Local Government
DDR	Detailed Design Report
DLR	Docklands Light Railway
EIA	Environmental Impact Assessment
ES	Environmental Statement
FMP	Flood Mitigation Project
FRA	Flood Risk Assessment
FSR	Flood Studies Report
GARDIT	General Aquifer Research Development and Investigation Team
ha	Hectare
LASI	Langley Silt Member
LFRZ	Local Flood Risk Zone
LUCRFR	London Underground Comprhensive Review of Flood Risk
LUL	London Underground Limited
NPPF	National Planning Policy Framework
m	Metres

Acronym	Definition
mm	Millimetres
OSD	Over Site Development
PPG	Planning Policy Guidance
ReFH	Revitalised Flood Hydrograph
RIBA	Royal Institute of British Architects
SuDS	Sustainable Drainage Systems
TPGR	Taplow Gravel Formation
TWAO	Transport and Works Act Order
TWUL	Thames Water Utilities Limited

1 Introduction

1.1.1 This Flood Risk Assessment (FRA) considers the flood risk to, and the potential impact on flood risk from, the proposed construction and operation of the Bank Station Capacity Upgrade (BSCU). This FRA also considers a replacement over site development (OSD) as a cumulative effect of this development.

1.1.2 The majority of the BSCU construction works are located below ground, with permanent surface level access points from Cannon Street. The Arthur Street Work Site is a temporary work site required throughout the construction of the BSCU.

1.1.3 The BSCU Work Sites are both located within Environment Agency Flood Zone 1 and are therefore considered to be at low risk of flooding from fluvial and tidal sources (<0.1 per cent annual exceedance probability). As the Whole Block Site covers less than 1 hectare (ha) in area, a FRA is not required by the *National Planning Policy Framework* (*NPPF*) (Department for Communities and Local Government (DCLG), 2012) to support the Transport and Works Act Order Application.

1.1.4 Though a FRA is not required for the above ground elements of the BSCU by planning policy, the Environmental Impact Assessment (EIA) scoping process identified the potential flood risk from a burst water main and water ingress from the disused City and South London tunnels. Furthermore, *LUL Category 1 Standard S1052 - Gravity Drainage Systems* (London Underground Limited (LUL), 2011) requires that flood risk be considered for LUL assets throughout their design lifetime (as detailed in Appendix 1 of this FRA). A FRA has therefore been undertaken to assess the risk to the BSCU and third party assets under both the existing and post-development conditions.

1.1.5 This 'Level 2' FRA has been prepared in full accordance with current guidance, *NPPF* and the associated *Planning Policy Guidance* (*PPG*). The Level 2 FRA includes the identification of flooding pathways by considering the local and site topography, the proximity of the flood source to the receptor and the potential flood conveyance routes local to the site.

1.2 Scope of Works

1.2.1 The objectives of this FRA are to:

- review existing information relating to the flood risk from all sources posed to the BSCU Work Sites as the below ground elements of the BSCU Project;
- consult the Environment Agency regarding the BSCU in relation to flood risk and the requirements of the *NPPF*;

- assess the flood risk to the BSCU under both the existing and post-development conditions (taking into account the potential effects of climate change); and
- outline any mitigation measures needed to meet with the requirements of the *NPPF* or any other design measures which will improve the functionality of the development with respect to flood risk.

1.3 FRA Methodology

Source-Pathway-Receptor Model

1.3.1 The aim of this FRA is to assess the risk of all forms of flooding both to and from the above ground and below ground elements of the BSCU. This assessment has therefore been undertaken using the Source-Pathway-Receptor model.

1.3.2 The Source-Pathway-Receptor model initially identifies the causes or 'sources' of flooding to and from the development. The identification is based on a review of available information, local conditions and consideration of the effects of climate change. The nature and likely extent of flooding arising from any one source is considered. This assessment addresses the risk from fluvial, tidal, surface water, groundwater, sewers and artificial sources.

1.3.3 The presence of a flood source does not always imply a risk. It is the exposure pathway or the 'flooding mechanism' that determines the risk to the receptor and the effective consequence of exposure. For example, sewer flooding does not necessarily increase the risk of flooding unless the sewer is local to the site and ground levels encourage surcharged water to accumulate and impact the area of interest.

1.3.4 For Level 1 and Level 2 FRAs, the identification of flooding pathways is undertaken by considering the local and site topography, the proximity of the flood source to the receptor and the potential flood conveyance routes local to the site. For more detailed Level 3 FRAs, hydrological or hydraulic modelling may be required to quantify the flood risk and identify specific pathways, for the particular flood source. A Level 3 FRA has not been determined as necessary for the BSCU at this time.

1.3.5 If a flooding mechanism is not identified as being present, then the risk from this source is considered to be negligible.

Assessment of Flood Risk to Receptors

1.3.6 The varying effect of flooding on the 'receptors' depends on the sensitivity of the target. Receptors may include any people or buildings within the range of the flood source, which are connected to the sources of flooding by a pathway.

1.3.7 In order for there to be a flood risk, all elements of the model (a flood source, a pathway and a receptor) must be present. Effective mitigation may be provided by removing any one element of the model.

1.3.8 The potential severity of the impact is determined by considering a combination of the type of flood source, the flood mechanisms identified, the layout and design of the proposed receptor and the vulnerability of the proposed receptor.

1.3.9 The Source-Pathway-Receptor approach involves a desk-based review of available information to establish:

- the likely flooding sources;
- the potential flooding mechanisms;
- the probability of a flood event occurring;
- the vulnerability of the potential receptors; and,
- the severity of the impact of a flood event on the receptor.

Data Sources and References

1.3.10 A key source of site specific information is the September 2013 Envirocheck report (Appendix A14.10 of the Environmental Statement (ES)), commissioned for this BSCU Baseline Assessment. Table 1.1 summarises the key data sources used in this FRA.

Table 1.1: Data Sources

Data Source / Report Reference	Author	Context
OSD Drainage Strategy: Stage C Report (Summarised in Appendix 2)	URS, 2013	Details of the surface water management strategy for an OSD
Water Resources Baseline Report (Appendix A13.2 of the ES))	Mott MacDonald, 2011	Assessment of water resources baseline conditions undertaken for the scheme in 2011
City of London Strategic Flood Risk Assessment (Publically Available)	City of London Corporation, 2012	Contains information on all sources of flooding across the City of London
City of London Surface Water Management Plan (Publically Available)	City of London Corporation, 2011	Contains information on surface water and sewer flooding
London Regional Flood Risk Appraisal (Publically Available)	Greater London Authority, 2009	Contains information on the strategic management of flood risk across London
March 2012 Geotechnical Desk Study (Appendix A14.2 of the ES)	Mott MacDonald, 2012	Contains hydrogeological background data
Report on the Management of London Basin Chalk Aquifer. Status Report (Publically Available)	Environment Agency, 2012	Information on the status of the deep Chalk Aquifer
C2 Asset Plans & Utilities Tracing Surveys Report (Confidential)	Mott MacDonald, 2012	Details of the TWUL local sewer and water supply network
S1064: Waterproofing (Confidential)	London Underground Ltd, 2011	LUL Category 1 Standard on waterproofing
S1052 Civil Engineering – Gravity Drainage Systems (Summarised in Appendix 1)	London Underground Ltd, 2011	LUL Category 1 Standard on gravity drainage systems and flood risk requirements
S1056 Civil Engineering – Pumped Drainage Systems (Confidential)	London Underground Ltd, 2011	LUL Category 1 Standard on pumped drainage systems and flood risk
T0003: Critical Pump Sites – Control Panel Specification (Confidential)	London Underground Ltd, 2011	LUL Technical Specification for critical pump control panels
T0004: Non-Critical Pump Sites – Control Panel Specification (Confidential)	London Underground Ltd, 2011	LUL Technical Specification for non-critical pump control panels

2 Site Description

2.1 Overview

2.1.1 The BSCU involves a major upgrade of the Bank Monument Station Complex to provide greatly improved passenger access, circulation and interchange. It includes provision of a new passenger entrance with lifts and escalator connections; a new Northern Line passenger concourse using the existing southbound platform tunnel; a new Northern Line southbound running and platform tunnel (and diversion of the Northern Line through this); and new internal passenger connections between the Northern Line, the Docklands Light Railway (DLR) and the Central Line.

2.1.2 The new Station Entrance will open on to Cannon Street at the junction with Nicholas Lane. An entrance hall will provide circulation space, as well as accommodating staff facilities, plant rooms and associated retail space. New passenger lifts will link the entrance hall directly with the Northern Line and DLR providing step free access. Escalators will also connect the entrance hall with the Northern Line.

2.1.3 The existing southbound platform for the Northern Line will be converted into a new passenger concourse. A new southbound running and platform tunnel will be located to the west of the existing platform. New cross passages will connect the Northern Line concourses and platforms. New walkways and escalators will better connect the Northern Line, the DLR and the Central Line. In particular, a tunnelled passageway fitted with moving walkways and new escalators will greatly improve interchange between the Northern Line and the Central Line.

2.1.4 Works to divert and protect utilities and to protect listed and other buildings from ground settlement, will also be undertaken. The compulsory purchase and temporary use of land, the temporary stopping up of streets, street works and ancillary works will also be required.

2.2 Site Location and Surrounding Area

2.2.1 The BSCU will be constructed from two main work sites. The first work site will be at the site bounded by King William Street, Nicholas Lane, Cannon Street and Abchurch Lane (the Whole Block Site) (see Figure 2.1). The Whole Block Site will be used to construct the escalators, cross passages and new Northern Line passenger concourse. A second smaller work site will be located on Arthur Street (see Figure 2.1). A shaft will be sunk at Arthur Street and used to excavate the new Northern Line southbound running tunnel. Approximately 80 per cent of the concrete required for construction will be prepared at the work sites. The remaining 20 per cent of the concrete will be delivered to the sites.

The disused King William Street underground station located beneath the junction of King William Street and Arthur Street will be used for logistics purposes during construction.

Above Ground Sites

2.2.2 The Whole Block Site is approximately 0.2 hectares (ha) in size and located 180m south-east of Bank Station and approximately 130m north-west of Monument Station centred at grid reference 532791, 180912. The Whole Block Site is bound to the north by King William Street, to the east by Nicholas Lane, to the south by Cannon Street and to the west by Abchurch Lane as shown by Figure 2.2.

2.2.3 The Arthur Street Work Site is located approximately 130m to the south of the Whole Block Site and is centred at grid reference 532796, 180775. The BSCU Work Sites are illustrated on Figure 2.1.

