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Traffic Data

A summary of the traffic data used in this assessment (see *Chapter 10 of ES Volume I*) is displayed in Table 1.

Table 1: Summary of Traffic Data used in this Assessment

Link	Scenario	Annual Average Daily Flow	% Car	% Taxi	% LGV	% HGV	% Bus and Coach	% Motor cycle	Speed
Queenstown Road – north of Battersea Park Road	2012 Baseline	24535	58.3	2.9	17.2	6.9	5.8	8.9	25
	2012 Construction (Option A)	24565	58.2	2.9	17.2	7.0	5.8	8.8	25
	2012 Construction (Option B)	24564	58.2	2.9	17.2	7.0	5.8	8.9	25
Prince of Wales Drive – east of Queenstown Road	2012 Baseline	5213	81.0	3.2	8.9	5.4	<0.1	1.5	17
	2012 Construction (Option A)	5243	80.5	3.2	8.8	6.0	<0.1	1.5	17
	2012 Construction (Option B)	5242	80.5	3.2	8.8	6.0	<0.1	1.5	17
Prince of Wales Drive – west of Queenstown Road	2012 Baseline	21371	81.6	3.2	8.9	4.7	<0.1	1.5	26
	2012 Construction (Option A)	21371	81.6	3.2	8.9	4.7	<0.1	1.5	26
	2012 Construction (Option B)	21371	81.6	3.2	8.9	4.7	<0.1	1.5	26
Battersea Park Road – west of Queenstown Road	2012 Baseline	21157	67.4	3.3	13.7	4.6	3.2	7.7	10
	2012 Construction (Option A)	21227	67.2	3.3	13.6	4.9	3.2	7.7	10
	2012 Construction (Option B)	21225	67.2	3.3	13.6	4.9	3.2	7.7	10
Battersea Park Road – east of Queenstown Road	2012 Baseline	30195	59.2	2.9	20.0	6.6	3.0	8.2	33
	2012 Construction (Option A)	30295	59.0	2.9	20.0	6.9	2.9	8.2	33
	2012 Construction (Option B)	30292	59.0	2.9	20.0	6.9	2.9	8.2	33
Queenstown Road – south of Battersea Park Road	2012 Baseline	13436	69.7	3.5	11.3	4.8	4.9	5.8	30
	2012 Construction (Option A)	13436	69.7	3.5	11.3	4.8	4.9	5.8	30
	2012 Construction (Option B)	13436	69.7	3.5	11.3	4.8	4.9	5.8	30
Wandsworth Road – north of Pascal Street of Battersea Park Road	2012 Baseline	16457	65.1	3.2	14.3	4.9	5.2	7.4	29
	2012 Construction (Option A)	16518	64.8	3.2	14.2	5.2	5.2	7.3	29
	2012 Construction (Option B)	16518	64.8	3.2	14.2	5.2	5.2	7.3	29
Wandsworth Road – south of Pascal Street of Battersea Park Road	2012 Baseline	16457	65.1	3.2	14.3	4.9	5.2	7.4	29
	2012 Construction (Option A)	16600	64.5	3.2	14.2	5.7	5.1	7.3	29
	2012 Construction (Option B)	16600	64.5	3.2	14.2	5.7	5.1	7.3	29
Wandsworth Road – north of Battersea Park Road	2012 Baseline	42889	63.3	3.1	18.3	4.7	2.1	8.5	38
	2012 Construction (Option A)	42950	63.2	3.1	18.3	4.9	2.1	8.5	38

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	2012 Construction (Option B)	42950	63.2	3.1	18.3	4.9	2.1	8.5	38
Vauxhall Bridge	2012 Baseline	41631	61.1	3.0	19.6	3.9	5.6	6.7	35
	2012 Construction (Option A)	41631	61.1	3.0	19.6	3.9	5.6	6.7	35
	2012 Construction (Option B)	41631	61.1	3.0	19.6	3.9	5.6	6.7	35
Albert Embankment	2012 Baseline	23024	52.6	11.9	13.2	5.0	4.3	13.0	35
	2012 Construction (Option A)	23085	52.4	11.9	13.2	5.3	4.3	13.0	35
	2012 Construction (Option B)	23085	52.4	11.9	13.2	5.3	4.3	13.0	35
Bondway	2012 Baseline	24913	79.1	3.1	8.7	5.3	2.3	1.5	15
	2012 Construction (Option A)	24913	79.1	3.1	8.7	5.3	2.3	1.5	15
	2012 Construction (Option B)	24913	79.1	3.1	8.7	5.3	2.3	1.5	15
Parry Street	2012 Baseline	38971	61.6	3.0	18.6	5.1	3.5	8.2	23
	2012 Construction (Option A)	38971	61.6	3.0	18.6	5.1	3.5	8.2	23
	2012 Construction (Option B)	38971	61.6	3.0	18.6	5.1	3.5	8.2	23
Kennington Lane – west of South Lambeth Road	2012 Baseline	39139	61.9	3.1	18.8	5.0	3.2	8.0	26
	2012 Construction (Option A)	39139	61.9	3.1	18.8	5.0	3.2	8.0	26

	2012 Construction (Option B)	39139	61.9	3.1	18.8	5.0	3.2	8.0	26
Kennington Lane – east of South Lambeth Road	2012 Baseline	23146	66.8	3.3	10.1	12.0	2.6	5.1	19
	2012 Construction (Option A)	23146	66.8	3.3	10.1	12.0	2.6	5.1	19
	2012 Construction (Option B)	23146	66.8	3.3	10.1	12.0	2.6	5.1	19
Kennington Lane – east of Durham Street	2012 Baseline	19387	69.3	3.4	16.0	5.1	1.5	4.6	25
	2012 Construction (Option A)	19387	69.3	3.4	16.0	5.1	1.5	4.6	25
	2012 Construction (Option B)	19387	69.3	3.4	16.0	5.1	1.5	4.6	25
South Lambeth Road – north of Parry Street	2012 Baseline	40416	61.7	3.1	18.5	5.2	3.0	8.5	27
	2012 Construction (Option A)	40416	61.7	3.1	18.5	5.2	3.0	8.5	27
	2012 Construction (Option B)	40416	61.7	3.1	18.5	5.2	3.0	8.5	27
South Lambeth Road – south of Parry Street	2012 Baseline	16877	65.9	3.3	14.6	3.9	4.7	7.6	26
	2012 Construction (Option A)	16877	65.9	3.3	14.6	3.9	4.7	7.6	26
	2012 Construction (Option B)	16877	65.9	3.3	14.6	3.9	4.7	7.6	26
Harleyford Road	2012 Baseline	21680	64.5	3.2	16.2	3.8	4.7	7.5	30
	2012 Construction (Option A)	21680	64.5	3.2	16.2	3.8	4.7	7.5	30

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	2012 Construction (Option B)	21680	64.5	3.2	16.2	3.8	4.7	7.5	30
Durham Street	2012 Baseline	17421	66.3	3.3	16.6	5.2	3.5	5.2	19
	2012 Construction (Option A)	17421	66.3	3.3	16.6	5.2	3.5	5.2	19
	2012 Construction (Option B)	17421	66.3	3.3	16.6	5.2	3.5	5.2	19
Fentiman road	2012 Baseline	7143	81.7	3.3	8.9	4.6	<0.1	1.5	23
	2012 Construction (Option A)	7143	81.7	3.3	8.9	4.6	<0.1	1.5	23
	2012 Construction (Option B)	7143	81.7	3.3	8.9	4.6	<0.1	1.5	23
Lansdowne Road	2012 Baseline	7910	76.8	3.1	8.4	5.8	4.5	1.4	18
	2012 Construction (Option A)	7910	76.8	3.1	8.4	5.8	4.5	1.4	18
	2012 Construction (Option B)	7910	76.8	3.1	8.4	5.8	4.5	1.4	18
Kennington Road	2012 Baseline	22471	68.1	3.4	12.6	2.1	4.8	9.0	23
	2012 Construction (Option A)	22481	68.1	3.4	12.6	2.1	4.8	9.0	23
	2012 Construction (Option B)	22485	68.1	3.4	12.6	2.1	4.8	9.0	23
Kennington Park Road – north of Kennington Road	2012 Baseline	31548	68.6	3.4	14.1	3.3	2.9	7.8	23
	2012 Construction (Option A)	31567	68.5	3.4	14.1	3.3	2.9	7.8	23

	2012 Construction (Option B)	31562	68.6	3.4	14.1	3.3	2.9	7.8	23
Kennington Park Road – south of Kennington Road	2012 Baseline	37834	63.7	3.2	14.0	3.3	5.9	9.9	29
	2012 Construction (Option A)	37859	63.6	3.2	14.0	3.3	5.9	9.9	29
	2012 Construction (Option B)	37854	63.6	3.2	14.0	3.3	5.9	9.9	29
Kennington Park Place	2012 Baseline	7531	79.9	3.1	8.8	6.7	<0.1	1.5	12
	2012 Construction (Option A)	7551	79.7	3.1	8.7	6.9	<0.1	1.5	12
	2012 Construction (Option B)	7545	79.8	3.1	8.7	6.9	<0.1	1.5	12
Braganza Street	2012 Baseline	8875	80.1	3.2	8.7	6.5	<0.1	1.5	21
	2012 Construction (Option A)	8875	80.1	3.2	8.7	6.5	<0.1	1.5	21
	2012 Construction (Option B)	8875	80.1	3.2	8.7	6.5	<0.1	1.5	21
Penton Place	2012 Baseline	2465	80.8	3.1	8.9	5.7	<0.1	1.5	19
	2012 Construction (Option A)	2465	80.8	3.1	8.9	5.7	<0.1	1.5	19
	2012 Construction (Option B)	2465	80.8	3.1	8.9	5.7	<0.1	1.5	19
Camberwell North Road	2012 Baseline	23357	68.8	3.4	13.8	3.5	5.2	5.2	15
	2012 Construction (Option A)	23357	68.8	3.4	13.8	3.5	5.2	5.2	15

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	2012 Construction (Option B)	23357	68.8	3.4	13.8	3.5	5.2	5.2	15
Clapham Road – south of Camberwell North Road	2012 Baseline	22889	62.5	3.1	17.3	3.8	2.6	10.8	21
	2012 Construction (Option A)	22914	62.4	3.1	17.2	3.9	2.6	10.8	21
	2012 Construction (Option B)	22909	62.4	3.1	17.3	3.9	2.6	10.8	21
Brixton Road – south of Camberwell North road	2012 Baseline	17963	62.7	3.1	10.8	3.6	10.3	9.4	24
	2012 Construction (Option A)	17963	62.7	3.1	10.8	3.6	10.3	9.4	24
	2012 Construction (Option B)	17963	62.7	3.1	10.8	3.6	10.3	9.4	24

G: Electromagnetic Compatibility

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NORTHERN LINE EXTENSION (NLE)

EMC ENVIRONMENTAL IMPACT REPORT

DOCUMENT REFERENCE: TIE-URS-2515-D03

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I. Issue History

Rev	Date	Purpose	Recipient
D00	14 January 2011	Released for comment	MJ : URS
D01	9th February 2011	Final release	MJ : URS
D02	27th September 2012	Issue 2	HW : URS
D03	11th January 2013	Issue 3	HW/FW :URS

II. Revision History

Rev	Date	Description	Editor
D00	14 January 2011	Released for comment	Alex McKay
D01	9th February 2011	Amendments and comments incorporated	Alex McKay
D02	27th September 2012	Further comments addressed & baseline data added	Alex McKay
D03	11th January 2013	Amendments to address LU comments ICNIRP tables updated	Alex McKay

III. Notes

Date	Comments	Editor

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Glossary of Terms

The following Abbreviations have been used in this document:

Term or Abbreviation	Definition
A/m	Amps per metre. A measure of magnetic field strength.
ALARP	'As Low As Reasonably Practicable' – a post mitigation level of risk, beyond which further reduction is not practical or feasible.
ATO	Automatic Train Operation – where speed governing information is passed from the track to train by means of 'codes' or low frequency radio signals.
CCTV	Closed Circuit Television.
CE	Conformitée Europeane – A pan European equipment marking regime, indicating all applicable Directives, including the EMC Directive have been applied and met.
EMC	Electromagnetic Compatibility – the ability of ***equipment*** to operate adequately in a given electromagnetic environment, while not introducing intolerable electromagnetic disturbances itself.
EMF	Electromagnetic Fields – generally applied under the concept of ***human health*** in the presence of high intensity electric and magnetic fields.
EMI	Electromagnetic Interference – a degradation of equipment performance due to disturbance from radio frequency electric or magnetic fields.
DC	Direct Current – the principle method of delivering Traction Current on the London Underground network.
HV	High Voltage – generally taken to mean supply voltages in excess of 11,000 volts.
Hz	Hertz. A measure of frequency. 1Hz = 1 cycle per second.
ICNIRP	International Commission on Non Ionising Radiation Protection – an international body providing recommendations on exposure limits of humans to radio frequency energy.
IGBT	Insulated Gate Bipolar Transistor – A modern high efficiency means of controlling heavy current, such as in speed control of rail traction systems.
LUL	London Underground Limited
NLE	Northern Line Extension
RF	Radio Frequency
R&TTE	Radio and Telecommunication Terminal Equipment Directive (99/5/EC), applicable to radio transmitting or receiving equipment or that connected to telecoms networks.
PFI	Private Finance Initiative.
SER	Signalling Equipment Room
SI	Statutory Instrument – a document specifying UK law by means of applying Regulation.
TfL	Transport for London.
μT	MicroTesla. A measure of magnetic flux density.
V/m	Volts per metre. A measure of electric field strength.

1 INTRODUCTION

1.1 Scope

The scope of this document discusses possible effects related to EMI (Electromagnetic Interference), EMC (Electromagnetic Compatibility) and EMFs (Electromagnetic Fields) as a result of the Northern Line Extension (NLE) scheme from Kennington to Battersea.

1.2 Purpose

This document is a Technical Report intended to support an Environmental Assessment chapter discussing EMC, EMI and EMF within the main Environmental Impact Assessment (EIA) performed by URS Infrastructure & Environmental Ltd in relation to the above scheme. The Environmental Impact Assessment is a supporting document to the Transport Works Order Act necessary for schemes of this nature.

1.3 Background

To support development as described in the Vauxhall, Nine Elms, Battersea (VNEB) Opportunity Area Planning Framework (OAPF) 2012, including the redevelopment of the disused Battersea Power Station, an extension of the Northern Line has been proposed, running from the Kennington Loop, with an intermediate station at Nine Elms and a terminus at the Battersea Power Station.

2 DISCUSSION

2.1 EMI Environment along the proposed Route 2

Description of route & current EMC environment.

The EMI environment along the proposed NLE Route 2 has been determined by desktop survey to be light industrial, commercial and residential in nature. This assumption has been confirmed by a measured electromagnetic baseline survey along the proposed alignment and, in particular, the proposed sites for the new stations. The survey was performed at street level and details can be found later in this report at **Annex A.**

The above ground EMI conditions are fairly benign in the context of potential for disruptive maloperation of equipment, consistent with that of a populated urban area.

Notable sources of EMI currently present are likely to be:

- Numerous mobile communication base station masts
- Electrified railway lines and rolling stock of the London Overground Network.
- London Underground's Victoria Line passes under part of the route.
- High power broadcast services from the main Crystal Palace and Croydon masts, some 7km to the South East.

- Lower power local broadcast services, unlicensed "pirate" stations and radio fixed links.
- Radar activities from ships on the Thames and possibly Heathrow/London City airport.
- Mobile transmissions from site radios, emergency services & public mobile telephones and devices.
- Mobile transmissions from vehicles such as buses, taxis and private licensed services.
- Low level EMI as a result of light industrial and commercial activities.
- Low level EMI as a result of residential activities, e.g. wireless networks, microwave ovens, electronic and power supply noise.
- Power frequency (50Hz) magnetic fields associated with power infrastructure, cables, substations, transformers etc.

These sources combine to form the existing EMI baseline in the frequency range 10Hz to 3GHz along the proposed route. It is against the context of this existing baseline that the electromagnetic environmental impact of the Northern Line Extension Project must be judged.

Since these sources are pre-existing and have been confirmed by an objectively measured radio frequency survey (see Annex A), no further discussion is required within the scope of this document beyond taking due cognisance of their existence and an assumption that a satisfactory current level of electromagnetic compatibility exists.

2.2 EMC Compliance of Equipment, Apparatus and Systems

Electromagnetic Compatibility (EMC) deals with the emissions and susceptibilities of electrical and electronic equipment of and to electromagnetic fields.

Since 1996, the European EMC Directive, now 2004/108/EC has sought to address many of the mechanisms and phenomena encountered with equipment electromagnetic compatibility via, most commonly, the application and testing to EMC standards. For example, an industrial piece of equipment may be tested to EN61000-6-4:2007 for emissions and EN61000-6-2:2005 for immunity aspects. A piece of communication equipment intended to be used in a railway environment would normally be tested to EN50121-4:2006.

In the United Kingdom, the European EMC Directive 2004/108/EC is transposed into national law as the Electromagnetic Compatibility Regulations, Statutory Instrument 2006 no. 3418.

As the NLE will be a capital project performed under the auspices of Transport for London (TfL), the project requirements are likely to mandate the compliance with London Underground Category 1 Standards throughout, except where concessions are negotiated for particular aspects. It is normally up to individual projects to establish a compliance framework whereby adherence to the individual requirements contained within LUL Category 1 Standards is achieved.

The relevant London Underground Category 1 Standards governing Electromagnetic Compatibility are as follows:

- LUL S1222, Electromagnetic Compatibility, Issue A2, dated 01.11.2012
- LUL 1-193, Electromagnetic Compatibility (EMC) with LU Signalling System Assets, Issue A2, dated 24.02.2009.
- LUL S1196, Signalling and Signalling Control - Concept and Requirements, Issue A4, dated 01.11.2011

The following is a London Underground Category 2 Standard concerning Electromagnetic Compatibility. Category 2 standards are advisory in nature.

- LUL S2514, Maximum allowable levels of electromagnetic interference in safety signalling assets - Issue A4, dated 01.03.2012

In addition, the following Guidance Document is published by LUL:

- LUL G-222, Manual of EMC Best Practice, Issue A1, dated 01.10.2007.

Normally, testing to recognised harmonised standards gives a good level of confidence that EMC issues will not be encountered when installation occurs and the item is taken into service, however, there can always be situations where additional special measures, suppression or mitigations are required in order to achieve a satisfactory level of Electromagnetic Compatibility.

2.3 Human Exposure to Electromagnetic Fields (EMF)

The study of the effects of human exposure to electromagnetic fields is considered under the general term of EMF exposure. Typically, field strength values involved are much larger than would be considered under EMC analysis. Concerns to human health of excessive exposure to EMFs is restricted to measureable physiological effects such as rf burns, rf micro-shocks and the localised heating of tissue.

Although legislation has been proposed in Europe governing human exposure to EMFs (historically under Directive 2004/40/EC), this has not yet been enacted. Additionally, legislation was only envisaged to cover the workplace, rather than the general public at large.

At the current time, international guidance on the matter is given by ICNIRP, the International Commission on Non Ionising Radiation Protection, under it's published document 7/99. Reference Levels are published for the permissible occupational and public exposure limits to time varying electric and magnetic fields

For reference, these values are given in Tables 1 and 2 overleaf.

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NORTHERN LINE EXTENSION (NLE)
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2.3.1 Table 1: ICNIRP (2010) Reference Levels for Occupational Exposure

Frequency Band (f)	Occupational Exposure Reference Level Electric Field (kV/m)	Occupational Exposure Reference Level Magnetic Flux Density (T)
1Hz-8 Hz	20	$0.2 / f^2$
8Hz-25Hz	20	$2.5 \times 10^{-2} / f$
25Hz-300Hz*	$5 \times 10^2 / f$	1×10^{-3}
300Hz-3kHz	$5 \times 10^2 / f$	0.3/f
3kHz-10MHz	1.7×10^{-1}	1×10^{-4}
Values below from 1998 guidance which are currently under review by ICNIRP		
10MHz-400MHz	61	0.2
400MHz-2000MHz	3 f1/2	0.01 f1/2
2GHz-300GHz	137	0.45

**Note that 50Hz yields values of 10kV/m and 1000µT*

2.3.2 Table 2: ICNIRP (2010) Reference Levels for Public Exposure

Frequency Band	Public Exposure Reference Level Electric Field (kV/m)	Public Exposure Reference Level Magnetic Flux Density (T)
1Hz-8 Hz	5	$4 \times 10^{-2} / f^2$
8Hz-25Hz	5	$5 \times 10^{-3} / f$
25Hz-50Hz*	5	2×10^{-4}
50Hz-400Hz	$2.5 \times 10^2 / f$	2×10^{-4}
3kHz-10MHz	1.7×10^{-1}	1×10^{-4}
Values below from 1998 guidance which are currently under review by ICNIRP		
10MHz-400MHz	28	0.092
400MHz-2000MHz	1.375 f1/2	0.0046 f1/2
2GHz-300GHz	61	0.2

**Note that 50Hz yields values of 5kV/m and 200µT*

Although the impact of human exposure to electromagnetic fields is normally confined to particular industries, notably power distribution, broadcast, medical imaging and industries using high power radio frequency sources such as RF welding or diathermy equipment, there can be considerations for rail projects such as the NLE. These are discussed in the relevant sections that follow.

3 EMI AND EMF IMPACT OF CONSTRUCTION ACTIVITIES

3.1 Construction plant, tools and related activities

Station construction activities are likely to involve the use of plant, machinery and tools. Site radios, temporary power arrangements (including possible use of generators) and widespread use of mobile telephones are likely. There may also be some inductive short range device operated security barriers to allow construction site access. Additionally, there may be some welding of structural steel although normally bolted. The EMI and EMF impact of these activities is not likely to be severe, since they are no different to other civil construction projects where generally no adverse impacts are experienced. The appointed EMC manager for the project should ensure that all equipment used is appropriately ‘CE’ marked to the EMC (2004/108/EC) or R&TTE (99/5/EC) Directives as appropriate.

The temporary erection of tower cranes to assist with the movement of materials on site is known to cause localised disruption to the reception of terrestrial broadcast services due to reflections and blocking, however, these effects are more pronounced on analogue services than digital. There are no longer any analogue terrestrial television services broadcast in the London area.

3.2 Tunnel Boring Machines (TBMs)

Tunnel Boring Machines require large amounts of electrical power and draw very heavy currents during their normal cutting activities.

Large currents in supply cables, motors and on board transformers are a typical source of large power and low frequency magnetic fields. Generally, when tunnelling near to other underground assets, other asset owners require assurance that perturbations caused by the TBM will not impact those other assets significantly. While major factors such as ground movement and vibration are a consideration for some asset owners, magnetic field disturbances are also of concern to London Underground and Power Utilities.

Since the proposed route passes over LUL’s Victoria Line, it is possible that LUL will require assurance that the magnetic and electric fields generated by the TBM will not cause interference to the signalling system and ATO (Automatic Train Operation) track codes in use on the Victoria Line.

EMF aspects are only likely to be a consideration for TBM operators working a normal 8 hour shift pattern within the body of the machine. Previous experience of TBM models indicates that occupational exposure limits (1000μT at 50Hz being the predominant element) are not exceeded in normal operation (see Table 1).

Assurance will be required that the EMI and EMF performance of the proposed TBM specification is within acceptable limits.

4 EMI AND EMF IMPACT OF NEW ASSETS & INFRASTRUCTURE

From knowledge of previous projects of this type, the following items of potential EMC significance are highlighted for further discussion.

- Traction Power arrangements
- Stray DC Currents
- Earthing and bonding
- Rolling Stock
- Signalling Systems
- Communications systems
- Mechanical & Electrical Systems

4.1.1 Traction Power Arrangements

Traction Power arrangements consist of high voltage feeders from the supply grid (EdF Powerlink) Bulk Supply Point to Substations (Claylands Road and Nine Elms) housing Transformer / Rectifiers, Breaker Cabinets (HV & DC) and HV / DC feeder cabling. Additionally, section switches are provided at strategic locations on the route.

Traction Power is fed along positive and negative conductor rails (currently -210V + 420V although this is likely to rise in the future on Sub Surface Lines to 750V between the rails) from where rolling stock picks up traction current.

Traction Power infrastructure has the potential to emit predominantly magnetic field disturbances, with highest emissions corresponding at the highest current loading. This is likely when two trains are accelerating on the same traction section.

Stray magnetic fields are confined to the immediate region surrounding the running tunnels, conductor rails and dc feeder cables. There is not likely to be any significant degradation from an environmental perspective for this reason.

It will be a requirement of any EMC management strategy that evidence as to the EMC performance of the Traction Power equipment (such as Declarations of Conformity or Technical Files) is obtained from the manufacturers or designers. A suitable EMC standard on which to base conformity assessment would be EN50121-5:2006.

In regard to EMFs and human exposure, highest levels of predominantly magnetic field are likely to be found in the substations or where there is a concentration of traction supply cables and switchgear.

Previous measurements of EMFs in LUL substations indicate that, although levels of power frequency magnetic field can be significant, they do not exceed the 1000μT guideline for occupational exposure at 50Hz, or, in public areas, the 200 μT guideline for public exposure.

4.1.2 Stray DC Currents

DC Railway Traction systems, such as those used by London Underground, have the potential to cause stray currents in the immediate environment. This is because the traction current return path is not always well insulated from earth and the earth itself and surrounding metallic structures may unintentionally become part of the return conducting path.

Principal environmental effects are the following:

- Corrosion and subsequent damage to metallic structures where stray DC currents exit those metallic structures.
- The flow of stray currents into earthing systems or cable shields unrelated to the railway may cause overheating, maloperation of electrical protection systems, or damage in extreme cases.

Nearby infrastructure which may be subject to the undesired effects of stray currents are:

- Pipelines for water and gas
- Structural steelwork
- Historic ironwork, such as bridges
- Steel reinforcement bars within concrete structures
- Buried metallic structures
- Cathodic protection systems
- Earthing systems not related to the railway

If not considered at the design stage by the traction power system designers, the undesired effects discussed above may be experienced.

Generally accepted mitigation methods include the following:

- Insulation of the traction power return circuit with respect to earth
- Improved conductivity of the return circuit
- Design of the traction power system

It would be a requirement that any traction power system designed as part of the NLE would be in accordance with EN50122-2:2010 in order to minimise the environmental effects of DC stray currents.

4.1.3 Earthing and Bonding arrangements

Correct earthing and bonding is an important aspect of installed system EMC. It is normal practise in commercial buildings to create a Common Bonded Network. By bonding electrical supply earths in addition to structural and non structural metalwork (such as rebars, cable trays, ductwork, metallic water and gas pipes etc) a low impedance Mesh Bonding Network. This type of network forms an integrated earth network and satisfies the requirements of electrical safety, signal integrity, equipment reliability and EMC. In general, for safety purposes, it would a requirement that non traction power system earthing will be designed in accordance with BS7671:2008 (IEE 17th edition wiring regulations).

In a railway environment there are additional complications in that it is necessary to prevent traction fault current entering equipment earthing systems and the earthing systems of nearby properties, buildings and infrastructure not related to the railway. In addition, there must be measures to prevent bridging between earthing systems, such that touch voltage limits are exceeded.

It would be a requirement that any earthing system designed as part of the NLE would be in accordance with EN50122-1:1998 in order to minimise the export of fault currents into the immediate environment.

4.1.4 Rolling Stock

Rolling Stock used on the Northern Line is designated as 1995 Stock, which uses modern IGBT based traction equipment. Although there are many benefits, a side effect of this traction equipment is the generation of harmonic noise in the traction power supply system. An additional EMI effect of rolling stock is the transient broadband interference caused by arcing of the current collector shoes. Arcing can occur in normal running, in addition to traversing gaps between traction power sectors, where it is perhaps most noticeable.

Rolling stock also has various on board systems, such as train management, CCTV and radio systems which contribute to it's overall EMI signature.

In general terms, the environmental impact of EMI from rolling stock is likely to be minimal above ground, since the proposed route runs exclusively in deep covered running tunnels. Impact on below ground assets (such as the Victoria Line at a separation of one core diameter) is also likely to be minimal due to the attenuation of earth of high frequency electric fields and the lack of parallelism between the two lines.

Assumptions as to the attenuation of the running tunnels and ground are shown later in this report.

EMF considerations are limited to driver and passenger exposure to low frequency magnetic fields sourced by traction power equipment and motors on the rolling stock. As part of the acceptance process for the rolling stock, levels of magnetic field are normally assessed in accordance with London Underground standards (currently Cat 1. LUL S1222), from the perspective of passengers with medical implants that could be affected.

4.1.5 Signalling Systems

The signalling system on the Northern Line is in the process of being upgraded to the Thales SelTrac S40 system (currently due for completion in 2014) as used on the Jubilee Line, but in general, signalling systems are not considered to be significant aggressors in terms of EMI. They are however given great attention in terms of immunisation and EMI protection, since they are safety critical.

Since the majority of signalling assets will be in the running tunnels or in Signalling Equipment Rooms (SERs) their EMI impact on the surrounding area will be low, due to the attenuation of ground and the tunnel itself.

Estimates of likely attenuation are given later in this report.

New signalling assets would be expected to conform with EN50121-4:2006, LUL S1196 and LUL S1222.

There are unlikely to be any significant EMF issues directly attributable to the signalling system.

4.1.6 Communications Systems

Communications systems on London Underground consist of a variety of long and short range wired and radio links, carrying data, audio/video and speech.

