CITY OF LONDON

STRATEGIC FLOOD RISK ASSESSMENT

NOVEMBER 2017

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City of London Corporation

Report (First Issue)

Project no: 70033014
Date: November 2017

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QUALITY MANAGEMENT

ISSUE/REVISION	FIRST ISSUE	REVISION 1	REVISION 2	REVISION 3
Remarks	Draft for Comment	Draft for Consultation	Final	
Date	July 2017	September 2017	December 2017	
Prepared by	Sophie Webber	Sophie Webber	Sophie Webber	
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Project number	70033014	70033014	70033014	
File reference	\\uk.wspgroup.com\central data\Projects\700330xx\70033014 - City of London SFRA 2017\02 WIP\DE Development\03 Document\02 City of London SFRA			

TABLE OF CONTENTS

T A B L E S

A P P E N D I C E S

EXECUTIVE SUMMARY

This review of the Strategic Flood Risk Assessment (SFRA) for the City of London builds upon the previous SFRAs prepared in 2007 and 2012. Since 2012 new information has been produced and national guidance relating to flood risk management has been updated, in particular in relation to the assessment of climate change. This SFRA incorporates the most up-to-date information on all sources of flood risk: fluvial (rivers), tidal, surface water, groundwater, sewers and water main bursting.

Flood risk data has been collected from the City of London Corporation, the Environment Agency and Thames Water. The SFRA has also been informed by additional modelling of surface water flood risk undertaken as part of this study. The most important changes since the 2012 SFRA are as follows:

- The Environment Agency released the Flood risk assessments: climate change allowances guidance in 2016 which provided new climate change allowances for peak river flows, sea level rise and peak rainfall intensity. For the City of London the changes to the allowances for peak rainfall intensity are most significant as this affects the assessment of flood risk from surface water in the future;
- New modelling has been undertaken by the Environment Agency of the risk of breaching of the River Thames flood defences. This new modelling considers the risk of defence breach along the entire length of the River Thames flood wall, within the City of London; whereas the previous results only considered one discrete location in neighbouring Westminster. Previous modelling only indicated a risk of flooding in the south western part of the City of London however now, there are additional areas along the entire River Thames frontage that are indicated to be at risk;
- New information on surface water flood risk has been provided and this study has undertaken a comprehensive review of the merits of the different approaches. Based on a comparison of the results it has been concluded that the surface water modelling outputs from the 2012 SFRA are to be used for this 2017 SFRA update in terms of policy and SFRA guidance. This is a pre-cautionary approach due to the high level of uncertainty in predictions, as these results provide the most conservative assessment of surface water flood risk in the City of London; and,
- The risk of water main bursting has been identified as a significant potential source of flooding in the City of London. Although no assessment of this risk has been possible in the SFRA review, the City of London Corporation will be working with Thames Water to better understand the risk of flooding from water main bursting and the impacts this may have.

1 INTRODUCTION

1.1 PROJECT BACKGROUND

The Strategic Flood Risk Assessment (SFRA) for the City of London was originally prepared by Mouchel Parkman in August 2007 and was updated by Halcrow in May 2012 to include a Level 2 assessment. Since then, there have been a number of updates in flood risk guidance and planning policy, and new flood risk data has been produced.

WSP were commissioned by the City of London Corporation to review the 2012 SFRA and incorporate any up-to-date information on flood risk which affects the City of London.

Flooding is a natural process which can occur at any time, in a wide variety of locations. The speed of inundation and duration of flood events can vary drastically which affects the severity of the impacts. As a result of climate change, the frequency, velocity, depth, patterns and severity of flood events will cause a greater risk of flooding and any subsequent damages.

Typically, fluvial and coastal sources are the principal causes of flooding however, in high density urban areas such as the City, there are other sources which may result in large flood damages i.e. pluvial, groundwater, sewer surcharge and burst water mains.

This SFRA provides information on all the likely sources of flooding within the City of London administrative boundary. It also acts as an evidence base in development planning, assisting with defining local flood risk policies and emergency planning procedures.

1.2 THE LOCAL CONTEXT

The City of London is located on the north bank of the River Thames within Greater London (see Figure 33014-COL-101 – Study Area in Appendix A). It is the historic core of London and was founded on higher ground than the neighbouring boroughs, which provides natural protection from tidal flooding. The topography for the City of London can be found in Figure 33014-COL-102 - Topography in Appendix A.

The City of London has an area of approximately 2.9km^2 and borders the London Boroughs of Camden, Islington, Hackney, Tower Hamlets and the City of Westminster. It also borders Southwark and Lambeth, on the opposite side of the River Thames (see Figure 33014-COL-103 – Borough Boundary and Neighbouring Boundaries in Appendix A).

Two historical watercourses flow through the City of London: the River Fleet and the River Walbrook. They join the Thames within the City of London boundary however; they are now culverted within the sewer network.

The City of London is heavily urbanised with primarily commercial buildings and infrastructure. Approximately 8,000 people live within the City of London in comparison to the working population of 450,000 people who commute to work within its boundaries[1]. The City of London is one of the main financial districts in the world. In addition to commercial buildings, it is also home to historical landmarks and buildings including St Paul's Cathedral and Mansion House. There are small areas of open space – primarily private and public gardens, and churchyards.

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[1] Source: City of London Resident Estimates and Projections 2016

1.3 OUTLINE APPROACH

This SFRA approach refines and builds upon the 2007 and 2012 SFRAs which assessed all forms of flood risk: fluvial, tidal, pluvial, groundwater and sewer, taking into account any future impacts as a result of climate change. The study builds upon the modelling results for tidal and surface water flooding produced as part of the Level 2 Assessment undertaken by Halcrow in 2012. In addition this study has highlighted the risk of flooding from water supply main bursting however at present no quantitative assessment of this risk has been possible as no information has been made available in terms of pipe sizes and locations.

Flood risk data has been obtained from the City of London Corporation, the Environment Agency and Thames Water. The SFRA has also been informed using additional modelling results undertaken as part of this study.

This report supersedes the two previous SFRA's written in 2007 and 2012.

1.4 SFRA REVIEW AIMS AND OBJECTIVES

The main aim of this SFRA review (Level 2) is to provide an improved and updated assessment of flood risk within the City of London, to inform planning and policy and to outline potential mitigation options for reducing the impact of any flooding. The objectives agreed with the City of London Corporation are as follows:

- Review fluvial, tidal and groundwater assessments, including breach assessments of River Thames flood defences;
- Update text in the SFRA document in relation to the Thames Estuary 2100 Plan (Environment Agency, 2012) and its current implementation through the Thames Estuary Asset Management 2100 programme (TEAM2100);
- Refine the assessment of surface water flood risk undertaken as part of the 2012 SFRA incorporating the results from the latest Thames Water sewer modelling;
- Assess the risk of flooding from burst water supply mains;
- Identify SuDS measures and, flood resilience and flood resistance measures;
- Review the flood risk policies of the City of London Local Plan and recommend additional policy options, if needed;
- Undertake an assessment of the consequences of flood risk including an economic assessment; and,
- Update the existing asset register held by the City of London Corporation.

This SFRA review provides the necessary information to assist with the application of the Sequential and Exception Test. It also forms part of the evidence base for the update of the local development plan. Alongside other planning policies, this SFRA allows the City of London Corporation to:

- Prepare appropriate policies for the management of flood risk;
- Inform the Sustainability Appraisal of planning policy documents so that flood risk is taken into account when considering options, and in the preparation of strategic spatial planning policies;
- Identify the level of detail and supplementary information required for site-specific flood risk assessments (FRAs); and,
- Help inform the acceptability of flood risk in relation to emergency planning capability.

2 PLANNING POLICY AND CONTEXT

2.1 NATIONAL POLICY

NATIONAL PLANNING POLICY FRAMEWORK

The National Planning Policy Framework (NPPF) was published in March 2012 and sets out the Government's strategy for planning in England.

The NPPF was accompanied by a series of Technical Guidance which was replaced by a series of Practice Planning Guidance (PPG) documents in March 2014. The PPG documents were updated in April 2015. The Flood Risk and Coastal Change (FRCC) PPG provides additional guidance on the preparation of Strategic Flood Risk Assessments (SFRA).

The FRCC PPG states that a local authority should use a SFRA to apply a risk-based approach to development, applying the Sequential Test to potential site allocations. Where the Sequential Test is unable to deliver a sufficient number of sites to meet planning requirements, the Exception Test should be applied to deliver additional development sites.

THE SEQUENTIAL TEST

The aim of the Sequential Test is to locate development in the areas of lowest flood risk. The application of the sequential test within the City of London is difficult as it relies on parcels of land being specifically allocated for development within the Local Plan. Individual site allocation is not generally promoted in the City of London as the majority of developable land is Brownfield (land that has been previously developed). However, the typical process of the sequential test is as follows:

- Only where no sites are available in Flood Zone 1 should a site in the higher risk flood zones be considered. Sequentially, development should be located in Flood Zone 2 before sites in Flood Zone 3a are considered. The functional floodplain, Flood Zone 3b, should be protected; only essential infrastructure development that passes the Exception Test and water compatible development should be permitted;
- When locating sites in Flood Zones 2 or 3a, it is necessary to take the vulnerability of the proposed development into account. The flood vulnerability reflects the land uses within the proposed development and is a measure of the level of resilience to damage from flooding. The FRCC PPG categorises land uses into five vulnerability classes, ranging from essential infrastructure to water compatible development. These categories are used to determine the appropriateness of a given land use within each flood zone. The flood risk vulnerability classification is shown in Table 2-1 which is taken from Table 2 of the FRCC PPG, and the flood risk vulnerability and flood zone 'compatibility' is indicated in Table 2-2 taken from Table 3 of the FRCC PPG; and,
- When allocating several developments of different vulnerabilities, it is practical to allocate the most vulnerable developments first to ensure optimum placement at lowest flood risk. However, less vulnerable developments should continue to follow the sequential approach within their boundaries in order to steer as much development as possible to Flood Zone 1. Developments should not simply be allocated to zones with an 'acceptable' level of flood risk, for example a 'more vulnerable' development should not be put in Flood Zone 2 if a suitable (i.e. taking other development considerations into account) Flood Zone 1 site is available. A specific consideration for the City of London is commercial basement properties where critical infrastructure such as IT equipment can be located below ground level. Further guidance on the approach for basements is included in Section 9.

Table 2-1 Flood Risk Vulnerability Classification (from Flood Risk and Coastal Change PPG Table 2)

CLASSIFICATION	LAND USES
Essential Infrastructure	→ Essential transport infrastructure (including mass evacuation routes) which has to cross the area at risk. → Essential utility infrastructure which has to be located in a flood risk area for operational reasons, including electricity generating power stations and grid and primary substations; and water treatment works that need to remain operational in times of flood. → Wind turbines.
Highly Vulnerable	→ Police and ambulance stations; fire stations and command centres; telecommunications installations required to be operational during flooding. → Emergency dispersal points. → Basement dwellings. → Caravans, mobile homes and park homes intended for permanent residential use. → Installations requiring hazardous substances consent. (Where there is a demonstrable need to locate such installations for bulk storage of materials with port or other similar facilities, or such installations with energy infrastructure or carbon capture and storage installations, that require coastal or water-side locations, or need to be located in other high flood risk areas, in these instances the facilities should be classified as 'Essential Infrastructure').
More Vulnerable	→ Hospitals. → Residential institutions such as residential care homes, children's homes, social services homes, prisons and hostels. → Buildings used for dwelling houses, student halls of residence, drinking establishments, nightclubs and hotels. → Non-residential uses for health services, nurseries and educational establishments. → Landfill and sites used for waste management facilities for hazardous waste. → Sites used for holiday or short-let caravans and camping, subject to a specific warning and evacuation plan.
Less Vulnerable	→ Police, ambulance and fire stations which are not required to be operational during flooding. → Buildings used for: shops; financial, professional and other services; restaurants, cafes and hot food takeaways; offices; general industry,

CLASSIFICATION	LAND USES
	storage and distribution; non-residential institutions not included in the ‘more vulnerable’ class; and assembly and leisure. → Land and buildings used for agriculture and forestry. → Waste treatment (except landfill and hazardous waste facilities). → Minerals working and processing (except for sand and gravel working). → Water treatment works which do not need to remain operational during times of flood. → Sewage treatment works, if adequate measures to control pollution and manage sewage during flooding events are in place.
Water-Compatible Development	→ Flood control infrastructure. → Water transmission infrastructure and pumping stations. → Sewage transmission infrastructure and pumping stations. → Sand and gravel workings. → Docks, marinas and wharves. → Navigation facilities. → Ministry of Defence, defence installations. → Ship building, repairing and dismantling, dockside fish processing and refrigeration and compatible activities requiring a waterside location. → Water-based recreation (excluding sleeping accommodation). → Lifeguard and coastguard stations. → Amenity open space, nature conservation and biodiversity, outdoor sports and recreation and essential facilities such as changing rooms. → Essential ancillary sleeping or residential accommodation for staff required by uses in this category, subject to a specific warning and evacuation plan.

Table 2-2: Flood Risk Vulnerability and Flood Zone 'Compatibility' (from Flood Risk and Coastal Change PPG, Table 3)

FLOOD RISK VULNERABILITY CLASSIFICATION	ESSENTIAL INFRASTRUCTURE	HIGHLY VULNERABLE	MOVE VULNERABLE	LESS VULNERABLE	WATER COMPATIBLE
Flood Zone 1	Suitable	Suitable	Suitable	Suitable	Suitable
Flood Zone 2	Suitable	Exception Test required	Suitable	Suitable	Suitable
Flood Zone 3a	Exception Test required *	Not suitable	Exception Test required	Suitable	Suitable
Flood Zone 3b	Exception Test required **	Not suitable	Not suitable	Not suitable	Suitable*

* In Flood Zone 3a, essential infrastructure should be designed and constructed to remain operational and safe in times of flood.

** In Flood Zone 3b (functional floodplain), essential infrastructure that has to be there and has passed the Exception Test, and water compatible uses, should be designed and constructed to:

- remain operational and safe for users in times of flood;
- result in no net loss of floodplain storage; and,
- not impede water flows and not increase flood risk elsewhere.

Within each flood zone new development should be directed to sites with lower flood risk, which generally involves allocating new development as close as possible towards the adjacent zone of lower probability.

The Sequential Test should also take account of other sources of flooding such as surface water runoff, groundwater or sewer flooding. The risk from other sources is not specified using zones (for tidal and fluvial flood risk) but the risk may be perceived as significant if persistent flooding has historically occurred or if modelling has become available which indicates a high likelihood of deep or fast flowing water.

More specifically, this SFRA identifies areas which are considered to have a high surface water flood risk. Proposed development within areas considered to be at a high risk of surface water flooding should be classified as though they are part of Flood Zone 3a when applying the Sequential and Exception Tests. However the majority of new development in the City of London falls within the Less Vulnerable classification and therefore the flood damages to people is likely to be limited.

THE EXCEPTION TEST

The Exception Test is appropriate where the Sequential Test is not able to deliver a sufficient number of suitable sites, and also where some continuing development is necessary for wider sustainable development reasons. This takes into account the need to avoid social or economic blight and the need for certain services to be near the communities they serve. For example, the flood risk due to siting a 'more vulnerable' health service in Flood Zone 2 may be outweighed by the needs of a local community to have a health centre within a practicable distance. It may also be appropriate to use the Exception Test where restrictive national designations such as heritage designations (e.g. Conservation Areas and Listed Buildings), prevent the availability of sites in lower risk areas.

As site allocation is not generally promoted within the City of London, an assessment of the suitability of any proposed development in areas considered to be at risk from flooding must be made in reference to Table 2-1 and Table 2-2.