2.2.4 Ground levels at Nicholas Lane are approximately 14 to 14.5m Above Ordnance Datum (AOD) falling to the south, and the proposed Arthur Street Work Site is at an elevation of approximately 10mAOD.

Tunnelling

2.2.5 The construction of the new tunnel, cross passages, openings, walkways and escalator barrels will be carried out using sprayed concrete lining method. This involves excavating the ground (at a rate of between one metre and three metres per day) and spraying the excavated surfaces with steel fibre reinforced concrete.

Utilities Works

2.2.6 Works to divert and protect utilities potentially affected by construction are also proposed. These will comprise:

- protective works to the Low Level 2 Sewer (an west-east sewer between Cannon Street and King William Street) and to the London Bridge Sewer (a north-south sewer running beneath King William Street);
- diversion of utilities at Arthur Street to allow construction of the shaft; and
- other minor protective works to utilities to minimise impacts from settlement.

2.2.7 Utilities work will be undertaken in accordance with relevant codes of practice, and with regular liaison with the City of London Corporation and Transport for London highway authority.

Figure 2.1: The BSCU Work Sites

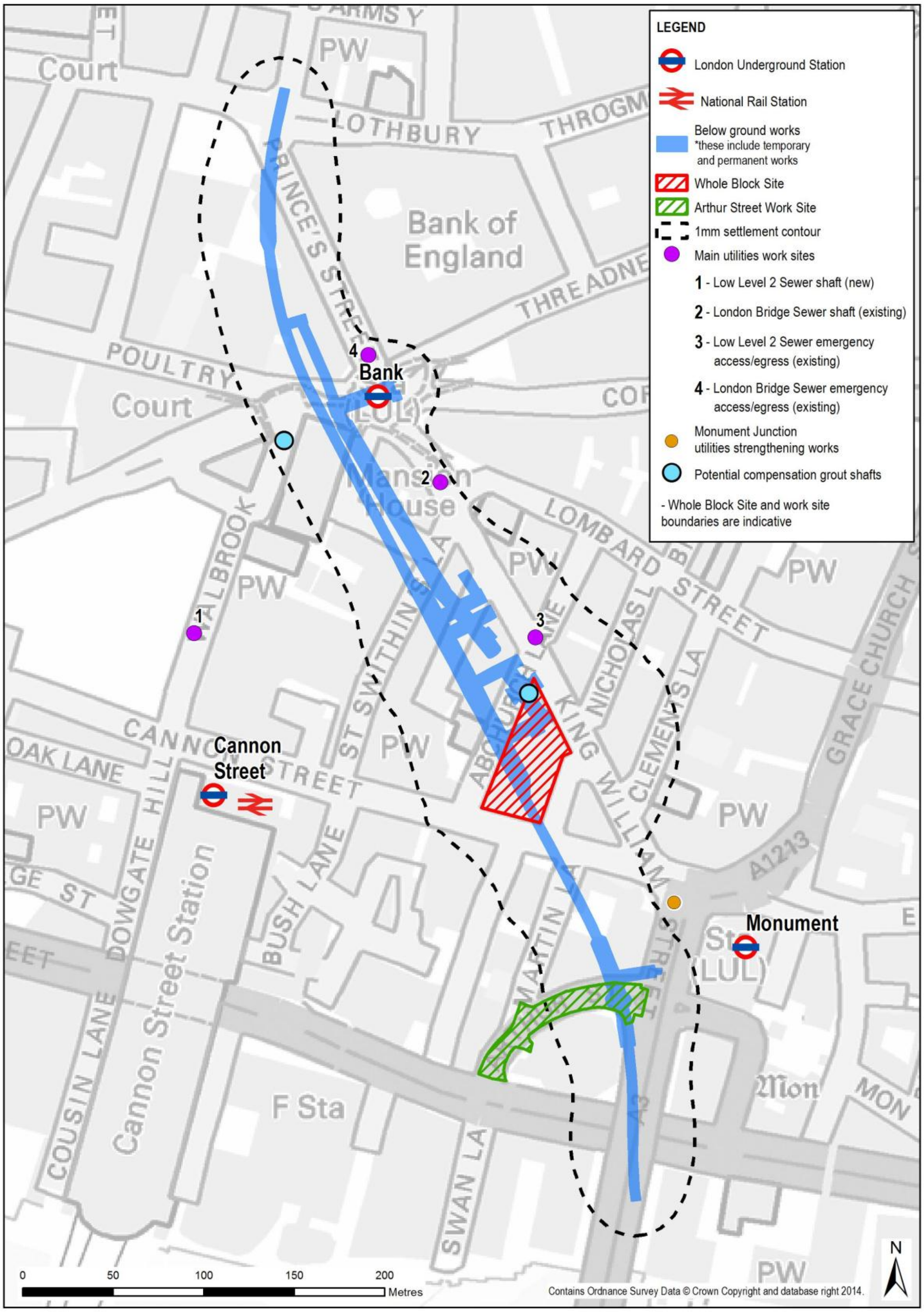


Figure 2.2: The Whole Block Site – Existing Buildings

3 Local Context

3.1 Surface Water Features

3.1.1 The Whole Block Site is located approximately 300m north of the tidal River Thames in the Thames River Basin District.

3.1.2 The Environment Agency defines the Thames River Basin District as the 16,133 km^2 hydrological catchment of the River Thames and its tributaries. The River Thames has its source in Gloucestershire and flows eastwards through London to the North Sea.

3.1.3 The Arthur Street Work Site is located approximately 120m north of the River Thames. The proposed below ground tunnelling works will not extend beneath the bed of the River Thames.

3.2 Lost Rivers

3.2.1 The *Water Resources Baseline Report* (Mott MacDonald, 2011) (see Appendix A13.2 of the ES) indicates that the Whole Block Site is located approximately 100m east of the culverted River Walbrook which is identified as one of the 'Lost Rivers of London'.

3.2.2 'Lost Rivers' is a term used for historic rivers in London which have been subsumed into the sewer network over time. The *Water Resources Baseline Report* (Mott MacDonald, 2011) states that the River Walbrook runs beneath Walbrook towards the River Thames.

3.2.3 Thames Water Utilities Ltd. (TWUL) sewer asset plans (ref: ALS/227340/SEWER) verify the findings of the *Water Resources Baseline Report*, indicating the presence of a large trunk sewer flowing from north to south beneath Walbrook (approximately 180m west of the Whole Block Site). It is understood that this combined sewer has an overflow outfall into the River Thames around Walbrook Wharf.

3.2.4 Map 7 in the *Strategic Flood Risk Assessment* (City of London Corporation, 2012) shows the historic line of the River Walbrook and the location of a number of large sewers within the City of London. The historic line of the River Walbrook is shown as flowing from north to south along Moorgate (north of the existing Bank Station).

3.3 Sewers

3.3.1 The *Stage C Below Ground Drainage Strategy* (URS, 2013) states that the Whole Block Site is adjacent to a number of existing TWUL combined sewers that vary in size from 300 to 1700mm in diameter.

3.3.2 TWUL Sewer Asset Plans (ref: ALS/227340/SEWER) show that these comprise the London Bridge trunk sewer underneath King William Street (of unknown dimensions) and one 3505mm diameter trunk sewer beneath Cannon Street. Two low level sewers run from north to south under Abchurch Lane (west of the site) and Nicholas Lane (east of the site). A further low level sewer runs west to east beneath Walbrook and King William Street. Two combined sewers also run parallel with the trunk sewer beneath Cannon Street.

3.3.3 The *Stage C Below Ground Drainage Strategy* (URS, 2013) states that there are several small connections serving the site that vary from 150mm to 225mm in diameter and it is anticipated these drain both surface water and foul water from the existing building.

3.3.4 The TWUL sewer asset plans indicate that a singular 1372 x 813mm combined sewer runs from east to south-west under the Arthur Street Work Site, with an additional connection coming in from a combined sewer under Martin Lane. The plans indicate that this sewer is located approximately 3 to 4.5m below ground level.

3.4 Water Supply Infrastructure

3.4.1 TWUL asset plans (ref: ALS/227340 WATER) indicate that 4” distribution mains are located around the Whole Block Site under Abchurch Lane, Nicholas Lane and Cannon Street. Both 6” and 4” distribution mains are present beneath King William Street and several 180mm High Pressure Polyethylene mains are present beneath Arthur Street.

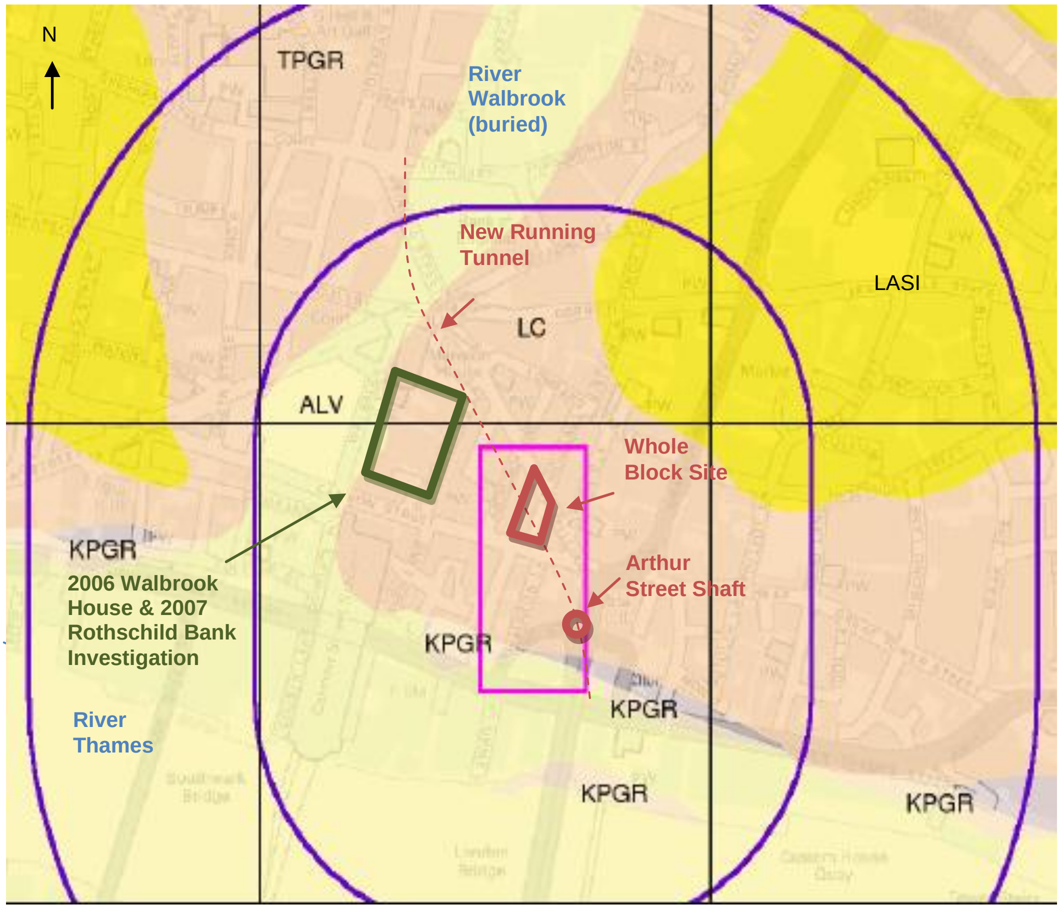
3.4.2 The *C2 Asset Plans & Utilities Tracing Surveys Report* (Mott MacDonald, 2012) identifies the location of existing utilities as based on received New Roads and Street Works Act Stage C2 utilities records and combined with additional information received from the City of London Corporation. The report states that it is anticipated that the tunnelling may have some impact on existing utilities, due to varying levels of settlement.