Cabled communication systems are not considered to be EMI threats, since cables are usually formed from twisted pair or shielded such that only very low levels of signal leakage are experienced. In common with signalling cabling, communications cabling is given consideration in terms of EMI protection by mean of cable segregation and careful route selection.

Radio communications systems that rely on the use of antennas and leaky feeders do, by their very nature, emit signals into the environment. However, the radio systems are designed by London Underground's Communications PFI Contractor and are specifically intended to give very tightly controlled coverage over a desired area, by means of carefully controlled transmit powers and antenna beamwidths. Generally the intended coverage areas are the running tunnels, station areas, maintenance and service areas, specific rooms and so on. This means that overspill radio coverage in to unintended areas is very rare, particularly since the operating frequencies are re-used in various locations around the network.

In any event, the frequencies used are licensed and allocated by the spectrum authorities, therefore environmental impact and likelihood of unintended EMI events will be low.

There are some minor EMF issues associated with the radio transmission elements of the communications systems. However, normal separation distances (generally >3m) from, in particular, radiating antennas are such that the reference levels of the ICNIRP guidelines, (61V/m Occupational and 28V/m Public @ 395MHz of the Connect Radio System) are not exceeded.

4.1.7 Mechanical & Electrical (M&E) Systems

The Mechanical and Electrical (M&E) Systems installed as part of the NLE and stations will act as both emitters and receptors of EMI. This will be particularly true of heavy current equipment such as lifts and escalators. Items such as fluorescent lighting are acknowledged as possible emitters (albeit low level) of radio frequency noise and therefore careful placement in relation to sensitive receptors such as radio system leaky feeders will be essential as part of the design coordination.

However, in terms of overall M&E system noise exported to the environment, total levels are expected to be low, with field strengths of interfering signals falling away with the square of distance for above ground assets, and being attenuated by tunnel shielding and / or the general mass of earth for below ground assets.

In general, it would be expected that equipment and systems would be procured as CE marked to the EMC Directive 2004/108/EC by their respective manufacturers to using standards appropriate to the environment of use. In addition, it would be expected that EMC would be managed and co-ordinated throughout the design and construction phase by an EMC Specialist. A suitable standard against which to base compliance of the fixed installation (or fixed installations) would be EN50121-2:2006.

These considerations lead to the conclusion that the environmental impact and likelihood of unintended EMI events due to the M&E systems will be low.

There are not anticipated to be any significant EMF issues associated with the M&E systems.

NORTHERN LINE EXTENSION (NLE)
EMC ENVIRONMENTAL IMPACT REPORT
DOCUMENT REFERENCE: TIE-URS-2515-D03

5 DATA, CALCULATIONS AND ASSUMPTIONS

Discussion of some of the proposed designs that would be implemented as part of the NLE and new stations refer to the shielding afforded by infrastructure being contained within deep level running tunnels.

This section estimates likely attenuation and, therefore, possible field strengths resulting at ground level from the new running tunnels.

5.1 Tunnel Shielding

The shielding effect of tunnels is primarily due to absorption loss (AdB) and is estimated using the following equation

$$A\,(\text{dB}) = 131.4t\,\sqrt{(f\,\mu_r\,\sigma_r)}$$

Where:

t is the thickness of the shield in cms.

f is the frequency in Hz.

μ_r is the relative permeability of the shield material.

σ_r is the relative conductivity of the shield material.

5.1.1 NLE Tunnel Lining

The lining is added as the tunnel is dug and the assumptions are:

Steel fibre reinforced concrete at the rate of 30kg/m^3.

Low frequency relative permeability, μ_r of steel = 1000

Relative conductivity, σ_r of steel = 0.1

Density of steel (iron)* = 7860kg/m^3

Lining Thickness, 0.15m.

The volume of steel used = 30/7860 m^3 i.e. 3.8 x 10^{-3}

This is "equivalent" to approximately 0.57mm (3.8 x 0.15) of continuous steel tunnel lining. Using these figures the shielding effectiveness is estimated to be 5.3dB at 50Hz (fault current frequency), 8dB at 117Hz (lowest frequency of a 125 DEV signal circuit), & 8.4dB at 125Hz (lowest frequency of an EP valve circuit), and increases in proportion to $\sqrt{f}$.

*Ref. EMP Engineering Practices Handbook Second Edition (NATO UNCLASSIFIED)

5.1.2 Attenuation of Radiated Emissions

Any radiated emissions from installed infrastructure or an operating TBM will be attenuated in principle by two mechanisms, namely reflection loss and absorption loss. Reflection loss occurs at any interface between the radiating sources in the noise source and the existing tunnel. Absorption loss occurs due to the magnetic and electrically lossy nature of any materials between the radiating sources and the existing tunnel. The absorption loss is a combination of the magnetic and electric field losses due to the steel fibre re-inforced concrete lining of the TBM tunnel being dug (or operating line), plus the losses due to the soil in between the tunnel and any threatened receptor.

The total attenuation (shielding effect in principle) is the sum of the reflection loss and absorption loss.

5.1.2.1 Reflection Loss

The reflection loss depends on many parameters including the type of noise source, the distance of the source to any barriers plus the type of barriers between the noise source and the tunnel wall. These parameters are not easily definable so a worst-case scenario is used i.e. the reflection loss is assumed to be zero (0dB).

5.1.2.2 Absorption Loss of Tunnel Lining

To obtain a representative figure, a VHF frequency of 165 MHz was chosen for a typical radio frequency emission:

The assumptions are:

Steel fibre reinforced concrete at the rate of 30kg/m^3.

Low frequency relative permeability, μ_r of steel = 1000

Relative conductivity, σ_r of steel = 0.1

Density of steel (iron) = 7860kg/m^3

Lining Thickness, 0.15m.

“Equivalent steel thickness” of continuous steel tunnel lining, 0.5725mm.

Using the equation below:

$$A\ (\text{dB}) = 131.4t\sqrt{(f\ \mu_r\ \sigma_r)}$$

gives a loss significantly greater than 100dB. The level of shielding increases as the frequency is increased, so at 165MHz, a high value would be expected.

5.2 Absorption Loss of Soil

The loss depends on the electrical characteristics of the soil and these can vary considerably. The absorption loss equation above assumes an exponential loss through the material of interest and is not ideally suitable for soil since it behaves more like a lossy dielectric with parameters not easily definable.

However, soil has a typical conductivity of between 10^{-3} S/m and 10^{-1} S/m and attenuation through it can be estimated, see [Ref. EMP Engineering Practices Handbook Second Edition (NATO UNCLASSIFIED) page 3-54 Table 3-7]. This reference gives the following estimates in soil attenuation at 100MHz:

0.52dB/m for a soil conductivity of 10^{-3}

5.2dB/m for a soil conductivity of 10^{-2}

42dB/m for a soil conductivity of 10^{-1}

Since the actual soil conductivity is unknown the lowest value will be assumed i.e. approx 2dB loss at 100MHz for a soil depth of 3.9m. This 2dB loss will be similar at 165MHz.

Examples of this combined effect on typical LUL emissive sources are shown below:

Total Attenuation = Source level (dBμX/m) – Tunnel Attenuation (dB) – Path Loss through soil (dB

Electromagnetic noise source	Typical signal level in free space	Attenuation of tunnel lining and 10m path through soil	Estimated signal at ground level
Rolling Stock Traction Equipment emitting at 10kHz	60dB(μA/m) (limit of EN50121-2:2006)	76dB +2dB = 77dB	-17dB(μA/m) (undetectable)
Connect Radio Antenna radiating at 395MHz @ 1meter	120dB(μV/m)	>150dB+>50dB = >200dB	<0dB(μV/m) (undetectable)

Table 3: Estimated Signal Strengths at ground level from a 10 metre deep tunnel

6 CONCLUSION

This report has looked that the initial information available regarding the proposed Northern Line Extension to Battersea in order to estimate potential environmental impact from an EMC perspective.

The existing, prevailing EMC environment of the route at street level has been deemed as Domestic, Commercial and Light Industrial and therefore, relatively benign, although consistent with that of a metropolitan area. Where the route passes near to existing Network Rail infrastructure, the EMC environment at the surface is considered to be a railway EMC environment.

After construction, parts of NLE assets appearing at surface level may also be considered as a railway EMC environment, but would be subject to an EMC zoning exercise as part of the design process.

The likely EMC environmental impact of new assets, infrastructure and equipment has been discussed, in addition to those effects likely to be encountered during construction of the NLE. This has been referenced to the legal requirements for EMC contained within the UK EMC Regulations SI 2006, No. 3418 and the European EMC Directive 2004/108/EC.

It is considered that under the legal framework governing EMC, the new stations and running tunnels will be considered as a ‘Fixed Installation’ or a series of ‘Fixed Installations’. They will be subject to the provisions of both the UK Regulations and the EU Directive in respect of meeting the associated ‘Essential Requirements’. It is therefore considered that an adequate EMC management strategy will need to be put in place, should the project progress, in order that these legal requirements are met.

Through the process of meeting the ‘Essential Requirements’ of the UK EMC Regulations and the EU Directive on EMC and having effective EMC management strategy in place it would be expected that, given information regarding existing emitters and receptors in the vicinity, the general EMC environment prevailing along the proposed route is not expected to be degraded significantly as a direct consequence of the project.

In addition, impacts on Human Health from exposure to electromagnetic fields would be managed to remain well below the reference levels specified in the ICNIRP recommendations.

Annex A :
Magnetic & Electric Field Baseline Measurements

A1: Introduction

This Annex details the findings of a street level survey of Electric Field and Magnetic Flux Density along the proposed route of the Northern Line Extension. The purpose of the survey is to obtain baseline readings against which to judge any possible future change due to the NLE scheme.

The route followed was as close as possible to the proposed Route 2a as defined in Halcrow horizontal alignment drawing, dated 23.02.2010.

The dates of the survey were 13.09.2012 and 14.09.2012.

Weather : Dry, 18°C

A2: Equipment Used

In order to characterise the EMC environment of the route and make measurements of fields attributable to existing sources, broadband electromagnetic field measurements were made with the following equipment:

Instrument	Manufacturer	Model & Serial Number	Cal. Due Date
Broadband E-Field Meter 150kHz-3GHz	Narda	NBM-550 SN: B-0326	26.5.2013
Magnetic Field Probe 1Hz-400kHz	Narda	ELT-400 SN: M-0172	4.6.2013

Table A1: Test Equipment

A3: Scope and Limitations

The survey locations were limited to street or park areas where measurements could be performed safely and access to private property was not required.

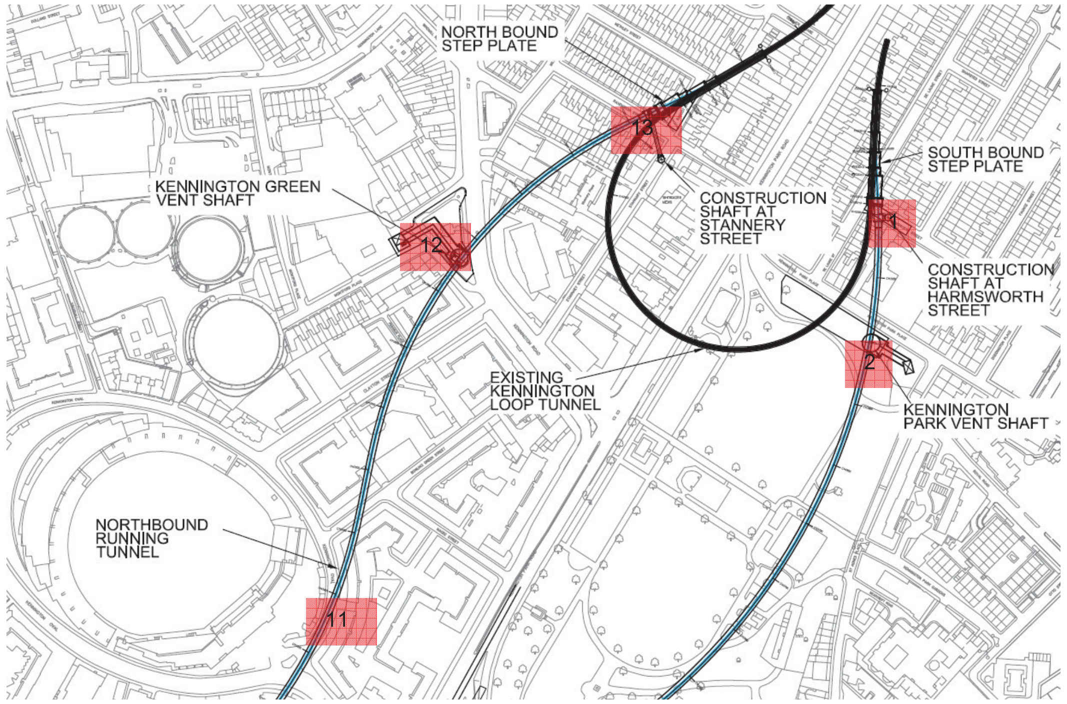
Values recorded were those prevailing at approximately 1.5m above ground level at the time of measurement. Some values will have been attributable to sources that were diurnal or otherwise time varying in nature and therefore, amplitudes can be expected to vary slightly from those recorded during the survey.

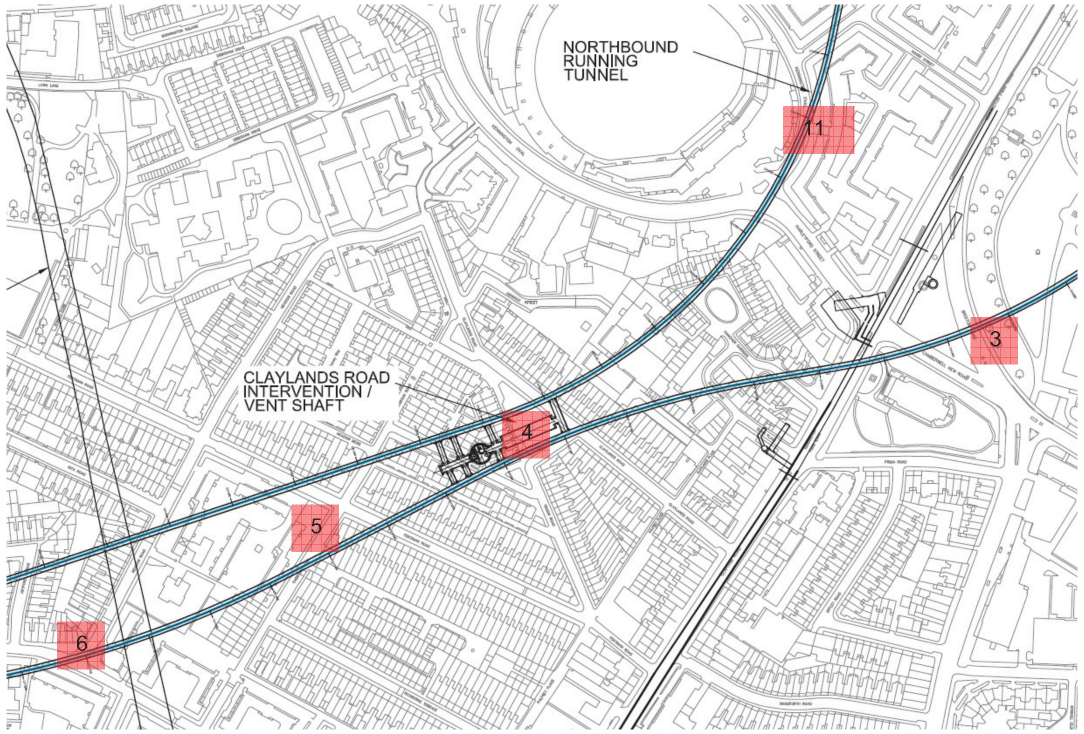
A4: Baseline Values Recorded

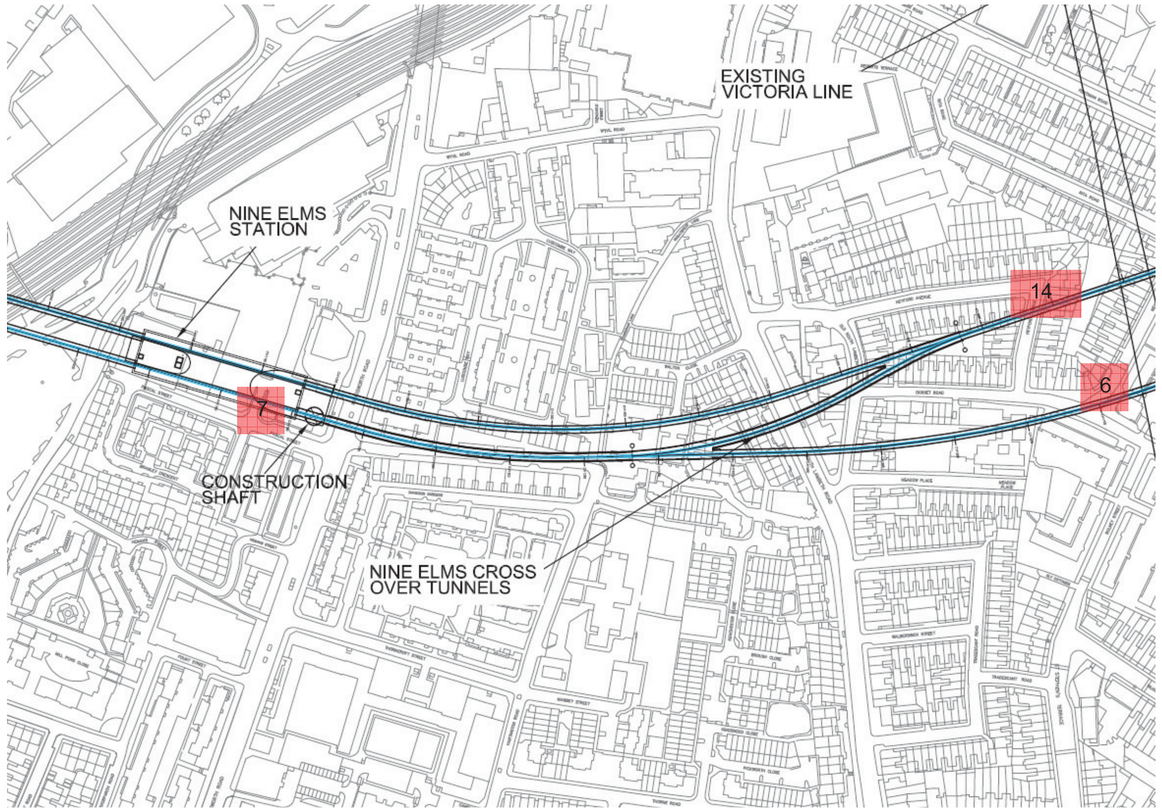
Map Location	Street Location	Electric Field (V/m)	Magnetic Flux Density (µT)
1	Harmsworth Street : Proposed site of Construction Shaft	0.40 V/m	0.118 µT
2	Kennington Park : Proposed Vent Shaft site	0.5 V/m	0.050 µT
3	Edge of Kennington Park at Brixton Road / Camberwell New Road	0.6 V/m	0.050 µT
4	Claylands Road Intervention / Ventilation Shaft	0.5 V/m	0.130 µT
5	Carroun Road	0.75V/m	0.055 µT
6	Junction of Meadow Road / Dorset Road	0.75V/m	0.055 µT
7	Pascal Street : Proposed Site of Nine Elms Station	0.45V/m	0.582 µT
8	Ponton Road : adjacent to NR overground viaduct	0.64V/m	0.370 µT
9	Kirtling Street : Power Station Site Entrance	0.75V/m	0.450 µT
10	Battersea Park Road :adjacent to proposed Battersea Station	0.30V/m	0.59 µT
11	Kennington Oval : adjacent to rental bike charging station / cricket ground entrance 'Hobbs Gate Turnstiles'	1.0V/m	0.203 µT
12	Kennington Green : Proposed Vent Shaft site	0.72V/m	0.208 µT
13	Junction of Ravensden Street / Stannary Street	0.49V/m	0.400 µT
14	Heyford Avenue	0.65V/m	0.055 µT

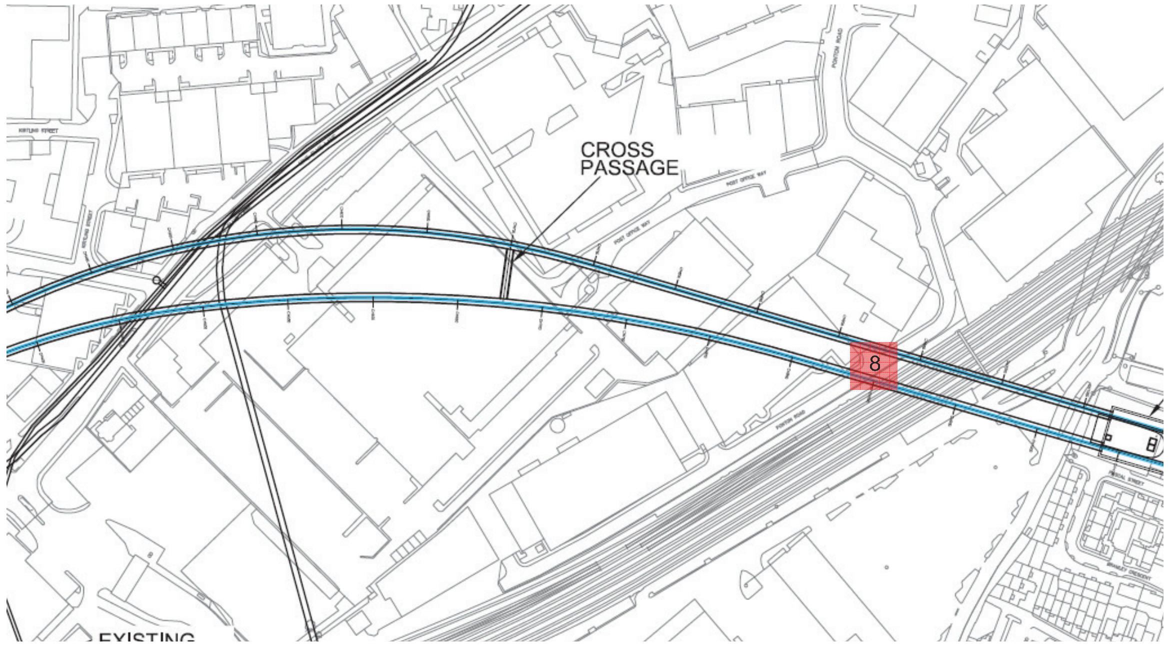
Table A2 : Recorded values

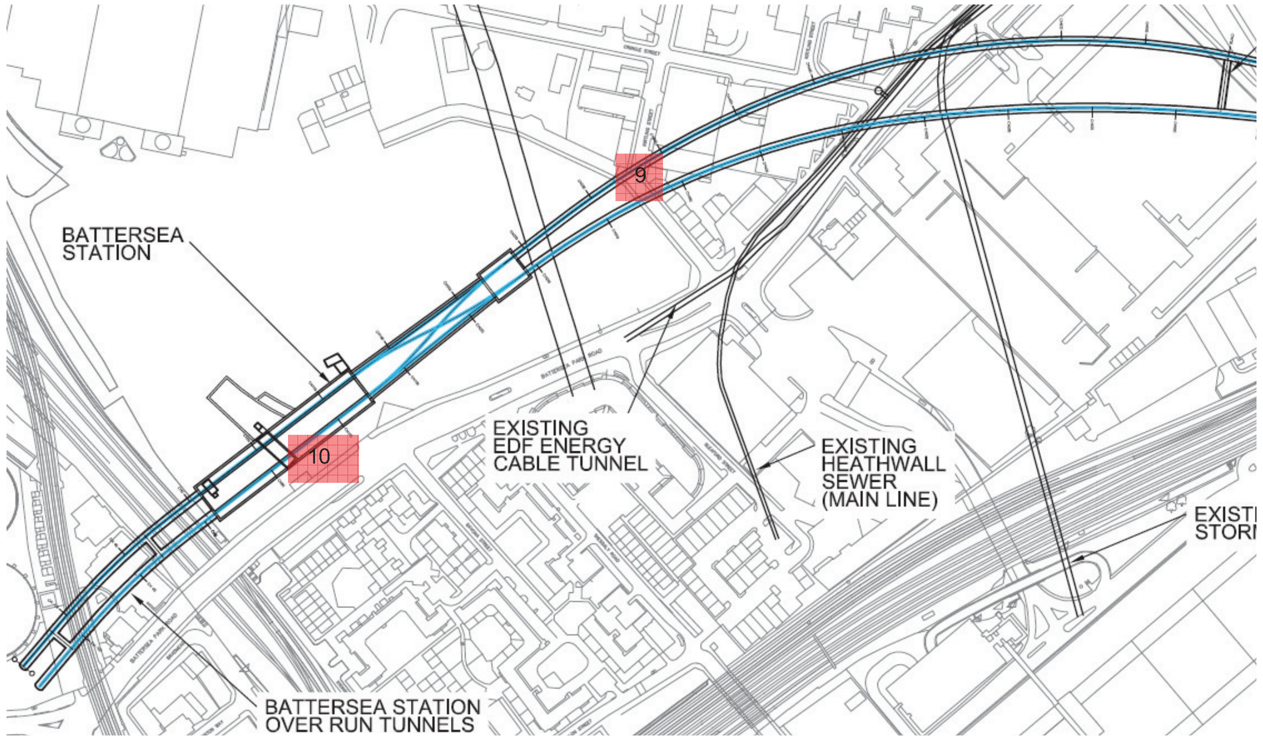
A5 : Maps of Survey Locations











A6 : Conclusions

The measured values confirmed the expectation of a relatively benign EM environment, consistent with an urban area consisting of residential, commercial and light industrial premises.

The following are the main findings:

- The low frequency magnetic fields (1Hz to 200kHz) were found to be below 0.8μT which is the recommended maximum ambient value for correct operation of Cathode Ray Tube screens such as legacy television sets and computer monitors. A maximum value of 0.582μT was recorded in Pascal street near the site of the proposed Nine Elms Station. It is likely that the source was an underground AC power cable or a BT cabinet noted at close proximity.
- The electric field values (150kHz to 3GHz) were found to be generally lower than 1V/m – a level at which disturbance to electronic and electrical apparatus would not be expected. One location, outside the Oval Cricket Ground, a value of 1V/m was recorded adjacent to the rental bike charging station. The recorded value reduced with increasing separation from the charging station. In any event, the value is below the 3V/m immunity threshold of most modern apparatus.
- All measured field levels are below the ICNIRP recommended values for exposure of the general public to non ionising radiation.

