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EPSOM & EWELL BOROUGH COUNCIL

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1 Introduction

1.1 Introduction

This report documents the development of a detailed hydraulic model of the Borough of Epsom & Ewell and its associated hydrological inputs. The model has been developed to inform a Surface Water Management Plan (SWMP) for the Borough. The purpose of the SWMP study is to identify sustainable responses to manage surface water flooding and to prepare an Action Plan. The accompanying *Preliminary Risk Assessment* report recognises that intense rainfall, surface runoff caused by high groundwater levels and the limited capacity of the sewer network are the main causes of surface water flooding in the Borough. This model therefore aims to represent, through two dimensional modelling, the resulting overland flow routes which often have their source in the higher Chalk hills in the south of the Borough.

1.2 Objectives of the Modelling

As stated in the Defra Guidance[1], the purpose of detailed modelling in a SWMP is to understand the causes, probability and consequences of surface water flooding in a greater level of detail, and to test mitigation measures to reduce surface water flooding. Benefits of detailed modelling typically include:

- Better understanding of the locations and mechanisms of flooding, especially in complex situations where different sources (e.g. surface water, sewer and fluvial) can occur together.
- Predictions of flood depth at individual receptors (e.g. properties) can provide a basis for the estimation of economic damages due to surface water flooding in the current situation. This provides an indication of the scale of mitigation measures which are likely to be cost beneficial.
- Predictions of flow velocities which may pose a risk to life if flow paths follow steep topography. Along with flood depth, this information can inform emergency planning.
- Flood hazard maps can be produced which will fulfil some requirements of the Flood Risk Regulations 2009[2], for which Surrey County Council are the Lead Local Flood Authority for the Borough of Epsom & Ewell.
- Models can be adjusted to represent potential mitigation options and therefore test their degree of benefit in reducing adverse consequences of flooding. Predicted depth of flooding can be used to estimate the 'with scheme' economic damages and, therefore, indicate the benefit-cost ratio.
- Results from detailed models are a standard form of evidence to support applications for funding identified mitigation options.

Detailed modelling can thus provide the evidence base to make decisions and inform the effectiveness of potential mitigation measures. The level of modelling

[1] Defra (2010) Surface Water Management Plan Technical Guidance. March 2010. Available at: http://www.defra.gov.uk/environment/flooding/manage/surfacewater/plans.htm
[2] http://www.opsi.gov.uk/si/si2009/uksi_20093042_en_1

effort should be proportional to the degree of surface water flood risk and the complexities of the system. It should be focussed on areas of greatest risk.

1.3 Focussing the Detailed Modelling

In order to focus the detailed modelling undertaken in this SWMP in the areas of greatest risk, the Preliminary Risk Assessment has provided an indication of the flood hazard in each area within the Borough. Interpreting this hazard within the identified Drainage Areas (Figure 1.1) suggests the following representation of areas within the detailed model:

- **Epsom Downs and the Wells**: The land use is predominantly rural and there are isolated incidents of recorded flooding. The Epsom Downs area is the source of a number of major flowpaths which flow north to Epsom town centre, for example. Epsom Downs will be represented at lower resolution in the detailed model to capture northerly flow.

- **West Park and Horton & West Ewell**: There are some flooding issues recorded and a series of major redevelopments which are underway. This area is the source of some major flowpaths which flow north. Both areas will be included at medium resolution in the detailed model to capture northerly flow, with key areas at high resolution.

- **Epsom Centre and Epsom West**: There are a number of flooding issues recorded in this area as well as substantial existing development and plans for redevelopment. A number of major flowpaths flow through this area. These areas will be included at higher resolution in detailed model.

- **Drift Bridge and Ewell**: There are some flooding issues recorded. Some major flowpaths flow through this area. These areas will be included at medium resolution in the detailed model to capture overland flow, with key areas at high resolution.

- **Hogsmill North, Stoneleigh and Worcester Park**: There are isolated flooding issues recorded and some overland flowpaths through developed areas. Hogsmill North and Stoneleigh areas will be included at medium resolution in detailed model.

1.4 Previous Surface Water Flood Modelling in the Borough

A hydraulic model was developed for the River Hogsmill IUD Study[3] to better understand the interaction of surface water, sewer and fluvial flows in the catchment. The model covered the entire Hogsmill catchment of 76km^2 (c.f. area of Borough of Epsom & Ewell is approximately 35km^2) and was developed using the InfoWorks CS2D software platform, which is able to represent:

- overland flow resulting from resulting from exceedence of the local drainage system capacity using a triangular mesh of size 50m^2 – 200m^2, depending on land use and key topographic features identified in the LiDAR and Ordnance Survey MasterMap data
- flow through a simplified version of the Thames Water surface water sewer network, representing pipes with a diameter greater than 300mm

[3] Jacobs (2008) River Hogsmill Integrated Urban Drainage DEFRA Pilot Study. Reference SL2303. June 2008

- flow in the watercourses (including Green's Lane Stream, Hogsmill Stream, Ewell Court Stream, Horton Stream and Hogsmill River) in simplified form.

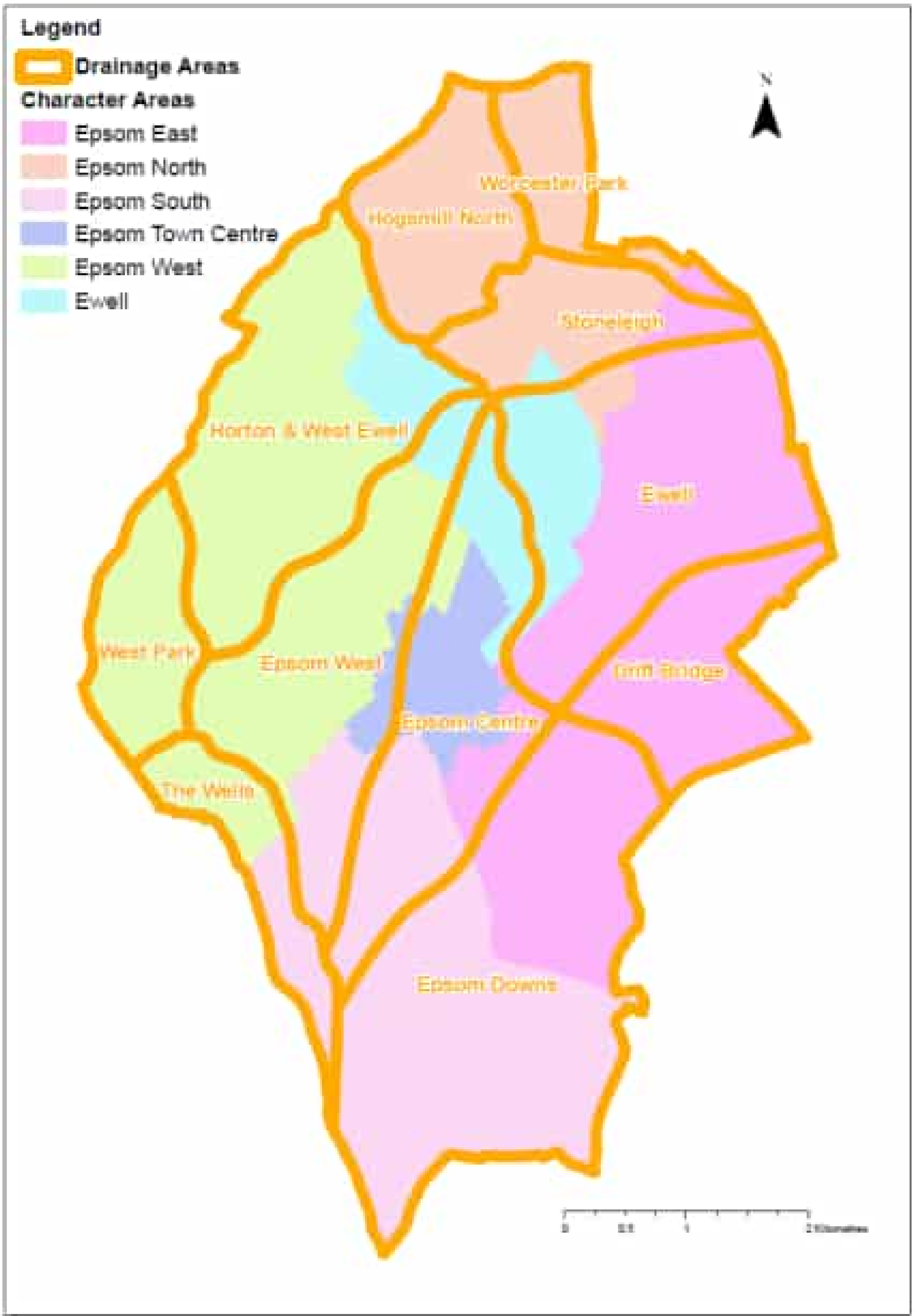

Figure 1.1 Drainage and Character Areas in the Borough

Runoff from subcatchments on the Chalk to the south of the area was represented through use of an arbitrary runoff coefficient of 1%, although it was acknowledged that this could vary substantially if the catchment is saturated or frozen. The critical storm duration which generated the maximum extent of flooding was determined and used to derive rainfall profiles and model runs for the 5% (1 in 20), 1% (1 in 100) and 0.1% (1 in 1000) annual chance events. The predicted depths of flooding were used to estimate economic damages due to surface water flooding.

Cut down versions of this model were subsequently improved locally for use in the pre-feasibility studies for flood attenuation areas in Nonsuch[4] and Rosebery[5] parks. The improvements made to the Hogsmill IUD model included:

- mesh size generally decreased in the vicinity of the parks to between 25m^2 and 100m^2; and
- the LiDAR data shows some embankments as continuous structures when they are actually pierced by bridges or culverts. Features in the 2D modelling software were used to ensure that all such flowpaths are made available.

A detailed hydrological and hydraulic model study was undertaken for the Environment Agency in 2003 of the River Hogsmill and its tributaries[6].

1.5 Agreed Approach to SWMP Detailed Modelling

A number of approaches were considered for undertaking the detailed modelling for the EEBC SWMP. These are set out in detail in Appendix A and included the use of alternative software (Tuflow and InfoWorks ICM) and the adoption of the existing model without further refinement. After considering the various options, the SWMP partnership agreed that the most appropriate approach to modelling is that set out in Option 2 in Appendix A, i.e. to modify the existing InfoWorks CS 2D model of the Hogsmill catchment so as to improve the representation of the key features of relevance to EEBC. It was agreed that the following modifications would be considered:

- Incorporate the local improvements in representation of topographic features made during the Nonsuch and Rosebery studies into the complete Hogsmill IUD (InfoWorks CS2D) model. This includes local refinement of the model mesh.
- Set mesh sizes in accordance with the locations identified through the preliminary risk assessment (Section 1.3). For example, refined meshes would be used in Epsom and Ewell town centres.
- Examine existing representation of Thames Water sewer network and determine whether improved results could be achieved through inclusion of smaller pipes. Include these where considered justified.
- Assess the run time of the entire model. If this is prohibitively long then the model domain size could be reduced to cover only the Borough of Epsom and Ewell. Otherwise, retain existing representation of the Hogsmill downstream of the Borough to enable impacts in Kingston to be assessed directly.

- Ensure hydrology used in the latest version of InfoWorks accounts for current best practice, including consideration of UKCP09[7] recommendations.

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[4] Environment Agency (2009) Nonsuch Park Flood Attenuation Area Pre-Feasibility Study. March 2009

[5] Environment Agency (2009) Rosebery Park Flood Attenuation Area Pre-Feasibility Study. March 2009

[6] Jacobs (2003) River Hogsmill Flood Study. Final Modelling Report Volume II – Hydraulic Modelling. December 2003

The modified model was agreed to be used within the SWMP study to:

- Better understand of the locations and mechanisms of flooding and thus inform identification of possible management options
- Predict flood depth at individual receptors (e.g. properties in the National Receptor Database) for the following design events: 50% (1:2 year), 10% (1:10 year), 3.33% (1:30 year - with and without climate change), 1.33% (1:75 year), 1% (1:100 year - with and without climate change) and 0.5% (1:200 year) annual probability. The flood depths would be used to estimate economic damages due to surface water flooding in the current situation.
- Predict flow velocities and depths which may pose a risk to life and, along with depths, inform emergency planning of flood risk.
- Produce flood hazard and risk maps.
- Further develop models to represent potential mitigation options and test their success at reducing the consequences of flooding.

1.6 Broad Description of the Detailed Model Area

As shown in Figure B.1 in Appendix B, the Borough of Epsom & Ewell lies mainly within the catchment of the River Hogsmill. The main watercourse in the Borough is, therefore, the River Hogsmill, which is fed by a number of tributaries that have their source in the Chalk hills in the south. The area of the Borough is approximately $34km^2$ and the area of the Hogsmill catchment to the point where it flows out of the Borough is approximately $56km^2$. Small portions of the Borough lay within adjacent catchments; the Rye at Ashtead drains to the Mole catchment and the Beverley Brook drains to the River Thames.

The main watercourses in the Borough are predominantly natural, although sections of the Greens Lane Stream and the majority of the Ewell Court Stream are culverted. The urban areas of the Borough generally drain into Thames Water surface water sewers, with the exception of the southern portion lying on the Chalk which generally drains directly to soakaways. An overview of drainage system in the Borough is shown in Figure B.2 in Appendix B.

In terms of geology, the Borough lies across a spring line between permeable Chalk to the south and impermeable London Clay to the north. The topography falls from around 170mAOD in the south to 20mAOD in the north, an overall gradient of around 1 in 100. In terms of land use, approximately 45% of the area is rural with the remainder ranging from densely urban to leafy suburb.

1.7 Structure of this Report

This Detailed Modelling Report documents the work undertaken and findings of the Risk Assessment stage of the project:

Section 2: Strategy and Data
Section 3: Model Construction
Section 4: Basecase Model Outputs
Section 5: Baseline Economic Damage Assessment
Section 6: Detailed Modelling of Selected Options
Section 7: Summary

[7] http://ukclimateprojections.defra.gov.uk/

2 Strategy and Data

2.1 Overall Modelling Strategy

As introduced in Chapter 1, the entire Borough within the Hogsmill Catchment has been modelled using InfoWorksCS 2D. Various considerations led to the conclusion that a 1D urban storm drainage model, coupled with a 2D model for simulating overland flows and a 1D hydraulic model for the river reaches would be appropriate for this study. The surface water sewers were modelled in combination with simplified river sections, taken from the Hogsmill Flood Study ISIS model. In addition to the river and sewer sections, a system of single point inflow manholes was added to represent the network of soakaways and allow flows in excess of their capacity to enter the 2D overland flow model.

The model was developed to visualise the areas at risk of surface water flooding in each rainfall event considered, and to allow the maximum flood depth and velocity at any location to be assessed. The model enables account to be taken of the predicted impacts of climate change. The model was also developed to enable the impacts of a reasonable range of management options to be assessed.

2.2 Sources of Model Data

Data for the construction of the model was obtained from the following sources:

2.2.1 Environment Agency

The Environment Agency provided 1m horizontal resolution LiDAR data for the development of a Digital Terrain Model and the determination of catchment areas. This same data was previously used to develop the Hogsmill IUD model.

The Environment Agency also provided the Hogsmill Flood Study ISIS Model[8], from which channel survey data has been extracted.

2.2.2 Thames Water

Thames Water provided sewer network data comprising pipe types and diameters, pipe lengths and invert levels, manhole locations and connections at manholes for the surface, foul and combined drainage systems. The data was provided in GIS MapInfo format.

2.2.3 Epsom & Ewell Borough Council

EEBC provided Ordnance Survey MasterMap data which has been used to represent buildings in the model, as well as in the estimation of the economic consequences of flooding.

2.2.4 Surrey County Council

SCC provided locations and approximate capacities of soakaways across the Borough.

[8] Jacobs (2003) River Hogsmill Flood Study. Final Modelling Report Volume II – Hydraulic Modelling. December 2003

3 Model Construction

3.1 Overview

The hydraulic model has been constructed using InfoWorks CS 2D (IWCS 2D) Version 10.5.12, with an unlimited 2D model size. This version was used to avoid potential issues with version-sensitive features. Any further option development work should consider migration to the version of the software current at that time.

The 1D representation of the surface water sewer network covers broadly the area to the north of Epsom i.e. Kingston By-Pass, from Chessington to Epsom Common in the West, Epsom town centre in the South and from Nonsuch Park to Old Malden to the East.

The 1D imported Hogsmill ISIS Model covers the following watercourses to the confluence with the River Hogsmill (see Figure C.1 in Appendix C):

- Greens Lane Stream
- Hogsmill Stream
- Ewell Court Stream
- Horton Stream
- Bonesgate Stream

The representation of the soakaway drainage system covers the area south and southeast of the Borough that is almost exclusively set on the Chalk escarpments. The extent of the drainage network, soakaways and river channels that are included in the SWMP Model is shown in Figure C.1 in Appendix C.

Data flags were used throughout the model to provide a record of the origin of data and decisions made.

3.2 Model Construction

3.2.1 IWCS 1D Sewer Model

The sewer network was constructed by importing data received from Thames Water in GIS format into IWCS to define a set of nodes (manholes) and conduits (pipes) to create the drainage network. The data imported covered pipe diameters and upstream and downstream invert levels as well as related ground level of the manholes.

The connectivity of the entire network was checked by investigating the long sections for every sewer branch within the model. Having excluded pipes less than 300mm in diameter, in general, about 25% of pipe diameters and 30% of levels were missing or suspect and had to be inferred using a combination of InfoWorks tools, LiDAR elevation data and expert judgement. Roughness height (k-value) of the pipes was set globally at 1.5mm as an initial central estimate.

The downstream boundary of the 1D sewer model was defined by a free outfall downstream of a railway embankment where it discharges into the River Hogsmill channel in the vicinity of Richard Challoner School in Old Malden.

3.2.2 IWCS 2D Soakaway Model

In areas where the Thames Water records indicated no surface water sewers, records from Surrey County Council generally indicated the presence of numerous soakaways. A subcatchment draining to a system of soakaways was modelled as a single point inflow into a 2D manhole connected to a virtual outfall by a pipe of insignificant hydraulic capacity so as to meet IWCS model validation requirements. This arrangement has the potential to represent the storage and infiltration capacities of the soakaway systems.

3.2.3 IWCS 1D River Model

The topographical and river channel survey data was obtained from the Hogsmill ISIS 105 Study in an ISIS format which was utilised by importing the cross sections into IWCS. The River component of the SWMP model was constructed by importing typical iSIS cross sections for a relevant river reach approximately every 50 meters. In the areas of significant hydraulic discontinuity (i.e. structures such as bridges or weirs), more iSIS cross sections were included in the model and at least at the upstream and downstream sides of a structure.

The imported sections were generally limited to the immediate area of the main river channel and surrounding flood plan was represented from the LiDAR survey.

Manning's *n* roughness for the river sections was set between 0.035 and 0.045 as used in the original iSIS modelling.

It is acknowledged that the approach taken to modelling river channels in IWCS differs from that in iSIS. IWCS assumes prismatic reaches whereas iSIS assumes that the geometry varies continuously between defined sections. IWCS cannot therefore exactly reproduce the levels and flows which would have been given by an iSIS model with matching inputs. This approach is, however, considered sufficiently realistic for use in the EEBC SWMP.

3.2.4 IWCS 2D Surface Drainage Model

A single 2D overland flow model was constructed to cover the entire Hogsmill catchment area within the Borough as shown in Figure C.1 in Appendix C. In general, interconnection between the 1D and 2D models takes place at '2D Manholes' where surcharging of the 1D model drives flow out into the 2D model whilst flow can enter the 1D model when the water level in the 2D model exceeds a defined level at a manhole on the 1D network.

The 2D model was based on the EA's LiDAR Digital Terrain Model data (filtered to remove buildings, including bridges, and vegetation), with all the building and road footprints represented from the OS MasterMap data. Road polylines from the MasterMap data were introduced in the model as breaklines. These force the mesh to form around key features and therefore ensure they are well represented. During development of the model, attempts were made to mesh the entire model domain with triangular elements of area between $25m^2$ and $100m^2$. However, this produced an unmanageable number of elements (>1 million) such that the model would not run. Limiting the fine mesh to identified urban areas centred on Epsom Town Centre produced around 600,000 elements and enabled the model to run effectively.

The effect of buildings on overland flows was represented by raising aggregated building footprints by 0.15m above the bare ground LiDAR elevations[9]. This building 'stub' of effectively impermeable material simulates the height of the threshold of a building. Above this level, water is assumed to flow freely through any buildings. The sensitivity of the model to the height of the building 'stubs' was assessed by raising them by 0.3m instead of 0.15m. In addition, buildings with completely impermeable walls were modelled by raising footprints by a nominal 5m. Both of these scenarios had a clearly discernable impact on the paths along which surface water was predicted to flow. However, the relatively large triangular elements used in some areas meant that elements were not necessarily constrained to lie within building footprints. Where elements had vertices on a building and on a road adjacent to the building, for example, an unrealistic 'pyramid' was formed. Using breaklines around the footprints of buildings to constrain the elements produced an unmanageable number of elements. Therefore, as stated earlier, impermeable building footprints were raised only by 0.15m. Future detailed local studies would be advised to review this element of the modelling, particularly in densely urbanised areas to ensure that flows are properly represented.

A global Manning's n value of 0.025 was adopted to represent surface roughness of the whole 2D Mesh Polygon. This value is higher than the recommended 0.0125 default value since many areas have a substantial urban component with higher roughness (obstacles against the flow). The value of 0.025 is consistent with that used on other similar studies and less than the 0.05 used for the original Hogsmill IUD modelling since building footprints are now explicitly represented.

Typical details of a 2D mesh polygon are as follows:

- Number of Triangular Mesh Elements ~600,000
- Maximum Triangle Element Area in Urban Area 100m^2
- Minimum Triangle Element Area in Urban Area 25m^2
- Maximum Triangle Element Area in Rural Area 200m^2
- Minimum Triangle Element Area in Rural Area 50m^2
- Minimum Triangle Element Angle 25°

3.2.5 IWCS Subcatchments

The modelled area draining to the surface water sewers and open river channels is shown in blue in Figure C.2 in Appendix C. The green area drains to the system of soakaways. Areas not coloured green or blue drain to adjacent catchments.

IWCS subcatchments represent areas which drain to model nodes (manholes). The subcatchment areas were defined after close examination of the LiDAR data, the Ordnance Survey mapping to determine land use and the sewer record data from Thames Water. (Note that sewer catchments provided by Thames Water related to the foul and not surface water network.) The subcatchments used in the IWCS models are shown in Figure C.2.

The properties of each IWCS subcatchment define the runoff contribution. Nine different types of subcatchment were defined for the SWMP model. For each subcatchment type, three different runoff surfaces were specified as shown in Table 3.1. The percentage of the subcatchment allocated to each runoff surface type is

[9] Building footprints from the OS MasterMap data were aggregated together when individual footprints lay within 5m of each other. This closes small hydraulic gaps between buildings and reduces the number of elements in the resulting mesh.

also given in this table. The subcatchment types ranged from “Greenfield” (with 10% roads and roofs) to “Commercial” (with just 10% permeable surfaces) representing the range of development density across the catchment.

Twelve runoff surfaces were defined each with an allocated Identification (ID) number. A fixed runoff coefficient is assumed for each runoff surface type, as given in Table 3.2. This is considered further in Section 3.4, below.

Table 3.1 Sub-catchment types, runoff surface IDs and areas

Sub-catchment	Runoff Surface ID - Roads	Area (%)	Runoff Surface ID- Roofs	Area (%)	Runoff Surface ID - Green	Area (%)
Commercial EEBC	10	60	20	30	22	10
Greenfield EEBC chalk	101	10	201	10	21	80
Greenfield EEBC clay	10	10	20	10	22	80
Greenfield Large chalk	101	15	201	15	21	70
Parks EEBC	10	15	20	5	22	80
Residential CS EEBC	10	40	20	20	22	40
Residential SA EEBC	10	40	20	20	22	40
Residential SA EEBC chalk	101	40	201	20	21	40
Residential SA Large	101	40	201	20	21	40
School CS EEBC	10	20	20	20	22	60
School SA EEBC	10	20	20	20	21	60
School SA EEBC chalk	101	20	201	20	21	60

Table 3.2 Surface IDs and runoff coefficients

Runoff Surface ID	Description	Fixed Runoff Coefficient (%)
10	Impermeable Surfaces; Roads	70
20	Impermeable Surfaces; Roofs	75
21	Permeable Surfaces on Chalk	1
22	Permeable Surfaces on Clay	50
101	Impermeable Surfaces; Roads on Chalk	40
201	Impermeable Surfaces; Roofs on Chalk	45

3.3 Model Hydrology

FEH rainfall (Flood Estimation Handbook) has been used over the whole catchment. Characteristics taken from the FEH-CDROM are given in Table 3.3 and shown in Figure 3.1. Two different approaches were tested to determine the runoff resulting from the rainfall which are briefly described below:

1. **Runoff with fixed percentages of the net rainfall contributing to the overland flows.** The model defines a fixed percentage of the net rainfall, which becomes runoff with different coefficients used for different areas of the catchment.

2. **Runoff that varies throughout a rainfall event which simulates changes in catchment wetness during a storm.** The New UK model was designed primarily to stop runoff from remaining constant throughout a rainfall event irrespective of catchment wetness.

In initial trials, the fixed runoff model showed a more believable response to variations of the runoff parameters than the New UK runoff model. In addition, the New UK model requires more detailed inputs, for example, the soil characteristics prior to a storm event, and is more applicable for long duration storms. Therefore, flows generated using the fixed runoff model were used in this study.

Table 3.3 FEH parameters

FEH Parameter	FEH Value	FEH Parameter	FEH Value
AREA	55.48	URBEXT1990	0.1516
ALTBAR	84	URBLOC1990	0.815
ASPBAR	338	URBCONC2000	0.885
ASPVAR	0.42	URBEXT2000	0.2531
BFIHOST	0.665	URBLOC2000	0.887
DPLBAR	8.43	C	-0.0267
DPSBAR	36	D1	0.35977
FARL	0.99	D2	0.36417
LDP	16.74	D3	0.26779
PROPWET	0.3	E	0.31437
RMED-1H	10.7	F	2.44192
RMED-1D	32.8	C(1 km)	-0.027
RMED-2D	42.8	D1(1 km)	0.375
SAAR	687	D2(1 km)	0.297
SAAR4170	701	D3(1 km)	0.253
SPRHOST	23.47	E(1 km)	0.316
URBCONC1990	0.713	F(1 km)	2.442

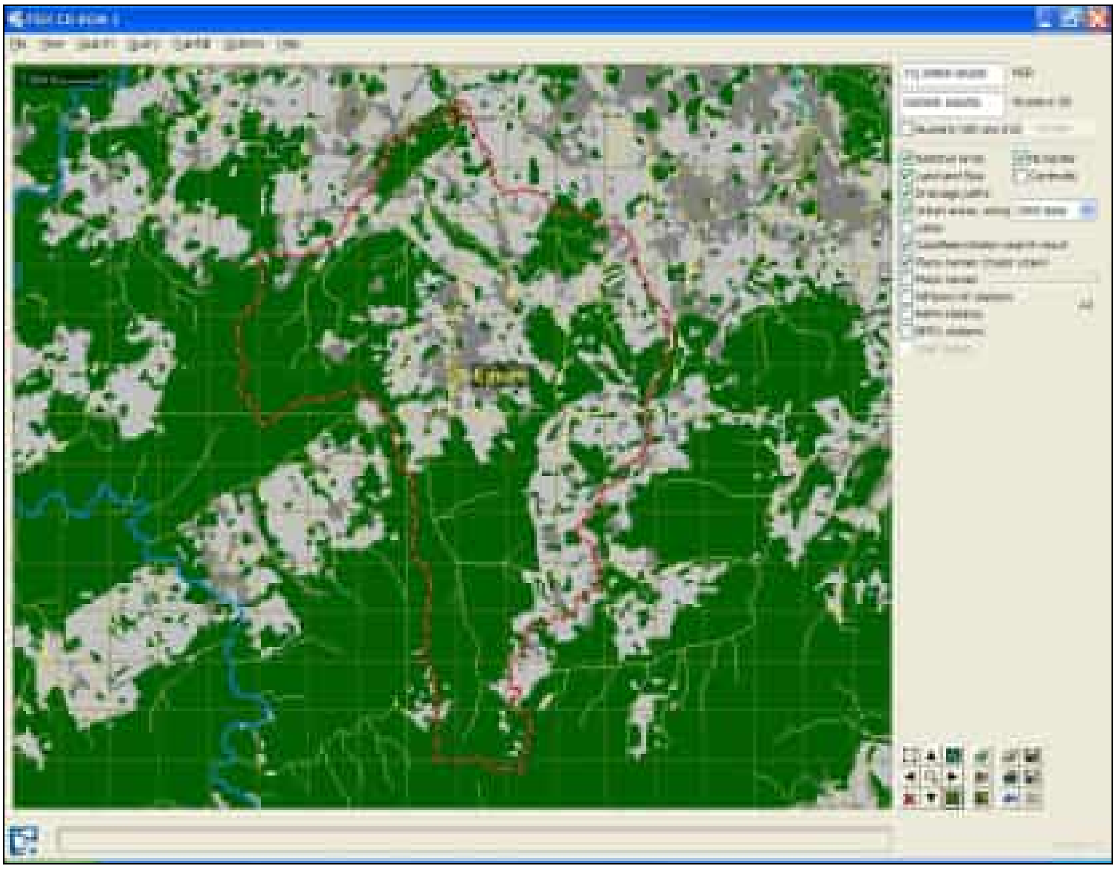


Figure 3.1Overview of FEH catchment

The critical storm duration was determined for this SWMP study in the Borough by running a range of event durations for the 1% (1:100 year) annual probability event through the model. A storm duration of 90 minutes was found to predict the maximum depth of flooding at key locations across the study area.

However, it was noted that runoff from the subcatchments overlying Chalk to the south of the Borough was not being appropriately delayed by the model. To improve the timing of peak flows entering the key areas of Epsom and Ewell town centres, additional storage was allocated to the upstream subcatchments. An increase in additional storage equivalent to 1.5% of subcatchment area was assumed for each relevant subcatchment, as shown in Figure C.3 in Appendix C. The adopted approach and method applied is explained in the following Section.

Appendix D reports that the UKCP09 climate change predictions for the Borough, with a time horizon of 2080 using the high emission scenario and 50% percentile values could increase rainfall intensity of 28%. This is interpreted as a 28% increase in rainfall depth values across all simulated events. It has no effect on runoff percentage as fixed runoff factors are used throughout the current study.

3.4 Model Verification and Sensitivity Testing

The study does not allow for flow surveys and there is little accurate historical information available with which the model could be calibrated and validated. However sufficient anecdotal evidence was obtained from the preliminary risk assessment to allow a more informal method, based on verifying that the model produced 'reasonable' results, to be adopted. To refine the SWMP model, engineering judgement was used to vary the default recommended values for various model parameters. These parameters included channel and pipe roughness and percentage runoff.

The immediate visualisation of the model results possible with IWCS allows modelling problems affecting flood depth and extents to be rapidly identified and addressed.

The extents of flooding of depth greater than 0.1m predicted by the model simulating both the 3.33% (1:30 year) and 0.5% (1:200 year) annual probability design events were compared with the outline of the respective 'shallow' (i.e. depth greater than 0.1m) Environment Agency Flood Map for Surface Water (FMfSW) maps. In the majority of locations, a reasonable fit was obtained – see Figure E.1 in Appendix E for comparison of the 0.5% events. In the south of the Borough, where the underlying geology is predominantly Chalk, the SWMP model predicts less extensive flooding than the FMfSW which is reasonable. The FMfSW is a national mapping product which is necessarily limited in its representation of key local features, including the infiltration capacity of the Chalk. However, it was noted that the SWMP model is predicting higher peak flows in the West Park area, when compared with the Environment Agency mapping, and the validity of this should be examined in any future detailed studies.

The sensitivity of the model to various parameters was tested in a subsection of the model in the southeast part of the Borough (Figure 3.2). Although Nork is in the Borough of Reigate & Banstead, it represents a large and predominantly urban catchment which flows into Epsom & Ewell. As can be seen in Figure 3.3, the steep topography means that overland flows are collected in the local valleys and than concentrated through the A240 Reigate road railway underpass at Drift Bridge.