3.5 Geology

3.5.1 A full review of the local geology and hydrogeology can be found within Chapter 13: Water Resources and Flood Risk of the ES. However, baseline conditions pertinent to flood risk are summarised below.

3.5.2 The 1:10,000 scale British Geological Survey (BGS) geological map for the study area is included in the *2013 Envirocheck report* and an extract is provided in Figure 3.1.

Figure 3.1: Geological Map



Map Colour	Lex Code	Rock Name	Rock Type	Min and Max Age
	ALV	Alluvium	Clay and Silt	Flandrian - Flandrian
	KPGR	Kempton Park Gravel Formation	Sand and Gravel	Devensian - Devensian
	LASI	Langley Silt Member	Silt	Devensian - Devensian
	TPGR	Taplow Gravel Formation	Sand and Gravel	Wolstonian - Wolstonian
	HAGR	Hackney Gravel Member	Sand and Gravel	Wolstonian - Wolstonian

Sourced from Envirocheck by Landmark. (Landmark, September 2013)

3.5.3 The superficial geology in the vicinity of the BSCU largely comprises the sands and gravels of the Taplow Gravel Formation ('TPGR' on Figure 3.1).

3.5.4 Ground investigations and a review of borehole information in and around the Whole Block Site have established that the base of the Taplow Gravel Formation can be expected at an elevation of between 4mAOD and 7mAOD.

Beneath the Whole Block Site they are expected to be up to around 3m to 4m thick.

3.5.5 Towards the south of the BSCU there are Alluvium deposits ('ALV' on Figure 3.1) comprising clay and silt associated with the River Thames. A ribbon of Alluvium associated with the buried River Walbrook also extends northwards from the River Thames near Cannon Street Station, crossing the proposed new running tunnel route.

3.5.6 The Langley Silt Member ('LASI' on Figure 3.1) overlies the Taplow Gravel Formation on higher ground, around 200m to the north-east of the Whole Block Site and also to the west of the buried River Walbrook.

3.6 Bedrock Geology

3.6.1 The bedrock geological sequence in the vicinity of the Whole Block Site is expected to comprise the base of the London Clay Formation at between -35mAOD and -40mAOD, with the base of the Lambeth Group at between -54 and -63mAOD and the base of the Thanet Formation at between -63 and -67mAOD. The Chalk then underlies the Thanet Formation.

3.7 Hydrogeology

Shallow Aquifer

3.7.1 The Taplow Gravel Formation forms a shallow 'Secondary A' aquifer perched on the London Clay Formation. The Environment Agency defines Secondary A aquifers on its website as *permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers* (Environment Agency, 2013).

3.7.2 The Alluvium is a 'Secondary Undifferentiated' aquifer, which suggests that it has a lower permeability than the Taplow Gravel Formation. However, for the purpose of this assessment the Alluvium and Taplow Gravel Formation are assumed to form a 'shallow aquifer' that is water-bearing and in hydraulic continuity despite variations in permeability of the underlying strata.

3.7.3 A review of ground investigation reports and borehole information in Chapter 13: Water Resources and Flood Risk of the ES suggests that the groundwater levels in the shallow aquifer are expected to vary between 4mAOD and 9.5mAOD in the vicinity of the BSCU, with the base of the aquifer at an elevation of between 4mAOD and 7mAOD. The neap high tides and spring high tides in the River Thames are around 3mAOD and 4mAOD, respectively. Therefore the tidal influence on groundwater levels in the shallow aquifer is considered to be negligible. It is therefore anticipated that groundwater levels in the vicinity will be controlled by the balance of urban recharge from rainfall/soakaways/pipeline leakage and outflows from natural/artificial drains.

3.7.4 The *March 2012 Geotechnical Desk Study* (Mott MacDonald, 2012) (see Appendix A14.2 of the ES) presents contours for the top of the London Clay Formation. These, combined with the available ground elevation and groundwater level data described above, suggest that flow in the shallow aquifer will generally be to the south or southwest in the vicinity of the BSCU. However, the thin saturated aquifer thickness, combined with the undulating surface of the bedrock and foundation/basement obstructions, mean that the aquifer is likely to be compartmentalised i.e. it may not behave as one aquifer.

Deep Aquifer

3.7.5 The Thanet Formation and Chalk form a 'principal aquifer' in the study area. The Environment Agency describes this type of aquifer on its website as comprising *layers of rock or drift deposits that have high intergranular and/or fracture permeability - meaning they usually provide a high level of water storage. They may support water supply and/or river base flow on a strategic scale* (Environment Agency, 2013). The Thanet Formation and Chalk principal aquifer is in partial hydraulic continuity with the Upnor Formation (a secondary aquifer), which is the lowest Formation within the Lambeth Group. For the purpose of this assessment, the Thanet Formation, Chalk and Upnor Formation are assumed to form the 'deep aquifer'.

3.7.6 The *Environment Agency Status Report 2012* for management of the London Basin Chalk Aquifer indicates that at the peak of abstraction in the 1960s, groundwater levels in London lowered to -88mAOD. However, with the decline in industry, levels subsequently rebounded. Since 1992 groundwater levels in the deep aquifer have been controlled by the General Aquifer Research Development and Investigation Team (GARDIT) Strategy to maintain the integrity of underground structures and foundations in the London Clay Formation.

3.7.7 The *Environment Agency Status Report* 2012 (Environment Agency, 2012) presents a hydrograph for a deep borehole at Leith House in Gresham Street (TQ38/241), which is close to the northern extent of the proposed new running tunnel. This hydrograph indicates that groundwater levels were around -50mAOD and rising in the early 1990s, with relatively stable levels since the year 2000 at around -35mAOD (+/- 5m). The latter is taken as the baseline condition for groundwater levels in the deep aquifer, with a hydraulic gradient (and therefore groundwater flow) to the west.

Unproductive Strata (including London Clay Formation)

3.7.8 A non-aquifer, which comprises London Clay Formation and the Reading and Woolwich Formations of the Lambeth Group, hydraulically separates the shallow and deep aquifers. Despite the label of 'Unproductive Strata', sandier layers or sand lenses might be encountered during excavations, leading to localised ingress of water.

Water Abstraction

3.7.9 The *Geotechnical Desk Study* (Mott MacDonald, 2012) states that two wells have been identified within the footprint of 10 King William Street from the available historic information and mapping. It is understood that Well ‘A’ dates from 1916 whilst Well ‘B’ dates from 1925 and both wells are understood to terminate within the Chalk. The wells are likely to have been associated with water abstraction and are not currently in use.

4 Flood Risk to the Development

4.1 Flooding from Rivers and the Sea (Fluvial & Tidal)

4.1.1 The Environment Agency Flood Zone Maps (accessed online in October 2013) identify that the BSCU Work Sites are located within Flood Zone 1.

4.1.2 Flood Zone 1 is defined by the Environment Agency as land which has less than a 0.1 per cent annual exceedance probability (AEP) of flooding from fluvial and tidal sources in any given year (i.e. a 1000 year return period).

4.1.3 It is currently anticipated that climate change will result in an increased frequency and magnitude of extreme water levels within the River Thames. However, water levels in the adjacent section of the River Thames are effectively controlled by the operation of the Thames Barrier. If levels and flows are forecast to be any higher than the permissible levels, the Thames Barrier is shut, ensuring that the tide is blocked and that the River Thames is maintained to a low level.

4.1.4 The Thames Barrier and associated defence system has a 1 in 1000 year standard of protection that ensures flood risk is managed up to an event that has a 0.1 per cent AEP.

4.1.5 The Thames Barrier requires regular maintenance and with additional closures in the future due to climate change, the opportunity for maintenance will be reduced. When this happens, river levels (for which the Environment Agency would normally shut the barrier) will have to be allowed through to ensure that the barrier is not shut too often. On this basis, extreme water levels upstream of the barrier will increase and the tidal walls will be heightened to match; this forms a statutory requirement as set out in the *Thames Estuary 2100 (TE2100) Environmental Report Summary Plan (*Environment Agency, 2009*).*

4.1.6 On the basis of the above it is therefore considered that the sites covered by the TWAO application are considered to be at low risk of flooding from fluvial and tidal sources under both the current baseline and under the effects of climate change.

4.1.7 Further to the above, it is also noted that LUL are currently embarked upon their Comprehensive Review of Flood Risk (LUCRFR), a project that aims to assess flood risk to all LUL vulnerable assets from all sources with a target completion date of December 2014. Though the technical assessment is not yet complete, it is anticipated that if any significant changes to the fluvial and tidal risk profile around the BSCU are identified that the appropriate corresponding mitigation measures will be implemented by LUL.

Flooding from a Breach in the River Thames Flood Defences

4.1.8 A breach in the River Thames flood defences could lead to rapid inundation of areas located behind the defences as the water in the river discharges through the breach. A breach can occur with little or no warning, although the *Strategic Flood Risk Assessment* (City of London Corporation, 2012) states that they are much more likely to occur with extreme tides or river levels when the stresses on flood defences are highest. Flood water flowing through a breach will normally discharge at a high velocity, depending on water levels in the River Thames, rapidly filling up the areas behind the defences, potentially resulting in significant damage to buildings and a high risk of loss of life.