H: Surface Water and Flood Risk

Environmental Statement

Volume II

H1: Buro Happold Flood Risk Assessment

Environmental Statement

Volume II

Northern Line Extension TWA Order

Document: Flood Risk Assessment Version: 02

GRNLEB-BHD-00-XX-REP-ENV-00005-02-01

Buro Happold
Flood Risk Assessment

22nd March 2013

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22nd March 2013

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Document history

This document has been issued and amended as follows:

Version	Date	Description	Created by	Verified by	Approved by
01	27/02/2013	Flood Risk Assessment GRNLEB-BHD-00-XX-REP-ENV-00005-01-01	A. Dannatt	J. Martin	S. Lewis
02	22/03/2013	Flood Risk Assessment GRNLEB-BHD-00-XX-REP-ENV-00005-02-01 Formal Issue	A. Dannatt	J. Martin	S. Lewis

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Glossary

Term	Definition
Actual Risk	The risk that has been estimated based on qualitative assessment of the performance capability of the existing flood defences
Attenuation	A method to reduce a flood peak to prevent flooding, increasing the duration of the flow
Breach	Failure of flood defences or other infrastructure acting as a flood defence, potentially causing flood related hazards
Brownfield	Land previously developed that has potential to be regenerated
Catchment Flood Management Plan	A CFMP is a large scale strategic planning framework for the integrated management of flood risks to people, natural and developed environment in a sustainable manner
Catchment	A river catchment is the area which the river drains either naturally or with artificial engineering. A surface water catchment is the area which water drains into a river. A groundwater catchment is the area that consists of the groundwater river flow.
Coastal Defence	To provide protection from coastal erosion and/or tidal flooding
Design Flood Level	This is the level of flooding that flood defences or mitigation measures are designed against. This is typically the 1% (1 in 100) flood level.
Discharge	The rate of flow of water measured in terms of volume per unit time
Flood Defence	A natural or man-made infrastructure used to prevent certain areas from inundation from flooding, and / or the provision of flood warning systems
Floodplain	Area of land adjacent to a water course on which water flows or is stored during a flood event, or would otherwise be flooded in the absence of

	flood defences
Flood Resilience	Improving flood resistance, e.g. reducing the risk of properties against flooding events
Flood Risk	The level of risk to personal safety and damage to property resulting from flooding due to the frequency or likelihood of flood events
Flood Risk Assessment	An assessment of the flood risks to the proposed development over its expected lifetime and the possible flood risks to the surrounding areas, assessing flood flows, flood storage capacity and runoff
Flood Risk Management	Managing/reducing flood risk to people, property and the environment
Flood Warning Systems	A system by which to warn the public of the potential of imminent flooding. This is typically linked to a flood forecasting system
Flood Zones	An area susceptible to flooding with a level of risk defined by the Environment Agency
Fluvial Flooding	Related or connected to a watercourse (river or stream)
Greenfield	Land which has not been previously developed
Groundwater	Water present within underground strata known as aquifers
Groundwater Flooding	Surface flooding resulting from a high ground water levels.
Inundation	Flooding of land with water
LIDAR	Airborne laser scanning of topography
Mitigation	Actions taken to reduce either the probability of flooding or the consequences of flooding or a combination of the two
Previously Developed Land	Land which is or was occupied by a permanent structure (excluding agricultural or forestry buildings) and fixed surface infrastructure
Refuge	Area for shelter / protection during flood events
Residual Risk	The risk that remains after risk management and

	mitigation measures have been implemented
Resilience	Improving the flood resistance, eg. Buildings
Risk	Risk is the probability that an event will occur and the impact (or consequences) associated with that event
Runoff	Water flow over surfaces to the drainage system. Runoff occurs if the ground is impermeable or if permeable ground is saturated.
Sequential Test	The sequential approach forms an integral part of the NPPF and PPS25 guidance and is a process which designates appropriate areas for vulnerable land uses within a region, dependent on flood risk and the land uses required within the region.
Strategic Flood Risk Assessment	An SFRA is the assessment and 'categorisation' of flood risk on an area-wide basis in accordance with the National Policy Planning Framework (NPPF). New development opportunities are sequentially tested to direct new development, to areas at least risk of flooding.
Surface Water Flooding	Surface water flooding occurs when the volume of water is unable to filtrate through the ground to enter drainage systems, and therefore runs quickly off land and results in localised flooding. This type of flooding is usually associated with intense rainfall.
Sustainable Drainage Systems	SuDS are used as a strategy to manage surface water in a sustainable manner or least damaging solution through management practices and physical structures.
Sustainable Development	Development which meets the needs of the present without compromising the ability of future generations to meet their own needs
Tidal Flooding	Related or connected to the sea or estuary
Water Table	The top surface of the saturated zone within the aquifer

Abbreviations

Term	Definition
AEP	Annual Probability of Exceedence
BPS	Battersea Power Station
DEFRA	Department of Food and Rural Affairs
EA	Environment Agency
EU	European Union
FRA	Flood Risk Assessment
FRM	Flood risk management
FWS	Flood warning system
LDF	Local Development Framework
LPA	Local Planning Authority
NLE	Northern line extension
NPPF	National Planning Policy Framework
PDL	Previously Developed Land
PPS25	Planning Policy Statement 25 *Policy Statement 25: Development and Flood Risk* (2010) was the overarching national Government policy guidance on development and flood risk management. Although PPS25 has now been withdrawn by Government and replaced by NPPF, it is widely recognised by developers and local planning authorities that it represents good practice guidance with respect to the development of land affected by flood risk.
RFRA	Regional Flood Risk Assessment
SFRA	Strategic Flood Risk Assessment
SuDS	Sustainable Drainage System

1 Executive Summary

This Flood Risk Assessment (FRA) has been prepared by Buro Happold Ltd on behalf of the Transport For London (TFL) for the proposed extension of the Northern line (NLE) at Battersea Power Station (BPS), Greater London. These proposals involve the construction of an underground rail route from Kennington to Battersea including two new underground stations at Nine Elms and Battersea station, and two permanent ventilation shafts at Kennington Green and Kennington Park. The extension is the subject of a Transport Works Act Order (TWA Order) that has required the preparation of an Environmental Impact Assessment (EIA) of the project by URS for TFL. A FRA, required for the EIA, has been conducted in accordance with the guidelines set out in National Planning Policy Framework (NPPF) as well as other guidelines and procedures.

The assessment was updated in March 2013 to ensure the assessment was contemporary with the NLE scheme proposals (RIBA Stage C Drawings) and assessment to the National Planning Policy Framework (NPPF).

The Environment Agency (EA) has stated that a FRA should accompany the EIA in order to adequately consider flood risk in the design of the scheme and provide mitigation should it be deemed necessary and has specifically requested that breach modelling be undertaken.

The route of the NLE, including the current location of Nine Elms Station, lies mainly within the tidal flood plain of the Thames (Flood Zone 3, defined as the 1 in 200 year flood extent). The flood plain is defended by the Thames Tidal Defences, generally to a standard that will accommodate a 1 in 1000 year tidal event, including an allowance for sea level rise due to climate change to the year 2030. The Thames Tidal Defences include the Thames Barrier, which is operated by the EA. All of these defences are maintained to a high standard, have significant levels of resilience and the risk of failure is considered to be very low.

Liaison with the EA through 2010 and 2011 has established, agreed and finalised multiple sites for breach analysis where a simulated breach in the Thames Tidal Defences has been modelled. Consideration of the baseline case which when compared against with the NLE proposals has provided an assessment of the likely scheme standard or mitigations that are required to be adopted.

A number of the breach locations presented no risk , whilst two of the breach locations required further more detailed study. The results of the breach analysis are included in this FRA, which has informed the overall flood risk management strategy that has allowed the timely integration of required mitigations in the developing design. Each of the sites for the NLE has been assessed in relation to the hazard that any breach in the Thames Tidal Defences presents.

A surface water drainage strategy has been designed for the NLE in two principal parts; firstly, the Battersea Station strategy is based on no attenuation and direct discharge to the Thames in the same manner as the BPS strategy. The second for Nine Elms Station is to discharge surface foul water separately by gravity into the existing Thames Water Sewers attenuated in accordance with the London Plan Essential Standards by 50%.

This FRA has concluded the following:-

Five breach locations have been discounted by the previous preliminary assessment as having no risk to the NLE project. Two further breach locations were identified to require more detailed assessment, including the **St George's Wharf breach** and the **Nine Elms breach** locations that drain into similar flood cells, concentrating on the depressions in topography around Nine Elms. Due to the location of the stations at Nine Elms and Battersea it was important that these two breach locations were modelled in detail so that appropriate mitigation measures could be incorporated to reduce flood risk if required.

The results from the current detailed breach analysis has informed the FRA which has subsequently detailed the flood risk management strategy proposal and ensured that the Stage C design has incorporated any mitigation that is required. Each of the sites for the NLE (at Battersea, Nine Elms, Kennington Green and Kennington Park) has been assessed in relation to the hazard that any breach in the Thames Tidal Defences presents.

The main flood risk to the site is the River Thames, which is tidally influenced for all the sites within the application. The sites are defended against flooding from extreme tidal events at Battersea, Nine Elms, Kennington Green and Kennington Park, but importantly the Environment Agency classifies areas into one of three Flood Zones based on risk of flooding from the river or sea, not taking into account any flood defences.

The breach modelling has shown that the St George's Wharf breach location is the most onerous giving a 1 in 1000 year flood level of 3.4mAOD. Nine Elms station has been removed from the flood extent by raising the finished floor levels for the two entrances whilst ensuring the central section of the station building has been lowered to minimise the impact of the station on the flood flow in the 1 in 1000 year event.

The proposed station at Battersea has no effect on flooding as it is located outside the flood extent for any of the breach locations. The 1 in 1000 year breach flood level was found to be 4.4m AOD.

With regard to the effects of climate change, the Environment Agency has indicated that tidal levels at all the sites for the NLE will decrease over time due to the anticipated revised operation of the Thames Barrier recommended by the TE2100 project. This assessment therefore takes into account the present day values, which represent a worst case scenario, ensuring the most up-to-date information on estimated flood levels has been used.

Following extensive consultation the model created is considered by the Environment Agency to be appropriate for the assessment of flood risk to the site for the assessment of the proposed case.

The Sequential Test is considered inappropriate to be applied in this case as the site provides Essential Infrastructure and these are considered the optimal locations.

2 Introduction

Halcrow and Buro Happold have been commissioned to undertake engineering consultancy services in connection with the proposed extension of the Northern Line (NLE) for TFL. These proposals involve the construction of an underground rail route from Kennington to Battersea including two new underground stations at Nine Elms and Battersea station, and two permanent ventilation shafts at Kennington Green and Kennington Park, herein referred to as the Site.

This Flood Risk Assessment (FRA) report describes the liaison with the key stakeholders (principally the Environment Agency to identify the key policy and technical requirements for the assessment.

A considerable portion of the baseline hydraulic modelling that supported the assessment for the main Battersea Power Station (BPS) FRA, by the previous site owners, has been utilised and extended, allowing further breach analyses to be undertaken at pre-determined locations, Nine Elms breach and St. George's wharf, to assess the risks to the site from the River Thames under the 1 in 200 year and 1 in 1000 year tidal events. Climate change impacts have also been considered.

The Northern Line Extension (NLE) is the subject of a Transport Works Act Order (TWA Order) that will require the preparation of an Environmental Impact Assessment of the project. URS has undertaken a Preliminary Environmental Assessment, of which this FRA is an appendix. Flood risk is also described in Chapter 12: Surface Water Resources and Flood Risk of ES Volume I.

This FRA has been undertaken in accordance with the National Planning Policy Framework and Planning Policy Statement 25 following meetings with the Environment Agency (Charlotte Amor and Tom Sly) on 13th April 2010, Tom Sly on 13th May 2010 and a joint meeting on 29th July 2010, which has included the preparation of detailed breach analysis and the development of a surface water drainage strategy.

The assessment work has been completed in accordance with National Planning Policy Framework.

The scope of the FRA was agreed which will support the TWA Order.

The FRA has incorporated the following:

- Liaison and ongoing consultation with the Environment Agency to agree the scope and monitor progress of the FRA

- Liaison and integration of the ongoing assessment with the wider ES process and design development
- Overtopping and breach analyses of the existing river wall flood defences, including flood velocity and the rate of onset of flooding
- Assessment of flood probability and flood depth
- Inclusion of appropriate allowances for climate change for the life of the development
- Flood risk mitigation measures to ensure a safe development
- Assessment and reporting of residual flood risks
- Incorporation of the surface water management strategy proposed for each Station location

3 Planning Context

3.1 National Planning Policy

3.1.1 National Planning Policy Framework

The National Planning Policy Framework (NPPF) released in 2012 aims to make the planning system less complex and more accessible, to protect the environment and to promote sustainable growth. The NPPF sets out the Government's planning policies for England and how these are expected to be applied. It provides a framework within which local people and their accountable councils can produce their own distinctive local and neighbourhood plans, which reflect the needs and priorities of their communities.

NPPF requires due consideration of climate change and potential impacts of the development in the future. Climate change has been taken into account in this assessment for the tidal fluctuations in the Thames near the Site.

3.1.2 Planning Policy Statement 25

This FRA has also been prepared in general accordance with the requirements of *Policy Statement 25: Development and Flood Risk* (PPS25) (2010) and supporting *Practice Guidance* (2008) and takes into account the potential impacts of climate change. Although this guidance has now been withdrawn by Government, it is widely recognised by developers, local planning authorities and the specialist consultants who advise these parties, that it continues to represent good practice guidance with respect to the development of land affected by flood risk.

The aims of this policy were:

"to ensure that flood risk is taken into account at all stages in the planning process to avoid inappropriate development in areas at risk of flooding, and to direct development away from areas at highest risk"

3.2 Other Development Guidelines and Requirements

3.2.1 Thames Region Catchment Flood Management Plan (summary document, December 2009)

The Thames Region Catchment Flood Management Plan illustrates the most sustainable direction for managing fluvial flood risk within the Thames region as outlined by the Environment Agency. The main messages outlined in the Section in the plan for "*Future direction for flood risk management*" (p10) are:

1. Flood defences cannot be built to protect everything
2. Climate change will be the major cause of increased flood risk in the future
3. The flood plain is our most important asset in managing flood risk
4. Development and urban regeneration can provide a crucial opportunity to manage the risk

To mitigate for these points as part of this assessment, suitable flood resilience measures and floodplain compensation measures must be introduced as part of the plan for this proposal. In the developed floodplain with built flood defences the plan notes that:

At present it is still possible and effective to maintain these flood defences

Climate change will mean that these defences will become less effective in the future. We therefore need to make sure that:

- any redevelopment reduces the residual flood risk in the areas benefiting from these flood defences using the measures set out in NPPF
- the natural floodplain is used upstream and downstream of these areas to accommodate additional floodwater

The document also outlines that *"Future growth plans should not assume that flood defences will be built"* and that *"Sustainable strategies are approved"*. Approval of sustainable strategies (the CFMP Policy options) will illustrate the progress of appropriate flood risk management implemented at a regional level.

3.3 Strategic Flood Risk Assessment

Flood risk should also be set in local context by the Strategic Flood Risk Assessment (SFRA) for the London Boroughs of Wandsworth, Merton, Sutton and Croydon and that for the London Borough of Lambeth.

3.3.1 Level 1 SFRA for LB Wandsworth (Dec 2008)

The Level 1 SFRA mapping provides the tools by which the Boroughs can gauge the degree of risk that flooding provides in their area. Importantly, it informs the process of how to undertake the Sequential

Test and Exception Test. This is achieved by presenting information to identify the variation in flood risk across their administrative areas, allowing an area-wide comparison of future development sites with respect to flood risk considerations.

The Level 1 SFRA states that according to Thames Water sewer flooding records the majority of the Borough is susceptible to significant sewer flooding. SuDS must therefore be used where possible throughout the borough to ensure the existing flooding problems are not exacerbated. SuDS should operate under the 100 year flood event with an increase of 30% in the rainfall intensity to account for climate change. SuDS solutions should seek to reduce flood risk and pollution and provide landscape with wild life benefits.

The SFRA requires that storm water is controlled in accordance with NPPF and it is a requirement that runoff rates from brownfield sites are reduced as a minimum to the pre-developed run off rates including an allowance for climate change.

3.3.2 Level 2 SFRA for LB Wandsworth (April 2009)

The aim of the study was to provide supplementary information to the Level 1 SFRA, to inform on flood risks associated with allocation sites that may require the Exception Test as identified in the LB Wandsworth Sequential Test as part of their preparation of the Local Development Framework (LDF).

The aim of the LB Wandsworth Level 2 SFRA, was to follow guidance set out in PPS25, with the following specific objectives:

- Carry out 2-D hydrodynamic modelling of agreed breach locations along the LB Wandsworth frontage for 0.1% and 0.5% annual probability tides under current scenarios;
- Provide depth and hazard mapping for both tidal modelling outputs to illustrate the distribution of flood risk across Flood Zones to enable a sequential approach to site allocation within Flood Zones;
- Provide guidance on application of the Exception Test in the potential development areas;
- Provide guidance to developers and SFRA users on the application of the Level 2 report.

The Level 2 SFRA states that the LB Wandsworth tidal frontage along the River Thames is protected from flooding by the Thames Tidal Defences including the Thames Barrier. Whilst the flood defences protect the land behind it from actual flooding, these areas are still considered to be at risk of flooding through failure or overtopping of the defences. According to the EA, the areas protected by defences in the Wandsworth study area are defended to a 1 in 1000 year return period event, and the defences are in good condition, strengthened with concrete and sheet piling and are maintained and inspected regularly by the EA. Therefore the risk of failure of the Thames Tidal Defences is **very low**.

The Level 2 SFRA requires detailed plans to show flood depth and hazard that potential development sites may experience. Due to the large extent of defended tidal floodplain in the LB Wandsworth, many of their potential allocation sites are located within areas of residual risk. Residual risk is defined as the risk remaining after flood management or mitigation measures have been put in place.

The Level 2 SFRA gives detailed guidance on a range of issues in order to make the development as safe as is practicably possible including:-

- Access and Egress
- Finished Floor Levels
- Building Design (relating to basements etc.)
- Flood Risk Assessments and Vulnerability
- Developments behind Flood Defences
- Flood Risk Management
- Surface Water Flooding and the use of SuDS

The guidance and findings have been considered and used in the preparation of the proposed development plan and FRA.

3.3.3 Level 1 SFRA for London Borough of Lambeth (June 2008)

The SFRA has been structured in two levels, Level 1 and Level 2. The Level 1 SFRA provided an overview of the flood risk issues across the Borough to enable application of the Sequential Test. Refer to Section 3.3.4 for detail of the Level 2 SFRA recommendations.

The SFRA summarises the main source of flooding as from the tidal River Thames. However taking into account the reported good condition of the Thames Tidal Defences and protection afforded by the Thames Barrier, the tidal floodplain area is considered as being

defended. It goes on to state that "*in the recent floods of 2007 mainly attributed to surface water flooding, no major flooding incidents were recorded in the Borough.*

The SFRA recommends that a spatial planning solution to flood risk management should be sought wherever possible and it is necessary for the Borough to consider, through the Sequential Test, how to steer vulnerable development away from areas affected by flooding. This should also take into consideration other relevant strategies and studies in the area seeking to reduce flooding to those already at risk within their areas. In particular the SFRA refers to Essential Infrastructure, stating in para 7. "*'Essential infrastructure' developments should also be preferentially located in the lowest flood risk zones, however this type of development can be located in Flood Zones 3a and 3b, where necessary, through application of the Exception Test. Where these types of development are located in Flood Zone 3a or 3b responses to parts 'a' and 'b' of the Exception Test will be required before 'part c' is tackled."* The SFRA has been structured in two levels, Level 1 and Level 2,. The Level 1 SFRA provided an overview of the flood risk issues across the Borough to enable application of the Sequential Test. Refer to section 3.3.4 for the detailed Level 2 SFRA recommendations.

Hydraulic modelling at four breach locations was completed along the River Thames frontage to assess the tidal flood risks as a result of a failure in the Thames Tidal Defences. The hydraulic modelling results provided a greater level of LB Lambeth Level 1 SFRA information on speed of inundation and flood depths, and enabled the residual risk (i.e. in the event of a defence failure) to be categorised into high, medium and low hazard.

3.3.4 Level 2 SFRA for London Borough of Lambeth (August 2008)

Whilst the SFRA mainly focuses on the Waterloo and Vauxhall areas, the NLE site runs through LB Lambeth for a short length. The Level 1 and Level 2 SFRA reports should be used in conjunction with each other to provide a more detailed overview of the flood risks to the LB Lambeth, to assist in the development of policies, strategic planning and flood risk management. In particular it recommends:-

Manage flood walls and embankments:-

- Raise defence levels over time by 0.5m to a maximum of 1.0m
- Install temporary defences at times of forecast high river flow and tide levels

- Some defences may be set back to make space for water and to improve access to the river – this can provide an opportunity to improve the riverside environment and restore historic or architectural features.

The Level 2 SFRA makes reference to the fact that the Environment Agency strongly recommends that suitable surface water mitigation measures are incorporated into any development plans in order to reduce and manage surface water flood risk to, and from any proposed development. This should ideally be achieved by incorporating Sustainable Drainage Systems (SuDS) which should be described as part of any FRA. It states 'The effective disposal of surface water from development is a material planning consideration in determining proposals for the development and use of land'.

The Level 2 SFRA states that when applying the Sequential Test to determine the type of development that may be appropriate in the area, the type of flood warning procedure that exists and the time between the flood warning and the flood peak should be analysed with reference made to local Flood Warning and Emergency Procedures. It goes on to mention that if the evacuation route in times of flood is extremely secure, there are multiple routes and the length of each route is fairly short, the Local Planning Authority (LPA) may wish to be more lenient with the types of development allowable in that area.

It recommends that floodplain management and emergency response activities must have a focus on key infrastructure such as the underground network and other properties that are below sea level.

3.3.5 LB Southwark Strategic Flood Risk Assessment

The London borough of Southwark produced a Strategic Flood Risk Assessment in February 2008. The SFRA provides an assessment of flood risk from various sources across the Borough. The greatest risk of flooding within the Borough arises from fluvial and tidal effects with approximately half the land area within the EA Flood risk Zone 3a.

There are five instances of flooding from groundwater within the Borough along with on historical flood event from surface water flooding in April 2004. There are 188 occurrences of properties flooded from overloaded sewers in the last ten years. To assess the risk of future flooding from these sources, the SFRA recommends a detailed, level 2 SFRA to consider the risk of flooding in greater detail.

The SFRA sets out recommendations based on the vulnerability of the proposed development including recommendations for finished floor levels above flood levels and safe internal access for occupants in the event of a flood event.

A Sequential Test has been carried out by Southwark Council to assist steering development away from areas at a high risk of flooding. As large areas of the Borough are within high flood risk zones, guidance is also offered for passing of the PPS25 (now the National Planning Policy Framework) Exception Test.

3.4 Consultation

3.4.1 Environment Agency

Considerable key stakeholder consultation has been undertaken with the Environment Agency (EA) throughout the FRA and creation of the BPS and NLE TUFLOW models. The EA have defined and approved a number of requirements for the flood risk analysis in the area, such as the location and nature of the breach analyses required.

A Breach Assessment report was finalised in July 2010 and approved by the EA in August 2010. The results from that report have been integrated into this FRA.

Key EA correspondence is provided in Appendix B.

3.5 Available Information

3.5.1 Data Sources

Information utilised within this assessment included the following:

- LiDAR of the site (GeoStore)
- Thames Tidal Hydrographs (Environment Agency)
- Development proposals (Halcrow/StudioDare/Buro Happold)
- Breach modelling flood extents from LB Wandsworth and LB Lambeth SFRAs.

3.5.2 Sequential Test

The extension to the underground line from Kennington Station to Battersea follows the alignment, as shown in Appendix A, which, together with its safeguarding corridor either side of the line, lies within protected Flood Zone 3a. The route for the NLE is considered the optimal location and no other routes would permit this underground extension and the two associated stations to be located such that the flood risk to the proposed development could be reduced. The question as to whether this piece of infrastructure could be placed in a location at lower flood risk therefore does not arise. Because of this, it is considered that the Sequential Test is not relevant or necessary. The focus has therefore been to assess the site-specific flood risk associated with this development, and then mitigate the negative effects to an acceptable standard, commensurate with the type of development and its associated risk.

4 Existing Conditions

4.1 The Site

The NLE site is located from Kennington to Battersea, Greater London from approximate grid reference TQ 315781 and TQ TQ315781 near Kennington Station through TQ in Nine Elms to TQ 289773 in Battersea.

The site alignment is generally bounded to the north by the River Thames, and passes in a similar corridor to the South West Trains railway line along Battersea Park Rd.

The NLE is described in ES Volume I, Chapter 4: Description of the NLE. Please refer to the 'Deposited Plans and Sections Drawings' submitted as part of the TWAO application.

4.2 Site Observations

The site alignment lies on the south bank of the River Thames floodplain and is protected by tidal flood defences to a 1 in 1000 year standard. The site topography generally rises from Kennington to Battersea with ground levels rising from 3mAOD to approximately 4mAOD over the length of the extension. The rivers Wandle, Graveney and Effra flow into this floodplain though the SFRA's summarise that they do not represent a significant flood risk.

The primary flood risk to the site is likely to occur due to a breach in the river wall, allowing tidal and fluvial water flows to enter the various elements of the site from the north. Potential breaches at various locations along the river may also impact on the site. These are considered in more detail in Section 6.

4.3 Flooding History

On 6th and 7th January 1928 overtopping of flood defences at BPS occurred during a storm surge. This surge coincided with high fluvial flows and the water level in the River Thames reached a height of 5.16mAOD.

There have been no other flooding events from records from other sources.

4.4 Flooding Mechanisms

See sections below for how each of the "Forms of Flooding" identified in NPPF have been addressed.

4.4.1 Flooding from Rivers

The site lies on the banks of the River Thames which currently has defences built to a statutory level of 5.41m. Neglecting these defences, the site is at high risk of flooding from the Thames. The indicative floodplain mapping for the area in Figure 4-3 shows that Battersea and Nine Elms stations, as well as all access shafts, whilst protected from flood defences, lie predominantly in Flood Zone 3 (mid blue). However, some lengths towards Kennington are in Flood Zone 1 (shown in white) and Flood Zone 2 (green). Existing flood defences are shown in purple (adjacent to the Thames) on the indicative floodplain mapping with the hatched area showing the protected zone. Refer to the EA detailed flood plain mapping shown in Appendix B – note, that a preliminary route is shown.

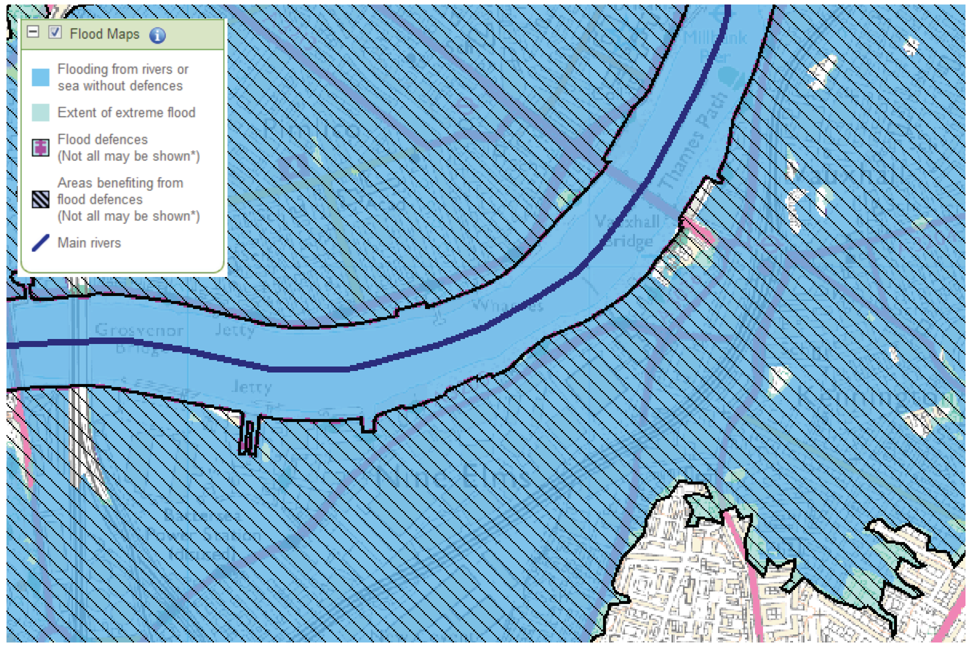


Figure 4-1 EA Indicative floodplain map

The River Thames in this location is tidal, and for this reason has been assessed with respect to extreme tidal events and not fluvial flows from upstream catchments. The high tide events represent a precautionary approach as they are the worst-case scenario for developments built near to the defences at this location.

An assessment of the various flood zones has been completed:-

NLE Section 1: Battersea Station to the Nine Elms Station

All of Section 1 is within the EA's Flood Zone 3 (0.5% (1 in 200) or greater chance of happening each year) and is, therefore, considered at a high-risk of flooding. As the proposed works falls into the "Essential Infrastructure" (refer to 3.33 for details), then development is permitted if designed and constructed to remain operational and safe for users in times of flood. The entire area is an area benefiting from flood defences.

NLE Section 2: Nine Elms Station to Kennington Green and Kennington Station (north running tunnel)

The majority of Section 2 is within the EA Flood Zone 3 with the route from chainage 2100m to approximate chainage 2250m overlying Flood Zone 2. Essential infrastructure projects are appropriate in these areas. From chainage 2250 to 2350m the route is within flood Zone 1 near the Oval station, where all developments are permitted. The route re-enters a flood zone 2 at chainage 2350m to 2450m with area near the Oval. From 2450m to Kennington Station the route is in Flood Zone 3. The entire section is an area benefiting from flood defences.

NLE Section 3: Nine Elms Station to the Kennington Park Shafts and Kennington Station (south running tunnel).

The majority of Section 3 is within the EA Flood Zone 3 with the route from chainage 1250 to 1300m and from 2100m to chainage 2250m overlying Flood Zone 2. Essential infrastructure projects are appropriate in these areas. From chainage 2250 to 2500m the route is within flood Zone 1, where all developments are permitted. The route briefly re-enters a flood zone 2 at chainage 2500m to 2550m at area to the east of The Oval station. The route then is in Flood Zone 3 with small pockets of Flood Zone 2 near Kennington Park and on to Kennington Station. The entire section is an area benefiting from flood defences.

4.4.2 Flooding from Groundwater

A data request was made to the EA regarding records of groundwater flooding in and around the BPS site. Buro Happold was informed by the EA on the 12th June 2008 that there were no existing records of groundwater flooding for this location, nor within a 500m radius of the site. No further records have been provided for the other sites at Nine Elms, Kennington Green or Kennington Park.

Nonetheless, groundwater levels must be considered during detailed design for proposed drainage systems. The surface water strategy is outlined in further detail in Section 8.

4.4.3 Tidal Flooding

Tidal flooding poses a threat to the site, as parts of the site lie below the 1 in 200 year Thames tide levels. Flood defences exist at the bank of the Thames which protect the Battersea, Nine Elms and Kennington area from tidal flooding. For this application, a requirement of the Environment Agency is that a series of breach analyses are carried out, using hydraulic modelling software to simulate the effects to the Site of a high return period event during a breach in the river wall. Seven breach locations have been identified by the EA, located at the river wall from Battersea to further locations downstream on the Thames – refer to section 7 for a location plan.

Information has been obtained from the Environment Agency detailing the tidal hydrographs for the 1 in 200 year flood, the 1 in 1000 year flood and the 1 in 1000 year flood with climate change. It should be noted that for the 1000 year with climate change event, the tidal peak is not as high as the 1000 year in the present day. This is due to a forecasted increase in the frequency of operation when the Thames tidal barrier is closed, which will result in fewer extreme tides upstream of the tidal barrier. Following advice from the Environment Agency, the 1000 year event with climate change has not been modelled, as there is no benefit to be gained from modelling this scenario.

The modelling undertaken for the tidal breach analysis is detailed in Section 6 of this report.

4.5 Tidal Hydrographs

Tidal Hydrographs have been obtained from the EA for the 200 year, 1000 year and 1000 year plus climate change tidal events. The peak level for each of the tides is shown in Table 4.1 below. The EA letter and set of hydrographs are presented in Appendix B.