The NPPF requires that for the Exception Test to be passed:

1. It must be demonstrated that the development provides wider sustainability benefits to the community that outweigh flood risk, informed by a SFRA where one has been prepared; and,
2. A site-specific FRA must demonstrate that the development will be safe for its lifetime taking account of the vulnerability of its users, without increasing flood risk elsewhere, and, where possible, will reduce flood risk overall.

Both elements of the test will have to be passed for development to be allocated or permitted.

Within the City of London, commercial development is the preferred option for sites adjacent to the River Thames, however residential development is occasionally proposed by applicants. Residential development is classified as ‘More Vulnerable’ and as land neighbouring the river is typically located within Flood Zones 2 or 3, this can conflict with the Sequential Test (refer to Table 2-1 and Table 2-2).

Due to the nature of flooding within the City of London, it is proposed that the Exception Test is also applied to areas of high local surface water or sewer flood risk, depending on the vulnerability classification of the proposed land use.

THE FLOOD AND WATER MANAGEMENT ACT

The Flood and Water Management Act (April 2010) is a key piece of legislation which was introduced to improve flood risk management and support continuity of water supply and other essential services. A key feature of the Act is to implement the recommendations made in the Pitt Review, following the exceptional flooding during the summer of 2007. The Flood and Water Management Act increases the emphasis on all sources of flooding, particularly surface water which was particularly devastating during the 2007 floods.

The Act has given the City of London Corporation, as a Lead Local Flood Authority (LLFA), a number of responsibilities and powers with regards to managing local flood risk, which includes surface runoff, groundwater and ordinary watercourses (including lakes and ponds). The City of London does not have any ordinary watercourses. LLFAs are encouraged to work in partnership with other organisations, who hold valuable local knowledge which in this case are Thames Water, Transport for London, the Environment Agency, the Greater London Authority and nearby London Boroughs.

THE FLOOD RISK REGULATIONS

The Flood Risk Regulations 2009 converts the EU Floods Directive into UK law. In accordance with this, the City of London Corporation has a duty to carry out a Preliminary Flood Risk Assessment (PFRA). The PFRA is a high level screening exercise looking at readily available flood risk information and determining flood risk areas of national significance. Information from the SFRA is used to inform the PFRA and vice-versa.

CIVIL CONTINGENCIES ACT 2004

The Civil Contingencies Act provides a single framework for civil protection in the United Kingdom. It is split into two separate parts:

- Part 1: Local arrangements for civil protection; and,
- Part 2: Emergency powers.

An emergency is defined as ‘an event or situation which threatens serious damage to human welfare in a place in the UK’ and ‘an event or situation which threatens serious damage to the environment of a place in the UK’.

Part 1 establishes a clear set of roles and responsibilities for those involved in emergency preparation and response at a local level. The City of London Corporation are a category 1 organisation and are subject to the following civil protection duties:

- Assess the risk of emergencies occurring and use this to inform contingency planning;
- Put in place emergency plans;
- Put in place business continuity management arrangements;
- Put in place arrangements to make information available to the public about civil protection matters and maintain arrangements to warn, inform and advise the public in the event of an emergency;
- Share information with other local responders to enhance co-ordination;
- Co-operate with other local responder to enhance co-ordination and efficiency; and,
- Provide advice and assistance to businesses and voluntary organisations about business continuity management.

Part 2 updates the 1920 Emergency Power Act to reflect any developments since the Act was written, and includes the current and future risk profile. Part 2 allows for the making of temporary special legislation to assist with the most serious emergencies.

FLOOD RISK ASSESSMENTS: CLIMATE CHANGE ALLOWANCES (APRIL 2016)

In February 2016, the Environment Agency released new guidance, ‘Flood risk assessments: climate change allowances’ guidance (Environment Agency, 2016) to support the NPPF (updated in April 2016). The climate change allowances are predictions of anticipated change for:

- Peak river flow by river basin district;
- Peak rainfall intensity;
- Sea level rise; and,
- Offshore wind speed and extreme wave height.

The most significant risks to the City of London arise from surface water flooding as the City is defended from fluvial and tidal flood risk; therefore the most relevant climate change considerations for this SFRA are associated with rainfall intensity. This impact is also relevant to the risk of flooding from the combined sewer system, as increased rainfall intensity will increase the volumes of water that the sewer system will have to cope with in the future.

Within the guidance it states that flood risk assessments should consider both the central and upper end allowances for increases in peak rainfall intensity to understand the range of impacts that may occur as a result of climate change. Over the next 100 years the central allowances for increases in peak rainfall intensity are expected to be:

- 5% in the 2020's (2015 – 2039);
- 10% in the 2050's (2040 – 2069); and,
- 20% in the 2080's (2070 – 2115).

The upper end allowances for increases in peak rainfall intensity are expected to be:

- 10% in the 2020's (2015 – 2039);
- 20% in the 2050's (2040 – 2069); and,
- 40% in the 2080's (2070 – 2115).

Climate change is predicted to have a major impact to the threat of flooding from the River Thames. Peak river flows in the Thames River Basin District (using the upper end estimates) are expected in increase by:

- 25% in the 2020's (2015 – 2039);
- 35% in the 2050's (2040 – 2069); and,
- 70% in the 2080's (2070 – 2115).

The sea level rise allowances for London are expected to increase by 1.21m between 1990 and 2115. Increases, per epoch, are listed below:

- 4mm/year (1990 – 2025);
- 8.5mm/year (2026 – 2055);
- 12mm/year (2056 – 2085); and,
- 15mm/year (2086 – 2115).

Sea level rise will gradually reduce the level of protection that defences offer. However, due to the presence of the Thames Barrier, sea level rise within the City of London will be different to the numbers indicated above. The TE2100 study supersedes these allowances when considering the combined tidal-fluvial risk to the City of London (for more information refer to details of the TE2100 study in Section 2.2).

The UK Climate projections (UKCP09) are currently being reviewed, with new projections expected in 2018.

2.2 LOCAL AND REGIONAL PLANS

LOCAL PLAN

The City of London Local Plan sets out the City of London Corporation's vision, strategy, objectives and policies for the City. The Local Plan was adopted in January 2015 and is being reviewed and rolled forward under the banner City Plan 2036.

Section 3.18 sets out Core Strategic Policy CS18 which aims to ensure the City of London remains at low risk from all types of flooding by:

- Minimising river flooding risk, requiring development in the City Flood Risk Area, defined in Figure S of the Local Plan, to seek opportunities to deliver a reduction in flood risk compared with the existing situation:
  - Applying the Sequential Test and Exception Test as set out in the NPPF and FRCC PPG and requiring Flood Risk Assessments to be submitted, in support of all planning applications in the City of London Flood Risk Area (Environment Agency Flood Zones 2 and 3 and surface water flood risk hotspots) and for major development proposals elsewhere; and,
  - Protecting and enhancing existing flood defences along the riverside, particularly those identified as fair or poor in the current City of London SFRA. Development adjacent to the River Thames must be designed to allow for maintenance of flood defences.
- Reducing the risks of flooding from surface water throughout the City of London, ensuring that development proposals minimise water use and reduce demands on the combined surface water and sewerage network by applying the London Plan drainage hierarchy;
- Reducing rainwater run-off, through the use of suitable Sustainable Drainage Systems (SuDS), such as green roofs and rainwater attenuation measures throughout the City of London;
- Ensuring that wider flood defences afford the highest category of protection for the City of London, participating in the development and implementation of the Environment Agency's Thames Estuary 2100 project; and,
- Reviewing and updating the City of London's Strategic Flood Risk Assessment at least every 5 years or more frequently if circumstances require, ensuring that changes in flood risk are identified and suitable responses implemented.

Policy CS18 is supported by three Development Management Policies which are as follows:

Policy DM 18.1 'Development in a City Flood Risk Area' states that:

- Where development is proposed within a City Flood Risk Area evidence must be presented to demonstrate that:
  - The site is suitable for the intended use, in accordance with Environment Agency and Lead Local Flood Authority advice;
  - The benefits of the development outweigh the flood risk to future occupants; and,
  - The development will be safe for occupants and visitors and will not compromise the safety of other premises or increase the risk of flooding elsewhere.
- Development proposals, including change of use, must be accompanied by a site-specific flood risk assessment for:
  - All sites within the City Flood Risk Area as shown on the Policies Map; and,
  - All major development elsewhere within the City of London.
- Site-specific flood risk assessments must address the risk of flooding from all sources and take account of the City of London Strategic Flood Risk Assessment. Necessary mitigation measures must be designed into and integrated with the development and may be required to provide protection from flooding for properties beyond the site boundaries, where feasible and viable;
- Where development is within the City Flood Risk Area, the most vulnerable uses must be located in those parts of the development which are least at risk. Safe access and egress routes must be identified;
- For minor development outside of the City Flood Risk Area, an appropriate flood risk statement may be included in the Design and Access Statement; and,

- Flood resistant and resilient designs which reduce the impact of flooding and enable efficient recovery and business continuity will be encouraged.

Policy DM 18.2 ‘Sustainable Drainage Systems (SuDS)’ states that:

- The design of the surface water drainage system should be integrated into the design of proposed buildings or landscaping, where feasible and practical , and should follow the SUDS management train and London Plan drainage hierarchy;
- SuDS designs must take into account of the City’s archaeological heritage, complex underground utilities, transport infrastructure and other underground structures, incorporating suitable SuDS elements for the City’s high density urban situation; and,
- SuDS should be designed, where possible, to maximise contributions to water resource efficiency, biodiversity enhancement and the provision of multifunctional open spaces.

Policy DM 18.3 ‘Flood protection and climate change resilience’ states that:

- Development must protect the integrity and effectiveness of structures intended to minimise flood risk and, where appropriate, enhance their effectiveness; and,
- Wherever practicable, development should contribute to an overall reduction in flood risk within and beyond the site boundaries, incorporating flood alleviation measures for the public realm, where feasible.

Core Strategic Policy CS9: Thames and Riverside promotes the City of London’s unique riverside location and provides a clause relating to ‘refusing development on or over the River, except for structures which specifically require a waterside location for river-related uses’.

THAMES CATCHMENT FLOOD MANAGEMENT PLAN

The Thames Catchment Flood Management Plan (CFMP) (Environment Agency, 2009) was produced by the Environment Agency in 2009. The CFMP provides an approach for managing flood risk and provides key policies and actions at a catchment scale.

The CFMP does not provide any flood risk management policies for the City of London and indicates that the future management of tidal flood risk in London is being addressed by the Thames Estuary 2100 Flood Risk Management Plan.

THAMES ESTUARY 2100 PLAN

The Thames Estuary (TE) 2100 Plan (Environment Agency, 2012) sets out the Environment Agency’s recommendations for flood risk management within London and the Thames Estuary until year 2100.

The TE2100 study has undertaken analysis of the impacts of climate change on flood risk from the River Thames to central London. Upstream of the Thames Barrier, the impact of climate change is less intuitive when considering the impact of joint probability on water levels. Because water levels are predicted to increase in the future, it is likely that the number of actual Barrier closures will increase. Statistical analysis has previously shown that the highest water levels upstream of the Barrier are attributable to ‘near closure’ events, when the Barrier remains open. The aforementioned report found that if the Barrier continues to operate to the current closure rules, joint probability water levels for a specific return period through Central London would be slightly lower under climate change conditions than they are for the present day (based on certain assumptions, including the use of only one climate change scenario and neglecting the consideration of the frequency of closure of the Barrier).

The City of London falls within Action Zone 2 – Central London which contains a number of highly vulnerable sites. The three main sources of flooding are tidal from the River Thames, surface water, and groundwater flooding. However, it is unlikely that flooding from the Thames would be an issue for the foreseeable future due to the presence of the Thames Barrier and the defences along the River Thames.

The policy for the action zone is P5 – take further action to reduce the risk of flooding (now or in the future). The TE2100 recommended actions are as follows:

- To agree a programme of floodplain management including local flood protection, resilience and emergency plans for vulnerable key sites in Action Zone 2;
- To agree partnership arrangements and principles to ensure that new development in the central London tidal flood risk area is safe and that where possible applies the NPPF to actually reduce the consequence of flooding. It is essential that flood risk management is factored into the planning process at all levels for the first 25 years from 2010 to the end of the century;
- To maintain, enhance or replace, the river defence walls and active structures through central London for the first 25 years of the plan from 2010 to the end of the century;
- To implement a programme of defence raising through central London in 2065; and,
- To agree a programme of managing flooding from other sources in the defended tidal floodplain.

Key actions are as below:

- In order to protect the Action Zone 2 area, there is the option to raise the existing tidal defences. Wherever possible, defences should be set back from the river bank which would allow areas of the riverside to be inundated by the tide occasionally.
- The TE2100 study has highlighted that long lengths of the foreshore are eroding within the Action Zone 2 area, including Blackfriars. It may be necessary to improve defences to avoid any further erosion.

CITY OF LONDON LOCAL FLOOD RISK MANAGEMENT STRATEGY

The Flood and Water Management Act (2010) places a duty on Lead Local Flood Authorities to produce Local Flood Risk Management Strategies. These documents help to understand the broad nature and extent of local flood risk and how it will be managed. The Local Flood Risk Management Strategy (LFRMS) is an over-arching strategy which is seen as the first step of understanding and managing local flood risk (risks from ordinary watercourses, surface water and groundwater). The LFRMS includes a Flood Risk Action Plan which identifies the practical steps that the City Corporation and other partners need to take to reduce the risks from flooding.

The City of London LFRMS has the following objectives that will be delivered through specific actions outlined in the action plan:

- To provide up to date information regarding the level of flood risk within the City taking account of emerging climate change impacts;
- To reduce the vulnerability and cost to City businesses, residents and visitors of flood risk;
- To respond effectively in the event of flooding providing emergency assistance to those in need;
- To assist in recovery enabling the City residents and businesses to resume normal activities promptly; and,

- To engage with other flood risk management authorities taking action to reduce flood risk through partnership working within and beyond the City's boundaries.

THAMES STRATEGY SUPPLEMENTARY PLANNING DOCUMENT

The London Plan requires Thames-side boroughs and the City Corporation to identify a Thames Policy Area and formulate policies and a strategy for this area. The City's part of the Thames Policy Area is identified in the Local Plan and on the Local Plan Policies Map. The Thames Strategy Supplementary Planning Document provides guidance on the following topics:

- Development and public realm enhancement within the Thames Policy Area;
- Assisting the implementation of improved river transport, navigation and recreation opportunities;
- Protection and enhancement of heritage assets;
- Inclusive access for all wherever practicable;
- Flood risk, climate resilience and biodiversity enhancement; and,
- The implications for development of site safeguarding at Blackfriars for the Thames Tideway Tunnel and at Walbrook Wharf for waterborne freight traffic including waste management.

THE LONDON PLAN

The current London Plan was adopted in March 2016. It provides an overall strategic plan for the Mayor of London, 32 London boroughs, the Mayoral Development Corporations and the City of London. The plan sets out an integrated economic, environmental, transport and social framework for any development in London over the next 20 – 25 years.

Policies 5.10, 5.11, 5.12 and 5.13 are related to improving water quality, flood mitigation and reducing flood risk through Sustainable Drainage Systems.

Policy 5.10 (Urban Greening) states that:

- The Mayor will promote and support urban greening, such as new planting in the public realm (including streets, squares and plazas) and multifunctional green infrastructure, to contribute to the adaptation to, and reduction of, the effects of climate change;
- The Mayor seeks to increase the amount of surface area greened in the Central Activities Zone by at least five per cent by 2030, and a further five percent by 2050;
- Development proposals should integrate green infrastructure from the beginning of the design process to contribute to urban greening, including the public realm. Elements that can contribute to this include tree planting, green roofs and walls, and soft landscaping. Major development proposals within the Central Activities Zone should demonstrate how green infrastructure has been incorporated; and,
- Boroughs should identify areas where urban greening and green infrastructure can make a particular contribution to mitigating the effects of climate change, such as the urban heat island.