4.1.9 An assessment of a breach in the River Thames flood defences was undertaken in the *Strategic Flood Risk Assessment* (City of London Corporation, 2012). Five critical breach locations were identified by the Environment Agency for the City Embankment Area, and ten for the Westminster Embankment Area. None of the breach locations were located within the City of London authority boundary. The two nearest critical breach locations to the site were simulated at St. Katherine's Way and at Temple Place. Flood extent maps presented within the report's appendix show that both the BSCU Work Sites would be located outside of the inundation extent for the 0.5 per cent AEP (i.e. a 200 year return period) breach flood event.

4.1.10 Further, the area is located upstream of the Thames Barrier and the occurrence of extreme high water levels leading to breach conditions is therefore unlikely.

4.1.11 The BSCU Work Sites can therefore be considered to be at a low risk of flooding resulting from a breach in the River Thames flood defences.

Conveyance of Fluvial and Tidal Floodwater through LUL Assets

4.1.12 The *London Regional Flood Risk Appraisal* (Greater London Authority, 2009) states that there are a total of 72 LUL and DLR stations located within floodplains in London. The majority of these are within the tidal Thames floodplain through central London. According to the *Appraisal* most of the stations had flood doors fitted prior to the construction of the Thames Barrier.

4.1.13 The *Appraisal* states that stations on the DLR branch to Stratford and the Jubilee Line from Stratford to Canning Town are also within the River Lee fluvial floodplain. There are also outlying stations which are in flood risk areas: Burnt Oak on the Northern Line (Silk Stream floodplain) and Colliers Wood on the Northern Line (River Wandle floodplain).

4.1.14 The *London Regional Flood Risk Appraisal* (Greater London Authority, 2009) states that flood water entering underground stations presents a particular hazard and a significant engineering problem. Pathways from the surface may include station access points (including emergency access) and ventilation shafts.

4.1.15 This risk from fluvial or tidal sources at surface level extended geographically below ground level as the tunnels could act as a conveyance route for flood water from a wide variety of locations.

4.1.16 The *London Regional Flood Risk Appraisal* (Greater London Authority, 2009) states that LUL has undertaken extensive flood risk assessments of its infrastructure and keeps them up to date. However, it is acknowledged that should a major tidal flood occur it is likely to overwhelm any local flood control measures in some circumstances.

4.1.17 Though the BSCU Work Sites are not directly identified as being at risk of fluvial and tidal flooding or from a breach of the flood defences at surface level, there is a potential residual risk of flooding to the below-ground aspects of the BSCU by floodwater propagating through the underground tunnel network from areas at risk.

4.1.18 Based on the information received to date, it has not been possible to quantify this risk. However, the probability of a breach of defences occurring in the area is generally considered to be low due to the condition of the defences and maintenance and inspection regimes. In addition, most of the areas located within flood zones also benefit from the presence of flood defences, reducing the risk. The distance that floodwater would need to travel to affect the below ground elements of the BSCU is extensive. Therefore, the likelihood of the tunnels for the BSCU being affected by floodwater from this source is considered to be low.

4.2 Flooding from Sewers

4.2.1 The *Strategic Flood Risk Assessment* (City of London Corporation, 2012) states that the majority of London's sewers were built during the 19^{th} Century and are typically old brick-work culverts with capacity for up to only about a 10 per cent AEP (i.e. a 10 year return period) rainfall event. Climate change is anticipated to result in summer storms becoming more intense and winter storms more prolonged, thereby reducing the capacity of the sewer system further and potentially leading to an increase in localised flooding.

4.2.2 The *Strategic Flood Risk Assessment* (City of London Corporation, 2012) states that TWUL only held one record of sewer flooding within the EC1 postcode (i.e. the St Bartholomew Hospital area, but also including parts of the Boroughs of Islington, Camden and Hackney) at the time of consultation. Further to this, Map 6 in the *Strategic Flood Risk Assessment* indicates that the TWAO sites are not within a 'critical sewer flooding area'.

4.2.3 A surcharging sewer could potentially result in localised flooding and ponding in topographic depressions. Surface level assets could be potentially at risk if there is an existing flowpath onto the site and the depth of flooding was deep enough to overcome kerbs and finished floor levels. Below ground elements of the BSCU could potentially be affected if floodwater were able to flow into surface level access points or ventilation shafts.

4.2.4 There is also a residual risk of flooding from sewers should they become blocked or suffer a collapse. However, the general large size of the local sewers is such that blockage is unlikely. TWUL also announced in January 2013 (TWUL, 2013) that it was investing £346 million to reduce the threat of sewer flooding and proposed carrying out surveys in areas with a history of sewer problems to determine if these are being caused by a blockage or collapse in the sewer. Survey and investigation of the sewers in problematic areas should therefore ensure that the residual risk of a blockage or collapse is minimised.

4.2.5 The risk of sewer surcharging is currently being investigated by the LUCRFR project, though detailed model outputs for the area around the BSCU are not currently available to inform this FRA. LUL are also currently in the process of investigating sewers, planning diversions to obtain access, undertaking modelling and determining the appropriate mitigation measures to reduce the potential for sewer surcharging during the construction phasing.

4.2.6 Whilst there is an absence of any reported historical sewer flooding incidents in the vicinity and the existing strategic assessments to date indicate that the risk in the area is low, it does not necessarily mean that there is no risk from this source. On this basis it is proposed that the forthcoming model outputs from the LUCRFR project be further utilised to quantify the site-specific hazard and to inform the necessary mitigation if and where it is considered to be appropriate.

Impact of a Breach on Sewer Flooding

4.2.7 The *Strategic Flood Risk Assessment* (City of London Corporation, 2011) states that there are relief sewers which provide a hydraulic connection across the whole of the northern bank of the Thames. This connection introduces a potential flood mechanism where a breach or overtopping of the defences in one area in London could result in flooding in another area. If an area defended by local flood defences becomes inundated, flood water could discharge into the relief sewer from ground level and discharge through the gravity relief sewers towards east London.

4.2.8 The volumes of flood water associated with a flood defence breach could significantly overload the capacity of the sewer and result in flooding elsewhere in London. However, outputs from the *Strategic Flood Risk Assessment* (City of London Corporation, 2012) identify that the BSCU Work Sites are not located within an area that is considered to be at risk from this flooding mechanism.

4.3 Surface Water Flooding

4.3.1 Overland flow and surface water flooding may arise when intense rainfall exceeds the infiltration capacity of the ground and/or capacity of the receiving drainage network. This source of flooding is often exacerbated in urban areas where impermeable surfaces limit the potential for infiltration.

4.3.2 The *Strategic Flood Risk Assessment* (City of London Corporation, 2012) indicates that climate change is currently predicted to increase the number and intensity of extreme events. An increase in the frequency of intense rainfall events may therefore mean an increase in the number of events which exceed the capacity of the sewer system and therefore an increase in the risk of flooding from this source.

Surface Water Hydraulic Modelling

4.3.3 Hydraulic modelling has been undertaken as part of the *Surface Water Management Plan* (City of London Corporation, 2011) to identify the areas at risk of surface water flooding.

4.3.4 The hydraulic modelling approach utilised the software package 'TUFLOW' to create a two-dimensional model of the Greater London area based on topographical ground maps. Rainfall was applied directly to the model which then routes it overland to provide an indication of potential flow paths, directions, velocities and areas where surface water will pond. The TWUL sewer network was not directly included in the hydraulic modelling, although an allowance for the capacity of the sewer systems was represented by removing an appropriate amount from the rainfall volumes applied to the model.

4.3.5 The surface water flood depth mapping provided within the *Surface Water Management Plan* (City of London Corporation, 2011) provides a strategic overview of surface water flood risk within the City of London, though it is not considered detailed enough to account for precise addresses as it does not account for local drainage arrangements or site-specific variations in topography. Reported below are the outputs from the modelling in relation to the site and surrounding area. However, they should be treated as an indication for potential flooding and not an exact representation of floodwater depths and hazards for the reasons outlined above.

4.3.6 The *Surface Water Management Plan* (City of London Corporation, 2011, Figure 3.2.1a) modelled surface water flood depths for a 1 per cent AEP (i.e. a 100 year return period) storm with an additional rain depth allowance for the effect of climate change. The modelling suggests shallow surface water depths around the Whole Block Site, being predominantly less than 0.1m, with a few localised areas showing depths up to 0.25m. Flood depths at the Arthur Street Work Site are also shown as being predominantly less than 0.1m and three localised areas show depths of over 0.5m. The mapping shows that ponding in the wider area is also shown as being predominantly less than 0.1m, with problematic areas in the borough being denoted by depths ranging from 0.25 to 1.5m.

4.3.7 The risk of hazards to people from surface water flooding was also assessed, as per the guidance set out in the *Defra Research and Development Report FD2320* (Defra, 2006). Flood hazard is defined as:

- *caution*: Flood zone with shallow flowing water or deep standing water;
- *moderate*: Flood zone with deep or fast flowing water. Dangerous for children, the elderly and the infirm;
- *significant*: Flood zone with deep fast flowing water. Dangerous for most people; and
- *extreme*: Flood zone with deep fast flowing water. Dangerous for all (including emergency services).

4.3.8 The outputs show that the area around the Whole Block Site is predominantly assigned a hazard rating of Caution (lowest hazard rating), with very localised areas of Moderate hazard. The Arthur Street Work Site is also predominantly assigned a hazard rating of Caution, with localised areas of Significant hazard around the 33 King William Street building.

4.3.9 The surface water modelling was utilised to map key flood risk areas, defined as critical drainage areas (CDAs) and Local Flood Risk Zones (LFRZs). LFRZs are defined as discrete areas/extents of predicted surface water flooding. A CDA is a discrete geographic area and usually a hydrological catchment, where multiple and interlinked sources of flood risk (surface water, groundwater, sewer, main river and/or tidal) cause flooding in one or more LFRZs. Four CDAs and three LFRZs were defined within the City of London through this process. The CDAs cover most of the area of the City of London.

4.3.10 Both the Whole Block Site and the Arthur Street Work Site are located within the ‘Group3_007’ CDA with the very southern part of the Arthur Street Work Site is located within the ‘3021’ LFRZ. The *Strategic Flood Risk Assessment* (City of London Corporation, 2012) states that this CDA/LFRZ pairing was been delineated to reflect the interaction between tidal flood levels and ‘tide-locking’ of the local relief sewer outfalls (as detailed in paragraph 4.2.7).