Initial model runs predicted substantial flooding of the Reigate Road around Drift Bridge in high frequency rainfall events which was not consistent with available anecdotal evidence. Therefore, additional storage was allocated for the upstream subcatchments where longer response times and a lower percentage of contributing runoff were justified. The criteria for additional storage was based on anecdotal evidence that there is unlikely to be flooding in the Nork area in a 50% (1:2 year) annual probability event. The modelled system of soakaways would, therefore, be expected to remove surface flow for this relatively low magnitude event. After some sensitivity analysis, it was determined that by increasing the additional storage for a subcatchment to about 1.5% of the subcatchment area, the total volume of overland flooding in the Nork area came close to zero in the 50% (1:2 year) event.

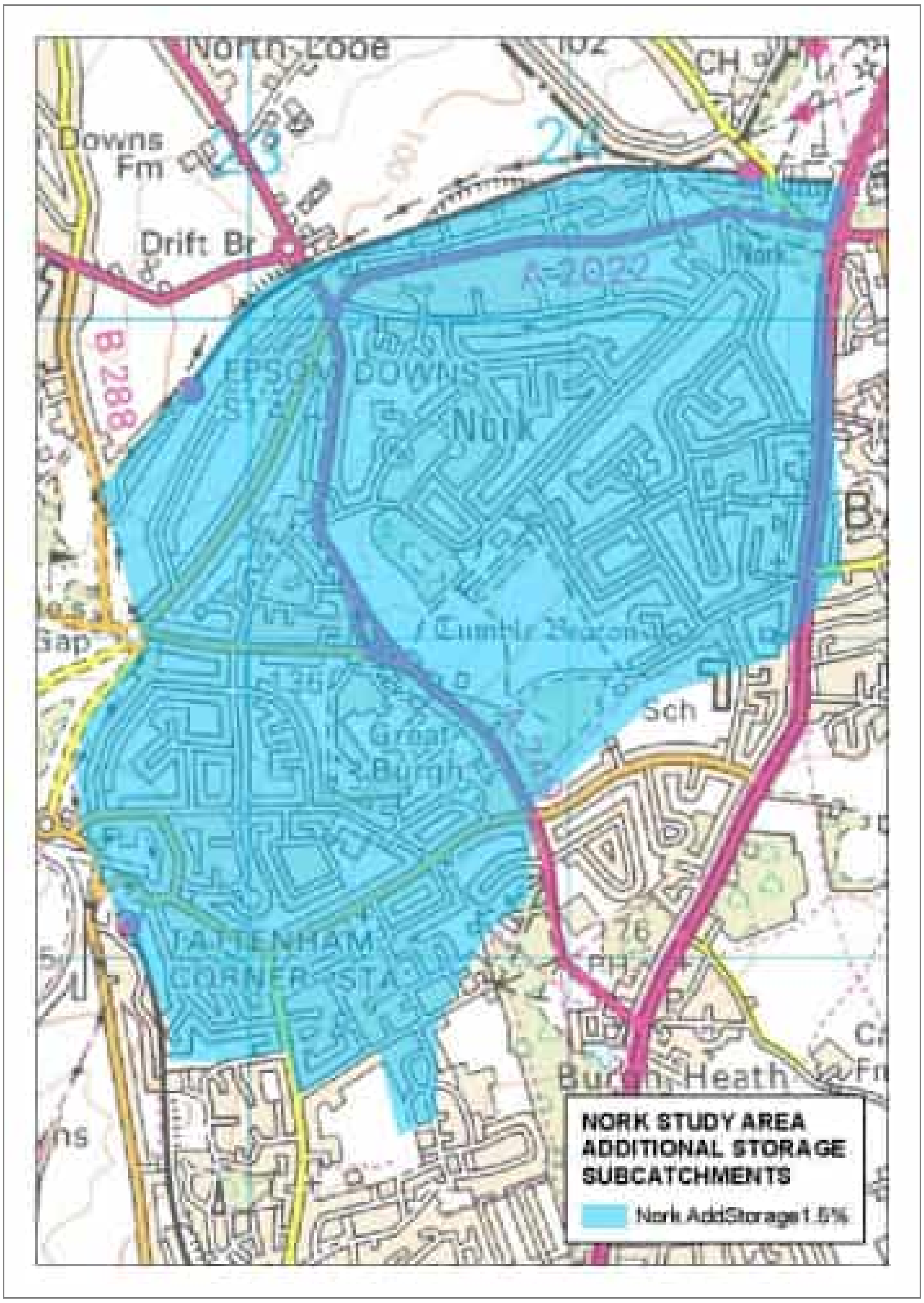


Figure 3.2 Nork study area where additional model storage was added

This additional storage was modelled and the results with and without the additional storage were compared at the embankment opening in the Drift Bridge area, as shown for the 3.33% (1:30 year) annual probability event in Figure 3.4. Flood depths at the lowest point in the road under the railway embankment opening were compared to determine the effect of the modelled increase in storage capacity. Results of the 'with storage' and 'without storage' case are given in Table 3.4.

It was concluded that the increase in additional storage capacity resulted in a more realistic representation of the southern part of the Borough. Subsequently, the same methodology was applied on the subcatchments which overly the chalk escarpments as shown in Figure C.3 in Appendix C.

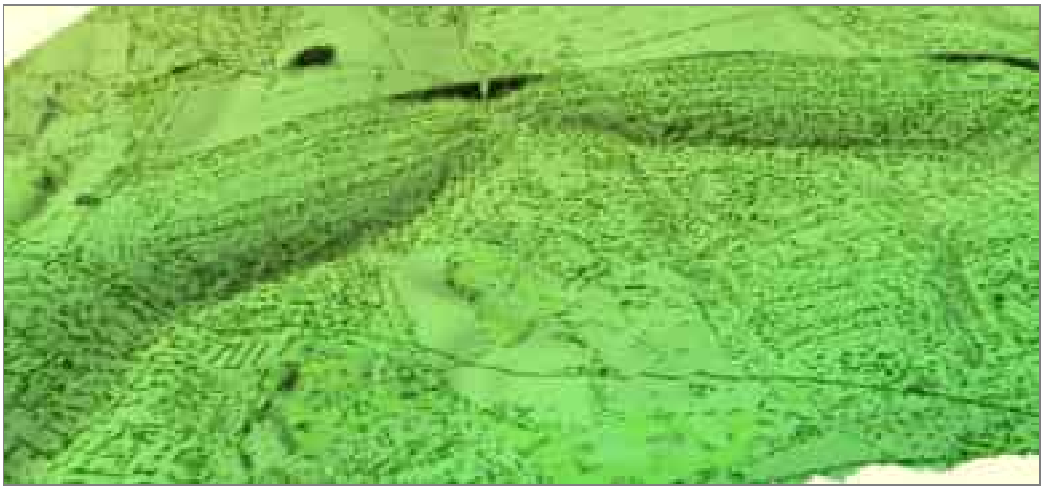


Figure 3.3 3D View of Nork area draining to railway underpass at Drift Bridge

Figure 3.4 Comparison of maximum flood depths at the Drift Bridge area downstream of Nork in the cases without and with additional storage

Table 3.4 Drift Bridge depth of flooding for the 'without' and 'with' additional storage

Design Event	Max Depth of Flooding in the Embankment Opening	
	Without additional storage	**With additional storage**
M30-90	0.8m	0.4m
M100-90	1.5m	0.7m

3.5 Conclusions

The SWMP model provides a reasonable representation of the likely risk of surface water flooding across those areas of the Borough which drain to the River Hogsmill. The maximum flood extents for the 3.33% (1:30 year) and 0.5% (1:200 year) design events compare well with the Flood Map for Surface Water produced by the Environment Agency. However, it is noted that the FMfSW is a national mapping product which is necessarily limited in its representation of key local features, including the infiltration capacity of the Chalk. Therefore, differences which do exist between the two sets of mapping could be reasonably attributed to the more detailed modelling undertaken in this SWMP. The model has been developed to represent the existing scenario across the Borough in as much detail as possible, although it is recognised that it is a large and hydrologically complex area. Therefore, the model should only be used for similarly large-scale and conceptual purposes and any detailed design should take account of the possible improvements and refinements to the model suggested in this report.

4 Basecase Model Outputs

4.1 Detailed Model Maps

The basecase model as developed represents the existing situation in the Borough. It can also be regarded as a 'Do minimum' model since it broadly represents the drainage system as it is today, maintained to present standards.

The model was run for the 90 minute duration storm for the following range of annual probability events: 50% (1:2 year), 10% (1:10 year), 3.33% (1:30 year – with and without climate change), 1.33% (1:75 year), 1% (1:100 year – with and without climate change) and 0.5% (1:200 year). For all events, maximum model results were exported to GIS and used to produce maps of maximum depth, velocity, hazard and time-to-peak depth. Due to the large study area, the number of storm events run and the number of output variables, illustrative maps presented in Appendices E – H have been included in this report for the 0.5% (1:200 year) event only. However, all model results have been supplied in GIS format.

- **Appendix E - Basecase Maximum Depth Maps:** maps show areas with a maximum depth greater than 0.1m predicted in each element during the model simulation. Note that Map E.1 shows comparison of the 0.5% (1:200 year) event with the Environment Agency Flood Map for Surface Water (FMfSW) 'shallow' map, i.e. where the flood depth is greater than 0.1m.

- **Appendix F - Basecase Maximum Velocity Maps**: maps show areas with a maximum velocity greater than 0.5m/s predicted in each element during the simulation

- **Appendix G - Basecase Hazard Maps:** maps show areas where the maximum hazard score predicted in each element during the simulation, where the hazard score is calculated using[10]

  HR = d (v + 0.5) + DF   (d = depth, v = velocity, DF = debris factor)

- **Appendix H - Basecase Time to Peak Maps:** maps show the time taken for each element in the model simulation to reach its peak flood depth from the onset of rainfall.

These maps can be used to inform planning policy, emergency response and other Local Government functions, and have been used in the development of management options.

4.2 Pattern of Surface Water Flooding in the Drainage Areas

The following subsections summarise the pattern of flooding in each Drainage Area as predicted by the detailed model[11]. Reference to the maps in the above

[10] Supplementary Note On Flood Hazard Ratings And Thresholds For Development Planning And Control Purpose – Clarification of the Table 13.1 of FD2320/TR2 and Figure 3.2 of FD2321/TR1. Suresh Surendran and Geoff Gibbs (Environment Agency), Steven Wade and Helen Udale-Clarke (HR Wallingford). May 2008

[11] Note that The Wells and Worcester Park areas do not drain to the River Hogsmill and have therefore not been included in the modelling.

appendices can be made for the 0.5% (1:200 year) event. Focus is given to where and of what magnitude of an event flooding is likely to be first observed.

4.2.1 Epsom Downs

Surface water with a depth greater than 0.1m is first observed in this Drainage Area in the 10% (1:10 year) event, with flow accumulating near Langley Vale Road. Surface flow northwards along Langley Vale is properly established by the 1.33% (1:75 year) event. In the 1% (1:100 year) event, flooding of isolated areas between South Hatch and Downs Avenue is predicted, including flooding of Downs Avenue. In the 0.5% (1:200 year) event, maximum flood depths of approximately 1m are predicted around the Thames Water pumping station adjacent to Langley Vale Road. The extent of water with depths greater than 0.1m is typically less than that shown on the FMfSW shallow map, with a number of the small drainage paths highlighted in the FMfSW not being predicted to have water depths greater than 0.1m in the SWMP model. Maximum velocities in the 0.5% event generally exceed 1.5m/s along the flow routes. The Defra hazard score in the 0.5% event suggests values between ‘danger for some’ and ‘danger for most’ along the Langley Vale flowpath.

4.2.2 West Park

It is thought that that the flows are being over-predicted due to the low resolution approach to modelling in this Drainage Area. Maximum flood depths of over 0.5m are predicted in the West Park site in the 50% (1:2 year) event, from northerly flow over Christchurch Road between Stew Pond and the Bonesgate Stream. By the 0.5% (1:200 year) event, maximum depths of over 1.0m as well as velocities approaching 2.0m/s are predicted in small areas. As noted previously, the SWMP flood extent appears high when compared to the FMfSW shallow map. The hazard score predicts ‘danger for most’ along the flowpath across the majority of the West Park site, with ‘danger for all’ to the adjacent to Christchurch Road.

4.2.3 Epsom West

In the 50% (1:2 year) event, there is an indication of flooding in the playing field of Rosebery School as well as in isolated areas adjacent to the Greens Lane Stream. By the 3.33% (1:30 year) event, the flowpath connecting Rosebery School and Longmead Road shows almost continuous surface flow of depth greater than 0.1m, with flooding between Upper Court Road and Longmead Road where the Greens Lane Stream is culverted. By the 1% event, there is substantial flooding along the Greens Lane Stream. In the 0.5% event, maximum depths of approximately 1.0m are predicted on the road where the Greens Lane Stream passes under Christ Church Mount, the Ridgeway, Gibraltar Crescent and Chessington Road. In addition, the majority of Longmead Road and Green Lanes roads are flooded. Comparison with the FMfSW shallow map suggests a generally good fit with the SWMP model, although each model shows a greater extent of flooding in some areas. Maximum velocities are generally less than 1.5m/s. ‘Danger for most’ is typically predicted along the flowpath until Longmead Road, with ‘danger for all’ along Greens Lane Stream further north.

4.2.4 Epsom Centre

In the 50% (1:2 year) event, there are some isolated patches of surface water flooding (maximum depth less than 0.5m) on the flowpath between Rosebery Park and the High Street. There are also isolated patches elsewhere in the Drainage Area. In the 10% (1:10 year) event, surface water is evidently ponding in areas along Greens Lane Stream and on the eastern side of the railway embankment. By the 3.33% (1:30 year) event, there is a continuous flowpath of depth greater than 0.1m between Dorking Road and the Greens Lane Stream via High Street and Hook Road. By the 1.33% (1:75 year) event, there is an almost continuous flowpath from Albert Road in towards the Utilities Site via Upper High Street. The 0.5% (1:200 year) event predicts continuous flow from Langley Vale into the Greens Lane Stream via the town centre, as well as flow from Albert Road into the Utilities site. Maximum flood depths of over 0.5m are predicted in the town centre. Comparison of the 0.5% event with the FMfSW indicates that the flooding predicted by the SWMP is in the same locations although to a smaller extent. Velocities in the 0.5% event are greater than 2.5m/s in some areas (e.g. railway underpass between High Street and East Street). There are numerous areas of the flowpaths where the hazard score indicates 'danger for most', with 'danger for all' indicated at the railway underpass along Hook Road and adjacent to Greens Lane Stream.

4.2.5 Drift Bridge

Continuous flooding to a depth greater than 0.1m is not observed in this Drainage Area until the 3.33% (1:30 year) event. In the 1% (1:100 year) event, depths of greater than 0.3m are predicted on Reigate Road downstream of the railway embankment. The extent in the 0.5% (1:200 year) event matches well with the FMfSW shallow map. Due to the steep nature of the catchment to the Drift Bridge railway underpass, maximum velocities of over 4m/s are predicted in the 0.5% event. As a result, a 'danger for all' hazard is indicated along Reigate Road and northwards along the flowpath.

4.2.6 Horton and West Ewell

Although isolated patches of surface water are observed in higher probability events, it is not until the 3.33% (1:30 year) event that almost continuous surface flow greater than 0.1m is predicted across the Drainage Area. In this event, there is predicted to be shallow flooding of some areas of the Clarendon Park development. The majority of the northerly flow is stopped at the pond in Horton Country Club. By the 0.5% (1:200 year) event, surface flow along both main flowpaths is well established, including flow through the Clarendon Park development. The flood extents compare well with those predicted by the FMfSW shallow map. Maximum velocities are relatively low, and almost always below 1.5m/s. There is 'danger for some' and 'danger for most' along most sections of the main flowpaths.

4.2.7 Ewell

The only surface water flooding of depth greater than 0.1m predicted for the 50% (1:2 year) event which will affect properties is for the superstore adjacent to the Ewell bypass. In the 1.33% (1:75 year) event, flooding along the major flowpaths is predicted, converging along the High Street in Ewell and passing through the railway underpass on Holmwood Road. By the 0.5% (1:200 year) event, almost continuous surface water flow of depth greater than 0.1m is predicted between Hampton Grove and Boleyn Avenue and the River Hogsmill near Bourne Hall and between Nonsuch Walk and Holmwood Road. Northwards flow is also predicted from the sports ground on Cheam Road through the school near Harefield Bridge and into Nonsuch Park. There is good agreement between the SWMP model and the FMfSW shallow map. Maximum velocities are generally less than 1.5m/s with 'danger for most' in the areas of deep ponding which are largely in open ground.

4.2.8 Stoneleigh

In the 10% (1:10 year) event, patches of surface water are predicted to pond along the line of the Ewell Court Stream, near the allotment gardens and adjacent to Kingston Road. By the 1.33% (1:75 year) event, this flooding forms an almost continuous flowpath between Nonsuch Park and the confluence of the Stream with the River Hogsmill, with depths in the 0.5% (1:200 year) event peaking at around 1.0m in some locations. Comparison with the FMfSW indicates that the flooding predicted by the SWMP is in the same locations although to a smaller extent. Maximum velocities are almost exclusively less than 1.5m/s with 'danger for most' in the areas of deep ponding, some of which are in residential areas.

4.2.9 Hogsmill North

Apart from ponding of surface water in the floodplain of the River Hogsmill in more frequent events, flooding of properties is likely to commence in the 3.33% (1:30 year) event in this Drainage Area. By the 1% (1:100 year) event, there is an almost continuous line of surface water of depth greater than 0.1m between the Kingston Road and the River Hogsmill adjacent to Old Malden Lane. There is also deep ponding predicted for properties between Ruxley Lane and Riverview Road. Comparison with the FMfSW indicates that the flooding predicted by the SWMP is in the same locations although to a smaller extent. Maximum velocities are almost exclusively less than 1.5m/s. In terms of the Defra hazard score, the danger is almost exclusively confined to corridors adjacent the River Hogsmill and the drain north of Wandgas Athletic Ground.

4.3 Impact of Climate Change

Climate change was represented in the model by increasing the rainfall intensities for the 3.33% (1:30 year) and 1% (1:100 year) events by 28%. Comparison of the maximum depths indicates that the 3.33% (1:30 year) plus climate change event is very similar to the 1.33% (1:75 year) event and that the 1% + climate change event is very similar to the 0.5% (1:200 year) event. This is consistent with experience elsewhere.

5 Baseline Economic Damage Assessment

5.1 Introduction

The maximum predicted flood depths from the basecase detailed modelling have been used to assess the likely Annual Average Damages (AAD) and Present Value Damages (PVD) to properties across the Borough from surface water flooding. This calculation of anticipated damages in the current situation can be used to inform an analysis of the benefits of the proposed management options.

5.2 Methodology

The National Receptor Database (NRD v1.1) provided by the Environment Agency contains 35,149 property points within the Borough. As recommended by the Environment Agency's guidance document[12], the economic damage assessment has excluded all property points with certain Ordnance Survey Base Functions (e.g. allotment, electricity sub station and post box – see guidance document for a full list). Furthermore, a number of the property points did not correspond to building footprints available in the Ordnance Survey MasterMap data and a number related to upper floor properties for which damages from surface water are unlikely. Excluding these property points reduced the total number of property points in the Borough for which damages may be incurred to 26,774. Of these, 25,476 are residential and 1,318 are non-residential. Since the NRD does not contain any information on property values, indicative market values have been identified for residential properties as shown in Table 5.1. These values are used to represent the maximum possible damage over 100 years for any individual residential property (see point 3 below).

Table 5.1 Average market values for residential properties in Epsom & Ewell

Residential Property Type	Average 2010 Market Price
Detached	£536,605
Semi-detached	£323,221
Terrace	£347,889
Flat	£192,790

Damages have been calculated for an average year and then applied over a planning horizon of 100 years. This has been done by first calculating damages for six different magnitude events, 50% (1:2 year), 10% (1:10 year), 3.33% (1:30 year), 1.33% (1:75 year), 1% (1:100 year) and 0.5% (1:200) annual probability events. The damages for these events have been estimated at individual properties using the maximum depth of flooding at the properties predicted by the detailed model and a depth-damage relationship as published in the Multi-Coloured Manual (MCM). As recommended in the Environment Agency guidance, the maximum depth of flooding can occur anywhere in the footprint of the building rather than at the arbitrary point defined in the NRD. The maximum flood depths have been adjusted to take account of property threshold levels since it is assumed, for surface water flooding, that damages will only be accrued when flood water exceeds the level of the property thresholds. Although building footprints were raised in the hydraulic model by 0.15m to represent property thresholds, closer inspection of some of the large triangular

[12] Environment Agency (2010) Flood Map for Surface Water Property Count Method

elements suggested that this adjustment was not consistent with smaller building footprints. Therefore, threshold values of 0.15m have been used to adjust the maximum flood depths which may mean, in some cases, an underestimation of the maximum flood depth. However, this is within the tolerance of the modelling and damage calculation. The methodology is as follows:

1. The damage experienced by each individual property in each of the six design flood event scenarios is combined to provide an annual average damage (AAD) estimate. This accounts for the damage associated with different probability events.

2. To provide damage estimates for each property over the 100 year planning horizon in terms of present day cost, the annual average damages are multiplied by a discount factor. This factor is 29.81 which accounts for year on year discounting of the present day value of the property, and follows HM Treasury guidance (3.5% for years 0 to 30, 3.0% for years 31 to 75 and 2.5% thereafter)

3. If the discounted annual average damage is greater than the present day market value of the property then the cost of damage is simply capped at the market value. The present day market value of the property thus represents the maximum possible estimate of damage over 100 years for any individual property.

4. In addition to the direct flood damages to the property, indirect and intangible damages are added for residential properties, as well as emergency costs according to the latest MCM guidance.

5. The direct damage for each property anticipated over 100 years is added to the indirect and intangible damages – for residential properties only - as well as the emergency costs over this same period. The individual PVD over the 25,476 individual properties in the Borough are summed to provide a total estimate of the PVD expected across the modelled area of the Borough over the next 100 years.

5.3 Baseline Economic Damages

Table 5.2 summarises the results of the baseline scenario economic damage assessment, assuming property thresholds are globally 0.15m above ground level. To determine the sensitivity of the calculation to the property threshold level chosen, Table 5.2 also provides values for thresholds of 0.3m above ground level.

Table 5.2 Estimate of economic damage due to surface water flooding

	Threshold Level (m)	
Metric	**0.15m**	**0.3m**
Number of residential properties with damages	1,400	400
Number of non-residential properties with damages	250	130
Present value damages (including indirect, intangible and emergency services for residential)	£110M	£40M
Annual average damage (per residential property)	£1,500	£1,500
Annual average damage (per non-residential property)	£6,000	£5,000

Note that all values have been rounded for presentation

The following observations can be made:

- The number of properties experiencing flooding is only a small proportion of the total number of properties in the Borough. For example, less than 6% of residential properties accrue damages, assuming a threshold level of 0.15m above ground level. Therefore, the impact of surface water flooding to properties is predicted to be concentrated in a few areas. The distribution of annual average damages is shown in Figure F.1 in Appendix F. The primary clusters of predominantly residential properties experiencing the highest damages are in the areas of:

  - Rosebery Park (including Epsom General Hospital) and between Rosebery Park and the Utilities Site, East Street
  - Between Upper High Street and the Utilities Site, East Street
  - Along the line of Greens Lane Stream, from Eastdean Avenue, near to Manor Green road, near to Blenheim High School and Blenheim Road business park
  - the superstore and High Street in Ewell, between Epsom Road and Reigate Road
  - Holmwood Road in East Ewell
  - Around the allotment gardens in Stoneleigh and westwards along the line of the Ewell Court Stream
  - Clarendon Park development
  - Adjacent to the River Hogsmill in West Ewell

  Note that the large annual average damages predicted for Epsom College are likely to be an overestimate since only a small proportion of the site is indicated to be flooded.

- The flood model predicts that a number of properties across the Borough will experience shallow depths of flooding in high frequency events. With the lower threshold assumption (0.15m), a large number of properties accrue relatively small damages with high frequency. Over the 100 year planning horizon, this leads to the estimate of present value damages of £110M, which equates to an average annual damage across the Borough of around £3.7M. With the higher threshold assumption, much of the flooding from these high frequency, shallow depth, events will be excluded and therefore the PVD drops substantially to around £40M. However, it should be emphasised whichever measure of damage to properties is selected, the potential damage to roads and open spaces, disruption and risk to life from surface water flooding is clear.

- The Borough of Epsom & Ewell represents a generally affluent area with relatively high property prices. Normally, with high frequency flooding, direct property damages (over the 100 year period) would be capped at the market value. However, due to the relatively high market values for properties in the Borough, damages for only a small number of properties are capped. It should also be noted that properties have not been written off in this assessment. It is common practice in fluvial and coastal economic damage assessments to write off to the market value any property which floods in an event equal or more frequent than the 50% (1:2 year) annual probability event. However, for relatively short duration and potentially shallower surface water flooding it is assumed that properties will not be written off.

- Large damages are predicted for a small number of large non-residential properties (e.g. Epsom General Hospital, superstore in Ewell adjacent to Epsom

Road). Only those non-residential properties contributing a significant proportion of the overall damage figure (>1%) have been capped, which is consistent with capping of residential properties.

It is clear from the nearly 3-fold increase in the number of properties which are predicted to be flooded at some point within 100 years, that the threshold level assumption has a significant impact. However, a threshold level of 0.15m is the standard value and the damages for this lower threshold assumption will be used. Therefore, in a baseline (i.e. do minimum) scenario, it is estimated that approximately £110M of damage (including indirect, intangible and emergency service costs where applicable) due to surface water flooding could be experienced across the Borough in the next 100 years. For the 1,400 or so residential properties which are predicted to experience such flooding, the average annual damage could be around £1,500. The total AAD due to surface water flooding across the Borough is estimated to be ~£3.7M.

It is recognised that these damages appear high, due in most part to the predicted shallow flooding at high frequency storm events. For comparison, the Hogsmill IUD pilot study (Appendix B.3[13]) estimated the annual average damage due to the combination of groundwater and surface water flooding in the Borough as approximately £1M. However, this assessment did not take into account contributions other than direct property damage, and assumed a linear increase in flood risk between onset of flooding at 10% (1:10 years) and 1% (1:100 years) events. It is also noted that the Defra guidance[14] on *Flood and Coastal Resilience Partnership Funding* indicates that funding will be based on the assumption that £30k of damage is sustained by each residential property in each flood event. (This figure is not specific to flooding caused by surface water, but has been derived in part from evidence from the 2007 floods, where approximately 60% of the flooding was due to surface water.) The PV damages per residential property in the Borough over a 100 year period, based on a threshold level of 0.15, are around £45k. Within this 100 year period, more than one flood event could be experienced at each property.

[13] Jacobs (2008) River Hogsmill Integrated Urban Drainage DEFRA Pilot Study. Reference SL2303. June 2008

[14] Defra (2011) Flood and Coastal Resilience Partnership Funding – an Introductory Guide. Available at: http://archive.defra.gov.uk/environment/flooding/funding/documents/flood-coastal-resilience-intro-guide.pdf

6 Detailed Modelling of Selected Options

6.1 Introduction

The accompanying *Options Appraisal* report describes the development of a number of options which have the potential to improve management of surface water in the Borough. As part of the development of these options and to test their impact, a number of them were represented in the detailed model. Within the scope of the project it was neither possible nor desirable to model all identified options – a number of options are relatively small and local and are unlikely to show a significant overall improvement in flood risk, particularly in this Borough-wide model. However, ten of the most substantial options across the Borough have been considered in the modelling. This section describes the modifications made to the basecase model and compares the results of the modified models with those from the basecase model in order to prioritise the options.

6.2 Representation of the Options

The options listed in Table 6.1 have been represented in the model – see location plan in Appendix J. Table 6.1 also provides a summary description of the changes made to the basecase model to represent the option. The screenshots of the model provided in Appendix J provide a graphical indication of the location and extent of the changes made.

It is recognised that the scope of this study and the schematisation of the basecase model justifies only conceptual representation of each option and further studies may need to undertake more detailed modelling. However, the modelling provided an opportunity for development and testing of the options which has been used to indicate their likely impact on surface water flood risk. Schematisation of the options has not been focussed to reduce flood risk in any particular annual probability event. Instead, options have been represented with 'reasonable' sizes and characteristics in mind which is in line with the overall strategy of incremental benefits across the Borough.

6.3 Results of Options Modelling

Based on the visualisation of maximum flood depths shown in the screenshots in Appendix J, and the comparison of flood volumes in Table 6.2, the predicted impact of each modelled option is briefly described below. Note that the comparison of flood volumes has been undertaken downstream of the option and aims to capture the area where maximum change is likely. All values are for comparisons of the respective 3.33% (1:30 year) annual probability event. The number of properties flooded in the basecase and option scenarios was estimated from intersection of the OS Mastermap layer of building footprints with the maximum flood depth map by assuming property thresholds of 0.15m[15]. Any potential improvements in the options which could be incorporated in further refinements to their development are noted.

[15] Where properties which were not predicted to flood in the basecase were shown as flooded in the option scenario, these were taken from the total number of protected properties.

