3.5.4 Historic Records – Flooding

Past records of surface water flooding within the study area have been provided by various stakeholders and previous studies undertaken for the study area. A breakdown of the data provided for the SWMP can be located within Figure 7 located within Appendix C. The model output shows a good correlation with the locations of the properties that experienced flooding during the 20 July 2007 event and other historic incidents, such as those in October 2006 in Notting Hill and Sloane Square Underground Stations, and the flooding of July 2007 affecting the Holland and Norland Wards. The localised areas of ponding shown by the modelling are indicative of areas which may be more susceptible to problems such as roads or risk of flooding to ground floors and basements.

Some areas that suffered flooding during the 20 July 2007 were not identified. It should be noted that the properties flooded during this event would have been a result of a combination of surface water and sewer (surcharge) flooding, whereas the modelling outputs only show indicative areas of surface water flooding

3.5.5 Methodology for Assessment of Pluvial Flooding

Modelling Overview

In order to continue developing an understanding of the causes and consequences of surface water flooding in the study area, intermediate level hydraulic modelling has been undertaken for a range of rainfall event probabilities. The purpose of this modelling is to provide additional information where local knowledge is lacking and forms a basis for future detailed assessments in areas identified as high risk. The following sections outline key aspects of the modelling methodology applied. For a more detailed description refer to Appendix B.

To facilitate the accurate identification, retrieval and review of model data a number of actions were undertaken, including:

- The use of a standard folder structure for all model files;
- A standardised naming convention that included the model name, grid size, scenario and version number;
- A model log was initiated at the start of the modelling process that provides a clear and concise record of model development; and
- The model was reviewed by a senior modeller following Capita standard Quality Assurance protocol. This review incorporated all the model files that were used in the model set-up.

An integrated modelling approach (see Table 3-2) has been selected where rainfall events of known probability are applied directly to the ground surface and water is routed overland to provide an indication of potential flow paths and areas where surface water will pond during an extreme event.

Table 3-2: Levels of pluvial modelling

	Rolling Ball	Surface water flow routes are identified by topographic analysis, most commonly in a GIS package
	Direct Rainfall	Rainfall is applied directly to a surface and is routed overland to predict surface water flooding
	Drainage Systems	Based around models of the underground drainage systems
	Integrated Approach	Representing both direct rainfall and drainage systems in an integrated manner, or through linking different models together dynamically

Hydraulic modelling of the pluvial and ordinary watercourses component of surface water flooding was undertaken using TUFLOW software (Build 2012-05-AE). TUFLOW simulates water level variations and flows for depth-averaged, unsteady two-dimensional (2D), free-surface flows and has been used successfully for many SWMPs to capture the hydrodynamic behaviour and flow patterns in complex urban environments.

The extent of the hydraulic model has been based upon catchment boundaries as agreed with the SWMP Client Steering Group. The Drain London Tier 2 model resolution of 5m was reduced to a 3m cell size to better understand the flowpaths and flood mechanisms within the Royal Borough. Figure 3-2, below, indicates the extent of the models utilised within the risk assessment.

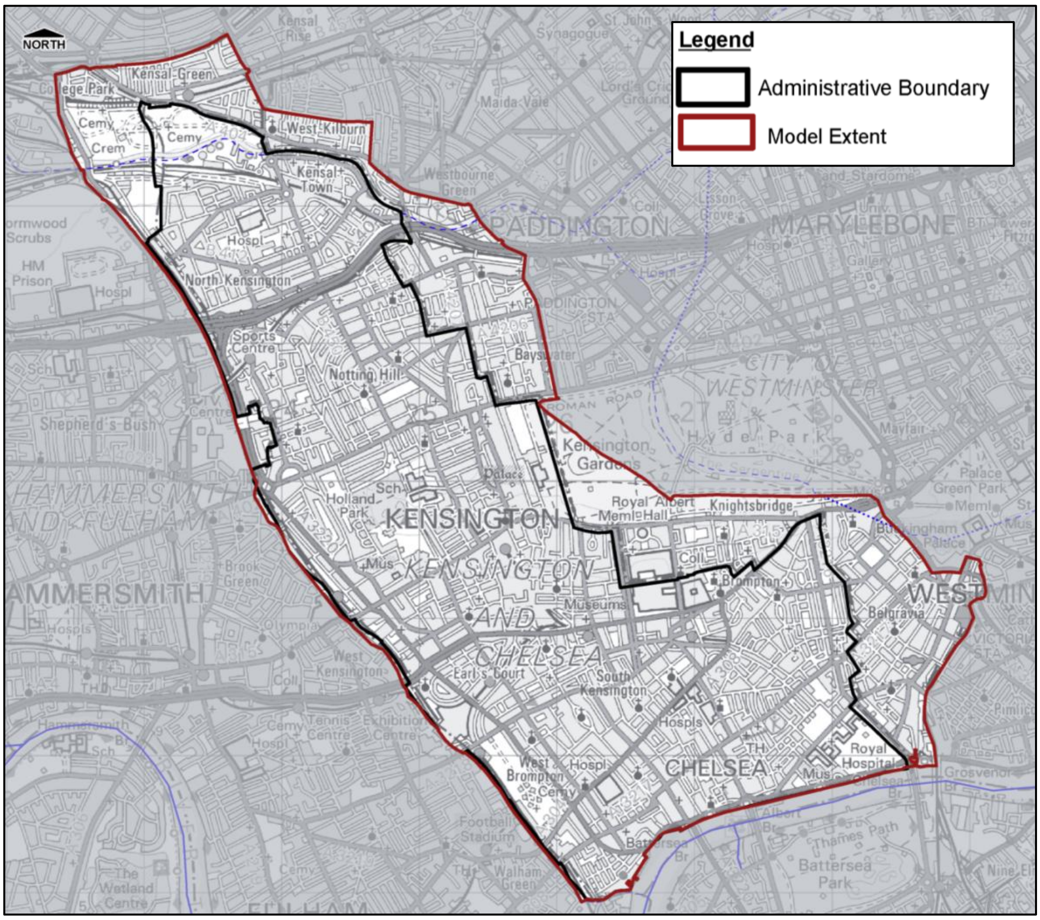


Figure 3-2 TUFLOW Model Boundaries

The selected return periods were chosen through consultation with the Steering Group. As part of this report, figures have been prepared for the modelled settlements based on the 1 in 100 year rainfall event (1% AEP). GIS layers of results for the remaining return periods have also been produced and are included in Appendix C. Additionally, ASCII grids and ESRI Shape files have been created and distributed to RBKC for use within their in-house GIS system. Table 3-3, below, provides details of the return periods that have been selected and the suggested uses of the various modelling outputs.

Table 3-3: Selected return periods and suggested use of outputs

Modelled Return Period	Suggested use
1 in 10 year event *(10% AEP)*	Event can be used in verifying hydraulic model outputs against Thames Water DG5 register and Thames Water standard model scenarios.
1 in 20 year event *(5% AEP)*	Thames Water utilise the 1 in 20 year results to identify properties that might be at risk of flooding. The identification of flooding from this scenario is also required for populating the Flood Defence Grant in Aid (FDGiA) funding applications as it assists with highlighting areas at a 'very significant' risk of flooding.
1 in 30 year event *(3.3% AEP)*	Assists in determining the benefit of flood risk management options should partnership funding with Thames Water be sought. This also corresponds to the Environment Agency updated Flood Map for Surface Water (uFMfSW).
1 in 50 year event *(2% AEP)*	For use in determining the benefit of flood risk management options should partnership with Thames Water be sought.
1 in 75 year event *(1.3% AEP)*	In areas where the likelihood of flooding is 1 in 75 years or greater insurers may not guarantee to provide cover to property if it is affected by flooding. This layer should be used to inform spatial planning as if property cannot be guaranteed insurance, the development may not be viable. Based on the new (January 2013) National Flood Risk Assessment (NaFRA) proposals by the EA, this return period event is considered to border the 'significant' flood likelihood band – results from this event will help provide an audit trail as flood likelihood bands change or some processes are slow to change.
1 in 100 year event *(1% AEP)*	Can be overlaid with Environment Agency Flood Zone 3 layer to show areas at risk under the same return period event from surface water and main river flooding. Can be used to advise planning teams – please note that the pluvial 1 in 100 year event may differ from the fluvial event due to methods in runoff and routing calculations. Also corresponds with the Updated Flood Maps for Surface Water being prepared by the Environment Agency.
1 in 100 year event (plus climate change)	NPPF requires that the impact of climate change is fully assessed. Reference should be made to this flood outline by the spatial planning teams to assess the sustainability of developments.

Modelled Return Period	Suggested use
1 in 200 year event *(0.5% AEP)*	To be used by emergency planning teams when formulating emergency evacuation plans from areas at risk of flooding. The new NaFRA banding indicates that this event is also required by Cabinet Office policy for determining the risk and resilience of critical infrastructure.
1 in 1000 year event *(0.1% AEP)*	Requested for consistency with the Updated Flood Maps for Surface Water being prepared by the Environment Agency.

A summer rainfall profile was selected as it produces a higher intensity storm event than a winter profile, which is considered to be the 'worst-case' scenario. Models simulations were run at double the critical duration in order to allow runoff to be conveyed down overland flow paths.

As part of this study, maps of maximum water depth and hazard for each of the return periods above have been prepared and are presented in Appendix C of this report. When viewing the maps, it is important that the limitations of the modelling are considered – refer to key assumptions and uncertainties later in this report.

The figures presented in Appendix C indicate that water is predicted to pond over a number of roads and residential/commercial properties (in particular basement properties). These generally occur at low points in the topography or where water is confined behind an obstruction or embankment.

Some of the records of surface water flooding shown in Figure 3-1 have been used to verify the modelling results. Discussions with Council staff have also provided anecdotal support for several of the locations identified as being susceptible to flooding.

The results of the assessment have been used to identify Critical Drainage Areas (CDAs) across the study area.

3.5.6 Uncertainty in flood risk assessment – Surface Water Modelling

The surface water modelling provides the most detailed information to date on the mechanisms, extent and hazard which may result from high intensity rainfall across the study area. However, due to the strategic nature of this study and the limitations of some data sets, there are limitations and uncertainties in the assessment approach of which the reader should be aware.

There is a lack of reliable measured datasets and the estimation of the return period (probability) for flood events is therefore difficult to verify. The broad scale mapping provides an initial guide to areas that may be at risk; however there are a number of limitations to using the information:

- The mapping should not be used in a scale to identify individual properties at risk of surface water flooding. It can only be used as a general indication of areas potentially at risk.
- Whilst modelled rainfall input has been modified to reflect the possible impacts of climate change it should be acknowledged that this type of flooding scenario is uncertain and likely to be very site specific. More intense short duration rainfall and higher volume more prolonged winter rainfall are likely to exacerbate flooding in the future.

3.5.7 Key Assumptions for Surface Water Modelling

The surface water modelling methodology for the study has used the following key assumptions:

- It has been assumed that land roughness varies with land type (e.g., roads, buildings, grass, water, etc) and therefore different Manning's roughness coefficients have been specified for different land types to represent the effect different surfaces have on the flow of water;
- The watercourses, within the study area, have been modelled at the elevations obtained when the DTM information was gathered;
- Building thresholds have been included in the model in order to represent the influence they have on surface water flow paths. All building polygons within the model were raised by 100mm, meaning they act as barriers to flood waters in the model, up until the water depth becomes greater than 100mm where it is assumed that the building would flood and water would flow through the building, as would be the case in an actual flood event;
- The presence of a roadside kerb can be a significant influence on the movement of flood water. The vertical accuracy of the LiDAR often means that the distinction between the road level and the pavement is not necessarily accurately represented. Therefore, the road features (defined by the OS MasterMap layer) have been lowered by 125mm to define this difference;
- A bespoke approach to modelling basements has been undertaken for this SWMP to reduce the overproduction of ponding within basement properties. Appendix C provides more details on the approach; and
- Infiltration from permeable landuses (based on MasterMap) occurs across the study area utilising the Green–Ampt Method, in which infiltration rates are based on hydraulic properties corresponding to the underlying soil types.

3.5.8 Hydrology

An important aspect of establishing suitable rainfall profiles is to estimate the critical storm duration for the study area. In order to ensure that the most appropriate scenario is assessed and the entire catchment is contributing surface water runoff, the critical storm duration must be estimated.

Two methods were used to calculate an estimate of the critical storm duration for the rainfall profiles used in the model. A summary of these methods is given below:

- The Bransby-Williams formula was used to derive the *time of concentration,* defined as the time taken for water to travel from the furthest point in the catchment to the catchment outfall, at which point the entire site is considered to be contributing runoff; and
- The Flood Estimation Handbook (FEH) equation for critical storm duration - the standard average annual rainfall (SAAR) value for each a catchment has been extracted from the FEH CD-ROM v3 and the Revitalised Flood Hydrograph method (ReFH) model has been used to derive the time to peak (Tp) from catchment descriptors.

Based on this assessment a critical storm duration of one and a half (1.5) hours was utilised within the direct rainfall model, with the model being run at a length of three (3) hours to capture the impacts of ponding and overland flow after a storm has passed.

The catchment descriptors, from the centre of each catchment, were exported from the Flood Estimation Handbook (FEH) into the rainfall generator within ISIS, which was used to derive rainfall hyetographs for a range of return periods. The hyetographs generated using this methodology, and incorporated within the pluvial model can be located within Appendix B.

3.5.9 Model Topography

The boundary of the models was based on a review of the topographical information available for the area. Light Detecting and Ranging data (LiDAR) was used as the base information for the model topography. LiDAR data is an airborne survey technique that uses laser to measure the distance between an aircraft and the ground surface, recording an elevation accurate to ±0.15m at points 1m apart. The technique records elevations from all surfaces and includes features such as buildings, trees and cars. This raw data is then processed to remove these features and provide values of the ground surface, which is merged to create a Digital Terrain Model. LiDAR data was available at a 1m resolution for the study area. Filtered LiDAR data (in preference to unfiltered) has been used as the base topography to provide the model with a smoother surface to reduce the potential instabilities in the model and areas of unexpected ponding.

An image of the DTM used to represent the topography of the study area in the pluvial model is shown in Appendix C – the general topography of the study can be seen in Figure 1-6. The ground elevations were represented in TUFLOW using a 3m grid. The decision to use a 3m grid is an optimisation of the computational time required due to the size of the study area and the need for accuracy in the model in order to resolve features in the urban environment.

3.5.10 Land Surface

The type of land surface has a significant effect on the flow of water along surface water flow paths due to the relatively shallow depths of flooding. As such, a number of roughness coefficients have been specified in order to accurately represent different land types within the hydraulic model and the effect they have on the flow of water.

OS MasterMap data has been used to produce different land type layers (such as roads, grass, water, etc, as shown in Figure 3-3), for which different Manning's roughness coefficients have been specified.

These layers have been applied across the modelled areas and included within the TUFLOW model in order to represent the different behaviour of water as it flows over different surfaces.

Figure 3-3: OS MasterMap land type layers

3.5.11 Improvements over Drain London Tier 2 SWMP Model

The following includes a list of the model improvements that have been applied to the detailed TUFLOW modelled built to represent RBKC (refer to Appendix B):

- Incorporation of a bespoke basement modelling approach to reduce the over prediction of flood depths within basement properties;
- Inclusion of the Thames Water drainage network. A reduction in capacity of 12.5% was included within the model to account for dry weather flows (i.e. normal wastewater flows) within the pipe network. This reduction factor is based on the average volume of wastewater (i.e. flow excluding the surface water component) as a percentage of total pipe

volume, which was calculated based on Thames Water data. The reduction accounts for the fact that a certain proportion of pipe capacity is unavailable for storage and conveyance of surface water flows;

- Inclusion of gulley assets to convey runoff into the Thames Water drainage network;
- Reduction of LIDAR levels along 'road' assets by 125mm to reflect the influents of kerbs on overland flowpaths.
- Identification of key structures that may influence flooding/overland flowpaths within RBKC;
- Infiltration from permeable landuses (based on MasterMap) occurs across the study area utilising the Green–Ampt Method; and
- Reduction in grid resolution (cell size) from 5m×5m (area = 25m2) to 3m×3m (area = 9m2) – refer to Figure 3-4, below, for a visual comparison of the two grid cell sizes.

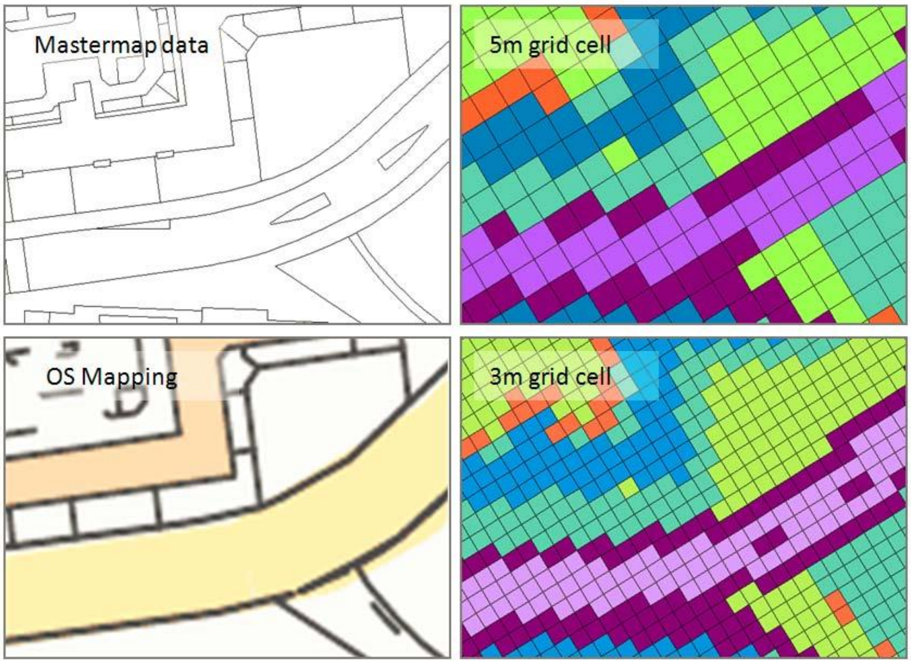


Figure 3-4 Comparison of Model Grid Size

3.5.12 Model Verification

It is important to ensure that the outputs from the modelling process are as reliable as possible. To this end, a number of actions and data sources have been used to check the validity of the model outputs, including the following:

Ground-truth model

This stage of verification involved reviewing the hydraulic model outputs against the initial site inspections/assessment to ensure that the predictions were realistic and considered local topography and identified drainage patterns. Where previous site inspection data did not provide sufficient information on a specific area within the study, the model outputs were assessed against aerial photography from third party sources to assist in the model verification.