Table 4-1 Peak Tidal Levels

Return Period	Peak Water Level (m
200 year	5.031
1000 year	5.065
1000 year plus climate change	5.021

The EA have confirmed that the 1 in 1000 year plus climate change event is expected to be lower than the 1000 year event due to a predicted increase in the use of the Thames Barrier and consequently fewer tides allowed through London from the estuary.

5 Proposed Development

5.1 Summary

The NLE works comprise the construction of an underground railway to form an extension of the Northern line (Charing Cross branch) from Kennington to Battersea. It will diverge from the existing railway south of Kennington station from a section of track used by terminating trains (known as the Kennington loop) and will comprise the following:

- twin bored running tunnels about 3,190 metres long northbound and approximately 3,275 metres long southbound including overrun/stabling tunnels west of the terminus station at Battersea, a crossover east of the terminus station and junctions serving each of the tunnels to link with the existing railway at the Kennington loop
- a terminus station at Battersea between Battersea Park Road and Battersea Power Station and an intermediate station at Nine Elms west of Wandsworth Road and north of Pascal Street, both providing step free access from trains to street level
- intervention shafts with head-houses at Kennington Green and Kennington Park to provide emergency access, tunnel ventilation and smoke control
- ancillary and mitigation works within the limits of deviation including providing power supply and additional cross passages at platform level at Kennington station.

5.2 The Proposals

The proposed route of the NLE, including the location of Nine Elms and Battersea Stations, lies mainly within the tidal flood plain of the Thames (Flood Zone 3, defined as the 1 in 200 year flood extent) – refer to Appendix B. The flood plain is defended by the Thames Tidal Defences, generally to a standard that will accommodate a 1 in 1000 year tidal event, including an allowance for sea level rise due to climate change to the year 2030. The Thames Tidal Defences include the Thames Barrier, which is operated by the EA. All of these defences are maintained to a high standard and the risk of failure is considered to be very low.

The NLE is described in ES Volume I, Chapter 4: Description of the NLE. Please refer to the 'Deposited Plans and Sections Drawings' submitted as part of the TWA Order application.

The proposed development is an extension to the Northern line from Kennington to Battersea on the south bank of the River Thames. 3km of twin bored tunnels are proposed with a terminus station at Battersea and an intermediate station at Nine Elms. Construction of two temporary shafts at Radcot Street and Harmsworth Street may also be required, and two permanent ventilation and intervention shafts at Kennington Park and Kennington Green, are required as part of the works. These will have to be set at an appropriate level. The shafts are expected to be approx. 30m deep and up to 13.5m diameter. Battersea Station is set to be 20m BGL with Nine Elms at 25mBGL. A traction sub-station within the headhouse at Kennington Park is also to be provided.

The planning application for BPS (LB Wandsworth 2009/3575) included significant retail and residential development and the proposals were submitted and determined as part of the planning application in 2009.

The design for Nine Elms Station has been informed by this FRA and in particular, the entrance levels to the station and public realm which have been set in relation to an appropriate flood level.

The proposals for the arrangements at the Site, including the temporary shafts at Radcot Street and Harmsworth Street, Kennington Park traction substation, Kennington Green shaft, Nine Elms Station and Battersea Station are shown in detail in the 'Deposited Plans and Sections Drawings' submitted as part of the TWAO application.

6 Breach Analysis Modelling

The key component of the assessment is the consideration of the implications of a failure of the flood defences during an extreme tidal event. This is referred to as **breach analysis**, and involves the hydraulic modelling of the depths, speed and duration of flooding that would result from a breach. The results of the modelling (both the baseline and with the development in place) identifies potential impacts, and from this informs any mitigation that may be necessary.

It is essential that the NLE is designed and constructed to remain safe and operational for users in times of flood, including a breach scenario as described above, however unlikely this event may appear.

The breach analysis has guided the evaluation of flood risk at each of the critical sites for the development proposals (Battersea Station, Nine Elms Station, traction substation and the shaft locations), has informed the suitable mitigation measures, and has advised on suitable finished floor levels that should be adopted in the designs.

6.1 Breach Locations

The EA has requested that seven breach locations are modelled as part of the FRA for the NLE and these seven locations are shown in Figure 6-1 and detailed in Table 6-1.Each of the breach locations have been reviewed with the available information, outlined in general terms, and the work undertaken as part of the assessment will be detailed.

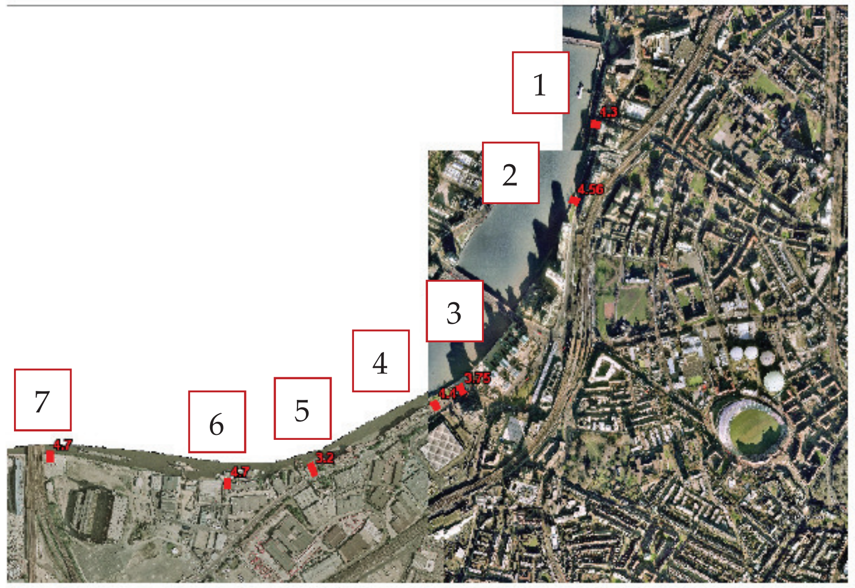


Figure 6-1: Breach Locations provided by the Environment Agency.

No.	Location	Level	Width
1	Tamesis Dock Albert Embankment	4.3	20m
2	Draw Dock Albert Embankment	4.56	20m
3	St George Wharf (u/s)	3.75	20m
4	Riverside Court (d/s)	4.4	20m
5	Nine Elms	3.2	20m
6	Cemex	4.7	20m
7	Battersea Power Station	4.7	20m

Table 6-1Breach locations and characteristics

Both station sites lie within the defended floodplain of the Thames, and the Nine Elms Station lies within the potential flood extent resulting from a breach in the tidal defences. The vulnerability of a site to a breach depends to a great extent on the location chosen for the breach, and these are considered by the Environment Agency Thames Barrier team to be locations that were considered to give rise to the worst anticipated flood risk.

6.1.1 (1) Tamesis Dock - Fire Brigade HQ, Albert Embankment

This breach location is positioned 230m to the north of the English Maid breach location (Section 6.1.2). This breach location is not referred to in the Lambeth Level 2 SFRA. Using the available LiDAR topographic survey information, it is apparent that the flood extent will spread further to the north than the English Maid breach but reference to LiDAR topographical survey shows that it is not expected to extend significantly further to the south than the English Maid breach. Therefore, Kennington Station and the access shafts, which lie approximately 1.2km and 1km to the south-east, are likely to be protected from flooding by topography in a similar manner to that outlined in Section 6.1.2.

6.1.2 (2) Draw Dock - English Maid, Albert Embankment

This breach location is referred to in the Lambeth Level 2 SFRA. The approximate flood extent for this breach location is shown in Figure 6-2 below.

Figure 6-2: English Maid breach extent from Lambeth L2 SFRA.

The depth map in Figure 6-2 shows that the flood depths reduce with distance from the breach location. Along Newburn Street, located on the eastern side of the map, the depth is approximately 0.5m or less, while ground levels along the road are approximately 2.9mAOD, giving an approximate flood level of 3.4mAOD. Moving east, this flood level will decrease, or in the most conservative case, will remain at the same level.

Cross sections were produced showing the ground levels between the flood extent from the SFRA and Kennington station. These cross sections were plotted using LiDAR (purchased from GeoStore). Kennington Station is the nearest part of the NLE to this flood extent. The cross sections have been taken along the lines shown in Figure 6-3 below.

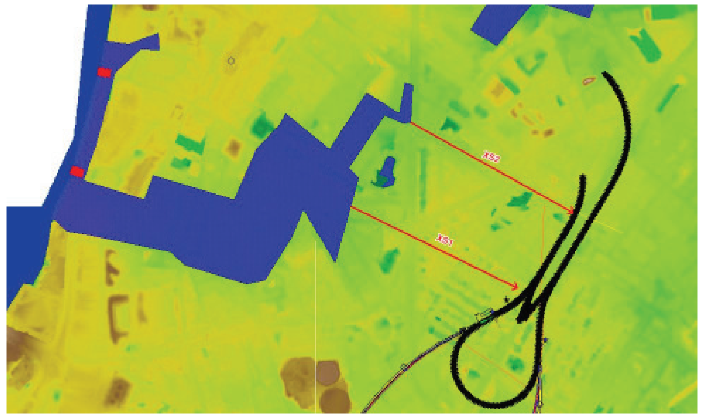


Figure 6-3: Location of LiDAR cross sections XS1 and XS2 in relation to the 1000yr flood extent.

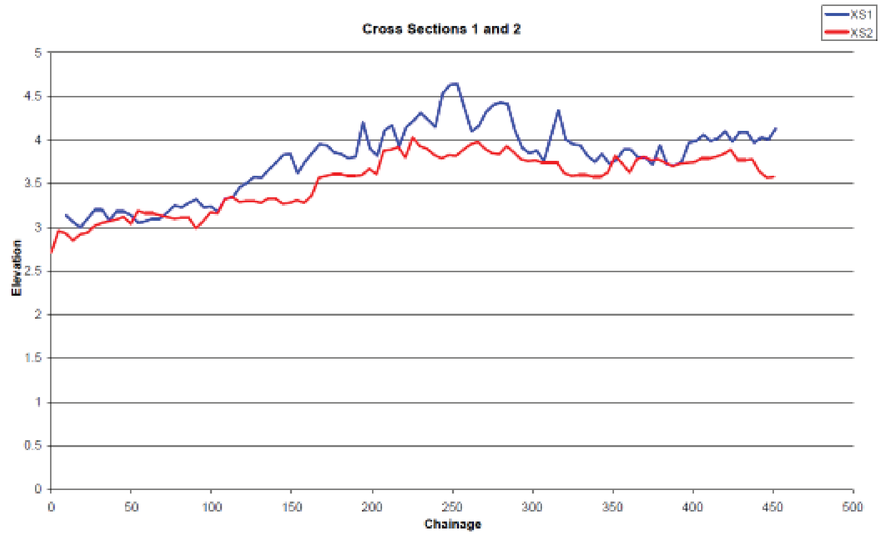


Figure 6-4: Ground profiles along XS1 and XS2.

The ground levels along these cross sections can be read from Figure 6-4 showing a rise above 3.4mAOD, with high points of approximately 4.5m at chainage 250m and 4mAOD at chainage 225m for XS1 and XS2 respectively. The ground profiles indicate that the flood extent from this breach would not reach Kennington station unless the flood levels were to rise significantly.

The level of 3.4mAOD for the flood level has been taken from the Level 2 SFRA. It is accepted that this level might not be correct and therefore this assessment has considered the possibility that flood levels across the breach extent shown in the SFRA are 100mm greater than assumed previously, giving a level of 3.5mAOD. The pink line in Figure 6-5 shows the 3.5mAOD contour. If the flood level were to reach 3.5mAOD, the flood extent would not reach Kennington Station or either of the shaft locations. While it is accepted that the flood extents derived for the Level 2 SFRA flood extents are not as accurate as expected from a full breach model; principally due to its reported assumption regarding impermeable buildings, it is expected that the accuracy is sufficient for the 3.5mAOD contour to be a conservative estimate of the flood extent.

It is therefore considered that the Kennington Station, Kennington Park Shaft and traction substation, Kennington Green Shaft and the two temporary shaft locations **are not** at risk from flooding from the English Maid breach location.

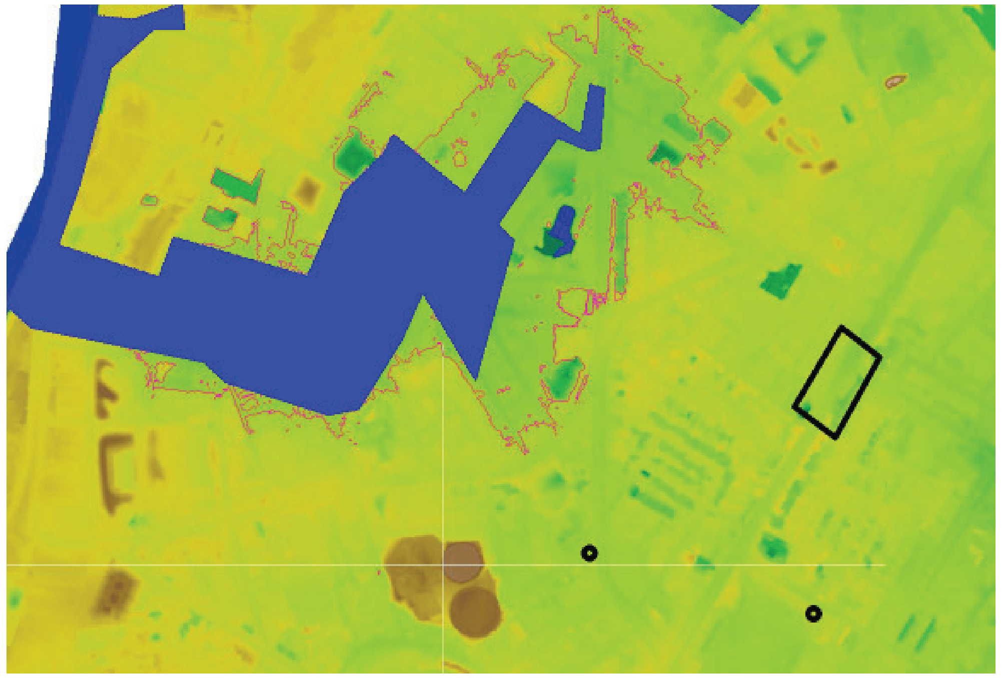


Figure 6-5: English Maid flood extent from Lvl2 SFRA with 3.5mAOD contour in red.

6.1.3 (3) St. George's Wharf and (4) Riverside Court - New Covent Garden Market.

These two breach locations pose the potential for water to flow onto Wandsworth Road and move towards the entrance to Nine Elms station, near Pascal Street. These breach locations are 75m apart and due to this short distance it is expected that the flood extents arising from each breach location will be almost exactly the same. It is necessary to determine the risk to the station and shaft locations when modelling a breach location in this approximate position. Since both the breach locations will cause water to flow into the same flood cell in the topographical depression around Nine Elms, it was considered that one of these breach locations is sufficient to determine the flood risk to the station and shaft locations. Since the St. George's Wharf breach location has the lower sill level and hence a greater capacity for inundating the flood cell, it was proposed that this breach location was modelled.

6.1.4 (5) Nine Elms

The Nine Elms breach was modelled as part of the Planning Application for the redevelopment of the BPS site in 2009. Flood water spreads south from the breach location and underneath the Waterloo rail line via the Thessaly Road underpass towards the New Covent Garden Market. Flood depths are in the order of 0.5m to the north of the rail line and slightly less to the south. The flood extent from the

Nine Elms breach is close to the entrance to both the Nine Elms station and the Battersea station and hence needed to be remodelled in detail to determine the flood risk to these stations. This modelling is shown in Section 7.3.

6.1.5 (6) Cemex

The Cemex breach location is located within the model extent for the Nine Elms breach model approved by the Environment Agency for the BPS redevelopment in June 2009.

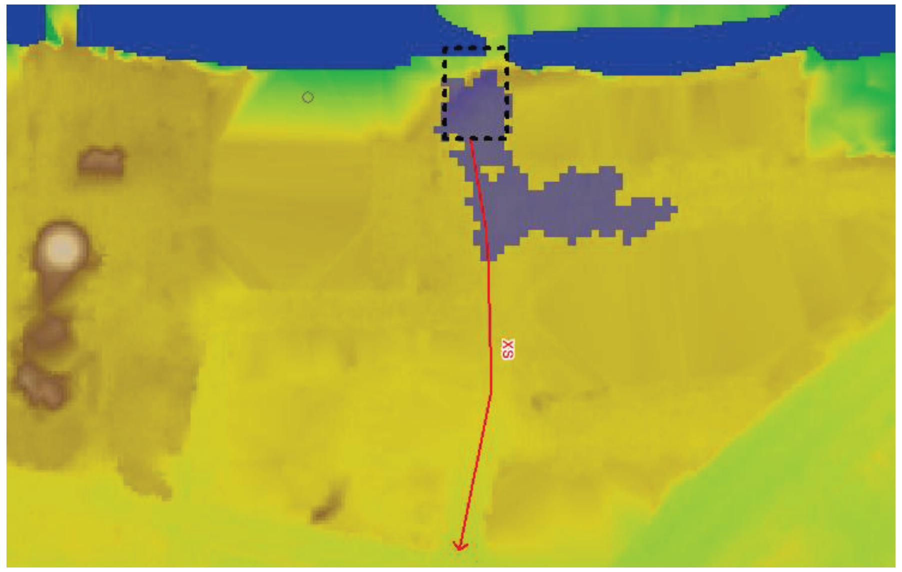


Figure 6-6: Location of Cemex breach, resultant 1000yr flood extent and cross section location.

The flood extent is shown in Figure 6-6 along with the cross section of the land levels provided in Figure 6-7.

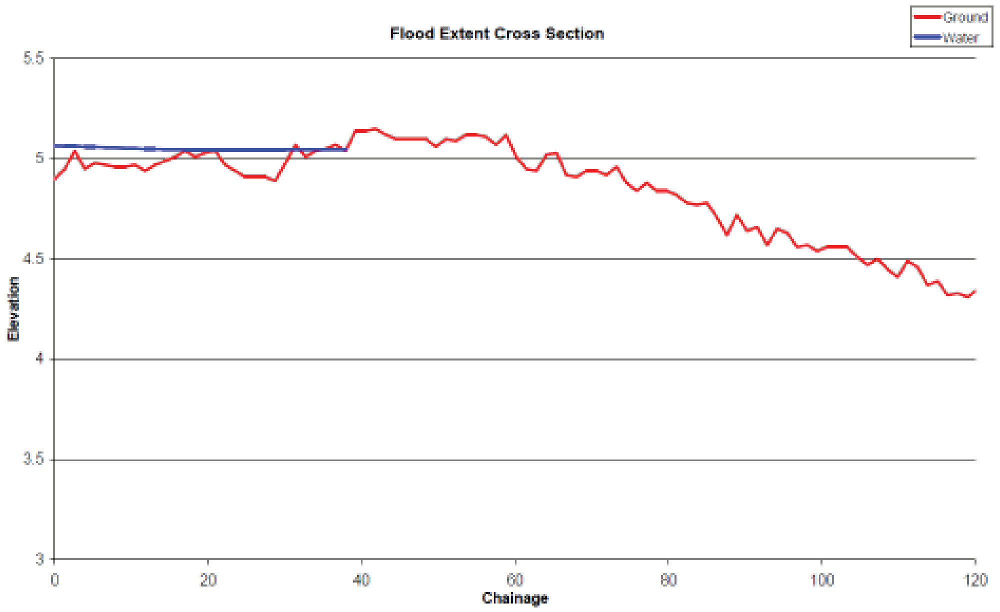


Figure 6-7: Cross section showing extent of water from Cemex breach in the 1000yr event.

Figure 6-7 shows that the water from the breach cannot continue down Kirtling Street as the crest of the road is above the maximum flood level. The freeboard between the crest of the road and the maximum flood level is of the order of 100mm. The LiDAR used in the Battersea model is the latest currently available and it is therefore highly likely that full re-modelling would replicate the results shown in this assessment.

6.1.6 (7) Battersea Power Station

The Power Station breach was included as part of the planning application for the redevelopment of the BPS. As part of the proposals for this development, the ground levels along the Power Station frontage behind the river wall were raised and widened to eliminate the likelihood of a breach. This result is a significant benefit to the area, with a train depot and some commercial properties removed from the flood extent in events up to the 1 in 1000 year event.

6.2 Breach locations considered

It was considered that sufficient information was available in five of the proposed breach locations (1, **2, 4, 6** and **7**) to ensure that further modelling was not required.

The Fire Brigade HQ site lies to the north of the **(2) Draw Dock, English Maid breach** location and to the south of **(1) Tamesis breach**. A review of the existing LiDAR indicates that while the flood extent

from these breach locations would extend further to the north and east, the flood extent would be no further to the south and south-east than the **(2) Draw Dock, English Maid breach**. Kennington Station, the traction substation and the shaft locations were not considered to be at risk from flooding from this breach location.

The **(2) Draw Dock, English Maid** breach location was modelled as part of the Lambeth Level 2 SFRA and the extent of flooding shown does not pose a risk to Kennington Station, the traction substation or the access shafts. Concerns were raised by the Environment Agency regarding the accuracy of this modelling exercise particularly in relation to building permeability, so an additional 100mm was added to a conservative estimate of the modelled flood level to provide an indication of the likely flood extent from this breach location. The station and shaft locations were not at risk from this conservative estimate of flooding.

The flood risk to the station and access shaft locations from the **(4) Riverside Court** (**New Covent Garden) breach** location will be replicated from the (3) St. George's Wharf breach modelling. Both of these breach locations drain into the same topographical depression and therefore the flood extents from the two breach locations are expected to be very similar. However, the lower sill level at the St. George's Wharf breach location implies that the risk to the station could potentially be greater from this breach.

The following breach locations do not pose a significant risk to the station, traction substation or access shaft locations due to topographical barriers between the breach location and the station, traction substation and access shaft locations.

The **(7) Power Station breach** is prevented by the widening and raising of ground levels behind the breach proposed as part of the Power Station planning application, while the **(6) Cemex breach** is prevented from impacting the site by ground levels along Kirtling Street. The **(6) Cemex breach** has been quickly modelled using the Environment Agency approved flood model submitted as part of the BPS planning application.

6.3 Breach locations to be considered further

It was considered that two breach locations, at **(4) St. George's Wharf** and **(5) Nine Elms**, need to be modelled in detail as the potential risk that they pose to the station and shaft locations could be significant.

The **(4) St George's Wharf** breach and **(5) Nine Elms breach** locations drain into similar flood cells, concentrating on the depressions in topography around Nine Elms. Due to the location of the stations at Nine Elms and Battersea it is important that these two breach locations are modelled so that appropriate mitigation measures can be considered to manage flood risk if required.

The NLE breach analyses undertaken to date for the two locations identified above are detailed below. A two-dimensional (2D) representation of the floodplain around the Battersea to Nine Elms site was created and run using TUFLOW software. This section identifies the methodology and assumptions used in defining the floodplain and breach parameters and how the proposed development was overlain.

6.3.1 Requirements

A two-dimensional (2D) representation of the floodplain for the flood cell that comprises Nine Elms Station and the BPS site was created and run using TUFLOW software. This section identifies the methodology and assumptions used in defining the floodplain and breach parameters and how the proposed development was overlain.

6.3.2 Breach Locations and Conditions

Breach locations and conditions to be modelled were specified by the EA, and are as follows:

- Two different breach locations, identified at grid-reference points TQ28774 77696 close to the Power Station and TQ29567 77646 at Nine Elms were tested separately;
- Breaches should be modelled over a 20m width parallel to the River Thames; and
- The breach in flood defences should be assumed to be open for 18 hours.

Figure 6-8 identifies the relevant breach locations.

Assessment of the available topography (LiDAR) in the area indicates that the two locations identified above are the only locations that would present a potential breach threat to the development proposals as there are no other direct flow paths below the levels stated.

Land elevations at breach locations (i.e. behind the flood defences) were set at the levels requested by the Environment Agency. The centre of the breach was set at the grid reference specified by the EA, with the

breach extending 10m either side of this point, ensuring that the lowest (worst case) ground levels were encompassed.

6.4 Mapping Data

Various mapping data was utilised in the development of the two-dimensional model for this assessment including:

- LiDAR ground survey (Surveyed December 2005, Received July 2008) – used for the definition of the floodplain of the model(www.geostore.com). LiDAR is generally quoted as having an accuracy of within 250mm, and is often much better.
- Aerial photography (Photographed July 2003, Received July 2008) – used in defining land use roughness coefficients (www.geostore.com).

6.5 Software

The software package TUFLOW was used for the construction and analysis of this hydraulic model. TUFLOW is a two-dimensional flood and tide simulation software package. 2D free-surface shallow water equations are used to simulate the hydrodynamics of floods. TUFLOW version 2009-07-AE was utilised solely for the 2D assessment of the floodplain for this analysis, and run in double precision mode.

6.6 Model Extents

The 2D model extents were selected based on analysis of the potential flood flow paths from the River Thames through the sites and beyond.

The south-western extent was set approximately 1.8km south-west of the BPS (Wandsworth Rd) where the land elevation begins to increase sharply. The model extends approximately 2km to the east and 0.35km to the west of the BPS building. This incorporates the Nine Elms area, in which one of the breach locations occurs. The outline of the modelled area is shown Figure 6-8 below. The breach locations identified in the figure are henceforth referred to as follows:

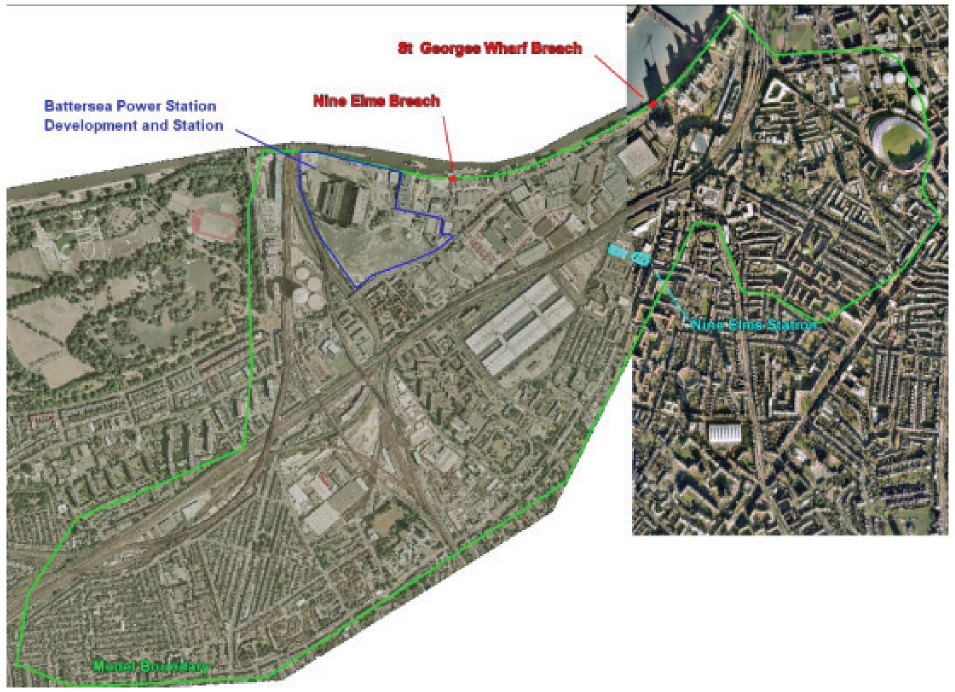


Figure 6-8 Extent of modelled 2D area

6.7 Model Geometric Data

6.7.1 Grid resolution

The grid defining the site characteristics was set to be at 5m x 5m resolution for the breach analysis modelling. This grid size was chosen based on assessment of flow paths through the model (e.g. road widths) and the resolution required to ensure that these were represented accurately. The 5m grid is considered to be appropriate to the level of detail required, and has provided a suitably accurate model representation of the region. A sensitivity analysis was carried out on the grid spacing and 5m was chosen as optimal.

6.7.2 Ground level elevations

Elevations were defined based upon LiDAR data and assigned to points on the grid at 2.5m spacings.

The BPS proposals were included in the baseline for the NLE model. The BPS proposals include raising the ground elevations within the site area, construction of buildings along Nine Elms Lane and changes to the levels of Kirtling Street at the junction with Nine Elms Lane.

6.7.3 Bank Levels

In accordance with EA approved standard practice for breach modelling, river bank levels at non-breach locations have been

assumed to provide a barrier between the site and river, thereby preventing additional incursion of floodwater onto the site. This also prevents "loss" of floodwaters from the floodplain back into the river except at breach locations.

6.8 Land Use

Land uses were defined throughout the floodplain, each with its own roughness coefficient. Defining land uses provides a more accurate representation of the flooding processes as the roughness (Mannings n) impacts the speed at which water can pass through an area.

Land uses were determined using aerial photography of the area**.** Table 6-2 below identifies the roughness coefficients assumed for different terrain types in this hydraulic model.

Buildings were assigned a roughness of 1, which therefore represents them as surfaces which do not stop the flow of water but offer a great deal of resistance. This represents best practice modelling methodology as it aims to simulate the slow intrusion of floodwaters into buildings. This is a considerable enhancement over modelling techniques adopted for the SFRA where buildings are assumed to be fully permeable.

Table 6-2 Material Roughness Coefficients

Terrain	Roughness (Manning's n)
Buildings	1.000
Light Woodland/Shrub	0.075
Railway	0.040
Road	0.016
Pasture	0.035
Inland Water	0.030
General Surface	0.025

6.8.1 Boundary Conditions

Boundary conditions for the breach analyses were set up as a relationship between river level and time through a tide event (Head-

Time boundaries) at the two breach locations. Tidal hydrographs were used to replicate water levels occurring in the 1 in 200 and 1 in 1000 year events. In any one simulation, only one boundary condition was used.