Table 6.1 Details of options represented in the detailed model

Option Ref.	Location of Option	Description of Option	Model details
1	Langley Vale / Woodcote	1. Reservoir, detention basin, pond or wetland adjacent to Langley Vale Road on RAC Golf Course land or adjacent Thames Water pumping station. 2. Interception swale at north end of RAC Golf Course land 3. Low bund around land containing existing pond on Woodcote Green Road to increase storage	This option was represented by: • A pond in the RAC Golf Course adjacent to Langley Bottom Road was modelled as a 1.0ha surface area pond, with the ground level lowered by 1.5m • Woodcote Pond was modelled as 0.3ha surface area pond, with the ground level lowered by 1.5m • Raising kerbs by 0.15m along Woodcote Hurst Road, for a length of approximately 500m • A bund around the Millennium pond as an approximately 300m bund of height 0.5m, predominantly along Woodcote Green Road.
2	Woodcote Green Road / Dorking Road / Ashley Road / Rosebery Park	1. Surface flow route connecting Woodcote Green Road, Dorking Road and Rosebery Park 2. Surface flow route connecting Ashley Road and Rosebery Park 3. Shallow detention basins and bund around northern perimeter of Rosebery Park	This option was represented by: • Raising kerbs along ~1000m of Woodcote Green Road by 0.15m, with the section between the junction with Dorking Road and the entrance to Rosebery Park on both sides of the road • Speed bump across South Street at entrance to Rosebery Park • Raising kerbs along ~450m of Dorking Road by 0.15m • Raising kerbs along ~1600m of Ashley Road and Ladbroke Road, with both sides of the roads protected north of the school on Ashley Road • Speed bump across Ashley Road at junction with Ladbroke Road • Shallow bund in Rosebery Park of height 0.25m and length ~90m • Second shallow bund of height 0.25m and length ~200m • Bund around the northern perimeter of Rosebery Park of height 0.5m and length 350m
3	Epsom Town Centre (including Utilities Site, East Street)	1. Surface flow route connecting Ashley Road and the High Street 2. Drainage infrastructure to convey surface water to Utilities Site, East Street 3. Detention basin, pond or wetland in Utilities Site, East Street	This option was represented by: • Raising kerbs along ~1200m of Ashley Road and the High Street by 0.15m, with kerbs raised along both sides of the High Street. A small section of Waterloo Road was also included. • Speed bump across the entrance to Ladbroke Road • New 1250mm x 1000mm (Width x Height) box culvert from High Street to Institute Field of length 550m. This included two new manholes, one in High Street and one under the railway line. • Lower ground level in Institute Field (0.7ha) by 1m (assuming LiDAR data is not properly filtered so that trees remain)
4	Epsom College area	1. Surface flow route connecting Downs Avenue and the park 2. Detention basin, pond or wetland in	This option was represented by: • Raising kerbs along ~400m of Downs Road and ~600m of Downs Avenue by 0.15m, with the installation of approximately two speed

Option Ref.	Location of Option	Description of Option	Model details
		the park adjacent to the junction of Downs Avenue and Downs Road 3. Detention basin or swale to store water adjacent College Road in Epsom College sports ground	bumps. • Epsom College detention basin was modelled as a 0.3ha surface area pond, with the ground level lowered by 1.0m
5	Reigate Road at Drift Bridge / Cuddington Golf Course	1. Reservoir, detention basin, pond or wetland on Cuddington Golf Course land. 2. Swale or detention basin on west side of Reigate Road between railway underpass and roundabout with A2022. 3. Swale or detention basin on west side of Reigate Road north of roundabout with A2022. Connected to previous swale with drainage pipe. 4. Swale or detention basin on east side of Reigate Road before junction with road to North Looe.	This option was represented by: • Pond in Cuddington Golf Course of surface area ~0.5ha, with the ground lowered by 1.0m • Drift Bridge Pond adjacent Reigate Road of surface area ~0.1ha, with ground lowered by 1.0m • Connection of this pond with the next via 0.725m culvert • Reigate Road Swale (left hand side) of length ~200m, width ~25m and ground level lowered by 0.5m • Connection of this swale with the next via 0.725m culvert • Reigate Road Swale (right hand side) of length ~120m, width ~30m and ground level lowered by 0.5m • Pond next to Sports Centre adjacent Banstead Road of surface area ~1ha, with the ground lowered by 1.5m.
6	Grounds of church on Longmead Road, Gibraltar Recreation Ground and existing Allotment Gardens and pond in Utilities Site, East Street	1. Disconnect surface water sewer upstream of open ground adjacent the church on Longmead Avenue, provide storage in a detention basin and permit re-entry of flows to the sewer system 2. Disconnect surface water sewer upstream of Allotment Gardens and existing pond in Utilities Site, provide storage in a detention basin and permit re-entry of flows to the sewer system 3. Increase storage in surface water sewer near West Street via underground tank in Gibraltar Recreation Ground.	This option was represented by: • Raising kerbs along ~600m of the B284 by 0.15m • A series of four swales adjacent Greens Lane Stream, with the ground level lowered by 0.5m in each case. The widths are approximately 15m, with the lengths being 150m for one and 200m for the remainder • Pond in grounds of church of surface area 1.2ha, with ground lowered by 1.0m. Surface water sewers coming from West Street and Utilities Site passing close to this pond were interrupted at the upstream extent. Outflow from the pond was restricted by an orifice of diameter 0.15m. • The surface water sewer from Blenheim Road Business Park was redirected into the adjacent Allotment Gardens of surface area ~0.1ha where the ground level is already low. • Lowering Gibraltar Recreation Ground by 1.0m, with a surface area of 1.5ha
7	Nonsuch Park	1. Detention basins, ponds or wetlands in Nonsuch Park	This option was represented by: • Bund around the western perimeter of Nonsuch Park adjacent to London Road of length ~600m and height 0.5m. Outflow is restricted

Option Ref.	Location of Option	Description of Option	Model details
			by an orifice of diameter 0.125m • Bund around northern perimeter of allotment gardens in Stoneleigh of height 0.5m and length ~300m. Surface water sewers coming from Park Avenue were interrupted at the upstream entrance to the allotment gardens. Outflow is restricted by an orifice of diameter 0.125m
8	King George Field (Auriol Park) and Wandgas Athletic Ground	1. Disconnect surface water sewer upstream of King George Field, provide storage in a detention basin and permit re-entry of flows to the sewer system 2. Disconnect surface water sewer upstream of Wandgas Athletic Ground, provide storage in a detention basin and permit re-entry of flows to the sewer system	This option was represented by: • A bund around the western perimeter of King George Field of height 0.5m and length ~400m. Surface water sewers coming from Amberley Gardens were interrupted at the upstream entrance of the field. Outflow from the field is restricted with an orifice of diameter 0.125m. • A bund around the western perimeter of Wandgas Athletic Ground of height 0.5m and length ~450m. Surface water sewers coming from Salisbury Road area were interrupted at the upstream entrance of the field. Outflow from the field is restricted with an orifice of diameter 0.125m.
9	Rosebery School / Stamford Pond	1. Disconnect surface water sewer upstream of Rosebery School playing field, provide storage in a detention basin and permit re-entry of flows to the sewer system 2. Detention basin in land surrounding Stamford Pond	This option was represented by: • Detention basin in Rosebery School of surface area 0.5ha, with ground levels lowered by 1.0m • Bund around the perimeter of Stamford Pond of height 1.0m and length ~200m. Outflow under Christ Church Road was restricted with an orifice of diameter 0.125m.
10	Clarendon Park / Horton Country Club	1. Swale to the south of McKenzie Way to direct surface runoff into surface water sewer. 2. Detention basin, pond or wetland adjacent to junctions of Horton Lane with B284 and B2200 3. Reservoir, detention basin, pond or wetland in Horton Country Club Golf Course adjacent disused railway embankment	This option was represented by: • Swale of width ~25m and length ~150m with ground levels lowered by 0.5m. This was connected into the existing surface water sewer. The bund around the northern perimeter of the swale was of height 0.5m. • Pond adjacent Horton Lane of surface area ~1.3ha with ground levels lowered by 1.0m • The outflow from the pond in Horton Golf Course was restricted by an orifice of diameter 0.125m

Table 6.2 Comparison of volumes of surface water in the basecase without climate change and option model runs

Option No.	Max Volume in Result Polygon for the 3.33% (1:30 year) Event		
	Basecase (m^3)	Option Case (m^3)	Percentage Decrease
1	5,505	2,435	56%
2	5,287	4,740	10%
3	8,903	7,374	17%
4	6,044	5,973	1%
5	2,469	2,068	16%
6	12,215	10,262	16%
7	7,546	5,868	22%
8	1,772	1,666	6%
9	3,162(u/s Stamford Pond) 13,863(d/s Stamford Pond)	2,267(u/s Stamford Pond) 9,669(d/s Stamford Pond)	28% 30%
10	3,145	2,121	33%

- **Option 1:** A 56% decrease in maximum flood volume is predicted in the area of the Epsom General Hospital. Approximately 14 fewer properties are predicted to flood in the area around the hospital. More properties along the east side of Woodcote Hurst road could likely be protected by raising kerbs on this side of the road also.

- **Option 2:** A 10% decrease in maximum flood volume is predicted in the area between Rosebery Park and Epsom High Street. Approximately five fewer properties are predicted to flood around Rosebery Park. More properties along Ladbroke Road could be protected by routing surface water further along Ashley Road rather than into Rosebery Park.

- **Option 3:** A 17% decrease in maximum flood volume is predicted in the area between Rosebery Park and the Utilities Site, East Street. This is evident in the lower flood depths predicted on the roads in the area, particularly at the two railway underpasses along East Street/High Street and Hook Road. In addition, approximately five fewer properties are predicted to flood between Ashley Road and Epsom High Street.

- **Option 4:** Only a 1% decrease in maximum flood volume is predicted in the area between Epsom College and Upper High Street. Similarly, only one less property in this area is predicted to flood. More properties in this area could be protected by improving individual resistance and resilience.

- **Option 5:** A 16% decrease in maximum flood volume is predicted in the area between Cheam Road and Holmwood Road. Three fewer properties are predicted to flood in this area. In addition, a decrease in maximum depths of more than 50% on the Reigate Road downstream of Drift Bridge is predicted.

- **Option 6:** A 16% decrease in maximum flood volume is predicted in the Longmead Road area downstream of Blenheim High School. Approximately three fewer properties are predicted to flood, mainly in the Blenheim Road Business Park. More properties along Hook Road could be protected by improving individual resistance and resilience.

- **Option 7:** A 22% decrease in maximum flood volume is predicted in the area between Nonsuch Park and Ewell Court House. Approximately six fewer properties are predicted to flood in this area.

- **Option 8:** A 6% decrease in maximum flood volume is predicted in the area to the west of King George's Field and Wandgas Athletic Ground. Approximately one less property is predicted to flood in this area.

- **Option 9:** Approximately a 29% decrease in maximum flood volume is predicted in the area between Rosebery School and Lower Court Road, excluding the increased volume of storage in Stamford Pond. This translates to approximately 80 fewer properties being predicted to flood along the line of the Greens Lane Stream, particularly between Upper Court Road and Blenheim High School.

- **Option 10:** An approximately 33% decrease in maximum flood volume is predicted through the Clarendon Park development site. Approximately 6 less properties are predicted to flood in this area.

6.4 Prioritisation of Represented Options

From the conceptual representation of the above options in the detailed model, the options can be prioritised in terms of their predicted reduction in surface water flood risk to properties. The results of this prioritisation are shown in Table 6.3. The option with the largest predicted impact is concerned with reducing inflows into the Greens Lane Stream. The second largest predicted impact is from attenuation of flows through the RAC Golf Club site. In terms of reduction in the number of properties flooded, the options with the third most significant impact are to protect properties in the Clarendon Park development through attenuation of overland flows and to increase storage in Nonsuch Park and the allotment gardens in Stoneleigh to protect properties along the line of the Ewell Court Stream.

Table 6.3 Prioritisation of modelled options based on reduction in number of properties flooded in the 3.33% (1:30 year) event

Priority based on model results	Option Number	Drainage Area	Location	Predicted Impact in 3.33% (1:30 year event)
1	9	Epsom West	Rosebery School / Stamford Pond	Approx. 80 fewer properties flooded
2	1	Epsom Centre	Langley Vale / Woodcote	Approx. 14 fewer properties flooded
3	10	Horton & West Ewell	Clarendon Park / Horton Country Club	Approx. 6 fewer properties flooded
4	7	Stoneleigh	Nonsuch Park	Approx. 6 fewer properties flooded
5	3	Epsom Centre	Epsom Town Centre (including Utilities Site, East Street)	Approx. 5 fewer properties flooded

Priority based on model results	Option Number	Drainage Area	Location	Predicted Impact in 3.33% (1:30 year event)
6	2	Epsom Centre	Woodcote Green Road / Dorking Road / Ashley Road / Rosebery Park	Approx. 5 fewer properties flooded
7	5	Drift Bridge	Reigate Road at Drift Bridge / Cuddington Golf Course	Approx. 3 fewer properties flooded and over 50% reduction in flood depth on Reigate Road
8	6	Epsom Centre	Grounds of church on Longmead Road, Gibraltar Recreation Ground and existing Allotment Gardens and pond in Utilities Site, East Street	Approx. 3 fewer properties flooded
9	9	Hogsmill North	King George Field (Auriol Park) and Wandgas Athletic Ground	Approx. 1 less property flooded
10	4	Ewell	Epsom College area	Approx. 1 less property flooded

7 Summary

A detailed two dimensional hydraulic model has been developed to support the Epsom & Ewell SWMP Action Plan. The model covers the majority of the Borough, with only those small portions not in the River Hogsmill catchment excluded and also covers, in less detail, areas draining into the Borough from the more southerly parts of the Hogsmill catchment. The approach adopted has been to modify the existing InfoWorks CS 2D model of the Hogsmill catchment which was available from the Hogsmill IUD study. Improvements to the Hogsmill model which have been made include:

- Incorporation of local improvements in representation of topographic features made during the Nonsuch and Rosebery Flood Alleviation Scheme studies.
- Mesh sizes set in accordance with the locations identified through the preliminary risk assessment, including refined meshes in Epsom and Ewell town centres.
- Checking and inclusion of more of the Thames Water surface water sewer network.
- Updating the model hydrology, including consideration of UKCP09 climate change recommendations for the Borough which states that rainfall intensity will increase by 28% by 2080 in a high emission 50% percentile scenario.
- Improved representation of the likely volume and timing of surface flows from the chalk and clay geology types.

Due to the long run time of the model covering the entire Hogsmill catchment downstream to Kingston upon Thames, the model domain has been reduced to cover only the Borough of Epsom and Ewell.

The modified model has been used to better understand the locations and mechanisms of flooding and inform identification and development of management options. The model has been used to predict the maximum flood depths, velocities, hazard and time to maximum depth across the Borough for the following range of design events: 50% (1:2 year), 10% (1:10 year), 3.33% (1:30 year - with and without climate change), 1.33% (1:75 year), 1% (1:100 year - with and without climate change) and 0.5% (1:200 year) annual probability. Based on comparison with the Environment Agency Flood Map for Surface Water and anecdotal evidence of flooding, the SWMP model provides a reasonable representation of the likely risk of surface water flooding. However, it is noted that the ~60km^2 model domain is a large and hydrologically complex area and that a number of simplifications have had to be made. Therefore, the model should only be used for similarly large-scale and conceptual purposes and any detailed design should include necessary improvements and refinements to the model.

Maximum depths at individual properties in the National Receptor Database have been used to estimate economic damages due to surface water flooding in the existing (‘do minimum’) situation. The mapping of economic damages in the basecase scenario can be considered to constitute a risk map. Assuming a standard threshold level of 0.15m, it is estimated that approximately £110M of damage (including indirect, intangible and emergency service costs where applicable) due to surface water flooding will be experienced across the Borough in the next 100 years. For the 1,400 or so residential properties which are predicted to experience such flooding, the average annual damage could be around £1,500. The total AAD due to surface water flooding across the Borough is estimated to be ~£3.7M. This high value is due in part to the predicted shallow flooding in high frequency events, and also the relatively high market values for properties.

As part of the development of the management options and to test their impact, ten of the most likely substantial options across the Borough have been represented in the detailed model in conceptual terms. Options have been represented with 'reasonable' sizes and characteristics in mind which is in line with the overall strategy of incremental benefits across the Borough. The conceptual modelling of has enabled the options to be prioritised in terms of their predicted reduction in surface water flood risk to properties:

1. The option with the largest predicted impact in the 3.33% (1:30 year) annual probability event is concerned with reducing inflows into the Greens Lane Stream upstream of Stamford Pond.

2. The second largest predicted impact is from attenuation of flows through the RAC Golf Club site.

3. In terms of reduction in the number of properties flooded, the options with the third most significant impact are to protect properties in the Clarendon Park development through attenuation of overland flows and to increase storage in Nonsuch Park and the allotment gardens in Stoneleigh to protect properties along the line of the Ewell Court Stream.

The depth, velocity, hazard, risk and time-to-peak maps, as well as information on the prioritisation of the options has been used in the development of the SWMP Action Plan.

Appendix A - Possible Approaches to Detailed Modelling

A.1 No Detailed Modelling

Undertaking no detailed modelling in the SWMP study is clearly the lowest cost option for the project but forfeits all the benefits listed in Section 1.2. Any decisions about mitigation options for surface water flooding developed within the study would have to be made on the basis of limited data and understanding and it is unlikely that external funding to undertake the works could be secured on this basis. Any benefits from measures proposed would be uncertain. Therefore, this option is not considered further.

A.2 Above Ground Modelling Only / Above Ground Modelling including Assumptions Regarding Losses

One of the simplest approaches to undertaking detailed modelling would be to develop a 2D model based on the best available LiDAR data which considers only some of the above ground flooding processes. This option would ignore the presence of the sewer network and surface watercourses. Although the model could estimate economic damages and test above-ground mitigation options, the analysis is likely to be highly conservative and potentially over-simplified since existing drainage infrastructure, and possibly important links, are ignored. A more detailed approach would be to make general assumptions about the capacity of the sewer network and watercourses and, therefore, represent a reduction in the volume of direct rainfall which can cause surface water flooding. Although this approach would be less conservative and would provide more benefits than the simplest approach, both of these approaches would not provide any significant improvement in understanding of the mechanisms of flooding. For these reasons, these options are discounted.

A.3 Above and Below Ground Modelling

The most detailed approach to modelling currently available is to couple explicit representation of flow in the sewer network and/or watercourses to the overground flow model, as achieved to a large extent in the available Hogsmill IUD model. In other words, rainfall can be routed as it travels above-ground and through the sewer network before attempting to discharge into a watercourse or is pumped from the system. Antecedent conditions in the sewer system and watercourses can be varied as boundary conditions. Such a detailed model would provide the greatest understanding of the mechanisms of flooding and the best available estimate of economic damages and testing of all likely mitigation options.

Given the availability of the detailed Hogsmill IUD model as a starting point for work in this study, a number of options using the Hogsmill IUD model are presented below, together with other options using different software packages. It is worth noting that a possible option to produce a combined InfoWorks 2D, CS and RS model was not considered further here since these individual packages are known not to operate robustly when linked, and current representation of the watercourses is deemed sufficient for a focus on surface water flooding.

The following possible approaches to undertaking the detailed modelling were considered:

1. Use existing InfoWorks CS2D model for Hogsmill catchment
2. Modify existing InfoWorks CS2D model of Hogsmill catchment
3. Develop a new InfoWorks ICM[16] model
4. Develop a new Tuflow model

Table A.1 below presents an analysis of the advantages and disadvantages of each of the above options.

Table A.1 Possible approaches to detailed modelling

Modelling Option	Advantages	Disadvantages	Relative Cost
Option 1: Use existing InfoWorks CS2D model for Hogsmill catchment	• Lowest cost to the project • Makes use of existing model development • Can be used immediately • Model covers entire Hogsmill catchment so it can be used to indicate impact of measures taken in Epsom & Ewell on water levels downstream in Kingston	• Mesh size in Hogsmill model is coarse. Therefore, areas recommended for detailed study will not be represented at sufficiently high resolution • Representation of sewer network only above a certain pipe size may make the model less comprehensive • Options may not be able to be tested thoroughly due to low resolution	Low
Option 2: Modify existing InfoWorks CS2D model of Hogsmill catchment	• Could improve mesh resolution in key focus areas, including improvements made during the Nonsuch and Rosebery studies • Could reduce model domain to reduce model run time • Could improve representation of surface water sewer network	• After Option 1 above, this would be the next lowest cost option • Representation of the watercourses will remain simplistic, but sufficient for a focus on surface water flooding	Medium
Option 3: Develop a new InfoWorks ICM model	• Potential to become an industry-leading single simulation engine that integrates above and below-ground manmade drainage, open channels, rivers and floodplains • Existing InfoWorks CS2D model should readily import into ICM • Could develop full representation of the watercourses to determine impact on surface water discharge	• Software is completing beta testing and may therefore not perform optimally • License is expensive and the cost would not be justifiable for this project • Partner organisations may decide not to use ICM and therefore will not be able to use model in future • Porting existing model into ICM may be time consuming and benefits, of e.g. better representation of the rivers, are not clear	High
Option 4: Develop a new	• Could develop full representation of the	• Regular meshing is less well suited to representing	High

[16] InfoWorks ICM is a new product which combines the currently separate CS (sewers), 2D (overground) and RS (river systems) products into one Integrated Catchment Modelling tool.

Modelling Option	Advantages	Disadvantages	Relative Cost
Tuflow model	watercourses to determine impact on surface water discharge	complex urban environments • Model runs typically take longer than comparable InfoWorks model runs • Porting existing model into Tuflow may be time consuming and benefits of, for example, better representation of the rivers, are questionable • Partner organisations may decide not to use Tuflow and therefore will not be able to use model in future	

Appendix B - River Hogsmill Catchment

Appendix C - Model Domain, Drainage Networks & Subcatchments

Appendix D - UKCP09 Climate Change Predictions

D.1 Summary of the UKCP09 Projections

In 2009, the UKCP09 climate change scenarios were released. These scenarios are designed to provide improved and more detailed descriptions of the likely climate the UK will experience throughout the 21st century. As such they supersede the earlier UKCIP02 climate change projections. The UK Climate Projections (UKCP09) provide projections of climate change for the UK, giving greater spatial and temporal detail, and more information on uncertainty than previous UK climate scenarios.

Over land, UKCP09 gives projections of changes for a number of climate variables, averaged over seven overlapping 30-yr time periods, at 25 km resolution and for administrative regions and river basins. Similar projections are given for a smaller number of variables averaged over marine regions around the UK.

UKCP09 is the first set of UKCIP[17] projections to attach probabilities to different levels of future climate change. The probabilities given in UKCP09 represent the relative degree to which each climate outcome is supported by the evidence currently available, taking into account our understanding of climate science and observations, and using expert judgement.

The Met Office Hadley Centre has designed a methodology to provide probabilistic projections for UKCP09, based on ensembles of climate model projections consisting of multiple variants of the Met Office climate model, as well as climate models from other centres. These ensembles sample major known uncertainties in relevant climate system processes

Each of the UKCP09 emission scenarios suggests a different pathway (storyline) of economic and social change over the course of the 21 century. Changes in population, economic growth, technologies, energy use, and land use are all considered in the determination of the emission scenario. They do not assume any planned mitigation measures, and importantly they cannot currently be assigned probabilities. The high emission scenario which was used for this analysis is as follows:

High emission scenario storyline:
Describes a future world of very rapid economic growth, and a population that increases from 5.3 billion in 1990 to peak in 2050 at 8.7 billion and then declines to 7.1 billion in 2100. Rapid introduction of new and efficient technologies is assumed, as is convergence among regions, including large reductions in regional differences in Gross Domestic Product (GDP). High use of fossil fuels is assumed.

For a fuller understanding refer to the UKCP09 technical reports (Murphy JM et al, 2009; Jones PD et al, 2009).

D.2 Projection Uncertainties

Uncertainty in climate change projections is a major problem for those planning to adapt to a changing climate. Adapting to a smaller change than that which actually occurs (or one of the wrong sign) could result in costly impacts and endanger lives,

[17] UKCIP = United Kingdom Climate Impacts Programme

yet adapting to too large a change (or, again, one of the wrong sign), could waste money. In addition there is the risk of maladaptation – adapting to climate change in a way that prevents or inhibits future adaptation. The 2009 projections are the first from UKCIP to be designed to treat uncertainties explicitly, by generating projections of change that are given, where justified, as estimated probabilities of different rather than giving a single realisation of possible changes from one model or a small sample of possible changes from several models. This means that probabilities are attached to different climate change outcomes, giving more information to planners and decision makers.

Uncertainty in projections of future climate change arises from three principal causes:

- natural climate variability;
- incomplete understanding of Earth System processes and their imperfect representation in climate models;
- uncertainty in future emissions.

Uncertainty in projections is presented in the UKCP09 in the form of probability density functions which are developed by repeatedly running the models with each run having plausible but not identical parameter values or initial states (i.e. a model ensemble). The outcomes are not identical and offer a spread of estimates. If enough runs are undertaken that adequately sample the range of plausible states then a general picture will develop showing a range of projections but with some more common than others (i.e. a probability density function).

The UKCP09 projections also incorporate projections from 12 other international models over and above the UK's Met Office model. The use of alternative climate models fulfils one of the main user requests identified from a review of UKCIP, that the projections should not be based solely on the Met Office model.

The progression to probabilistic projections based on large ensembles has meant that not all of the properties and characteristics of the UKCIP02 scenarios could be carried across to UKCP09 — the direct provision of daily time series from climate model output, for example. Thus the new projections are not a "drop in" replacement or straightforward update of UKCIP02.

D.3 Weather Generator

UKCP09 provides a tool known as a weather generator, capable of providing plausible realisations of how future daily time series of several variables could look, which are consistent with changes in the characteristics of monthly average climate sampled from the probability distributions. It does not provide a weather forecast for a particular day in the future; rather it gives statistically credible representations of what may occur given a particular future climate.

The UKCP09 Weather Generator provides synthetic daily time series of temperature (mean, maximum and minimum), precipitation, relative humidity, vapour pressure, potential evapotranspiration (PET) and sunshine at a resolution of 5 km, for each of the three emission scenarios. The weather generator does not add any additional climate change information over that which is present in the 25 km probabilistic projections. However it does add local topographical information (e.g. hills, valleys) at the 5 km scale, as it is based on observed data which is representative of this scale. For more detailed information on the UKCP09 weather generator refer to Jones PD et al (2009).

D.4 10-year rainfall modelling exercise

Extreme rainfall estimates such as the 10-year rainfall event is not the subject of UKCP09 pre-prepared graphics, and it has been necessary to undertake bespoke analysis of climate change time-series generated by the UKCP09 Weather Generator. The 10 –year rainfall is defined in this study as the extreme daily rainfall depth that has a return period of 1 in 10 years. (Equivalent to an annual occurrence probability of 0.1)

The model developed for Extreme Rainfall analysis extracts daily rainfall 30-year time series from the Weather Generator output. The model carries out the extreme value frequency analysis on each of the 30-year time series from which the 10-year rainfall for each of the 100 weather generator runs is derived. Probability analysis is then undertaken to provide the probability density functions and to supply the 10, 50 and 90 percentile values of the 10-year (or 2-year) extreme daily rainfall depth and the change between baseline and scenario runs.

The projected changes to the variables resulting from the analysis of the weather generator data have been tabulated in the following way:

The percentiles of the changes are calculated by comparison of each of the 100 paired weather generator runs for the variable of interest. (ie each of the 100 runs has a baseline and a future scenario and the change in the variable of interest is calculated for each of these 100 year runs. The predicted changes can be used to create a probabilistic distribution of the change in that variable and the 10%, 50%, and 90%-tiles of the changes can be worked out for this).

D.5 Results

For the Borough of Epsom & Ewell, the projected percentage change in the 10-year rainfall for the time horizon of 2080s and the high emission scenario, broken down in the 10th, 50th and 90th percentiles is given in the following table.

	Percentiles		
% Change in 10-year rainfall estimates per location	**10th**	**50th**	**90th**
% change Epsom	16%	28%	41%

For this SWMP study, a predicted increase of 28% has been adopted.

Appendix E - Basecase Maximum Depth Maps

Appendix F - Basecase Maximum Velocity Maps

Appendix G - Basecase Hazard Maps

Appendix H - Basecase Time to Peak Maps

Appendix I - Basecase Economic Damage Assessment Map

Appendix J - Location Plan for Modelled Options

Appendix K - Options Modelling Results

Screenshots on the following pages show the maximum flood depths predicted for the 3.33% (1:30 year) annual probability event for the basecase (left-hand image) and options (right-hand image) scenarios. For each of the ten options modelled, the first set of images in each figure indicates the schematisation of the option. The second set of images in each figure shows the area within which maximum flood volumes were calculated.

Depth band(m)	Colour
0.1 – 0.3m	
0.3 – 0.5m	
0.5 – 1.0m	
>1.0m	

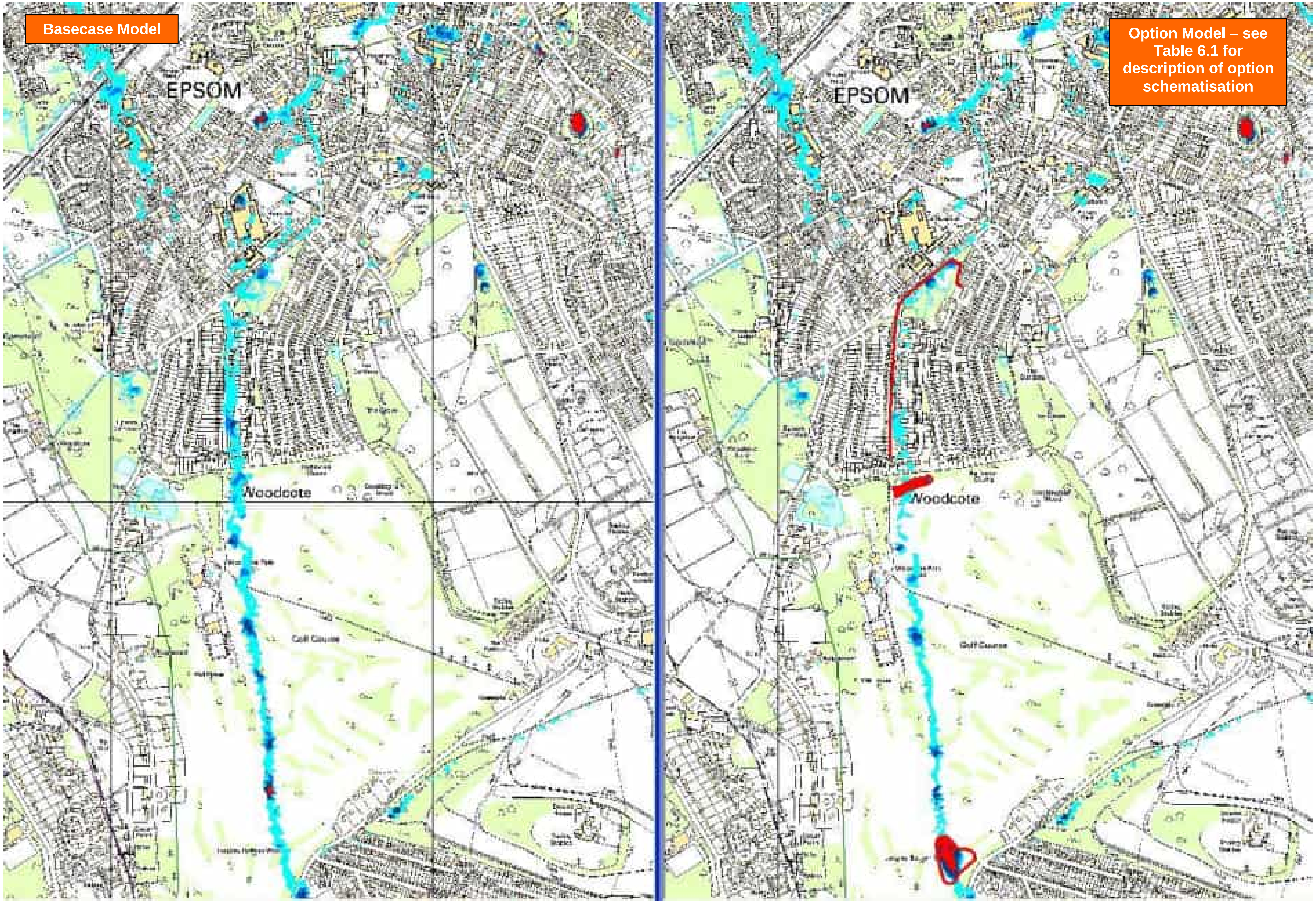


Figure K.1a Comparison of maximum flood depths in the (left) basecase and (right) option 1 scenarios

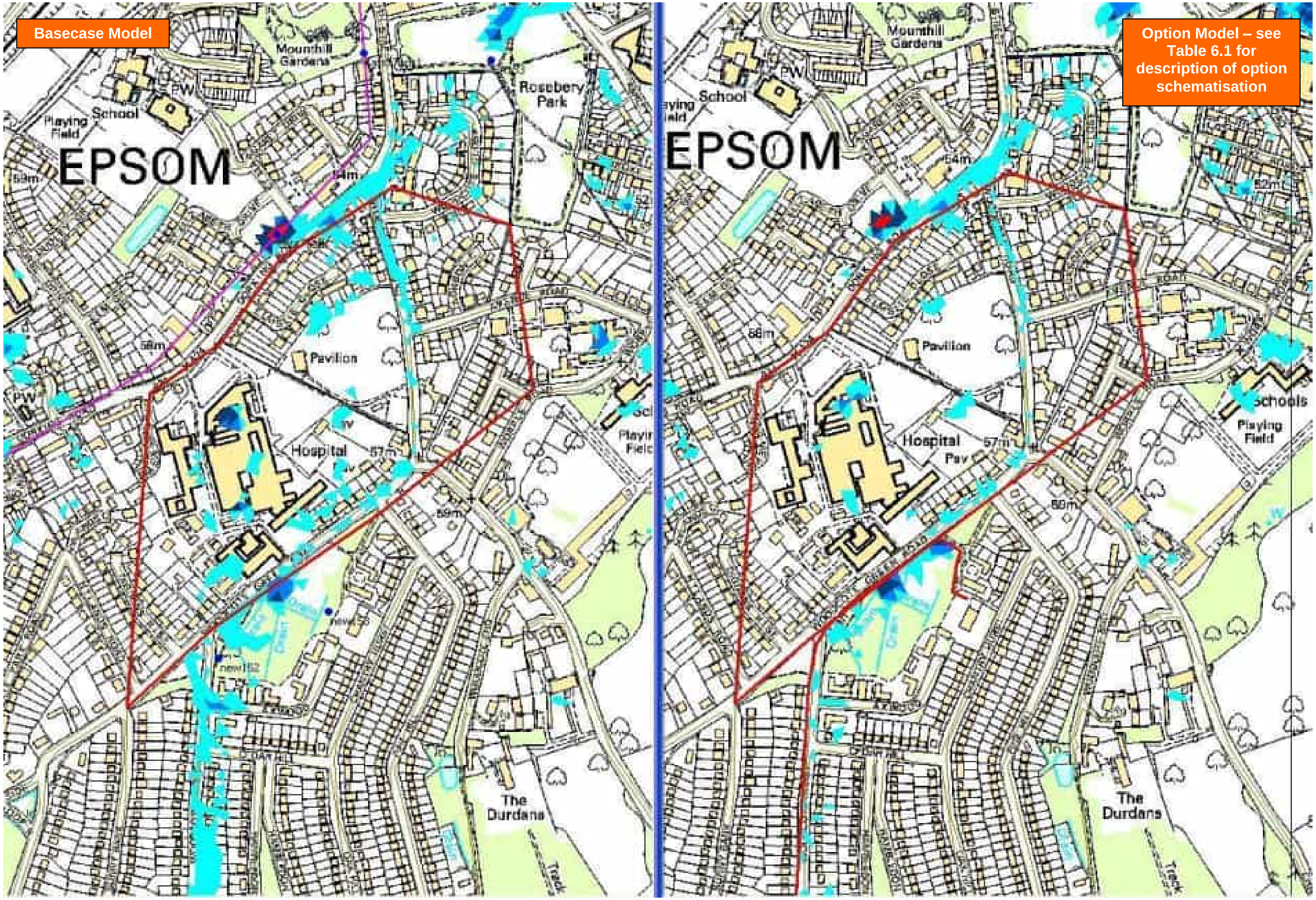


Figure K.1b Area of volume comparison for the (left) basecase and (right) option 1 scenarios