Policy 5.11 (Green Roofs and Development Site Environs) states that:

- Major development proposals should be designed to include roof, wall and site planting, especially green roofs and walls where feasible, to deliver as many of the following objectives as possible:
    - Adaption to climate change (i.e. aiding cooling);
    - Sustainable urban drainage;

- Mitigation of climate change (i.e. aiding energy efficiency);
- Enhancement of biodiversity;
- Accessible roof space;
- Improvements to appearance and resilience of the building; and,
- Growing food.

→ Within the Local Development Frameworks (LDFs) boroughs may wish to develop more detailed policies and proposals to support the development of green roofs and the greening of development sites. Boroughs should also promote the use of green roofs in smaller developments, renovations and extensions where feasible.

Policy 5.12 (Flood Risk Management) states that:

→ The Mayor will work with all relevant agencies, including the Environment Agency, to address current and future flood issues and minimise risks in a sustainable and cost effective way;

→ Development proposals must comply with the flood risk assessment and management requirements set out in the NPPF and the associated technical guidance on flood risk over the lifetime of the development and have regard to measures proposed in Thames Estuary 2100 and Catchment Flood Management Plans;

→ Developments which are required to pass the Exception Test set out in the NPPF and the Technical Guidance will need to address flood resilient design and emergency planning by demonstrating that:

- The development will remain safe and operational under flood conditions;
- A strategy of either safe evacuation and / or safely remaining in the building is followed under flood conditions;
- Key services including electricity, water etc. will continue to be provided under flood conditions; and,
- Buildings are designed for quick recovery following a flood.

→ Development adjacent to flood defences will be required to protect the integrity of existing flood defences and wherever possible should aim to be set back from the banks of watercourses and those defences to allow their management, maintenance and upgrading to be undertaken in a sustainable and cost effective way; and,

→ In line with the NPPF and FRCC PPG, boroughs should, when preparing Local Development Frameworks, utilise SFRAs to identify areas where particular flood risk issues exist and develop actions and policy approaches aimed at reducing these risks, particularly through redevelopment of sites at risk of flooding and identifying specific opportunities for flood risk management measures.

Policy 5.13 (Sustainable Drainage) states that:

→ Development should utilise SuDS unless there are practical reasons for not doing so, and should aim to achieve greenfield runoff rates and ensure that surface water runoff is managed as close to the source as possible in line with the following drainage hierarchy:

1. Store rainwater for later use;
2. Use infiltration techniques, such as porous surfaces in non-clay areas;
3. Attenuate rainwater in ponds or open water features for gradual release;
4. Attenuate rainwater by storing in tanks or sealed water features for gradual release;
5. Discharge rainwater direct to a watercourse;
6. Discharge rainwater to a surface water sewer/ drain; or,
7. Discharge rainwater to a combined sewer.

- Drainage should be designed and implemented in ways that deliver other policy objectives of this Plan, including water use efficiency and quality, biodiversity, amenity and recreation; and,
- Within LDFs boroughs should, in line with the Flood and Water Management Act, utilise Surface Water Management Plans to identify areas where there are particular surface water management issues and develop actions and policy approaches aimed at reducing these risks.

The London Plan promotes the use of green roofs which in turn will provide multiple benefits to London amenity, biodiversity and water quality.

The Mayor is reviewing the London Plan and intends to publish a draft plan for consultation by the end of 2017, with a view to formally adopting the plan in late 2019.

DRAIN LONDON

The Drain London Partnership includes the 32 London Boroughs and the City of London, the Environment Agency, Thames Water, Transport for London and the Greater London Authority; they are working together to mitigate the risk to London from surface water flooding and to increase the use of sustainable drainage.

The Drain London Partnership was set up to deliver Surface Water Management Plans (SWMP) and the first round of Preliminary Flood Risk Assessments (PFRA) in 2012 for the 32 London Boroughs, the City of London and the Mayoral Development Corporations (the London Legacy Development Corporation and the Old Oak and Park Royal Development Corporation).

Additionally, the partnership has produced the London Sustainable Drainage Action Plan and has undertaken detailed studies into flood risk areas and assessed the vulnerability of critical infrastructure.

LONDON SUSTAINABLE DRAINAGE ACTION PLAN 2016

The London Sustainable Drainage Action Plan was published by the Greater London Authority in December 2016. The main focus of the action plan is on the ‘retrofitting of sustainable drainage to existing buildings, land infrastructure’, subsequently managing rainwater as a valuable resource as opposed to a waste product. The action plan includes 40 actions to be undertaken within the next 5 years. Actions include:

- Providing strategic guidance on sustainable drainage requirements for major development locations;
- Providing guidance and good examples of sustainable drainage applicable to all sectors (education, housing, retail etc.); and,
- Identifying opportunities and funding for sustainable drainage retrofit at the same time as planned maintenance, repair and improvement works in all sectors (education, housing, retail etc.).

3 FLUVIAL AND TIDAL FLOOD RISK

3.1 THE NPPF FLOOD ZONES

The City of London is located on the north bank of the tidal River Thames and is defended from fluvial and tidal flooding by the Thames Barrier and its defences along the River Thames. Parts of the City of London are however within Flood Zones 2 and 3 because these zones have been created assuming that there are no defences in place (see Figure 33014-COL-301 – Flood Map for Planning – Flood Zone 2 Extent and Figure 33014-COL-302 – Flood Map for Planning – Flood Zone 3 Extent in Appendix A).

In accordance with the NPPF, the City of London Corporation and developers must take into account the potential flood risk to the City of London using the Sequential and Exception Tests which aim to promote development in areas with the lowest probability of flooding. The tests provide a risk based approach which categorises flood risk using flood zones which have been defined by the Environment Agency.

FLOOD ZONE 1

Land within Flood Zone 1 is considered to have a low probability of flooding with land assessed as having less than a 1 in 1000 annual probability of flooding from rivers and seas (<0.1%). All land uses are considered appropriate within Flood Zone 1.

The policy aims for this zone are for developers and local authorities to seek opportunities to reduce the overall level of flood risk in this area and beyond through the layout and form of the development, and the appropriate application of SuDS.

FLOOD ZONE 2

Land within Flood Zone 2 is considered to have a medium probability of flooding, with land assessed as having between a 1 in 100 and 1 in 1,000 annual probability of river flooding (1% - 0.1%), or between a 1 in 200 and 1 in 1,000 annual probability of sea (tidal) flooding (0.5% - 0.1%) in any year. As set out in Table 2-2, the appropriate uses are essential infrastructure, water compatible developments, less vulnerable and more vulnerable uses. Highly vulnerable uses (i.e. police and ambulance stations) are only appropriate if the Exception Test is passed.

The policy aims for this zone are for developers and local authorities to seek opportunities to reduce the overall level of flood risk in the area through the layout and form of the development, and the appropriate application of SuDS.

FLOOD ZONE 3A

Land within Flood Zone 3a is considered to have a high probability of flooding, with land assessed as having a 1 in 100 or greater annual probability of river flooding (>1%), or a 1 in 200 or greater annual probability of flooding from the sea (>0.5%) in any year. Water compatible and less vulnerable uses are appropriate in this zone. Highly vulnerable uses are not permitted. More vulnerable uses and essential infrastructure are only permitted if the Exception Test is passed.

The policy aims for this zone are to reduce the overall level of flood risk in the area through the layout and form of the development, and the appropriate application of SuDS. Existing development should be relocated to zones with a lower probability of flooding. Space should be created for flooding to occur by restoring the floodplain and flood flow pathways, and by identifying, allocating and safeguarding open space for flood storage.

FLOOD ZONE 3B

Land within Flood Zone 3b is where water has to flow or be stored in times of flood. The areas and boundaries of the functional floodplain should be agreed with the Environment Agency, and identified in the SFRA. The probability of flooding within Flood Zone 3b is defined between the Local Planning Authority and the Environment Agency. However, it is typically a 1 in 20 annual probability of flooding from rivers and seas (5%).

There is no flood zone 3b in the City of London as all rivers apart from the River Thames have been culverted and form part of the combined sewer network, and the River Thames Floodplain has been completely defended by a continuous line of walls.

3.2 IDENTIFICATION OF FLUVIAL AND TIDAL FLOOD RISK

The Flood Map for Planning (Rivers and Sea) (Environment Agency, 2017) has been prepared by the Environment Agency to show the natural floodplain, ignoring the presence of defences for flood events occurring from rivers or the sea. The maps provide a high level assessment for flood risk for England and Wales and should be supplemented with information from local investigations.

The maps have been produced from a combination of a national generalised computer model, more detailed local modelling (where available), and some historic fluvial flood event outlines.

The majority of the City of London, beyond 200m from the River Thames, is within Flood Zone 1 and therefore, has a low probability of flooding. This is due to a rise in ground topography northwards away from the River Thames. In contrast, the areas within 200m from the River Thames are within Flood Zones 2 and 3.

The Flood Map's for the City of London are provided in Figures 33014-COL-301- Flood Map for Planning – Flood Zone 2 Extent and 33014-COL-302 - Flood Map for Planning – Flood Zone 3 Extent in Appendix A.

3.3 HISTORICAL FLOODING

The City of London is protected by large scale defences due to its economic importance. Subsequently, there have been limited historical flood incidents. The last recorded incident of tidal flooding in the City of London was in 1928. Significant flooding was noted along the entire river frontage, extending northwards through Inner Temple Gardens, along Castle Baynard Street and Lower Thames Street. The flooding was caused by tidal inundation, which resulted in overtopping of the existing defences.

The Historic Flood Map for the City of London is provided in Figure 33014-COL-303 – Historic Flood Map in Appendix A.

3.4 THE THAMES DEFENCES

The Thames Barrier is one of the largest movable flood barriers in the world, spanning 520m across the River Thames near Woolwich. It protects approximately 125km^2 of Central London from flooding caused by tidal surges. Additional structures to protect London from flooding include approximately 350km of flood defence walls and embankments, tidal barriers, flood gates and pumping stations. The City of London's defences were designed to offer protection against an event that has an annual probability of occurrence of 1 in 100 (1%) up to 2030.

The statutory flood defence level within the City of London upstream of London Bridge is 5.41m AOD, and downstream of London Bridge is 5.28m AOD. However, the flood defences in the City of London currently range between 5.28m AOD and 6.75m AOD. These levels were obtained from the Environment Agency's Spatial Flood Defence shapefile (Environment.data.gov.uk, 2017) The flood defences are generally in fair condition which means that there are defects that could reduce the performance of the asset.

In 2002, the Thames Estuary 2100 project was set up by the Environment Agency with the aim of developing a strategic flood risk management plan for London and the Thames Estuary through to 2100. A series of options have been proposed and have been designed to be undertaken in three phases to allow for adaptability as the knowledge of climate change improves:

- For the first 25 years (2010 – 2034), the Environment Agency recommends continuing with how flood risk is managed today by actively maintaining and improving the existing flood protection in London and the Thames Estuary. Space for future flood risk management will be safeguarded. All TE2100 information will be made available so that it can be used to inform regional and local strategic and spatial planning;
- The middle 35 years (2035 – 2069) will see major renewal and replacement of Thames tidal flood defences which will bring opportunities to reshape and renew the riverside. Defences will require raising approximately 1m during this time period, however this is dependent on the rate of sea level rise. During this period, a decision will be made on the option to be adopted for implementation by the end of the century; and,
- The final 30 years (2070 – 2100) are designated for preparing and moving to the 22nd Century. Based on current climate change guidance, it is envisaged that a major change in how flood risk is managed in London and the Thames Estuary will be required. The two options at the forefront at present are, to continue to maintain and improve existing defences or to build a new barrier at Long Reach.

The existing flood defences map (and associated condition rating) for the City of London is provided in Figure 33014-COL-304 – Flood Defence Condition Map in Appendix A.

3.5 FLUVIAL AND TIDAL RESIDUAL FLOOD RISK

Areas behind defences are at risk of residual flooding from fluvial or tidal sources due to a breach or overtopping of the defences.

Breaching of flood defences can cause rapid inundation of areas behind flood defences due to a defence collapsing or failing. Breaching is caused by water eroding the material through the embankment (typically earth embankments) or the surface of the defence i.e. the structure toe. It does not affect the crest level of the structure. Breaching of defences generally occurs with little to no warning and coincides with extreme tides or water levels. There is a significant risk of damage to buildings or loss of life.

Overtopping of flood defences occurs when the water level from an extreme event exceeds the height of the defence. This can cause rapid inundation and prolonged flooding behind a defence. Cyclic overtopping is caused by wave action on water levels below the height of the defence. Climate change will increase the chance of overtopping occurring.

Typically, the height of the defence includes a freeboard to reduce the chance of overtopping occurring. The Maximum Likely Water Level for the City of London is between 4.80m AOD and 4.83m AOD, which means that flood defences in the City of London have a minimum freeboard of 0.48m.

As part of the TE2100, a Thames Tidal Upriver Breach Inundation Assessment (May 2017) has been carried out by the Environment Agency. Hydraulic modelling was carried out downstream of Teddington Lock to consider the velocity, depth and path of flooding should failure of defences occur. The breach modelling was undertaken for the 'Maximum Likely Water Level' (MLWL). The MLWL was calculated based on the maximum water levels allowed upstream of the Thames

Barrier, based on the barrier operating under the current closure rule. The modelling was run for two climate change epochs: 2005 and 2100. Thames tidal water level profiles were obtained from the existing Thames 1D ISIS River Model.

The Thames tidal defence line was used to define the breach locations. It was assumed that the breach length for hard defences was 20m and 50m for soft defences. This resulted in 5,679 potential breach locations. The breach modelling makes assumptions regarding the physical formation of a breach, particularly the sill level and scour zone. A sill level is required to lower the ground model to represent the breaching of the defence and resultant scouring that would occur. The lowered ground model was represented within the model at the start of the simulation and subsequently assumes that the failure of the defence occurred before the water fully abuts the defence line.

The breach mapping for the present day in Appendix A shows more detailed modelling results on flood depth, velocity and flood hazard (Figures 33014-COL-306 to 33014-COL-308). The flood hazard mapping combines water depth, velocity and debris to calculate hazard areas. The majority of the Embankment is classified as ‘danger to most’ with the exception of a 350m frontage in Blackfriars which is classified as ‘danger for all’.

The breach mapping for the 2100 epoch can be found in Appendix A (Figures 33014-COL-309 to 33014-COL-3011). The majority of the Embankment is classified as ‘danger to most with the exception of Temple Avenue and part of Blackfriars Underpass are classified as ‘danger for all’.

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4 SURFACE WATER FLOOD RISK

4.1 OVERVIEW

Surface water flooding occurs when intense rainfall is unable to drain away by traditional means such as into drainage systems which may already be overloaded, or infiltrating into the ground. Due to the built-up nature of the City of London, and its limited drainage capacity, surface water flooding is the most likely cause of flooding.

Climate change means that the number of extreme rainfall events within the City of London will increase due to an increase in peak rainfall intensity. The capacity of existing drainage systems will be exceeded more frequently and the ground will be more saturated - runoff will exceed the rate at which it can soak into the ground. This will result in an increased risk of surface water flooding.

This SFRA has built upon the existing understanding of surface water flooding developed as part of the 2012 update of the SFRA and additional surface water modelling undertaken as part of this commission.

4.2 HISTORICAL FLOODING

There is little evidence of historical flooding from surface water within the City of London apart from fire brigade records which however do not determine if flooding has been the result of surface water flooding or other sources.

There are no formal records of significant surface water flooding in the City of London. However, historical flood records are not a good indicator of future flood risk as climate change means that surface water flood events are likely to increase.

The City of London Local Flood Risk Management Strategy commits the City of London Corporation as LLFA to investigate flooding where more than one property is affected by a single flood event. Information on these flood investigations is available on the flood risk pages of the City Corporation's website.