EA national surface water mapping

The Environment Agency has produced two national surface water datasets using a coarse scale national methodology:

- Areas Susceptible to Surface Water Flooding (AStSWF); and
- Flood Map for Surface Water (FMfSW).

As a method of validation, the outputs from these datasets have been compared to the SWMP modelling outputs to ensure similar flood depths and extents have been predicted. There are slight variations, due to the more accurate methodology used in the SWMP risk assessment, but generally the outputs with relation to ponding locations and flow paths are very similar. However, the extent of the depths was noticed to vary, as shown in the example in Figure 3-5, overleaf.

This observation provides confidence in the final model outputs as the variation in the results is concluded as being related to the more refined DTM (used within this study) and the catchment specific critical durations (as the Environment Agency FMfSW maps utilised a single duration to represent runoff throughout England) defined in this report.

Please note that the Environment Agency is preparing new surface water mapping products coming out shortly that LLFAs will be able to utilise which improve the level of detail and confidence in the predicted surface water flood risk. LLFAs will be able to utilise this data or more detailed modelling outputs (such as those presented in this study) to display the predicted risk in an area.

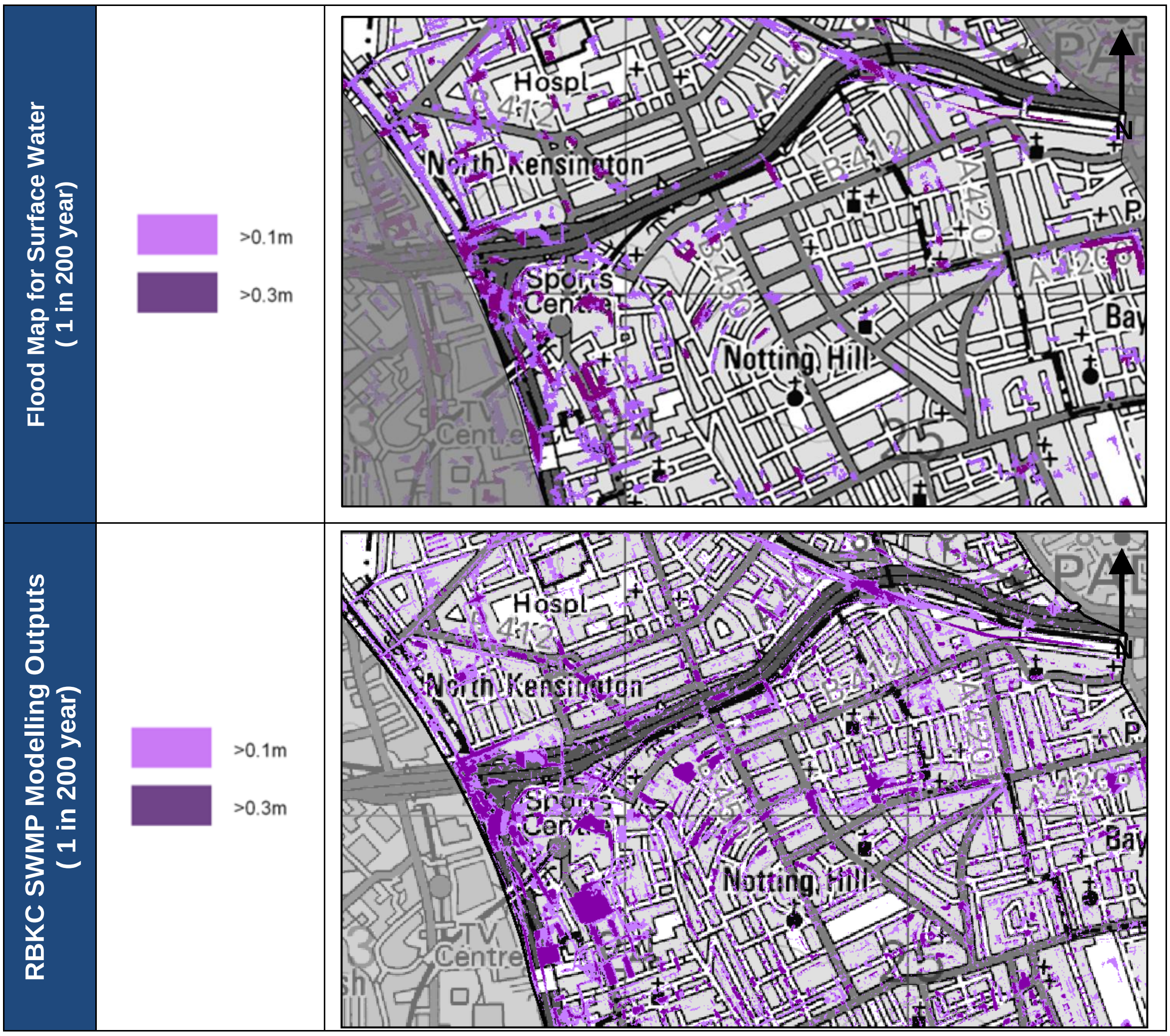


Figure 3-5 Example comparison between FMfSW and SWMP model outputs

Flood history and local knowledge

Recorded flood history has also been used to verify areas which are identified as being at risk of flooding with previous known flood events. As discussed in Section 3.2, information on historical flood events was collected from a number of sources. In addition to this, members of the Flooding Steering Group, have an extensive knowledge of the study area and the drainage and flooding history as they live locally. The use of a stakeholder workshop, with Council representatives, was also an effective way to validate the model outputs. The members who attended the workshop examined the modelling outputs and were able to provided anecdotal information on past flooding which confirmed several of the predicted areas of ponding.

Mass balance checks

The accuracy of the hydraulic calculations driving the TUFLOW model, and the performance of the model itself, can be checked using a simple analysis of the data from the model. The percentage mass error is calculated every five (5) minutes and output with the other results files. The percentage mass error is a mass error based on the maximum volume of water that has flowed through the model and the total volume of water in the model.

It is normal for the figure to be large at the start of a simulation, particularly with steep models using the direct rainfall approach, as the cells are rapidly becoming wet as it begins to rain but flow through the model is relatively small. Mass balance graphs can be located within Appendix B and show that the cumulative error of the model is within the recommended range of +/-1% throughout the simulation for all assessed rainfall events.

3.5.13 Model Outputs

TUFLOW outputs data in a format which can be easily exported into GIS packages. As part of the surface water modelling exercise, a series of ASCII grids and MapInfo TAB files have been created including:

- Flood depth grids;
- Flow velocity grids; and
- Flood hazard grids.

Flood hazard is a function of the flood depth, flow velocity and a debris factor (determined by the flood depth). Each grid cell generated by TUFLOW has been assigned one of four hazard rating categories: ‘Extreme Hazard’, ‘Significant Hazard’, ‘Moderate Hazard’ and ‘Low Hazard’. Guidance on the depths and velocities (hazard) of floodwater that can be a risk to people is shown within Figure 3-6 (overleaf).

The hazard rating (HR) at each point and at each time step during a flood event is calculated according to the following formula (Defra/Environment Agency FD2320/TR1 report, 2005):

$$HR = d\,(v + 0.5) + DF$$

Where: HR = flood hazard rating
d = depth of flooding (m)
v = velocity of floodwater (m/s)
DF = Debris Factor, according to depth, d (see below)

Guidance within the FD2320 report recommends the use of a Debris Factor (DF) to account for the presence of debris during a flood event in the urban environment. The Debris Factor is dependent on the depth of flooding; for depths less than 0.25m a Debris Factor of 0.5 was used and for depths greater than 0.25m a Debris Factor of 1.0 was used.

The maximum hazard rating for each point in the model is then converted to a flood hazard rating category, as described in Table 3-4, below. These are typically classified as caution (very low hazard), moderate (danger for some), significant (danger for most), extreme (danger for all).

HR	Depth of flooding - d (m)												
	DF = 0.5				DF = 1								
Velocity v (m/s)	0.05	0.10	0.20	0.25	0.30	0.40	0.50	0.60	0.80	1.00	1.50	2.00	2.50
0.0	0.03+0.5= 0.53	0.05+0.5 = 0.55	0.10+0.5 = 0.60	0.13+0.5 = 0.63	0.15+1.0 = 1.15	0.20+1.0 = 1.20	0.25+1.0 = 1.25	0.30+1.0 = 1.30	0.40+1.0 = 1.40	0.50+1.0 = 1.50	0.75+1.0 = 1.75	1.00+1.0 = 2.00	1.25+1.0 = 2.25
0.1	0.03+0.5= 0.53	0.06+0.5 = 0.56	0.12+0.5 = 0.62	0.15+0.5 = 0.65	0.18+1.0 = 1.18	0.24+1.0 = 1.24	0.30+1.0 = 1.30	0.36+1.0 = 1.36	0.48+1.0 = 1.48	0.60+1.0 = 1.60	0.90+1.0 = 1.90	1.20+1.0 = 2.20	1.50+1.0 = 2.55
0.3	0.04+0.5= 0.54	0.08+0.5 = 0.58	0.15+0.5 = 0.65	0.19+0.5 = 0.69	0.23+1.0 = 1.23	0.30+1.0 = 1.30	0.38+1.0 = 1.38	0.45+1.0 = 1.45	0.60+1.0 = 1.60	0.75+1.0 = 1.75	1.13+1.0 = 2.13	1.50+1.0 = 2.50	1.88+1.0 = 2.88
0.5	0.05+0.5= 0.55	0.10+0.5 = 0.60	0.20+0.5 = 0.70	0.25+0.5 = 0.75	0.30+1.0 = 1.30	0.40+1.0 = 1.40	0.50+1.0 = 1.50	0.60+1.0 = 1.60	0.80+1.0 = 1.80	1.00+1.0 = 2.00	1.50+1.0 = 2.50	2.00+1.0 = 3.00	2.50+1.0 = 3.50
1.0	0.08+0.5= 0.58	0.15+0.5 = 0.65	0.30+0.5 = 0.80	0.38+0.5 = 0.88	0.45+1.0 = 1.45	0.60+1.0 = 1.60	0.75+1.0 = 1.75	0.90+1.0 = 1.90	1.20+1.0 = 2.20	1.50+1.0 = 2.50	2.25+1.0 = 3.25	3.00+1.0 = 4.00	3.75+1.0 = 4.75
1.5	0.10+0.5= 0.60	0.20+0.5 = 0.70	0.40+0.5 = 0.90	0.50+0.5 = 1.00	0.60+1.0 = 1.60	0.80+1.0 = 1.80	1.00+1.0 = 2.00	1.20+1.0 = 2.20	1.60+1.0 = 2.60	2.00+1.0 = 3.00	3.00+1.0 = 4.00	4.00+1.0 = 5.00	5.00+1.0 = 6.00
2.0	0.13+0.5= 0.63	0.25+0.5 = 0.75	0.50+0.5 = 1.00	0.63+0.5 = 1.13	0.75+1.0 = 1.75	1.00+1.0 = 2.00	1.25+1.0 = 2.25	1.50+1.0 = 2.50	2.00+1.0 = 3.00	3.50	4.75	6.00	7.25
2.5	0.15+0.5= 0.65	0.30+0.5 = 0.80	0.60+0.5 = 1.10	0.75+0.5 = 1.25	0.90+1.0 = 1.90	1.20+1.0 = 2.20	1.50+1.0 = 2.50	1.80+1.0 = 2.80	3.40	4.00	5.50	7.00	8.50
3.0	0.18+0.5= 0.68	0.35+0.5 = 0.85	0.70+0.5 = 1.20	0.88+0.5 = 1.38	1.05+1.0 = 2.05	1.40+1.0 = 2.40	1.75+1.0 = 2.75	3.10	3.80	4.50	6.25	8.00	9.75
3.5	0.20+0.5= 0.70	0.40+0.5 = 0.90	0.80+0.5 = 1.30	1.00+0.5 = 1.50	1.20+1.0 = 2.20	1.60+1.0 = 2.60	3.00	3.40	4.20	5.00	7.00	9.00	11.00
4.0	0.23+0.5= 0.73	0.45+0.5 = 0.95	0.90+0.5 = 1.40	1.13+0.5 = 1.63	1.35+1.0 = 2.35	1.80+1.0 = 2.80	3.25	3.70	4.60	5.50	7.75	10.00	12.25
4.5	0.25+0.5= 0.75	0.50+0.5 = 1.00	1.00+0.5 = 1.50	1.25+0.5 = 1.75	1.50+1.0 = 2.50	2.00+1.0 = 3.00	3.50	4.00	5.00	6.00	8.50	11.00	13.50
5.0	0.28+0.5= 0.78	0.60+0.5 = 1.10	1.10+0.5 = 1.60	1.38+0.5 = 1.88	1.65+1.0 = 2.65	3.20	3.75	4.30	5.40	6.50	9.25	12.00	14.75

Figure 3-6 Combinations of flood depth and velocity that cause danger to people (Source: DEFRA/Environment Agency research on Flood Risks to People - FD2320/TR2)

Table 3-4: Derivation of Hazard Rating category

Degree of Flood Hazard	Hazard Rating (HR)		Description
Low	<0.75	Caution	Flood zone with shallow flowing water or deep standing water
Moderate	0.75b – 1.25	Dangerous for some (i.e. children)	Danger: Flood zone with deep or fast flowing water
Significant	1.25 -2.5	Dangerous for most people	Danger: Flood zone with deep fast flowing water
Extreme	>2.5	Dangerous for all	Extreme danger: Flood zone with deep fast flowing water

3.6 Ordinary Watercourse Flooding

3.6.1 Description

All watercourses in England and Wales are classified as either 'Main Rivers' or 'ordinary watercourses'. The difference between the two classifications is based largely on the perceived importance of a watercourse, and in particular its potential to cause significant and widespread flooding. However, this is not to say watercourses classified as ordinary watercourses cannot cause localised flooding. The Water Resources Act (1991) defines a 'main river' as "a watercourse shown as such on a Main River Map". The Environment Agency stores and maintains information on the spatial extent of the Main River designations. The Flood and Water Management Act (2010) defines any watercourse that is not a Main River an ordinary watercourse – including ditches, dykes, rivers, streams and drains (as in 'land drains') but not public sewers.

The Environment Agency has duties and powers in relation to Main Rivers. Local Authorities, or in some cases Internal Drainage Boards, have powers and duties in relation to ordinary watercourses.

Flooding from ordinary watercourses occurs when water levels in the stream or river channel rise beyond the capacity of the channel, causing floodwater to spill over the banks of the watercourse and onto the adjacent land. The main reasons for water levels rising in ordinary watercourses are:

- Intense or prolonged rainfall causing rapid run-off increasing flow in watercourses, exceeding the capacity of the channel. This can be exacerbated by wet antecedent (the preceding time period) conditions and where there are significant contributions of groundwater;
- Constrictions/obstructions within the channel causing flood water to backup;
- Blockage/obstructions of structures causing flood water to backup and overtop the banks; and
- High water levels in rivers preventing discharge at the outlet of the ordinary watercourse (often into a main river).

A review of the EA Main River dataset indicates that there are no ordinary watercourses within RBKC that the Council is at risk of and needs to maintain as part of the FWMA.

3.7 Groundwater Flooding

3.7.1 Description

Groundwater flooding is water originating from sub-surface permeable strata which emerges from the ground, either at a specific point (such as a spring) or over a wide diffuse location, and inundates low lying areas. A groundwater flood event results from a rise in groundwater level sufficient for the water table to intersect the ground surface and inundate low lying land.

The actual flooding can occur some distance from the emergence zone, with increased flows in local streams resulting in flooding at downstream constrictions / obstructions. This can make groundwater flooding difficult to categorise. Flooding from groundwater tends to be long in duration, developing over weeks or months and continuing for days or weeks.

There are many mechanisms associated with groundwater flooding, which are linked to high groundwater levels, and can be broadly classified as:

- Direct contribution to channel flow;
- Springs emerging at the surface;

- Inundation of drainage infrastructure; and
- Inundation of low-lying property (basements).

3.7.2 Impacts of Groundwater Flooding

The main impacts of groundwater flooding are:

- Flooding of basements of buildings below ground level – in the mildest case this may involve seepage of small volumes of water through walls, temporary loss of services etc. In more extreme cases larger volumes may lead to the catastrophic loss of stored items and failure of structural integrity;
- Overflowing of sewers and drains – surcharging of drainage networks can lead to overland flows causing significant but localised damage to property. Sewer surcharging can lead to inundation of property by polluted water. Note: it is complex to separate this flooding from other sources, notably surface water or sewer flooding;
- Flooding of buried services or other assets below ground level – prolonged inundation of buried services can lead to interruption and disruption of supply;
- Inundation of roads, commercial, residential and amenity areas – inundation of grassed areas can be inconvenient; however the inundation of hard-standing areas can lead to structural damage and the disruption of commercial activity. Inundation of agricultural land for long durations can have financial consequences; and
- Flooding of ground floors of buildings above ground level – can be disruptive, and may result in structural damage. The long duration of flooding can outweigh the lead time which would otherwise reduce the overall level of damages.