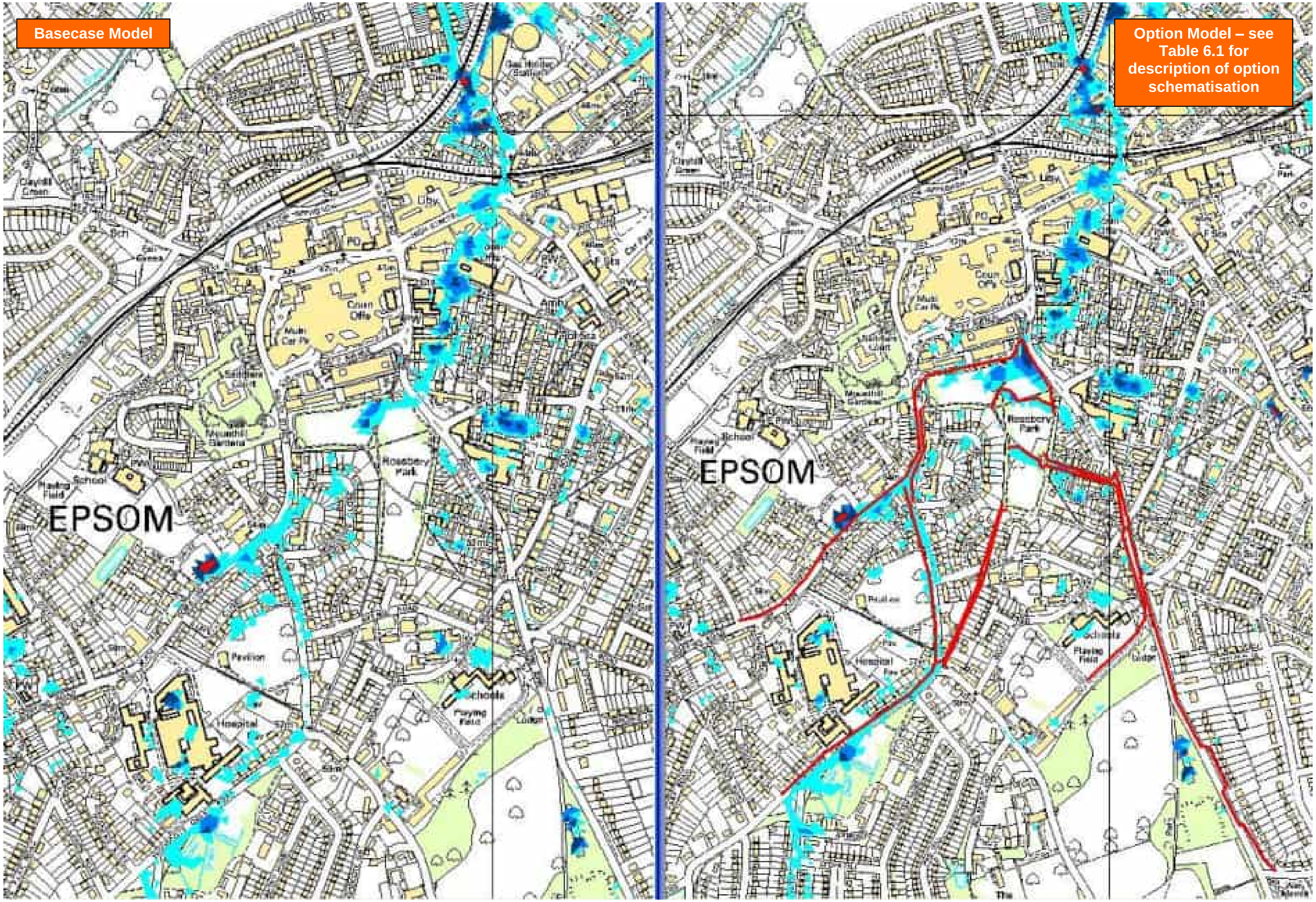


Figure K.2a Comparison of maximum flood depths in the (left) basecase and (right) option 2 scenarios

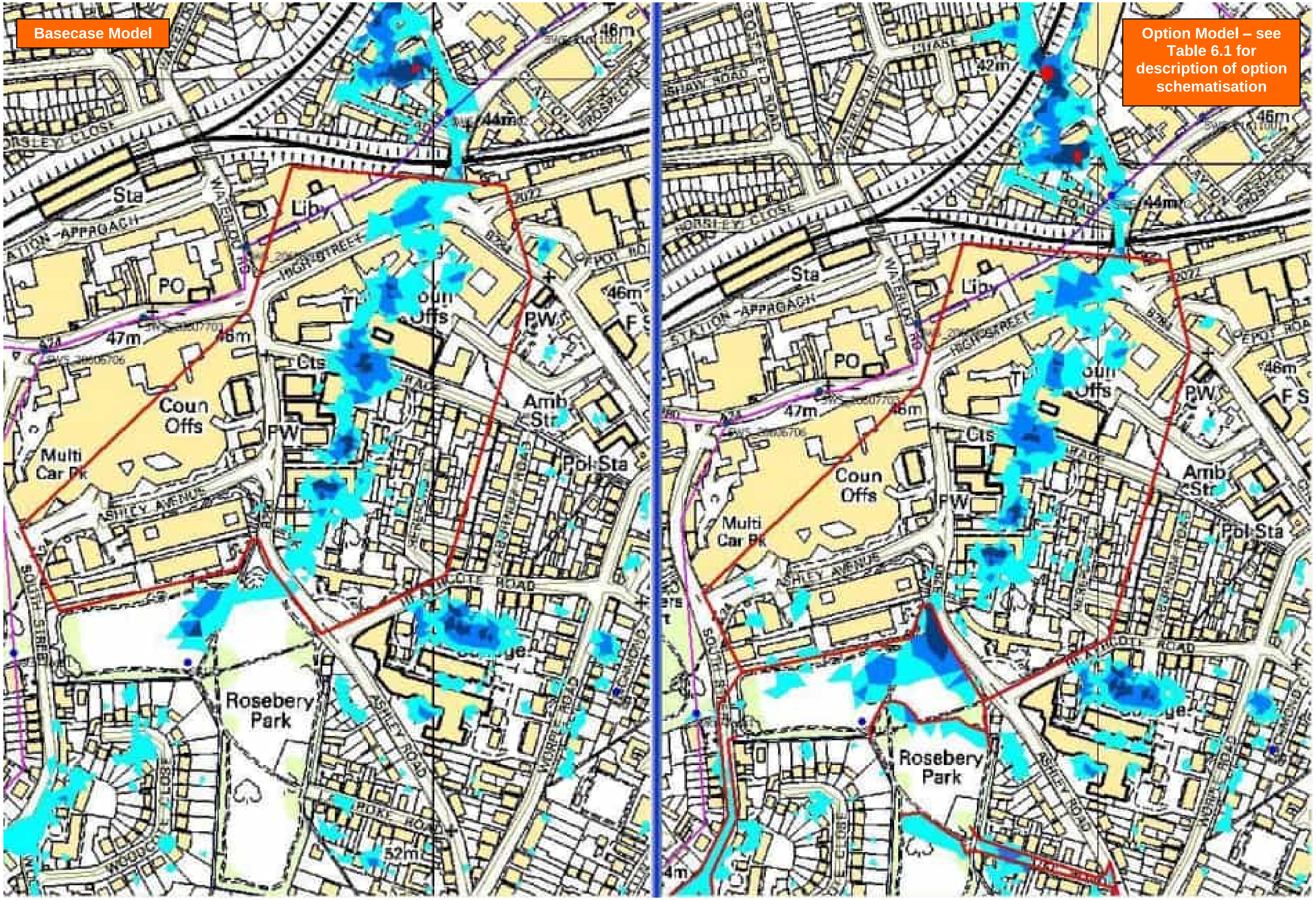


Figure K.2b Area of volume comparison for the (left) basecase and (right) option 2 scenarios

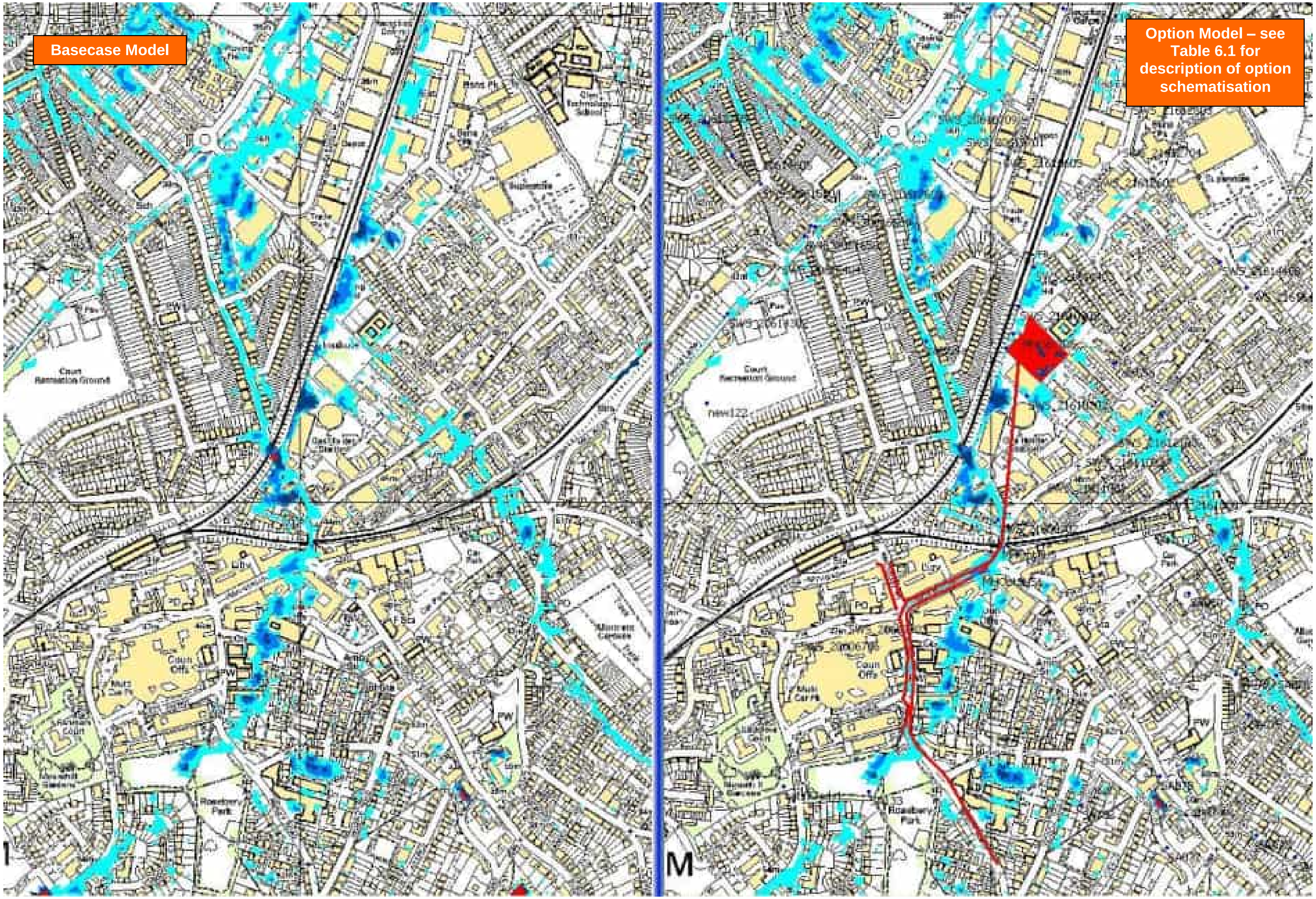


Figure K.3a Comparison of maximum flood depths in the (left) basecase and (right) option 3 scenarios

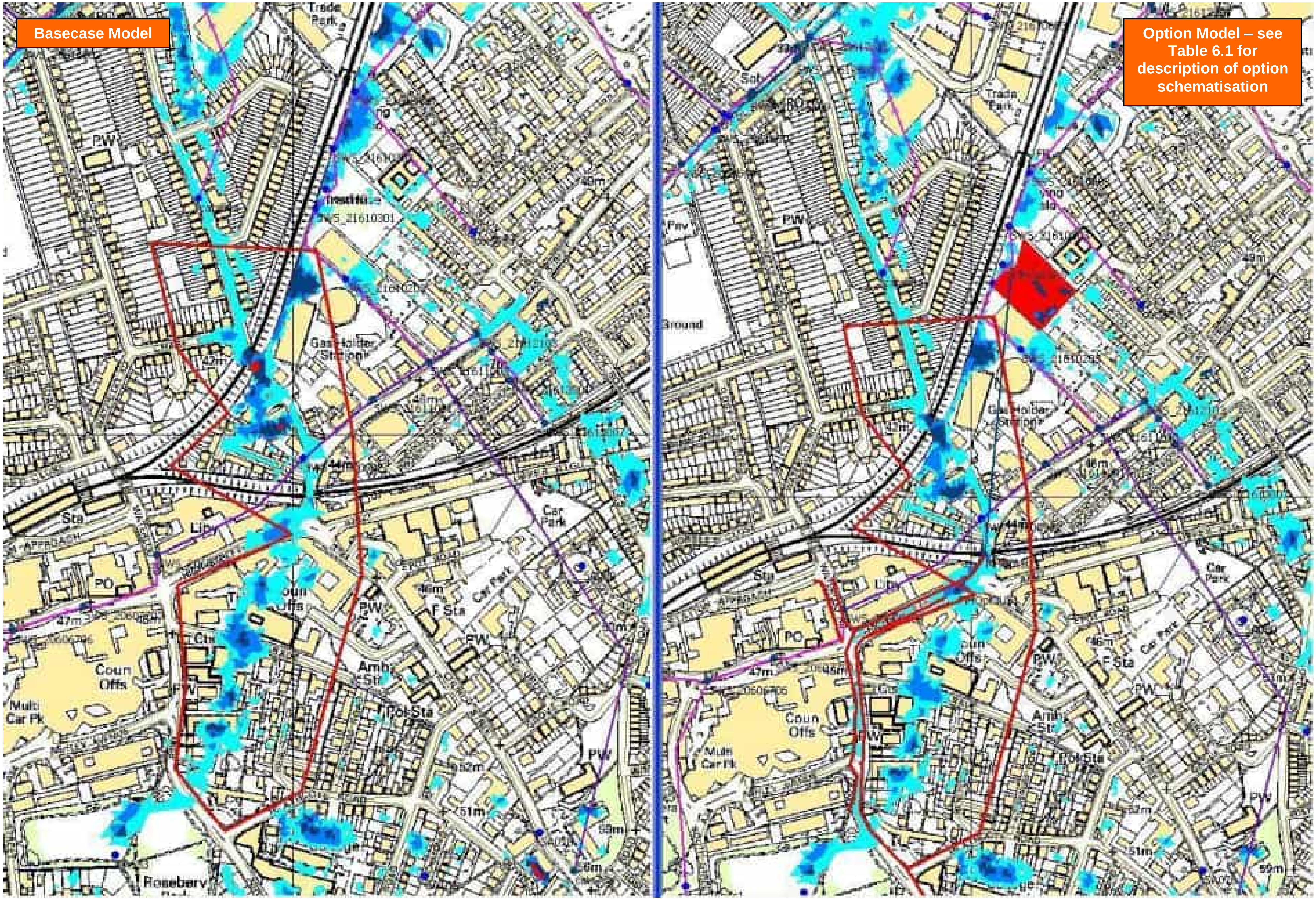


Figure K.3b Area of volume comparison for the (left) basecase and (right) option 3 scenarios

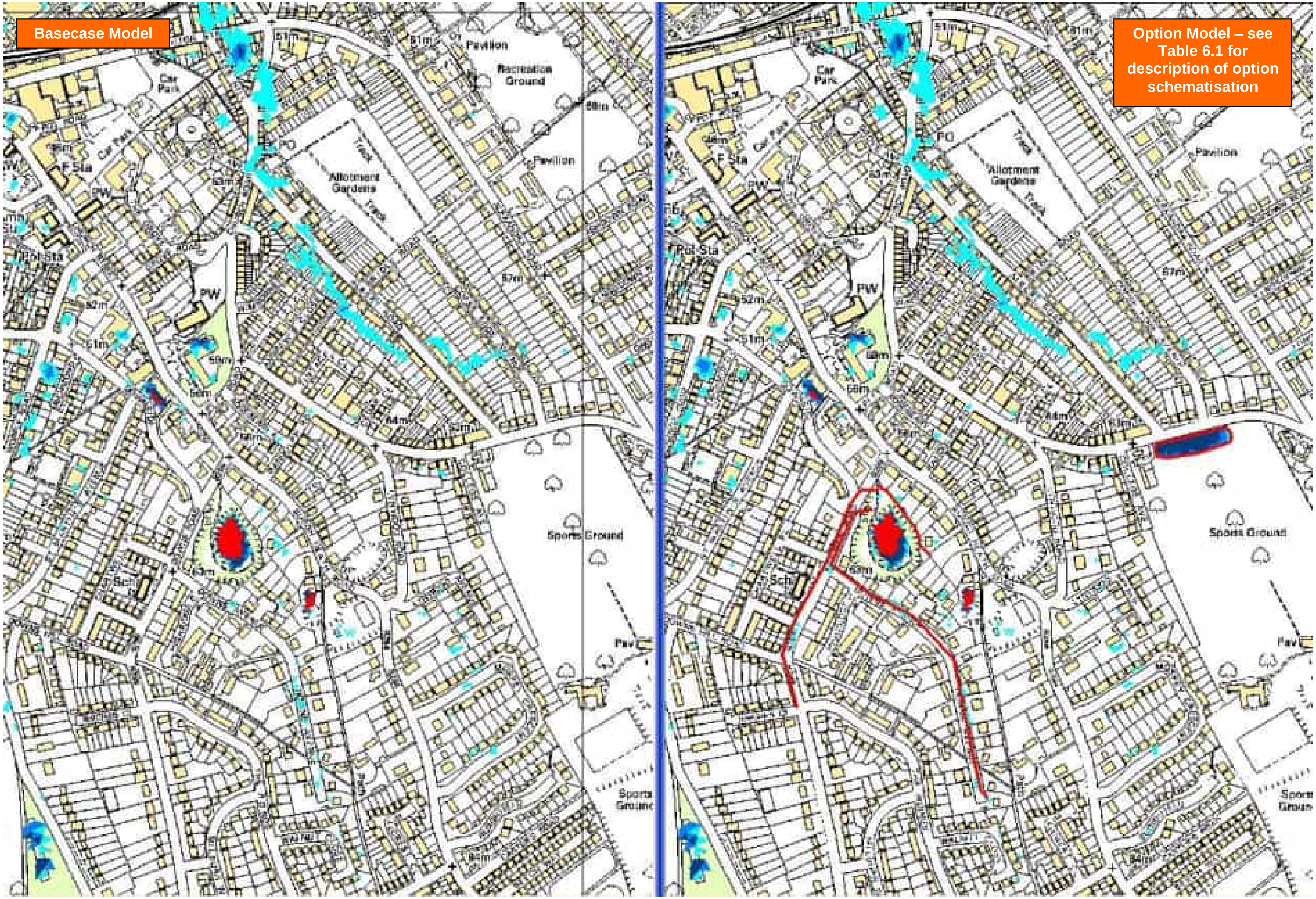


Figure K.4a Comparison of maximum flood depths in the (left) basecase and (right) option 4 scenarios

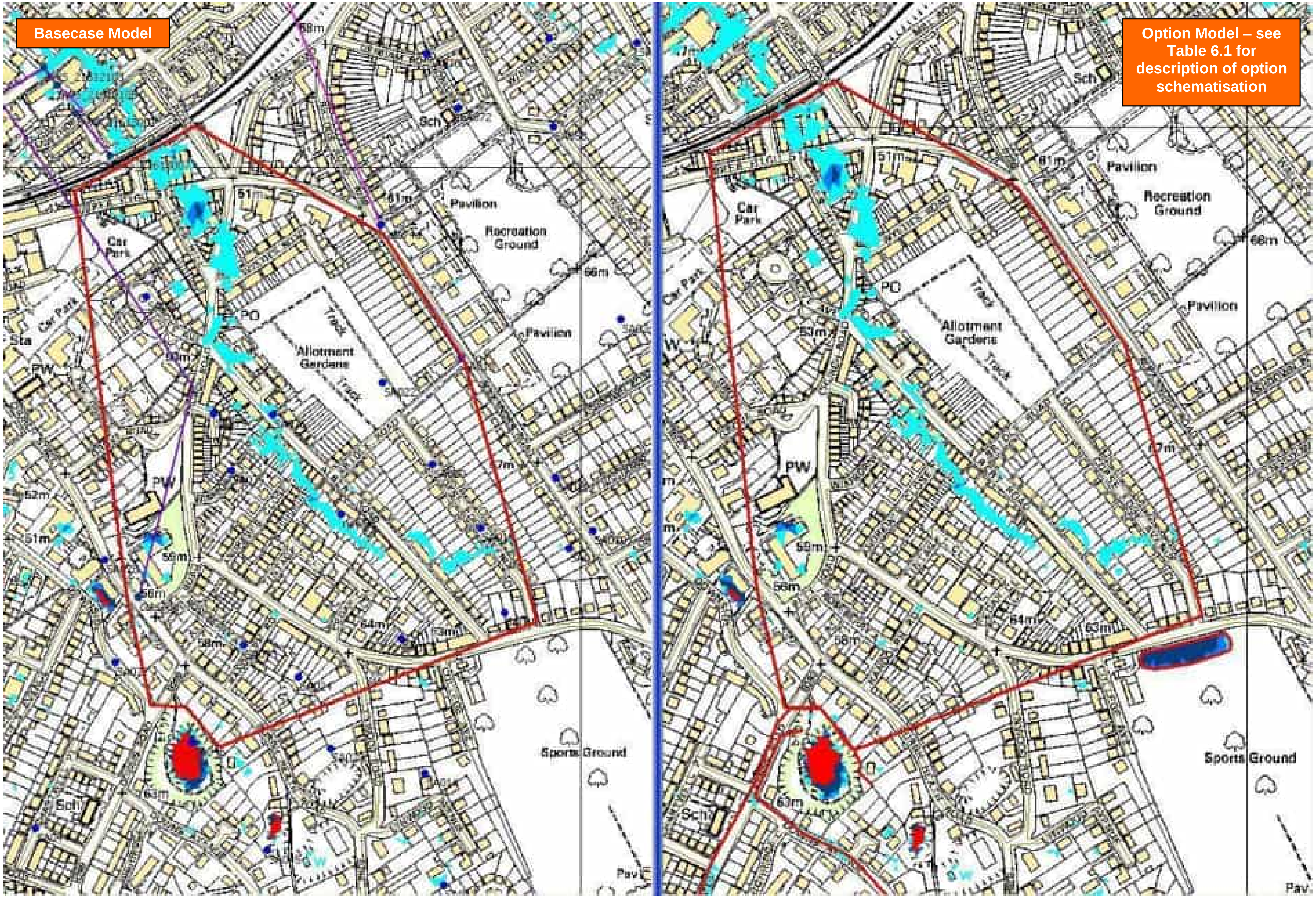


Figure K.4b Area of volume comparison for the (left) basecase and (right) option 4 scenarios

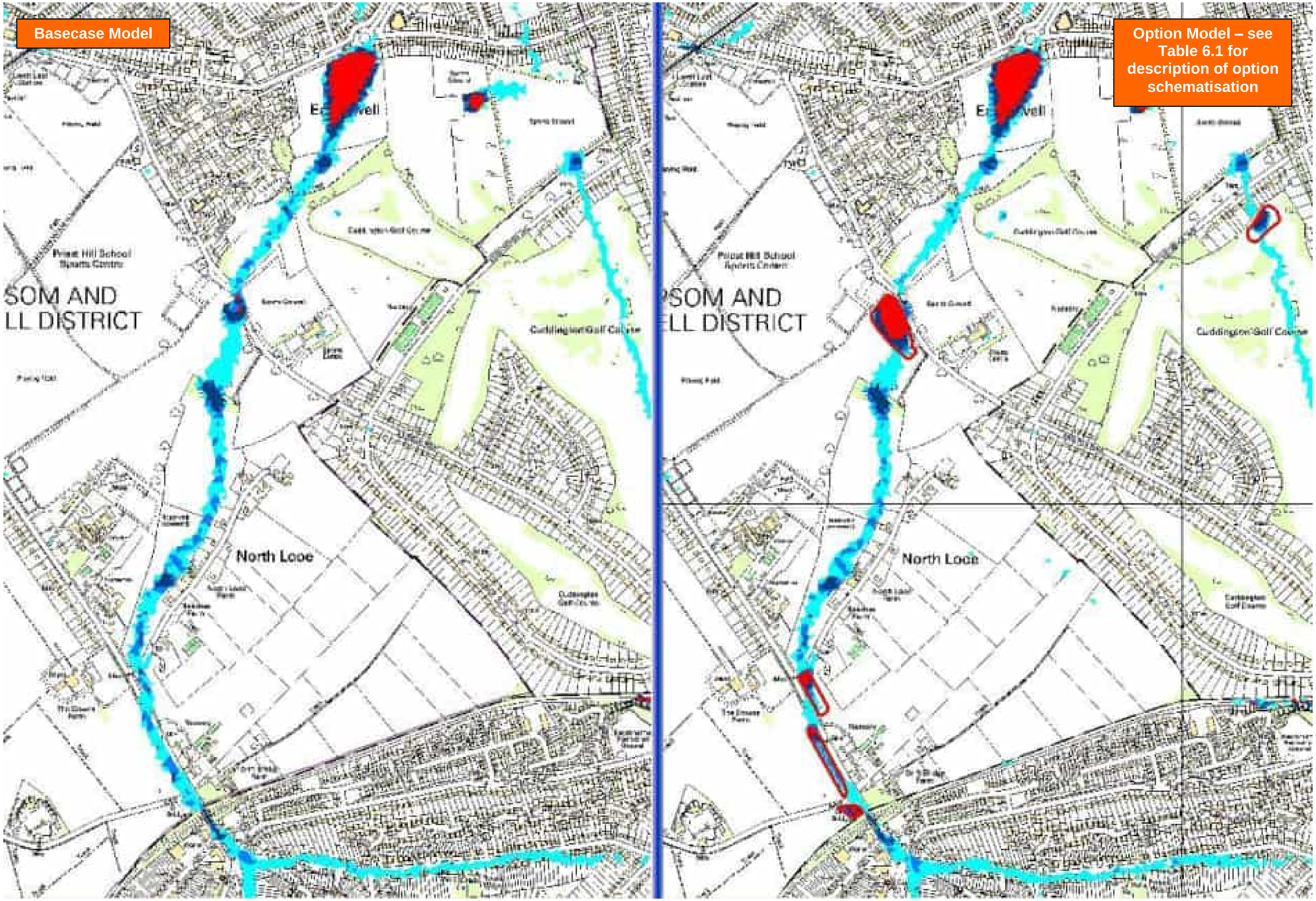


Figure K.5a Comparison of maximum flood depths in the (left) basecase and (right) option 5 scenarios

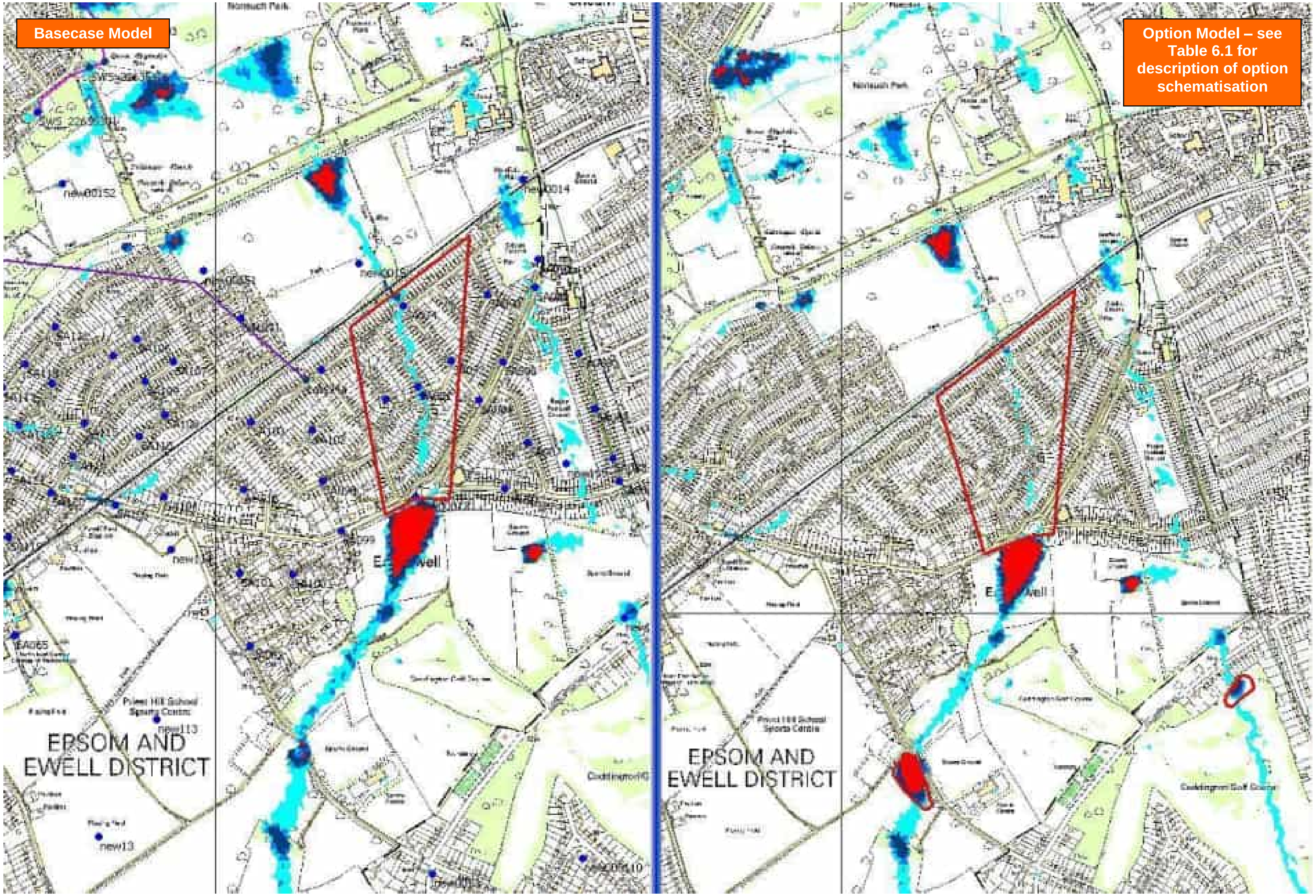


Figure K.5b Area of volume comparison for the (left) basecase and (right) option 5 scenarios