4.3 UPDATED FLOOD MAP FOR SURFACE WATER

The Environment Agency has published the updated Flood Map for Surface Water (uFMfSW) which was based on computational hydraulic modelling. The City of London provided additional modelling results for the uFMfSW as a result of the detailed 1d-2d modelling undertaken for the 2012 SFRA, which included the Thames Water sewer network (refer to Section 4.5). The mapping provides surface water flood extents for three storm events: the 1 in 30 annual probability, 1 in 100 annual probability and 1 in 1000 annual probability. The mapping also provides information on the depth and velocity of flooding expected.

The updated Flood Map for Surface Water for the City of London is provided in Figure 33014-COL-401 – Environment Agency Risk of Flooding from Surface Water Mapping in Appendix A.

4.4 DRAIN LONDON MODELLING

The Drain London partnership (refer to Section 2.2) undertook 2d modelling to assess the surface water flood risk within London as part of the SWMP studies.

The 2d model of Greater London was undertaken using TUFLOW. Due to the size of the model of Greater London, it was split into a subset of group areas. The City of London falls within Group 3.

The modelling had a number of limitations. These included:

- The sewer network was not modelled;
- The allowance for the pipe flows was taken off directly from the rainfall in all land use areas;
- Kerbs were not modelled;
- The modelled topography used a constant 5m grid;
- Obstructions such as railway embankments were modelled however, culvert crossings beneath them were not modelled;
- Infiltration was modelled through the use of variable runoff rates depending on land use, however this was limited to the land uses defined by OS MasterMap; and,
- Modelling runs did not include the 0.5% annual probability event.

The Drain London project mapped key flood risk areas and defined Local Flood Risk Zones (LFRZs) and Critical Drainage Areas (CDAs). The LFRZs are defined as discrete areas/ extents of predicted surface water flooding. The CDAs are discrete geographic areas, usually a hydraulic catchment, where there are multiple and interlinked sources of flood risk.

Within the City of London, 4 LFRZs and 3 CDAs were identified.

Table 4-1 describes all the LFRZs and CDAs within and surrounding the City of London. The LFRZs and CDAs surrounding the City of London are highlighted in grey.

Table 4-1: City of London CDAs and LFRZs from Drain London

CDA	LFRZ	SITE ID	SOURCE OF FLOODING	VERIFIED?
3003	3020	Historic river valley of the River Fleet, Farringdon Street – City Thameslink	SW flooding due to topography (hump in road prevents drainage to the Thames)	Yes
	3004	Caledonian Road (LB Islington)		
	3005	Clerkenwell Road (LB Islington)		
	3013	Gospel Oak (LB Camden)		
	3024	Primrose Hill (LB Camden)		
3006	3019	Barbican	Pluvial	Yes
	3022	Liverpool Street Station	Pluvial	Yes
	3007	St Luke's (LB Islington)		
3007	3021	Blackfriars to Tower Pier – Terrace by the river (50m strip)	Water trapped behind the River Thames flood defence wall and surface water unable to drain into the River Thames	Yes

4.5 THE 2012 SFRA MODEL

As part of the 2012 update of the City of London SFRA, Halcrow developed a detailed model (the 2012 SFRA model) which removed many of the assumptions of the model undertaken as part of the Drain London project. It investigated how surface water will behave in the City, taking into account the interaction with the existing combined sewer network, the local topography and urbanisation. The study recommended a number of high-level options to resolve flood risk.

The 2012 SFRA model was a 1d-2d model. It used the 1d Thames Water Infoworks sewer Beckton model (the 1d Beckton model) and then was expanded to 2d, to simulate flow paths and flood depths over the digital ground terrain of the City of London.

The 2012 SFRA model applied the event rainfall across the whole of the upstream combined sewer network catchment, which resulted in large flows in the combined sewers in the City. These large flows resulted in flooding at critical locations in the City due to surcharging and overflowing of manholes and gullies, combined with overland flows not been able to enter into the surcharged sewers. A large catchment-wide storm covering many London Boroughs is a rarer event than a localised storm in the City and therefore it represents a conservative assessment of surface water flood risk.

The hydraulic modelling considered the following return periods: 1 in 5, 30, 75, 200 and 100 annual probability plus climate change (30% increases in rainfall intensity). Since then the 40% increase in rainfall intensity run has been undertaken to take account of the latest guidance for climate change.

The 2012 SFRA model identified the following flooding mechanisms at four main flood risk areas:

- *Farringdon Street* is located on the Fleet sewer, a culverted watercourse that drains a large catchment and subsequently, fills to capacity during large rainfall events. Additionally, there is a dip in ground levels on Farringdon Street which results in lower water levels required to surcharge the Fleet Sewer. Finally, due to the proximity of Farringdon Street to the River Thames, water is often unable to discharge into the river and subsequently, water backs up along the Fleet sewer. With the construction of the Thames Tideway scheme (which has the purpose of intercepting overflows into the River Thames) backing up will occur less frequently; however this is still anticipated to take place for the design catchment-wide storm adopted in the 2012 SFRA modelling, as the tunnel itself will be full;
- *New Bridge Street* experiences surface water flooding as an extension to the Farringdon Street flooding. Additionally, the proximity of New Bridge Street to the River Thames means that manholes are more likely to surcharge if surface water cannot be discharged into the river. The Thames Tideway scheme will also in this case reduce the frequency of backing up of water however not for catchment-wide storms as the tunnel itself will be full;
- *Victoria Embankment* experiences surface water flooding, during an event with a 3.33% annual probability, due to a single surcharging manhole near to Blackfriars Bridge. Additional rainfall will cause flooding along Victoria Embankment due to two more manholes surcharging at Tallis Street and Temple Avenue. However, due to the local topography, the majority of flooding is relatively shallow; and,
- *St Pauls Walk, Thames Riverside* floods due to several manholes surcharging at different locations around St Pauls Walk. The surcharging is caused by the relatively low ground levels relative to the sewer interceptor which they will ultimately discharge into.

During more extreme flood events, the modelling indicated that additional flooding occurs at the eastern end of the Thames Embankment and along Blomfield Street, Appold Street, Worship Street and Curtain Road to the north east of the City of London.

4.6 THE WCC MODEL

In 2015 Westminster City Council (WCC) undertook similar detailed modelling as for the City of London 2012 SFRA; it used the 1d Beckton model from Thames Water and expanded to 2d. The WCC model is relevant for this study as the outputs expanded beyond Westminster and included the adjacent City of London to the east. As part of this commission it has been possible to update/improve the WCC model, by modelling in further detail within the City of London.

There were two improvements in the WCC model (and its recent updated version within the City of London) when compared to the 2012 SFRA model:

1. The 1d Beckton model provided to Westminster City Council in 2015 was a calibrated version for a number of events at key locations in the sewer system (whereas the 1d Beckton model provided for the 2012 SFRA model was not calibrated). None of the calibration events however were large enough to result in flooding of roads or property and therefore, there is still uncertainty in terms of accuracy of the 1d Beckton model for extreme events.
2. In the WCC model and its updated version, direct rainfall was applied on roads in the upstream catchment and surrounding areas to better represent the dynamic attenuation storage and conveyance of roads, whereas the 2012 SFRA model had inflows directly into manholes (with no attenuation on roads).

The Updated WCC model and its updated version include the following rainfall events: 1 in 5, 1 in 30, 1 in 100 and 1 in 100 year plus climate change (40% increase in peak rainfall intensity) annual probability.

A comparison of the results between the 2012 SFRA model and the updated version of the WCC model indicate that the flood mechanism is the same and the flood risk areas are in general similar. However the extents, depth and frequency of flooding are reduced in the updated version of the WCC model (for further details refer to Appendix C).

4.7 LATEST 1D BECKTON MODEL

Since the release of the 1d Beckton model in 2015 (calibrated version), Thames Water has further improved it and has a new updated version; this new version is no longer available for expansion to 2d as, due to its complexity, Thames Water has decided to only provide the 1d results (not the model).

The latest 1d Beckton model includes all the return periods and climate change scenarios as for the updated WCC model.

The results from the latest 1d Beckton model cannot be represented in 2d and the accuracy of the model is significantly reduced for return periods above the 1 in 30 annual probability event (a 1d model). Despite these limitations it has been possible to map manholes where these overflow into the 2d domain and to compare against similar maps (of overflowing manholes) from the 2012 SFRA model and the updated WCC model.

A comparison of the results (the number and locations of overflowing manholes) for the City of London, from the 2012 SFRA model, the updated WCC model and the latest 1d Beckton model, indicate that the flood mechanism is the same and the flood risk areas are in general similar from all these models. However the extents, depth and frequency of flooding from the latest 1d Beckton model fall between the results from the 2012 SFRA model and the updated WCC model (for further details refer to Appendix C).

4.8 MODELLING OUTPUTS FOR USE IN THIS SFRA

This Section has summarised all the relevant catchment-wide storm modelling undertaken to date for the City of London (sensitivity tests for localised models are included in Appendix C). Based on the comparison of the results it is recommended that the surface water modelling outputs from the 2012 SFRA model are used as part of this 2017 SFRA update, to inform policy and SFRA guidance. This is a pre-cautionary approach when compared to using the least conservative outputs from the updated WCC model, since the results from the latest 1d Becton model fall in between the more conservative 2012 outputs and the least conservative 2017 outputs (in terms of number and locations of manholes overflowing). Mapping showing the extent and depth of surface water flood risk for a range of flood risk events are provided in Appendix A (Figures (Figures 33014-COL-402 to 33014-COL-405).

This assessment confirms that there is a large uncertainty in the results depending on the type of modelling (1d versus 1d-2d and the level of detail and approach taken in the 2d element), the adopted design storm and the accuracy of the 1d Beckton model. Because of this, it is important that future SFRA updates follow a similar approach to this study; to compare any new modelling outputs against previous modelling prior to selecting the surface water modelling outputs for use in the future SFRAs.

5 GROUNDWATER FLOOD RISK

5.1 OVERVIEW

Groundwater flooding is caused when the level of water within rock or soil rises significantly, due to long periods of abnormally high rainfall. It can cause significant damage to property and infrastructure. The two most vulnerable settings for groundwater flooding are chalk and river valleys which are underlain by permeable superficial deposits. LLFAs are responsible for managing groundwater flood risk.

In January 2014, extensive groundwater flooding occurred in South East of England. Exceptional rainfall was unable to infiltrate into already saturated ground and ran off into watercourses. Whilst rivers returned to normal, groundwater levels continued to rise for weeks/ months in some areas; within Hampshire, groundwater levels rose more than 30m. Groundwater flooding in the City of London is less likely as groundwater levels are maintained artificially low (refer to Section 5.2).

This section outlines the conceptual ground modelling study which was undertaken as part of the Level 1 SFRA (Mouchel Parkman, 2007) and which is still considered to be an adequate assessment of groundwater flood risk within the City of London. More details on data collection, methodology, assumptions and results can be found in Appendix A.

For the purpose of this SFRA as no new information is available, the previous mapping of groundwater flood risk from the Level 1 SFRA and the Drain London SWMP (Halcrow, 2011) is still the most relevant information available.

5.2 GROUNDWATER RISK

It is not always possible to accurately map groundwater level due to interactions between rainfall, the local variations in geology within the same strata, tide levels and underground obstructions. However, as there is a strategic understanding of the groundwater regime within the London Basin, a certain degree of confidence can be placed on determining the areas considered to be at most risk of experiencing groundwater flooding.

The City of London is underlain by two natural aquifers: River Terrace Deposits, and Upper Chalk.

The Chalk aquifer is located approximately 68m below ground level, below a layer of London Clay. The chalk aquifer is heavily managed throughout the London Basin, with groundwater levels maintained between -30m AOD and -50m AOD by the General Aquifer Research Development and Investigation Team (GARDIT). The Level 1 SFRA mapped groundwater levels in the chalk aquifer. Although it only provided an assessment of groundwater levels, as opposed to groundwater flood risk, it showed that the chalk layer is confined beneath a low-permeability clay layer. Subsequently the groundwater flood risk from the chalk aquifer is considered to be low.

The River Terrace Deposits comprises a sand and gravel aquifer with high porosity and high permeability. It is at a relatively shallow depth and provides a large storage volume below ground and in the vicinity to the River Thames.

Groundwater levels within the River Terrace Deposits are unknown. Four potential flood risk mechanisms have been identified for this aquifer:

- Prolonged and above average rainfall in the River Terrace Deposit outcrop;

- High tide levels;
- Leaky drains and sewers; and,
- Basements/ foundations interrupting groundwater flow paths.

The Drain London SWMP provides an estimation of the areas considered to be most at risk from groundwater flooding within the River Terrace Deposits (Figure 33014-COL-5010 – Increase Potential for Elevated Groundwater). This is based on geology and topography. The mapping shows areas where the aquifer is at its thinnest in depth, most notably within the lower lying areas within the City of London. In these areas, basements are most likely to obstruct groundwater flows which will increase the risk of flooding to these buildings.

Typically the areas, where the aquifer is thinnest in depth, cover a small area of the City of London and are primarily covered by impermeable areas such as buildings and roads. In these areas, rainwater cannot infiltrate into the ground and subsequently raise groundwater levels. The main cause for rising groundwater levels is therefore caused by sewers leaking and the lateral transmission of high water levels from the River Thames. Due to the impermeable surfaces in these areas, groundwater flooding is most likely to affect basements and utilities that are not waterproofed properly.

In addition to the natural geology beneath the City of London, there can be a substantial depth of made ground that comprises material that has been deposited as a result of human occupation and development since settlement by the Romans in the 1st century AD. This material which sits above the other geologies is highly variable but can hold perched groundwater and therefore pose a risk of groundwater flooding to basements and other buried structures.

Groundwater flood risk is not expected to increase in the short to medium term. However, climate change is likely to increase the existing groundwater flood risk due to higher rainfall, and increased leakage from drains and sewers infiltrating into ground. Sea level rise will increase the water level within the River Thames which will also increase groundwater levels, although this will dissipate with distance from the river. Additionally, the defence improvements by the TE2100 and Thames Barrier may help to mitigate this.

5.3 RECOMMENDATIONS IN RELATION TO GROUNDWATER FLOOD RISK

To avoid increasing groundwater flood risk within the City of London, the following recommendations are proposed in the areas identified at risk from the Drain London SWMP (Figure 33014-COL-5010 – Increase Potential for Elevated Groundwater):

- Avoid where possible adding new basements to developments. If basements are proposed in these areas the applicant must prove that the proposed development will not be at risk from groundwater flooding and that it will not lead to an increase in the risk of flooding from groundwater elsewhere;
- Undertake site investigations to assess winter groundwater levels before proposing infiltrating SuDS (as part of schemes or for development proposals), to ensure that infiltrating rainwater would not cause groundwater levels to rise and increase flood risk;
- GARDIT to continue to maintain groundwater levels in the London Basin;
- Thames Water to continue to maintain and renovate the sewers to reduce the risk of leakage;
- Basements and underground utilities to be waterproofed where possible;
- If required, pumps can be installed to remove flood water;
- Relocate sensitive uses within buildings to higher floors i.e. computers; and,
- Use of SuDS i.e. green roofs, rainwater harvesting and grey water recycling, to reduce the amount of water in sewers (which would indirectly reduce the leakages in the sewer system).

6 SEWER FLOOD RISK

6.1 OVERVIEW

Sewer flooding occurs when there is increased flow in a sewer which may result in the system reaching capacity, and becoming overwhelmed. Sewage overflows from manholes and gullies flood land, rivers, gardens and, in extreme scenarios, commercial buildings and homes. Within the Thames Water network, 1,216 properties experienced internal flooding as a result of sewer flooding in 2015/2016 (Thames Water, 2017a).

Sewer flooding is typically caused by heavy rainfall or blockages in the system. The frequency of sewer flooding is increasing due to climate change, population growth and increased impermeable areas. There is an increased risk of sewer flooding within the City of London due to London having combined sewers, as opposed to separate networks which deal with foul waters and surface water separately.