4.3.11 This flooding mechanism is not anticipated to pose a significant risk to either of the BSCU Work Sites, as the area that could be potentially inundated by the interaction of the relief sewers with the River Thames is constrained to the land immediately behind the flood defences, as shown by Map 6 in the *Strategic Flood Risk Assessment* (City of London Corporation, 2012).

4.3.12 The *Strategic Flood Risk Assessment* (City of London Corporation, 2012) sought to improve upon the modelling undertaken in the *Surface Water Management Plan* (City of London Corporation, 2011) by providing a more detailed representation of topography, the sewer network and urbanisation. This process identified four main flooding 'hotspots'.

4.3.13 The outputs from the improved surface water modelling show that the BSCU Work Sites are not located within a surface water flooding 'hotspot'.

4.3.14 The BSCU Work Sites are considered to be at low risk of flooding from overland flow due to the absence of any historical flood events and low hazard depicted by the surface water modelling.

4.4 Flooding from Groundwater

4.4.1 Surface level groundwater flooding may be caused by the emergence of water from underlying aquifers. Below ground structures may be subject to groundwater ingress if constructed within an aquifer with inadequate waterproofing.

4.4.2 The *Strategic Flood Risk Assessment* (City of London Corporation, 2012) indicates that the effects of climate change may increase the risk of groundwater flooding as higher rainfall over outcrop areas of the shallow aquifers and enhanced leakage from drains and sewers cause groundwater levels to rise through infiltration.

Shallow Aquifer

4.4.3 Groundwater levels within the shallow aquifer are anticipated to be between 4mAOD and 9.5mAOD in the vicinity of the BSCU.

4.4.4 Figure 3.2.3 in the *Surface Water Management Plan* (City of London Corporation, 2011) shows the 'Increased Potential for Elevated Groundwater' mapping across the City of London. This mapping shows those areas where there is an increased potential for groundwater to rise sufficiently to interact with the ground surface or to be within 2m of the ground surface. The *Groundwater Conceptual Modelling Not*e (City of London Corporation, 2012) states that it is based upon:

- The British Geological Survey Groundwater Flood Susceptibility Map;
- Jacobs' Groundwater Emergence Maps;
- Jeremy Benn Associates' Groundwater Flood Map; and,

- Environment Agency Thames Estuary 2100 (TE2100) groundwater hazard maps.

4.4.5 The mapping indicates that there are two main areas with increased potential for elevated groundwater within the Borough: Liverpool Street Station to the south of the Bank of England on Walbrook, and back up to the west of Finsbury Circus. The Whole Block Site is not shown as being located within an area that is considered to have an 'increased potential for elevated groundwater', though several of the existing station entraces around Cornhill (i.e. those within the Walbrook valley) are within this zoning.

4.4.6 Due to the depth to groundwater in the shallow aquifer and the presence of predominantly impermeable surfaces at and surrounding the site, the likelihood of groundwater emergence at the surface is considered to be low. Therefore the elements of the BSCU located at and above ground level are considered to be at low risk of groundwater flooding.

4.4.7 The risk posed to below ground structures located within the upper shallow aquifer is considered to be high as it may be in contact with groundwater. The risk from the shallow aquifer and proposed mitigation measures are discussed further within paragraph 5.5.1.

4.4.8 Elements of the below ground structures terminating within the London Clay are considered to be at low risk of groundwater ingress due to the impermeability of the strata.

Deep Aquifer

4.4.9 The BSCU will terminate within the impermeable London Clay; the flood risk from the groundwater in the deep Chalk aquifer is therefore considered to be negligible.

4.5 Flooding from Artificial Sources

4.5.1 Artificial sources of flooding include the risks posed by features such as canals, reservoirs and water mains.

Reservoirs

4.5.2 The Queen Mary and Queen Mother Reservoirs are located 30km upstream and to the west of the BSCU. Environment Agency Flood Inundation Mapping identifies that failure of either of these structures would not result in floodwater being routed through either of the BSCU Work Sites.

4.5.3 As there is no pathway from this source, the risk from reservoirs is considered to be negligible.

Canals

4.5.4 There are no canals located within 1km of the site. It is therefore considered that there is no pathway from this source which could impact upon either of the BSCU Work Sites. The risk from canals is considered to be negligible.

Water Mains

4.5.5 Burst or damaged water mains may lead to highway and property flooding. If a burst were to occur as a result of damage or ground settlement from the BSCU or from third party development, surface water runoff is likely to be routed along the highway towards drainage points (gullies) which connect with the local highway's drainage arrangements. This would continue until TWUL could isolate the water supply network and undertake repair work.

4.5.6 A pathway for water ingress into the below ground works from a burst pipe could occur through existing surface level access/ventilation or via percolation through the shallow groundwater aquifer and pose a risk to people below ground. If flooding were deep enough to overcome kerbs and finished floor levels then water could be potentially routed into the below ground works via access points within any above ground structure. Damage to a water main during the construction and excavations works for the BSCU could also result in water rapidly discharging directly into the below ground works until the network was isolated.

4.5.7 In 1999 LUL commissioned an assessment to quantify the risk of flooding from water mains to existing LUL assets as part of the *Flood Mitigation Project* (*FMP*) (LUL, 1999). The assessment specifically considered the safety risk across 13 known entrances to Bank Station and the potential flow pathways at street level, through the station and within the running tunnels.

4.5.8 On the basis of the above the *FMP Assessment* concluded that the risk to life from flooding of Bank station was very low. The assessment considered that (with the exception of the Waterloo & City Line) that there was sufficient effective floodwater storage within the station to give rise to a substantial delay to the loss of traction power in any one line. It was therefore concluded that there would be sufficient time to assess the flow route and identify the lines that would be affected by the flooding, allowing lines to be closed and trains evacuated from the tunnel dips with sufficient warning.

4.5.9 It was considered that the delay in the loss of traction power in the Waterloo & City Line would be approximately half that of other lines, although it was still considered to be a sufficient period of time to evacuate the line.

4.5.10 The *FMP Assessment* concluded that the calculated inflow rates were high enough to result in flooding of some of the running tunnels before the source could be isolated by TWUL. On this basis it recommended that flood boards be provided within the station, though this would be primarily for reducing the damage to infrastructure and assets, rather than to control the risk to life.

4.5.11 In a subsequent assessment titled the *Manex Final Report* (LUL, 2001), it was considered that additional flood mitigation (including flood boards) was unnecessary due to a 'very low' original risk rating for Bank Station.

4.5.12 Since the *FMP Assessment* was completed in 1999, the effective risk of flooding from a burst water mains may have changed over time due to changes to TWUL infrastructure, flow rates and third party development in the area. However, one of the aims of the ongoing LUCRFR project is to address and quantify the risk from water mains in both safety and business terms.

4.5.13 Provisional 2D hydrodynamic burst water mains modelling outputs have been provided by the LUCRFR project team. These draft model outputs are based upon a model of the existing water mains network and operational parameters provided by TWUL. Critical breach locations have been derived using a risk-based approach developed by the LUCRFR project team.

4.5.14 The provisional mapped outputs provided by the LUCRFR project team indicate that a number of the existing Bank station entrances are within the inundation extent that are simulated as resulting from a water mains burst, thereby confirming the findings of the *1999 FMP Assessment* (LUL, 1999).

4.5.15 The provisional outputs show that the Whole Block Site is not identified as being at significant risk of flooding from one of the simulated water mains bursts. A breach of the mains beneath King William Street is shown as resulting in flooding that routes away from the Whole Block Site towards the South-East. Flood depths immediately adjacent to the Whole Block Site are shown as being between 25mm and 100mm and it is considered that this is sufficiently shallow to be constrained by kerb heights and building thresholds.

4.5.16 A simulated breach of the trunk mains directly adjacent to the proposed station entrance at the southern side of the Whole Block Site is shown as resulting in flooding that propagates to the west along Cannon Street. Flood depths immediately adjacent to the proposed entrance are shown to be a maximum of approximately 25mm. Floodwater is shown as routing away from the site rather than towards it due to the local topography.

4.5.17 A breach in the trunk mains beneath Cannon Street would result in shallow flooding) that routes along Arthur Street (at a depth of approximately 25 to 100mm) whilst continuing to head southwards towards the River Thames, thereby having the potential to affect the proposed construction activities on Arthur Street.

4.5.18 The *FMP Assessment* (LUL, 1999) concludes that the risk to life at Bank Station was very low. Provisional LUCRFR outputs confirm the potential for the existing station entrances to be affected, though the Whole Block Site is not modelled as being at significant risk from burst mains. Shallow flood depths of up to 100mm have been simulated along the Arthur Street Work Site.

4.5.19 Finalised LUCRFR outputs, which are expected to be published later in 2014, will be considered at the detailed design stage and utilised to inform any necessary additional mitigation for the BSCU.

Flooding from Disused LUL Running Tunnels

4.5.20 There may be a potential risk of water ingress from the disused City and South London running tunnels and from the existing disused LUL King William Street Station through which the Arthur Street Shaft will be constructed.

4.5.21 The source and pathway for leakage into the existing tunnels and the King William Street Station is uncertain. Ponding was observed during a site visit to King William Street Station and the disused City and South London Lines on 4th June 2013.

4.5.22 It has not been possible to assess quantitatively the risk from this source at the time of writing. However, any water ingress via this pathway is unlikely to pose a significant hazard to the site staff during the construction phase as it is expected to comprise small volumes of slow-moving water.

4.5.23 The risk from this source is considered negligible as the pathway will also be temporarily isolated during the construction phase through the adoption of temporary flood bulkheads. It will also be permanently removed after construction through mitigation by design. Further information about the proposed mitigation measures is provided within paragraph 6.3.1 of this FRA.

4.6 Other Sources

4.6.1 Other possible sources of water ingress in the existing below ground tunnels include ‘drippage’ from wet trains and water from fire-fighting activities.

4.6.2 Drippage from wet trains may occur as a consequence of exposure to precipitation at surface level or from condensation within the LUL running tunnels. Although a source of water, it is considered unlikely to pose a flood risk to the existing LUL running tunnels.

4.6.3 Any drippage will be collected and removed by the existing track and tunnel drainage arrangements.

4.6.4 There is a residual risk that during fire-fighting activities firewater may result in flooding of the platform and track. The likelihood of this occurring is considered to be low and LUL has procedures in place to deal with removing firewater.

5 Potential Impact of the Development on Flood Risk

5.1 Fluvial and Tidal Flooding

5.1.1 Due to the location of the Whole Block Site and the Arthur Street Work Site within Flood Zone 1, it is considered that the development will not exacerbate the risk of flooding from tidal or fluvial sources.