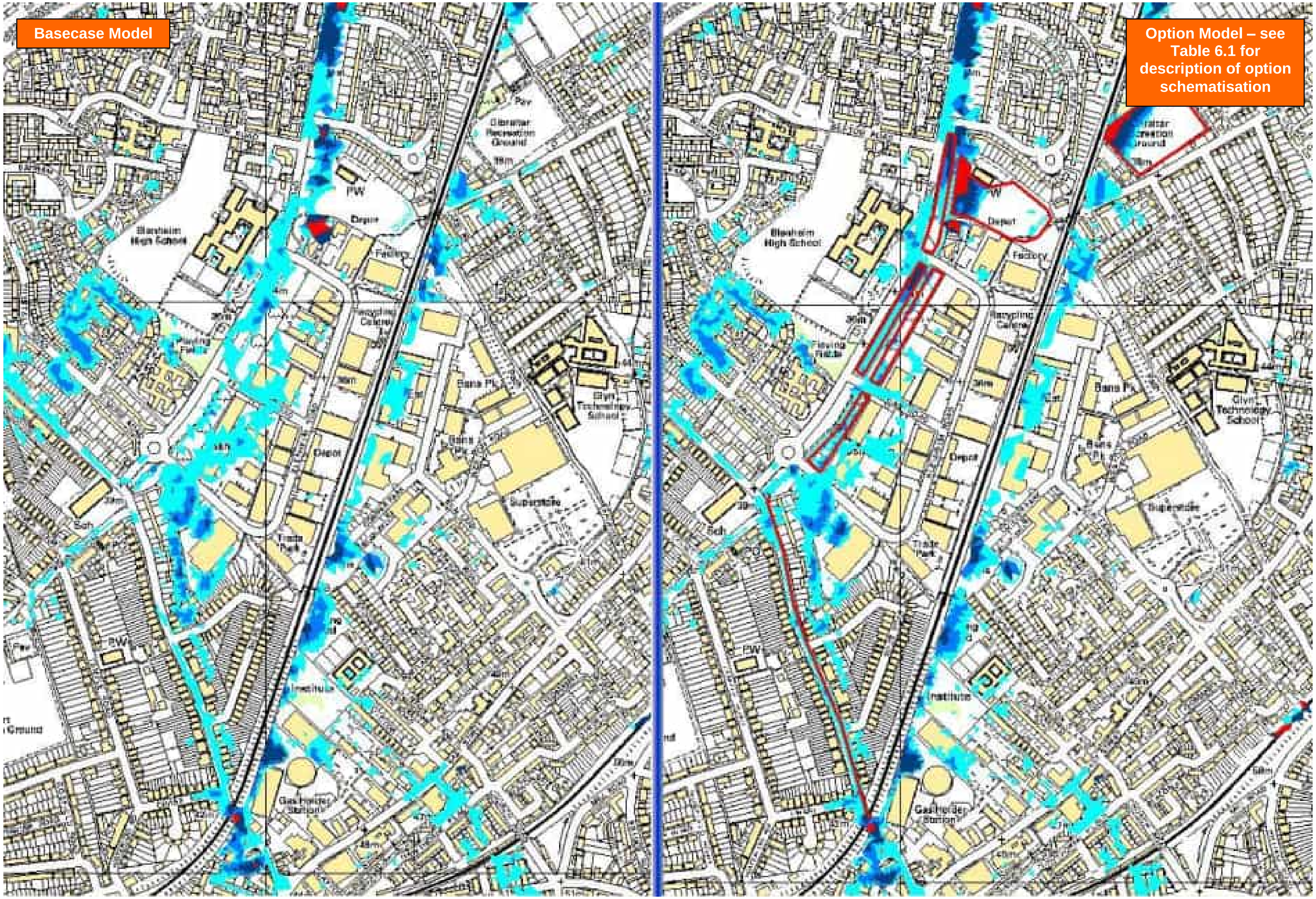


Figure K.6a Comparison of maximum flood depths in the (left) basecase and (right) option 6 scenarios

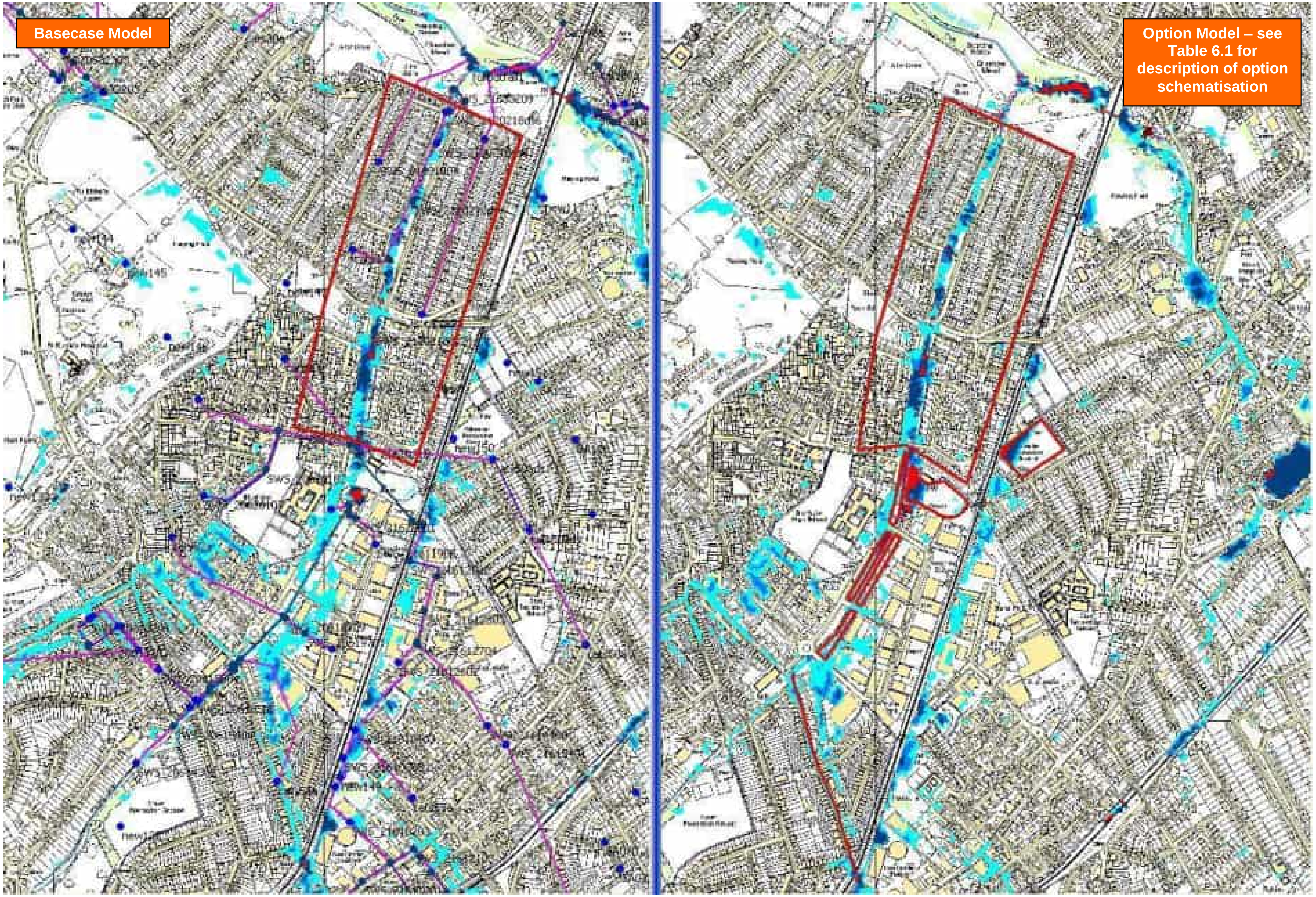


Figure K.6b Area of volume comparison for the (left) basecase and (right) option 6 scenarios

Figure K.7a Comparison of maximum flood depths in the (top) basecase and (bottom) option 7 scenarios

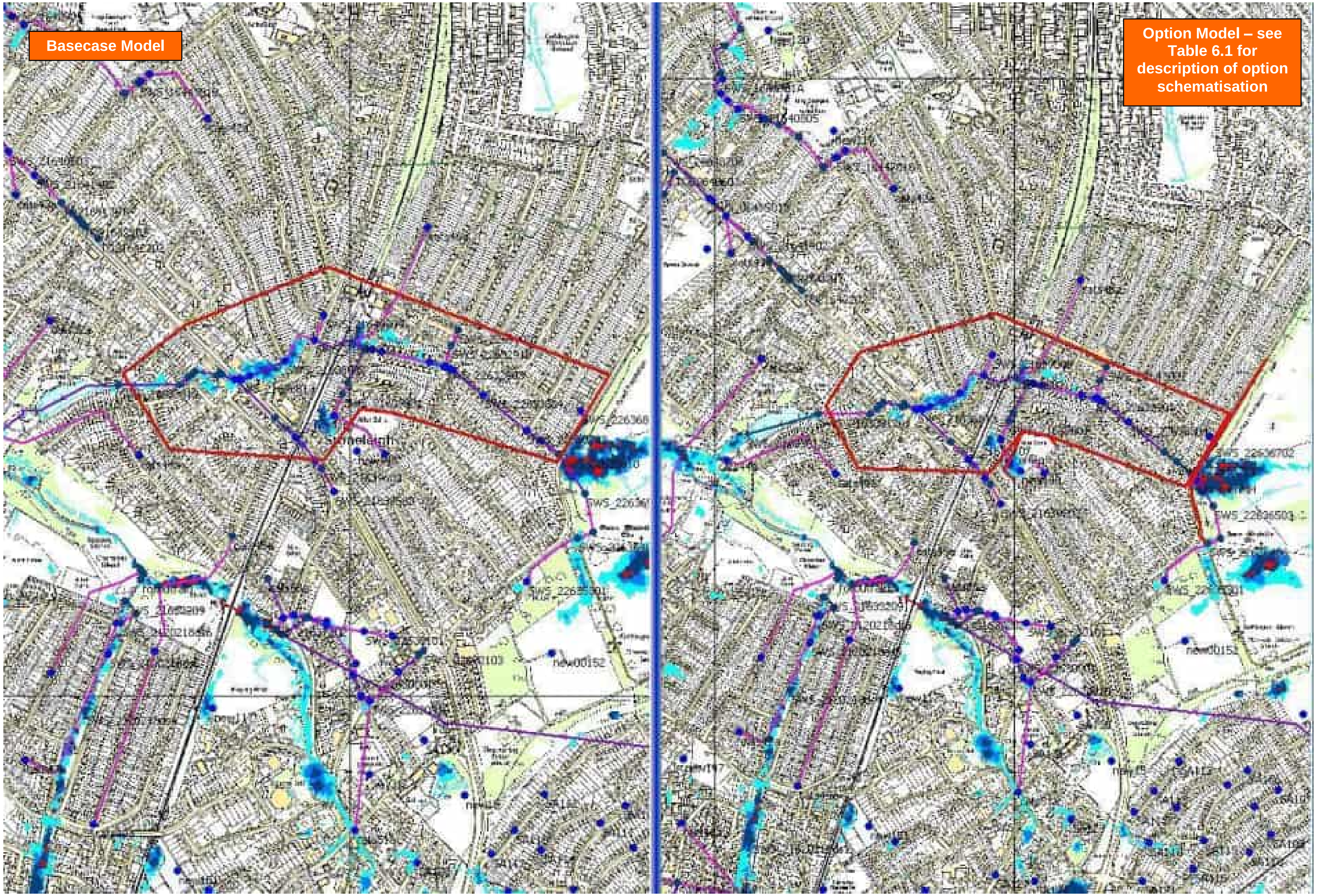


Figure K.7b Area of volume comparison for the (left) basecase and (right) option 7 scenarios

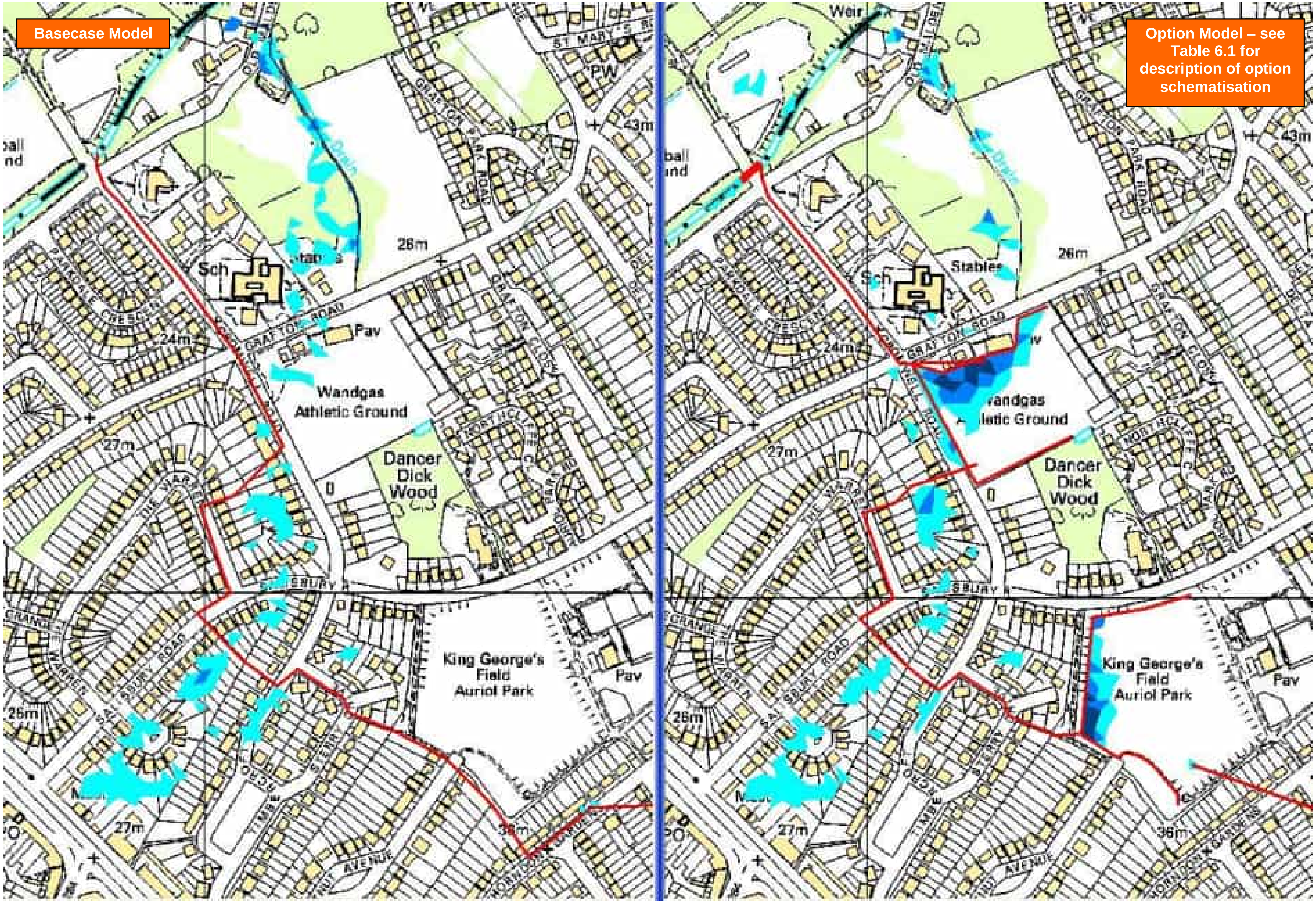


Figure K.8a Comparison of maximum flood depths in the (left) basecase and (right) option 8 scenarios

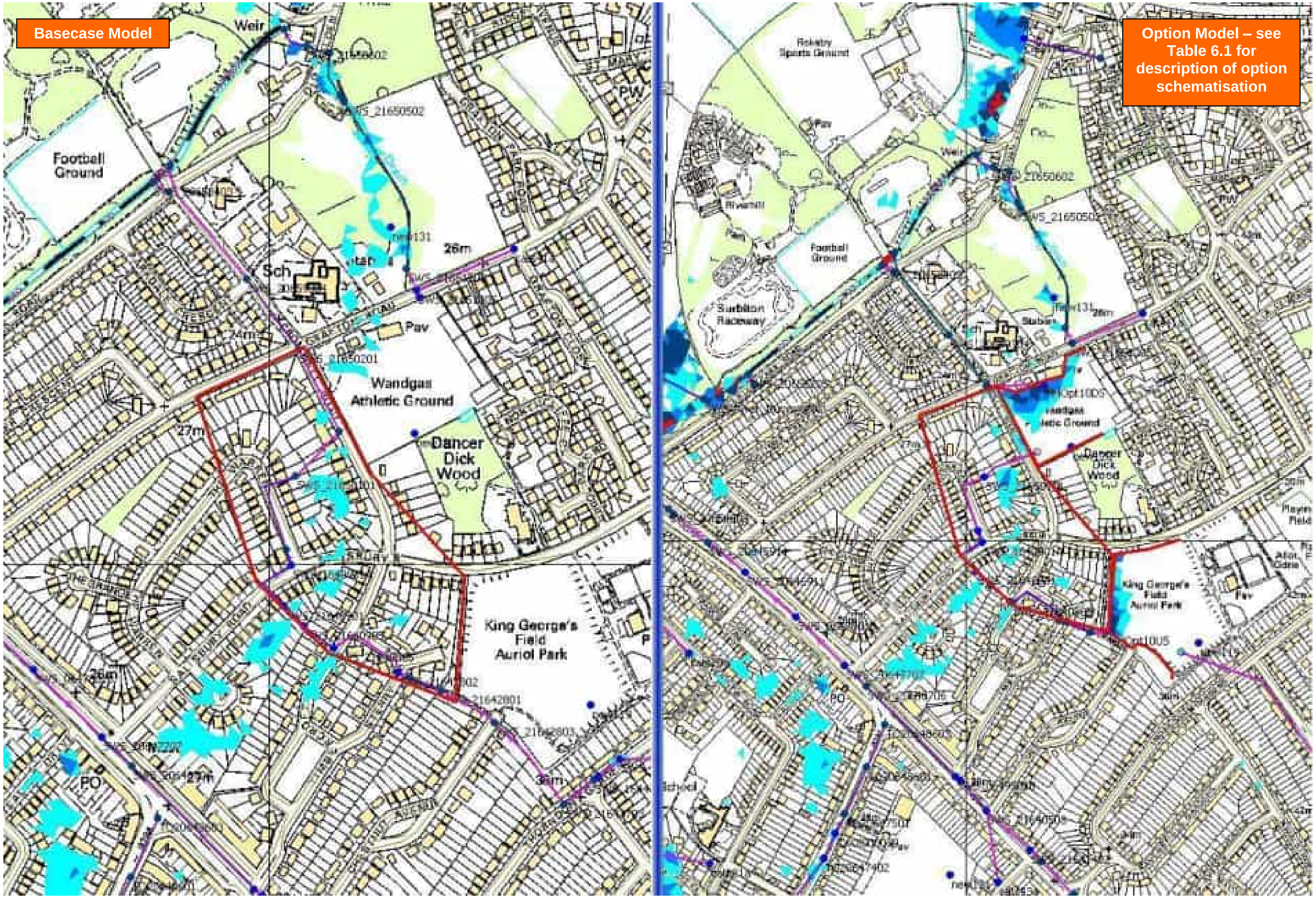


Figure K.8b Area of volume comparison for the (left) basecase and (right) option 8 scenarios

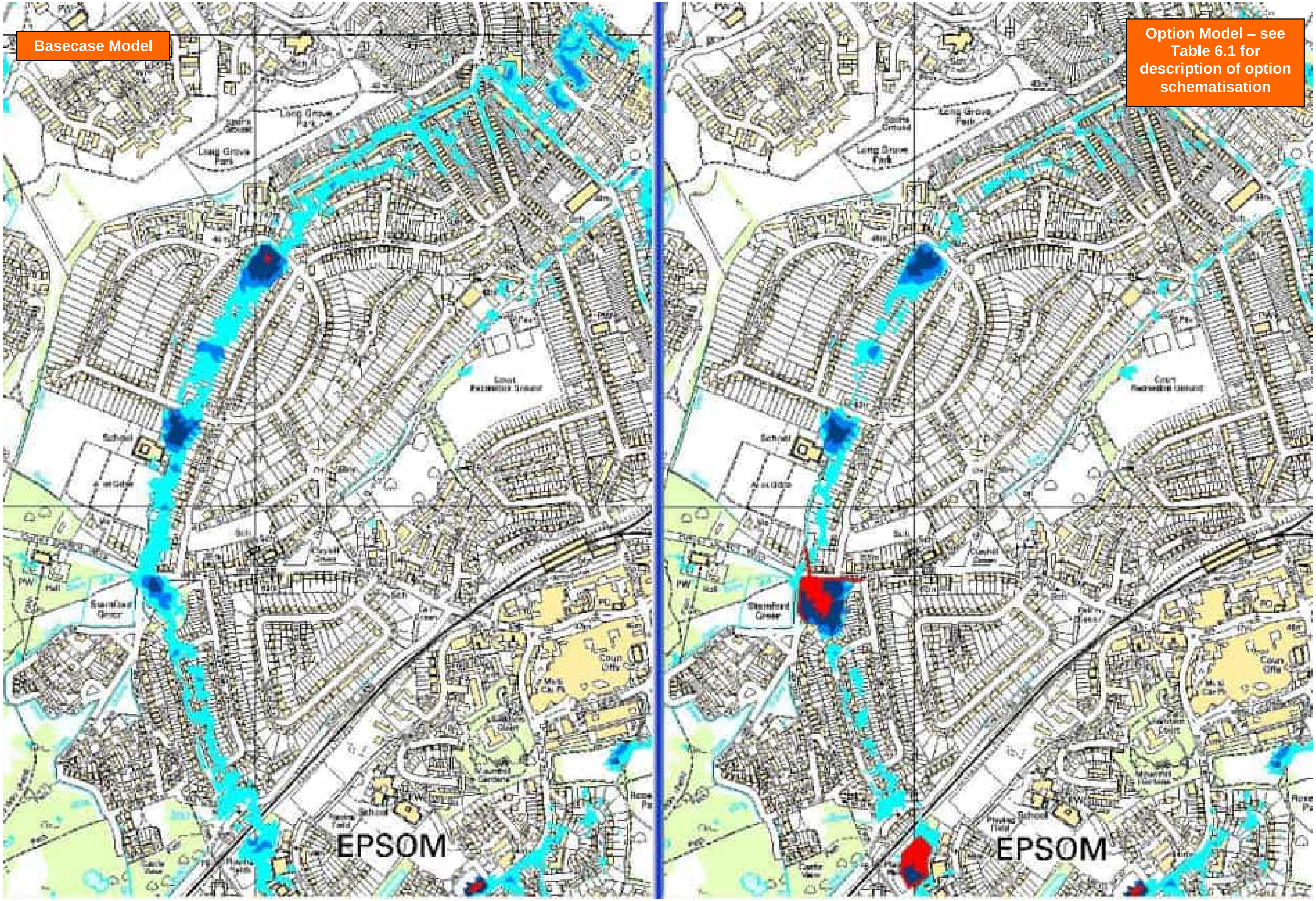


Figure K.9a Comparison of maximum flood depths in the (left) basecase and (right) option 9 scenarios

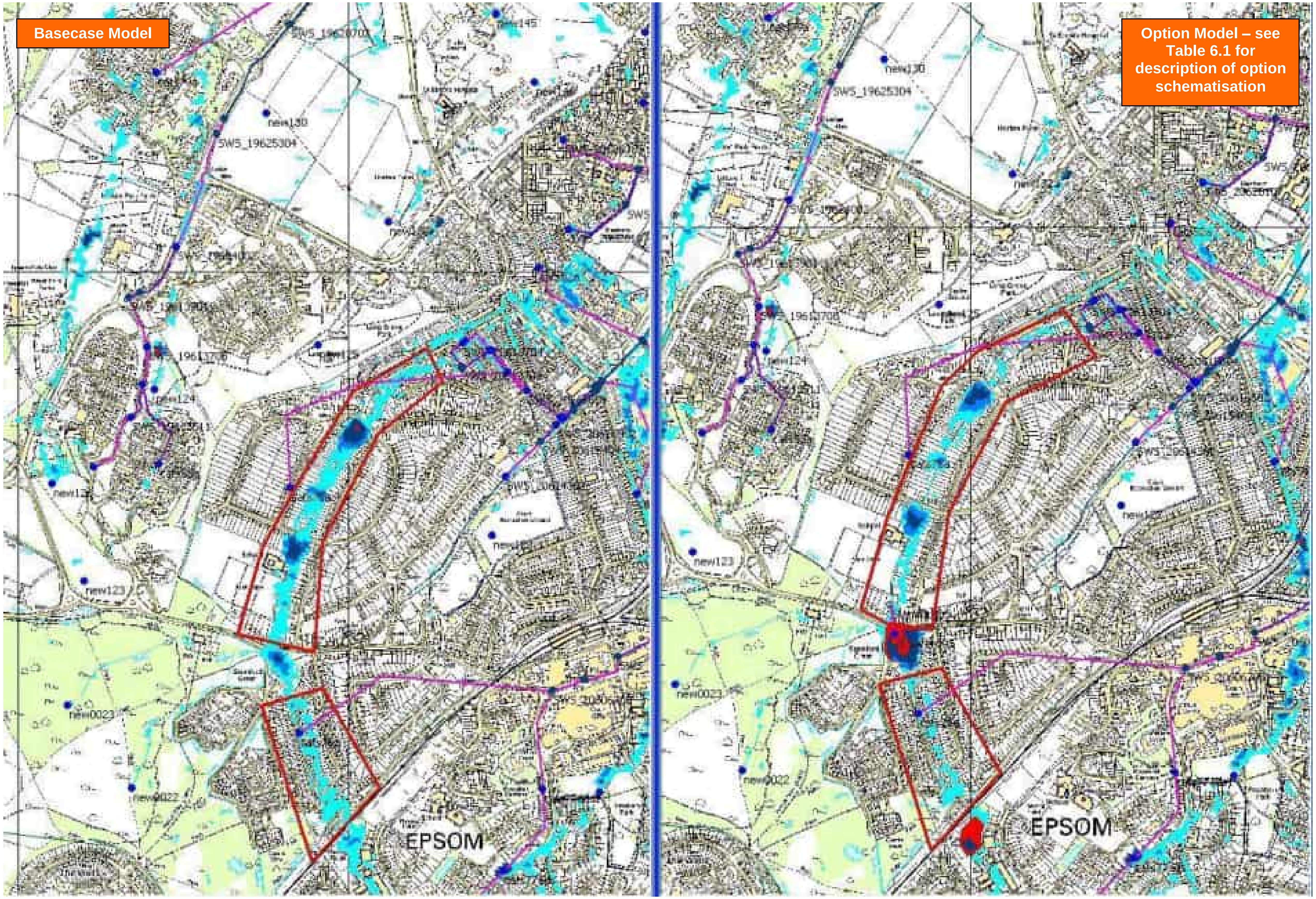


Figure K.9b Area of volume comparison for the (left) basecase and (right) option 9 scenarios

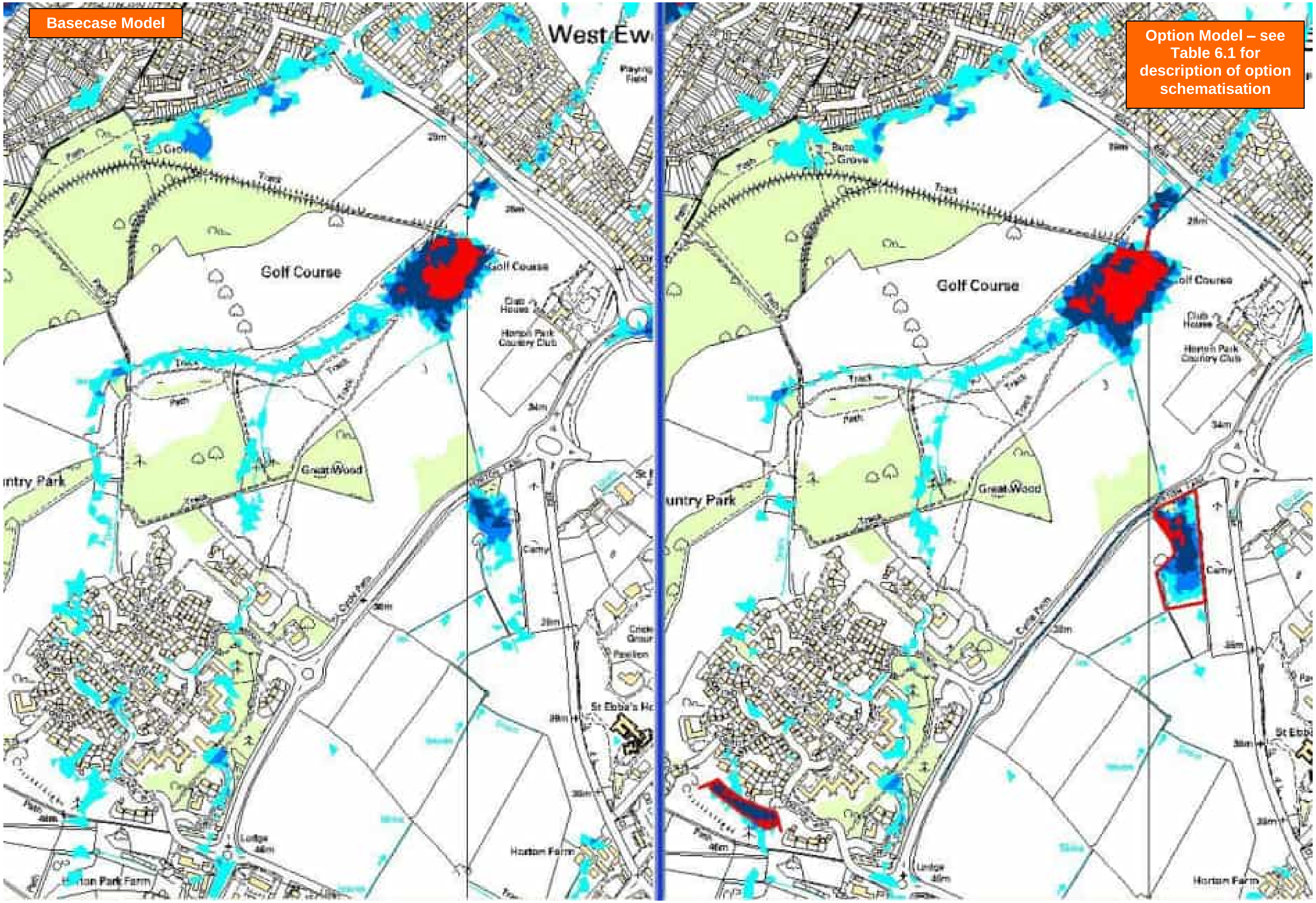


Figure K.10a Comparison of maximum flood depths in the (left) basecase and (right) option 10 scenarios