In general terms groundwater flooding rarely poses a risk to life. Figure 3-7 shows the Environment Agency Areas Susceptible to Groundwater Flooding dataset.

3.7.3 Groundwater Flooding Risk Assessment

The data sources listed below have been reviewed to produce an overall interpretation of groundwater flood risk in the study area.

- Increased Potential for Elevated Groundwater Maps (GLA 2011); and
- EA Areas Susceptible to Groundwater Flooding Map (EA 2012).

The information sources listed above were reviewed as part of this study. Table 3-5 summarises the content of each source and how it has been used within the risk assessment.

Table 3-5: Review of Available Groundwater Information

Source	Summary	Risk Assessment Application
EA Areas Susceptible to Groundwater Flooding (AStGWF) Map	This data has used the top two susceptibility bands of the British Geological Society (BGS) 1:50,000 Groundwater Flood Susceptibility Map. It shows the proportion of each 1km grid square where geological and hydrogeological conditions show that groundwater might emerge.	This provides an overview of proportional area that is at high or very high risk of groundwater flooding. The categories are as follows: <25% (low) ≥25%<50%(moderate) ≥ 50% <75% (high) >=75% (very high)
EA Groundwater Flooding Database	Use of records provided within the Draft Tier 2 SWMP (2011).	Review of predicted and known groundwater risk locations

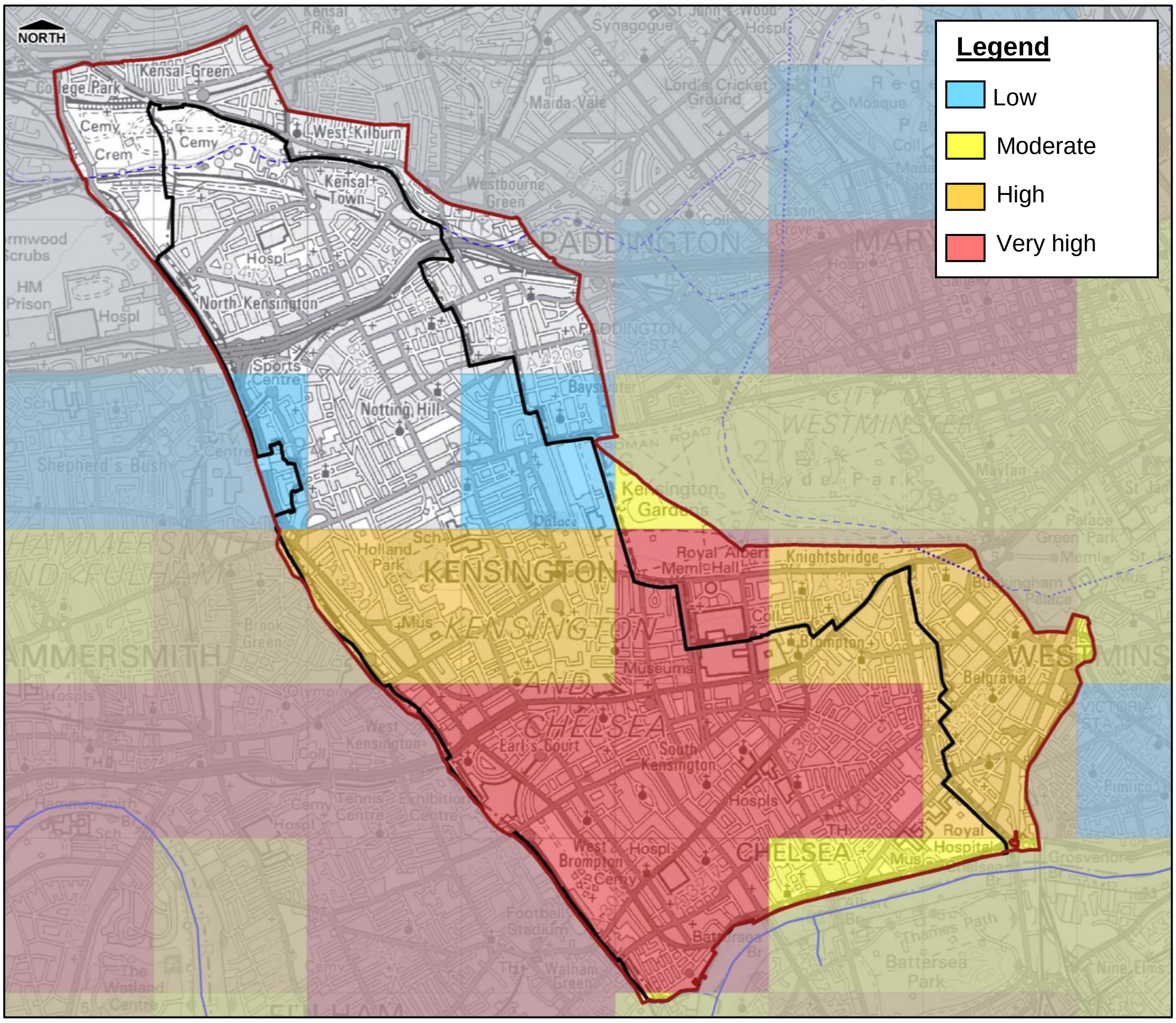


Figure 3-7 Environment Agency Areas Susceptible to Groundwater Flooding

A review of the EA Areas Susceptible to Groundwater Flooding (AStGWF) map highlights that the southern half of the study are highly susceptible to groundwater flooding. This 'very high' – 'high' area of risk correlates well with the known areas that have experienced groundwater flooding (refer to Figure 3-8) for the groundwater flooding records provided for the Drain London Tier 2 SWMP).

The latest dataset for assessing groundwater flood risk in the study is predominantly the EA Areas Susceptible to Groundwater Flooding map. This map uses underlying geological information to infer groundwater flood susceptibility. If more detailed data relating to the risk of groundwater flooding is required, it is recommended that the reader contact the British Geological Society in order to obtain the Groundwater Flooding Susceptibility Maps. This data covers consolidated aquifers (chalk, sandstone etc., termed 'clearwater' in the data attributes) and superficial deposits. It does not take account of the chance of flooding from groundwater rebound and classify the susceptibility into the following categories; very low, low, moderate, high and very high and is not restricted to identifying the risk with 1km square grids.

3.7.4 Potential for Elevated Groundwater

Large areas within the Drain London area are underlain by permeable substrate and thereby have the potential to store groundwater. Under some circumstances groundwater levels can rise and cause flooding problems in subsurface structures or at the ground surface. The mapping technique used aims to identify only those areas in which there is the greatest potential for this to happen and in which there is the highest possible confidence in the assessment.

The following four data sources have been utilised to produce the increased Potential for Elevated Groundwater map which was created as part of the Drain London Tier 2 project (reproduced within Figure 3-8, overleaf)

- British Geological Survey (BGS) Groundwater Flood Susceptibility Map;
- Jacobs Groundwater Emergence Maps (GEMs);
- Jeremy Benn Associates (JBA) Groundwater Flood Map; and
- Environment Agency/Jacobs Thames Estuary 2100 (TE2100) groundwater hazard maps.

The increased Potential for Elevated Groundwater map shows those areas within the Royal Borough where there is an increased potential for groundwater to rise sufficiently to interact with the ground surface or be within 2m of the ground surface.

This mapping indicates that elevated groundwater from permeable superficial soils are located from the northern end of the A3220 (Holland Road) to the boundary with Hammersmith and Fulham in the west and Addison Road to the east. Proceeding south until Addison Road meets Kensington High Street the area affected extends across the entire Borough from West Brompton to Brompton and down into Chelsea. The area south of West Brompton surrounding Battersea is not affected and neither is the area around the Royal Hospital (Chelsea).

In areas with an increased potential for groundwater, basements of buildings below ground level, buried surfaces and other assets held below ground level are vulnerable to flooding from groundwater. This can also lead to inundation of roads, commercial, residential and amenity areas as well as flooding of ground floors of buildings above ground level and overflowing of sewers and drain.

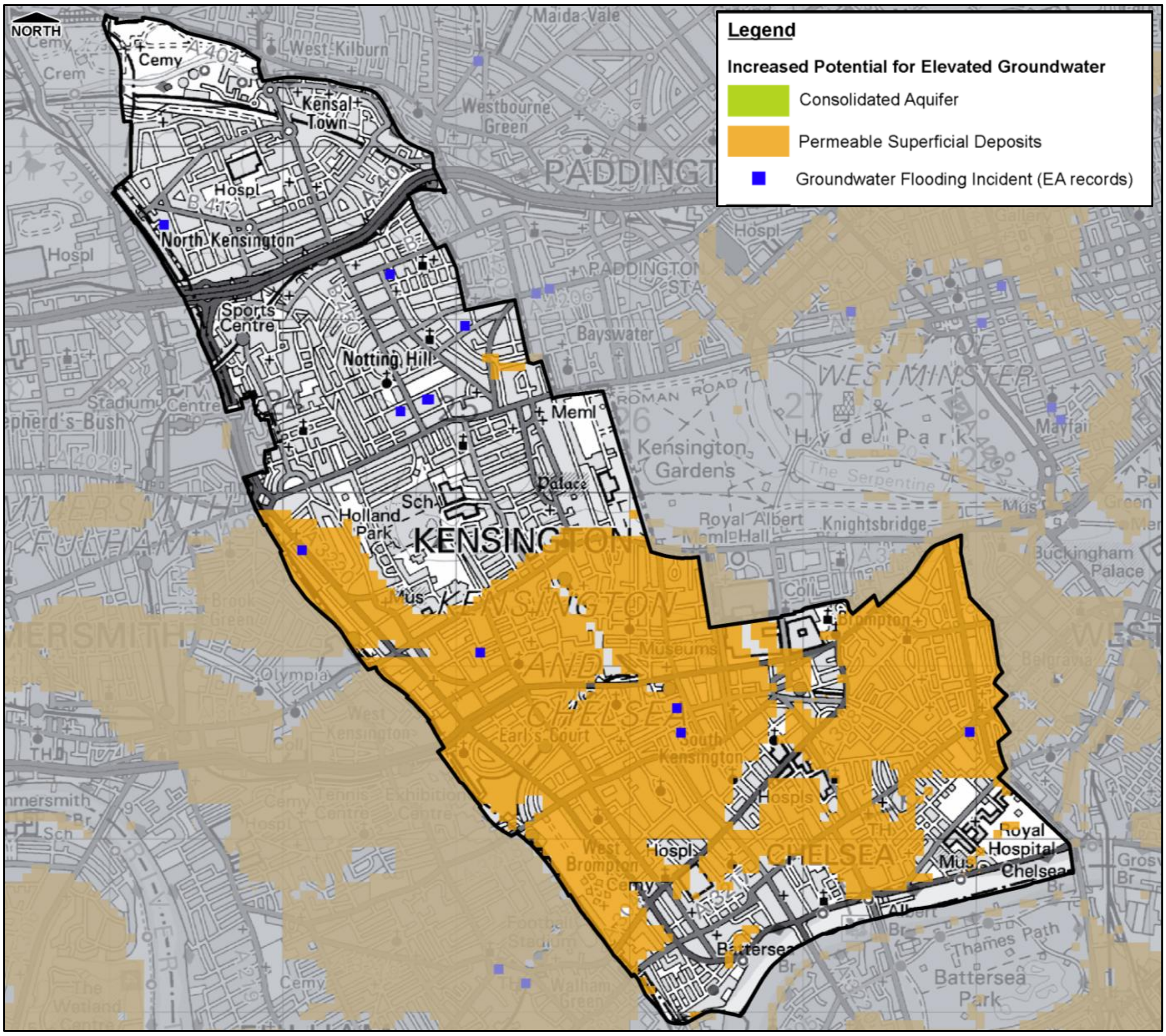


Figure 3-8 Increased Potential for Elevated Groundwater

3.7.5 Groundwater Historic Records

No historic groundwater flooding records were provided by stakeholders for the updated SWMP. However, a review of the SFRA and Drain London Tier 2 SWMP indicates that there are several groundwater flooding records identified within the RBKC boundary. The Tier 2 SWMP indicated that:

- Flooding from rising groundwater may pose a problem to underground infrastructure at various underground stations across the Royal Borough as indicated, although there was only one record of groundwater flooding in the vicinity of Gloucester Road tube station; and
- The Environment Agency records of groundwater flooding which broadly correlate with the Potential for Elevated Groundwater map (Figure 3-8), with the exception of the records of flooding shown around Notting Hill and North Kensington which do not correlate with the groundwater modelling. The locations of historic groundwater locations (as of 2011) are identified within Figure 3-8.

3.7.6 Geology

A geological map for the study area is provided in Appendix C (Figure 4), reproduced from the British Geological Survey (BGS) 1:50,000 scale geological series. The RBKC sits primarily over the London Clay Formation in the north from Harrow Road (A404) to just north of Holland Park Secondary School, with an intrusion from the west of the Langley Silt Member from St Quintin Gardens along St Quintin Avenue to the junction with St Marks Road and down to the junction of Abbotsbury Road and Holland Park in the south.

In the immediate vicinity of Holland Park Secondary School there is an outcropping of the Boyn Hill Gravel Member, before giving way to the Lynch Hill Gravel Member to the east, and the Taplow Gravel Formation to the south. The Taplow Gravel formation extends from Abbotsbury Road to Elvaston Place. South of the Taplow Gravel Formation the remainder of the Royal Borough (South Kensington, West Brompton, Brompton and Chelsea) is underlain by the Kempton Park Gravel Formation.

3.7.7 Groundwater Flooding Management

Management is highly dependent upon the characteristics of the specific situation. The costs associated with the management of groundwater flooding are highly variable. The implications of groundwater flooding should be considered and managed through development control and building design. Possible responses include:

- Raising property ground or floor levels or avoiding the building of basements in areas considered to be at risk of groundwater flooding.
- Provide local protection for specific problem areas such as flood-proofing properties (such as tanking, sealing of building basements, raising the electrical sockets/TV points etc).
- Replacement and renewal of leaking sewers, drains and water supply reservoirs. Water companies have a programme to address leakage from infrastructure, so there is clear ownership of the potential source.
- Major ground works (such as construction of new or enlarged watercourses) and improvements to the existing surface water drainage network to improve conveyance of floodwater from surface water of fluvial events through and away from areas prone to groundwater flooding.

Most options involve the management of groundwater levels. It is important to assess the impact of managing groundwater with regard to water resources, and environmental designations. Likewise, placing a barrier to groundwater movement can shift groundwater flooding from one location to another. The appropriateness of infiltration based drainage techniques should also be questioned in areas where groundwater levels are high or where source protection zones are close by.

3.7.8 Uncertainties and Limitations – Groundwater Flooding

Within the areas delineated, the local rise of groundwater will be heavily controlled by local geological features and artificial influences (e.g. structures or conduits) which cannot currently be represented. This localised nature of groundwater flooding compared with, say, fluvial flooding suggests that interpretation of the map should similarly be different. The map shows the area within which groundwater has the potential to emerge but it is unlikely to emerge uniformly or in sufficient volume to fill the topography to the implied level. Instead, groundwater emerging at the surface may simply runoff to pond in lower areas.

Locations shown to be at risk of surface water flooding are also likely to be most at risk of runoff/ponding caused by groundwater flooding. Therefore the susceptibility map should not be used as a “flood outline” within which properties at risk can be counted. Rather, it is provided, in conjunction with the surface water mapping, to identify those areas where groundwater may emerge and what the major water flow pathways would be in that event.

It should be noted that this assessment is broad scale and does not provide a detailed analysis of groundwater; it only aims to provide an indication of where more detailed consideration of the risks may be required.

The causes of groundwater flooding are generally understood. However, groundwater flooding is dependent on local variations in topography, geology and soils. It is difficult to predict the actual location, timing and extent of groundwater flooding without comprehensive datasets.

There is a lack of reliable measured datasets to undertake flood frequency analysis on groundwater flooding and even with datasets this analysis is complicated due to the non-independence of groundwater level data. Studies therefore tend to analyse historic flooding which means that it is difficult to assign a level of certainty.

The impact of climate change on groundwater levels is highly uncertain. The UK Climate Impact Programme (UKCIP) model indicates that, in future, winters may be generally wetter and summers substantially drier across the UK. The greater variability in rainfall could mean more frequent and prolonged periods of high or low water levels. The effects of climate change on groundwater in the UK therefore may include increased frequency and severity of groundwater-related floods. It should be noted that although winter rainfall may increase the frequency of groundwater flooding incidents, the potential of drier summers and lower recharge of aquifers may counteract this effect.

3.7.9 Infiltration SuDS

Improper use of infiltration SuDS could lead to contamination of the superficial deposit or bedrock aquifers, leading to deterioration in aquifer quality status or groundwater flooding / drainage issues. However, correct use of infiltration SuDS is likely to help improve aquifer quality status and reduce overall flood risk.

The Environment Agency provides guidance on infiltration SuDS at the following website: http://www.environment-agency.gov.uk/business/sectors/36998.aspx. These documents should be considered by developers and their contractors, and by the Councils when approving or rejecting planning applications. Other reference materials for the UK can be located on the CIRIA website http://www.ciria.org, www.wsud.co.uk and the professional community website http://www.susdrain.org/resources/ which provides resource links and SuDS case studies.