5.1.2 The *Water Resources Baseline Report* (Mott MacDonald, 2011) states that settlement modelling undertaken to establish the potential impact of the BSCU did not identify any potential impact on the River Thames Flood Defences. Though the assessment was for a previous iteration (Mott MacDonald Base Case RIBA D, 2011) of the design, this is still effectively considered to be the case. The BSCU will therefore not impact upon the risk of flooding from fluvial and tidal sources.

5.2 Overland Flow and Surface Water Runoff

5.2.1 The below ground aspects of the BSCU will have no impact upon overland flowpaths or the generation of surface water runoff. It will therefore have no impact on the risk from these sources and is therefore compliant with the requirements of the *NPPF*.

5.2.2 The new Station Entrance Hall will be located within an existing building footprint and will therefore have no negative impact on the generation of surface water runoff or overland flow. Further to this, an indicative drainage strategy has been prepared for an OSD at the site and this is described in Appendix 2.

5.3 Flooding from Disused LUL Running Tunnels

5.3.1 The construction of the Arthur Street Shaft will pass through the disused King William Street Station, potentially creating a pathway for water ingress into the below ground works from the City and South London tunnels and the King William Street Station. However, it is not anticipated that the construction of the below ground works will increase the risk of flooding from this source as no additional floodwater or surface water runoff will be introduced below ground.

5.3.2 Once the construction phase is completed the development will be permanently isolated from the disused LUL assets so preventing any potential ingress of water from this source. Further information about the temporary and permanent mitigation measures associated with this pathway may be found within paragraph 6.3.1 of this FRA.

5.3.3 Between Bank and London Bridge Stations are ‘moth-balled’ floodgates (Floodgate No. 20 southbound, No. 21 northbound), installed to prevent significant water ingress from the London Bridge direction at times of flood.

These are assumed to be outwith the project area, unaffected by the project and their detail and performance requirements are unaffected by the design.

5.4 Artificial Sources: Water Mains and Sewers

5.4.1 The risk of damaging existing water mains is likely to be greatest during the construction phase, which could result in an uncontrolled release of water from the TWUL network. Settlement from the BSCU could also impact upon the integrity of the existing water mains or sewers and the appropriate passive preventative mitigation measures are described in Section 6.4 of this FRA.

5.4.2 Should any damage to the network occur then it is anticipated that this will be isolated by TWUL promptly and any flooding will be localised and of a short-duration.

5.4.3 Once the development is operational and after any settlement has occurred, the risk of the BSCU Project damaging the water mains is considered negligible as there will be no further excavation around the existing water supply.

5.5 Groundwater Flooding

5.5.1 Construction work at the Arthur Street Shaft and the Whole Block Site (escalator box) will require excavation through the shallow aquifer. Secant pile walls will be used to minimise the ingress of groundwater and therefore dewatering of the shallow aquifer. A potential consequence of this may be localised raised groundwater levels up-gradient of obstructions to flow resulting from the BSCU.

5.5.2 A simple numerical groundwater model of the shallow aquifer was developed for the study area to assess the potential increase in groundwater levels due to the introduction of obstacles to flow. The model was calibrated to the highest groundwater level recorded in the study area. Further details of the groundwater modelling may be found within Chapter 13: Water Resources and Flood Risk of the ES.

5.5.3 The groundwater modelling suggests that under peak groundwater level conditions (i.e. the worst case scenario), obstructions to flow such as the escalator box at the Whole Block Site might lead to a rise in groundwater levels of between 0.25m and 0.4m (up-gradient and to the north and north-east).

5.5.4 The closest buildings to the north and north-east of the Whole Block Site are numbers 75, 81 and 85 King William Street. To the east is 18 King William Street (Phoenix House). The closest buildings to the north and north-east of the Arthur Street Shaft are 24 to 28 King William Street. The *October 2012 Geotechnical Baseline Report* provides information available to LUL on basements and foundations:

- 18 King William Street (Phoenix House): This building has a lower ground floor and basement with a bored piled retaining wall. The building is assumed to be founded on piles;
- 85 King William Street, 10-16 Lombard Street, Post Office Court: The nature of the basement of this building is currently unknown, but it is assumed to contain at least one basement level. It is understood that the perimeter foundation of a previous building on the site has been re-used, with underpinning undertaken to a level of -11.7mAOD along the Abchurch Lane elevation;
- 81 King William Street: This building has a lower ground floor and basement;
- 75 King William Street: It is not yet confirmed whether this building has a basement, although it is assumed to contain one for the purposes of this assessment. The building is also assumed to be founded on piles; and
- 24-28 King William Street: This building has a single basement level.

5.5.5 The existing lower basement level within 10 King William Street on the northern side of the Whole Block Site is measured at 7.67mAOD. Based on the conceptual model for the area the aquifer is expected to be unsaturated for much of the time. However, assuming a worst case scenario where groundwater levels rise to 9.5mAOD (based on a single manual dip further to the west near Walbrook), the 10 King William Street lower basement may already create a partial obstacle to groundwater flow. The proposed secant pile walls associated with the escalator box in the Whole Block Site will extend through the full thickness of the shallow aquifer, enhancing the obstacle to groundwater flow. However, given the limited dimensions of the escalator box, the rise in groundwater levels is expected to be localised. Considering the basement information, together with the conceptual and numerical groundwater model, on balance the potential magnitude of impact is assessed to be very low.

5.5.6 The Arthur Street Shaft is of a smaller dimension than the piled wall of the Whole Block Site escalator box and is anticipated to have a negligible impact on groundwater flows and levels. The closest buildings at 24-28 King William Street have a single basement level and are therefore at lower risk of being impacted by the groundwater table in the shallow aquifer. The potential magnitude of impact is assessed to be very low.

5.5.7 On the basis of the above, the BSCU is deemed to have a very low impact on groundwater levels and therefore on flood risk from the shallow aquifer.

5.6 Flood Risk from the Deep Aquifer

5.6.1 The construction of the BSCU does not involve excavation to depths that would encounter the deep aquifer, which is confined by the overlying unproductive strata (predominantly London Clay Formation). As there is no pathway to the deep Chalk Aquifer, the risk from this source is considered to be negligible.

6 Flood Risk Management Measures

6.1 Surface Water Flooding and Overland Flow

Permanent Mitigation

6.1.1 No mitigation is considered necessary to protect the site from fluvial and tidal flooding as it is located within the Environment Agency's Flood Zone 1 (the zone of lowest flood risk).

6.1.2 There is a low residual risk of flooding from pluvial and sewer sources to the new Station Entrance. Residual risk will be managed through the provision of passive flood resilience and resistance measures in accordance with clause 3.1.6.2.2. of *LUL Category 1 Standard S1052 - Gravity Drainage Systems* (LUL, 2011). Wherever practical, threshold levels will be elevated an additional 300mm above the 0.5 per cent AEP (1 in 200 year) surface water flood level in accordance with the requirements of the *Category 1 Standard S1052* (LUL, 2011).

6.1.3 The critical entrance threshold levels will be determined through detailed surface water modelling of the Whole Block Site and the surrounding area. Further, quantitative model outputs from the forthcoming LUCRFR study will be utilised to inform the specification of the passive flood mitigation measures at detailed design and thereby reduce any residual risk to the BSCU to be as low as reasonably practical.

6.1.4 If, at detailed design, it is determined that passive mitigation measures cannot effectively eliminate the residual flood risks to the site then any outstanding pathway to the below ground assets will be effectively removed through the provision of an automatic flip-up barrier at the new Station Entrance. The barrier would be automatic, but also controlled with a manual override by staff within the Bank Monument Station Complex Operations Room. The details of this flood barrier and the required flood mitigation measures for the other back-of-house entrances to the station would be developed further during detailed design with the Station Operational Manager.

6.1.5 If the design of the flip-up barrier is not considered to be feasible, then alternative protection measures and/or a reduction in the level of flood protection will be considered as set out in the *Category 1 Standard S1052* (LUL, 2011).

Temporary Works

6.1.6 The temporary construction works will be designed and controlled in accordance with *LUL Standard S1062: Pumped Drainage Systems* (LUL, 2011). Pertinent mitigation measures include the following:

- the construction shaft at the Arthur Street Work Site will be provided with an upstand shaft wall and construction platform with 300mm of freeboard above the maximum flood depth for the 0.5 per cent AEP (1 in 200 year) critical duration storm. This will also prevent the ingress of surface water into the excavation; and
- there will also be a temporary sump and pump within the base of the Arthur Street Shaft during construction.

6.1.7 The Arthur Street Shaft will be backfilled, waterproofed and capped off post-construction to achieve water tightness to prevent water ingress when the running tunnel is operational.

6.2 Surface Water Drainage Strategy

6.2.1 As there is very little permanent above ground infrastructure associated with the BSCU, it has negligible impact upon the generation of surface water runoff. Instead, as a cumulative development to the BSCU, an OSD will need to incorporate a strategy for drainage of surface water (see Appendix 2 of this FRA).

6.3 Flooding from LUL Running Tunnels

6.3.1 The residual risk of flooding from this source will be mitigated during construction by isolating the City and South London tunnels from the King William Street Station. There are currently two bulkheads in place which will be surveyed as part of the stage 1 works to confirm their structural integrity and capacity for preventing water ingress in the unlikely event that the disused City and South London tunnels are flooded.

6.3.2 The King William Street Station bulkheads are typically closed during normal operating conditions and will remain closed during the construction of the Arthur Street Shaft. The flood bulkheads will, however, be occasionally opened for maintenance and access purposes, thereby creating a potential temporary pathway for floodwater to enter the station. There remains a very low residual risk that the station could be affected by floodwater, in the unlikely event that the disused City and South London tunnels are flooded and the bulkheads are also open.

6.3.3 The Arthur Street Shaft will be decommissioned prior to the new running tunnel becoming operational. A permanent capping structural slab with a 120 year design life will be constructed above the crown of the new tunnel and below the invert of the disused King William Street Station. This slab will act as a permanent flood mitigation measure that protects the Northern Line tunnels from the residual risk of inundation by isolating them from the City and South London tunnels and the disused King William Street Station.

6.4 Artificial Sources: Water Mains

6.4.1 Where existing utilities cannot be avoided during construction it is proposed to protect the existing utility in-situ or to divert it to a location that will remain undisturbed during the construction works. A full utilities assessment will therefore be undertaken prior to works commencing construction as outlined in the draft Code of Construction Practice (see Appendix A4.1 of the ES).