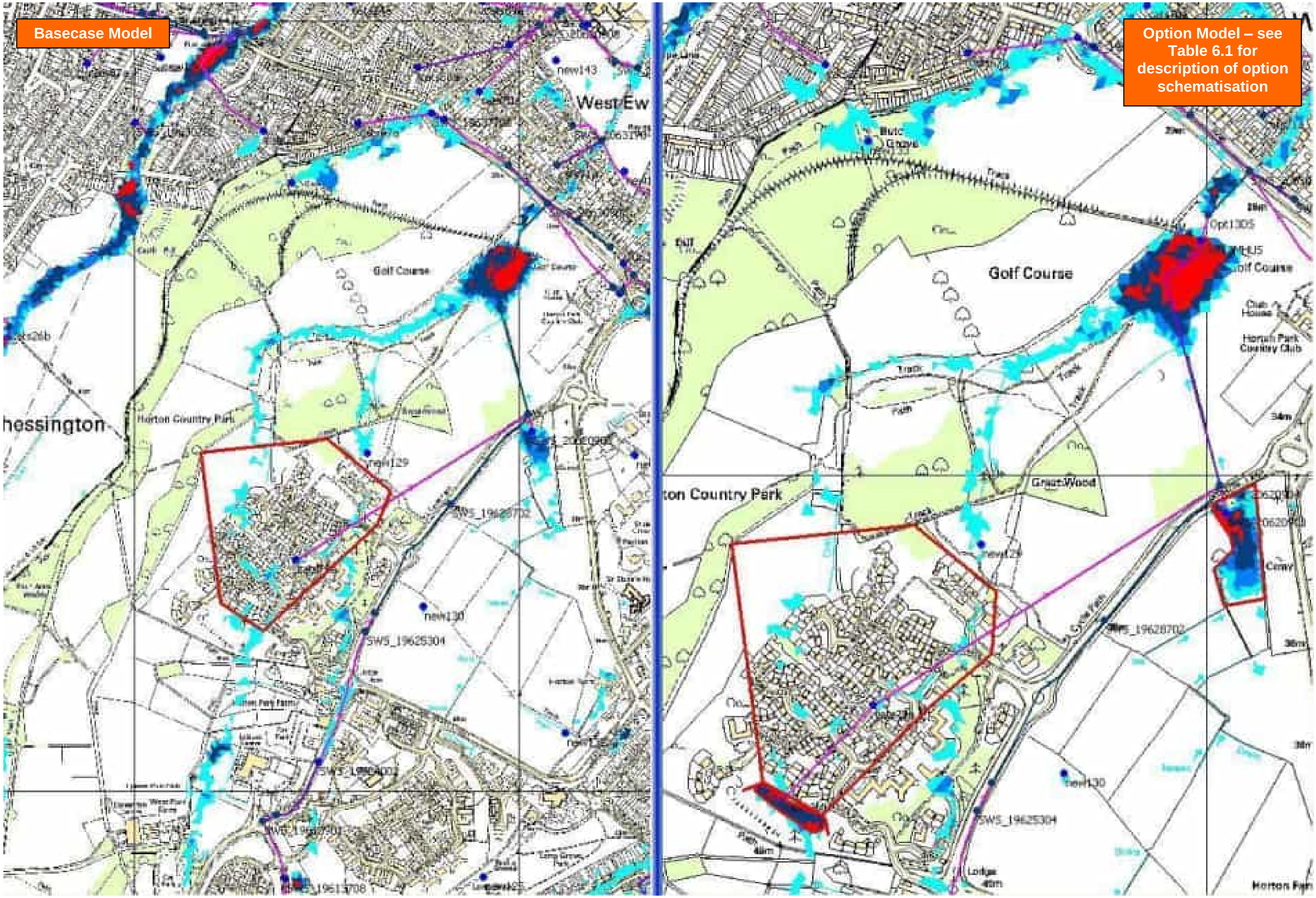
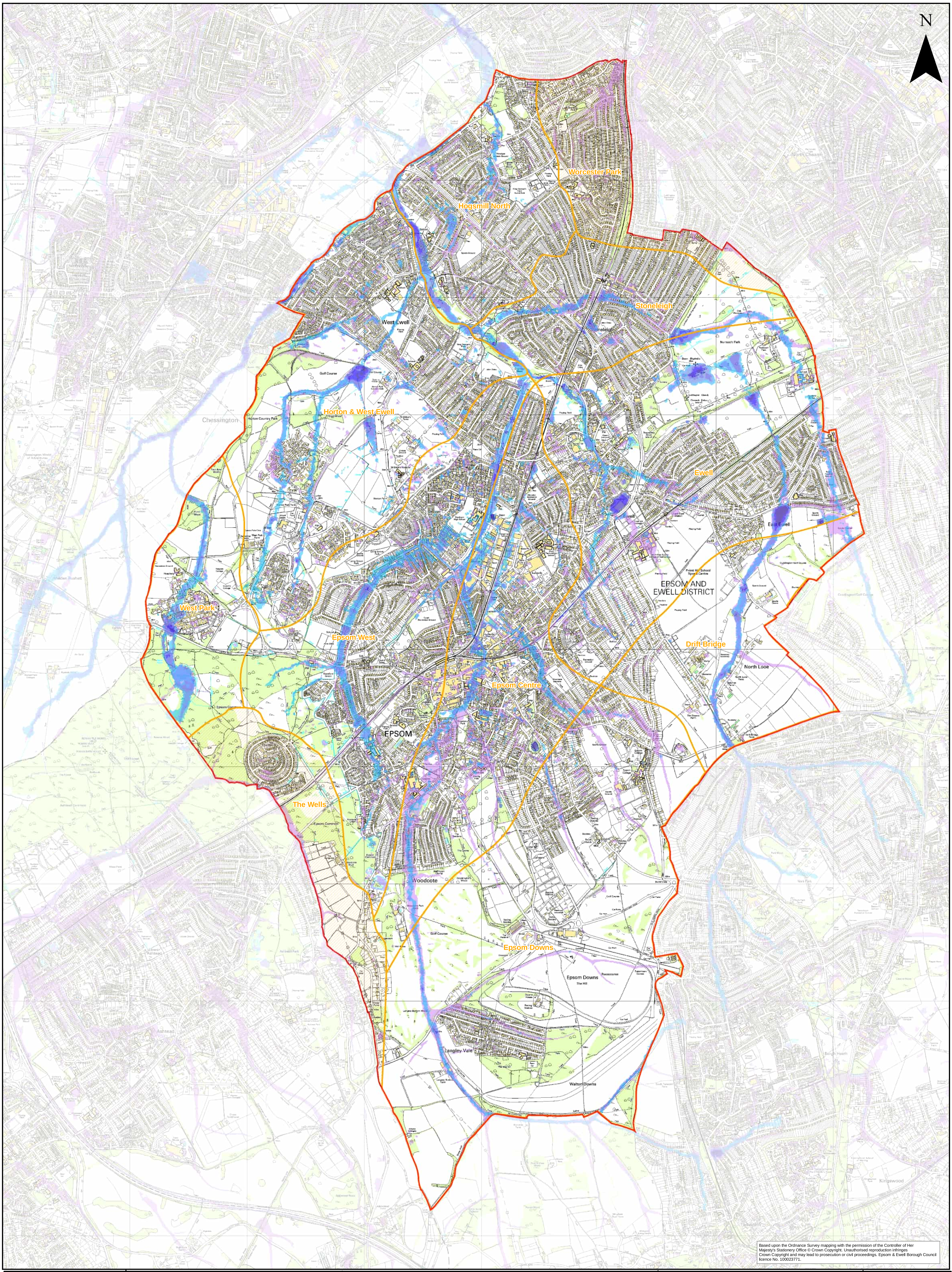
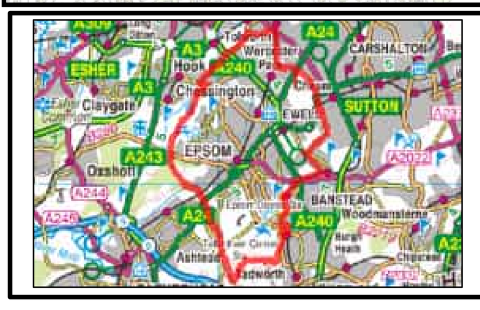


Figure K.10b Area of volume comparison for the (left) basecase and (right) option 10 scenarios





Legend

Drainage Areas
- Within model domain
- Outside model domain (The Wells)
- Outside model domain (Worcester Park)

Flood Map for Surface Water (1:200yr)
- > 0.1m

Maximum Depth (m) 0.5% (1:200 year)
- <0.1m
- 0.1 - 0.25m
- 0.25 - 0.5m
- 0.5 - 1.0m
- 1.0 - 1.5m
- >1.5m

Drawing Title
Comparison of 0.5% (1:200 year) Annual Probability Event

Drawing Number
Figure E.1

0 0.375 0.75 1.5 Kilometers

Epsom & Ewell SWMP

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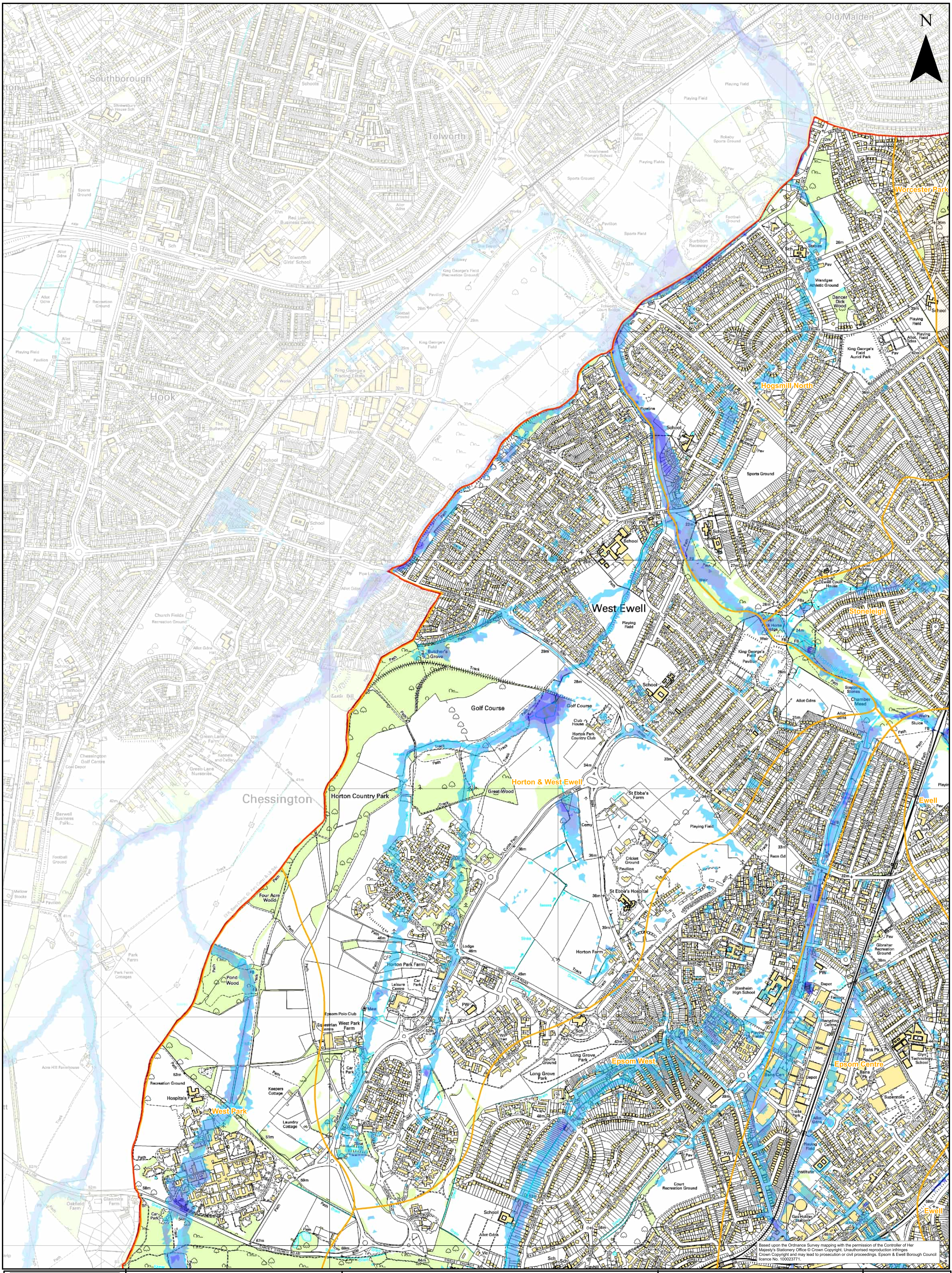

Legend

Drainage Areas
- Within model domain
- Outside model domain (The Wells)
- Outside model domain (Worcester Park)

Maximum Depth (m) 0.5% (1:200 year)
- <0.1m
- 0.1 - 0.25m
- 0.25 - 0.5m
- 0.5 - 1.0m
- 1.0 - 1.5m
- >1.5m

Drawing Title
Maximum Depth 0.5% (1:200 year) Annual Probability Event

Drawing Number
Figure E.2

0 0.25 0.5 1 Kilometers

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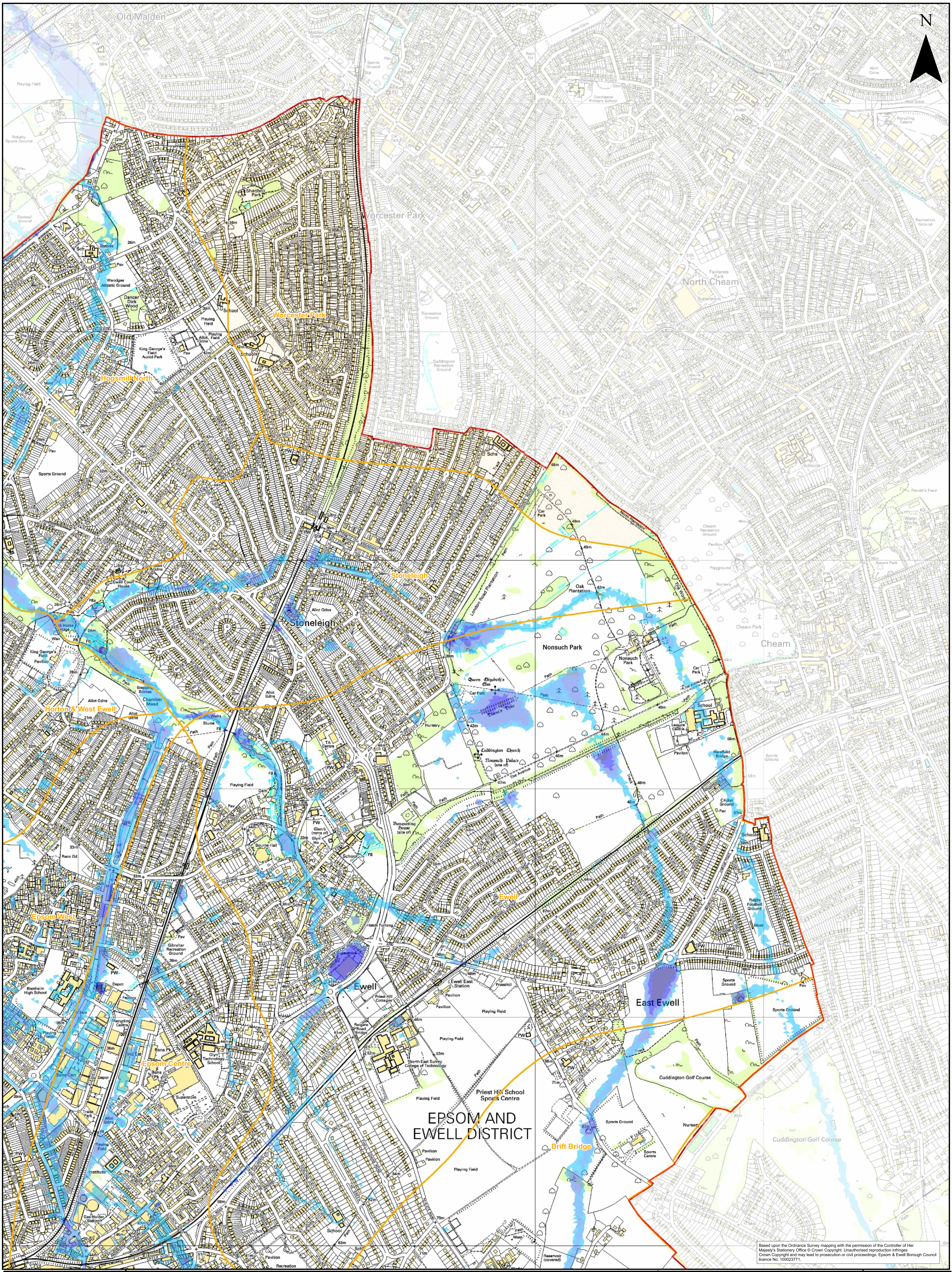

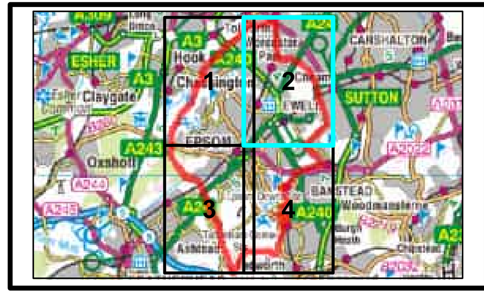

Legend

Drainage Areas
- Within model domain
- Outside model domain (The Wells)
- Outside model domain (Worcester Park)

Maximum Depth (m) 0.5% (1:200 year)
- <0.1m
- 0.1 - 0.25m
- 0.25 - 0.5m
- 0.5 - 1.0m
- 1.0 - 1.5m
- >1.5m

Drawing Title
Maximum Depth 0.5% (1:200 year) Annual Probability Event

Drawing Number
Figure E.3

0 0.25 0.5 1 Kilometers

Epsom & Ewell SWMP

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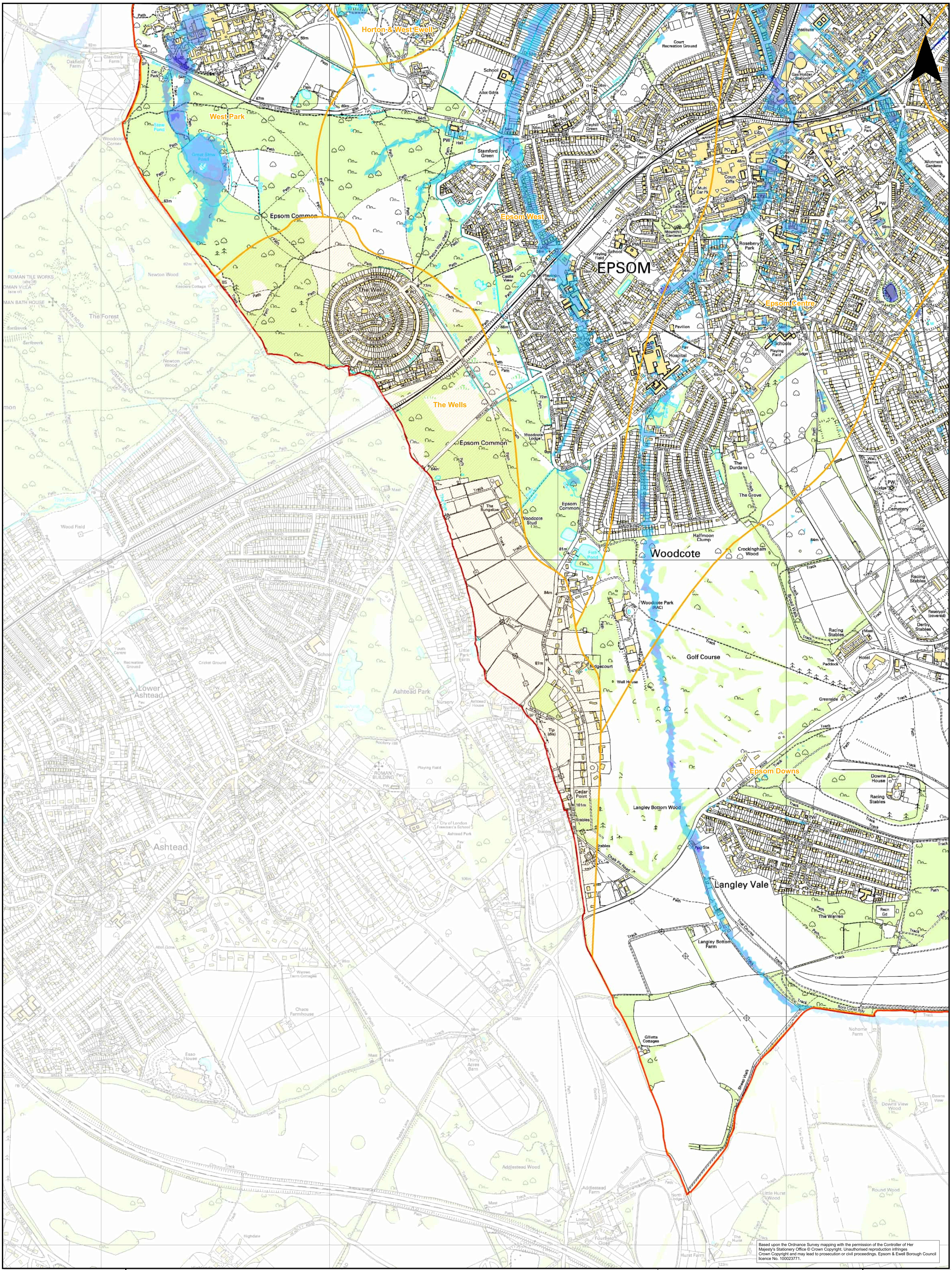

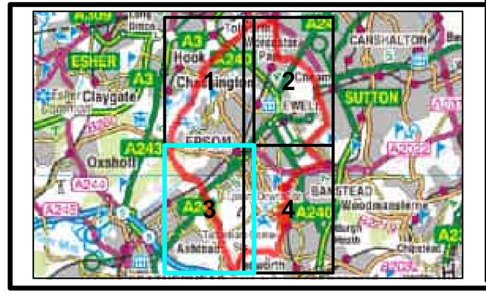

Legend

Drainage Areas

- Within model domain
- Outside model domain (The Wells)
- Outside model domain (Worcester Park)

Maximum Depth (m) 0.5% (1:200 year)

- <0.1m
- 0.1 - 0.25m
- 0.25 - 0.5m
- 0.5 - 1.0m
- 1.0 - 1.5m
- >1.5m

Drawing Title

Maximum Depth 0.5% (1:200 year) Annual Probability Event

Drawing Number

Figure E.4

0 0.25 0.5 1 Kilometers

Epsom & Ewell SWMP

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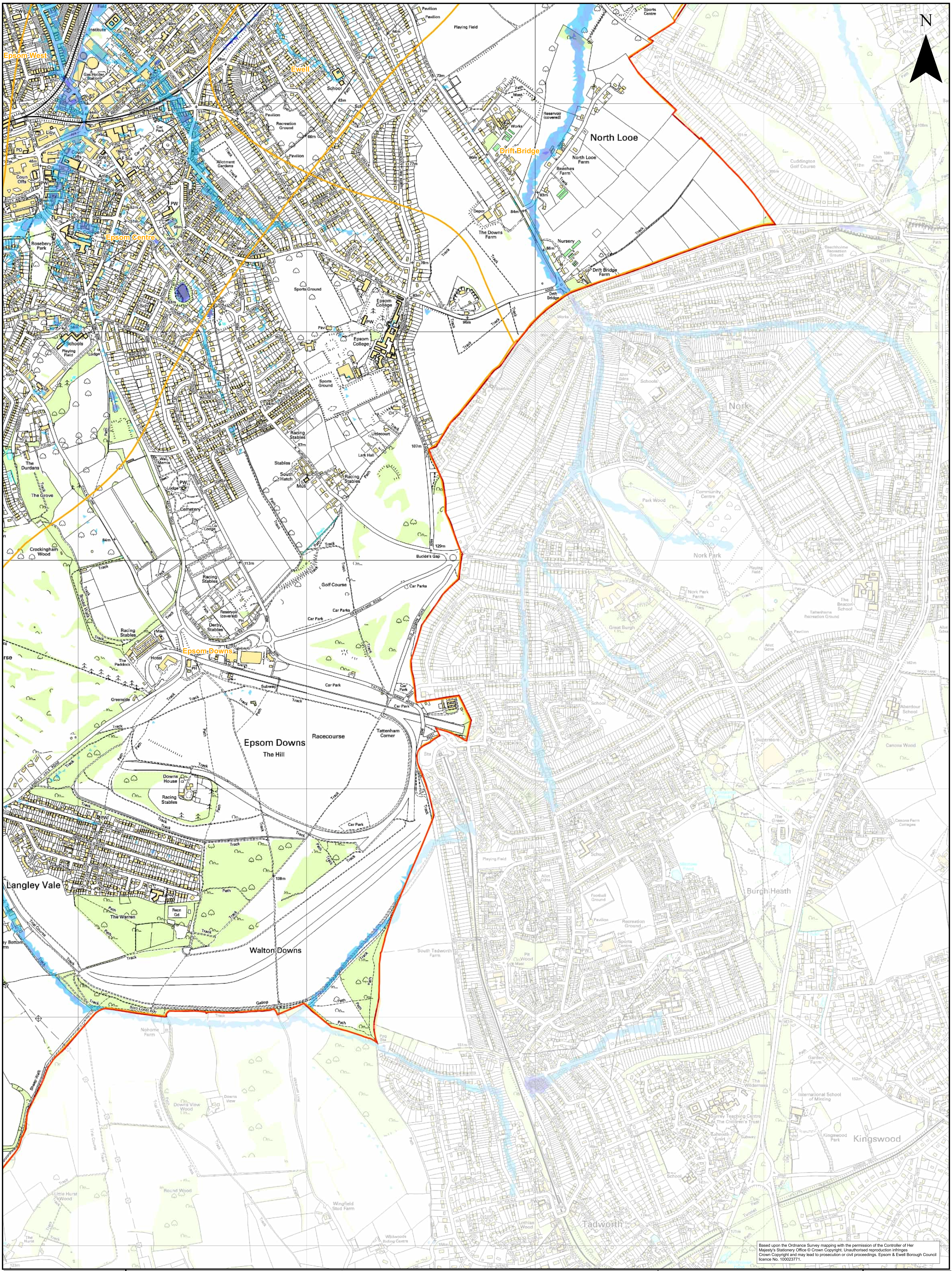

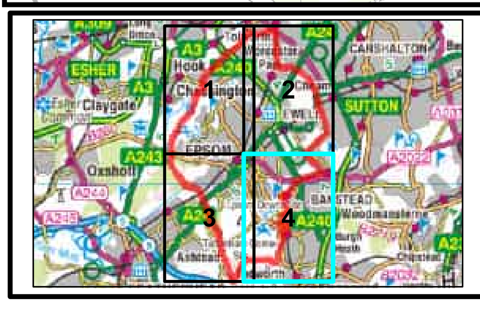

Legend

Drainage Areas
- Within model domain
- Outside model domain (The Wells)
- Outside model domain (Worcester Park)

Maximum Depth (m) 0.5% (1:200 year)
- <0.1m
- 0.1 - 0.25m
- 0.25 - 0.5m
- 0.5 - 1.0m
- 1.0 - 1.5m
- >1.5m

Drawing Title

Maximum Depth 0.5% (1:200 year) Annual Probability Event

Drawing Number

Figure E.5

0 0.25 0.5 1 Kilometers

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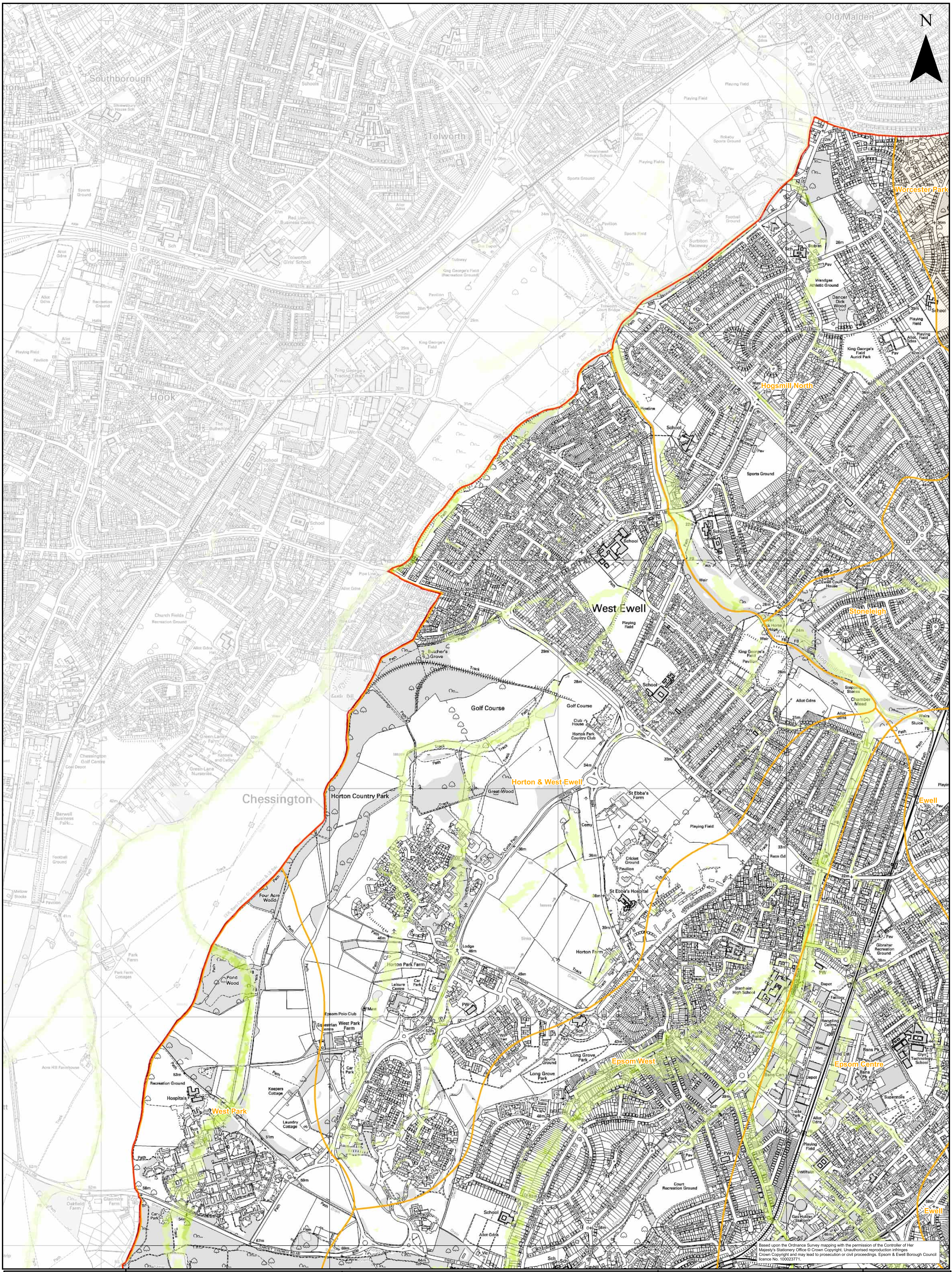

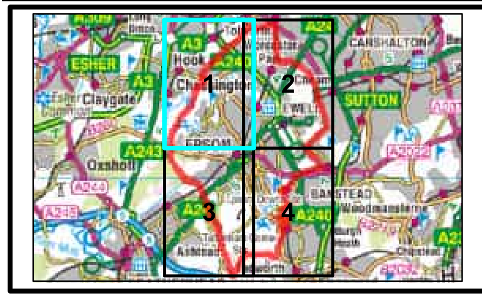

Legend

Drainage Areas

- Within model domain
- Outside model domain (The Wells)
- Outside model domain (Worcester Park)

Maximum Velocity (m/s) 0.5% (1:200 year)

- 0.500 - 1.500
- 1.501 - 2.500
- 2.501 - 3.500
- 3.501 - 4.500
- 4.501 - 10.000

Drawing Title

Maximum Velocity0.5% (1:200 year) Annual Probability Event

Drawing Number

Figure F.1

0 0.25 0.5 1 Kilometers

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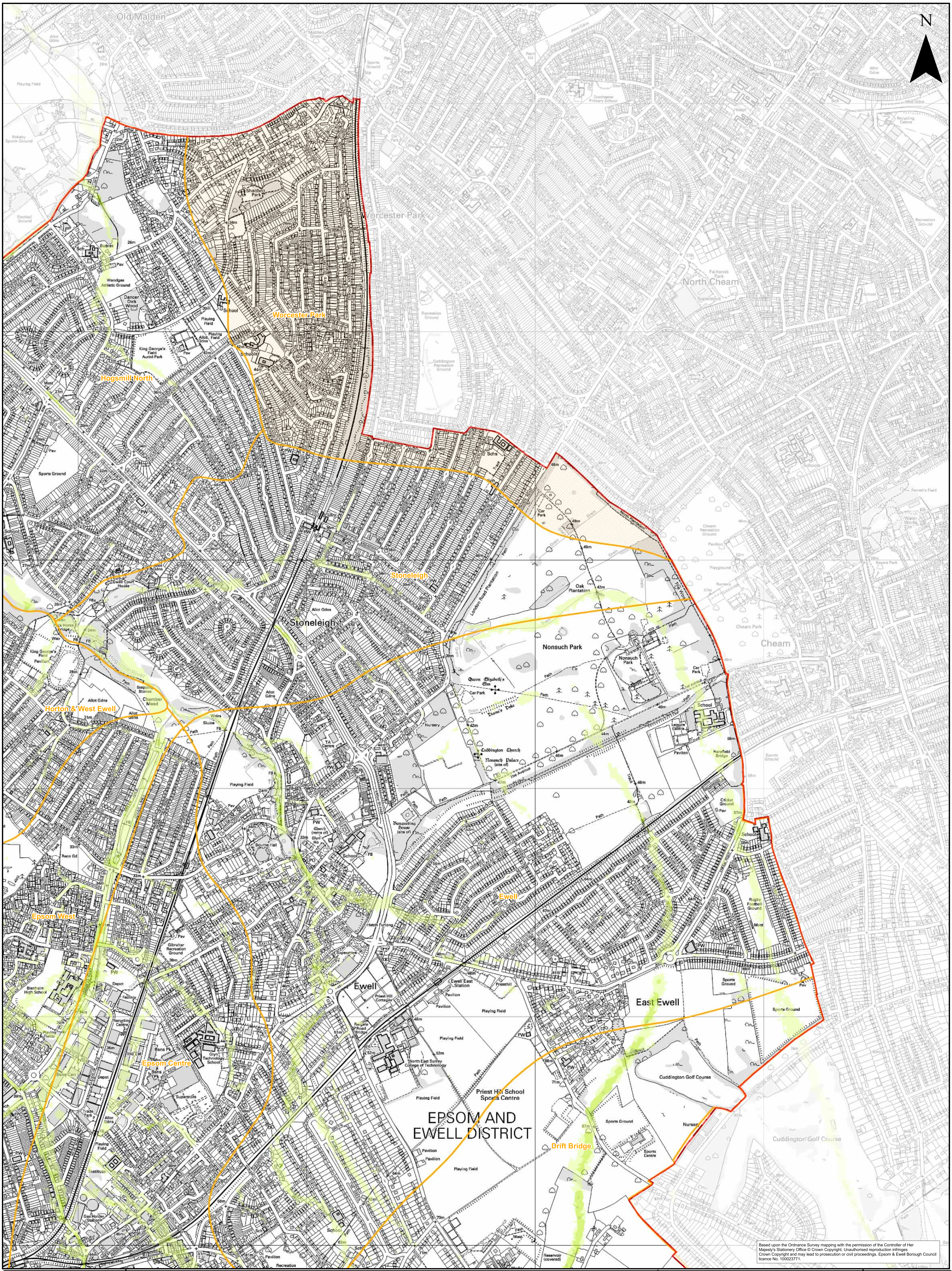