In accordance with the EA requirements, simulations assumed an 18 hour opening within the flood defences. The 18 hour selection was taken from the 80-hour EA tidal hydrographs so that two tidal peaks were incorporated in the model, including the highest peak. Peak tide levels modelled are presented in Table 6-3. The tidal hydrographs used in the model are presented in Figure 6-9 below.

Table 6-3 Modelled Peak Tide Levels

Event	Peak 1	Peak 2
1 in 200 Year	4.292m AOD	5.031m AOD
1 in 1000 Year	4.321m AOD	5.065m AOD

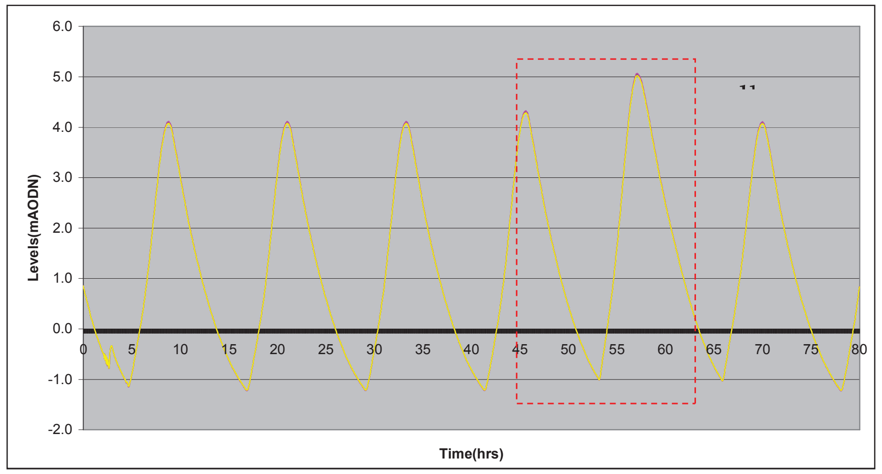


Figure 6-9: Modelled Tidal Levels (from EA data, July 2008)

6.8.2 Model Timing

The model was run using a 2-second time step over a period of 25 hours. While the breach was only modelled as being open for 18 hours (as identified above) the simulation was run for 25 hours to show the potential spread of water within the floodplain post breach closure.

6.9 Model Alterations

6.9.1 Ground levels at Nine Elms

LiDAR, while providing a good representation of overall ground levels, is subject to "noise" on the small scale due to surface features and filtration of the surface data. In the TUFLOW modelling undertaken, elevations are read in every 2.5m. The "coarseness" of the LiDAR means that in some locations elevations can vary considerably between adjacent points. Generally this is fine for the purposes of breach modelling, however in areas of high velocity and flow these differences can cause instabilities in the model.

At the Nine Elms breach location, one such instability was generated. In order to stabilise the model, a 170m x 120m section of ground levels were smoothed at the breach entrance. LiDAR levels were averaged over a 5 x 5m grid, with elevations in this area re-read into the model. This improved the computational process without compromising the accuracy of the results. Figure 6-10 presents an example section through the altered area showing the original LiDAR values against the "smoothed" values.

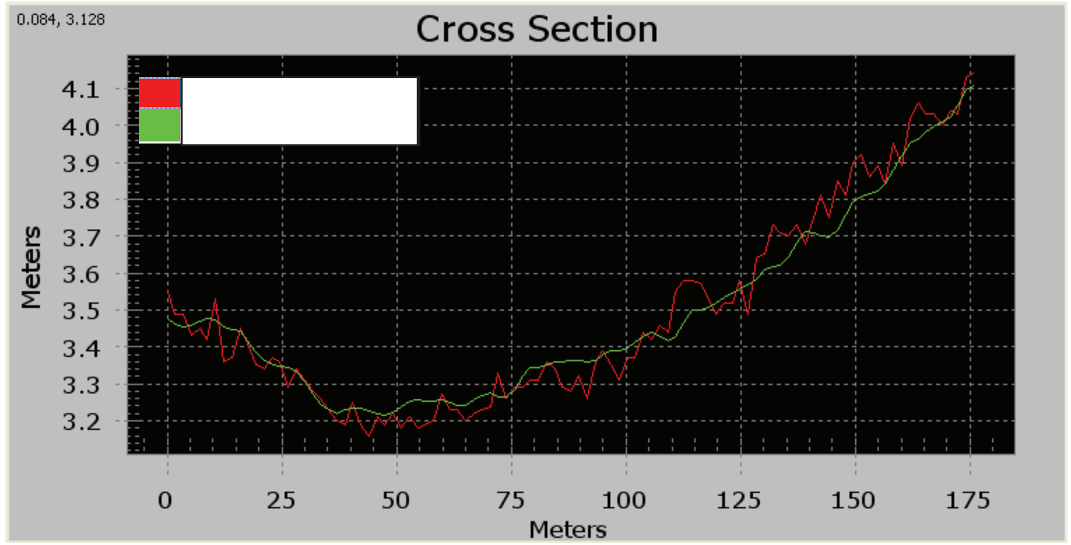


Figure 6-10: Example of LiDAR alteration at Nine Elms

6.9.2 Elevation Correction at Railway

The surveyed LiDAR data does not take into account the underpasses beneath the railway embankment at two locations:-

- The entrance to the New Covent Garden Market (TQ 29434 77200) and
- Along Thessaly Road (TQ 29289 77081).
- To overcome this, elevations were altered to realistically represent these paths/roads beneath the railway line. Land elevations were

lowered by interpolating between the 'upstream' and 'downstream' levels of the path/roadways so that these underpasses were included in the hydraulic model.

6.10 Scenarios

As previously discussed, the **(3) St George** and **(5) Nine Elms** breach locations were tested under the 1000 year tides, assessed for both baseline and proposed conditions (four separate scenarios).

6.11 Sensitivity Analysis

Sensitivity analyses were undertaken on the Grid cell size and Manning's roughness values assumed for the various land uses. Scenarios investigated the impacts of altering grid size and the corresponding time-step, roughness and simulation length.

Grid size – Changes in grid size from 5m to 2.5m 8m, and 15m were assessed. In models with larger grid sizes, the large resolution resulted in some of the important flow routes becoming cut off and sufficient detail was not observed. Models with a smaller grid size showed greater detail but the length of the model runs were unacceptable. The 5m grid size was considered the optimal compromise between resolution and run speed for the modelling that has been performed.

Roughness – Sensitivity testing of changes to the roughness coefficient by ±10% for the catchment has shown that reduction in roughness values increase the rate of propagation of flood waters through the catchment, while increased roughness values reduce the rate of propagation. Roughness sensitivity runs have shown changes in the depth of flooding of approximately 5%.

For the purposes of modelling, the assumptions used in the "base" case for roughness values are considered to be appropriate. The changes resulting from a change in roughness are relatively minor across the majority of the flood envelope and represent little actual alteration in risk.

Simulation Length - In addition to alterations in roughness, a 40 hour length of simulation (compared with 25 hour) was trialled for the 1 in 1000 year events to assess whether additional areas were at risk of flooding. In reality however, the length of time it takes for floodwaters to reach these outer areas would allow temporary defence measures (e.g. sand bags) to be put in place before properties were threatened.

The 25 hour simulation time is therefore considered to be appropriate for the purposes of this assessment.

In summary, the sensitivity analyses showed that the modelling was sufficiently robust for the purposes of the site specific FRA.

7 Development Flood Risk

7.1 General

Flood extent maps showing the depth of flooding across the study area for both the **(3) St George's Wharf** and **(5) Nine Elms** breach locations are presented in Appendix D. The following sections discuss the results of the detailed modelling undertaken.

7.2 St George's Wharf

7.2.1 Baseline

The first tidal peak modelled causes limited local flooding in the area immediately behind the breach location. The second peak causes water to spill out of the St George's Wharf area onto Nine Elms Lane. Water moves down Wandsworth Lane towards the Sainsbury's supermarket arriving at the supermarket 40 minutes after the start of the second period of overtopping.

Water spreads in a south-west direction between Wandsworth Road and the New Covent Garden Market reaching Heathbrook Park after approximately 3 hours. By this stage, water is no longer overtopping at the breach location, and the increases in flood extent are due to the propagation of flood water through the flood cell.

The breach route passes to the south of the entrance of the arch/ underpass beneath the main railway line. Whilst detailed modelling has not been undertaken with this link element in place it is considered that flow would pass from south to north in the existing breach run. Levels upstream and downstream in the vicinity of the arch would be slightly elevated.

Water continues to head in a south-west direction terminating in the vicinity of Queenstown Road.

7.2.2 Proposed Case

This is the principal flow route and critical event that produces the highest flood levels in the vicinity of the Nine Elms Station site.

Nine Elms station has been removed from the flood extent by raising the finished floor levels for the two entrances. The central section of the station building has been lowered to minimise the impact of the station on the flood flow.

There are small increases in flood extent at the south-western end of the flood extent as water is displaced by the two station entrances. Water levels upstream of the station are increased by approximately 75mm, and decreased by approximately 40mm immediately downstream of the station in the 1 in 1000 year event. Increases in peak flood level further downstream of the station in the 1 in 1000 year event are increased by approximately 6mm as a result of the displaced water.

The breach route passes to the south of the entrance of the arch/ underpass beneath the main railway line. Whilst detailed modelling has not been undertaken with this detail in place it is considered that flow would pass from south to north in the proposed breach runs. Levels upstream and downstream in the vicinity of the arch would be slightly elevated. We consider that the difference between the runs would be insignificant. It is unlikely mitigation would be necessary.

The proposed station at Battersea has no effect on flooding as it is located outside the flood extent.

7.3 Nine Elms Breach

7.3.1 Baseline

Under the Nine Elms breach, the first tidal peak is seen to flood the section of Nine Elms between the River Thames and the elevated railway, with some water passing underneath the railway to the east of Thessaly Road underpass and opposite Kirtling Street.

Flood water spreads south underneath the railway, using Thessaly Road underpass and Wandsworth Road flooding the area between Wandsworth Road and the railway. Water heads south-west passing underneath the railway into Heathbrook Park. Water spreads in a westerly direction, passing over Queenstown Road and affecting John Burns Primary School and the residential area to the west of the school.

To the north of the main railway corridor water continues along Nine Elms Lane, and onto the railway line adjacent to Stewart's Road. Water flows both north, back towards the River Thames at Chelsea Bridge, and south to join up with the flood route from Heathbrook Park.

7.3.2 Proposed Case

For the Nine Elms breach, the proposed station development at Nine Elms has minor increases in associated flood risk at the south-western end of the flood extent as a result of the displaced water from the addition of the station building. There are small increases in peak flood level of the order of 5mm in these locations.

The proposed station at Battersea has no effect on flooding as it is located outside the flood extent.

7.4 Flood Risk Considerations

7.4.1 St Georges Wharf Breach

Detailed baseline (existing conditions) breach modelling results were obtained. The initial results from this baseline breach model show that the 1 in 1000 year flood levels are 3.4mAOD at the Nine Elms Station. Appendix D1 shows the flood extents from this breach model run.

With the addition of the required freeboard, the finished floor level for the Nine Elms Station has been set at 4.0mAOD, as the previously untested St George's Wharf breach location was found to be the critical breach location for the Nine Elms Station.

The early results indicated that the proposed development marginally increased the flood extents to the south west of the station site leading to the flooding of an industrial building not previously affected. Flood levels were also affected, with an increase in flood level by approximately 100mm to the north of the station site. Mitigation for these marginal adverse impacts has been incorporated into the design. This allows for the above ground elements between the ticket hall and the rear access being reduced in level from 3.7m AOD to the current site ground level of approximately 2.7m AOD. The results of this model run are shown in Appendix D2, from which it can be seen that the increased flood extent (red shading) on Appendix D1 has been eliminated.

This mitigation suggests that the potential effect on the flood plain was managed by amending the design of the station building.

7.4.2 Nine Elms Breach

The Nine Elms breach model results are shown in Appendix D3. For comparison, the original BPS planning application breach run (shown in purple) have been illustrated together with the additional flood extents from the NLE breach run (shown in red). A considerable increase in flood extent is apparent and results directly from the change in the size of the breach the EA requested to be used for the Nine Elms NLE breach analysis.

7.4.3 Conclusions

The results indicate that the estimated flood level at Nine Elms Station site is 3.43m AOD, so similar to the flood level of 3.4m AOD from the St George's Wharf breach. This result has been reviewed and checked, and indicates a more onerous flooding scenario than the Nine Elms breach simulation undertaken for the BPS FRA.

It should also be noted that the latest Nine Elms breach results indicate a flood level of about 4.4 AOD at the Battersea Station site. This compares to the previous modelled flood level of 4.19m AOD referred to above, and so represents an increase in estimated flood level of about 200mm. However, because the minimum finished floor level at the station has been set at 6.7m AOD, this increase in estimated flood level would not have any additional implications for the station development.

The finished floor level at Nine Elms has been selected and designed to be 4.0m AOD. The Stage C design has shown that the station layout can accommodate this requirement. This has been agreed by the architect team where an extension to the external ramps to the western end of the station building has been incorporated.

7.4.4 Further Liaison with the Environment Agency

A further meeting with the EA was held on 28th July 2010 where the EA agreed to the desktop studies and the detailed breach analysis with the supporting design mitigations that had been incorporated. The EA requested that the design for the temporary shaft entries were amended and this is shown in Section 7.8.

7.5 Hazard Zone Ratings

Assessment of the potential hazard to people under the breach scenarios has been undertaken in accordance with the publication *Flood Risks to People* (Defra/EA, 2006). This takes into account flood depths, velocities and possible debris to define varying degrees of risk to people, as follows:

Hazard Rating = depth x (velocity+0.5) + Debris Factor

Debris Factor = 0 for depths less than 0.25m

= 1 for depths greater than 0.25m and/or velocities greater than 2m/s.

Hazard Rating maps have been produced and are available on request

7.6 Flood Levels

From the results of the hydraulic breach modelling, the flood levels at the Nine Elms and Battersea Stations are shown in Table 6.4:-

Table 6-4: Flood levels at St George Wharf and Nine Elms.

Event	Nine Elms flood level	Battersea flood level
1 in 1000 Year – St George Wharf Breach	3.40m AOD	4.4m AOD
1 in 1000 Year- Nine Elms Breach	3.43m AOD	-

These flood levels for Nine Elms and Battersea set a lower limit of 4.4m AOD to the ground floor levels in the proposed station. The flood level in other parts of the flood plain is only marginally affected by the development. The largest increases in flood level are immediately upstream of the station site as a result of water trying to pass by the station.

7.7 Protection of the Proposed Development

The Environment Agency currently requires flood defence levels along the BPS development river wall to be maintained to at least 5.41m AOD. Furthermore, these levels should either be raised by 600mm at the development stage (i.e. to 6.01m AOD) or allowance made for this increase to occur in future. The responsibility for incorporating these works remains with BPSDC.

This requirement has not been altered as the future operation of the Thames Barrier investigated as part of the TE2100 project, with the effects of anticipated sea level rise, is undecided and the 6.01m AOD level takes this uncertainty into account.

Neither of the station sites are susceptible to flooding during a breach in the river wall at **(5) Nine Elms** or **(3) St George's Wharf** as they are located above the peak flood level. The floor level at the entrance to the Nine Elms station has been set at 4mAOD to ensure there is no ingress of water during a 1 in 1000 year flood event including freeboard.

7.8 Shaft Locations

At the meeting with the EA on 29th July 2010 it was agreed that further information relating the shafts, both temporary construction shafts and vent shafts, in the vicinity of Kennington Oval, and in particular the

proposals for retaining a protective height of shaft ring above the surrounding ground levels should be provided. This information was presented on 4th August 2010.

Temporary Construction Shafts

The temporary shafts will be constructed using precast concrete segments. They are at Radcot Street and Harmsworth Street. Road levels are indicated as 3.7m and 4.0m , respectively, with the detail incorporating a shaft ring 1m in height that is to be left proud of the ground during construction. This will give a threshold up to greater than 4mAOD, providing edge protection to the excavation, and sealed such that they also provide a watertight seal to 1m above current ground level in order to protect the works from a possible breach of the Thames flood defences and for mitigation of surface water flows.

The shaft detail showing the upstand for the two temporary shaft locations are shown in the 'Deposited Plans and Sections Drawings' submitted as part of the TWA Order application.

As a result, it is considered that there is an insignificant risk of flooding to this site.

Kennington Green Vent Shaft and Headhouse

The permanent vent shaft and headhouse at Kennington Green is to be constructed adjacent to Montford Place. The road level adjacent to the structure is 3.40mAOD, with the kerb level shown approx. 100mm above this at approx. 3.5mAOD, with a level threshold.

From Section 6.1.2 it was shown that the risk of breach flows reaching Kennington Station was considered extremely unlikely. Montford Place is located further to the south and it is therefore considered that the vent shaft location is not at risk from flooding from the English Maid breach.

7.9 Kennington Park Ventilation Shaft and Traction Substation

A traction substation located in the north east corner of Kennington Park will be constructed using secant piling techniques to form the basement areas. The ground floor elements have been designed to have a threshold level of 3.725mAOD.

From Section 6.1.2 it was shown that the risk of breach flows reaching Kennington Station was considered extremely unlikely. Kennington Park is located further to the south. It is therefore considered that the

Traction Substation location is not at risk from flooding from the English Maid breach.

The traction substation detail showing the proposals are shown in the 'Deposited Plans and Sections Drawings' submitted as part of the TWA Order application.

7.10 Access and Egress

The station building thresholds at both Battersea and Nine Elms have been set above the 1 in 1000 year flood level plus 600mm freeboard. In the unlikely event of a breach a Flood Management Plan should be adopted, reviewed and tested to ensure the safe evacuation of people from the station.

It is recommended that the safest method of evacuation should be to close the station entrances adjacent to the breach and provide signing and route direction for people to evacuate by the underground. Once the station has been fully closed further underground trains should not stop at the station until safe to do so.

Surface water flows should be mitigated with the appropriate threshold design.

7.11 Sequential and Exception Tests

In flood risk vulnerability terms, the proposed underground extension would be classified as "Essential Infrastructure". It is considered that the Sequential Test, outlined in Section 3.5.2, is not relevant in this case. By definition, the extension to the Northern line from Kennington Station to Battersea has to follow the Reference Alignment which, together with its alignment corridor, lies within protected Flood Zone 3a. There are no other routes that would permit this underground extension and the two associated stations to be located such that the flood risk to the proposed development could be reduced.

8 Surface Water Drainage Strategy

8.1 Battersea Station

The proposed drainage strategy for the NLE Battersea Stationhas been developed in consultation with the Environment Agency and coordinated with the BPS surface water drainage strategy. The EA has given their approval for works on the BPS site – See Appendix B.

Reference should be made to the document "Battersea Power Station Drainage Strategy" included with the BPS planning application (2009). A summary of the conclusions have been included below:-

- A 94% improvement to the Thames Water combined sewers will be provided in terms of storm water discharge. This will be achieved by keeping 6% of the storm water catchment area currently draining to the combined Thames Water sewers draining to the sewer and re-routing the rest of the storm water catchment to drain to the River Thames.
- The proposed storm water drainage strategy for the main Power Station site is to discharge 97% of the site area to the River Thames. This provides a substantial improvement on the current scenario where approximately 84% of the site drains to the Thames Water public sewer.
- The main Power Station site's storm water drainage network to the River Thames will be a combination of a gravity, syphonic and pumped system. 75% of the site will be drained via a gravity/syphonic system to the river with the remainder 25% pumped. A number of new outfalls will need to be installed in the river wall, and will be subject to approval of the EA and the Port of London Authority. Existing outfalls will be reused wherever possible.
- SuDS will be incorporated into the strategy via brown and green roofs.
- Pollution control measures will be installed to prevent pollution to the sewer and river.
- There will be separate foul and storm water networks within the site boundaries.
- A series of foul water connections will be made to the Thames Water combined sewers surrounding the site.

- Existing drainage connections to the Thames Water sewer will be reused, if possible. Otherwise new connections will be made. This will be established at detailed design stage along with the exact locations of the required connections.
- The EA has been consulted throughout the development of the surface water drainage strategy and has worked together with the design team to develop the drainage strategy. They have given their approval for the strategy for the BPS site.

Notwithstanding the above the Battersea Station was not included as part of the above BPS drainage strategy as details were not developed at the time of the planning application.

Where feasible, the discharge from the proposed station will discharge directly to the River Thames with no attenuation proposed because of direct discharge to source (River Thames) in accordance with the London Plan and EA guidelines.

With regard to dealing with surface water flows in the vicinity of the station entrance there is an average 125mm kerb face on the Battersea Park Road north channel. The natural overland flow follows the Battersea Park Road north channel west to east away from the proposed Battersea Park Station. Threshold drainage should be considered if required.

8.2 Nine Elms Station

The surface water strategy is based on the guidelines from NPPF, PPS 25, the London Plan, Sewers for Adoption, and Approved Document H Building Regulations. A 30% allowance has been made for climate change.

It is proposed to discharge the proposed surface water and foul water separately by gravity before discharging into the existing Thames Water sewers. The proposed development is approximately 0.629Ha in area and run-off rates will be determined by reducing the overall pre-developed surface water flow by 50% in line with the London Plan Essential Standard. The attenuation will be placed within the building, in the location indicated on the plan attached – in Appendix F.

Surface Water Drainage Design Parameters

Storm event	100 years
Climate change	30%

No. discharge points	2
Catchment area	Station roof + hardscape (0.435 ha + 0.194 ha) = 0.629 ha
Rainfall intensity	67.12 mm/hr
Q_{TOTAL} =	117.37 L/s
$Q_{ALLOWABLE}$ =	58.69 L/s

Free discharge to the existing public sewer within Pascal Street (east) is calculated at 19.97 L/s. The attenuated discharge point is limited to 38.72 L/s with attenuation volume of 219 m^3 and discharge is to the existing sewer within Pascal Street (east).

Refer to Appendix F .

8.2.1 Design Guidelines

The surface water drainage system has been designed in accordance with the following guidelines

- NPPF and PPS 25 – Development and Flood Risk
- Sewers for Adoption 6th Edition
- BS EN 752
- Approved Document H building regulations

9 Conclusions

The FRA has been completed in accordance with NPPF and PPS25 with liaison throughout with the Environment Agency. The FRA has considered flooding from all likely sources. The FRA has included breach analysis of the seven breach locations as required by the EA and has assessed the likely risk of flooding to the stations and shaft locations from each breach considered. The breach analysis with supporting calculations was submitted and approved by the EA in July 2010.

The EA have indicated that they would like to see all development on site protected from possible breaches in the Thames defences demonstrating a precautionary approach. This has been achieved through raising ground levels and setting finished floor levels above the 1 in 1000 year flood level where appropriate and reducing the risk.

This FRA has concluded the following:-

Five breach locations have been discounted by the preliminary assessment as having no risk to the NLE project. Two breach locations required more detailed assessment, including the (3) St George's Wharf breach and the (5) Nine Elms breach locations that drain into similar flood cells, concentrating on the depressions in topography around Nine Elms. Due to the location of the stations at Nine Elms and Battersea it was important that these two breach locations were modelled in detail so that appropriate mitigation measures could be incorporated to reduce flood risk if required.

The results from the detailed breach analysis has informed the FRA which has detailed the flood risk management strategy proposed and ensured that the detailed design has incorporated any mitigation that is required. Each of the sites for the NLE has been assessed in relation to the hazard that any breach in the Thames Tidal Defences presents.

The main flood risk to the site is the River Thames, which is tidally influenced at the Site. The site is defended against flooding from extreme tidal events at Battersea, Nine Elms and Kennington, but importantly the EA classifies areas into one of three Flood Zones based on risk of flooding from the river or sea, **not** taking into account any flood defences. The NLE site is identified to be within Flood Zones 2 and 3, as defined in NPPF.

The breach modelling has shown that the St George's Wharf breach location is the most onerous giving a 1 in 1000 year flood level of

3.4mAOD at Nine Elms, and 4.4mAOD at Battersea Station. Nine Elms station has been removed from the flood extent by raising the finished floor levels for the two entrances whilst ensuring the central section of the station building has been lowered to minimise the impact of the station on the flood flow in the 1 in 1000 year event.

The proposed station at Battersea has no effect on flooding as it is located outside the flood extent for any of the breach locations. The 1 in 1000 year breach flood level was found to be 4.4m AOD.

With regard to the effects of climate change, the Environment Agency has indicated that tidal levels at the site will decrease over time due to the anticipated revised operation of the Thames Barrier recommended by the TE2100 project. This assessment therefore takes into account the present day values, which represent a worst case scenario, ensuring the most up-to-date information on estimated flood levels has been used.

The model created is considered by the Environment Agency to be appropriate for the assessment of flood risk to the site for the assessment of the proposed case.

The design of the NLE has taken into account the results of the breach analyses. Key responses to flood risk include:

At Battersea Station:-

- At Battersea Station finished floor levels of buildings have been set well above the 1 in 1000 year breach flood level of 5.0mAOD at 6.7mAOD.

At Nine Elms:-

- At Nine Elms station finished floor levels of buildings will be set above the 1 in 1000 year breach flood level of 3.40mAOD at 4.0mAOD.

Construction and Vent Shafts

- The temporary construction shafts for the NLE have been designed to incorporate an upstand to accommodate the 1 in 1000 year flood level in the event of a breach in the Thames tidal defences and for mitigation of surface water flows.
- The permanent vent shaft and head house at Kennington Green, for the NLE, has been designed with a threshold level of greater than 3.4mAOD and is considered to be at a negligible risk from

flooding. Surface water flows should be mitigated with the appropriate threshold design.

Traction substation

- The permanent traction substation for the NLE and headhouse at Kennington Park has been designed to incorporate a threshold of 3.725mAOD to accommodate the 1 in 1000 year flood level in the unlikely event of a breach in the Thames tidal defences.

The Sequential Test is considered inappropriate to be applied in this case as the site provides **Essential Infrastructure** and the NLE routing is considered the optimal location.

10 References

1. Defra (2006). Flood Risks to People, Phase 2 Guidance Document. Department for the Environment, Food and Rural Affairs and the Environment Agency, Flood and Coastal Defence R&D Programme FD2321/TR2, March 2006.
2. Communities and Local Government (2010). National Planning Policy Framework, The Stationery Office, March 2012.
3. Communities and Local Government (2010). Planning Policy Statement 25: Development and Flood Risk, The Stationery Office, March 2010.
4. Communities and Local Government (2011). Planning Policy Statement 25: Development and Flood Risk Practice Guide, The Stationery Office, December 2006.
5. London Boroughs of Wandsworth, Merton, Sutton and Croydon (2008). Level 1 Strategic Flood Risk Assessment.
6. London Boroughs of Wandsworth, Merton, Sutton and Croydon (April 2009). Level 2 Strategic Flood Risk Assessment.
7. London Borough of Lambeth L2 Strategic Flood Risk Assessment (SFRA) (August 2008)
8. Defra/Environment Agency (2006): Flood Risks to People Phase 2, FD2321/TR2
9. Defra/Environment Agency (2007): Improving the Flood Performance of New Buildings, Flood Resilient construction.
10. Mayor of London, (2009): The London Plan (Draft Replacement)
11. Greater London Authority, (2010): The London Plan Supplementary Planning Guidance
12. Environment Agency (2009): Thames Region Catchment Flood Management Plan
13. Battersea Power Station Planning Application (2009)
14. Battersea Power Station Flood Risk Assessment (FRA) (June 2009) Buro Happold
15. LiDAR topographic survey information – Geostore, (June 2010)

Appendix A

Appendix A NLE Route

Appendix A NLE Route

Please refer to the 'Deposited Plans and Sections Drawings' submitted as part of the TWA Order application.

Appendix B

Appendix B EA Correspondence

Appendix B EA Correspondence

Product 4 (Detailed Flood Risk) for Proposed Northern Line Extension

Our ref: SE19160

Product 4 is designed for developers where Flood Risk Standing Advice FRA (Flood Risk Assessment) Guidance Note 3

i) "all applications in Flood Zone 3, other than non-domestic extensions less than 250 sq meters; and all domestic extensions", and
ii) "all applications with a site area greater than 1 ha" in Flood Zone 2.

Product 4 includes the following information:

Ordnance Survey 1:25k colour raster base mapping;
Flood Zone 2 and Flood Zone 3;
Relevant model node locations and unique identifiers (for cross referencing to the water levels, depths and flows table);
Model(s) extents;
FRA site boundary (where a suitable GIS layer is supplied);
Flood defence locations (where available/relevant) and unique identifiers; (supplied separately)
Flood Map areas benefiting from defences (where available/relevant);
Flood Map flood storage areas (where available/relevant);
Historic flood events outlines (where available/relevant, not the Historic Flood Map) and unique identifiers;
Statutory (Sealed) Main River (where available within map extents);

A table showing:
- i) model node X/Y coordinate locations, unique identifiers, levels, flows and JFLOW depths;
- ii) Flood defence locations unique identifiers and attributes; (supplied separately)
- iii) Historic flood events outlines unique identifiers and attributes; and
- iv) local flood history data (where available/relevant).

Please note:

If you will be carrying out computer modelling as part of your Flood Risk Assessment, please read the enclosed guidance which sets out our requirements and best practice for computer river modelling.

This information is based on that currently available as of the date of this letter. You may feel it is appropriate to contact our office at regular intervals, to check whether any amendments/ improvements have been made. Should you re-contact us after a period of time, please quote the above reference in order to help us deal with your query.