The 2007 SFRA collated important information on the existing sewer system which is summarised within this section. Additionally, as part of the 2012 SFRA, the surface water modelling undertaken by Halcrow included the sewer network and subsequently includes an assessment of sewer flood risk combined with overland flows not been able to enter the system (these combined source of flooding has been included in the surface water flood risk in Section 4.5).

6.2 THE SEWER SYSTEM

The existing sewer system in London was constructed in the 19th century. The sewer system consists of combined sewers which were initially designed to collect foul waters only. However, the spare capacity of the sewers at the time and surface water flood risk incidents, resulted in a decision to use the sewers, also for the collection of surface water. Six main interceptor sewers were built and fed by 450 miles of main sewers and 13,000 miles of local sewers which historically discharged into the River Thames.

The main sewers and local sewers within the City of London receive flows from Westminster, Kensington and Chelsea, Hammersmith and Fulham, and Camden and Islington. Flows from these ultimately discharge into the 2 low level relief sewers which pass through the City of London, running parallel to the River Thames. The 2 low level relief sewers transfer flows towards Tower Hamlets. As a failsafe, 57 combined sewer overflows (CSOS) were built to discharge into the Thames (refer to Section 6.5 for additional information) during extreme events.

The six main interceptors incorporated some of London’s lost rivers including the River Fleet and the River Walbrook which drained through the City of London. The River Fleet originated from springs on Hampstead Heath and drained through Kentish Town, Camden Town and Holborn before joining the River Thames at Blackfriars Bridge. The River Walbrook has a much smaller catchment as it historically drained a marsh area within the City of London boundary. A map of the sewers within the City of London can be found in Figure 33014-COL-601 – Sewer Locations in Appendix A. Figure 33014-COL-602 – River Fleet and Walbrook Catchments in Appendix A shows the indicative catchments of the sewers that the Rivers Fleet and Walbrook are contained within.

The combined sewers have brickwork culverts which outfall into the River Thames. Based on present day forecasting for heavy rainfall events, it is predicted that the culverts only have capacity for the 1 in 10 annual probability flood event. Additionally, any new surface water sewers have been designed to hold the 1 in 30 annual probability flood event. Subsequently, London experiences flooding as a result of a lack of sewer capacity, although they are generally of small consequence (mainly flooding of roads). However, climate change will result in summer storms increasing in frequency, and winter storms becoming more prolonged. This means that the current standard of protection for the existing sewer system will be reduced and more frequent localised flood events, as a result of sewer flooding, can be expected.

Due to the large sewer catchment of the 2 low level relief sewers, development upstream of the City of London could have a significant impact on flood risk in the City of London if surface water runoff is not properly managed. Similarly, development in the City of London could increase flood risk in Tower Hamlets to the east. The sewer catchments of the surface water flood risk hotspots in the City of London are shown in Figures 33014-COL-603 – Farringdon Street Sewer Catchment Area and Figures 33014-COL-604 – Paul's Walk Sewer Catchment Area in Appendix A.

6.3 SEWER FLOOD RISK WITH FLUVIAL/ TIDAL INTERACTION

The sewer interceptor, which provides a hydraulic connection across the northern bank of the River Thames introduces a potential flood risk mechanism. Breaching or overtopping of defences could result in the defended area becoming inundated with flood water which will discharge into the interceptor sewer towards Tower Hamlets to the east. If the interceptor sewer reaches capacity, flooding may occur elsewhere due to the sewer surcharging. If there was not a sewer interceptor, flood water would naturally flow into the Thames when river levels recede.

This highlights the importance of maintaining the existing flood defences. However, there is still the potential for breaching or overtopping occurring due to riparian owners cutting through defences or carrying out activities which destabilise flood defences without permission.

6.4 IMPROVEMENT WORKS

As demonstrated in the previous sections, London's existing sewer system has little capacity to deal with increased rainfall. At present, excess rainfall is discharged into the River Thames through 57 storm overflows. The storm overflows within the City of London are located at Blackfriars, Bell Wharf Lane and Custom House. However, should water levels in the River Thames be higher than the overflows, storm water would be unable to discharge into the river and subsequently, the sewers would back up and surcharge. Whilst this risk is relatively low (due to the rarity of a high tide, storm surge and heavy rainfall occurring simultaneously), there is a chance of flooding to the low lying areas within the Fleet Valley and areas behind the existing defences.

As the existing sewers are combined, flows in the sewers are contaminated with foul waste. In London, 39 million tonnes of foul waste is discharged into the River Thames annually. As little as 2mm of rain can cause sewers to discharge which occurs approximately once a week. Foul waste in the River Thames can damage water quality, endanger wildlife and poses a risk to human health.

As part of the Thames Tidal Tunnel, works are currently in progress to construct two new relief sewers: the Lee Tunnel and the Thames Tideway Tunnel to reduce overflows into the River Thames. Additional works are being undertaken to improve London's five principal sewage treatment works to enable them to deal with additional flows.

With this new sewer interceptor in place, there is still the possibility of backing up and surcharging once the sewer interceptor is full. This situation would only occur however during a rare catchment-wide storm and will not be related to high water levels in the River Thames combined with heavy rainfall.

The Thames Tideway Tunnel is currently under construction with completion expected in 2023. A tunnel is to be constructed under the tidal section of the River Thames which connects to 34 of the most polluting sewage overflows and subsequently, reduce overflows to approximately 3 or 4 per year. This number is likely to increase due to population growth and climate change. The tunnel will capture, store and ultimately convey raw sewage and rainwater to the Lee Tunnel. The primary purpose of the tunnel is to prevent pollution of the River. Thames Water has indicated that it has reduced sewer flooding for localised storms within London.

The Lee Tunnel is London’s new super sewer which runs from East Ham to Stratford. The tunnel is designed to convey sewage and rainwater which would otherwise have discharged into the River Thames. Annually, it is designed to capture 16 million tonnes of sewage which is collected from the lowest point of the Thames Tideway Tunnel. The sewage and rainwater is pumped up to Beckton Sewage Treatment Works. Subsequently, clean water is discharged into the Thames. To date, it has cut waste flowing into the Thames by 40%.

7 WATER MAIN BURST FLOOD RISK

7.1 OVERVIEW

A burst water main can occur at any time and can have a serious impact on both property and infrastructure.

Any pipe burst can result in flooding of roads and property however the locations at most risk are considered to be low points in the topography along roads and tunnels and locations where large water mains run along streets and open spaces. This is because flood water would accumulate at low points and burst flows are much larger for larger pipes.

Thames Water has recently undertaken a review of bursts on their trunk main network following a series of incidents in 2016 (Thames Water, 2017b). This review came to the following findings regarding the causes of bursts;

> *'there is no single common cause of the bursts. Whilst age and condition of the pipes is an underlying factor in the eight high-profile failures, there were no systematic failings that could be said to have consistently caused or enabled the bursts.'*

At present no assessment of the risk of water main burst flooding has been undertaken as it has not been possible to obtain water main asset information, such as pipe sizes and locations. Therefore as a pre-cautionary approach and in the absence of 2d modelling or data from Thames Water, any infrastructure or property in the vicinity of the areas at high risk (low points and large water mains) can be assumed to be at high risk from this source.

Good management of the infrastructure itself is the key to minimising the threat of flooding from these sources.

7.2 THE WATER MAIN SYSTEM

The Thames Water mains water distribution network in London dates from Victorian times and is the oldest network in the UK, with an average age of 70 years. Two-thirds of their water mains have been in use for more than 50 years and the frequency of water mains bursting has increased dramatically in recent years. This water distribution network also covers the City of London.

Thames Water outlines their plans to improve their distribution network in order to reduce leakage and the risk of burst mains; this is set out in their 'Long-Term Strategy 2015-2040' document. The Thames Water documents can be viewed at http://www.thameswater.co.uk/about-us/836.htm. The programme to replace the oldest and leakiest pipes has already started and replacement of trunk mains will start from 2020. Thames Water will make use of latest technology to monitor and manage the performance of their system and to reduce losses of water. Information from 'smart' meters will help target key locations to improve performance. Improved knowledge of deterioration rate of trunk mains and improved monitoring will help, to better predict and prevent these bursts.

7.3 RECOMMENDATIONS IN RELATION TO WATER MAIN BURST FLOOD RISK

→ To enhance our understanding of water main burst flood risk within the City of London, the following recommendations are proposed: Obtain locations of large water mains within the City of London and assume that any properties in the vicinity are at risk, as a pre-cautionary approach;

- Collaborate with Thames Water to undertake a quantitative assessment of the risk of flooding from water main burst in the City of London, assessing the risk of flooding and the potential consequences that may arise.

8 CONSEQUENCE OF FLOOD RISK

8.1 OVERVIEW

The City of London due to its topography is at relatively low risk of flooding in comparison to some other parts of London. As a result, the consequences of flooding are limited to specific areas that are generally defined by the lower parts in the landscape. The key areas where the consequences of flooding could be greatest are Thames Riverside (where the fluvial flood risk is the highest) and Farringdon Street where the natural topography leads to the greatest risk of surface water and sewer flooding.

The consequences of flood risk are heavily dependent upon the severity of the extreme event and can affect individuals directly and indirectly. Failure of drainage assets can exacerbate flooding considerably.

Flood waters can damage residential and commercial properties, particularly if they have a basement and water is able to infiltrate rapidly from the street. Flooding can also damage critical infrastructure such as sub-stations or water supply assets which may leave many properties without electricity or water. These direct consequences of flooding are restricted to a relatively small geographical area in the City of London. For these locations the consequences of flooding can be minimised through the implementation of appropriate resistance and resilience measures.

High flood depths and fast flowing water can result in the loss of life or severe injuries. Diseases can be spread by combined foul and surface water as a result of surcharging sewers.

Indirect effects of flooding can be caused by road traffic disruption; within the City of London, main transport routes likely to be affected as a result of flood water are Farringdon Street and Victoria Embankment. Alternatively flooding of rail infrastructure including underground stations or overground railway lines or station would have a significant impact on the functioning of the City of London. Flooding of commercial properties can result in disruption to critical commercial activities, including trading and communications infrastructure and could result in significant financial and reputational loss as well as a loss of customers. Other utility infrastructure such as electricity supplies can also be vulnerable to flooding leading to widespread disruption if key assets such as sub-stations are affected. This could have a negative economic impact to the City of London, the wider London economy and the nation as a whole.

Finally, indirect effects can be caused by the inconveniences of recovery after a flood event and the increased vulnerability of affected people.

8.2 PROPERTIES AT RISK OF FLOODING

As part of this SFRA, the numbers of properties likely to be affected by flooding, within high risk areas, have been assessed for the following sources: Tidal/Fluvial Flood Zones 2 and 3, groundwater, surface water and Tidal/Fluvial breach modelling. These numbers are conservative as individual properties may not flood based on their threshold levels which have not been accounted for in the calculations. However, it does give an indication of the estimate for the potential consequences. The results are shown in Table 8-1.

Table 8-1: Properties at direct risk of flooding

	RESIDENTIAL	COMMERCIAL	TOTAL
Flood Zone 2*	64	78	141
Flood Zone 3*	64	69	133
Groundwater#	81	695	776
Surface Water 1 in 30 Annual Probability**	18	40	58
Surface Water 1 in 100 Annual Probability****	34	73	107
Tidal/Fluvial Breach Modelling (Present Day)##	46	33	79
Tidal/Fluvial Breach Modelling (2100)##	56	70	126

* based on Environment Agency fluvial and tidal flood zones.

based on the 'increased potential for groundwater' maps from the SWMP.

** based on the SFRA surface water modelling for the 1 in 100 annual probability event.

based on the Thames Tidal Upriver Breach Inundation Assessment undertaken by Atkins.

The distribution of the properties at direct risk from flooding from the various sources are shown in Figures 33014-COL-801 - Figures 33014-COL-807, in Appendix A.

In addition to the properties at direct risk of flooding, there are a significant number of properties on upper floors whose access would be compromised by flooding of ground floor and basement properties beneath them. The numbers of properties at risk of loss of access/egress are shown in Table 8-2.

Table 8-2: Properties at risk of lost access/egress due to flooding

	RESIDENTIAL	COMMERCIAL	TOTAL
Flood Zone 2*	520	19	539
Flood Zone 3*	517	15	532
Groundwater#	700	291	991
Surface Water 1 in 30 Annual Probability**	175	12	187
Surface Water 1 in 100 Annual Probability****	197	20	217
Tidal/Fluvial Breach Modelling (Present Day)##	450	7	457
Tidal/Fluvial Breach Modelling (2100)##	474	20	494

* based on Environment Agency fluvial and tidal flood zones.

based on the 'increased potential for groundwater' maps from the SWMP.

** based on the SFRA surface water modelling for the 1 in 100 annual probability event.

based on the Thames Tidal Upriver Breach Inundation Assessment undertaken by Atkins.

8.3 IMPACTS ON CRITICAL INFRASTRUCTURE

To assess the impact of flooding on critical infrastructure, the following assets at risk from flooding in the present day scenario have been identified:

- Major roads (A Roads);
- Railway lines and stations;
- Docklands Light Railway and stations;

- Underground stations (The London Underground Comprehensive Review of Flood Risk (London Underground, 2016) found that the most significant source of flood risk to underground stations is from burst water mains, this is not included in Table 8-3 as a quantitative assessment of this risk was not possible);
- Medical centres i.e. hospitals and GP surgeries;
- Educational centres i.e. Schools, Universities and Libraries;
- Police Stations; and,
- Electricity Sub-Stations.

The assets at risk are identified in Figure 33014-COL-808 – Critical Infrastructure in Appendix A, and the number of different types of assets at risk at different annual probability events for the present day is given in Table 8-3.

Table 8-3: Critical Infrastructure at Risk of Flooding

	ROADS	RAILWAY AND DLR	UNDERGROUND STATIONS	MEDICAL CENTRES	EDUCATIONAL CENTRES	POLICE STATIONS	ELECTRICITY SUB-STATIONS	FIRE STATIONS	AMBULANCE STATIONS
Flood Zone 2	Victoria Embankment / Upper Thames Street / Blackfriars Underpass (A3211), Queen Street Place (A300)		Blackfriars	0	0	0	4		0
Flood Zone 3	Victoria Embankment / Upper Thames Street / Blackfriars Underpass (A3211), Queen Street Place (A300)		Blackfriars	0	1	0	3	1	0
Groundwater[#]	Farringdon Street (A201), Poultry / Mansion House Street (A40), London Wall (A1211), Princes Street/Moorgate (A501)	Moorgate Station, Liverpool Street Station	Moorgate, Bank, Cannon Street, Liverpool Street	6	3	1	5	0	0
Surface Water 1 in 30 Annual Probability**	Farringdon Street (A201), Victoria Embankment / Blackfriars Underpass (A3211)	0	0	0	0	0	2	0	0
Surface Water 1 in 100 Annual Probability **	Farringdon Street (A201), Victoria Embankment / Blackfriars Underpass (A3211)	0	0	0	0	0	3	0	0

	ROADS	RAILWAY AND DLR	UNDERGROUND STATIONS	MEDICAL CENTRES	EDUCATIONAL CENTRES	POLICE STATIONS	ELECTRICITY SUB-STATIONS	FIRE STATIONS	AMBULANCE STATIONS
Tidal/Fluvial Breach Modelling 2005##	Victoria Embankment / Blackfriars Underpass (A3211)	Blackfriars Station	Blackfriars	0	0	0	2	0	0
Tidal/Fluvial Breach Modelling 2100##	Victoria Embankment / Blackfriars Underpass (A3211)	Blackfriars Station	Blackfriars	0	1	0	5	1	0

8.4 ECONOMIC ASSESSMENT OF FLOOD RISK IMPACTS

An assessment of the economic impacts from flooding as a result of flooding from surface water sources has been updated (when compared to the 2012 SFRA assessment) using the approaches outlined by the Flood and Coastal Erosion Risk Management – A Manual for Economic Appraisal (Flood Hazard Research Centre, 2013). This has assessed the impact of flooding on properties, costs to the emergency services and the cost of evacuation of residents and the work population. This has been based on the flood depths that the surface water modelling outputs from the 2012 SFRA indicates that the properties will experience. The present day, Average Annual Damages and Present Value Damages over the next 100 years are summarised in Table 8-4 for the City of London for the surface water hotspot areas.