RBKC also has a tool for assisting small developments (up to a maximum of 10 dwellings or 1,000m² of non-residential property) with determining suitable SuDS measures that can assist with managing runoff volumes discharging from the site. The website for accessing this toolkit is http://www.rbkc.gov.uk/planningandconservation/planningpolicy/sudstool-smalldevelopment.aspx.

The areas that may be suitable for infiltration SuDS exist where there is a combination of high ground and permeable geology. However, consideration should be given to the impact of increased infiltration SuDS on properties further down gradient. An increase in infiltration and groundwater recharge will lead to an increase in groundwater levels, thereby increasing the susceptibility to groundwater flooding at a down gradient location. This type of analysis is beyond the scope of the current report, but it could be as significant problem where there is potential for perched water tables to develop. Figure 3–9 (overleaf) provides the summary outputs of the Infiltration SuDS Map across RBKC.

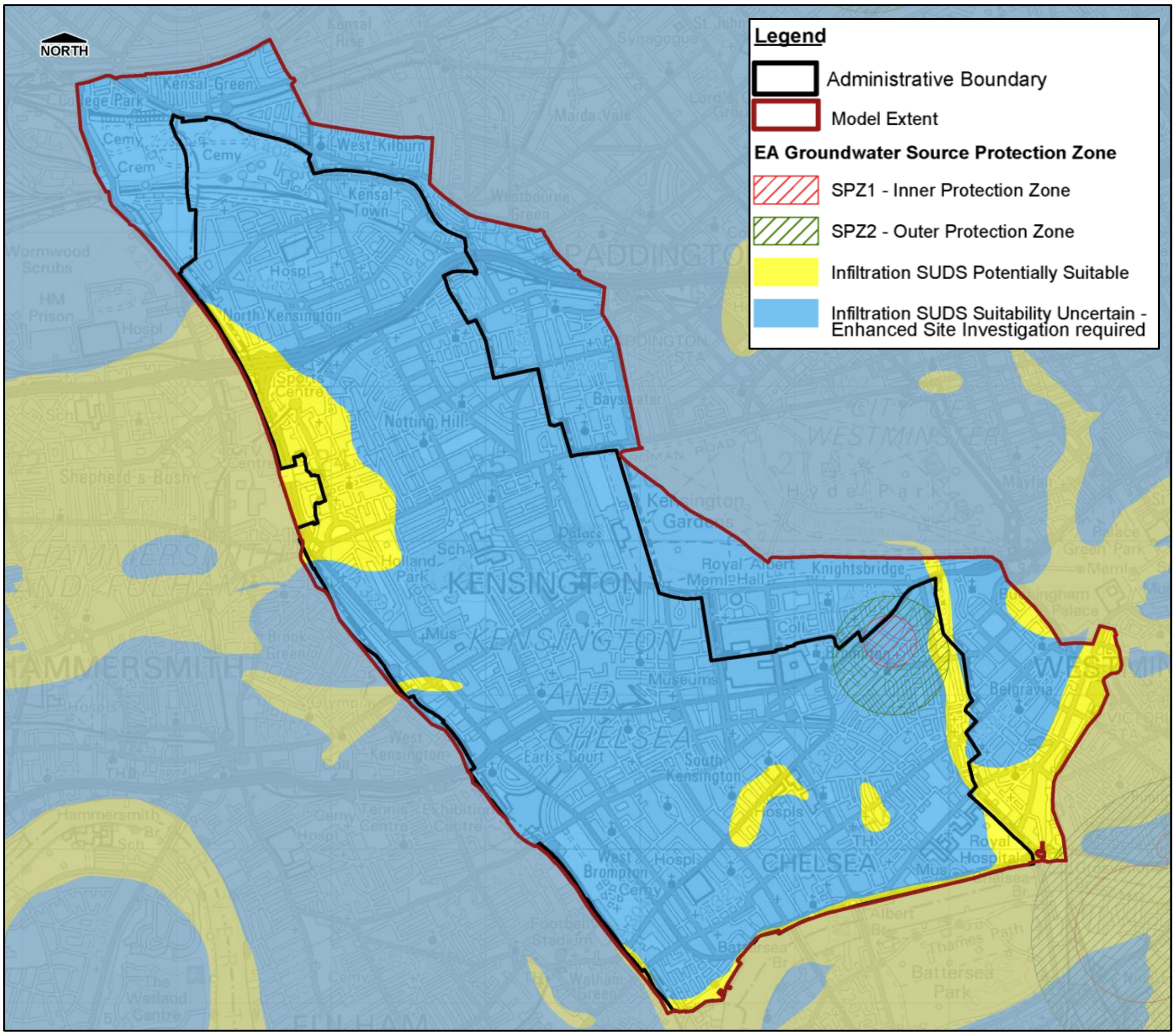


Figure 3-9 SuDS Suitability Mapping – Infiltration Suitability

Due to the underlying geology the suitability for incorporating infiltration SuDS measures is largely uncertain and developers will need to undertake infiltration tests to confirm the suitability of utilising these SuDS measures.

Source protection zones (SPZs) should be considered when applying mitigation measures, such as SuDS, which have the potential to contaminate the underlying aquifer if this is not considered adequately in the design. Generally, it will not be acceptable to use infiltrating SuDS in an SPZ 1 if the drainage catchment comprises trafficked surfaces or other areas with a high risk of contamination. Restrictions on the use of infiltration SuDS apply to those areas within Source Protection Zones (SPZ). Developers must ensure that their proposed drainage designs comply with the available Environment Agency guidance.

3.8 Sewer Flooding

3.8.1 Description

Flooding which occurs when the capacity of the underground drainage network is exceeded, resulting in the surcharging of water into the nearby environment (or within internal and external building drainage networks) or when there is an infrastructure failure. The discharge of the drainage network into waterways and rivers can also be affected if high water levels in receiving waters obstruct the drainage network outfalls. In the study area, the sewer network is a combined system which receives both surface and sewer water.

3.8.2 Causes of sewer flooding

The main causes of sewer flooding are:

- Lack of capacity in the sewer drainage networks– this is often a result of the original design criteria requiring a reduced standard of protection which was acceptable at the time of construction (Victorian era);
- Lack of capacity in sewer drainage networks due to an increase in flow (such as climate change and/or new developments connecting to the network);
- Exceeded capacity in sewer drainage networks due to events larger than the system designed event;
- Loss of capacity in sewer drainage networks when a watercourse has been fully culverted and diverted or incorporated into the formal drainage network (lost watercourses);
- Lack of maintenance or failure of sewer networks which leads to a reduction in capacity and can sometimes lead to total sewer blockage;
- Failure of sewerage infrastructure such as pump stations or flap valves leading to surface water or combined foul/surface water flooding;
- Additional paved or roof areas i.e. paved driveways and conservatories connected onto existing network without any control;
- Lack of gully maintenance restricting transfer of flows into the drainage network;
- Groundwater infiltration into poorly maintained or damaged pipe networks; and
- Restricted outflow from the sewer systems due to high water or tide levels in receiving watercourses (‘tide locking’).

3.8.3 Impacts of Sewer Flooding

The impact of sewer flooding is usually confined to relatively small localised areas but, because flooding is associated with blockage or failure of the sewer network, flooding can be rapid and unpredictable. Flood waters from this source are also often contaminated with raw sewage and pose a health risk. The spreading of illness and disease can be a concern to the local population if this form of flooding occurs on a regular basis.

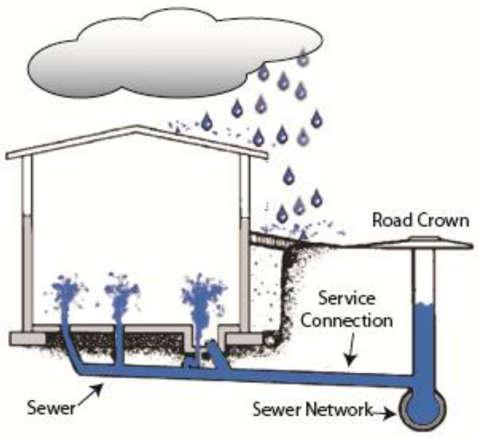


Figure 3-10 Surcharging of the sewer system within a road (left) and internally within a property (right)

Drainage systems often rely on gravity assisted dendritic systems, which convey water in trunk sewers located at the lower end of the catchment. Failure of these trunk sewers can have serious consequences, which are often exacerbated by topography, as water from surcharged manholes will flow into low-lying urban areas.

The diversion of "natural" watercourses into culverted or piped structures is a historic feature of the study area drainage network. Where it has occurred, deliberately or accidentally it can result in a reduced available capacity in the network during rainfall events when the sewers drain the watercourses catchment as well as the formal network. Excess water from these watercourses may flow along unexpected routes at the surface (usually dry and often developed) as its original channel is no longer present and the formal drainage system cannot absorb it.

In order to clearly identify problems and solutions, it is important to first outline the responsibilities of different organisations with respect to drainage infrastructure. The responsible parties are primarily the Highways Authority and Thames Water.

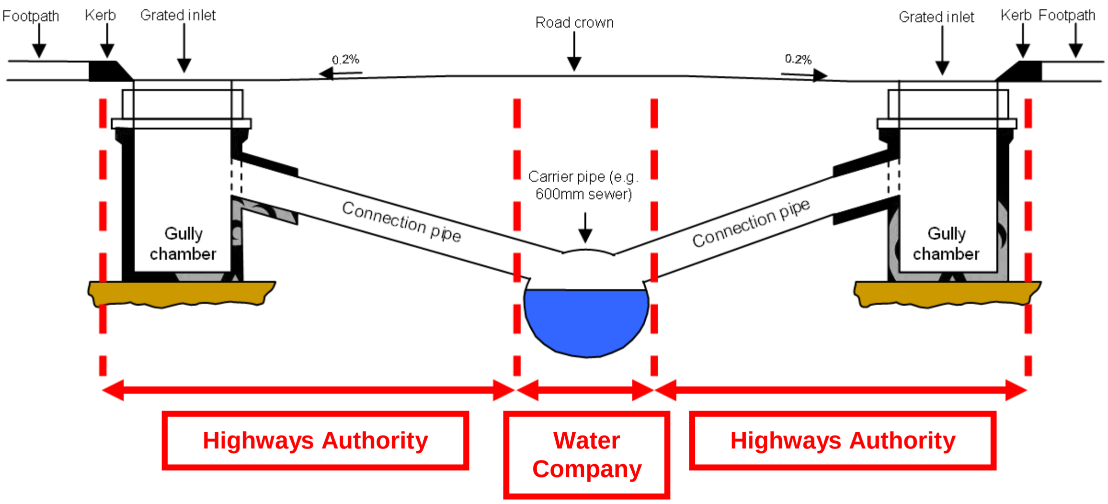


Figure 3-11 Surface water sewer responsibility

As illustrated in Figure 3-11, RBKC and TfL, as the Highways Authorities, are responsible for maintaining an effective highway drainage system including kerbs, road gullies and the pipes which connect the gullies to the trunk sewers and soakaways. The sewerage undertaker, in this case Thames Water, is responsible for maintaining the trunk sewers.

New drainage networks are designed as separate foul and surface water sewers. New surface water systems are typically designed to accommodate 1 in 30 year storm events. New foul sewers are designed for the population which is to be served, with allowance for infiltration.

Thames Water has provided post code-linked data (DG5 register) on records of sewer flooding up to August 2013 for use in this SWMP. Figure 7 (Appendix C) provides a graphical representation of the DG5 data provided by Thames Water.

3.8.4 Drainage Network

A number of different data sources were used to obtain a detailed understanding of the sewer network across RBKC, primarily through consultation with Thames Water. Thames Water (TW) is keen to work with RBKC, in order to mitigate flood risk issues in an integrated manner.

Thames Water provided details of the infrastructure network including sewers, manholes, pumping stations and outfalls in GIS format. This information was incorporated into the pluvial model (along with known and assumed gulley inlet locations) to reflect the benefit of the drainage network within the catchment. Thames Water currently does not have a hydraulic model for the surface water drainage network within the study area.

Thames Water has a hydraulic model for their drainage assets within the study area (Counters Creek Catchment flowing to Beckton Sewage Treatment Works), and have provided modelled outputs along with details of the infrastructure network including sewers, manholes, pumping stations and outfalls in GIS format. This information was incorporated into the pluvial model (along with known and assumed gulley inlet locations) to reflect the benefit of the drainage network within the catchment.

3.8.5 Methodology for Drainage Network Modelling

The hydraulic model created for this SWMP has utilised the available data provided by Thames Water in order to model their assets and where relevant undertaken assumptions based on consultation with the Steering Group. Gulley information was provided by RBKC, TfL and Network Rail – although the latter did not include asset dimension information and therefore was not included within the hydraulic model. Where gulley data appeared to be missing, a visual assessment utilising aerial photography was utilised to approximately locate the asset. Further detailed on the methodology of including the Thames Water drainage network can be found in Appendix B.

3.8.6 Assumptions for the Drainage Network Model

- All gully inlets are assumed to be standard UK "Type R" gullies[4];
- A tide locked scenario was used on all ultimate discharge points into tidal watercourses;

[4] Highways Agency (2009). *Design Manual for Roads and Bridges (DRMB),* Vol. 4, Section 2. Department for Transport

- No drainage losses have been applied to the impervious surfaces in RBKC. It has been assumed that no infiltration occurs in regions where the surfaces are impervious, for example, paved areas such as roads and buildings;
- No pumping stations have been included within the model. A 'worst case scenario', in which all pumps fail, has been assumed in order to provide conservative estimates of surface water flood depths and extents;
- Where no pipe invert information was provided a standard cover level (plus pipe depth) was included within the model schematisation;
- Unknown pipes were assumed to have a 150mm diameter unless interpolation from connected pipe inferred an alternative size; and
- Unknown pipe and manhole types were assumed to be circular.

3.8.7 Uncertainties in Flood Risk Assessment – Sewer Flooding

Assessing the risk of sewer flooding over a wide area is limited by the lack of data and the quality of data that is available. Furthermore, flood events may be a combination of surface water, groundwater and sewer flooding.

The number of assumptions included within the drainage element of the model can impact the final result and should be reviewed once more detailed data is available to ensure the model reflect the actual assets included within the study area.

Use of historic data to estimate the probability of sewer flooding is the most practical approach; however it does not take account of possible future changes due to climate change or future development. Nor does it account for improvements to the network, including clearance of blockages, which may have occurred.

3.8.8 Thames Water Model Verification Process

The Thames Water Counters Creek model was run for the following scenarios:

- 1 in 10 year 1.5 hour rainfall event;
- 1 in 30 year 1.5 hour rainfall event (for events greater than 1 in 30 year, it is assumed that the sewer system is at capacity); and
- 2007 rainfall validation event.

Model outputs provided by Thames Water from the Counters Creek detail the flood volumes at each of the manholes (represented as nodes). As the Counters Creek modelling is solely one-dimensional (1D), it is not appropriate to plot the flood extents resulting from the manholes where they are shown to surcharge. Therefore, to compare the two modelling approaches an analysis of the spatial correlation between manholes shown to surcharge in the Counters Creek model and the SMWP model has been undertaken.

The Counters Creek hydraulic modelling results indicate the main areas that are likely to flood from the surcharging of sewers would be to the west and north west of Holland Park, Notting Hill and North Kensington. Smaller clusters of potential surcharging sewers are shown around South Kensington and Knightsbridge.

By comparison, the SWMP model shows much more widespread flooding across the study area. An initial comparison of the results for the 2007 rainfall event model runs shows a reasonable correlation between surcharging manholes from the Counters Creek model and the SWMP model.

The Counters Creek model suggests there would be fewer surcharging sewers within the central and southern part of the Royal Borough, where the SMWP model indicates there to be a high number. This potentially indicates that the flooding shown in the SWMP model is due to the overland surface water component of the model rather than flooding resulting from the sewer network.

It should be noted that there are a number of large differences between the Counters Creek model and the SWMP model that mean a direct comparison in results is not appropriate. These include:

- The catchment area for the Counters Creek extends well beyond the RBKC administrative area. Therefore the time to peak of the design storms will differ between the models;
- The Counters Creek model allows for storm inflows to enter the upstream areas of RBKC: potentially indicating greater flooding in the northern parts;
- The extent of the 1D network in the SWMP models not accounting for the potential backing up of water downstream in the sewer network;
- The function of the Combined Sewer Overflows (CSOs) is not modelled in the SWMP model. CSOs allow sewer outflows into the River Thames when pumping stations are not sufficiently able to pump wastewater to a wastewater treatment works, either due to pump failure or hydraulic overload. By omitting CSOs from the model, water is not 'lost' from the model at these points, providing a more conservative estimate of the sewer network capacity. The influence of this on the total flood extents will be most noticeable during the smaller return period events, as beyond this, the capacity of the sewer system to receive flows is exceeded resulting in more surface flooding in the upper catchment; and
- The SWMP model potentially has isolated areas ('pockets') of surface water storage within the 2D domain resulting from depressions in the land surface that are not connected to the sewer network.

The Counters Creek model is likely to provide a more accurate representation of sewer flooding at lower magnitude rainfall events due to the explicit representation of the sewer network. The SMWP model however will be a better representation of high magnitude rainfall events as the function of the sewer network in these scenarios is less significant.

Sewer flooding records from the past 10 years have been provided by Thames Water as part of the verification exercise. A visual comparison of the Thames Water sewer flooding records against the flood records held by the RBKC show a strong correlation between these flood records for most of the study area.

However the records show there to be little correlation between historic sewer flooding incidents and modelled areas of surface water flooding. The most notable differences are apparent in the area to the west of Holland Park and around Knightsbridge. This potentially shows that surface water flooding within the RBKC is a result of overland flow defined by the local topography, rather than the influence of the sewer network.