This information is provided subject to the enclosed notice which you should read.
This letter is not a Flood Risk Assessment. The information supplied can be used to form part of your Flood Risk Assessment. Further advice and guidance

http://www.environment-agency.gov.uk/research/planning/82584.aspx

If you would like advice from us regarding your development proposals you can complete our pre application enquiry form which can be found at

http://www.environment-agency.gov.uk/research/planning/33580.aspx

Modelled in-channel levels SE19160

Modelled water levels in the Thames for locations close to your site are shown in the tables below. In modelling the levels, three main factors were considered; the astronomical tide, the surge tide and the flow coming from the non-tidal Thames. The location, or node, closest to your site is 3.05.

Modelled River Levels (mAODN)
Location node 2.29
Grid ref: TQ 28577 77781

Year	Annual Probability of Occurrence						
	10%	5%	2%	1%	0.5%	0.2%	0.1%
2005	4.91	4.95	4.99	5.01	5.03	5.05	5.07
2055	4.96	4.97	4.98	4.99	5.00	5.01	5.02
2107	4.98	4.99	4.99	5.00	5.00	5.01	5.02

Modelled River Levels (mAODN)
Location node 2.30
Grid ref: TQ 29599 77749

Year	Annual Probability of Occurrence						
	10%	5%	2%	1%	0.5%	0.2%	0.10%
2005	4.89	4.93	4.97	4.99	5.01	5.03	5.04
2055	4.94	4.95	4.96	4.97	4.98	4.99	5.00
2107	4.97	4.97	4.98	4.98	4.99	5.00	5.01

Modelled River Levels (mAODN)
Location node 2.31
Grid ref: TQ 30331 78387

Year	Annual Probability of Occurrence						
	10%	5%	2%	1%	0.5%	0.2%	0.1%
2005	4.87	4.91	4.95	4.97	4.99	5.01	5.03
2055	4.93	4.94	4.95	4.96	4.96	4.97	4.98
2107	4.95	4.96	4.96	4.97	4.98	4.99	5.00

Model notes

SE19160

Model: **Tidal Thames Extreme Water Levels 2008**

Notes:

Our water levels are created from a 2-D joint-probability computer hydraulic model. As this is a joint-probability model the confluence of different factors such as astronomical tides, tide surge and river flows have been taken into account. In summary, the calculation of extreme water levels involves two main stages:
1) Estimating a matrix of water levels at various locations (or model nodes) along the estuary 2) Calculating the statistical frequency (return period) with which a particular water level might be expected to occur at each of the model nodes.

This study modelled water levels to various annual probabilities (10%, 5%, 2%, 1%, 0.5%, 0.2% and 0.1%) Each of these probabilities have been modelled for present day (2005) and future years (2055 and 2107) taking into account DEFRA's climate change allowances as set out in the Planning Policy Statement 25 (PPS25)

Climate change allowances:

Some of the levels are lower for the more extreme probabilities when including climate change because the hydraulic model used to produce these levels takes into account the Thames Barrier closure rule (circumstances/conditions of closure) and assumes that it remains unchanged up to 2107. Increased sea levels and fresh water flows mean that the Thames Barrier closure rule will be met more often. This means that a smaller number of tides will be allowed to flow up into central London each year. The highest tides experienced upstream of the Thames Barrier occur when the circumstances are within a fine margin of meeting the closure rule, and the decision is taken not to close (a near closure event). As there will be fewer tides per year upstream of the Barrier, and the ratio of near closure levels to regular tidal levels within this smaller number of tides remains constant, the number of near closure events will decrease, and therefore so do the modelled levels.

Thames Barrier, Eastmoor Street, Charlton, London, SE7 8LX
Customer services line: 08708 506 506
Email: enquiries@environment-agency.gov.uk
www.environment-agency.gov.uk

Historic flood data

SE19160

Our records show that the area of your site has not been affected by tidal flooding.
Information on floods that have affected areas near your site is provided in the table below, and is shown on the attached map

Historic Flood Events Unique ID	Flood Event Code	Flood Event Name	Start Date	End Date	Source of Flooding	Cause of Flooding
EA0619280300029	EA061928a	TTD_FEO_1928	06/01/1928	07/01/1928	Tidal River Thames	Overtopping of defences

Extra historic flood information:

An approximate level in the Thames at the time of the 1928 flood was 5.17 m AODN.

Please note the Environment Agency maps show flooding to land not individual properties. Floodplain extents are an indication of the geographical extent of a historic flood. They do not provide information regarding levels of individual properties, nor do they imply that a property has flooded internally.

Thames Barrier, Eastmoor Street, Charlton, London, SE7 8LX
Customer services line: 08708 506 506
Email: enquiries@environment-agency.gov.uk
www.environment-agency.gov.uk

Flood Defences

SE19160

General description:

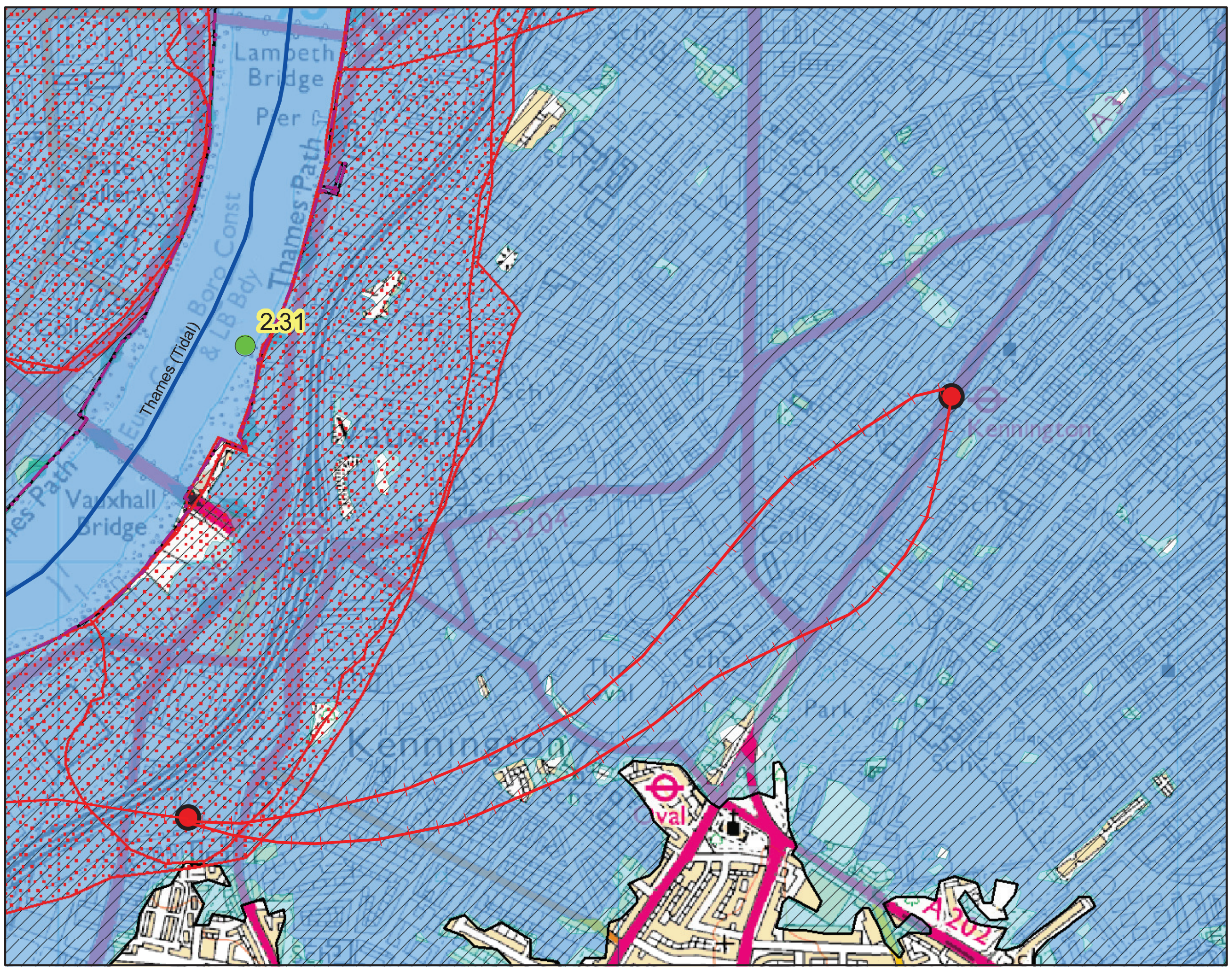
The defences along the tidal Thames in this area are all raised, man-made and privately owned. We inspect them twice a year to ensure that they remain fit for purpose. They must be maintained by their owners to the flood defence level in the area (5.41 mAODN). The overall condition grade for defences in the area is 2 (good), on a scale of 1 (very good) to 5 (very poor). The exception is the defences located at St George's Wharf, where the condition grade is 3 (Fair) Some repair works are taking place currently to improve its condition grade to 2.

Standard of protection provided by the tidal defences

The river Thames defences along this section of the river provide a standard of protection of 1 in 1000. This means that the defences protect against a tidal flooding event that has a 0.1% annual probability of occurring. This remains true up to the year 2070. After 2070 the standard of protection will decrease over time. However the Thames Estuary 2100 project that has studied options to manage flood risk in the Thames estuary up to the year 2100. Public consultation of this study has finished, but you can access all the information here:
http://www.environment-agency.gov.uk/research/library/consultations/106100.aspx

Thames Barrier, Eastmoor Street, Charlton, London, SE7 8LX
Customer services line: 08708 506 506
Email: enquiries@environment-agency.gov.uk

Detailed FRA/FCA [Northern Line Proposed Extension] - Created 22nd April 2010 [Ref: SE19160]



Environment Agency

0 125 250
Metres

Legend

- Proposed Station Location
- Model Nodes
- Proposed underground route
- Flood Map - Defences
- Main Rivers
- 1928 Flood Outline
- Areas Benefiting from Flood Defences
- Flood Map - Flood Zone 3
- Flood Map - Flood Zone 2

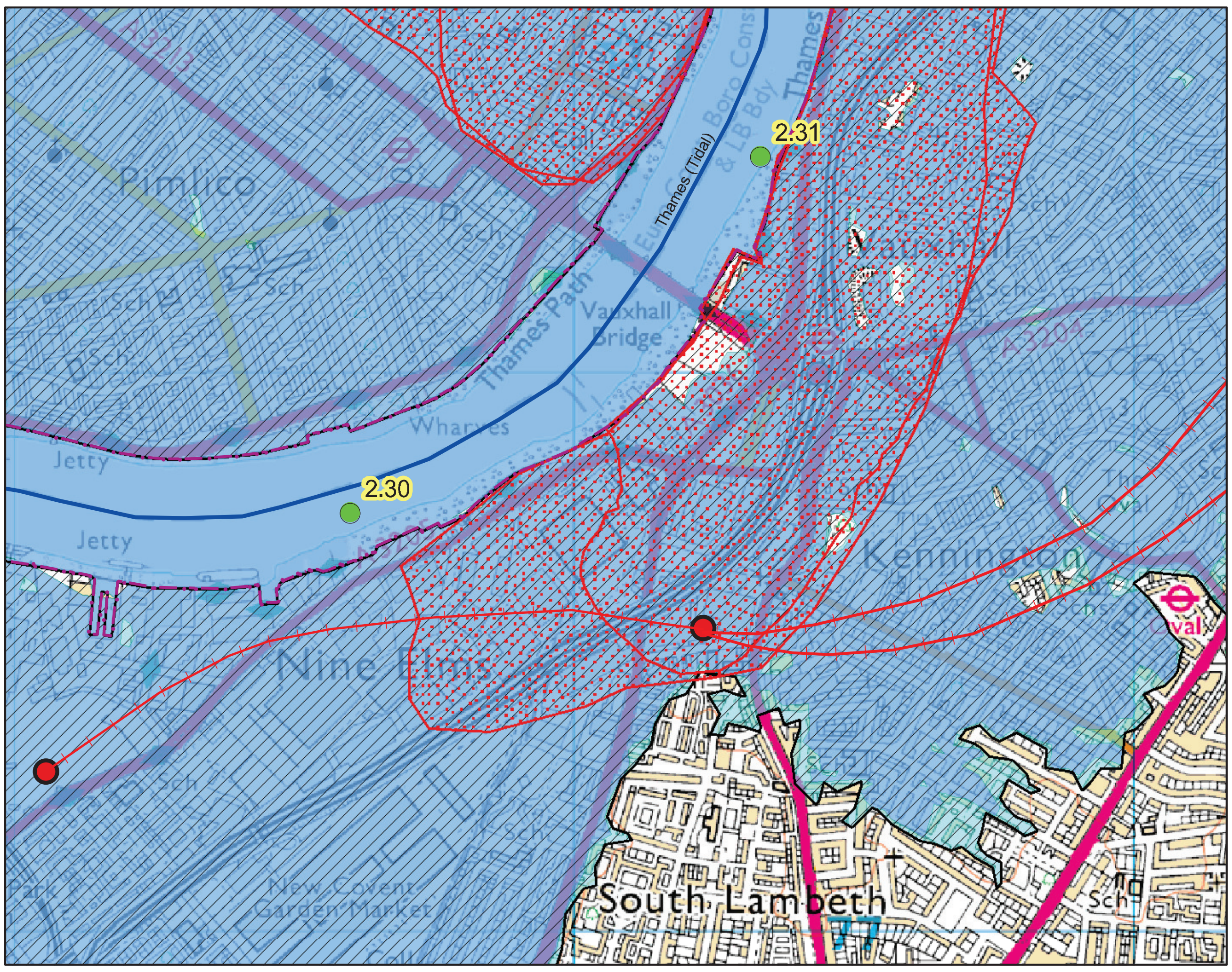
Flood Map Areas (assuming no defences)

Flood Zone 3 shows the area that could be affected by flooding:
– from the sea with a 0.5% or greater chance of occurring each year
– or from a river with a 1% or greater chance of occurring each year.

Flood Zone 2 shows the extent of an extreme flood from rivers or the sea with up to a 0.1% chance of occurring each year.

Contact Us: National Customer Contact Centre, PO Box 544, Rotherham, S60 1BY. Tel: 08708 506 506 (Mon-Fri 8-6). Email: enquiries@environment-agency.gov.uk

Detailed FRA/FCA [Northern Line Proposed Extension] - Created 22nd April 2010 [Ref: SE19160]



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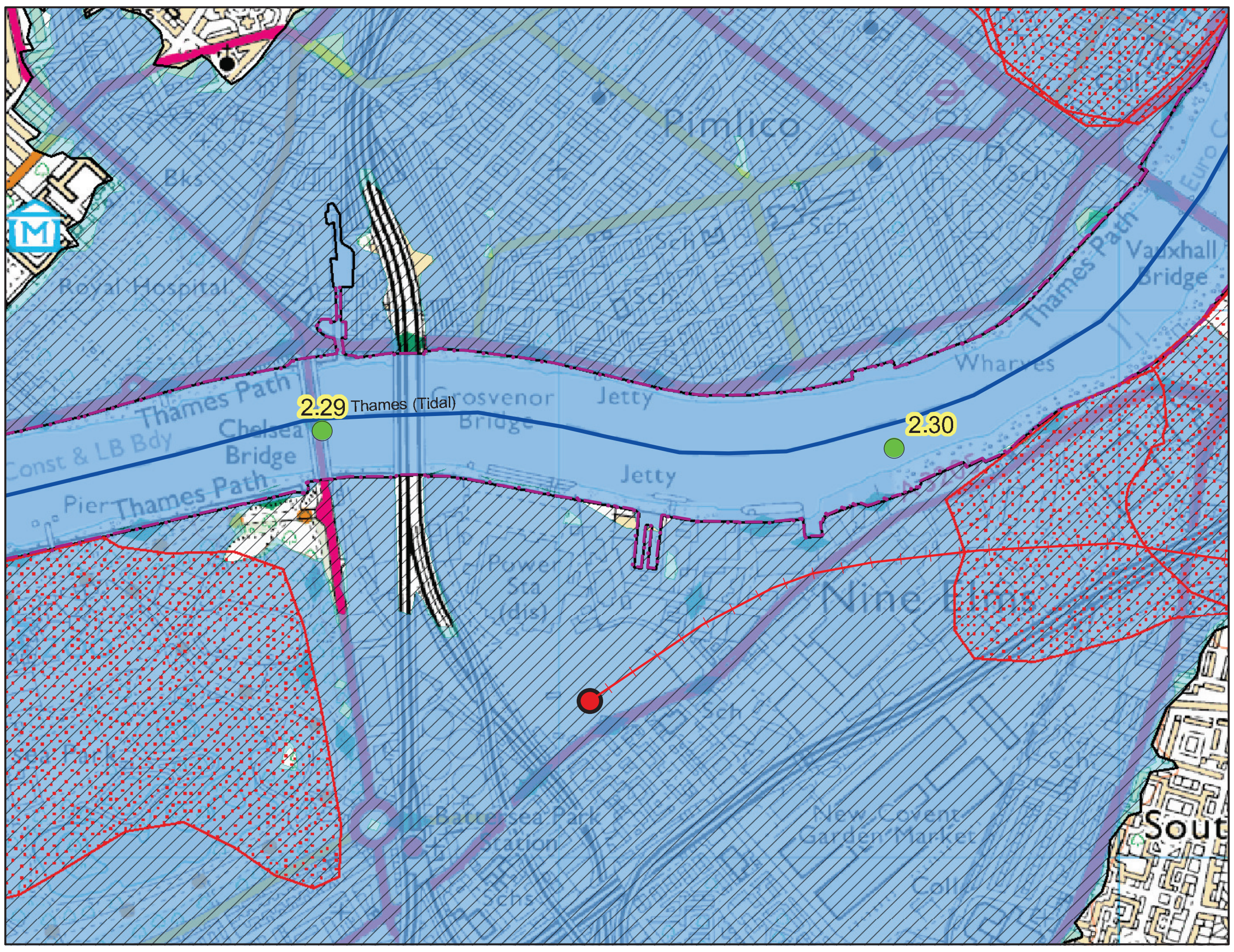

Environment Agency

0 125 250
Metres

Legend

- Proposed Station Location
- Model Nodes
- Proposed underground route
- Flood Map - Defences
- Main Rivers
- 1928 Flood Outline
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- or from a river with a 1% or greater chance of occurring each year.

Flood Zone 2 shows the extent of an extreme flood from rivers or the sea with up to a 0.1% chance of occurring each year.

Contact Us: National Customer Contact Centre, PO Box 544, Rotherham, S60 1BY. Tel: 08708 506 506 (Mon-Fri 8-6). Email: enquiries@environment-agency.gov.uk

Andrew Dannatt

From: Duncan Ker-Reid
Sent: 30 July 2010 14:34
To: anthony.hammond@environment-agency.gov.uk
Cc: Andrew Dannatt; 026932 Northern Line Extension Reference Design TWAO; Alan Travers
Subject: RE: Model Reviews

Anthony,

Following our telephone conversation this afternoon, please find below the link to the FTP site. I have placed the FRA and the EA correspondence letter regarding the breach levels in a folder under today's date and titled "Flood Risk Assessment". The PO and MB *.csv files are located in a folder under today's date and titled "Additional Outputs".

Northern Line Extension FTP site

Or

Address: ftp://ftp.burohappold.com
Logon: NorthernLineExt
P/W: N1neElms

Please let me know if you have problems accessing the FTP site.

Regards,

Duncan

Duncan Ker-Reid
Engineer
Buro Happold Ltd
Tel: +44 1225 320600 (ext. 2247)
www.burohappold.com

From: Andrew Dannatt
Sent: 30 July 2010 11:45
To: Alan Travers; Duncan Ker-Reid
Cc: 026932 Northern Line Extension Reference Design TWAO
Subject: FW: Model Reviews

All

Please see Anthony's review of the Cemex model and the other reviews he mentioned yesterday.

Regards

Andrew Dannatt Associate
Buro Happold Environment + Infrastructure
Mobile: +44 (0)7918 156026 (Mobex 8890)

From: Hammond, Anthony [mailto:anthony.hammond@environment-agency.gov.uk]
Sent: 30 July 2010 11:09
To: Andrew Dannatt
Cc: Sly, Tom
Subject: Model Reviews

Andrew,

Good to meet you all at the meeting yesterday.
As discussed I have attached the model reviews. There are two model reviews by Halcrow; which are reviews of the Lambeth and Wandsworth SFRA MIKE 21 models. Also attached is my review of your Battersea modelling.

Have a good holiday

Kind Regards

Anthony Hammond
Flood Risk Mapping & Data Management
Thames Barrier
Environment Agency
☎Tel 020 8305 4106
anthony.hammond@environment-agency.gov.uk

Memorandum

to Tom Sly (Environment Agency)

from Duncan Ker-Reid, Alan Travers (Buro Happold)

date 4th August 2010

job no 026932 Northern Line Extension

copied to Northern Line Extension Project Team

subject **Shaft construction**

Buro Happold

We refer to our meeting on 29th July 2010 regarding the Northern Line Extension from Kennington to Battersea and the flood risk aspects in particular. We agreed to write to you with further information relating the temporary construction shafts in the vicinity of the Kennington Oval, and in particular the proposals for retaining a protective height of shaft ring above the surrounding ground levels.

It is envisaged that the five permanent and temporary shafts associated with the Northern Line Extension in the vicinity of the Kennington Oval will be constructed using precast concrete segments. In order to provide edge protection to the excavation, additional temporary rings will be constructed at ground level to provide this protection. These will be sealed such that they also provide a watertight seal to 1m above current ground level in order to protect the works from a possible breach of the Thames flood defences.

As a result, it is not believed that breach modelling of the English Maid site will be required to assess the impact of flooding on the access and ventilation shafts.

Andrew Dannatt

From: Sly, Tom [thomas.sly@environment-agency.gov.uk]
Sent: 16 August 2010 16:28
To: Andrew Dannatt
Cc: Amor, Charlotte; Hammond, Anthony
Subject: RE: NLE Shaft Construction

Andrew,

Many thanks for sending the memo note across, please take this email as confirmation that we agree that the English Maid breach does not need to be modelled on the basis that the construction methodology for the shafts around the Kennington Oval will have a constant threshold 1m above ground level at all times.

I can therefore confirm that we will therefore require the modelled outputs for the Nine Elms and St Georges Wharf breaches as discussed during the meeting.

Kind regards

Tom

From: Andrew Dannatt [mailto:Andrew.Dannatt@Burohappold.com]
Sent: 16 August 2010 15:39
To: Sly, Tom
Subject: RE: NLE Shaft Construction

Tom

No problem. Please find attached memo and for your records, Duncan's email sent on 4th August.

I'll call you later on to discuss if that is OK with you.

Regards

Andrew Dannatt Associate
Buro Happold Environment + Infrastructure
Mobile: +44 (0)7918 156026 (Mobex 8890)

From: Sly, Tom [mailto:thomas.sly@environment-agency.gov.uk]
Sent: 16 August 2010 15:36
To: Andrew Dannatt
Subject: RE: NLE Shaft Construction

Hi Andrew,

Apologies, please can you re-send the memo outlining the above ground construction - I'm afraid I can not find this on my system?

Many thanks, Tom

From: Andrew Dannatt [mailto:Andrew.Dannatt@Burohappold.com]
Sent: 16 August 2010 14:26
To: Sly, Tom
Cc: Duncan Ker-Reid
Subject: FW: NLE Shaft Construction

Tom

Further to Duncan's email a couple of weeks ago I tried to call you earlier this afternoon. When you return to your desk could you call me, or if it is more convenient I will call you later this afternoon?

Thanks

Andrew Dannatt Associate
Buro Happold Environment + Infrastructure
Mobile: +44 (0)7918 156026 (Mobex 8890)

From: Duncan Ker-Reid
Sent: 04 August 2010 17:33
To: Sly, Tom
Cc: McCann, David; Jim Fleming; Alan Travers; 026932 Northern Line Extension Reference Design TWAO; Noak, Martyn; Tim Kelly; Andrew Dannatt
Subject: NLE Shaft Construction

Tom,

Please find attached to this email a memo outlining the above ground construction of the 5 temporary and permanent access shafts for the Northern Line Extension as agreed following the meeting on 29th July 2010

We hope that this memo confirms the points made in the meeting that the shafts will be watertight up to 1m above the current ground level and that as a result modelling of the English Maid breach is not required.

If you have any questions regarding this note or require any additional information, please do not hesitate to contact me.

Regards,

Duncan

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Appendix C

Appendix C Existing Site Plans

Appendix C Existing Site Plans

Please refer to the 'Deposited Plans and Sections Drawings' submitted as part of the TWA Order application.

Appendix D

Appendix D Breach Flood Risk Maps

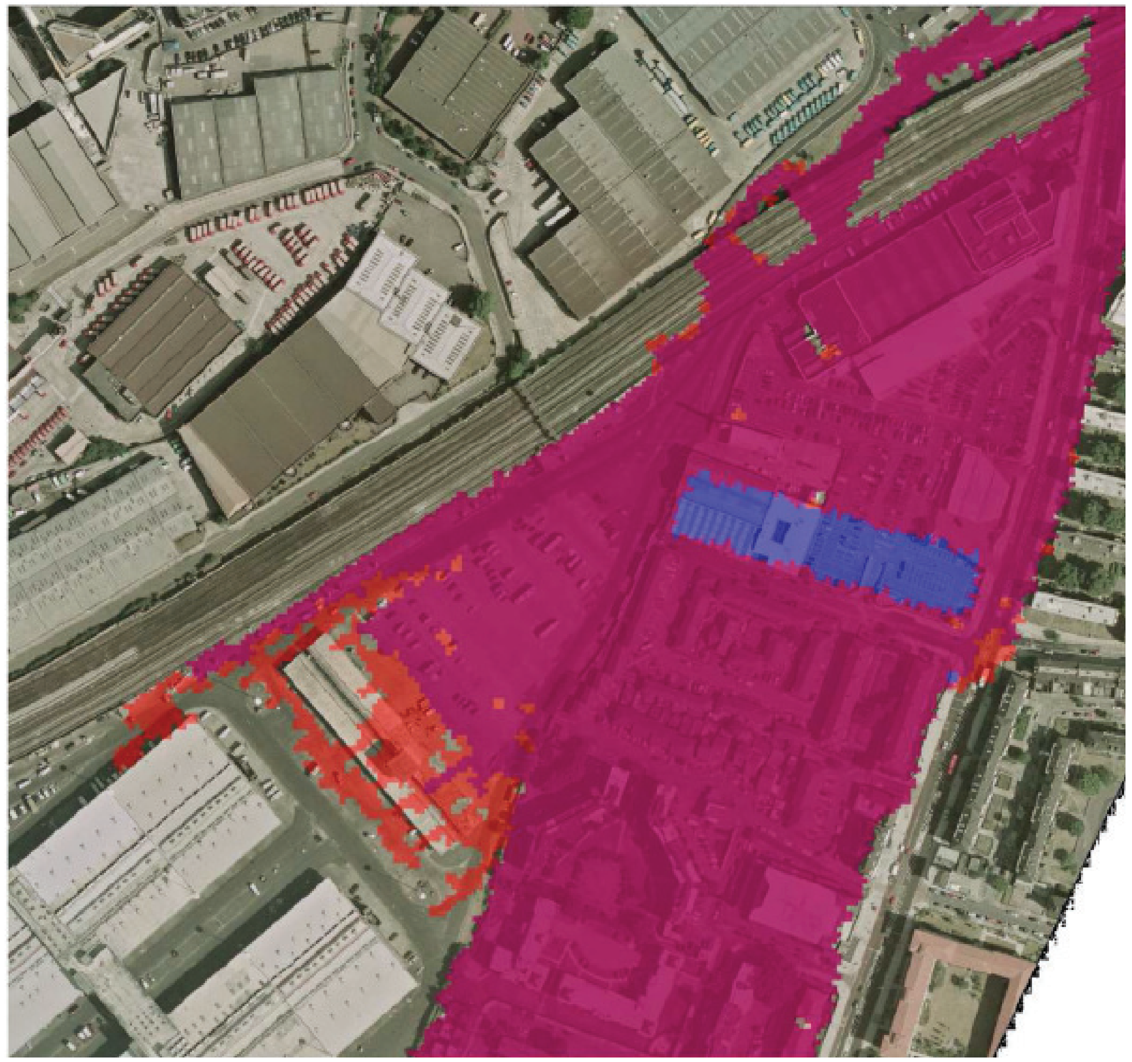
For details of your nearest Halcrow office, visit our website
halcrow.com

Appendix D Breach Flood Risk Maps

Appendix D1 – St Georges Wharf breach model results - Baseline

Appendix D2 – St Georges Wharf breach model results - Proposed

Appendix D3 – Nine Elms breach model results – 2009 – 2010 comparison

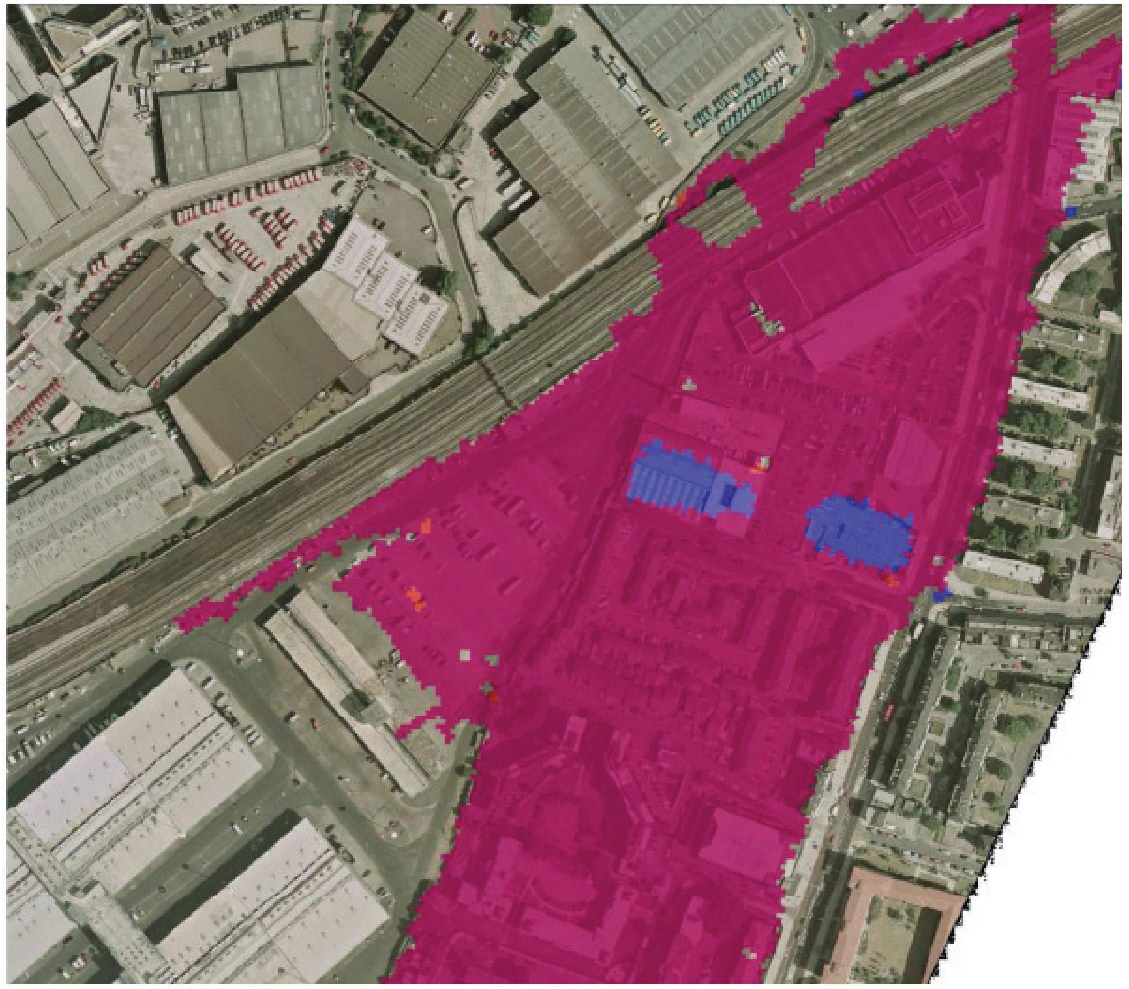


Appendix D1 Breach Extents

Change in flood extent as a result of the Nine Elms station proposals. Red indicates an increase in flood extent as a result of the proposals, blue indicates a decrease in flood extent, and purple indicates no change.