6.4.2 For the area within the 1mm settlement contour, work is being undertaken to ascertain the risk of damage to the utilities and consequent mitigation works (e.g. strengthening or replacement). Monitoring of key assets identified will also be undertaken during the construction phasing.

6.4.3 The 1999 *FMP Assessment* (LUL, 1999) concluded that the risk to life from burst water mains at the existing Bank Station was very low and that further mitigation was not recommended. Provisional model outputs from the LUCRFR study indicates that the proposed entrances at the Whole Block Site are not simulated as being at significant risk from burst water mains. On this basis, the provision of passive mitigation measures described in paragraph 6.1.2. (i.e. entrance threshold raising) and/or a proposed flip-up flood barrier should also effectively manage the residual possibility of a flood from burst water mains affecting the new Station Entrance Hall.

6.4.4 Finalised model outputs from the ongoing LUCRFR project will be utilised to determine if additional mitigation is required at the detailed design stage.

6.4.5 The upstand shaft wall and elevated construction platform at the Arthur Street Work Site should also effectively manage the risk of a flood from burst water mains, with provisional outputs from the LUCRFR project simulating depths of approximately 100mm in this area.

6.4.6 The temporary sump and pump within the base of the Arthur Street Shaft during construction will be suitably designed to remove floodwater from the work site. TWUL will be responsible for isolating the water supply and it is anticipated that this will be undertaken within 2 hours following notification.

6.4.7 If any additional mitigation measures are considered necessary they will be designed in accordance with clause 3.1.6.2.2. of *LUL Category 1 Standard S1052 - Gravity Drainage Systems* (LUL, 2011), placing emphasis on the preference for passive mitigation measures including raised thresholds and flood resilient and/or flood resistant construction techniques.

6.5 Flooding from Groundwater

6.5.1 The risk of groundwater ingress will be mitigated through design consideration of expected long term and elevated short term water table in the event of a burst water main percolating into the shallow aquifer. A waterproofing strategy has been developed for the escalator box and piled passenger lift shaft at the Whole Block Site:

- secant pile wall through superficial deposits, with sufficient embedment into the London Clay Formation (1 to 2m);
- contiguous pile wall through the clay layer extending to a depth below the base slab;
- structural reinforced concrete lining wall of 600mm thickness, tied back to the piles at regular intervals, designed in accordance with *British Standard EN 1992-1+UK NA* and *British Standard EN 1997-1:2004+UK NA*;
- a temporary bunding will be constructed to prevent the ingress of water from the escalator box and passenger lift shaft during construction, following construction of the link tunnels and adits;
- a drained cavity wall is provided in public and staff areas; and
- any residual water ingress is collected via channels and pipes from drained cavities in public areas, and slab up stand kerbs in plant rooms. Water is removed via a pumped sump.

6.5.2 The waterproofing is required to mitigate the risk of groundwater flooding to the BSCU and existing tunnels and platforms.

6.5.3 Groundwater monitoring will be undertaken in the near vicinity of the Whole Block Site to identify groundwater levels and permeability of the shallow aquifer, its chemistry and temperature. This monitoring will take place prior to construction to confirm baseline conditions and during construction to monitor for any impacts.

6.5.4 The method of construction for the upper section of the Arthur Street Shaft will involve piling. The piles will provide a low permeability barrier between the Arthur Street Shaft and the shallow aquifer. A sprayed concrete lining will reduce seepage through the piling.

Running Tunnels

6.5.5 The running tunnels will be waterproofed to prevent the ingress of water in accordance with *LUL Category 1 Standard S1064: Waterproofing* and *British Standard 8102* (2009).

6.6 Seepage, Track and Tunnel Drainage

6.6.1 There is a pathway for the tracks and tunnels to be affected by seepage, drippage from trains, flooding from damaged drainage and water supply infrastructure and water from fire fighting.

Seepage

6.6.2 Seepage water will be collected by draining of membranes in ground contact slabs and half round channels at the base of ground contact walls. In addition all escalator lower machine chambers and the base of lift shafts will be provided with sumps, pumps and level controls, to collect seepage from the escalator barrels and water discharged by the fire suppression systems.

6.6.3 The discharge from these systems will be collected and discharged to the sewage tank and pump located in the pump room below the new Northern Line platform. From here the water will be pumped to the new TWUL sewer connection at the new Station Entrance Hall. It is anticipated that the track and seepage drainage would not amount to more than 0.05 l/s.

6.6.4 Any waste water generated from fire suppression systems will not be attenuated and will be routed directly to sewer at a maximum rate of 25l/s. This discharge is considered by TWUL as being acceptable during exceptional circumstances.

6.6.5 The pumping system will achieve compliance with the required flood management duties outlined in *LUL Standard: S1056 Pumped Drainage Systems* (LUL, 2011). Further information about LUL obligatory flood risk duty requirements may be found within Appendix 1: LUL Standards and Specifications.

Track Drainage

6.6.6 The track and tunnel drainage, which will normally only carry tunnel seepage, will be in the form of surface channels. These will discharge to a longitudinal carrier drain in the tunnel invert in accordance with *LUL Standard S1052 Gravity Drainage Systems* (LUL, 2011). This will follow the fall in gradient to sumps provided in both sections of the tunnel. Duty and assist pumps within each sump will pump directly to the new sewer connection in the new Station Entrance Hall.

6.6.7 Future surveys of existing pumping systems may identify opportunities to make further use of existing systems.

6.6.8 The pumping system will achieve compliance with the flood management duty requirements outlined in *LUL Standard: S1056 Pumped Drainage Systems* (LUL, 2012). It is therefore considered that the drainage arrangements will be sufficient to manage the risk of ponding within the track, tunnel and station from ingress and seepage.

Pump Controls

6.6.9 Criticality of the pumps will undergo a full assessment and review with the relevant parties in LUL as prescribed by *LUL Standard S1056* (LUL, 2011) at the detailed design stage.

6.6.10 It is deemed that failure of the track pumps or the packaged sewage tank, by their function and location, could pose a significant risk to the operation of the Northern Line and the station (i.e. through the release of an uncontrolled discharge that affects passengers or LUL infrastructure following asset failure). They are therefore deemed critical and will be controlled by panels conforming to *LUL Standard T0003: Critical Pump Sites – Control Panel Specification* (LUL, 2011), with a provision for connecting, by others, to the LUL central pump monitoring system.

6.6.11 The remaining pumps are deemed non-critical and will be controlled by panels conforming to *LUL Standard T0004: Non-Critical Pump Sites – Control Panel Specification* (LUL, 2011). A high level pump alarm panel will be provided in the Station Operations Room.

6.7 Emergency Response and Evacuation Planning

6.7.1 Whilst both passive and active mitigation measures will be utilised to manage the flood risks to the BSCU, there remains a very low residual risk that the mitigation measures could fail or their standard of design be exceeded.

6.7.2 In the event of a flood affecting the station it will be promptly evacuated by site staff in accordance with standard LUL contingency planning procedures. With these procedural documents in place and regularly updated, the residual risk to life from flooding is therefore considered to be very low.

7 Summary

7.1 Risk of Flooding to BSCU Infrastructure

7.1.1 The BSCU Work Sites are located within Environment Agency Flood Zone 1 and are therefore considered to be at low risk of fluvial and tidal flooding.

7.1.2 The sites are not considered to be at risk from a breach in the River Thames flood defences.

7.1.3 There is a residual risk that LUL and DLR portals within an existing floodplain could act as a potential pathway for the conveyance of fluvial and tidal floodwater through the LUL network. However, the distance that floodwater would need to travel to affect the below ground elements of the BSCU Project is extensive. Therefore, the likelihood of the tunnels at the development site itself being affected by floodwater from this source is considered to be low.

7.1.4 Both sites are considered to be at low risk of flooding from surface water and sewers.

7.1.5 The risk of groundwater flooding at the surface level is considered to be low.

7.1.6 Structures within the shallow aquifer will be waterproofed, thereby mitigating the risk from this source. Structures terminating within the London Clay are considered to be at low risk of flooding from groundwater ingress due to the limited permeability of the strata.

7.1.7 There is no risk of flooding from the failure of a reservoir or canal.

7.1.8 A burst water main poses a risk to surface-level and below ground assets. Outputs from the *FMP Assessment* (LUL, 1999) indicated that water mains bursts were considered to pose a very low risk to life at Bank Station at the time of the assessment, though it is acknowledged that the risk from this source may have changed over time.

7.1.9 Finalised outputs from the forthcoming LUCRFR assessment will be utilised to inform the detailed design of any mitigation measures if and where it is considered to be necessary. Provisional ouputs provided by the LUCRFR project team do, however, indicate that the risk to the BSCU Work Sites from burst water mains is low and the depths simulated can be successfully managed through threshold raising and other passive mitigation measures.

7.1.10 There is a low risk of water ingress from the disused City and South London running tunnels and from the existing disused LUL King William Station through which the Arthur Street Shaft will be constructed.

7.2 Impact on Flooding from BSCU Infrastructure

7.2.1 The assessment considers that the BSCU should not adversely impact the baseline risk of fluvial or tidal flooding to off-site areas.

7.2.2 A replacement OSD would not increase the volume of surface water runoff generated on the Whole Block Site as an indicative drainage strategy has been prepared, as described in Appendix 2.

7.2.3 A temporary shaft is planned to be constructed through the disused City and South London tunnels (which run below the River Thames), thereby potentially creating a pathway for water to enter the below ground structures.

7.2.4 There is a risk of damaging existing TWUL supply distribution mains. The risk of the construction phase damaging TWUL assets is considered to be low as full utility surveys will be undertaken and provided to the construction contractors prior to works commencing at the site and the appropriate mitigation measures will be identified. Any damage to the network will be isolated by TWUL promptly and any flooding will be short-duration and localised.

7.2.5 There is a risk that the below ground works may provide an obstruction to groundwater flow and lead to localised increases in groundwater level. However, the impact on flood risk is considered to be low.

7.3 Flood Risk Mitigation

7.3.1 The risk of surface water and sewer flooding at the new Station Entrance Hall will be mitigated by the provision of passive mitigation measures (i.e. entrance threshold raising) in accordance with the requirements of *S1502* (LUL, 2011) and informed by the outputs of the ongoing LUCRFR study. The provision of an active automatic flip-up flood barrier will be considered if the potential pathway into the TWAO site cannot be eliminated through passive means.