3.9 Main River Fluvial, Tidal Flooding and Other Sources

Interactions between surface water and fluvial flooding are generally a result of watercourses unable to receive and convey excess surface water runoff. Where the watercourse in question is defended, surface water can pond behind defences. This may be exacerbated in situations where high water levels in the watercourse prevent discharge via flap valves through defence walls.

The Royal Borough of Kensington and Chelsea benefits from being protected from tidal and fluvial flooding (from the River Thames) by defences that provide a high standard of protection. The

Environment Agency flood zones provide a good representation of flooding from fluvial and/or tidal flood risk assuming that defences are not in place. As the main source of this type of flood risk is from the River Thames other important maps relate to the risk of breaching and/or overtopping of the defences. The Strategic Flood Risk Assessment (SFRA) provides information about the extent of flooding from breaching of the Thames defences and in particular identifies rapid inundation zones.

Other influences include the Grand Union Canal and the Serpentine in Hyde Park, of which there is limited interaction for the main sources of flood risk in the Royal Borough. As the Grand Union Canal has its water level carefully monitored by the Canal and River Trust and the risk of flooding from this asset is low. A review of the Environment Agency's Flood Risk Zones indicates that the risk of fluvial flooding from Main Rivers and Tidal sources is largely concentrated along the south-western and southern boundary of the Royal Borough. Figure 3-12 (below) displays the Flood Risk Zones and identifies the areas benefiting from defences.

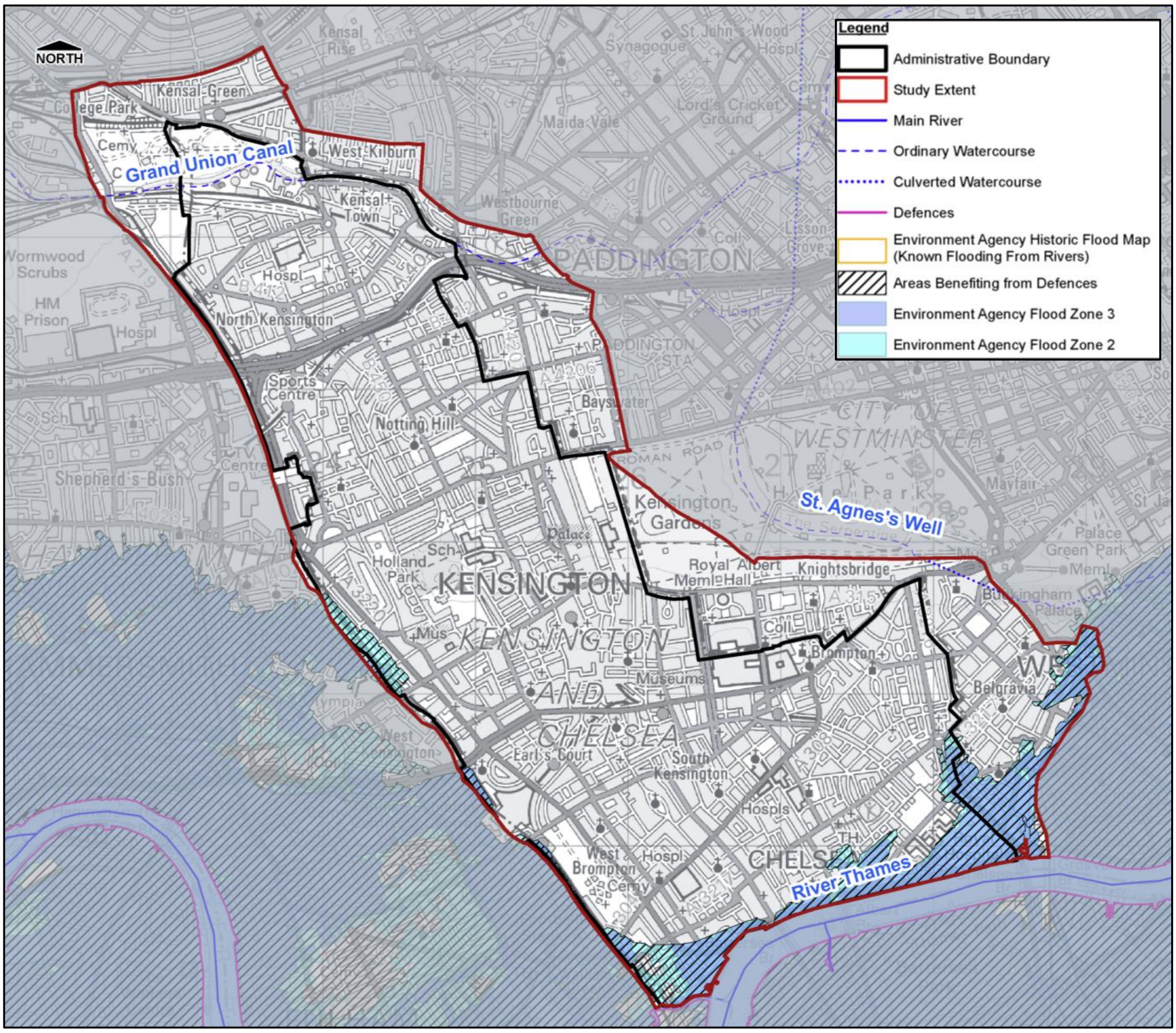


Figure 3-12 Flood Zones and Defence Locations within the Study Area

Note that the effects of main river flooding have not been assessed as part of this study; more information can be found in the Catchment Flood Management Plan (CFMP) and SFRA documents. Further information on fluvial (Main River) flooding can be found in the RBKC SFRA.

4 Identification of Flood Risk Areas

4.1 Overview

The purpose of the intermediate risk assessment is to identify those parts of the study area that are likely to require more detailed assessment to gain an improved understanding of the causes and consequences of surface water flooding. The intermediate assessment was used to identify areas where the flood risk is considered to be most severe; these areas are identified as Critical Drainage Areas (CDAs). The working definition of a CDA in this context has been agreed as:

> *'a discrete geographic area (usually a hydrological catchment) where multiple or interlinked sources of flood risk cause flooding during a severe rainfall event thereby affecting people, property or local infrastructure.'*

The CDA comprises the upstream 'contributing' catchment, the influencing drainage catchments, surface water catchments and, where appropriate, a downstream area if this can have an influence on CDA. They are typically located within Flood Zone 1 but should not be excluded from other Flood Zones if a clear surface water (outside of other influences) flood risk is present. In spatially defining a CDA, the following should be taken into account:

- **Flood depth and extent** – CDAs should be defined by looking at areas within the study area which are predicted to suffer from deep levels of surface water flooding;
- **Surface water flow paths and velocities** – Overland flow paths and velocities should also be considered when defining CDAs;
- **Flood hazard** – a function of flood depth and velocity, the flood hazard ratings across the modelled study area should also be used to define CDAs;
- **Potential impact on people, properties and critical infrastructure** – including residential properties, main roads (access to hospitals or evacuation routes), rail routes, rail stations, hospitals and schools;
- **Groundwater flood risk** – based on groundwater assessment and the Environment Agency AStGWF dataset identifying areas most susceptible to groundwater flooding;
- **Sewer capacity issues** – based on sewer flooding assessment and information obtained from Thames Water and their sewer modelling consultants;
- **Significant underground linkages** – including underpasses, tunnels, large diameter pipelines (surface water, sewer or combined) or culverted rivers;
- **Cross boundary linkages** – CDAs should not be curtailed by political or administrative boundaries;
- **Historic flooding** – areas known to have previously flooded during a surface water flood event;
- **Definition of area** – including the hydraulic catchment contributing to the CDA and the area available for flood mitigation options; and
- **Source, pathway and receptor** – the source, pathway and receptor of the main flooding mechanisms should be included within the CDA.

Where CDAs are difficult to identify, it is recommended that Local Flood Risk Zones (LFRZ) are identified to enable further investigation to determine if they are part of a wider CDA. A LFRZ is defined as discrete areas of flooding that do not exceed the national criteria for a 'Flood Risk Area' but still affect properties, businesses or infrastructure. A LFRZ is defined as the actual spatial extent of predicted flooding in a single location. In RBKC, CDAs, instead of LFRZs, have been defined as a result of the intermediate assessment.

4.2 CDA Assessment

Based on the above criteria, and identified flood risk within the study area, it has been concluded that there are four (4) CDAs, which are reviewed within the following sections. In order to quantify the risk across the CDAs an assessment has been carried out to determine the amount of properties and critical infrastructure at risk from surface water flooding during a range of flood events. Details on this assessment are included in the following sections. Figure 4-1 (below) identifies the location of the CDAs within the Royal Borough along with the predicted 1 in 100 year depth outputs (refer to Appendix C for more detailed figures).

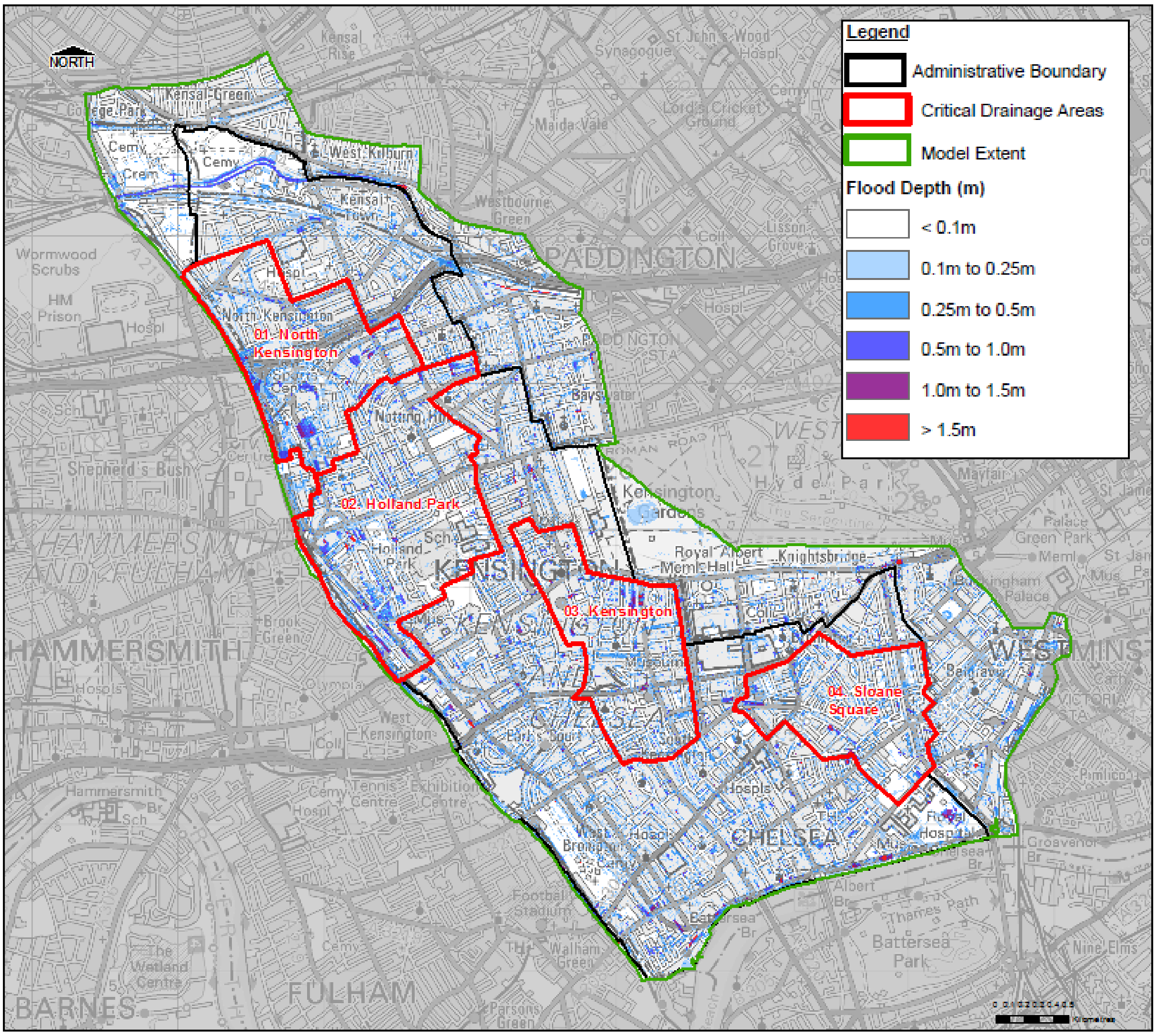
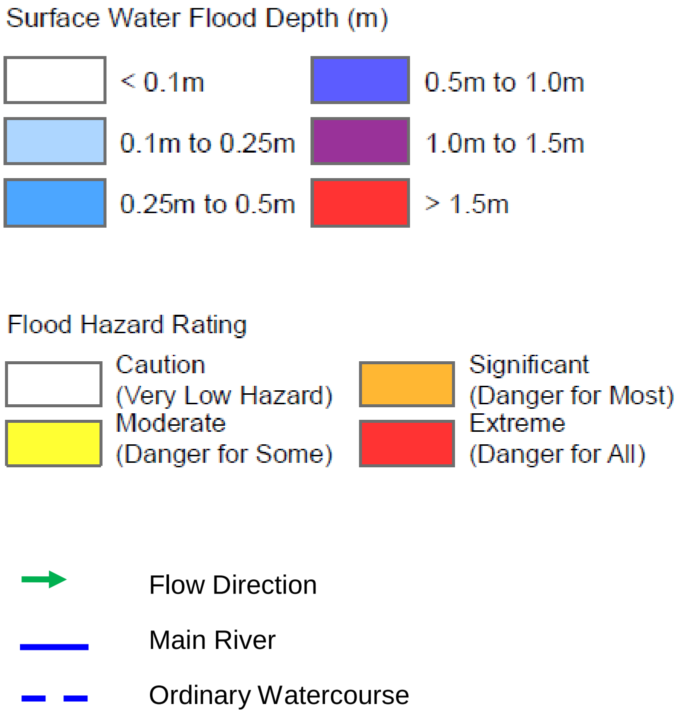


Figure 4-1 Critical Drainage Areas with Predicted 1 in 100 Year Event (Surface Water Flooding) Results

The following legend applies to all of the CDA summaries.