Key:-

BLUE	Decrease in flood extents
RED	Increase in flood extents
PURPLE	No change in flood extents

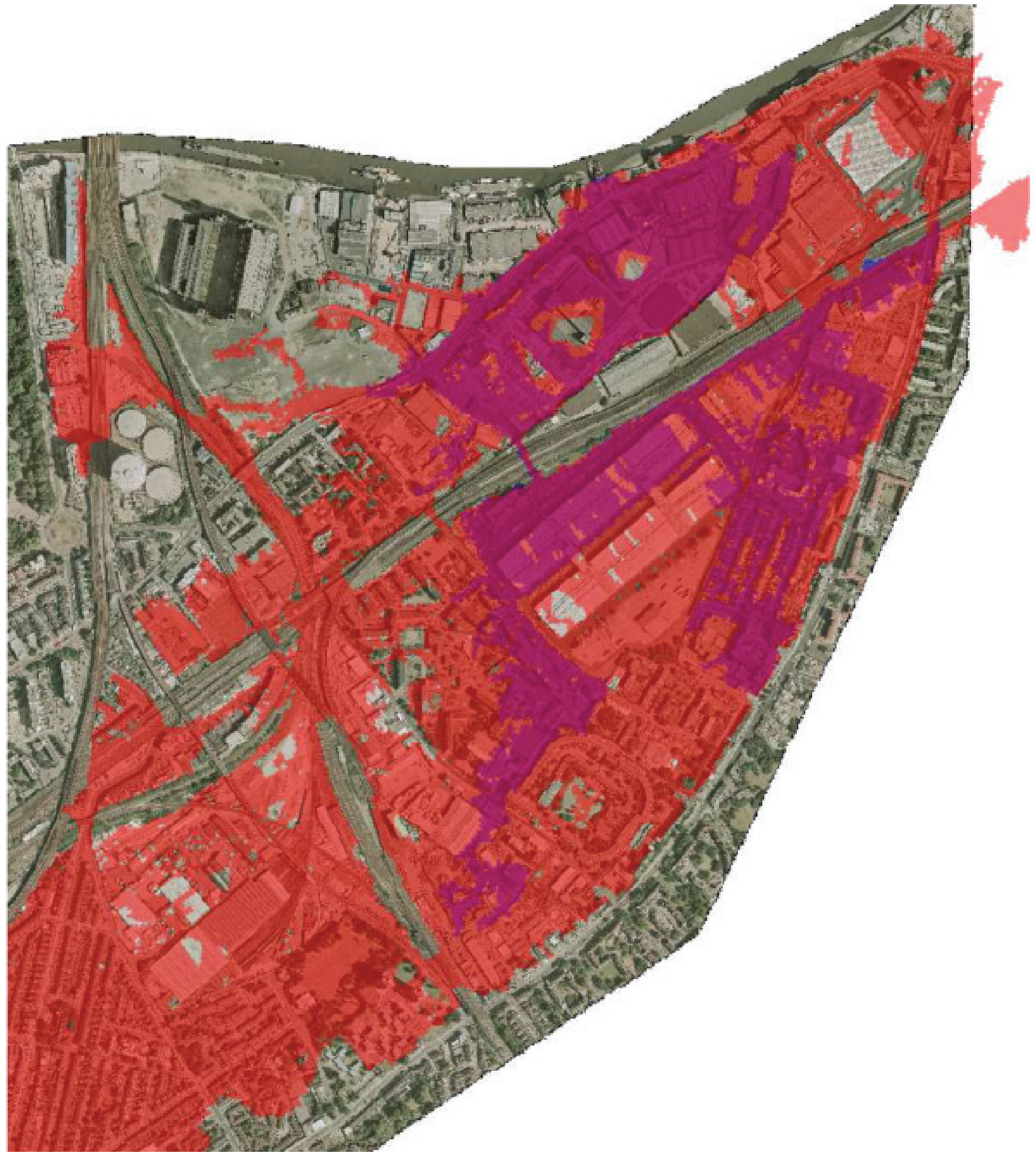


Appendix D2 Breach Extents

Change in flood extent as a result of the Nine Elms station proposals including mitigation options. Red indicates an increase in flood extent as a result of the proposals, blue indicates a decrease in flood extent, and purple indicates no change.

Key:-

BLUE	Decrease in flood extents
RED	Increase in flood extents
PURPLE	No change in flood extents



Appendix D3 Breach Extents

Change in flood extent between the 2009 BPS model and the 2010 NLE model for the Nine Elms breach. Red indicates a increase in flood extent from 2009 to 2010, blue indicates a decrease in flood extent and purple indicates no change.

Key:-

BLUE	Decrease in flood extents
RED	Increase in flood extents
PURPLE	No change in flood extents

Appendix E

Appendix E Hazard Rating Maps

Appendix E Hazard Rating Maps

The Hazard rating maps have been created for the 1 in 200 and 1 in 1000 year events using the EA/Defra Flood Risks to People Guidance FD2321 Technical Report 2.

The mapping is available on request.

Appendix F

Appendix F Surface Water Drainage Plan

Appendix F Surface Water Drainage Plan

Appendix F Surface Water Drainage Strategy – Nine Elms

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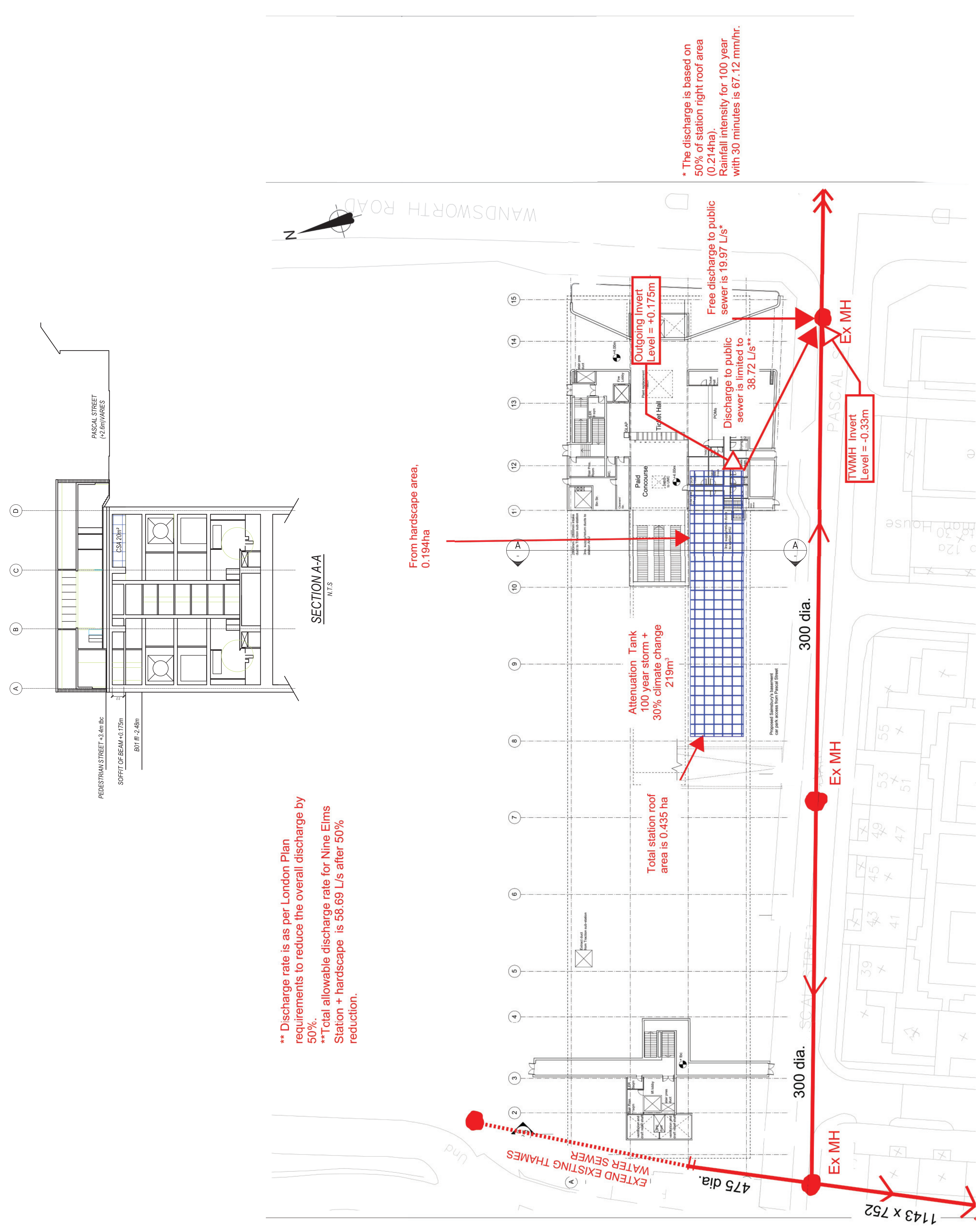

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H2: Water Framework Directive Assessment

Environmental Statement

Volume II

URS

Northern Line Extension

Water Framework Directive Assessment

April 2013

46370144

Prepared for:
Transport for London

REVISION SCHEDULE

Rev	Date	Details	Prepared by	Reviewed by	Approved by
1	April 2013	Draft Water Framework Directive Assessment	Gemma Hoad Water Scientist	Neil Williams Senior Geomorphologist David Kirby Ecologist	Carl Pelling Principal Consultant

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1 INTRODUCTION

This document presents the findings of a Water Framework Directive assessment (WFDa) for the Northern Line Extension (NLE) project due to the jetty works which are proposed to take place in the River Thames.

The Water Framework Directive (WFD) is a European Union Directive (2000/60/EU) that sets out a legislative framework for the analysis, planning and management of water resources and the protection of aquatic ecosystems (Reference 1). EU member states are required to classify the current 'status' (or potential) of waterbodies and set a series of objectives for maintaining or improving waterbodies so that they maintain or reach 'good status' or 'good potential'.

In line with the European Directive, consented schemes that do not uphold the objectives of the WFD can be reported to the European Union. Local Planning Authorities (LPAs) can ultimately be fined for issuing consents for schemes that cause waterbodies to deteriorate or prevent the objectives of the WFD from being met.

To ensure that the principles of the WFD are upheld, a WFDa is required for any planned development or activity that could have a detrimental effect on a waterbody. A WFDa is required to form part of the Transport and Works Act Order in the same way as a flood risk assessment and other standard planning support documents.

The WFD recognises that some waterbodies have been physically altered, for example for navigation or flood defence, and allows for these water bodies to be designated as Heavily Modified Water Bodies (HMWB) or Artificial Water Bodies (AWB). These waterbodies are required to achieve good 'potential' rather than good 'status'. Ecological potential means that the waterbody is managed according to the ecology and biodiversity that can realistically be achieved given the need to maintain the modified condition for which the waterbody is used.

The Environment Agency is the competent authority for implementing the WFD in England and Wales and has reported waterbody status and objectives via a series of River Basin Management Plans (RBMPs) (Reference 2). As part of its role, the Environment Agency must consider whether proposals for new development have the potential to affect the objectives of the WFD in protecting the water environment as set out in the RBMPs. These four key specific objectives of the WFD are:

- WFD objective 1: Prevent deterioration of the status of all bodies of surface water and groundwater.
- WFD objective 2: Protect, enhance and restore all bodies of surface water and groundwater, with the aim of achieving good status by 2015 (or 2027 where measures will take longer to implement).
- WFD objective 3: Protect and enhance all artificial and heavily modified bodies of water, with the aim of achieving good ecological potential (GEP) and good chemical status of all water bodies by 2015 (or 2027 where measures will take longer to implement).
- WFD objective 4: Reduce pollution from priority substances and cease or phase out emissions, discharges and losses of priority hazardous substances.

Planning for any new development that has the potential to impact waterbodies should therefore ensure that the proposals are assessed for compliance against WFD objectives.

The jetty works proposed in the Middle Thames for the NLE project have the potential to impact both positively and negatively on WFD objectives. A WFDa has therefore been identified as a requirement for the project.

1.1 Project Description Overview

The NLE project is the proposed construction and operation of the Charing Cross branch of the Northern Line from Kennington to Battersea with an intermediate station located at Nine Elms. The key features of construction and operation of the NLE in the context of waterbodies classified under the WFD are as follows:

- The project would require the construction of tunnels, shafts and associated structures through geological strata under Kennington, Lambeth and Nine Elms, with the potential to intercept groundwater bodies along the route.
- The River Thames will be used for the movement of uncontaminated excavated materials by barge. In order to facilitate this, it is proposed that strengthening and improvement works are undertaken for the existing jetty at Battersea Power Station which will be used for the mooring of barges and transfer of material both from and to the barges. The improvements works to the jetty would include the creation of new structures within the Thames in this location and therefore has the potential to affect the Thames Middle surface waterbody.

2 METHODOLOGY

2.1 WFD Assessment Process

Although the Environmental Impact Assessment (EIA) for the project has considered the impacts of the proposed NLE project and identified the effects that are likely on many of the supporting elements used in WFD classification, a standalone WFDa was considered to be appropriate because:

- Some supporting elements which determine surface water WFD status (or potential) span several EIA disciplines (e.g., hydromorphology) and hence are not assessed in a way that is entirely consistent with WFD requirements.
- The Environmental Statement for the project is a substantial document with the relevant topic areas relevant to the WFD reported in different sections and as such, for clarity and ease of reference, a separate single documentation of WFD compliance assessment has been produced.

There is currently no published guidance on the undertaking of a WFD assessment, so a bespoke assessment process has been developed for this assessment based on a suggested proforma provided by the Environment Agency (Reference 3). Broadly, the assessment follows a three stage process:

- A **screening phase** is used to consider all possible WFD-related impacts of all proposed activities in order to determine whether WFDa is required.
- A **preliminary assessment**, if required, is used to determine the waterbodies that could be affected, gather WFD-related information about the waterbodies and determine which supporting elements of WFD status or potential could be affected.
- A **detailed assessment**, if required, is used to analyse how project elements that cannot be screened out as not having an impact on WFD objectives would affect waterbodies, appraise other designs and options that could uphold the objectives of the WFD, and if necessary, analyse mitigation measures to compensate for impacts of the proposed activities.

2.2 WFD Classification Process

Prior to detailing the assessment process and results, this section of the report details what constitutes a waterbody's status or potential under the WFD. The description of WFD status or potential

2.2.1 *Surface Waterbodies*

The Environment Agency has allocated status/potential classification to surface waterbodies, on a scale of high, good, moderate, poor and bad, where high represents largely undisturbed conditions.

The overall status/potential for surface waterbodies is made up of two main elements; an ecological status/potential and (where applicable) a chemical status. An overview of the status elements is shown in Figure 1 and explained in more detail below.

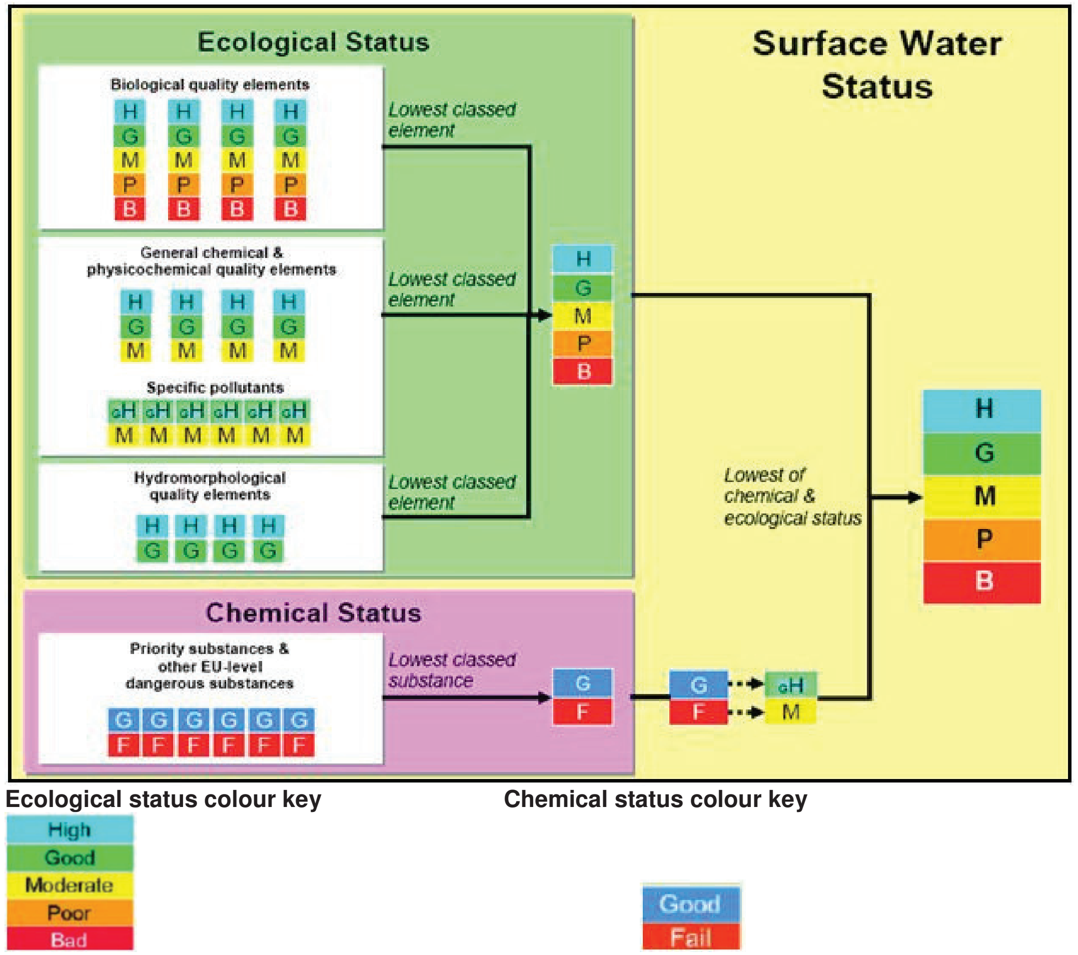

Figure 1 – Elements making up overall status/potential of a surface water body (Reference 4)

Ecological Status/Potential

Ecological status/potential is broken down into a range of supporting elements covering water quality parameters (physico-chemical and specific pollutants); biological indicators (e.g. the presence and diversity of fish); and the amount of water and physical condition (or physical form) of the waterbody (termed hydromorphology).

The physico-chemical assessment uses elements such as temperature and nutrient levels, which support the biological communities. The hydromorphological assessment uses water flow, sediment composition and movement, continuity (in rivers) and the structure of physical habitat.

The waterbody ecological status is classified on the scale of high, good, moderate, poor and bad, where high represents largely undisturbed conditions. The classification is based on the lowest (worst) scoring quality element; known as the 'one-out-all-out' approach. For example, if a waterbody achieved good status for physico-chemical assessments, but only achieved moderate status for the biological assessment; it would be classed overall as having moderate

ecological status. It is also important to note that water quality supporting elements can only influence status down to moderate; as such, only biological elements can determine poor or bad status.

In addition, Heavily Modified Waterbodies (HMWBs) have an additional classification step that considers whether all the mitigation measures that are required in order to reach good potential are in place (see Appendix A). If they are not, the 'potential' of that waterbody is limited to moderate.

Chemical Status

Chemical status is recorded as 'good' or 'fail' based on concentrations of a range of key pollutants that are priority substances and/or priority hazardous substances listed in the Environment Quality Standards Directive (2008/105/EC), known as 'Annex X' substances.

Chemical status is determined by the worst scoring chemical (known as the 'one-out-all-out' approach). Assessment of pollutants is only required in waterbodies where there are known discharges of these 'Annex X' substances.

2.2.2 *Groundwater Bodies*

Application of the WFD by the Environment Agency involves allocating an overall status classification to all groundwater bodies, on a scale of good and bad, where good represents largely undisturbed conditions.

The overall status for groundwater bodies is made up of two main elements; a quantitative status and a chemical status. An overview of the elements that make up the status of groundwater bodies is shown in Figure 2 and explained in more detail below.

Quantitative status

Quantitative status is recorded as good or poor based on the overall measure of the water balance of the groundwater body and on three other tests that must be satisfied for the groundwater body to be at good status (see Figure 2). This includes impacts to Groundwater Dependent Terrestrial Ecosystems (GWDTEs), surface water and saline or other intrusions.

Quantitative status is determined by the worst case classification from the four quantitative tests and is reported as the overall quantitative status.

Chemical status

Chemical status is recorded as good or poor based on threshold values for pollutants (or prescribed groundwater quality standards for nitrates and pesticides) that must be satisfied for the groundwater body to be at good status. This includes values for general quality and saline or other intrusions and for impacts to Drinking Water Protected Areas, GWDTEs and surface water bodies.

Chemical status is determined by the worst classification from the five chemical tests and is reported as the overall chemical status.

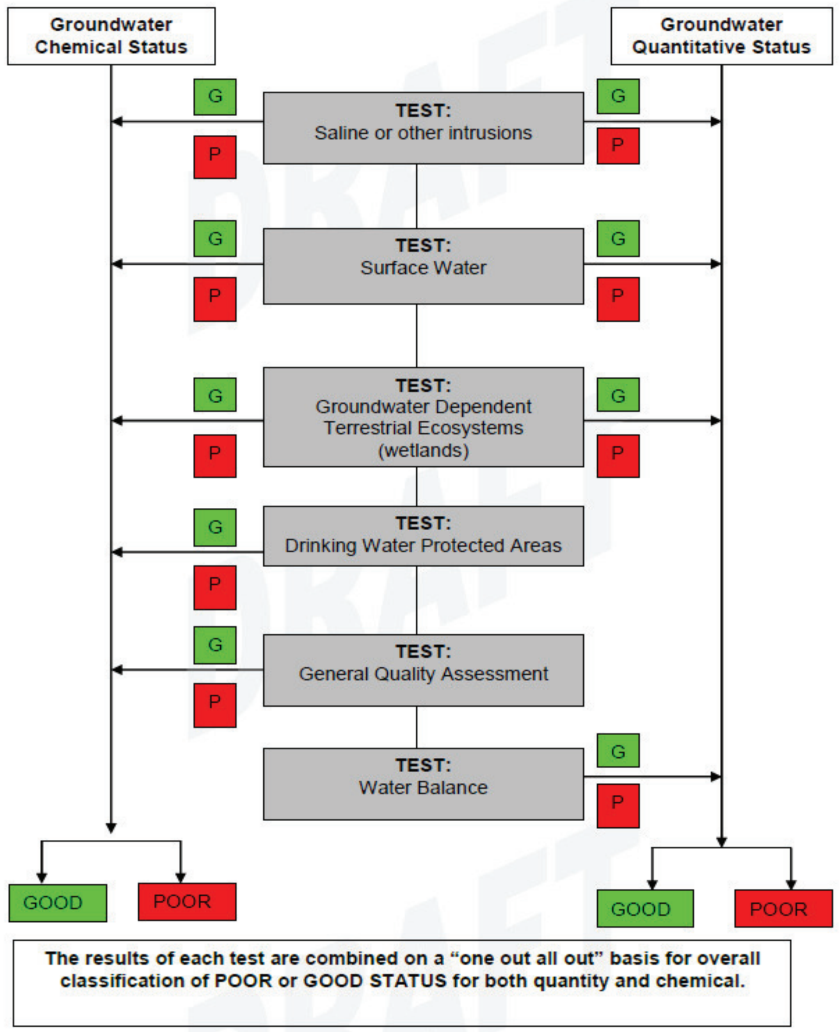

Figure 2 – Elements making up overall status/potential of a surface water body[1]

3 SCREENING PHASE

The purpose of the screening phase is determine the elements of the project (both construction and operation) that have the potential to impact on associated waterbodies so that they can be considered for the preliminary assessment.

The EIA process has been reported in the separate Environmental Statement (ES) and has been used in this screening phase of the WFDa to determine both the surface water and groundwater bodies that could be affected by the construction and operation of the proposed NLE project based on the impacts, pathways and waterbody receptors identified.

3.1.1 *Surface Waterbodies*

The EIA process concluded that the Thames Middle waterbody is the only surface waterbody that has the potential to be affected by the project. Whilst the Thames Lower waterbody is connected to the Thames Middle, the EIA concluded that direct effects to the Thames Middle waterbody would be localised. In considering the scale of the project elements that could impact the WFD supporting elements of the Thames Middle waterbody potential classification (see following sections), it is also concluded in this WFDa that the Thames Lower waterbody's current and future potential would not be affected.

No other surface waterbody has impact pathways between impact and waterbody that would lead to changes in the supporting elements making up WFD status or potential.

As the Thames Middle is classified as a HMWB, it is only required to reach Good Potential, and hence the waterbody potential (as opposed to Status) is referred to henceforth within this WFDa report.

The impact pathway in relation to the Thames Middle waterbody is the requirement to undertake strengthening and improvement works to the existing jetty at Battersea. The elements of this work (both construction and operation) that have been screened for potential assessment are described below:

Piled fenders in the River

Improvement works to the existing jetty to facilitate the movement of material by barge will require seven additional twin H-pile fenders to be inserted on the river face of the existing jetty, which will be approximately 350mm in diameter. They are required as the spacing between the existing fenders is too great for size of the vessels that are likely to be used. The H-piles have the potential to alter flow dynamics around the new structures which in turn has the potential to result in scour and deposition of sediments with the potential to also affect ecology. ***Piled fenders were therefore screened in for further assessment.***

Dredging

Dredging may also be required to allow sufficient draft for vessels to moor during construction of the NLE. Dredging will only be undertaken in the area in front of the Battersea Power Station jetty, although, the extent and depth is still be confirmed, as an update to bathymetric survey is required. However, dredging could cause changes to channel morphology and the release of fine sediments stored in the river bed into suspension. ***Dredging was therefore screened in for further assessment.***

Refurbishment works

Refurbishment works will also be carried out on the footbridge, coaling cranes and jetty, none of which will extend the structures, or reduce the cross-section of the river or conveyance, or affect the banks or bed of the river. These activities are therefore considered to be low impact maintenance activities that will not affect the Middle Thames waterbody. Refurbishment works were therefore ***screened out of further assessment.***

3.1.2 *Groundwater Bodies*

Chapter 13: Land Quality and Groundwater within the ES provides an assessment on groundwater resources that could be affected through the NLE project. In summary, the tunnels and subsurface structures extend through the River Terrace Deposits and into the London Clay. However, some parts of the tunnels and structures would extend into the top of the Lambeth Group, although they would not extend into the Upnor Formation at the base of the Lambeth Group, which forms part of the lower aquifer.