Table 8-4: Economic Impacts of Surface Water Flooding

LOCATION	AVERAGE ANNUAL DAMAGE (£)		PRESENT VALUE DAMAGE (£)		
	Residential	Commercial	Residential	Commercial	Total
Farringdon Street	0	391,500	0	12,473,500	12,473,500
New Bridge Street	3,900	463,200	169,100	9,066,700	9,235,800
Victoria Embankment	32,700	91,200	715,900	3,178,000	3,893,900
Thames Riverside	56,800	150,600	1,966,100	5,636,400	7,602,500
Total	**93,400**	**1,096,500**	**2,851,100**	**30,354,600**	**33,205,700**

Although no assessment has been undertaken, it is likely that the indirect impacts to the economy due to disruption to the large work force and nature of work undertaken in the City, will be larger than the figure above. Additional economic impacts that have not been valued but would increase the total damages include road traffic disruption, delays to railway services, disruption to businesses and risk to life.

9 ENGINEERED SOLUTIONS AND POLICY OPTIONS

9.1 OVERVIEW

This section outlines the potential solutions for managing flood risk within the City of London at a local scale, using engineered solutions, or at a strategic scale, through policy change or development. The solutions focus on new development and retro-fitting of existing development to improve the existing situation.

9.2 FLUVIAL AND TIDAL

The Environment Agency is responsible for ensuring the integrity of the existing defences along the River Thames. Riparian owners have a legal responsibility to maintain their defences. Under the terms of the Thames River (Prevention of Floods) Acts 1879 – 1962, the statutory flood defence levels must be maintained at all times, with temporary works when necessary. It is envisaged within the TE2100 study that the defences (walls and embankments) will need to be raised to mitigate the impacts of climate change. There is also a commitment to the continued operation of the Thames Barrier. In order to carry out certain works that will directly affect the existing flood defences, or are within 16m of the structures, an environmental permit is required from the Environment Agency.

It is recommended that the Local Plan continues to include policies which seek to reduce fluvial and tidal flood risk within the City of London. The CFMP states that new development should provide opportunities to move buildings and defences away from the edge of the river which will allow for additional floodplain storage, however this is likely to be impractical within the City of London due to the density of buildings. The Sequential and Exception tests should be used to prevent unsustainable development being constructed in areas of flood risk hazard. It is also recommended that new developments which include, or are adjacent to, flood defences should demonstrate how the crest of defences can be raised in the future to protect the City of London from sea level rise as a result of climate change.

Basements for dwellings are categorised as highly vulnerable by the NPPF and subsequently are not allowed in Flood Zone 3, and must pass the Exception Test to be constructed in Flood Zone 2.

The City of London has a significant number of basements, however these are principally in commercial buildings and classified as less vulnerable. As such they are acceptable in all Flood Zones with the exception of Flood Zone 3.

Irrespective of their usage, basement flooding is likely to result in severe economic damage. There is a need of a change in attitude of basement use for vulnerable assets. It is important that developers building owners, commercial occupiers and residents (where applicable) are aware that although the probability of a defence breach or defence overtopping is very low, the consequences could be very high and that comprehensive flood resilience measures can mitigate this risk. Details of appropriate resistance and resilience measures that could be used to mitigate this risk are included in Section 11.

9.3 SURFACE WATER

The City of London in its role as the LLFA has responsibility for the management of surface water flood risk. Management of surface water runoff within the City of London is closely linked to the operation and maintenance of the highway drainage assets (gullies and pipes), and how these connect to and interact with the Thames Water combined sewer system. The City of London is vulnerable to sewer surcharge as a result of actions taken outside of the City's boundary in the wider Thames Water combined sewer catchment. Figures 33014-COL-603 and 33014-COL-604 shows the extent of the sewer catchments that drain through the City of London where surface water management activities could impact on the risk of flooding in the City.

Sustainable Drainage Systems (SuDS) offer the key mechanism by which surface water can be managed, both as part of new development within the City of London and through retrofitting to reduce flood risk elsewhere. The following sections provide information on how SuDS should be promoted and managed to reduce surface water flood risk wherever possible and combined with water re-use, as well as providing additional benefits including water quality treatment, water conservation, amenity and biodiversity.

For areas identified as at risk from surface water flood risk, there are a range of potential options to manage this risk. Options to reduce the risk of flooding could include retrofit SuDS solutions on buildings and if space allows at ground level. Further details of potential SuDS measures that could be implemented are included in the subsequent parts of Section 9.3. In addition the viability of options for increasing the capacity of highways drainage and the combined sewer system should be considered to increase the rate at which water can be conveyed away from the risk areas. This could include larger sewer pipes, below ground tank storage and additional road gullies. If these potential solutions are not considered viable then individual property owners could consider the use of resistance and resilience measures to reduce the risk to their own property. In addition hybrid solutions incorporating elements of any of these options should be considered, including the potential for resistance and resilience measures to complement more strategic options such as retrofit SuDS and upgrades to the sewer systems.

NEW DEVELOPMENT

The use of SuDS for management of surface water runoff from new development is promoted by the City of London through planning policy. Policy CS18 of the Local Plan requires *Reducing rainwater run-off, through the use of suitable Sustainable Drainage Systems (SuDS), such as green roofs and rainwater attenuation measures throughout the City.* In addition there are several Development Management policies that give greater detail on the management of surface water and SuDS. Policy DM18.2 (Sustainable Drainage Systems) states that:

1. The design of the surface water drainage system should be integrated into the design of proposed buildings or landscaping, where feasible and practical, and should follow the SuDS management train and London Plan drainage hierarchy.
2. SuDS designs must take account of the City's archaeological heritage, complex underground utilities, transport infrastructure and other underground structures, incorporating suitable SuDS elements for the City's high density urban situation.
3. SuDS should be designed, where possible, to maximise contributions to water resource efficiency, biodiversity enhancement and the provision of multifunctional open spaces.

The London Plan focuses on making new development as sustainable as possible for example through green infrastructure (Policy 5.10) and SuDS (Policy 5.13). Linking those two requirements Policy 5.11 recommends the use of green roofs and green walls where feasible.

Policy 5.13 of the London Plan focuses on sustainable drainage stating that development should utilise sustainable drainage systems unless there are practical reasons for not doing. The policy also indicates that development should aim to achieve Greenfield run-off rates, re-use water and discharge in line with the following drainage hierarchy:

1. store rainwater for later use;
2. use infiltration techniques, such as porous surfaces in non-clay areas;
3. attenuate rainwater in ponds or open water features for gradual release;

4 attenuate rainwater by storing in tanks or sealed water features for gradual release;
5 discharge rainwater direct to a watercourse;
6 discharge rainwater to a surface water sewer/drain; or,
7 discharge rainwater to the combined sewer.

Additional relevant policies in relation to Flood Risk can be found in the Local Plan, namely Policy CS9, and Policy 5.12 in the London Plan.

It is worth noting that at the time of preparing this SFRA for the City of London, the Local Plan and London Plan are being updated and subsequently the above policies may be revised.

The need for significantly reducing any proposed discharge rates from any proposed re-development is confirmed by the Sustainable Design and Construction Supplementary Planning Guidance (SDC SPG) (Greater London Authority, 2014); the guidance also recommends aiming to achieve greenfield rates where feasible for brownfield re-development. If there are specific constraints it is acceptable in certain circumstances for a proposed development to provide 50% attenuation of the site's surface water runoff at peak times as the maximum acceptable rate of discharge. Peak times include all rainfall events from the 1:1 annual probability storm through to the 1:100 annual probability storm plus an allowance for climate change, as such a site should not discharge at a rate greater than 50% of the existing rate for any of these rainfall events. This is particularly relevant to the City of London where all new development takes place on brownfield land.

SuDS design must also comply with the Non-statutory Technical Standards for Sustainable Drainage Systems (DEFRA, 2015). Additional useful documentation on the use of SuDS within London can be found in:

- Transport for London's 'SuDS in London – a guide'; and,
- The London Sustainable Drainage Action Plan 2016 (Greater London Authority, 2016).

Opportunities for infiltration SuDS (e.g. soakaways) are expected to be limited due to the local bedrock geology (i.e. Clay) and the density of urban development including underground development. If Applicants wish to use infiltration as the destination for surface water runoff adequate proof that is possible should be provided. This should include the results on infiltration testing at the site during winter conditions (December to March), groundwater monitoring over the same period and prove that infiltration will not affect the stability of new buildings on the site or buildings and other structures such as roads on adjacent land. In addition the Applicant must prove that infiltration will not mobilise contaminants held in the ground as a result of previous uses of the site that could lead to a detrimental impact on groundwater quality.

Development located along the River Thames should discharge surface water runoff directly (in some cases with some treatment – oil interceptors) into the river where feasible and appropriate subject to obtaining the necessary permits (e.g. Environment Agency). Discharging surface water runoff directly into the River Thames helps in reducing the amount of surface water discharged into the public drainage network; it can also be cost effective as no surface water attenuation is required apart from that necessary to manage tide lock. This is also consistent with the London Sustainable Drainage Action Plan which explains that *for residential locations next to the Thames, tidal rivers or docks, a relatively easy approach is to divert rainwater into the river or dock. This is not normally considered to be a form of sustainable drainage. However for the heavily urbanised areas of London it is a more sustainable approach to managing rainwater that would otherwise be carried into the combined sewer system.* Any discharge directly to the River Thames should incorporate appropriate water quality treatment features to ensure that pollutants are not discharges into the river.

MINOR DEVELOPMENTS

Minor Developments are classified as:

- The provision of dwellinghouses where:
    - The number of dwellinghouses to be provided is less than 10;
    - The development is to be carried out on a site having an area of less than 0.5ha;
- The provision of a building or buildings where the floor space to be created by the development is less than 1,000 square metres; and,
- Development is carried out on a site having an area of less than 1ha.

In high risk surface water zones, the finished ground floor level shall be set to 0.3m above the 1 in 100 annual probability peak water level taking account of climate change. If this is not feasible then the ground floor shall be flood resilient up to 0.6m above floor level. For new basements these shall be protected by the surrounding building (including the entrance) by a threshold set to 0.3m above the 1 in 100 annual probability peak water level taking account of climate change. If this is not feasible the basement shall be flood resilient up to 1m above basement floor level. An evacuation plan shall be required for all basements with the high risk surface water flood zone.

The City of London expects applicants to seek opportunities for the use of SuDS in these developments. At the planning stage a short drainage statement should be produced (as part of the FRA if that is required). The statement should follow the requirements of the above policy and explain:

- How surface water runoff will be managed at the site;
- Where runoff will be discharged and the proposed discharge rates; and,
- The SuDS measures which are being proposed and the reason for the choice.

In addition Minor Developments should follow Policy CS18 and DM18.2.1 from the Local Plan, the general recommendations of the London Plan and the SDCSPG.

MAJOR DEVELOPMENTS

The planning applications for major development should be accompanied by an outline surface water drainage strategy, where appropriate as part of an FRA; the outline surface water drainage strategy must be developed in consultation with the City of London Corporation in their role of Lead Local Flood Authority and in line with the above policies and the London Plan recommendations. A pre-application discussion should be held with the LLFA team to enable a suitable solution for drainage of the site to be developed.

The City of London Corporation manages the local sewer network under contract on behalf of Thames Water and should be contacted to understand capacity constraints within the public sewer network (if applicable) and a pre-development enquiry submitted (drainage.services@cityoflondon.gov.uk). It is recommended that expected foul water discharge rates are factored in when submitting a pre-development enquiry to the City of London Corporation in order to better understand the impact that the development might have on public drainage infrastructure. Further details on new connections to the combined sewer system in the City of London is available from the City developer guidelines for incoming utility services[2]

The strategy must demonstrate the sustainable management of surface water runoff in line with best practice and policy.

In high risk surface water zones, the finished ground floor level shall be set to 0.3m above the 1 in 100 annual probability peak water level taking account of climate change. If this is not feasible then the ground floor shall be flood resilient up to 0.6m above floor level. For new basements these shall be protected by the surrounding building (including the entrance) by a threshold set to 0.3m above the 1 in 100 annual probability peak water level taking account of climate change. If this is not feasible the basement shall be flood resilient up to 1m above basement floor level. An evacuation plan shall be required for all basements with the high risk surface water flood zone.

SUDS APPROPRIATE FOR THE CITY OF LONDON

For a full review of the range of SuDS options available please refer to wider literature (e.g. the SuDS Manual); in this section we provide an outline summary of the SuDS which are generally expected to be more appropriate for the City of London.

Although many different types of SuDS exist, the most appropriate solutions depend on the nature of the development proposed and need to take into account local conditions, opportunities and constraints. On this basis for the City of London some SuDS are expected to be more appropriate than others.

GREEN/BLUE ROOFS

Green roofs are areas of living vegetation, installed on the top of buildings or on terraces throughout buildings, and can provide multiple benefits including biodiversity and water quality enhancement, improved building performance, reduce urban heat island effect and reduced runoff (both in terms of peak runoff rate and overall volume discharged). Their performance in terms of runoff attenuation depends on several factors including depth and slope. A blue roof is a roof design that is intended to store water and can include open water surfaces, storage within or beneath a porous medium or modular surfaces; a green roof which include a reservoir storage zone beneath the growing medium can also be called a blue roof.

Green/Blue roofs are an appropriate solution for dense urban environment and can be used for many of the commercial buildings being developed in the city. Their use is consistent with the Local Plan Policy CS19: Open Space and Recreation.

Further information can be found in the City of London Local Plan Monitoring Report – Green Roofs.

PERMEABLE / POROUS PAVEMENTS

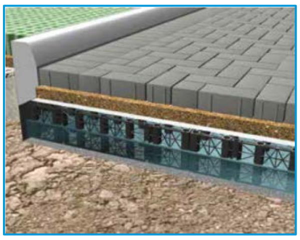
Permeable or porous pavements allow a suitable surface for pedestrian or vehicle access while also allowing water to infiltrate through the surface into the underlying storage layers. The surface

[2] https://www.cityoflondon.gov.uk/services/environment-and-planning/planning/design/Documents/City-Developer-Guidelines.pdf

can be formed of block paving with gaps between the blocks or porous surfaces such as specially designed asphalt. Water can be stored in the underlying layers attenuating flows and allowing for water quality treatment.

The generally accepted guidance for the design of permeable pavements is provided by Interpave (Interpave, 2010). The design of permeable pavements is dependent upon the following factors:

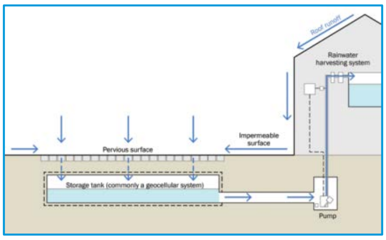
- The loading that they need to be able to withstand;
- If water is expected to infiltrate into the ground below the pavement or if it is stored and then transferred into either the next element of the SuDS treatment train or the surface water sewer system;
- The level of the groundwater and whether this is a limiting factor for the depth of the pavement; and,
- The amount of water that needs to be stored within the pavement.



In the case of the City of London, permeable/porous surfaces may not be suitable due to restrictions imposed by the City's Public Realm Supplementary Planning Document that restricts the palate of materials that may be used for surface finishes. If such approaches are proposed, a full assessment of the ground conditions and constraints imposed by underground structures and services will be required.