Legend

Drainage Areas	Maximum Velocity (m/s) 0.5% (1:200 year)
Within model domain	0.500 - 1.500
Outside model domain (The Wells)	1.501 - 2.500
Outside model domain (Worcester Park)	2.501 - 3.500
	3.501 - 4.500
	4.501 - 10.000

Drawing Title
Maximum Velocity0.5% (1:200 year) Annual Probability Event

Drawing Number
Figure F.2

0 0.25 0.5 1 Kilometers

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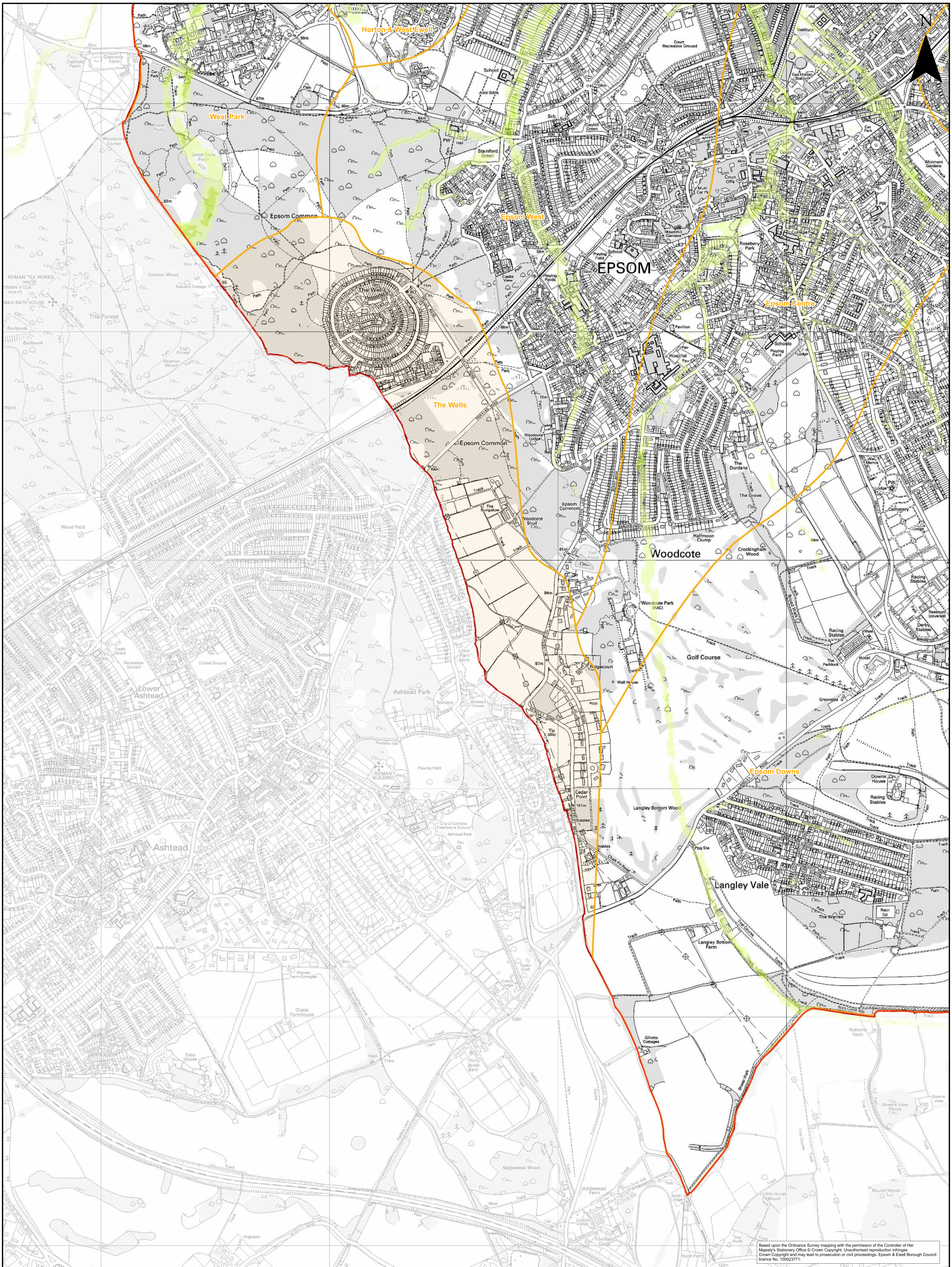

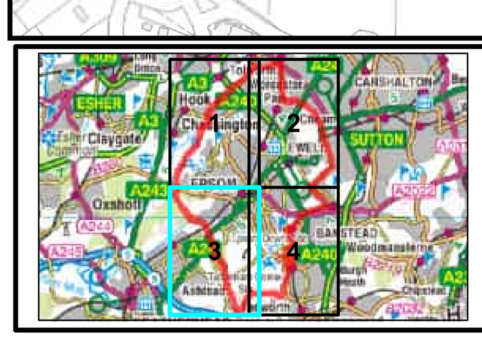

Legend

Drainage Areas
- Within model domain
- Outside model domain (The Wells)
- Outside model domain (Worcester Park)

Maximum Velocity (m/s) 0.5% (1:200 year)
- 0.500 - 1.500
- 1.501 - 2.500
- 2.501 - 3.500
- 3.501 - 4.500
- 4.501 - 10.000

Drawing Title
Maximum Velocity0.5% (1:200 year) Annual Probability Event

Drawing Number
Figure F.3

0 0.25 0.5 1 Kilometers

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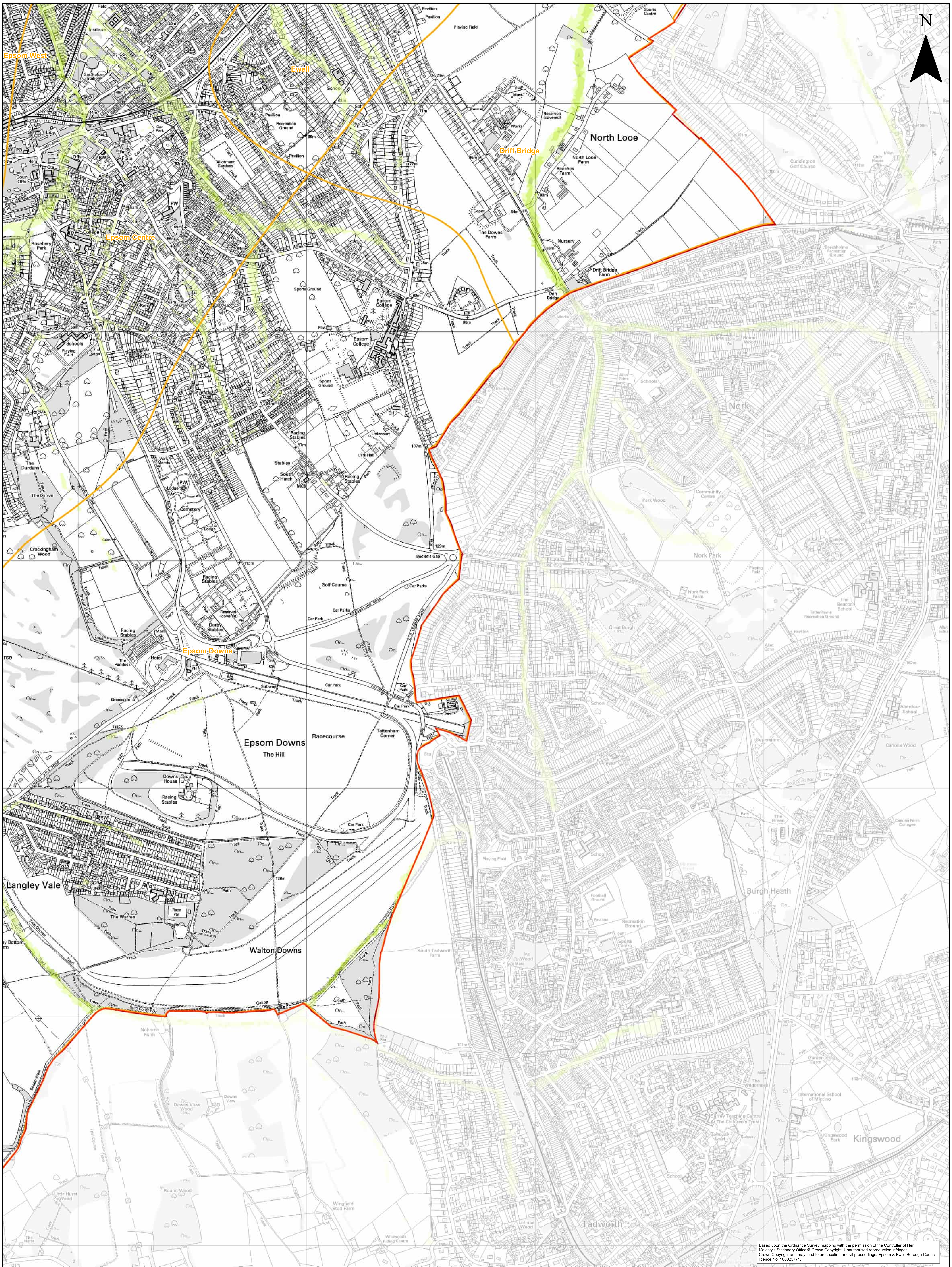

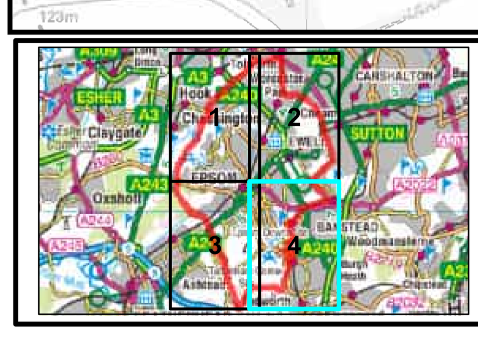

Legend

Drainage Areas
- Within model domain
- Outside model domain (The Wells)
- Outside model domain (Worcester Park)

Maximum Velocity (m/s) 0.5% (1:200 year)
- 0.500 - 1.500
- 1.501 - 2.500
- 2.501 - 3.500
- 3.501 - 4.500
- 4.501 - 10.000

Drawing Title

Maximum Velocity0.5% (1:200 year) Annual Probability Event

Drawing Number

Figure F.4

0 0.25 0.5 1 Kilometers

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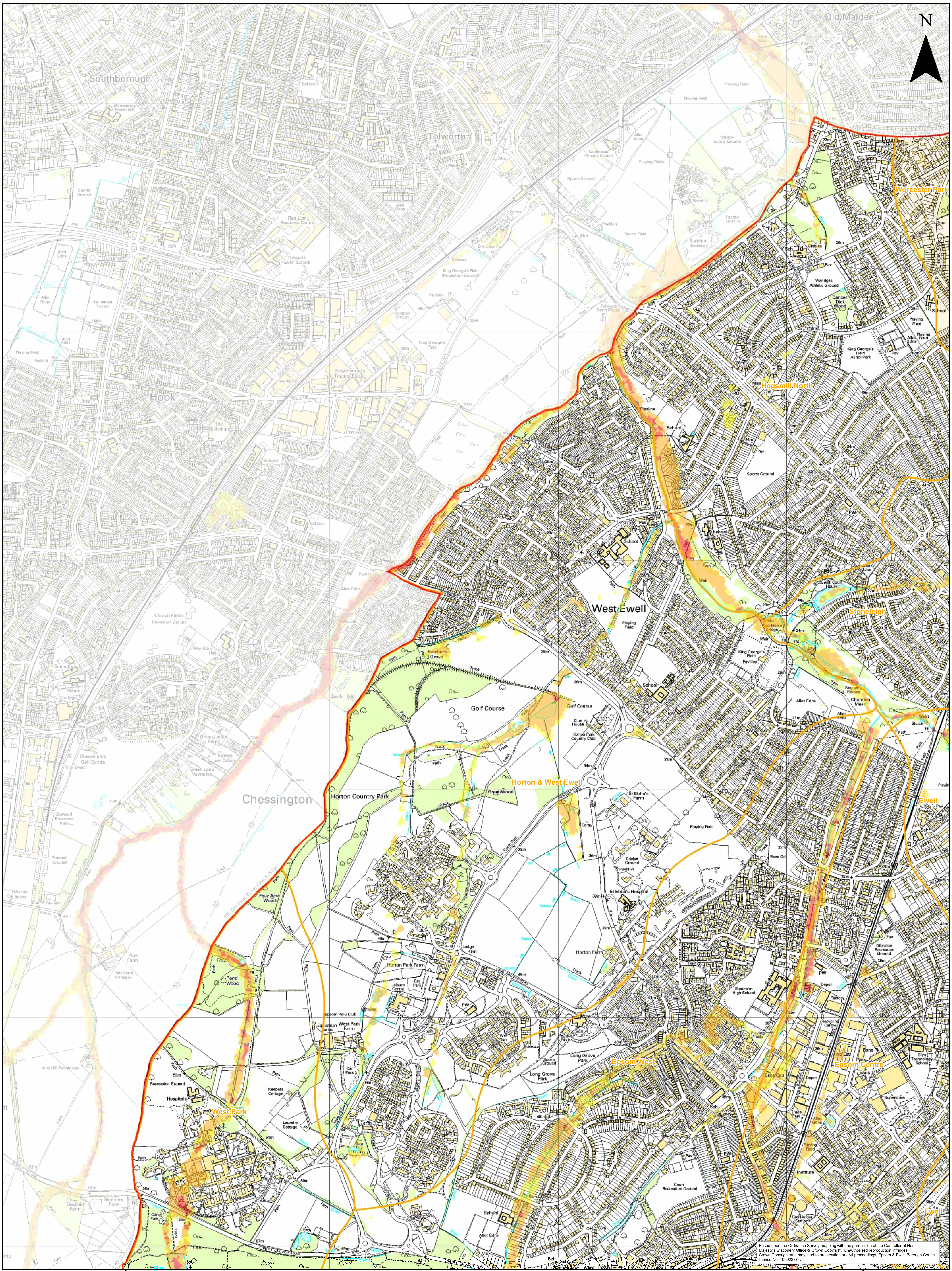

Legend

Drainage Areas	Maximum Hazard 0.5% (1:200 year)
Within model domain	Very low hazard
Outside model domain (The Wells)	Danger for some
Outside model domain (Worcester Park)	Danger for most
	Danger for all

Drawing Title
Maximum Hazard 0.5% (1:200 year) Annual Probability Event

Drawing Number
Figure G.1

0 0.25 0.5 1 Kilometers

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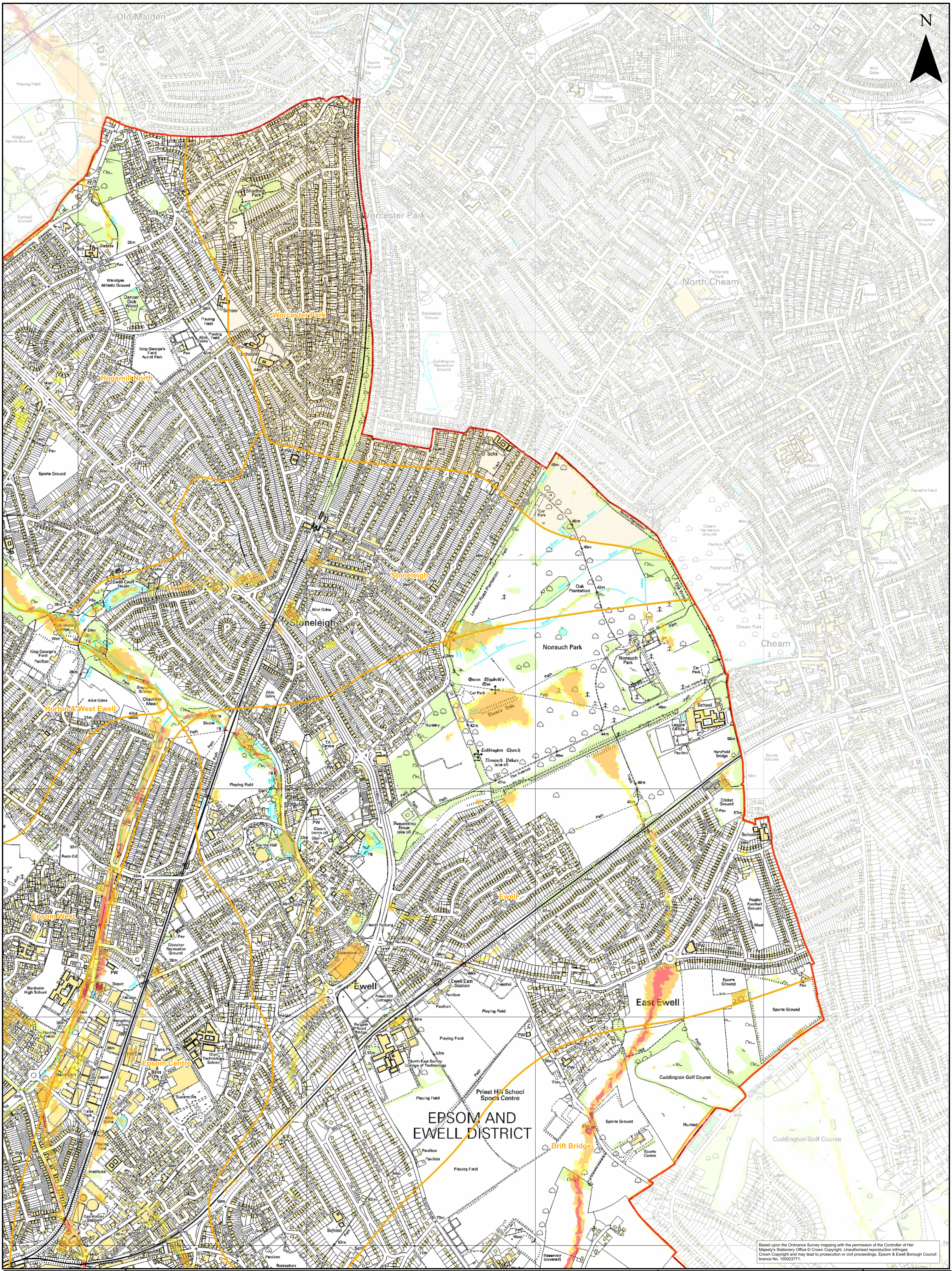

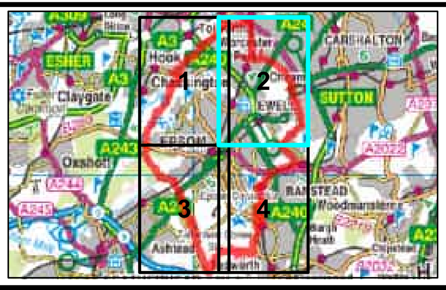

Legend

Drainage Areas
- Within model domain
- Outside model domain (The Wells)
- Outside model domain (Worcester Park)

Maximum Hazard 0.5% (1:200 year)
- Very low hazard
- Danger for some
- Danger for most
- Danger for all

Drawing Title
Maximum Hazard 0.5% (1:200 year) Annual Probability Event

Drawing Number
Figure G.2

0 0.25 0.5 1 Kilometers

Epsom & Ewell SWMP

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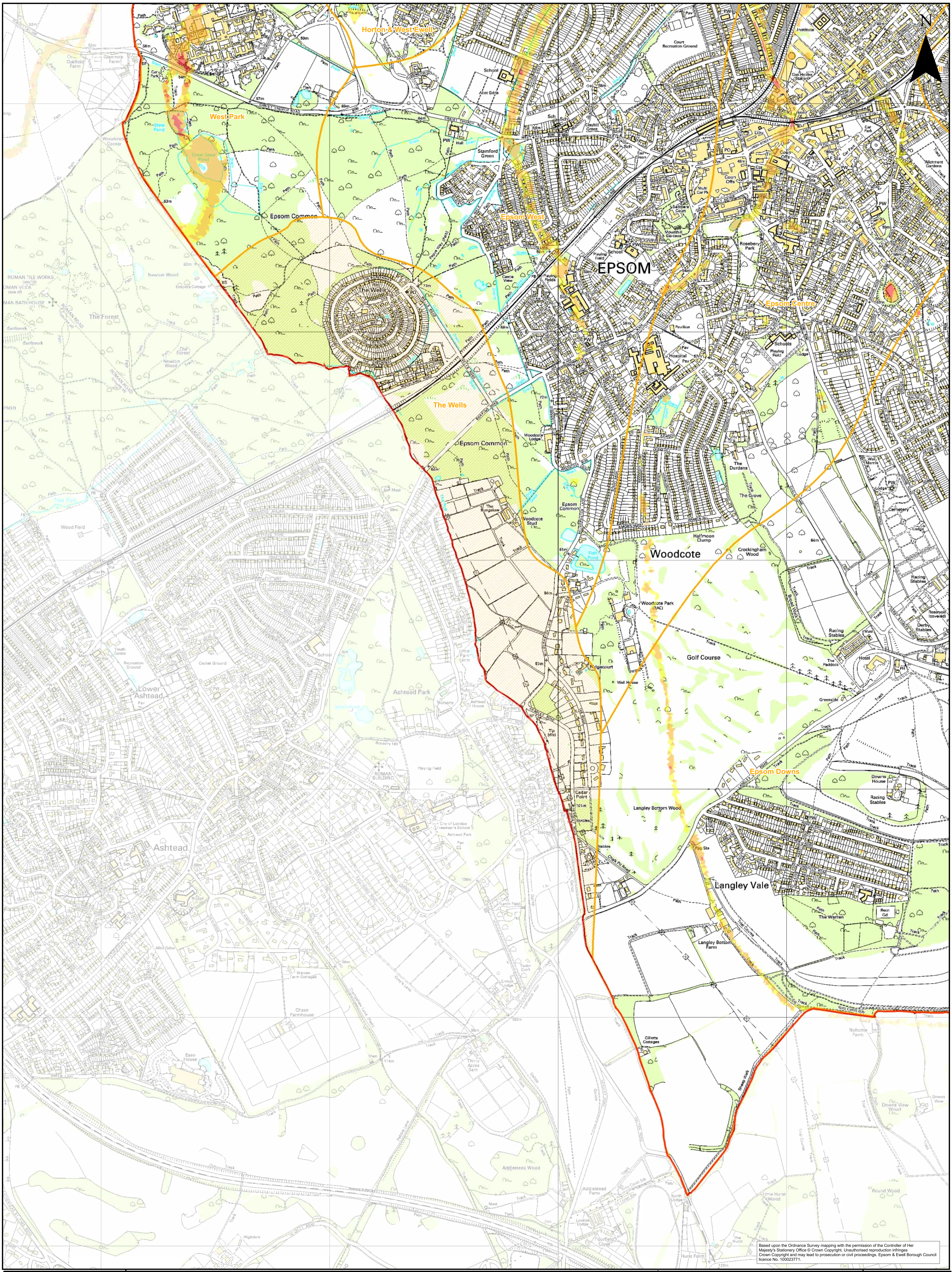

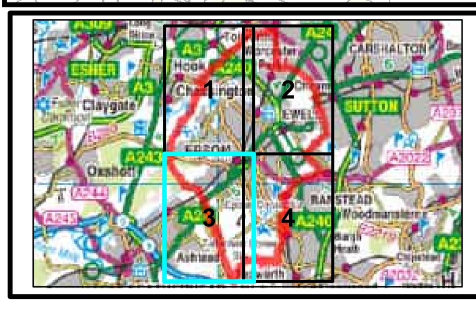

Legend

Drainage Areas
- Within model domain
- Outside model domain (The Wells)
- Outside model domain (Worcester Park)

Maximum Hazard 0.5% (1:200 year)
- Very low hazard
- Danger for some
- Danger for most
- Danger for all

Drawing Title
Maximum Hazard 0.5% (1:200 year) Annual Probability Event

Drawing Number
Figure G.3

0 0.25 0.5 1 Kilometers

Epsom & Ewell SWMP

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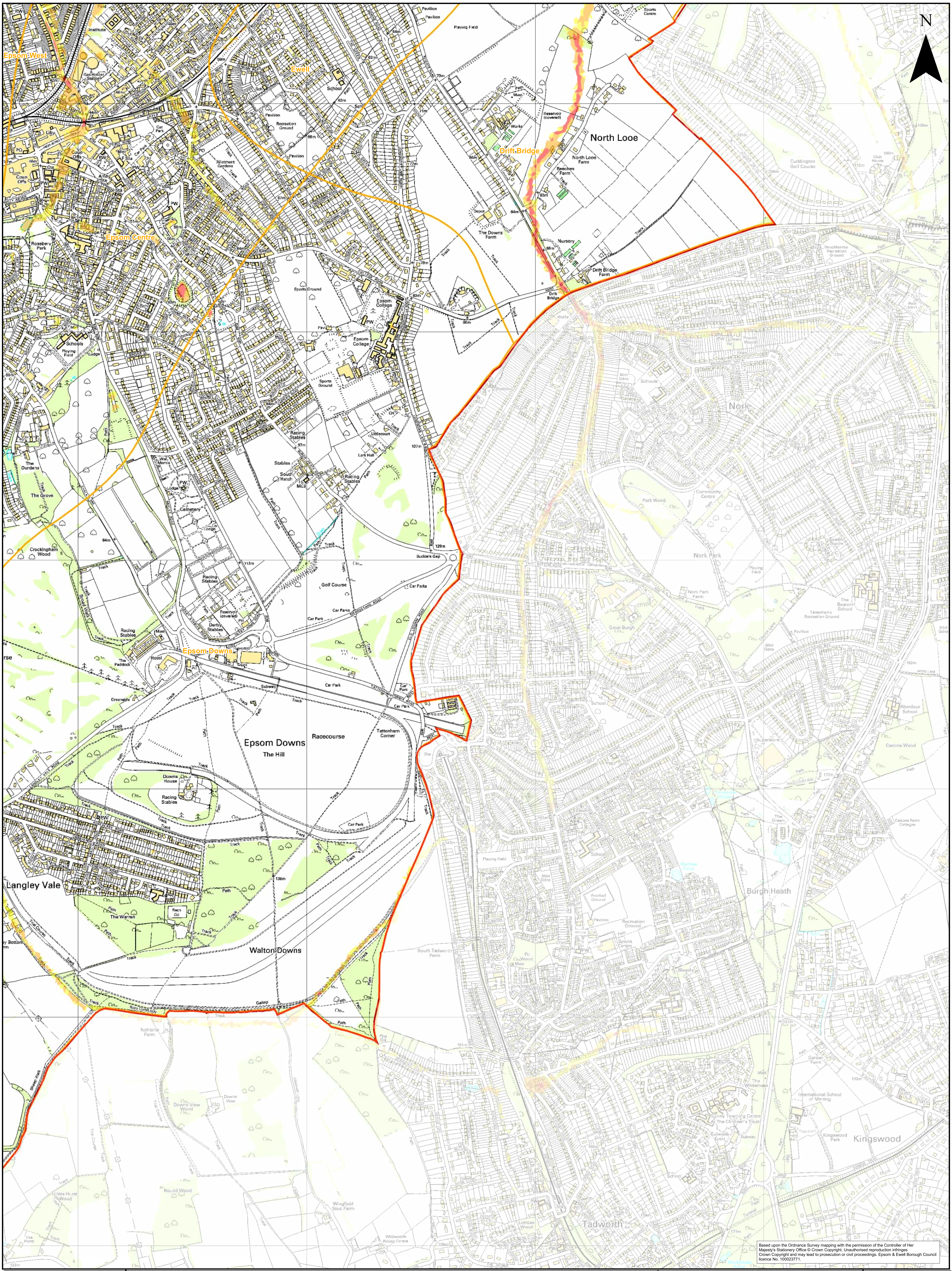

Legend

Drainage Areas
- Within model domain
- Outside model domain (The Wells)
- Outside model domain (Worcester Park)

Maximum Hazard 0.5% (1:200 year)
- Very low hazard
- Danger for some
- Danger for most
- Danger for all

Drawing Title

Maximum Hazard 0.5% (1:200 year) Annual Probability Event

Drawing Number

Figure G.4

0 0.25 0.5 1 Kilometers

Epsom & Ewell SWMP

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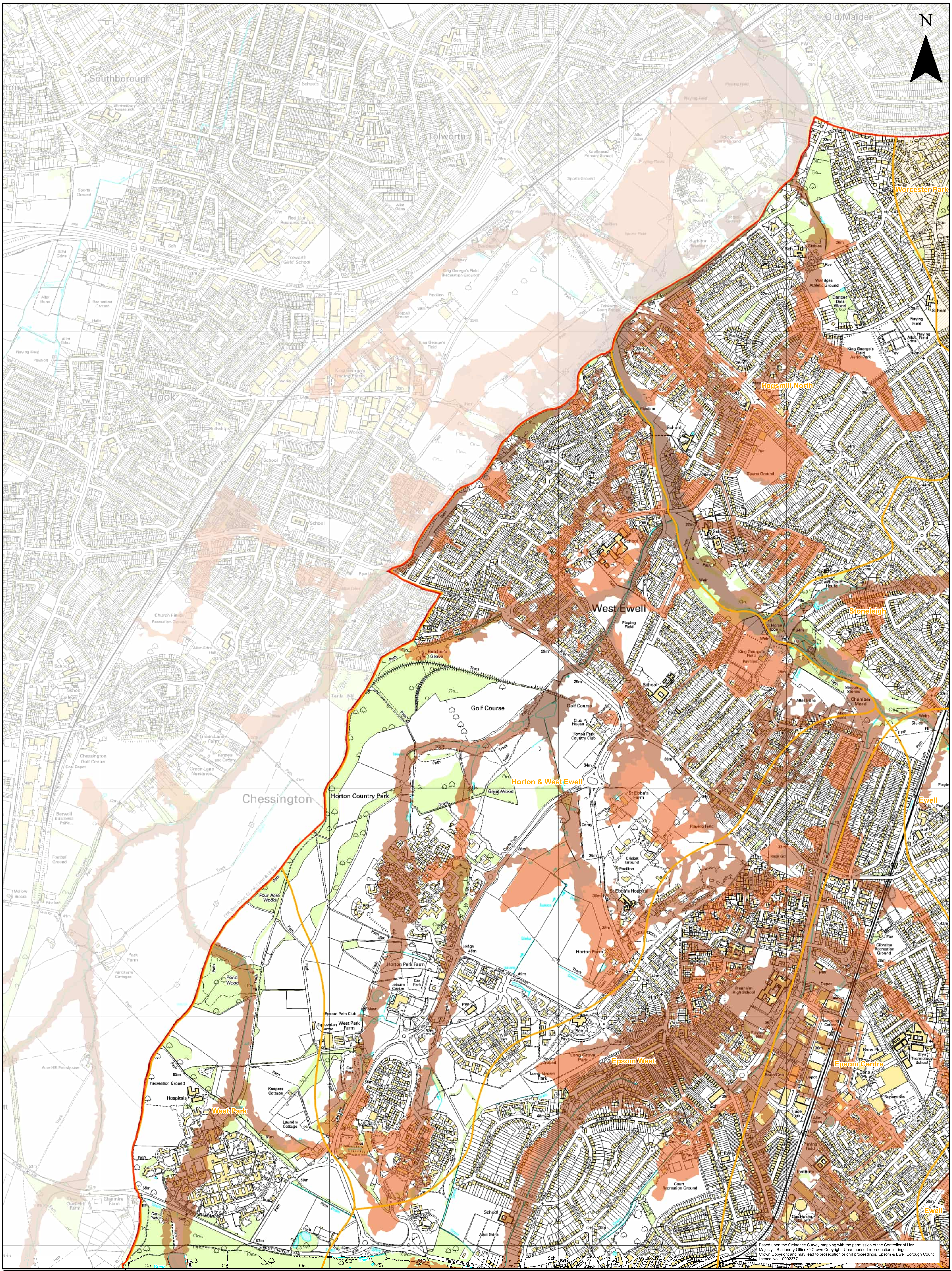