CDA 01 – North Kensington Area

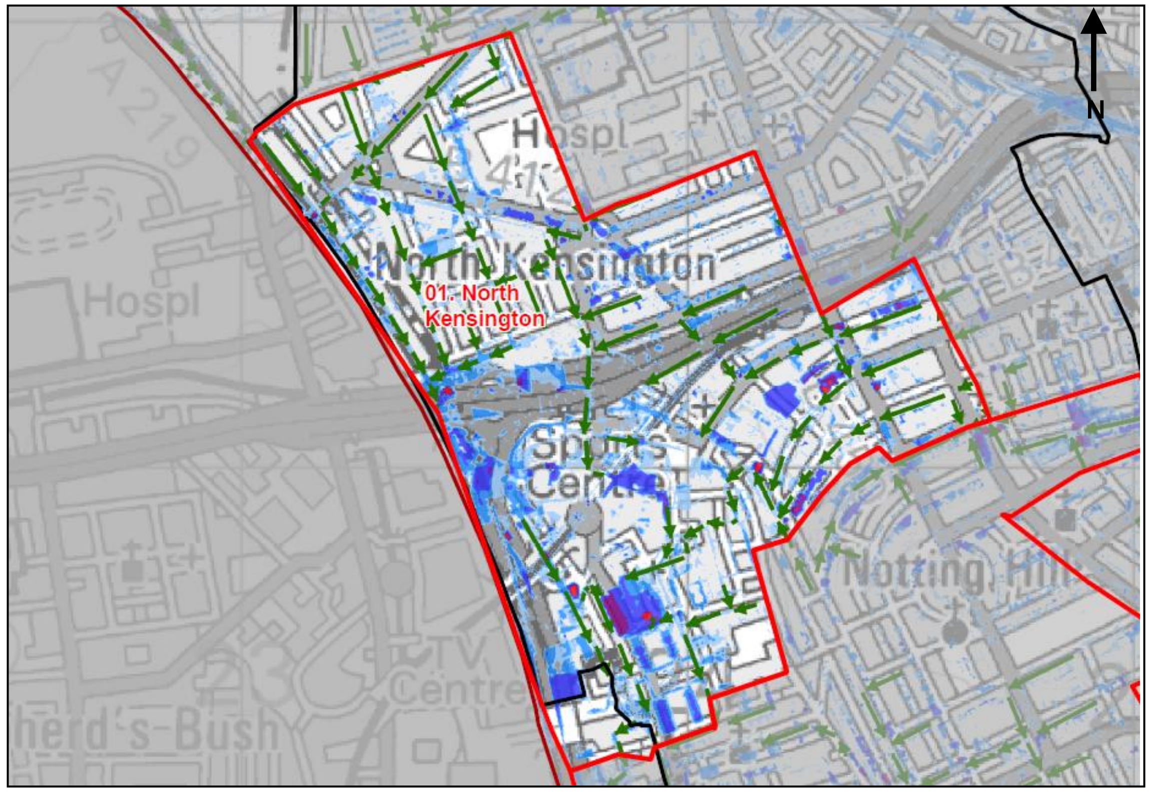


Figure 4-2 CDA 01 - 1 in 100 year Depth Results

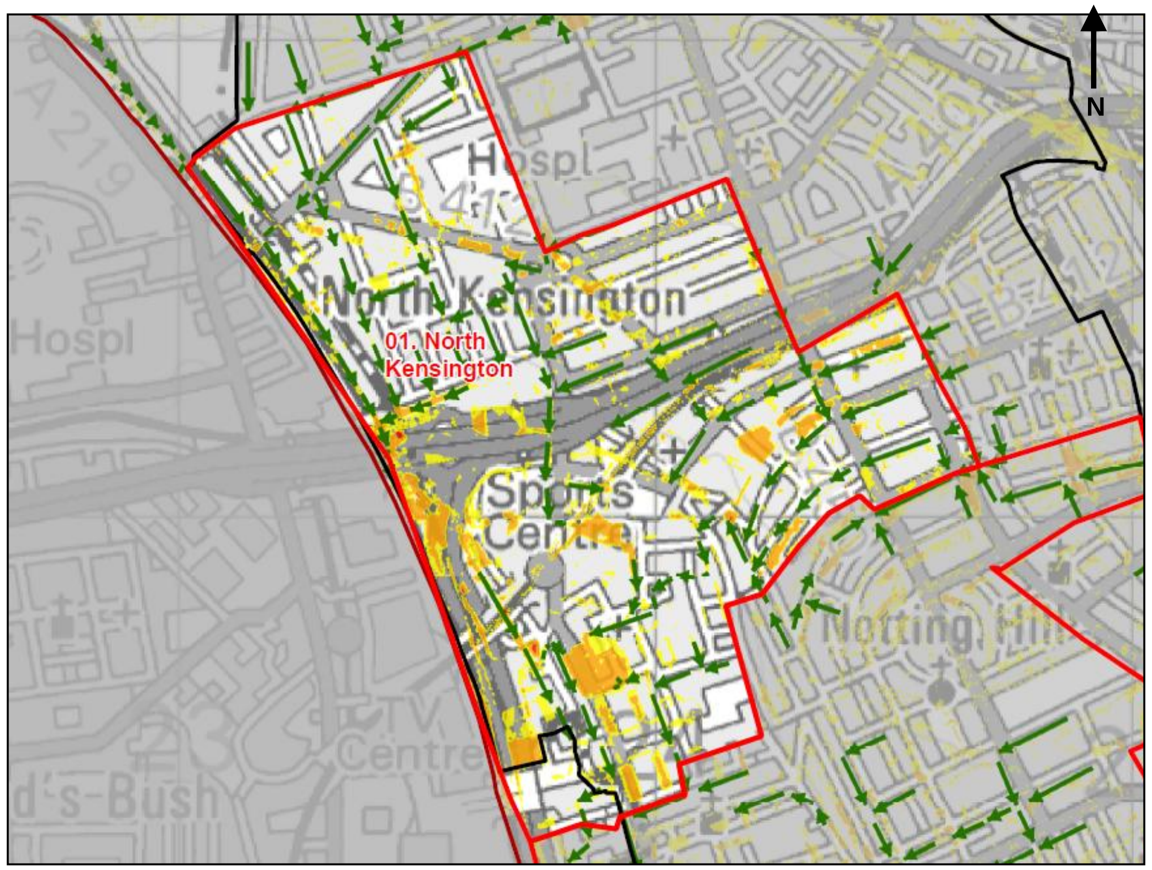


Figure 4-3 CDA 01 - 1 in100 year Hazard Results

Summary of risk:

This CDA is located in the North Kensington area of the Royal Borough.

Surface water is predicted to flow generally from east to west towards the A3220. The pluvial modelling indicates predicted surface water flooding across various locations of the CDA (as a result of the topography and water being trapped behind raised building pads and within lowered basements). Surface water runoff flows from the upper catchment in a westerly direction (predominantly via the road network).

The CDA is located within Flood Zone 1 as it is not at risk of fluvial and tidal flooding.

Table 4-1 Summary of local flood risk within the CDA 01 – North Kensington Area

Flood Classification/ Type	Source	Pathway	Receptor
Overland flow	In extreme rainfall events surface water runoff is conveyed as overland sheet flow via the road network.	Due to the topography of the area a natural overland flow path is conveyed into the western portion of the CDA from higher ground.	Open space, residential properties and roads.
Ponding of surface water	Natural and artificial depressions and topographic low spots.	The main areas of ponding are located between St Ann's Road and Sirdar Road, Thomas Jones Primary School and adjacent to the A3220. A large proportion of flooding appears to be within basement properties throughout the CDA.	Open space, residential properties, gardens, places of worship, schools, commercial uses and roads.
Hazard	Predominantly 'low' with 'moderate' and 'significant' hazard risk predicted within larger areas of ponding.		
Sewer	The drainage network within the CDA is a combined surface water drainage system. Thames Water drainage modelling indicates that there is a risk of surcharging sewers within the CDA with the detailed hydraulic model indicating that the pipe network is running at or near capacity during an extreme event.		
Validation	Numerous historic flood records are located within the western boundary of the CDA which support the predicted modelling results.		
Groundwater	The south-western portion of the CDA is highlighted to be at a low susceptibility to groundwater flooding.		

CDA 02 – Holland Park Area

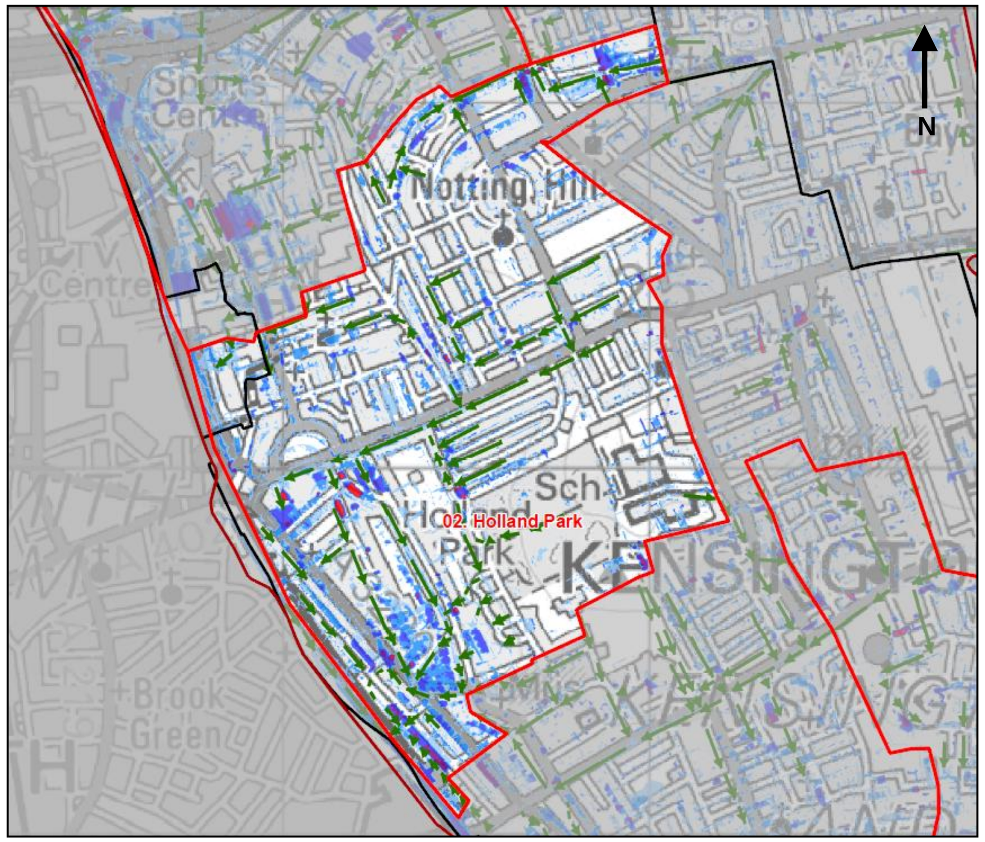


Figure 4-4 CDA 02 - 1 in 100 year Depth Results

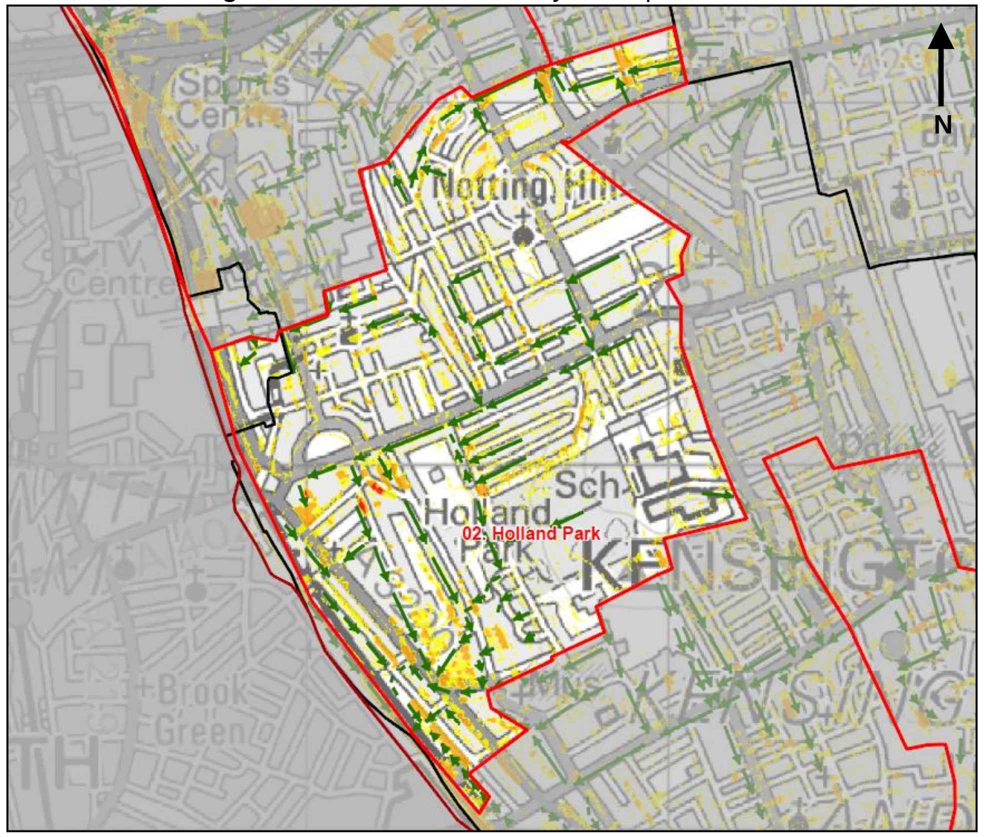


Figure 4-5 CDA 02 - 1 in100 year Hazard Results

Summary of risk:

This CDA is located in the Notting Hill and Holland Park area of the Royal Borough.

Surface water is predicted to flow generally from east to southwest towards the A3220 and London Underground line. The pluvial modelling indicates predicted surface water flooding across various locations of the CDA (as a result of the topography and water being trapped behind raised building pads and within lowered basements). Surface water runoff flows from the upper catchment in a west – south-westerly direction (predominantly via the road network). The majority of areas predicted to be at risk are basement properties.

The majority of the CDA is located within Flood Zone 1. However, the south western boundary (west of the A3220) is at risk of tidal flooding (Flood Zone 2 and Flood Zone 3), but currently benefits from flood defence infrastructure that protects the area.

Table 4-2 Summary of local flood risk within the CDA 02 – Holland Park Area

Flood Classification/ Type	Source	Pathway	Receptor
Overland flow	In extreme rainfall events surface water runoff is conveyed as overland sheet flow via the road network.	Due to the topography of the area a natural overland flow path is conveyed into the western portion of the CDA from higher ground.	Open space, residential properties and roads.
Ponding of surface water	Natural and artificial depressions and topographic low spots.	A large proportion of flooding appears to be within basement properties throughout the CDA. The main areas of ponding (without basements) are located near Somerset Square and Lorne Gardens.	Open space, residential properties, gardens, places of worship, educational establishments, commercial uses, transport link and roads.
Hazard	Predominantly 'low' with 'moderate' and 'significant' hazards predicted within formal flow routes and areas of ponding.		
Sewer	The drainage network within the CDA is a combined surface water drainage system. Thames Water drainage modelling indicates that there is a risk of surcharging sewers within the CDA with the detailed hydraulic model indicating that the pipe network is running at or near capacity during an extreme event.		
Validation	Numerous historic records confirm the risk in the area.		
Groundwater	The north-western and eastern portions of the CDA are at a 'low' susceptibility risk of groundwater flooding, whilst the central to southern half of the CDA is highly susceptible to groundwater flooding.		

CDA 03 – Kensington Area

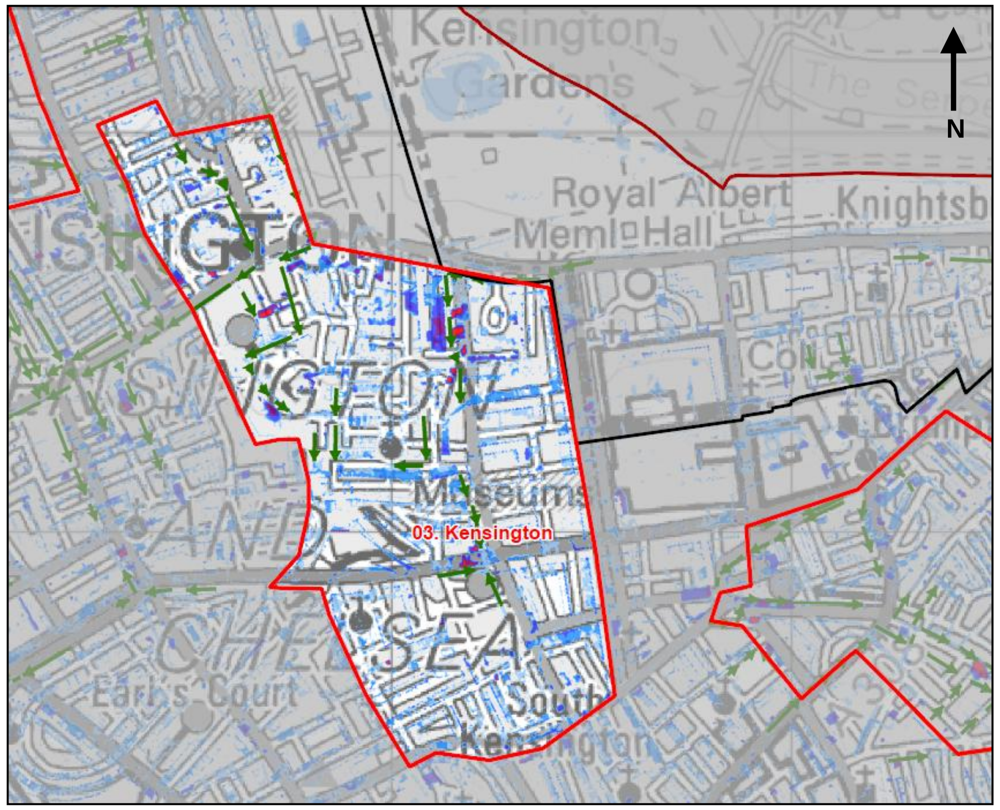


Figure 4-6 CDA 03 - 1 in 100 year Depth Results

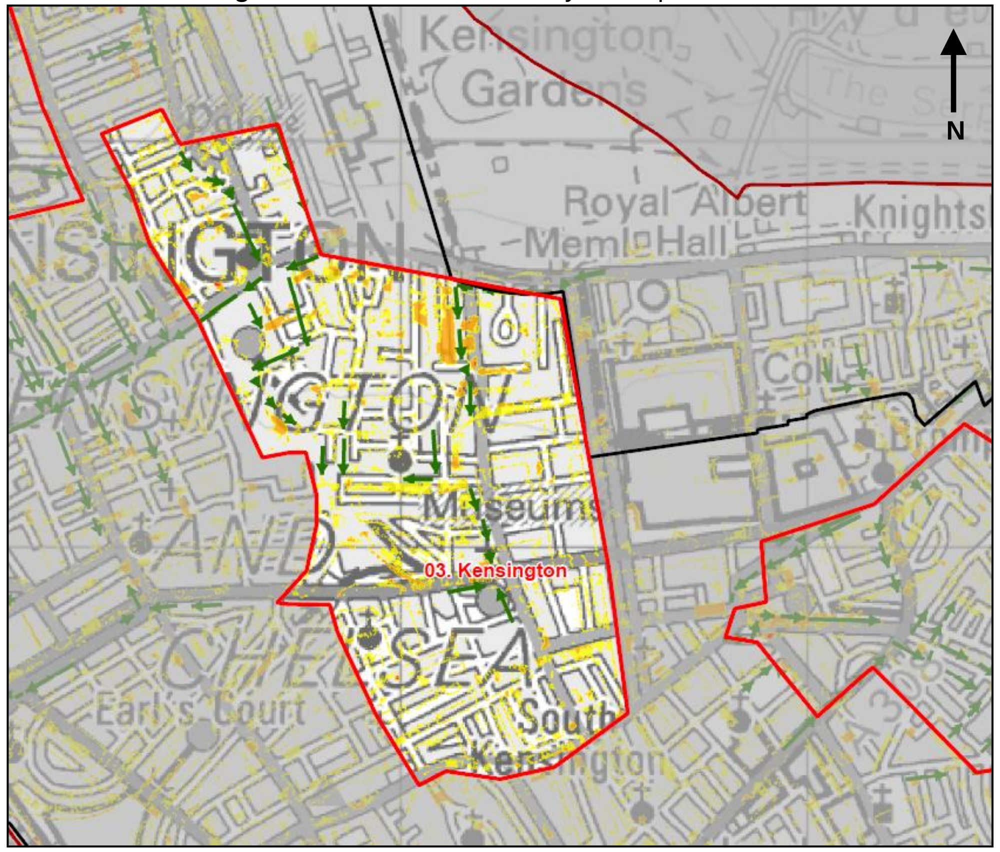


Figure 4-7 CDA 03 - 1 in100 year Hazard Results

Summary of risk:

This CDA is located around the Kensington area of the Royal Borough. Surface water is predicted to flow generally from north to south. The pluvial modelling indicates predicted surface water flooding across various locations of the CDA (as a result of the topography and water being trapped behind raised building pads and within lowered basements). The majority of areas predicted to be at risk are basement properties.