RAINWATER HARVESTING

Rainwater harvesting is the collection of rainwater runoff and its re-use as a supply of water for various purposes including commercial, residential and industrial. As explained in the SuDS Manual Rainwater harvesting can meet part of a development's water demand in favour of sustainability and reduce the volume of runoff from a site. Through 'smart water' technologies it is now also possible to combine rainwater harvesting and surface water runoff attenuation: this allows limiting peak and volumetric discharge rates while conserving water for re-use.



A rainwater harvesting system has been implemented at the Museum of London in 2011; the system collects rainwater from an area of over 850m^2 of the museum's flat roof and high walkway and supplies water for the toilet blocks and irrigation.

RAIN GARDENS

Rain gardens are a combination of natural processes and storage units that do not only provide more surface water capacity within the network but also treat the runoff from the roads to improve water quality overall.

In addition, their installation provides additional amenity and improvements to the streetscape through increased vegetation.

Practical examples of possible implementation within the City of London are shown in Appendix B.

TREE PLANTING AND PITS

Trees in the context of the City of London can be used as standalone features within soil-filled tree pits, tree planters or structural soils. Tree pits and planters can be designed to collect and attenuate runoff by providing additional storage within the underlying structure.

The tree planting zone should be designed to be as large as possible to accommodate the largest tree size possible which will increase its capacity to manage runoff. That being said, any tree pit or planter should provide adequate soil volume.

RETROFIT SUDS

Good opportunities exist within the public realm for SuDS. SuDS can be introduced adopting an 'opportunistic' approach (i.e. introducing SuDS when works are needed irrespective) or a more strategic retrofitting of SuDS. Key for the implementation of SuDS in the public realm is a strong partnership between the various stakeholders involved; including but are not limited to the City of London Corporation (Highways and LLFA functions), The Mayor of London and Transport for London Environment Agency, businesses, developers and landowners, Thames Water, local residents. Useful information on how to ensure the future implementation of SuDS throughout London is contained within the London Sustainable Drainage Action Plan.

Opportunities for retrofit SuDS and their suitability in certain locations is typically dependent upon the following criteria:

- Availability of space at ground level to provide SuDS storage;
- Constraints posed by buried utility pipes and cable to storage of water below ground level and achieving a feasible connection to the combined sewer system; and,
- Acceptability of SuDS solutions given historic landscape designations such as Conservation Areas.

Examples of potential options for introducing SuDS in the public realm are provided in Appendix B.

9.4 GROUNDWATER

Basements are particularly vulnerable to groundwater flooding. In general, the groundwater levels within the City of London are 30-60m below ground level (bgl); they are expected to remain at this level due to GARDIT (for more information refer to Section 5.2). The risk of groundwater flooding to property is considered to be low. However, much of the superficial deposits within the City of London are River Terrace Deposits (RTD). The levels of the RTD are likely to coincide with basements and subsequently could result in perched groundwater flood risk. It is therefore recommended that new basements or enlarged basements are avoided where there are permeable superficial deposits, where possible. Where basement construction, or other underground development, cannot be avoided (i.e. underground stations), the walls must be fully waterproofed to prevent seepage and must have adequate pump drainage and ventilation.

Groundwater is a constraint when considering the suitability of SuDS features. Infiltration SuDS are not suitable where soil has insufficient capacity. Additionally, an increase in infiltration may increase flood risk to the surrounding properties due to recharging groundwater and causing groundwater levels to rise. It is recommended that site investigations and infiltration testing is undertaken for individual developments prior to the detailed design of SuDS features.

Due to its highly developed nature, there are a number of additional considerations to take into account when determining SuDS feasibility within the City of London:

- There are archaeological remains present under many areas which may be uncovered during construction. Archaeological investigations may be required prior to the installation of SuDS features;

- There is extensive utility infrastructure under the City of London's streets including electricity and telecommunications cables, gas, water and sewerage pipes, underground railway lines and tunnels, and pipe subways and tunnels that are both operational and redundant. Surveys must be undertaken prior to excavation; and,
- Security bollards and basements create further constraints extending under pavements and incorporating extensive underground structures. 136 streets within the City of London have Special Engineering Difficulties (i.e. underground stations or tunnels) which make excavation difficult or are so full of utility infrastructure that they are considered 'full'.

9.5 SEWERS

In general, the measures discussed in Section 9.3 for surface water will help to reduce the flood risk from sewers by reducing the amount of water within the sewer system and subsequently lower the risk of the sewers exceeding their capacities.

It is recommended that new developments are constructed with separate down pipes for foul and surface water which will aid with conversion in the future should new surface water pipes be constructed within the City of London. Thames Water recommends that site drainage should only be combined at the final manhole prior to leaving the site and entering the combined sewer.

Additionally, it is imperative that the outfall flap gates into the River Thames from the sewer system are maintained and functional. Failure of the outfall flap gates can result in the pipes upstream surcharging.

Due to the sewer network stretching across London, new development can result in an increased potential for flooding in other boroughs. Similarly, new development in boroughs within the same catchment could result in an increased potential for flooding within the City of London. It is recommended therefore that a close partnership continues between LLFAs within the sewer catchment to maintain a co-ordinated approach to sewer and surface water management.

10 REVIEW OF FLOOD RISK ASSETS

10.1 OVERVIEW

Under the Flood and Water Management Act, all LLFAs are required to keep an asset register which will include all structures or features that are considered to have a significant effect on flood risk within the area. The asset register should be completed in accordance with regulations made by the Secretary of State and must be available for inspection at all reasonable times. Alongside the public register LLFA must keep a record of the ownership of each asset and the state of repair of the structure. The asset register is a live document and should be updated as LLFAs:

- Respond to flood incidents;
- Conduct investigations; and,
- Carry out maintenance works on assets.

The Environment Agency has produced an example template for an asset register which has been used as a basis for the City of London's asset register. It has been created in GIS so that a user can locate and query assets within a spatial environment.

10.2 IDENTIFICATION OF ASSETS

Information about the City of London's Flood Risk Asset Register can be found at https://www.cityoflondon.gov.uk/services/environment-and-planning/sustainability/Pages/Flood-risk-asset-register.aspx.

Assets are identified using data obtained from the Environment Agency, Thames Water and the surface water modelling outputs.

The Environment Agency produces the National Flood and Coastal Defence database (NFCDD) which catalogues features and structures that influence fluvial and tidal flooding. It is provided in a GIS format: polylines identify defences (walls and embankments) whilst points identify structures (i.e. weirs and sluices).

Thames Water has produced an Infoworks hydraulic model which includes dimensions of pipes and other structures. It is also provided in GIS format. For the purposes of the City of London asset register, the City of London sewers plus a 200m buffer have been included in the database.

The surface water and sewer flooding (obtained from Thames Water) model includes structures and features above the ground which have a significant effect on surface water flooding, including gullies. These have been identified by post processing the results and analysing the flow patterns.

The records of asset ownership and state of repair have not been published.

10.3 CURRENT POLICY OF FLOOD DEFENCES

The majority of the assets identified in the City of London's asset register (except gullies) are the responsibility of the Environment Agency and Thames Water.

The Environment Agency is committed to maintaining and improving the flood defences along the River Thames to ensure that the level of protection is maintained for a flood event with a 0.1% annual probability of occurrence. Until 2069, their focus will be on increasing the crest level of defences to take into account the effects of climate change. Additionally, opportunities offered by redevelopment will be used to move defences back from the river's edge which will allow more space for flood waters to flow. However, due to the highly developed nature of the City of London (which includes historic buildings and landmarks), such opportunities will be limited. Post 2070, it is anticipated that major flood defence works will be required however, further information and consultation is required to inform the final option decision.

Thames Water is committed to reducing the risk of sewer flooding within London. They are aiming to reduce the flood risk to approximately 2,100 properties by 2020 by improving the sewer system. This will be done by increasing sewer capacity, upgrading sewer treatment works and offering mitigation measures to homes at risk. In order to protect London against increasing sewer flooding as a result of Climate Change, Thames Water have raised the design standards for new sewers and are developing innovative solutions to increase capacity. They are also investigating 14 locations to prevent heavy rainfall from soaking into the sewer systems. Thames Water will be installing protective measures onto 24 sewage works. Furthermore, in partnership with the London Borough's, Thames Water is managing flood risk from sewers through new development by:

- Ensuring that there is sufficient capacity within sewers before connecting a new development;
- Protecting green spaces which have the potential for infiltration;
- Participating in the production of SWMP's, helping to identify flooding hotspots and providing strategies for reducing flood risk; and,
- Promoting the use of SuDS.

Additionally, the Thames Tideway scheme will reduce the number of overflow events into the River Thames to approximately 3 or 4 per year which will improve water quality by capturing most of the pollution which would otherwise end up with the River Thames. The combined sewer overflow (CSO) at Blackfriars within the City of London will be captured as part of the Thames Tideway scheme.

In addition to this, Thames Water is willing to provide funding contributions to schemes where surface water flows to the combined sewer system are reduced, which links well with LLFA's SuDS retrofitting schemes and surface water flood alleviation schemes.

10.4 CONDITION OF ASSETS

The asset register contains minimal information in relation to the condition of assets, with the exception of the walls and embankments along the River Thames which form part of the NFCDD database from the Environment Agency. The condition of the defences is categorised as 'excellent', 'good', 'fair', 'poor' and 'very poor' on a scale of 1 (very poor) to 5 (excellent). Within the City of London boundary, one asset has a 'poor' condition. The remainder are categorised as 'fair' and 'good' (Refer to Figure 33014-COL-304 – Flood Defence Condition Map in Appendix A).

It is worth noting that assets without a condition rating are part of formal, active systems which undergo ongoing maintenance and improvements.

11 PROPOSED POLICIES IN RELATION TO TIDAL/FLUVIAL FLOOD RISK

The following recommendations are proposed for development within the Tidal Breach Flood Extent in Flood Zone 3:

Land Use

- Any proposals for the re-development of highly vulnerable land uses such as self-contained basement dwellings, emergency command centres and power stations (sub-stations) should where possible be located/re-located outside of the modelled tidal breach flood extent. No basement development, or extension of existing basements to be permitted in the Tidal Breach Flood Extent.
- Proposed development types or changes in land use (identified in the NPPF and the Environment Agency's Flood Risk Standing Advice as requiring an FRA) within the tidal flood extent should pass the Exception Test. This will include a detailed Flood Risk Assessment that considers all sources of flood risk.
- Proposed developments within areas at risk of tidal breach flooding will need to use flood resilient construction measures.

Flood Resistance Measures

- Flood resistant buildings with appropriate measures to prevent the ingress of water should be designed in the areas likely to be inundated (especially in areas at the highest risk of surface water flooding and tidal flood risk). Current guidance states that flood resistance measures are effective up to 600mm above a property's threshold level.
- Approaches could include the following:
  - **External walls**: careful consideration of materials using low permeability materials to limit water penetration (avoiding using timber frame and cavity walls). Consider applying a water resistant coating.
  - **Doors:** flood resistant doors should be used to prevent water ingress, these should be designed to withstand 600mm of flood water and withstand damage from floating debris.
  - **Windows**: flood resistant windows should be used if they are to be located below the maximum water level expected for the 1 in 200 annual probability tidal flood event. These windows should be water tight and be able to withstand the high pressure exerted on them, when submerged under flood water (and the debris contained in the water).
  - **Air vents**: should not be located below the maximum water level expected for the 1 in 200 annual probability tidal flood event and should be set at a suitable high level to mitigate against surface water flooding (the level of which may be dependent on improved surface water software/methodologies or studies carried out at a higher resolution).
  - **Drainage systems and pipes:** Fit anti-flooding devices to drainage systems to prevent surcharged flooding through toilets. These devices act as one-way valves, preventing contaminated flood water backing up into the buildings through the toilets.

Flood Resilience Measures

- Flood resilient buildings (constructed from water resistant materials where applicable) should be designed in the areas likely to be inundated (especially in areas at the highest risk of surface water flooding and tidal flood risk) to minimise the consequences of flooding and facilitate recovery from the effects of flooding sooner than conventional buildings.

- Approaches could include the following:
  - **Floors:** although access to the lower ground basement levels should be set above the maximum water level expected for the 1 in 200 annual probability tidal flood event, the lower ground level should still avoid use of chipboard floors. Use of concrete floors with integrated and continuous damp-proof membrane and solid concrete floors are preferable.
  - **Internal walls:** avoid the use of gypsum plaster and plasterboard at the lower ground level; use more flood resistant linings (e.g. hydraulic lime, ceramic tiles). Avoid use of stud partition walls.
  - **Fitting, fixture and services:** if possible, locate all fittings, fixtures and services above the maximum water level expected for the 1 in 200 annual probability tidal event and at a suitable height to minimise damage by flood waters. Avoid chipboard and MDF (Medium Density Fibreboard). Consider the use of removable plastic fittings. Use solid doors treated with waterproof coatings. Avoid fitted carpets. Locate electrical, gas and telephone and digital/IT equipment and systems above design flood level.

Levels of Floors and Thresholds/Openings

- No self-contained residential basement development will be granted planning permission within Tidal Breach Flood Extent.
- More vulnerable basements will not be considered with tidal breach flood extents unless the entrance to these basements have threshold levels (entrances, windows, vents etc.) that are 300mm above the maximum water level expected for the 1 in 200 annual probability tidal breach flood event scenario (this level will be site specific and will require consultation with the Environment Agency).
- Access to the ground level of new 'more vulnerable' developments (please refer to Table 2-1 for more information) within the modelled tidal breach flood extents, should have threshold levels designed to a level agreed with the Environment Agency. Ideally this should be 300mm above the maximum water level expected for the 1 in 200 annual probability tidal flood event (this level will be site specific).

Recommendations for Evacuation Access and Egress

- In addition, for planning permission to be granted for basements, an internal stair access should be provided to a safe haven within the building to a level above the threshold level (i.e. 300mm above the maximum water level expected for the 1 in 200 annual probability tidal flood event). Such a haven should be sufficient in size for all potential users and be reasonably accessible to the emergency services.
- A robust Evacuation Plan should be implemented for all proposed development within the modelled tidal flood extent. This should include:
  - Sign up to the Environment Agency's Flood Warning Direct service;
  - Procedures for acting on a Flood Warning received, including evacuation procedures from the building for vulnerable people, for example, children and those with impaired hearing, sight or mobility; and,
  - Advice from the Local Authority Emergency Planning Team and from the Emergency Services relevant to the site.

12 PROPOSED POLICIES IN RELATION TO SURFACE WATER FLOOD RISK

The modelling undertaken as part of this SFRA update provides a more detailed assessment of surface water flood risk within the City of London. The modelling results can be used to facilitate sustainable development in the future. It can also be used to test development proposals at key hotspot locations or at locations where highly vulnerable development is proposed.

The following policies are recommended within the City of London in relation to surface water flood risk:

- Any development proposed within the areas at high risk of surface water flooding, as identified in this SFRA, should undertake a Flood Risk Assessment and pass the Exception Test.
- Any essential infrastructure, highly or more vulnerable development which needs to pass the Exception Test should undertake a Flood Risk Assessment which will also focus on mitigating surface water flood risk. Surface water flood levels for the development site should be obtained from the City of London Corporation;
- Building owners and occupiers should undertake an assessment of surface water flood risk for all basements that contain highly valuable items.
- Any development that contributes runoff to the high risk areas should implement measures to control surface water runoff so that runoff does not leave the site at more than Greenfield runoff rates and volumes. If limiting discharge to Greenfield rates is not viable or feasible, then attenuation must reduce runoff as much as possible for the flood with a 1 in 1 and 1 in 100 annual probability of occurrence. If a reduction in the volume of discharge cannot be achieved then the peak discharge should be restricted to 2 l/s/ha for all storm design events. Water recycling and re-use should be adopted to reduce runoff. Discharge of water directly to the river, rather than the sewer system, should be implemented wherever possible to avoid impacting other sites;
- Any development that requires a Flood Risk Assessment should set the ground floor finished floor levels 0.3m above the design flood event (1 in 100 annual probability plus climate change event);
- In high risk surface water zones, the finished ground floor level shall be set to 0.3m above the 1 in 100 annual probability peak water level taking account of climate change. If this is not feasible then the ground floor shall be flood resilient up to 0.6m above floor level. More vulnerable basements will not be considered with high surface water flood extents unless they are protected by the surrounding building (including the entrance) by a threshold set to 0.3m above the 1 in 100 annual probability peak water level taking account of climate change. Less vulnerable basements will be considered if they are be flood resilient up to 1m above basement floor level. An evacuation plan shall be required for all basements with the high risk surface water flood zone;
- Any new development within the City of London should have separate surface water drainage arrangements to allow for future connection to any new surface water sewers; and,
- It is recommended that the City of London Corporation maximises opportunities for redirecting runoff from roof down pipes to open spaces, to form a visually attractive safe water environment or to use for storage and re-use in small City of London gardens and open spaces. Only excess volumes should be returned to the combined system (please refer to the London Plan Drainage Hierarchy in Policy 5.13 SUSTAINABLE DRAINAGE).