7.3.2 The construction shaft at the Arthur Street Work Site will be provided with an upstand shaft wall and construction platform with sufficient freeboard for any foreseeable flood events during construction.

7.3.3 The risk of flooding and ingress from the under-river sections of the City and South London tunnels will be mitigated by isolating the tunnels from the King William Street Station during construction.

7.3.4 The Arthur Street Shaft will be decommissioned and backfilled prior to the new running tunnel becoming operational. This slab will act as a permanent flood mitigation measure that protects the Northern Line tunnels from the risk of inundation by isolating them from the City and South London tunnels and the disused King William Street Station.

7.3.5 A waterproofing strategy has been developed for the escalator box at the Whole Block Site to prevent any groundwater ingress. The running tunnels will be waterproofed to prevent the ingress of water in accordance with *LUL Category 1 Standard S1064: Waterproofing* (LUL, 2011) and *British Standard 8102 (2009).*

7.3.6 Track, tunnel and seepage drainage will be compliant with LUL standards for Gravity Drainage and Pumped Drainage Systems.

7.3.7 Criticality of any track and seepage drainage pumps will undergo a full assessment and review with the relevant parties in LUL as prescribed in *LUL Standard: S1056 Pumped Drainage Systems* (LUL, 2012) at the detailed design stage.

References

British Standards Institution, 2009. *British Standard 8102: Code of practice for protection of below ground structures against water from the ground*

City of London Corporation, 2011. *Surface Water Management Plan*

City of London Corporation, 2012. *The City of London Strategic Flood Risk Assessment*. Document 1, Version 1.2, 31 May 2012

City of London Corporation, 2012. *Groundwater Conceptual Model Technical Note.*

Department for Communities and Local Government, 2012. *National Planning Policy Framework: Technical Guidance*

Defra, 2006. *Research and Development Report FD2320*.

Environment Agency, 2006. *Report on Groundwater Quality Review: London Basin. Analysis of the London Basin Groundwater Chemistry*.

Environment Agency, 2012. *Report on the Management of the London Basin Chalk Aquifer*. Status Report 2012.

Environment Agency, 2013. "*New aquifer designations*". Accessed online in November 2013 at: http://www.environment-agency.gov.uk/homeandleisure/117020.aspx

Greater London Authority, 2009. *The London Regional Flood Risk Appraisal*

Greater London Authority, 2013. *London Plan Supplementary Planning Guidance: Sustainable Design and* Construction (Consultation Draft)

Landmark, September 2013. Envirocheck Report, Order number 49557448_1_1.

London Underground Ltd, 1999*. Flood Mitigation Phase 4 – Assessment for 28 Stations – Revision A*

London Underground Ltd. 2001. *Magnex Final Report.* LUL Reference 11/4/105/Magnex/LUL/10019/R/005

London Underground Ltd, 2011*. LUL Category 1 Standard S1064: Waterproofing*

London Underground Ltd, 2011. *LUL Category 1 Standard: S1052 Civil Engineering – Gravity Drainage Systems*

London Underground Ltd, 2011. *LUL Technical Specification T0003: Critical Pump Sites – Control Panel Specification*

London Underground Ltd, 2011. *LUL Technical Specification T0004: Non-Critical Pump Sites – Control Panel Specification*

London Underground Ltd, 2011. *LUL Work Instruction W0438: Pump System Criticality*

London Underground Ltd, 2012. *LUL Category 1 Standard: S1056 Civil Engineering – Pumped Drainage Systems*

Mott MacDonald, 2011. *Water resources baseline report for the Bank Station Capacity Upgrade*. 1. LUL document number N133-BCR-MMD-00-Z-DC-N-0007-S0-0.1.

Mott MacDonald, March 2012. Geotechnical desk study for the Bank Station Capacity Upgrade issued by. LUL document number LUSTN-0008798-DOC-001205 v1.0.

Thames Water Utilities Ltd. Sewer Asset Plans. Ref: ALS/227340 WATER / ALS/227340/SEWER

Thames Water Utilities Ltd, 2013, “What we're doing to tackle sewer flooding”. Accessed online in November 2013 at: http://www.thameswater.co.uk/about-us/7497.htm

URS, 2013. Bank Station Capacity Upgrade. Over Site Development Below Ground Drainage Strategy Stage C Report

Appendix 1: Summary of LUL Standards

A1.1 The proposed mitigation measures be designed to be compliant with LUL Standards and Technical Specifications. Of particular relevance to this FRA is *S1052 Civil Engineering – Gravity Drainage Systems* (LUL, 2011) as it details specific flood risk requirements for LUL assets.

A1.2 It is noted that *S1056 Civil Engineering – Pumped Drainage Systems* (LUL, 2011) is also relevant to a number of the proposed mitigation measures.

A1.3 A summary of the pertinent flood risk requirements in Standard S1052 is presented below.

S1052 Civil Engineering – Gravity Drainage Systems

A1.4 *Standard S1052 Civil Engineering – Gravity Drainage Systems* sets out LUL specific requirements for gravity drainage systems standards which apples to:

- track and off-track gravity drainage systems
- stations, depots and other operational buildings gravity drainage systems; and
- other gravity drainage systems.

A1.5 The design of the drainage arrangements for the track and tunnel will adhere to the requirements set out in the *Category 1 Standard: S1052* (ibid). This document defines the life cycle requirements for gravity drainage system assets in performance terms and sets of out the requirements from design, construction, maintenance through to decommissioning.

A1.6 The *Category 1 Standard: S1052* (ibid) states that the inception and design of works to gravity drainage system assets shall ensure that the assets meet with their 'Required Duty'. The document details ten main aspects to LUL 'Required Duty' and the specific flood risk requirements for drainage assets include:

- assets shall operate without risk of blockage or failure to minimise the risk of flooding or disruption to railway operations.
- assets shall provide sufficient hydraulic capacity to convey flow requirements.
- assets shall provide appropriate access and egress for all planned uses, and for reasonably anticipated emergency uses.

A1.7 The *Category 1 Standard: S1052* (ibid) also details the hydraulic design criteria for LUL assets. Pipe and channel sizing shall be undertaken in accordance with the *Modified Rational Method* (HR Wallingford, 2006), with conduits being sized to convey (without surcharge) the peak flow generated by the 1 in 5 year return period storm event of critical duration (i.e. the critical storm).

A1.8 Where base flow is included within the hydraulic design, conduits shall be sized such that the base flow is confined to a maximum of half the conduit cross sectional flow area.

A1.9 Track drainage design to be in accordance with the Flood Studies Report (FSR) and Revitalised Flood Hydrograph (ReFH):

- all rainfall hyetographs shall have 20 per cent added to them to account for the potential impact of climate change to 2085; and
- gravity drainage system designed such that when it is subjected to the critical storm event with a return period of 1 in 50 years some surcharging is permitted in accordance with specific requirements.

A1.10 The *Category 1 Standard: S1052* states that LUL assets shall be designed for event exceedance, with new and rehabilitated gravity drainage systems checked against the effects of the critical storm duration with a return period of 1 in 100 years plus an additional climate change allowance. This is to be undertaken to ensure that excess water can be safely stored on or conveyed from LUL land without any adverse offsite impact.

A1.11 New discharges to public sewers require agreement of the sewerage undertaker.

A1.12 LUL supports the use of Sustainable Urban Drainage Systems (SuDS) in line with the recommendations of *The London Plan* (Mayor of London, 2013). SuDS shall be incorporated where such systems are considered compatible with the requirements of the *S1052 Standard* and are cost-justifiable. SuDS shall generally be designed in accordance with the guidance in *CIRIA C697: The SUDS Manual* (CIRIA, 2006).

A1.13 The *S1052 Standard* also outlines flood protection design criteria for LUL assets and states that:

- tunnels and shafts shall be protected against the risk of inundation from pluvial, fluvial and tidal flood events with a return period of 1 in 200 years;
- pluvial flooding shall assume an additional 30 per cent increase for climate change through to the year 2115, fluvial sources an additional 20 per cent increase to 2115 and tidal sources an additional 15mm/year through to 2115;
- in the first instance, protection against inundation shall be provided by inherently safe passive measures (i.e. measures not requiring intervention), such as elevating the relevant threshold above the predicted flood level (plus an additional 300mm of freeboard);

- where passive protection measures are not possible or are considered to give rise to excessive or prohibitive cost, then alternative protection measures and/or a reduction in the level of flood protection may be considered by presenting them in a Conceptual Design Statement (CDS) and/or Detailed Design Report (DDR) for approval under the relevant assurance process; and
- under all scenarios the residual flood risk shall be demonstrably as low as reasonably practicable and this shall be presented in the CDS or DDR for the work under the relevant assurance process.

Appendix 2: Indicative Drainage Strategy for an Over Site Development

A2.1 Following demolition of the existing buildings on site (excluding 20 Abchurch Lane) and construction of the BSCU with the new Station Entrance Hall, an Over Site Development (OSD) will be built on the same footprint at the Whole Block Site.

A2.2 Indicative surface water drainage strategy principles for an OSD structure have been considered and are outlined below:

- The drainage strategy will provide betterment on the existing baseline by complying with the requirements of the *London Plan Supplementary Planning Guidance: Sustainable Design and Construction* (Greater London Authority, 2014) and the *National Planning Policy Framework* (Department for Communities and Local Government, 2012).
- The strategy will restrict surface water runoff to 50 per cent of the existing runoff rate for all design storms up to the 1 per cent AEP event including an allowance for the effects of climate change (i.e. +30 per cent increase in rainfall intensity).
- sustainable drainage systems (SuDS) will be used where practicable throughout the site to provide source control, to improve water quality, to reduce flood risk and provide amenity benefits.

A2.3 The indicative surface water drainage strategy is compliant with the requirements of the *National Planning Policy Framework Construction* (Greater London Authority, 2014) and would also provide minor betterment with respect to the local risk of flooding from surface water and sewer sources.

A2.4 There is a temporary interim case where the station entrance has been constructed but construction of an OSD has not taken place. For this case TWUL have advised that surface water drainage from the station entrance can be treated as a temporary drainage connection and therefore no attenuation is required and that TWUL would accept this situation for period of up to 1 year.

A2.5 TWUL have also advised that if an OSD does not take place within 1 year of completion of the station entrance then they would wish to review the situation and this could then require the surface water discharge to be attenuated and a temporary surface water storage arrangement to be installed on the site. The temporary surface water storage would likely be located within the OSD site and the attenuation would reduce the surface water discharge by 50 per cent, similar to that associated with a fully built-out OSD.