The CDA is located within Flood Zone 1.

Table 4-3 Summary of local flood risk within the CDA 03 – Kensington Area

Flood Classification/ Type	Source	Pathway	Receptor
Overland flow	In extreme rainfall events surface water runoff is conveyed as overland sheet flow via the road network.	Due to the topography of the area a natural overland flow path is conveyed into the western portion of the CDA from higher ground.	Open space, residential properties and roads.
Ponding of surface water	Natural and artificial depressions and topographic low spots.	A large proportion of flooding appears to be within basement properties throughout the CDA. The main area of ponding (outside of basement dwellings) is located within the exposed areas of the TfL underground network (north of the A4 - Cromwell Road).	Embassies, open space, residential properties, gardens, places of worship, educational establishments, commercial uses, transport link (underground line) and roads.
Hazard	'Moderate' and 'significant' hazards are predicted within the main areas of ponding and along the predicted flow paths.		
Sewer	The drainage network within the CDA is a combined surface water drainage system. Thames Water drainage modelling indicates that there is a risk of surcharging sewers within the CDA with the detailed hydraulic model indicating that the southern half of the pipe network (within the CDA) is running at or near capacity during an extreme event.		
Validation	Numerous historic records assist with verifying the risk in the area.		
Groundwater	The north-western portion of the CDA is classified as having a 'high' susceptibility risk of groundwater flooding. The balance of the CDA is identified as having a 'very high' susceptibility risk to flooding from groundwater sources.		

CDA 04 – Sloane Square Area

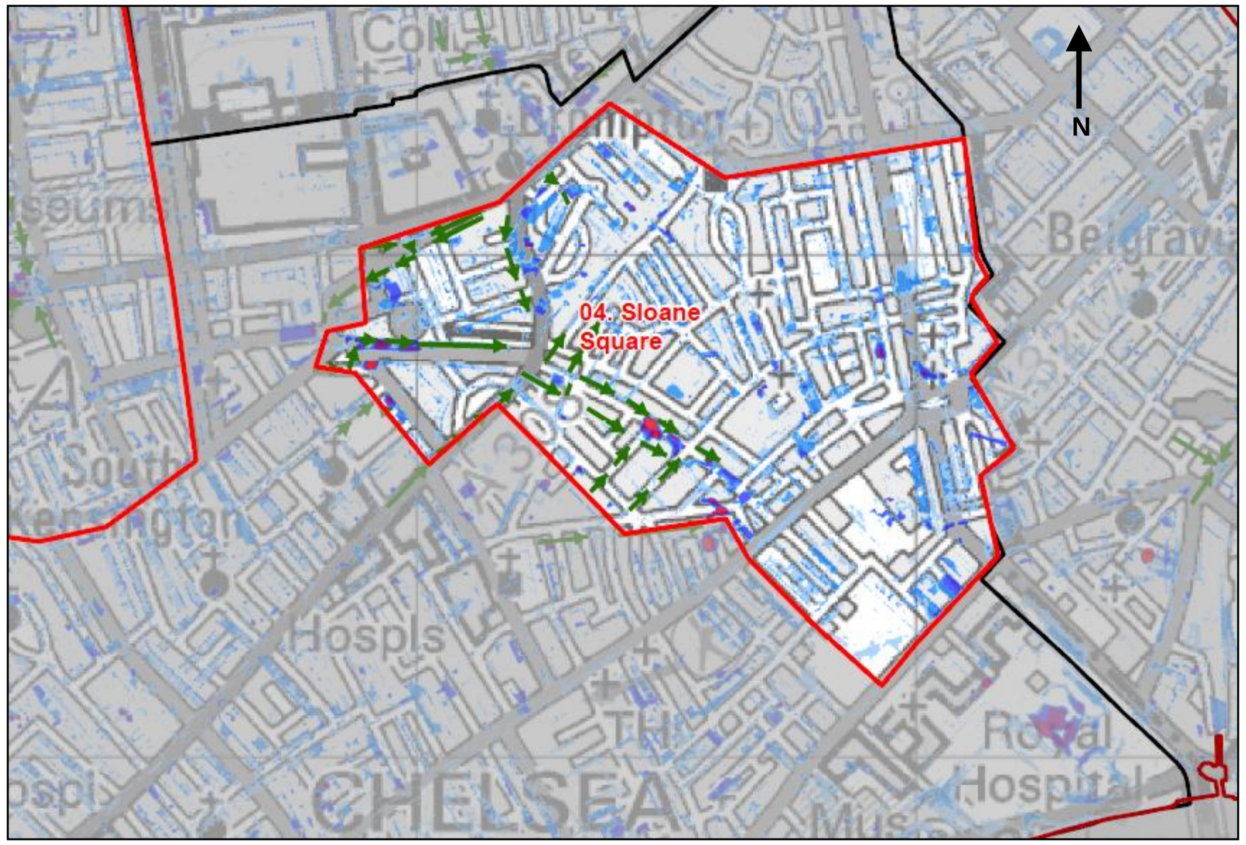


Figure 4-8 CDA 04 - 1 in 100 year Depth Results

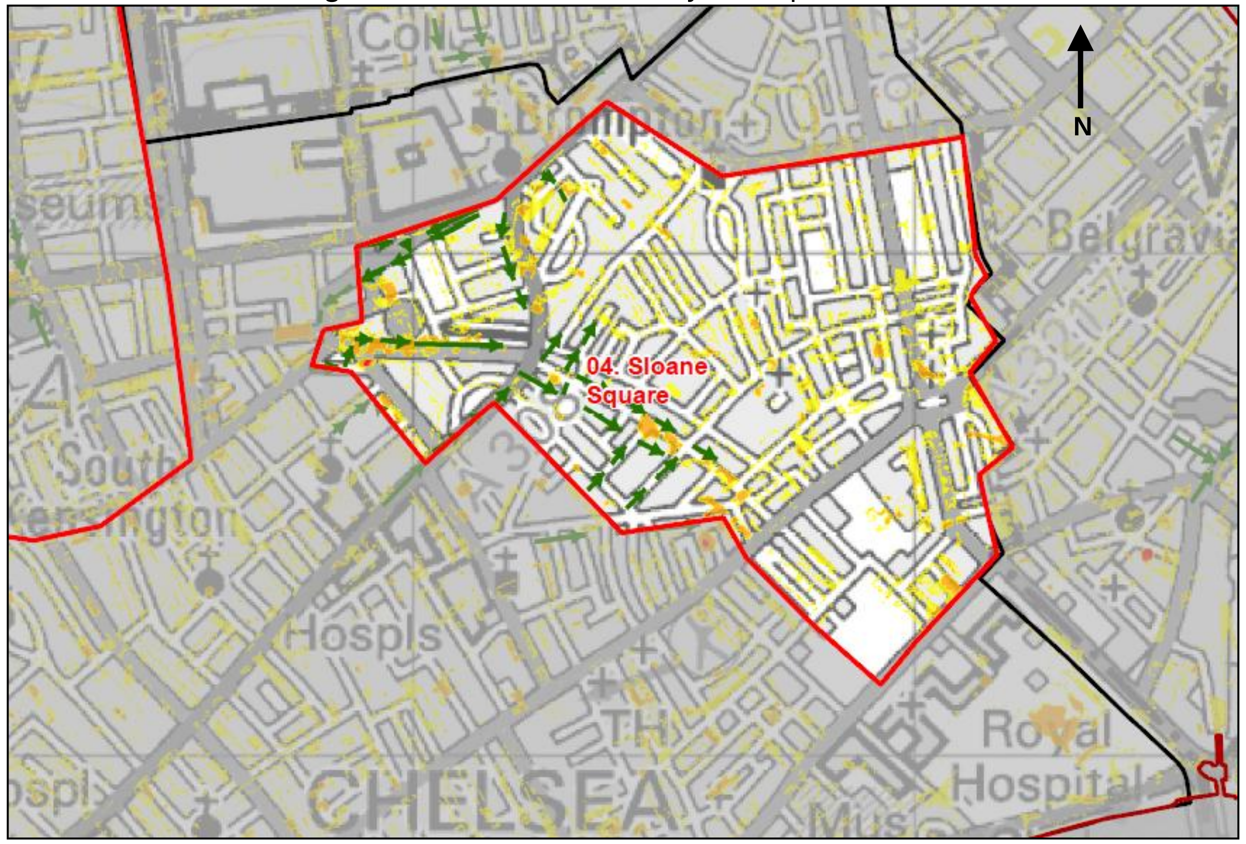


Figure 4-9 CDA 04 - 1 in100 year Hazard Results

Summary of risk:

This CDA is located in the Sloane Square area of the Royal Borough. The topography in the area is generally flat with overland flow being conveyed in a north-east to south-west direction. The pluvial modelling indicates predicted surface water flooding across various locations of the CDA (as a result of the topography and water being trapped behind raised building pads and within lowered basements). The majority of areas predicted to be at risk are basement properties.

The small area in the southeast of the CDA is located within both Flood Zone 2 and Flood Zone 3 (tidal). However, the CDA benefits from flood defence infrastructure that protects the area from this source of flooding.

Table 4-4 Summary of local flood risk within the CDA 04 – Sloane Square Area

Flood Classification/ Type	Source	Pathway	Receptor
Overland flow	In extreme rainfall events surface water runoff is conveyed as overland sheet flow via the road network.	Due to the topography of the area a natural overland flow path is difficult to determine, but the hydraulic modelling results indicate a south-westerly direction of flow.	Open space, residential properties and roads.
Ponding of surface water	Natural and artificial depressions and topographic low spots.	A large proportion of flooding appears to be within basement properties throughout the CDA. The main area of ponding (outside of basement dwellings) is located within the exposed areas of the TfL underground network (east of South Kensington Station).	Embassies, open space, residential properties, gardens, places of worship, educational establishments, commercial uses, transport link (underground line) and roads.
Hazard	'Moderate' and 'significant' hazards are predicted within the areas of ponding.		
Sewer	The drainage network within the CDA is a combined surface water drainage system. Thames Water drainage modelling indicates that there is a risk of surcharging sewers within the CDA with the detailed hydraulic model indicating that the southern half of the pipe network (within the CDA) is running at or near capacity during an extreme event.		
Validation	Historic events are located within the CDA which confirm the predicted risk.		
Groundwater	The majority of the CDA is identified as having a 'very high' susceptibility to groundwater flooding, with areas along the northern and eastern boundary showing a 'high' susceptibility to flooding from groundwater.		

4.3 Flood Risk Summary

4.3.1 Overview of Flood Risk in RBKC

The results of the detailed level risk assessment, combined with site visits and a detailed review of existing data and historical flood records, indicate that there is moderate to very high risk to the Royal Borough from surface water, groundwater and sewer flooding[5] – particularly as rainfall intensities increase. The results indicate that the flood risk is very widely dispersed across the study area with areas with low elevations within the catchment and / or adjacent to obstructions to flow (raised road, rail embankments etc) being at the greatest risk.

Surface water modelling indicates a widespread vulnerability to surface water flooding across the Royal Borough and most of central London. This is in part due to the relatively 'flat' topography and 'noisy' digital terrain data (noise is caused in the digital terrain model as a result of dense vegetation, high buildings, basements and differences between base aerial photography due to development. This can cause errors to the digital ground level and creates 'steps' in these areas).

In consultation with RBKC, four CDAs have been identified within the study area. These CDAs were corroborated by modelling data (both pluvial and Thames Water sewer modelling) and historical incidents. The CDAs were validated during the virtual site visits utilising:

- LiDAR (terrain, structures);
- Detailed pluvial model results,
- Environment Agency's Flood Map for Surface Water,
- Thames Water Sewer models, and
- AStGWF mapping.

Two of these CDAs are connected to the Counter's Creek sewer system which may benefit from the proposed Thames Tideway scheme proposed by Thames Water.

In general, flooding across the study area is moderate to high in the lower order rainfall events (such as the modelled 1 in 20 year event) and is predicted to experience greater levels of flooding across the study area during higher order events (such as a 1 in 100 year event). This is reflected in the analysis of risk to properties, businesses and infrastructure that is discussed below.

4.3.2 Predicted Risk to Existing Properties & Infrastructure

Maps of predicted flood depths and extents which have been generated from the surface water modelling results are included in Appendix C. In order to provide a quantitative indication of potential risks, building footprints (taken from the OS MasterMap dataset) and the National Receptor Dataset have been overlaid onto the modelling outputs to estimate the number of properties at risk within the study area. The National Receptor Dataset is not entirely comprehensive and may not include all known or recent properties.

Table 4-5 and Table 4-6 identify the categories used in the assessment of flooded properties. Please note that in addition to the standard sub-categories provided in these tables, self-contained basements may be considered "highly vulnerable" and residential dwellings may be considered "more vulnerable".

[5] Methodology and limitations relating to each source of flooding can be located within Section 2.

Table 4-5 Infrastructure Sub-Categories

Category	Description
Essential Infrastructure	• Essential transport infrastructure which has to cross the area at risk • Mass evacuation routes • Essential utility infrastructure which has to be located in a flood risk area for operation reasons • Electricity generating power stations and grid and primary substations • Water treatment works
Highly Vulnerable	• Police stations, Ambulance stations, Fire stations, Command Centres and telecommunications installations • Installations requiring hazardous substances consent
More Vulnerable	• Hospitals • Health Services • Education establishments, nurseries • Landfill, waste treatment and waste management facilities for hazardous waste • Sewage treatment works • Prisons

Table 4-6 Household and Basement Sub-Categories

Category	Description
Households	• All residential dwellings • Caravans, mobile homes and park homes intended for permanent residential use • Student halls of residence, residential care homes, children's homes, social services homes and hostels
Deprived Households	• Those households falling into the lowest 20% of ranks by the Office of National Statistics' Indices of Multiple Deprivation.
Non-Deprived Households	• Those households not falling into the lowest 20% of ranks by the Office of National Statistics' Indices of Multiple Deprivation
Basements	• All basement properties, dwellings and vulnerable below ground structures (where identified in existing dataset including those provided by the Environment Agency's National Receptor Database).

Table 4-7, overleaf, indicates the approximate number of predicted properties and critical infrastructure which may be affected during a 1 in 100 year probability rainfall event (1% AEP).

Table 4-7 Flooded Properties Summary 1 in 100 year probability event

Property Type	Flood Risk Vulnerability Classification	Modelled Depths Greater Than –		
		0.1m	0.3m	0.5m
Infrastructure	Essential Infrastructure	1	1	1
	Highly Vulnerable	15	7	1
	More Vulnerable	129	23	8
	Sub-total	**145**	**31**	**10**
Households	Non-Deprived (All)	15,820	3,678	1,288
	Non-Deprived (Basements Only)	368	82	33
	Deprived (All)	2,441	679	348
	Deprived (Basements Only)	173	43	15
	Sub-total	18,261	4,357	1,636
Commercial / Industrial	Units (All)	1,266	316	114
	Units (Basements Only)	1	-	-
Others	Other Flooded Properties	1,248	289	111
	Infrastructure Other	33	4	-

An analysis was also carried out to determine the predicted risk to properties and infrastructure from a lower order rainfall event, which would have a higher probability of occurring. The 1 in 20 year probability event (5% AEP) was used for this assessment and the results are summarised in Table 4-8 below.

Figure 4-10 identifies the difference in flooded properties between the two events.

Table 4-8: Flooded Properties Summary 1 in 20 year probability event

Property Type	Flood Risk Vulnerability Classification	Modelled Depths Greater Than –		
		0.1m	0.3m	0.5m
Infrastructure	Essential Infrastructure	1	1	1
	Highly Vulnerable	11	1	-
	More Vulnerable	65	4	2
	Sub-total	**77**	**6**	**3**
Households	Non-Deprived (All)	103	14	5
	Non-Deprived (Basements Only)	1190	212	105
	Deprived (All)	1293	226	110
	Deprived (Basements Only)	213	22	6
	Sub-total	**8737**	**955**	**326**
Commercial / Industrial	Units (All)	679	91	20
	Units (Basements Only)	1	-	-
Others	Other Flooded Properties	706	92	23
	Infrastructure Other	12	6	-

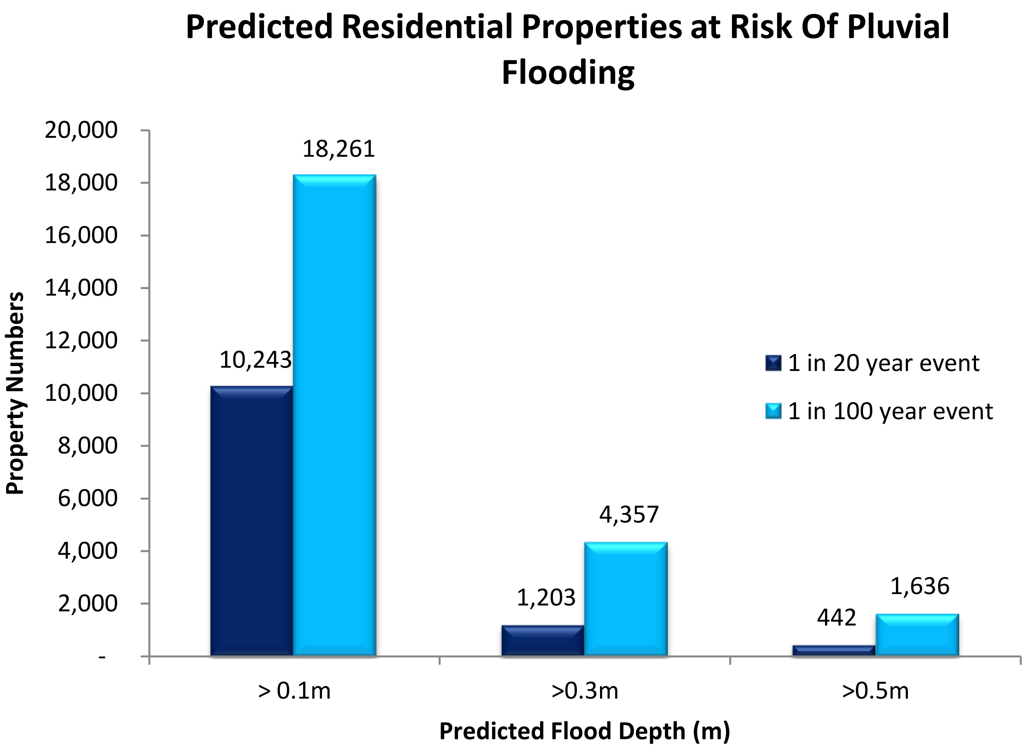


Figure 4-10 Comparison of Predicted Flooded Properties for the 1 in 20 year and 1 in 100 year Rainfall Event

As can be expected, the number of properties at a shallow flood risk (>0.1m) are greater than those at a deeper risk (>0.5m), with the number of properties at risk increasing as the storm probability decreases. This is due to the increasing volume of predicted rainfall within the storm.