13 CONCLUSION

This 2017 SFRA review has assessed the latest and most up-to-date information of the risk of flooding to the City of London from all sources. It has been informed from recent updates to policy and guidance from national Government and other relevant organisations such as the Environment Agency and Defra. Significant changes since the previous SFRA that was prepared in 2012 include:

- → Updated guidance from the Environment Agency on appropriate allowances for climate change that should be used when assessing flood risk;
- → New modelling of the risk of flooding from breach of the River Thames tidal flood defences. This has increased the areas at risk from breaches as a result of a new approach to modelling, which considers the risk of breaching along the entire length of the defence rather than at discrete locations;
- → New information on the risk of flooding from surface water has been used to consider a range of possible scenarios; and,
- → A recognition of the potential risk of flooding as a result of burst water mains.

The fluvial and tidal flood zones have not changed since the 2012 SFRA with the southern part of the City of London in the immediate vicinity of the River Thames, being the only area at risk. The City of London is protected by the wall along the River Thames and the Thames Barrier.

A review of the surface water flood risk modelling available has concluded that the modelling undertaken for the 2012 SFRA remains the best available assessment of risk, providing a conservative approach due to the large uncertainty in prediction. The significant risk areas within the City of London therefore are still Farringdon Street, New Bridge Street, Victoria Embankment and St Paul’s Walk.

Information on the risk of flooding from groundwater sources remains limited; the GARDIT scheme which maintains groundwater levels in the deep chalk aquifer below London ensures that the risk of flooding from this source remains low. However there is a risk of flooding from groundwater in superficial deposits and made ground near to the surface which sits on top of clay. This may arise from leaking pipes or high water levels in the River Thames. Basements are particularly vulnerable to high groundwater levels and these are numerous throughout the City of London.

To manage the risk of surface water flood risk in the City of London this SFRA provides details of the potential approaches that could be used including retrofit SuDS, and property level resistance and resilience measures. SuDS and water re-use continue to be promoted in new development and the City of London Corporation will do this through planning policy.

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Appendix A

MAPS AND FIGURES

Appendix B

RETROFIT SUDS EXAMPLES

Appendix C

SURFACE WATER FLOOD RISK MODELLING COMPARISON

SURFACE WATER FLOOD RISK COMPARISON

This appendix summarises the modelling undertaken as part of this commission in addition to the surface water modelling undertaken in the past, as listed in Table C.1 below

Table C.1 – Surface Water Modelling in the City of London

Name	Type	Thames 1d model version	Key Features	Purpose
Drain London model (localised storm)	2d	n/a	No detailed 2d with direct rainfall everywhere. No kerbs, no gullies, no buildings, limited allowance for permeability coefficients and only allows for sewer flows by removing part of the rainfall.	To inform SWMPs.
2012 SFRA model (catchment-wide storm)	1d-2d	2012 (detailed not calibrated)	Detailed 1d and 2d. Modelled buildings and kerbs. Sewers modelled only in the vicinity of the City. Does not have direct rainfall on roads.	Used for the 2012 SFRA.
WCC updated model (catchment-wide storm)	1d-2d	2015 (detailed calibrated)	Detailed 1d and 2d. Sewers modelled in the entire catchment Direct rainfall on roads to allow for the conveyance and attenuation of flows in roads).	Used for the development of business cases for the City of Westminster since 2015, however it includes relevant results for the City of London.
Latest 1d Beckton model (catchment-wide storm)	1d	2017 (detailed calibrated and further improved from 2015 version)	Most up to date detailed 1d.	To inform the locations where manholes overflow in the City of London, for the 2017 SFRA review.
2017 Gully Blockages model (localised storm)	2d	n/a	Detailed 2d. Includes kerbs, detailed mesh and allowance for permeability coefficients.	Sensitivity test to inform gully maintenance regimes as part of this 2017 SFRA review.

The table above indicates that the model that used the most advanced techniques as the WCC updated model as it allows for the conveyance and storage in roads as a result of applying direct rainfall on roads. Kerbs are then used as a fist line of defence. The 2012 SFRA model did not have direct rainfall on roads.

A comparison of results is difficult as the latest Beckton model does not have a 2d element however it has been possible to compare all models (except those that are 2d models only – the Drain London and the gully blockages models) in terms of locations and number of manholes that overflow from the sewers. This comparison has enabled to asses which modelling would result in the larger, medium or least flood extents and depths respectively.

Figures C1, C2 and C3 show the locations where manholes overflow for the 2012 SFRA model, the updated WCC model and the latest 1d Beckton model respectively for the 1 in 100 year flood event.

1 IN 100 YEAR STORM

- Flood Depth > 0
- Flood Depth < 0

Flood depth > 0 with the red coloured manholes means that there is floodwater overflowing from the manhole. The green coloured manholes are therefore not overflowing.

Figure C1 – Locations of Manholes Overflowing (2012 SFRA Model)

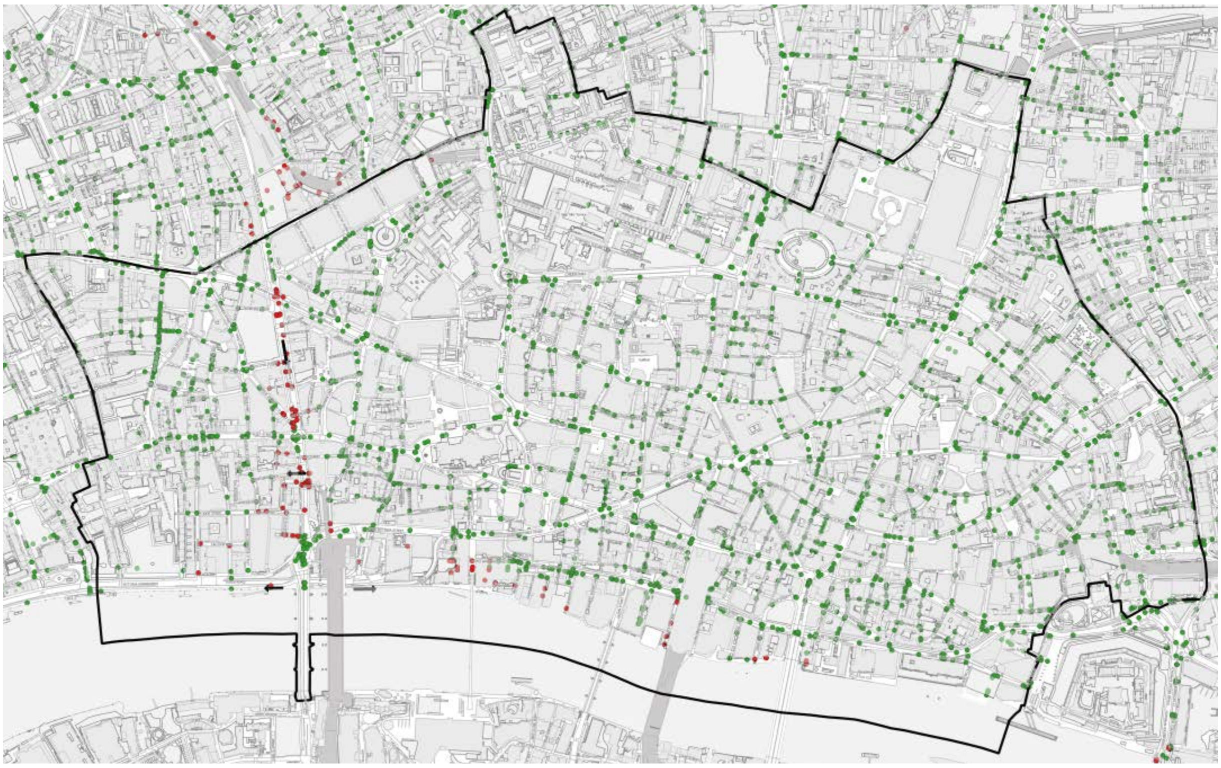


Figure C2 – Locations of Manholes Overflowing (Updated WCC model)

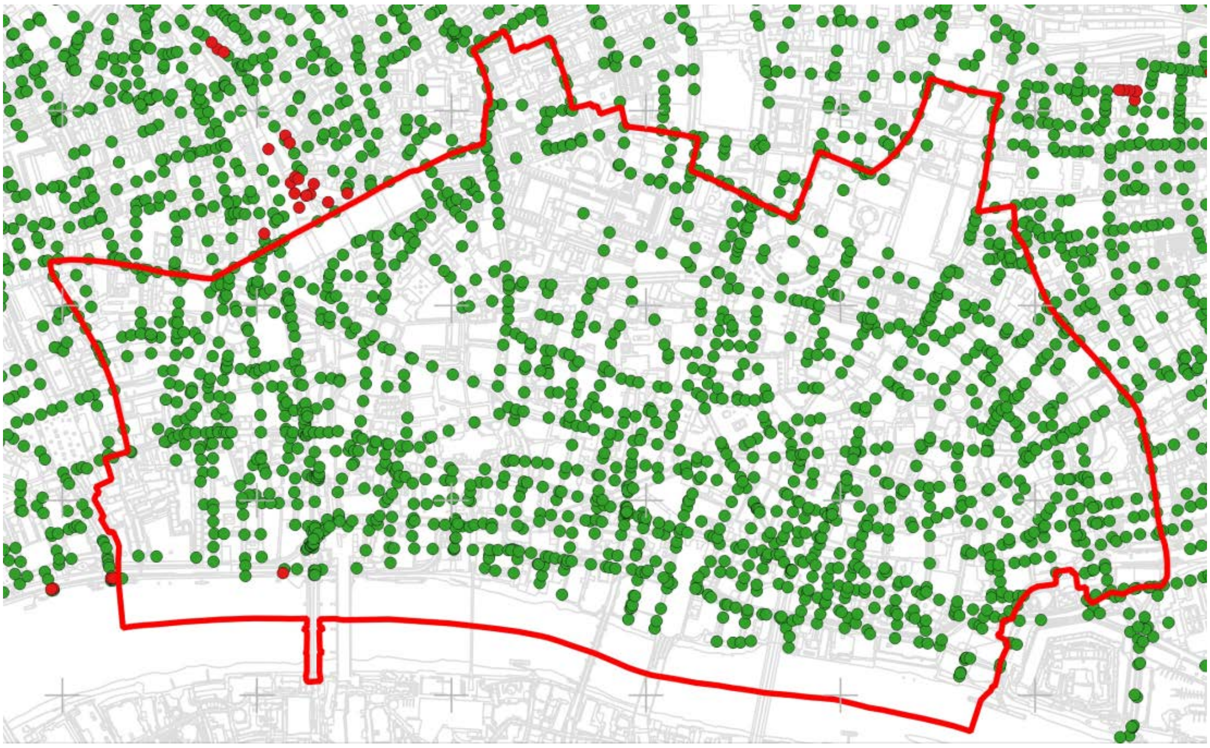
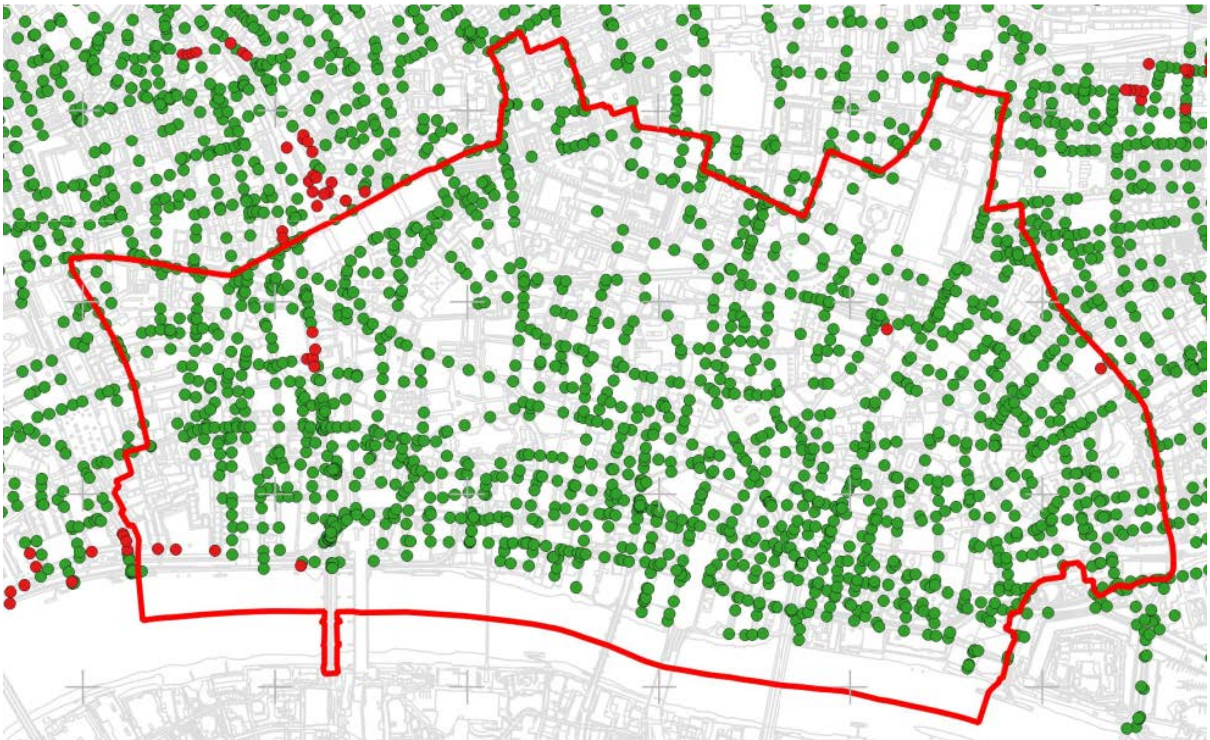


Figure C3 – Locations of Manholes Overflowing (Latest 1d Beckton Model)



The results from Figures C1 to C3 indicate that based on the number of locations of manholes:

→ All models follow a similar mechanism of flooding and the main flood risk areas are similar.

- The most conservative estimates are from the 2012 SFRA model (the largest number of manholes overflowing)
- The least flooding from overflowing manholes is from the updated WCC model
- The results from the latest 1d Beckton model are in between the two above.

As a precautionary approach the surface water modelling outputs from the 2012 SFRA model have been used to inform this SFRA and the flood depths and extents of this modelling are provided in Figures 33014-COL-402 to 33014-COL-405. In terms of gully blockages it is important to provide an indication of the locations where flooding could occur as a result of a high intensity localised storm as overland flows will be accumulating at low points. Although this modelling is conservative (all gullies are assumed to be blocked at the same time), this mapping could be useful to prioritise asset gully maintenance. It can also be used to promote flood resilience measures at these locations. Figure C.4 provides the peak water depths for the gully blockage scenario, for the 1 in 100 year flood event.

Figure C.4 – Peak flood depths for the Gully Blocked Scenario