The Thames RBMP (Reference 2) shows that the Lambeth Group (Upnor Formation only), Thanet Sands and Upper Chalk Formation underlying the NLE tunnel and outcropping further to the east are designated as the Greenwich Chalk and Tertiaries groundwater body. This groundwater body also includes the alluvium and River Terrace Deposits where in hydraulic continuity with the lower aquifer. However, the alluvium and River Terrace Deposits are not part of a designated groundwater body within the NLE study corridor.

As the NLE tunnel does not extend into the Lambeth Group (Upnor Formation) and the protected waterbody, **groundwater bodies are *screened out of further assessment.***

4 PRELIMINARY ASSESSMENT

4.1 Methodology Overview

The preliminary WFD assessment for the NLE project involves a high level review of the project elements that have been screened in to the assessment and how it could either affect the current Moderate overall potential of the Thames Middle waterbody, or prevent future Good potential from being attained.

The project elements involved in the construction and operation of the scheme that could affect WFD supporting elements for the Thames Middle are summarised in Table 4-1.

All other activities involved in the NLE scheme were screened out on the basis that they could not affect any waterbodies (see section 2).

Table 4-1 – Project Elements Assessed

Construction (temporary)	Operation (permanent)
- Dredging - H-piles	- Permanent H-pile Structures

As identified at the screening phase, the only surface waterbody that could be affected by the project is the Thames Middle waterbody which, along with the Thames Upper and Thames Lower waterbodies makes up the tidal Thames.

The current and target overall status for the Thames Middle waterbody is summarised in Table 4-2. The worst scoring quality element (i.e. the element that determines the current overall status) is also shown.

Table 4-2 – Surface Waterbodies status classified by WFD

Waterbody Name/ID	Hydro-morphological Status	Current Ecological Potential	Current Chemical Status	Worst Scoring Quality Element	2015 Predicted Ecological Status	2015 Predicted Chemical Status
Thames Middle GB530603911402	Heavily modified	Moderate	Fail	Not all mitigation measures in place (Moderate)	Moderate	Fail

4.1.1 *Surface water assessment approach*

The current and target potential was then identified for each of the WFD supporting elements that make up the potential classification of the waterbody.

Each WFD supporting element was assessed against each of the identified project elements. Each project element was considered in terms of whether it could:

- Result in deterioration of the classification for that supporting element; or

- Prevent delivery of any of the mitigation measures identified as being required to improve failing waterbodies to their target potential.

The supporting elements considered are for transitional waterbodies as listed in Environment Agency guidance (Reference 3 and 4), since this part of the River Thames is tidal. These elements and the current classification for each of these elements are detailed in Table 4-3 for each waterbody.

There is no classification available for the hydromorphological elements of the waterbody, other than it is a HWMB. However hydromorphological elements are key elements supporting the biological elements, so the effects of the scheme on hydromorphology are still an important part of the assessment,

Table 4-3 – WFD Supporting Elements and Current Classification for each Surface Waterbody

WFD Supporting Element	WFD Quality Element	Thames Middle GB530603911402
Hydromorphological Elements	Hydrological Regime	No classification for HMWBs
	River Continuity	No classification for HMWBs
	Morphological conditions	No classification for HMWBs
	Tidal Regime	No classification for HMWBs
Biological Elements	Macroalgae	High
	Phytobenthos	Not listed in the RBMP
	Benthic Invertebrate fauna	Moderate
	Fish Fauna	Moderate
Critical Sensitive Habitats	Priority Habitats and Species	Intertidal mudflat Subtidal gravels Smelt Eel
Physico-chemical Elements	Nutrient Concentrations (Dissolved Inorganic Nitrogen)	Moderate
	Oxygen Balance	Moderate
Chemical Elements	Priority or other substances	Fail

The following WFD supporting elements were not considered in the preliminary assessment for the following reasons and are not included in Table 4-3.

- Protected Sites – there are no protected sites within the waterbody
- Other aquatic flora, including angiosperms, sea grass, seaweed, and habitats including salt marsh, which make up component parts of the biological supporting elements, have

also been scoped out of the WFD assessment on the basis that they do not occur within the waterbody likely to be affected by the scheme.

- Physico-chemical elements – The following parameters do not have an impact pathway associated with any of the project elements and hence were not included in the assessment: salinity, pH, acid neutralising capacity, or temperature.

In determining potential for deterioration, reference was made to the Environment Agency's published document on classification of surface waterbodies. For the impact on mitigation and hence future target potential, proposed mitigation measures have been taken from the Thames RBMP.

It should be noted that the preliminary assessment was based on readily available information and assessments already undertaken for the Environmental Statement. No additional modelling was deemed necessary

4.2 Future Good Potential - Mitigation Base Case

As described in Section 1, HMWBs have an additional classification step that considers whether all the mitigation measures required in order to reach good potential are in place. If they are not in place, the waterbody is limited to moderate potential, whereas the objective for all HMWBs is to achieve good potential by 2027.

In order to assess whether the proposed development would prevent the Middle Thames waterbody reaching good potential, it is necessary to consider whether it would prevent any of the mitigation measures listed in the RBMP being implemented by 2027 at the latest. The relevant mitigation measures are listed in Table 4-4.

Table 4-4 – RBMP Identified Mitigation Measures for Thames Middle waterbody

Mitigation Measures in Place	Mitigation Measures not in Place
Vessel management Modify vessel design Manage disturbance Site selection (dredged material disposal) (e.g. avoid sensitive sites) Sediment management Alter timing of dredging / disposal Reduce sediment resuspension Reduce impact of dredging Prepare a dredging / disposal strategy Avoid the need to dredge (e.g. minimise under-keel clearance; use fluid mud navigation; flow manipulation or training works)	Indirect / offsite mitigation (offsetting measures) Operational and structural changes to locks, sluices, weirs, beach control, etc Not In Place Preserve and where possible enhance ecological value of marginal aquatic habitat, banks and riparian zone Managed realignment of flood defence Remove obsolete structure

Many of the proposed measures are fairly generic in nature and it is therefore necessary to refine them and to quantify which are likely to be implemented by 2027. This can then form the base case against which the effects on RBMP mitigation measures can be assessed.

An update to the Thames RBMP is due for publication in 2015, which will identify broad areas in the tidal Thames and its tributaries where these mitigation measures could be delivered. It will also determine whether any of the measures are technically infeasible or disproportionately expensive and hence will not be implemented by 2027. As this is not available for this assessment, a precautionary approach has been adopted whereby it is assumed that all of the mitigation measures *could* be put in place by 2027. The relevant policies in the Thames Estuary 2100 (TE2100) project (Reference 5) have also been referenced. The project elements as listed in Table 4-4 have therefore been assessed to consider whether they could prevent any of the mitigation measures from being implemented, and hence theoretically prevent Good Ecological Potential being achieved.

4.3 Preliminary assessment results

The results of the preliminary assessment of the project elements against WFD supporting elements and mitigation measures for the Middle Thames waterbody are presented in detail in Appendix A and Appendix B.

Appendix A summarises details of whether the NLE would result in deterioration of the existing status of each supporting element.

Appendix B summarises details of the assessment of the project elements against the HMWB mitigation measures that are not currently in place, and hence considers where project elements have the potential to impact on future attainment of good potential.

The results are discussed below.

4.3.1 *Summary - No Deterioration*

The results demonstrate that no project elements could affect the status elements of the Middle Thames waterbody.

Hydromorphology Elements

- Hydrological regime – small and highly localised impacts on flow dynamics would result from both the temporary and permanent structures, however, this would not affect the quantity of flow in the Thames Middle waterbody.
- Morphological conditions (river depth and width variation, and structure and substrate of the river bed and the riparian zone/intertidal zone) – local scour of bed is likely around new H-pile structures; however the total bed area impacted by the jetty works is less than 1% of the waterbody. The distance of the H-pile fenders from riparian zone and banks means local scour is unlikely to impact on these areas. It is therefore considered that any impact will be negligible.

Biological Elements

- Benthic invertebrate fauna (composition and abundance), fish fauna (species composition and abundance, presence of type-specific disturbance sensitive species and age structure of fish communities and priority habitats and species ie, Common smelt (Osmerus eperlanus) and European eel (Anguilla anguilla), and intertidal mudflats and subtidal gravels – the total length of the bed impacted is less than 5% of the total Thames Middle Waterbody length, and riparian zone/bank is unlikely to be affected. It is therefore considered that any impact will be negligible.
- Migration of fish - there will be no impact on the shoals of fish migrating through the Middle Thames waterbody with or without the temporary and permanent structures.
- Migration of aquatic mammals - the hydraulic impact of the temporary and permanent structures on the migration of marine mammals within the Middle Thames (comprising

various cetacean and piniped species) was considered to be negligible. The effects of noise on migratory patterns were also considered. Given the vibro piling techniques proposed for construction of the H-pile fenders, effects were not considered significant.

In summary, it is considered that none of the WFD supporting elements making up the current potential classification of the Thames Middle waterbody would be adversely affected by the NLE, and hence the project would not cause deterioration in WFD potential for the Thames Middle waterbody

4.3.2 *Summary – Future Good Potential*

To ensure that there will be no impact on future Good potential in the affected waterbodies, the preliminary assessments have reviewed relevant mitigation measures that are not currently in place and therefore have the potential to be compromised by new developments. 'Identified measures' refers to the programme of measures that are still being developed as part of the Thames RBMP which are needed to improve failing waterbodies towards their future target Status or Potential. The mitigation measures identified as not being in place in the RBMP for the Thames Middle waterbody are presented in Table 4-4.

At the time of undertaking the preliminary WFD assessment, the Environment Agency was not able to confirm when (or which of) the proposed RBMP mitigation measures are scheduled for delivery. This is because the Environment Agency is currently assessing whether the proposed mitigation measures are 'technically feasible' and 'cost proportionate' and therefore realistically achievable. Therefore, for the purposes of this assessment, a judgement has been taken on a precautionary basis to assume that all of the mitigation measures could be delivered and the project assessed against whether it could prevent any of these measures being implemented.

The full assessment is presented in Appendix B. In summary, none of the project elements are considered to affect the delivery of the mitigation measures and prevent future Good potential for being achieved.

4.3.3 *Delivery of offsite mitigation measures*

The NLE scheme does not have the potential to deliver any offsite mitigation measures listed in the Thames RBMP.

4.3.4 *Sensitive habitats and species check*

Two sensitive habitats (intertidal mudflat, and intertidal and subtidal gravels) and two sensitive species (Common smelt *Osmerus eperlanus* and European eel *Anguilla anguilla*) have been identified by the screening assessment. The potential effects on these are identified in Appendix A, but they are not considered to be significant from a WFD classification perspective.

5 CONCLUSION

Overall, dredging require for the the NLE's jetty strengthening works at Battersea Power Station is unlikely to have any significant adverse effects on the Middle Thames waterbody.

The construction of the seven H-piles and the dredging around the existing jetty, have the potential to result in a very minor reduction in morphological and ecological diversity, however the proposed footprint of the works on the river bed is less than 1% of the Middle Thames waterbody bed area and it is therefore considered that any impact will be negligible.

In addition, the jetty works would not prevent any of the potential mitigation measures required to move the Thames Middle waterbody to Good potential from being implemented.

Therefore, the NLE would not prevent WFD objectives from being met.

REFERENCES

- **Reference 1** - Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy
- **Reference 2** - Environment Agency, *River Basin Management Plan, Thames River Basin District* (2009)
- **Reference 3** - Environment Agency, *Assessing new modifications for compliance with WFD: detailed supplementary guidance* (2010)
- **Reference 4** - Environment Agency, *Method Statement for the Classification of Surface Water Bodies v2.0 – Monitoring Strategy* (2011)
- **Reference 5** - Environment Agency, *Thames Estuary 2100 (TE2100) Plan* (April 2009)

APPENDIX A – NO DETERIORATION RESULTS

Waterbody Name	Thames Middle
Waterbody ID	GB530603911402
Current status	Moderate potential
Status objective	Good by 2027
Waterbody designation	HMWB
Reasons for failure	Not all mitigation measures in place

			Operation	Detailed assessment needed
WFD QUALITY ELEMENTS	Dredging	H-pile fender construction	Permanent structures	
Hydromorphological elements				
Hydrological regime:				
• Quantity and dynamics of water flow	X	X - structures will not affect the quantity of flow, although small localised impacts on dynamics will result. These have been assessed for the morphological effects that could result (see rows 16 to 21 below)	X - structures will not affect the quantity of flow, although small localised impacts on dynamics will result. These have been assessed for the morphological effects that could result (see rows 16 to 21 below)	X
• Connection to groundwater bodies	X	X - There are no WFD classified groundwter bodies that could be affected by the piling required for the fender construction	X	X
River continuity:				
• Migration of aquatic organisms	X	X	X	X
• Sediment transport	X - Sediment releases from construction would be negligible compared to overall sediment releases to the Tidal Thames	X - Sediment releases from construction would be negligible compared to overall sediment releases to the Tidal Thames	X	X
Morphological conditions:				
• River depth and width variation	X there would be a local variation in depth if dredging were required, however the effect would be temporary during construction of the project and would be <1% of the waterbody bed area	X - Pilling will have a negligible effect on flow dynamics (turbulence) and sediment transport and bed scour. The area of works are <1% of the waterbody length impacted	X - Permanent structures will have a negligible effect on flow dynamics (turbulence) and sediment transport and bed scour. The area of works are <1% of the waterbody length impacted	X
• Coastal/estuarine depth variation	X	X	X	X
• Structure and substrate of the river bed	X - The amount of sediment and substrates removed by dredging would be negligible compared to natural loads	X - Pilling will have a negligible effect on flow dynamics (turbulence) and sediment transport and bed scour. The area of works are <1% of the waterbody length impacted	X - Permanent structures will have a negligible effect on flow dynamics (turbulence) and sediment transport and bed scour. The area of works are <1% of the waterbody length impacted	X
• Quantity, structure and substrate of the coastal/estuary bed	X	X	X	X
• Structure of the riparian zone/intertidal zone	X	X - Pilling will have a negligible effect on flow dynamics (turbulence) and sediment transport and scour on the riparian/interitdal zone. The fender piles are located some distance from the ro[arian and interdial zone and will have limited impact	X - Permanent structures will have a negligible effect on flow dynamics (turbulence) and sediment transport and scour on the riparian/interitdal zone. The fender piles are located some disctance from the ro[arian and interdial zone and will have limited impact	X
Tidal regime:				
• Tidal flow	X	X	X - impacts of permanent structures on tidal prism and flows would be negligible at the proposed scale of development	X
• Wave exposure	X	X	X - impacts of permanent structures on wave exposure would be negligible at the proposed scale of development	X
Biological elements				
Phytoplankton: • Taxonomic composition • Average abundance • Planktonic bloom frequency and intensity • Biomass				
Macrophytes and phytobenthos:				
• Taxonomic composition	X	X	X	X
• Average macrophytes and phytobenthic abundance	X	X	X	X
Other aquatic flora (e.g. macroalgae, angiosperms, sea grass, sea weed salt marsh): • Composition				
Benthic invertebrate fauna:				
• Composition	X - Dredging will result in disturbance to burrowing and feeding habitat, however the overall works area is less than <5% of the waterbody length impacted, so the impact is negligible	X	X	X
• Abundance	X - Dredging will result in disturbance to burrowing and feeding habitat, however the overall works area is less than <5% of the waterbody length impacted, so the impact is negligible	X	X - Permanent structures will result in temporary land take from burrowing and feeding habitat, however the overall works area is less than <5% of the waterbody length impacted, so the impact is negligible	X
Fish fauna:				
• Species composition and abundance	X - Dredging will result in disturbance to burrowing and feeding habitat, however the overall works area is less than <5% of the waterbody length impacted, so the impact is negligible	X - Piling noise may impact fish species, however the overall works area is less than <5% of the waterbody length impacted, so the impact is negligible	X - Permanent structures will result in loss of habitat, however the overall works area is less than <5% of the waterbody length impacted, so the impact is negligible	X
• Presence of type-specific disturbance sensitive species	X - Dredging will result in disturbance to burrowing and feeding habitat, however the overall works area is less than <5% of the waterbody length impacted, so the impact is negligible	X - Piling noise may impact fish species, however the overall works area is less than <5% of the waterbody length impacted, so the impact is negligible	X - Permanent structures will result in loss of habitat for all species, however the overall works area is less than <5% of the waterbody length impacted, so the impact is negligible	X
• Age structure of fish communities	X	X - Piling noise may impact fish species, however the overall works area is less than <5% of the waterbody length impacted, so the impact is negligible	X - Permanent structures will result in loss of habitat for all ages of fish, however the overall works area is less than <5% of the waterbody length impacted, so the impact is negligible	X
Critical sensitive habitats/species				
Protected sites:				
• SACs	X	X	X	X
• SPAs	X	X	X	X
• RAMSAR	X	X	X	X
• SSSI	X	X	X	X
Priority habitats and species:				
Common smelt (*Osmerus eperlanus*)	X - Dredging will result in removal and accretion of habitat, however the overall works area is less than <5% of the waterbody length impacted, so the impact is negligible	X - Piling noise may impact fish species, however the overall works area is less than <5% of the waterbody length impacted, so the impact is negligible	X - Permanent structures will result in loss of habitat for all ages of fish, however the overall works area is less than <5% of the waterbody length impacted, so the impact is negligible	X
European eel (*Anguilla anguilla*)	X - Dredging will result in removal and accretion of habitat, however the overall works area is less than <5% of the waterbody length impacted, so the impact is negligible	X - Piling noise may impact fish species, however the overall works area is less than <5% of the waterbody length impacted, so the impact is negligible	X - Permanent structures will result in loss of habitat, however the overall works area is less than <5% of the waterbody length impacted, so the impact is negligible	X
Intertidal mudflat	X - Dredging will result in removal and accretion of habitat, however the overall works area is less than <5% of the waterbody length impacted, so the impact is negligible	X	X - Permanent structures will result in loss of habitat, however the overall works area is less than <5% of the waterbody length impacted, so the impact is negligible	X
Intertidal and subtidal gravels	X - Dredging will result in removal and accretion of habitat, however the overall works area is less than <5% of the waterbody length impacted, so the impact is negligible	X	X - Permanent structures will result in loss of habitat, however the overall works area is less than <5% of the waterbody length impacted, so the impact is negligible	X
Physico-chemical elements				
• Salinity	X	X	X	X
• Nutrient concentrations	X	X	X	X
• pH	X	X	X	X
• Oxygen balance	X	X	X	X
• Acid neutralising capacity	X	X	X	X
• Temperature	X	X	X	X
• Transparency	X	X	X	X
• Pollution by all priority substances identified as being discharged into the water body	X	X	X	X
• Pollution by other substances identified as being discharged in significant quantities into the water body	X	X	X	X

Key

✓ (red)	Likely negative impact requiring further detailed assessment
X	No significant impact likely
✓ (green)	benficial effect

APPENDIX B – FUTURE GOOD POTENTIAL RESULTS

Waterbody Name	Thames Middle
Waterbody ID	GB530603911402
Current status	Moderate potential
Status objective	Good by 2027
Waterbody designation	HMWB
Reasons for failure	Not all mitigation measures in place

					Operation	
Mitigation measures not in place	**Are mitigation measures likely to be implemented by 2027?**	**TE2100 Policy**	**Dredging**	**H-pile fender construction**	**Permanent structures**	**Further assessment needed**
Indirect / offsite mitigation (offsetting measures)	Yes	N/A	X	X	X	X
Operational and structural changes to locks, sluices, weirs, beach control, etc	No structures (locks, sluices, weirs, beach control, etc) identified in the vicinity of Battersea Power Station Jetty	N/A	X	X	X	X
Preserve and where possible enhance ecological value of marginal aquatic habitat, banks and riparian zone	Yes	N/A	X	X	X - riparian zone and banks unlikely to be affected by intrusive jetty works	X
Managed realignment of flood defence	Considered to be unfeasible for the defences at Battersea Power Station Jetty, a situtation which would not be altered by the proposed works.	A.2.6. To maintain, enhance or replace, the river defence walls and active structures through central London over the first 25 years of the Plan from 2010 to 2034.	X	X	X - Managed realignment is unlikely due to the intensive urban use of land immediately behind the new structures	X
Remove obsolete structure	None identified at the Battersea Power Station Jetty	N/A	X	X	X	X

Key

✔ (red)	Potential to prevent or obstruct mitgation measure - detailed assessment required
X	No potential to prevent or obstruct mitgation measure
✓ (green)	Potential to enhance or improve mitigation measure

APPENDIX C – MORPHOLOGICAL IMPACTS OF SCHEMES

Type of modification		Guidance on level of WFD assessment required		
		Detailed impact assessment unlikely - follow best practise guidance	**Detailed impact assessment unlikely - follow best practise and record in the iRBM data solution**	**Detailed impact assessment may be required - use thresholds of concern as guidance. River water body length is provided in the River Basin Characterisation data set in the iRBM data solution. If no detailed assessment is undertaken follow best practise and record in the iRBM data solution**
Channel / Watercourse alteration	Watercourse alteration including - resectioning, straightening, realignment, channelisation			Calculate the length of river water body impacted. Detailed assessment should be undertaken where >2% of the river water body length is impacted.
	Channel diversions			All channel diversions will need detailed assessment.
	By pass channel/flood relief channel,			Calculate the river water body length to be by passed. Detailed assessment should be undertaken where >3% of the river water body length is bypassed.
	Bank protection	Green/soft bank reinforcement or re-profiling ≤10m or ≤ one channel width in length (whichever is greater).	Green/soft bank reinforcement or re-profiling ≤50m in length.	Calculate the total length of bank protection, remembering to include the length of protection on both banks. For green/soft engineering detailed assessment should be undertaken where total length of bank protection is >5% of the river water body length. For grey/hard engineering detailed assessment should be undertaken where total length of bank protection is >3% of the river water body length.

Type of modification		Guidance on level of WFD assessment required		
		Detailed impact assessment unlikely - follow best practise guidance	**Detailed impact assessment unlikely - follow best practise and record in the iRBM data solution**	**Detailed impact assessment may be required - use thresholds of concern as guidance. River water body length is provided in the River Basin Characterisation data set in the iRBM data solution. If no detailed assessment is undertaken follow best practise and record in the iRBM data solution**
	Bed protection		Bed reinforcement ≤10m in length downstream of closed culverts to prevent scour immediately downstream.	Calculate the length of the water body impacted. Detailed assessment should be undertaken where >1% of the water body is impacted.
Defence (linear flood defence)	Embankment / flood banks			Calculate the total length of the embankment/flood bank, remembering to include the length for both banks. Detailed assessment should be undertaken where total length of embankment/flood bank is >3% of the water body length.
	Set-back embankment / flood banks			Calculate the total length of the set-back embankment/flood bank, remembering to include the length for both banks. Detailed assessment should be undertaken where total length of set-back embankment/flood bank is >5% of the water body length.
	Revetment			Calculate the total length of revetment remembering to include the length for both banks. Detailed assessment should be undertaken where the total length of revetment >3% of water body length.
	Wall			Calculate the total length of the wall, remembering to include the length for both banks. Detailed assessment should be undertaken where total length of wall is >3% of the water body length.

Type of modification		Guidance on level of WFD assessment required		
		Detailed impact assessment unlikely - follow best practise guidance	**Detailed impact assessment unlikely - follow best practise and record in the iRBM data solution**	**Detailed impact assessment may be required - use thresholds of concern as guidance. River water body length is provided in the River Basin Characterisation data set in the iRBM data solution. If no detailed assessment is undertaken follow best practise and record in the iRBM data solution**
	Set back wall			Calculate the total length of the set-back wall, remembering to include the length for both banks. Detailed assessment should be undertaken where total length of set-back wall is >5% of the water body length.
Channel / Watercourse structures	Infrastructure surrounding a outfall/intake, sluice, pipe, inlet, outlet, off-take, pumping stations			Calculate the total length of bank/bed impacted. Detailed assessment should be undertaken where >3% of the bank or bed is impacted.
	Structures such as small boat slipways, piers, jetties and platforms			Calculate the total length of bank/bed impacted. Detailed assessment should be undertaken where >5% of the bank or bed is impacted.
	In stream structures such as croys, groynes, boulder placement and other flow deflectors	Boulder placement in a river occupying <10% of channel width.		Calculate the length of river over which the in stream structures will be placed. Detailed assessment should be undertaken when >2% of water body length is impacted. A threshold approach does not work particularly well for this type of structure. Consideration should be made as to whether they are the appropriate solution to the problem and advice should be sought from a geomorphologist.
	Lock			All locks require detailed assessment
	Culvert			All culverts will generally require a detailed assessment. Use a common sense approach, for example a small pipe culvert used under a footpath is unlikely to cause a significant morphological risk

Type of modification		Guidance on level of WFD assessment required		
		Detailed impact assessment unlikely - follow best practise guidance	**Detailed impact assessment unlikely - follow best practise and record in the iRBM data solution**	**Detailed impact assessment may be required - use thresholds of concern as guidance. River water body length is provided in the River Basin Characterisation data set in the iRBM data solution. If no detailed assessment is undertaken follow best practise and record in the iRBM data solution**
Impoundment structures (including changes to existing structures)	Barrage / dam (including components & installations)			All barrages and dams will need detailed assessment
	Weir / sluice- raising height of existing weir, changing capacity of impoundment or operational changes to existing structures			Calculate the length of the additional impounded water. Detailed assessment should be undertaken where the additional impounded water >1% water body length.
	Weir / sluice - removal			All weir or sluice removals will need detailed assessment
	Weir / sluice - new structure			All new weir or sluice structures will need detailed assessment.
Power generation	Hydroelectric power scheme - changing height of existing weir, changing capacity of the impoundment or operational changes to existing structures			Calculate the length of the additional impounded water. Detailed assessment should be undertaken where the additional impounded water >1% water body length.
	Hydroelectric power scheme - new weir structure			All new weir / barrage / barrier structures will need detailed assessment.

Type of modification		Guidance on level of WFD assessment required		
		Detailed impact assessment unlikely - follow best practise guidance	**Detailed impact assessment unlikely - follow best practise and record in the iRBM data solution**	**Detailed impact assessment may be required - use thresholds of concern as guidance. River water body length is provided in the River Basin Characterisation data set in the iRBM data solution. If no detailed assessment is undertaken follow best practise and record in the iRBM data solution**
	Hydroelectric power scheme			Calculate the length of the depleted reach. Detailed assessment should be undertaken where the depleted reach is >1% water body length.
Fish passage	Installation of a fish pass			Consideration should first be made as to whether the impoundment could be removed or modified. Where a fish pass is the appropriate option then calculate the length of the structure. Detailed assessment should be undertaken where > 2% of the water body length is impacted.
Flood storage area	Flood storage area			All flood storage areas require detailed assessment
Capital dredge	Capital dredge			All capital dredges will require a detailed assessment
Maintenance activities	Sediment management			Calculate the length of river over which sediment is to be removed, moved or manipulated. Detailed assessment should be undertaken where >2% of the water body is impacted.
	Management of woody debris			Thresholds for detailed assessment are not appropriate for the management of woody debris. Detailed assessment may be required depending on circumstances and scale of activity and expert judgement should be applied. Good practise guidance can be found in the mitigation measure manual at http://evidence.environment-agency.gov.uk/FCERM/en/SC060065/MeasuresList/M5/M5T3.aspx

Type of modification		Guidance on level of WFD assessment required		
		Detailed impact assessment unlikely - follow best practise guidance	**Detailed impact assessment unlikely - follow best practise and record in the iRBM data solution**	**Detailed impact assessment may be required - use thresholds of concern as guidance. River water body length is provided in the River Basin Characterisation data set in the iRBM data solution. If no detailed assessment is undertaken follow best practise and record in the iRBM data solution**
Vegetation management	Removal/management of riparian vegetation			Detailed assessment is required where the asset is being managed to target condition 2 and/or if undertaking grass control at M1 or M2; weed control at W1 or W2, WB1 or WB2 and tree control at TB1 or TB2 under the "Delivering consistent standards for sustainable asset management guidelines" (http://ams.ea.gov/ams_root/2009/301_350/301_09_SD05.pdf). If the vegetation management activity is not covered by the ASM standards then calculate the length of water body that vegetation is being removed from or managed. Detailed assessment in required where >5% of water body length is being impacted
	Removal/management of in stream vegetation			
Bridges and other types of crossing structure	Bridges	Minor bridges with no construction on bed or banks	Bridges with no construction on bed (e.g. no piers or in-channel supports) and ≤20m of total bank affected.	All bridges with > 20m bank affected or an in channel support require detailed assessment
		Temporary bridges in rivers <5m wide		
	Fords			Refer to thresholds for bed and bank protection as appropriate

Type of modification		Guidance on level of WFD assessment required		
		Detailed impact assessment unlikely - follow best practise guidance	**Detailed impact assessment unlikely - follow best practise and record in the iRBM data solution**	**Detailed impact assessment may be required - use thresholds of concern as guidance. River water body length is provided in the River Basin Characterisation data set in the iRBM data solution. If no detailed assessment is undertaken follow best practise and record in the iRBM data solution**
Removal of natural barriers	Removal of natural barriers (removal of waterfalls and other in-stream natural barriers, usually to permit upstream fish migration)			All cases of natural barrier removal need detailed assessment

ardent

BIRCHAM DYSON BELL

Buro Happold

CORDEROY

Halcrow

JOHN McASLAN + PARTNERS

Quod

steer davies gleave

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URS

Volterra