4.3.3 Risk to Future Development

As discussed in Section 1.9, a number of sites have been identified for future development through Site Allocation Plans. It is therefore important that surface water flood risk identified within the report should be a consideration in the Site Allocation Plans as their current locations can either assist or exacerbate the risk to existing properties within RBKC. It is recommended that these developments adhere to specific policy relating to flooding in addition to the requirements of NPPF.

4.3.4 Effect of Climate Change

The effect of climate change on surface water flood risk has also been analysed through the risk assessment phase of this study. Based on current knowledge and understanding, the effects of future climate change are predicted to increase the intensity and likelihood of summer rainfall events, meaning surface water flooding may become more severe and more frequent in the future.

To analyse what impact this might have on flood risk across the Royal Borough in the future, the surface water model was run for a 1 in 100 year probability event (1% AEP) to include the effect of climate change. Based on current guidance (taken from Table 2 of NPPF) an increase in peak rainfall intensity of 30% was assumed for this model scenario.

The depth grids for these model runs are included in Appendix C along with the other mapped outputs from the modelling process.

Figure 4-11, overleaf, provides a comparison between the 1 in 100 year probability event and the 1 in 100 year probability event with climate change. The area of red indicates where the climate change events results are predicted to be greater and is most obvious in topographic low points of the Royal Borough areas that have flow obstructions (raised ground downstream). The greatest increase can be seen west of Notting Hill and Holland Park, along the western boundary of the Royal Borough.

This comparison highlights that although the predicted effects of climate change may increase the flood risk within certain areas of RBKC the predicted impacts from the 1 in 100 year are suitable for assessing the risk to the study area.

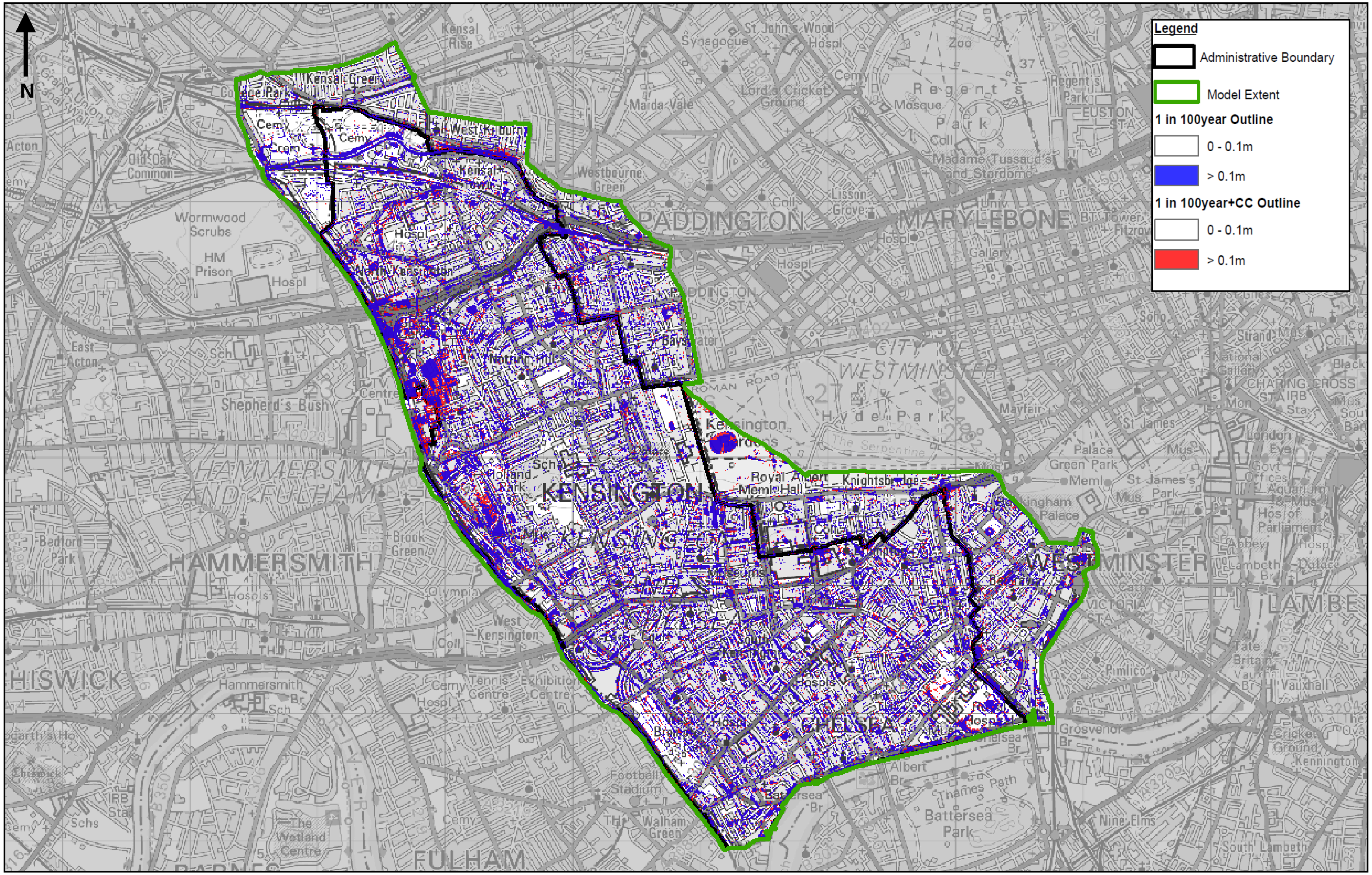


Figure 4-11 Comparison of Predicted 1 in 100 year Pluvial Flood Extents and 1 in 100 year with an Allowance for Climate change (30% Increase in Rainfall Volumes) Flood Extents (Depths >0.1m)

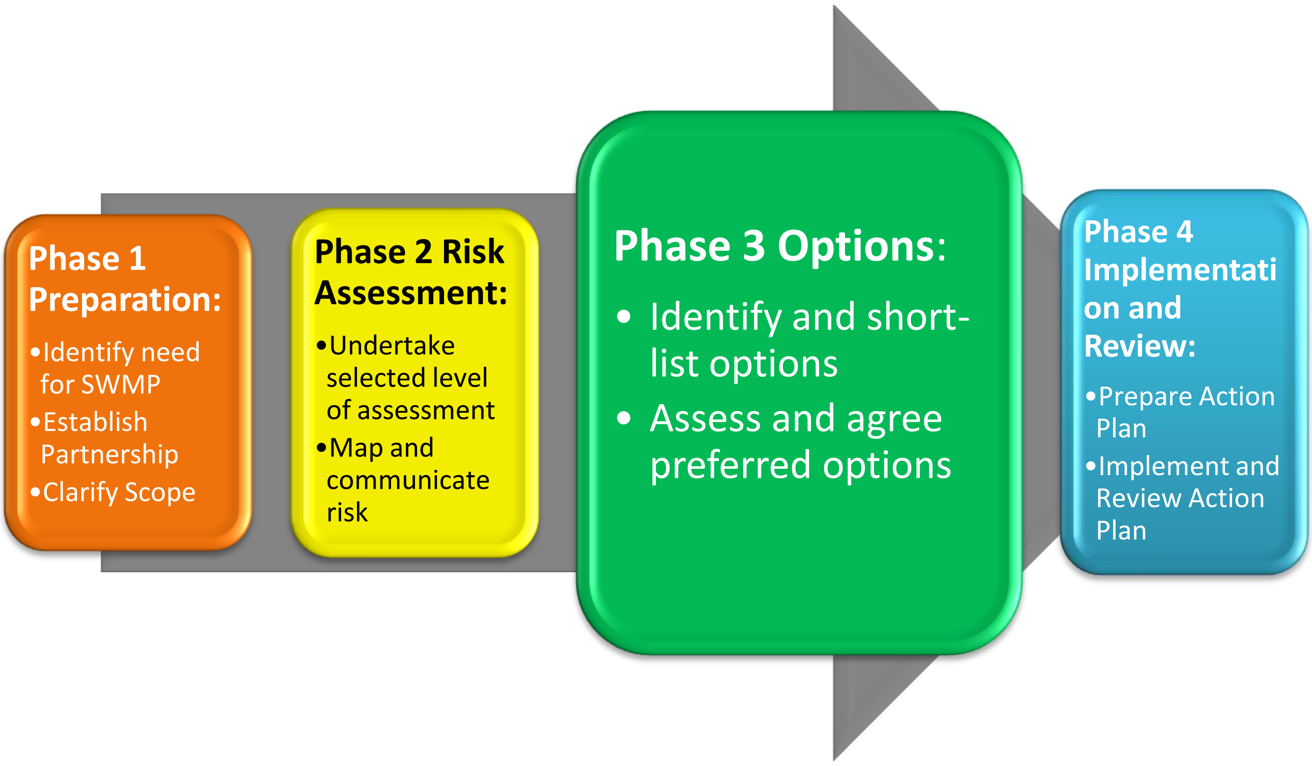
4.4 Summary of Risk – CDAs

Table 4-9 (below) summarises the surface water flood risk to infrastructure, households and commercial/industrial receptors for each of the CDAs for the 1 in 100 year event.

Table 4-9: Summary of Surface Water Flood Risk in CDAs

Property Type	Flood Risk Vulnerability Classification	Critical Drainage Areas							
		01		02		03		04	
		>0.1m deep	>0.5m deep	>0.1m deep	>0.5m deep	>0.1m deep	>0.5m deep	>0.1m deep	>0.5m deep
Infrastructure	Essential Infrastructure					1	1	1	1
	Highly Vulnerable	1		1	1	1		1	
	More Vulnerable	10	1	10	4	17	2	12	1
	Sub-total	11	1	11	5	19	3	14	1
Households	Non-Deprived (All)	279	36	1,853	351	1,930	115	1,435	101
	Non-Deprived (Basements Only)	12	2	65	11	17		14	3
	Deprived (All)	1003	228	195	44				
	Deprived (Basements Only)	55	5	14	5				
	Sub-total	1,349	271	2,127	411	1,947	115	1,449	104
Commercial / Industrial	Units (All)	72	16	54	14	165	27	75	4
	Units (Basements Only)	1							
Total		1,433	288	2,192	430	2,131	145	1,538	109

PHASE 3: OPTIONS



5 Options Assessment Methodology

5.1 Objectives

Phase 3 provides the methodology for undertaking a high level options assessment and indicates what options are generally available for reducing flood risk within RBKC. This involves identifying a range of structural and non-structural options for alleviating flood risk in the study area, and assessing the feasibility of these options. As well as surface water, consideration must be given to other sources of flooding and their interactions with surface water flooding, with particular focus on options which will provide flood alleviation from combined flood sources.

The purpose of this phase of work is to assess and shortlist options in order to eliminate those that are not feasible or cost beneficial. Options which are not suitable are discarded and the remaining options are developed and tested against their relative effectiveness, benefits and costs. Measures which achieve multiple benefits, such as water quality, biodiversity or amenity, should be encouraged and promoted. The target level of protection is typically set as the 1 in 75 year probability event (1.3% AEP); this will allow potential solutions to be aligned with the current level of insurance cover which is available to the public.

The flow chart below (Figure 5-1) presents the process of identifying and short-listing options that have been identified as part of the Phase 3.

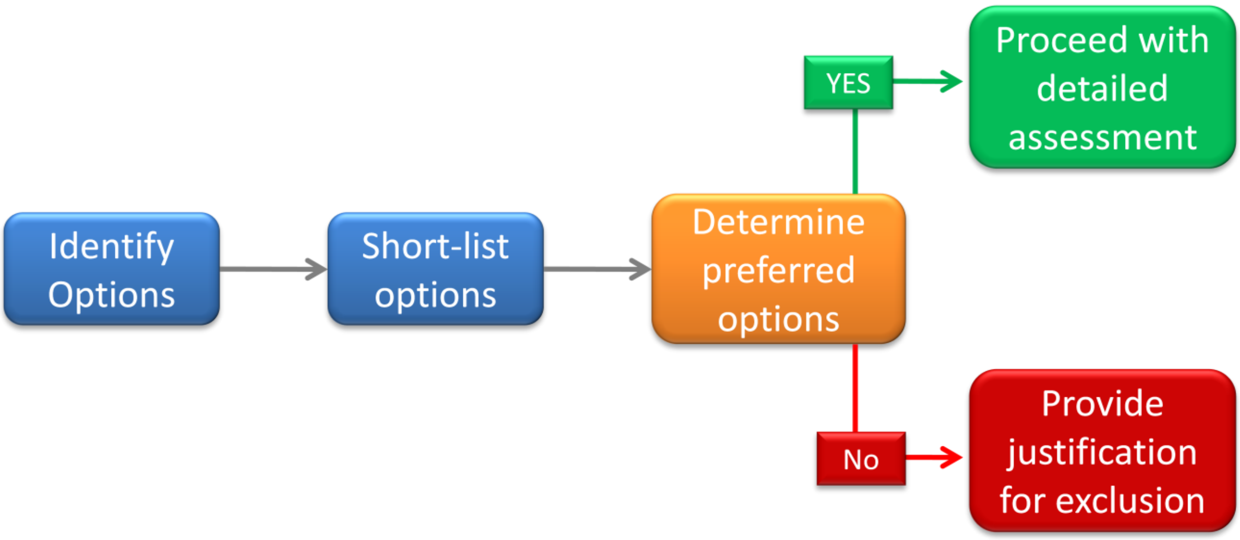


Figure 5-1 Process of identifying and short-listing options and measures [adapted from Defra SWMP Guidance]

To maintain continuity within the report and to reflect the flooding mechanisms within the study area, the options identification should take place on an area-by-area basis following the process established in Phase 2. Therefore, the options assessment undertaken as part of the SWMP identifies the options which are applicable to the study area as a whole and then further detail is provided for each CDA where locally specific measures should be considered.

The options assessment presented here follows the high level methodology described in the Defra SWMP Guidance and is focussed on highlighting areas for further analysis and immediate 'quick win' actions.

5.2 Links to Funding Plans

It is important to consider local investment plans and initiatives and committed future investment when identifying measures that could be implemented within the Royal Borough.

The following schemes could provide linked funding solutions to flood alleviation work in the Royal Borough, which would provide a cost effective and holistic approach to surface water flood risk management:

- Local Green Infrastructure Delivery Plans;
- Local Enterprise Plans (funding plan for delivery of the Local Plans);
- Major commercial and housing development is an opportunity to retro-fit surface water management measures (housing associations and private developers);
- TfL and RBKC Highways department investment plans;
- Thames Water Business Plan / Asset Management Plan; and
- Environment Agency Flood Defence Grant in Aid (FDGiA) funding.

5.3 Options Identification

The Defra SWMP Technical Guidance defines measures and options as:

> *"A measure is defined as a proposed individual action or procedure intended to minimise current and future surface water flood risk or wholly or partially meet other agreed objectives of the SWMP. An option is made up of either a single, or a combination of previously defined measures."*

This stage aims to identify a number of measures and options that have the potential to alleviate surface water flooding across the Royal Borough. It has been informed by the knowledge gained as part of the Phase 1 and Phase 2 assessment. Where possible, options have been identified with multiple benefits such as alleviating flooding from different sources. At this stage the option identification pays no attention to constraints such as funding or delivery mechanisms to enable a robust assessment.

The options assessment considers all types of options including[6]:

- Options that change the source of risk;
- Options that modify the pathway or change the probability of flooding;
- Options that manage or modify receptors to reduce the consequences;
- Temporary as well as permanent options;
- Options that work with the natural processes wherever possible;
- Options that are adaptable to future changes in flood risk;
- Options that require actions to be taken to deliver the predicted benefits (for example, closing a barrier, erecting a temporary defence or moving contents on receiving a flood warning);
- Innovative options tailored to the specific needs of the project; and
- Options that can deliver opportunities and wider benefits, through partnership working where possible.

[6] Environment Agency (March 2010) *'Flood and Coastal Flood Risk Management Appraisal Guidance',* Environment Agency: Bristol.