Legend

Drainage Areas

- Within model domain
- Outside model domain (The Wells)
- Outside model domain (Worcester Park)

Time to Max Depth (min) 0.5% (1:200 year)

- < 30 minutes
- 30 - 60 mins
- 60 - 120 mins
- >120 mins

Drawing Title

Time to Peak 0.5% (1:200 year) Annual Probability Event

Drawing Number

Figure H.1

0 0.25 0.5 1 Kilometers

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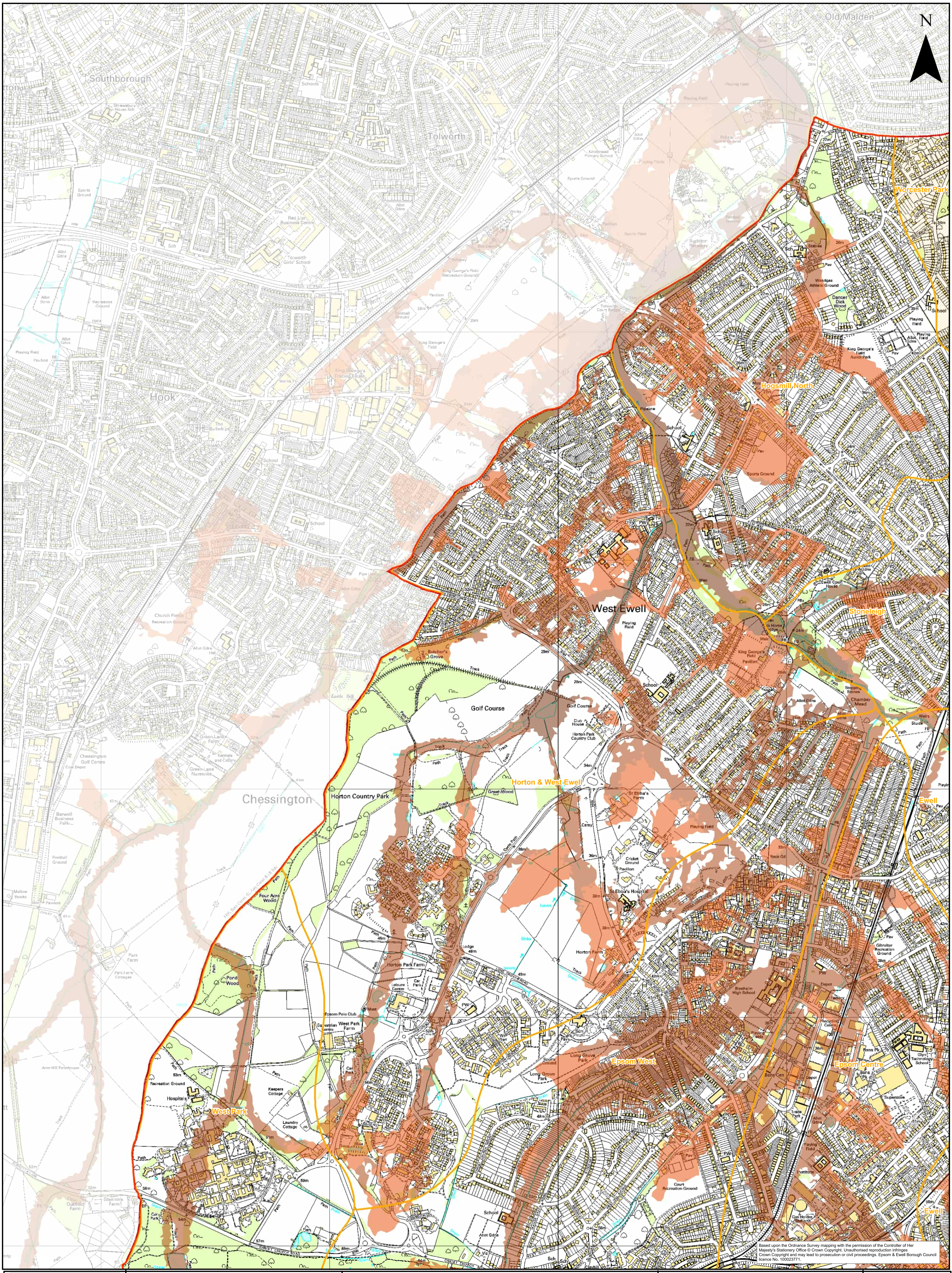

Legend

Drainage Areas
- Within model domain
- Outside model domain (The Wells)
- Outside model domain (Worcester Park)

Time to Max Depth (min) 0.5% (1:200 year)
- < 30 minutes
- 30 - 60 mins
- 60 - 120 mins
- >120 mins

Drawing Title
Time to Peak 0.5% (1:200 year) Annual Probability Event

Drawing Number
Figure H.1

0 | 0.25 | 0.5 | 1 Kilometers

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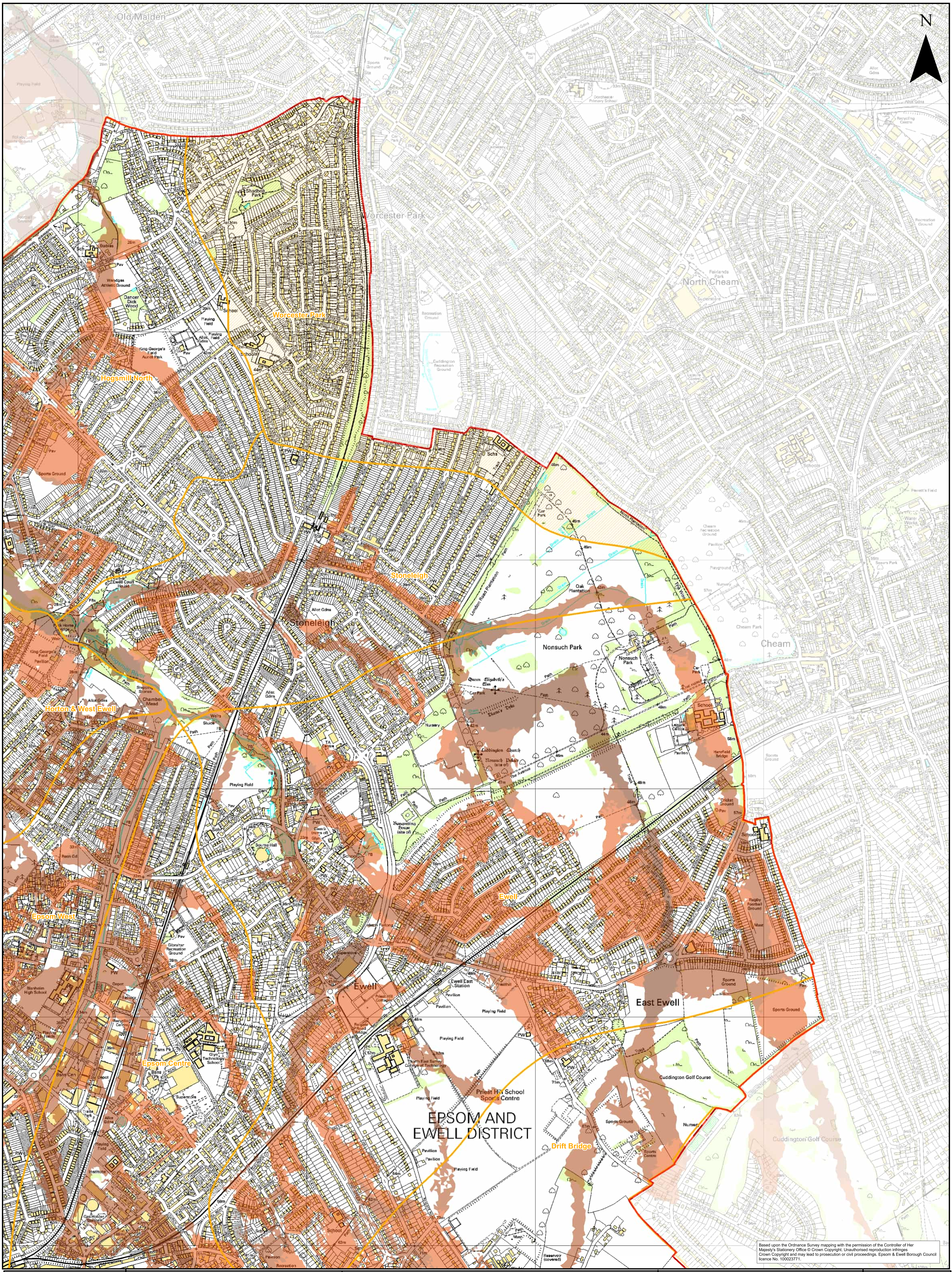

Legend

Drainage Areas

- Within model domain
- Outside model domain (The Wells)
- Outside model domain (Worcester Park)

Time to Max Depth (min) 0.5% (1:200 year)

- < 30 minutes
- 30 - 60 mins
- 60 - 120 mins
- >120 mins

Drawing Title

Time to Peak 0.5% (1:200 year) Annual Probability Event

Drawing Number

Figure H.2

0 0.25 0.5 1 Kilometers

Epsom & Ewell SWMP

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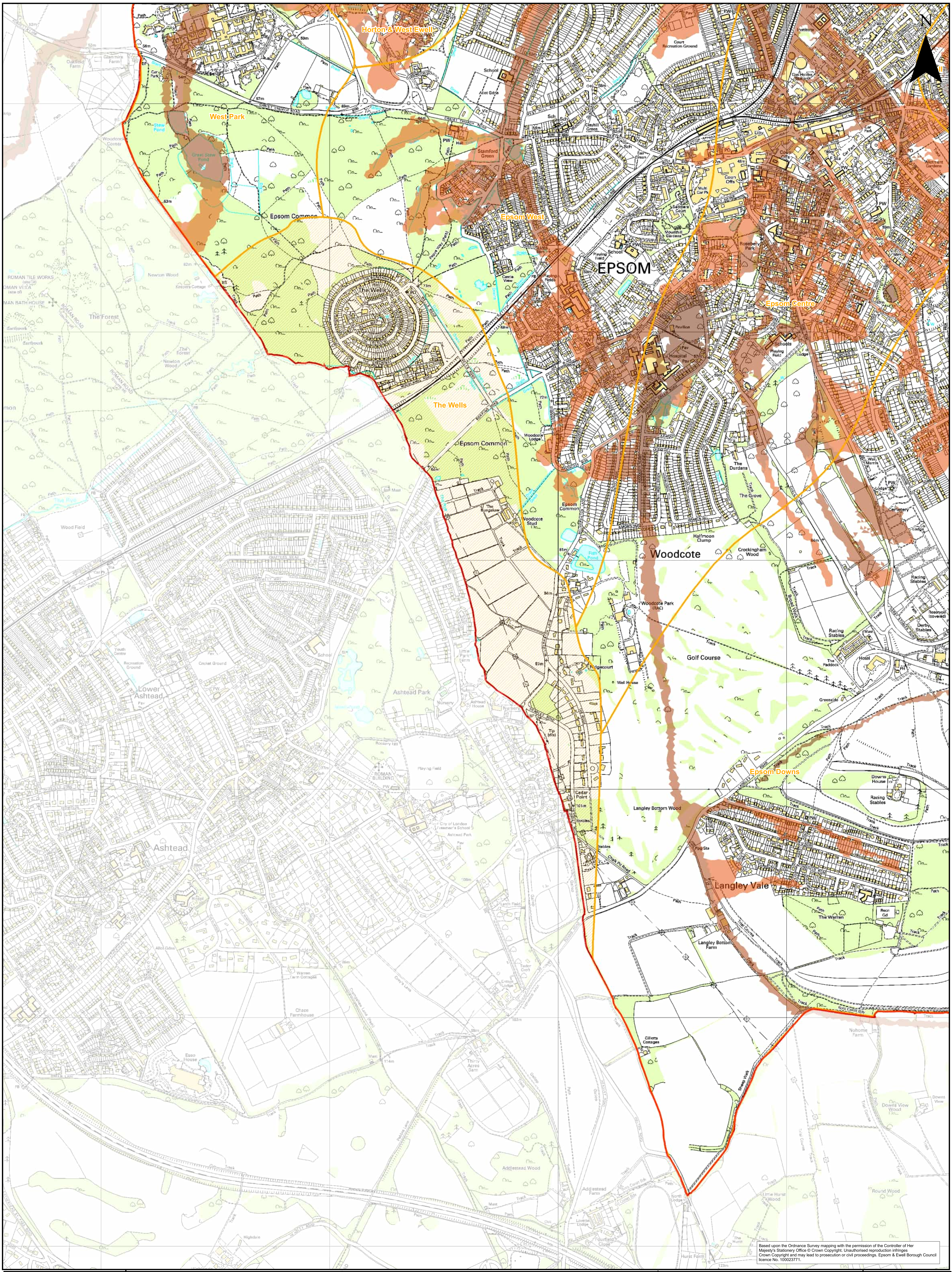

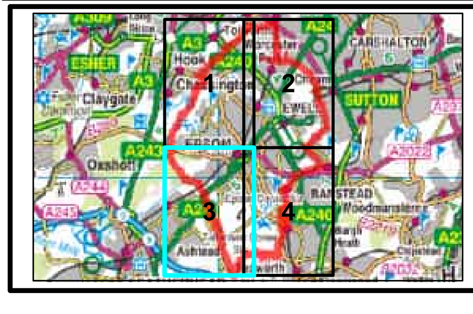

Legend

Drainage Areas

- Within model domain
- Outside model domain (The Wells)
- Outside model domain (Worcester Park)

Time to Max Depth (min) 0.5% (1:200 year)

- < 30 minutes
- 30 - 60 mins
- 60 - 120 mins
- >120 mins

Drawing Title

Time to Peak 0.5% (1:200 year) Annual Probability Event

Drawing Number

Figure H.3

0 0.25 0.5 1 Kilometers

Epsom & Ewell SWMP

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Legend

Drainage Areas
- Within model domain
- Outside model domain (The Wells)
- Outside model domain (Worcester Park)

Time to Max Depth (min) 0.5% (1:200 year)
- < 30 minutes
- 30 - 60 mins
- 60 - 120 mins
- >120 mins

Drawing Title
Time to Peak 0.5% (1:200 year) Annual Probability Event

Drawing Number
Figure H.4

0 0.25 0.5 1 Kilometers

Epsom & Ewell SWMP

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JACOBS
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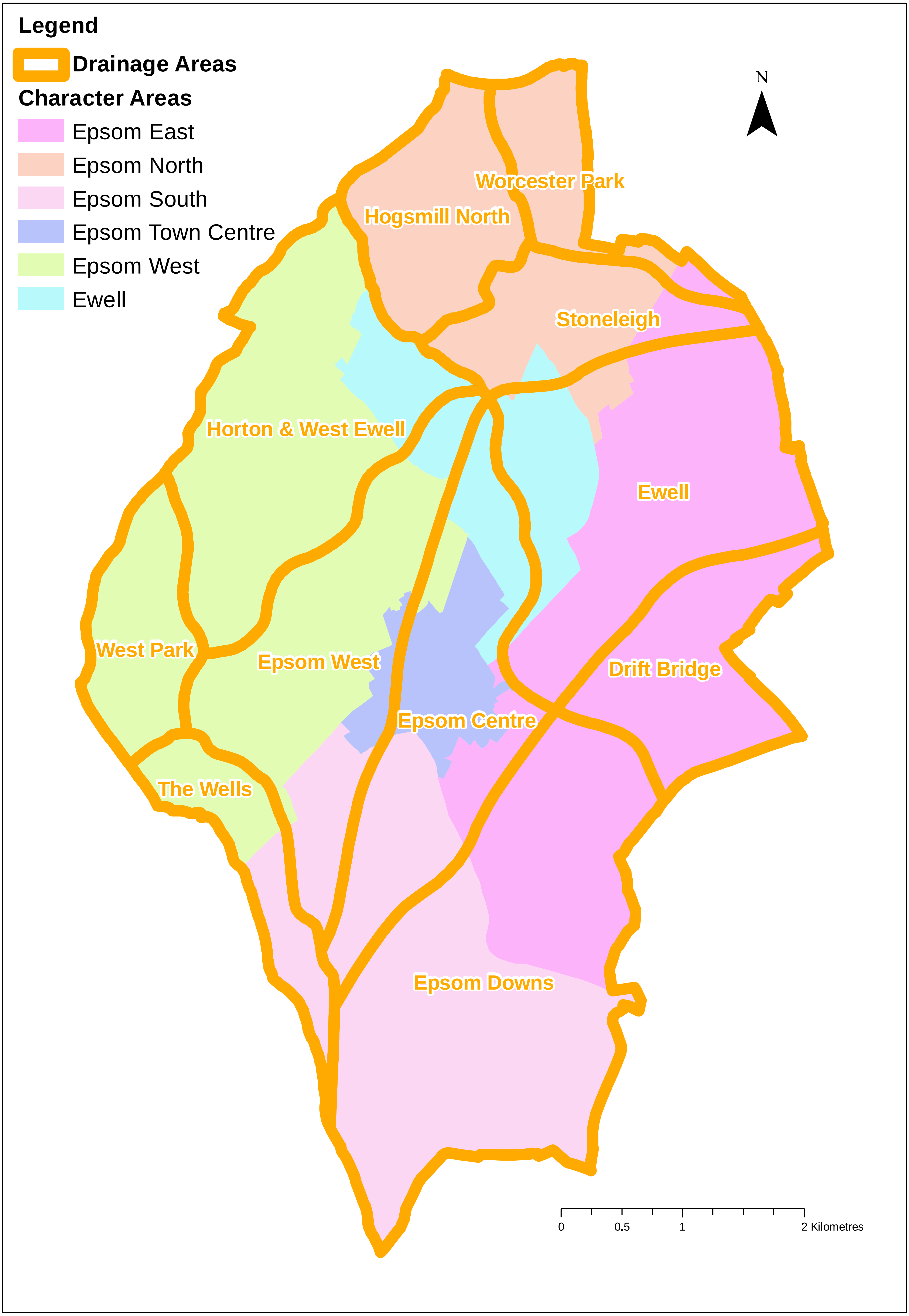
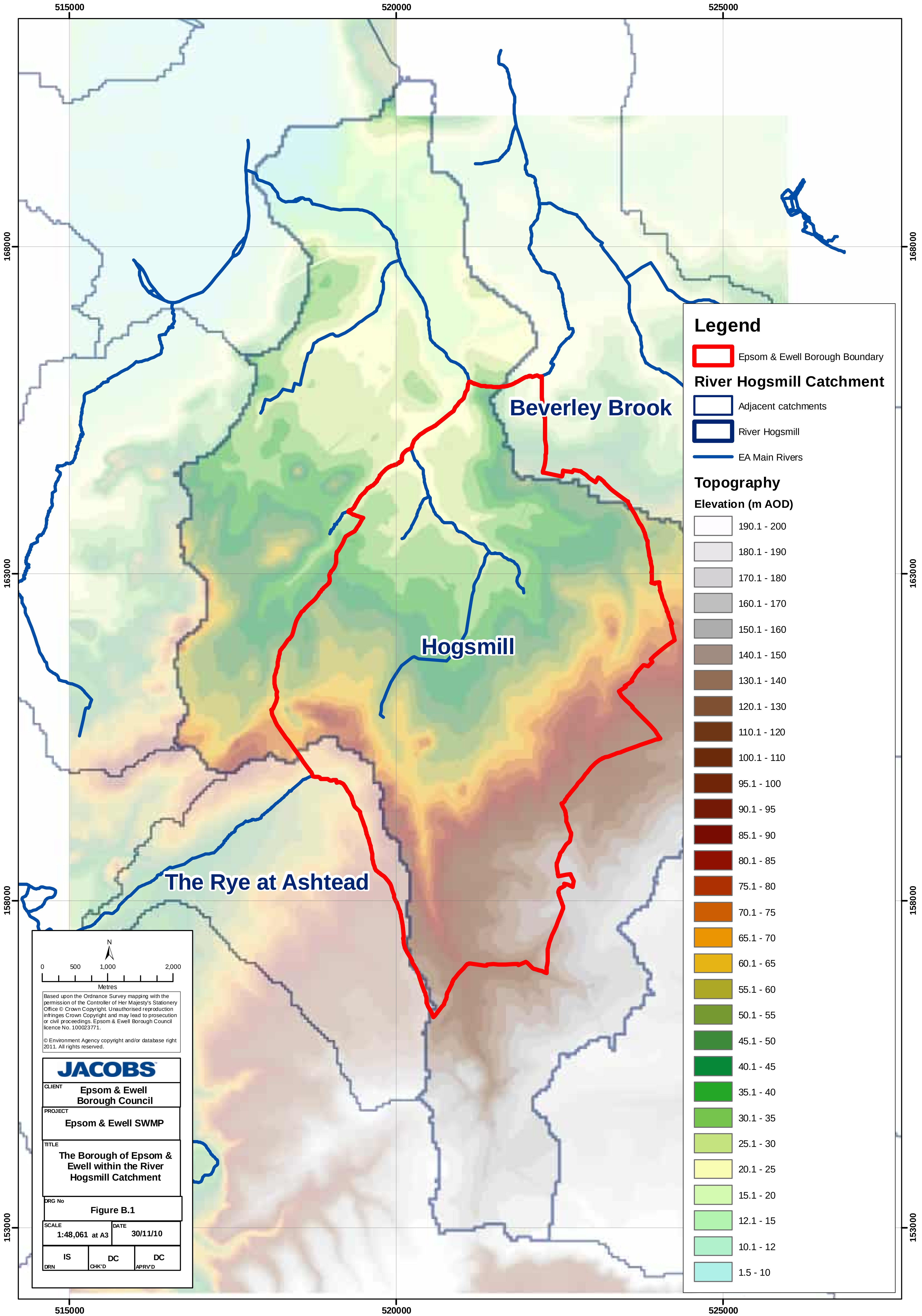

Legend
Drainage Areas
Character Areas
Epsom East
Epsom North
Epsom South
Epsom Town Centre
Epsom West
Ewell
N
Worcester Park
Hogsmill North
Stoneleigh
Horton & West Ewell
Ewell
West Park
Epsom West
Drift Bridge
Epsom Centre
The Wells
Epsom Downs
0
0.5
1
2 Kilometres



515000
520000
525000
168000
163000
158000
153000
Beverley Brook
Hogsmill
The Rye at Ashtead
Legend
Epsom & Ewell Borough Boundary
River Hogsmill Catchment
Adjacent catchments
River Hogsmill
EA Main Rivers
Topography
Elevation (m AOD)
190.1 - 200
180.1 - 190
170.1 - 180
160.1 - 170
150.1 - 160
140.1 - 150
130.1 - 140
120.1 - 130
110.1 - 120
100.1 - 110
95.1 - 100
90.1 - 95
85.1 - 90
80.1 - 85
75.1 - 80
70.1 - 75
65.1 - 70
60.1 - 65
55.1 - 60
50.1 - 55
45.1 - 50
40.1 - 45
35.1 - 40
30.1 - 35
25.1 - 30
20.1 - 25
15.1 - 20
12.1 - 15
10.1 - 12
1.5 - 10
N
0
500
1,000
2,000
Metres
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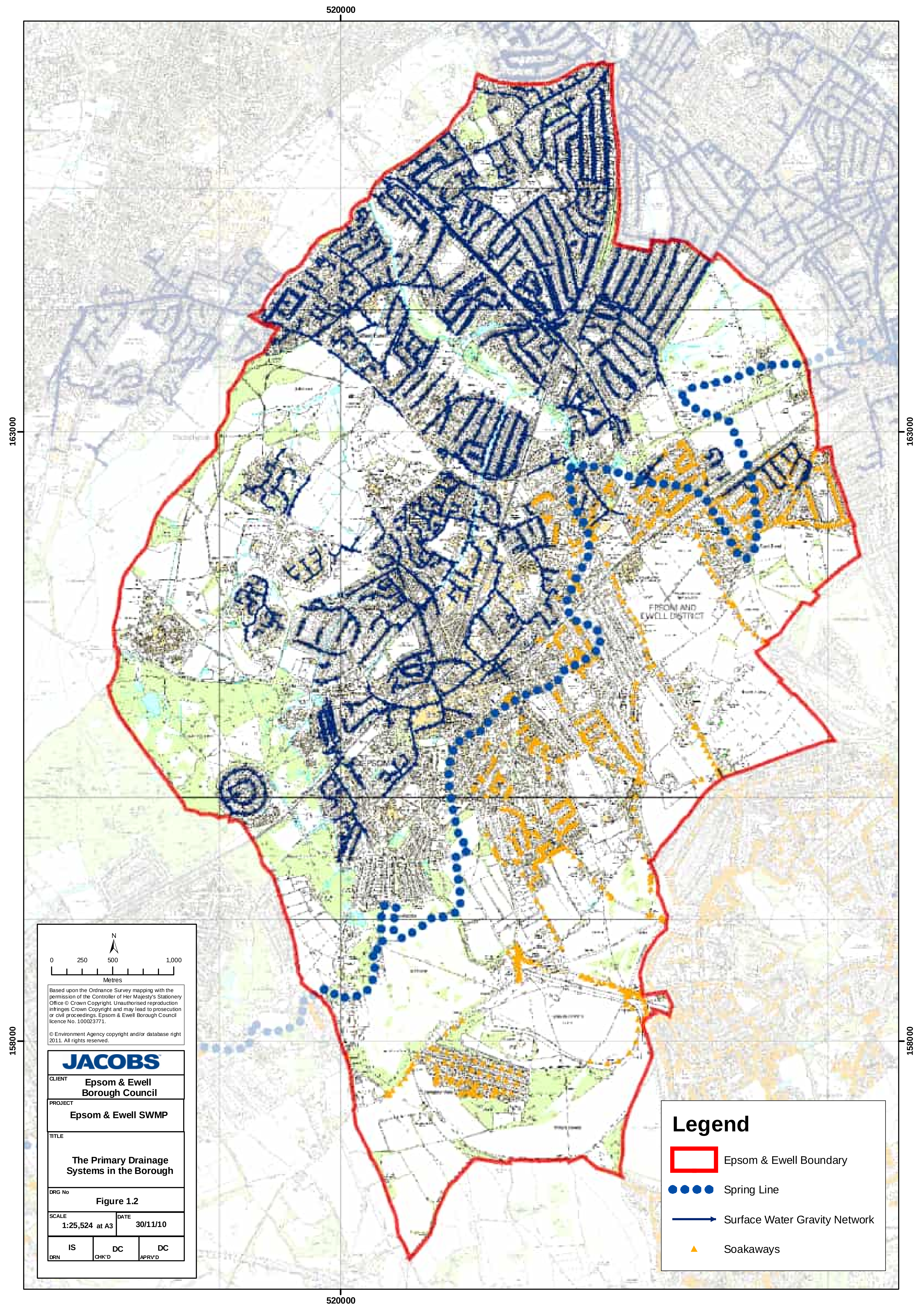
JACOBS
CLIENT
Epsom & Ewell Borough Council
PROJECT
Epsom & Ewell SWMP
TITLE
The Borough of Epsom & Ewell within the River Hogsmill Catchment
DRG No
Figure B.1
SCALE
1:48,061 at A3
DATE
30/11/10
IS
DRN
DC
CHK'D
DC
APRV'D


520000
163000
158000
EPSOM AND
EWELL DISTRICT
N
0
250
500
1,000
Metres
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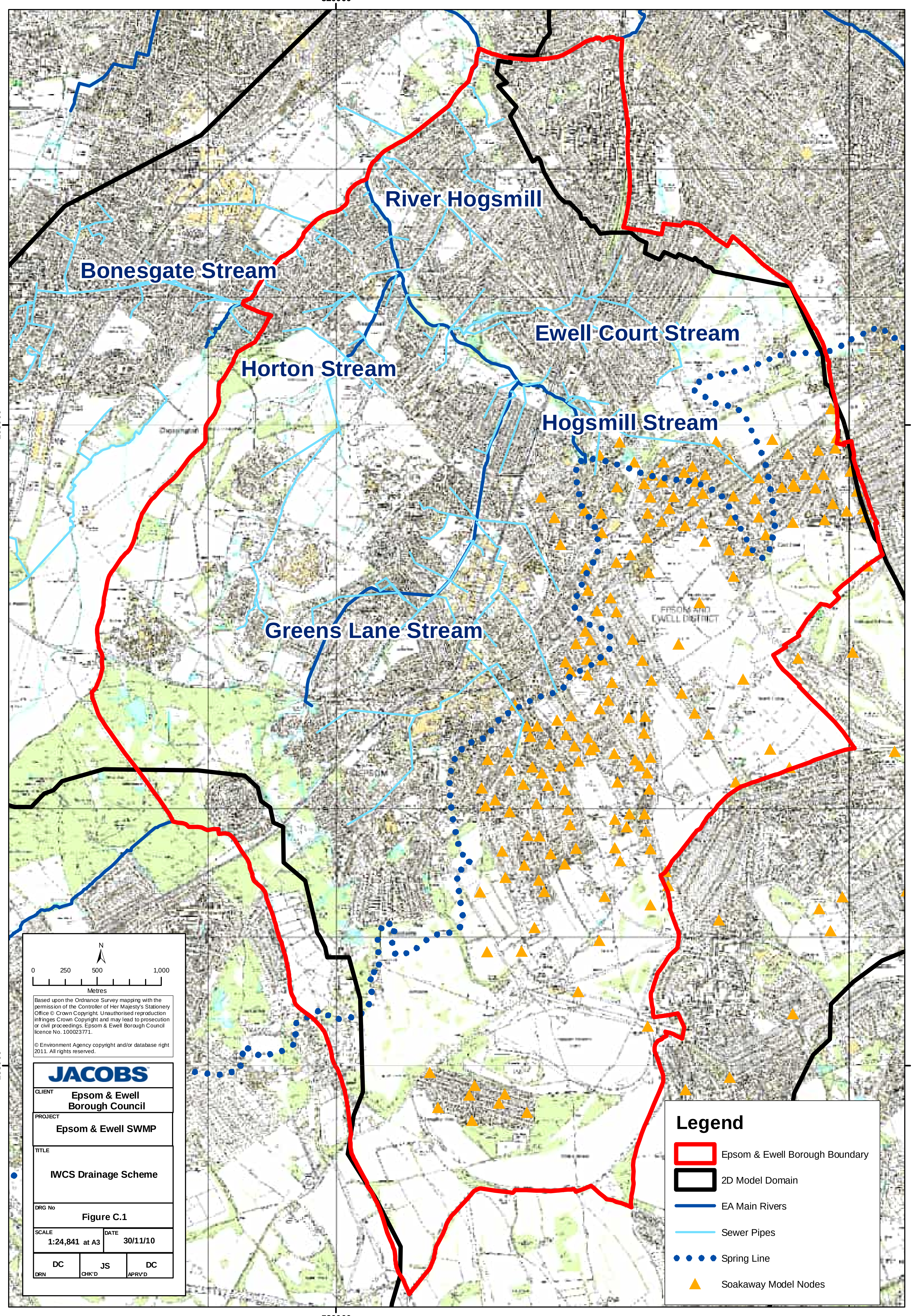
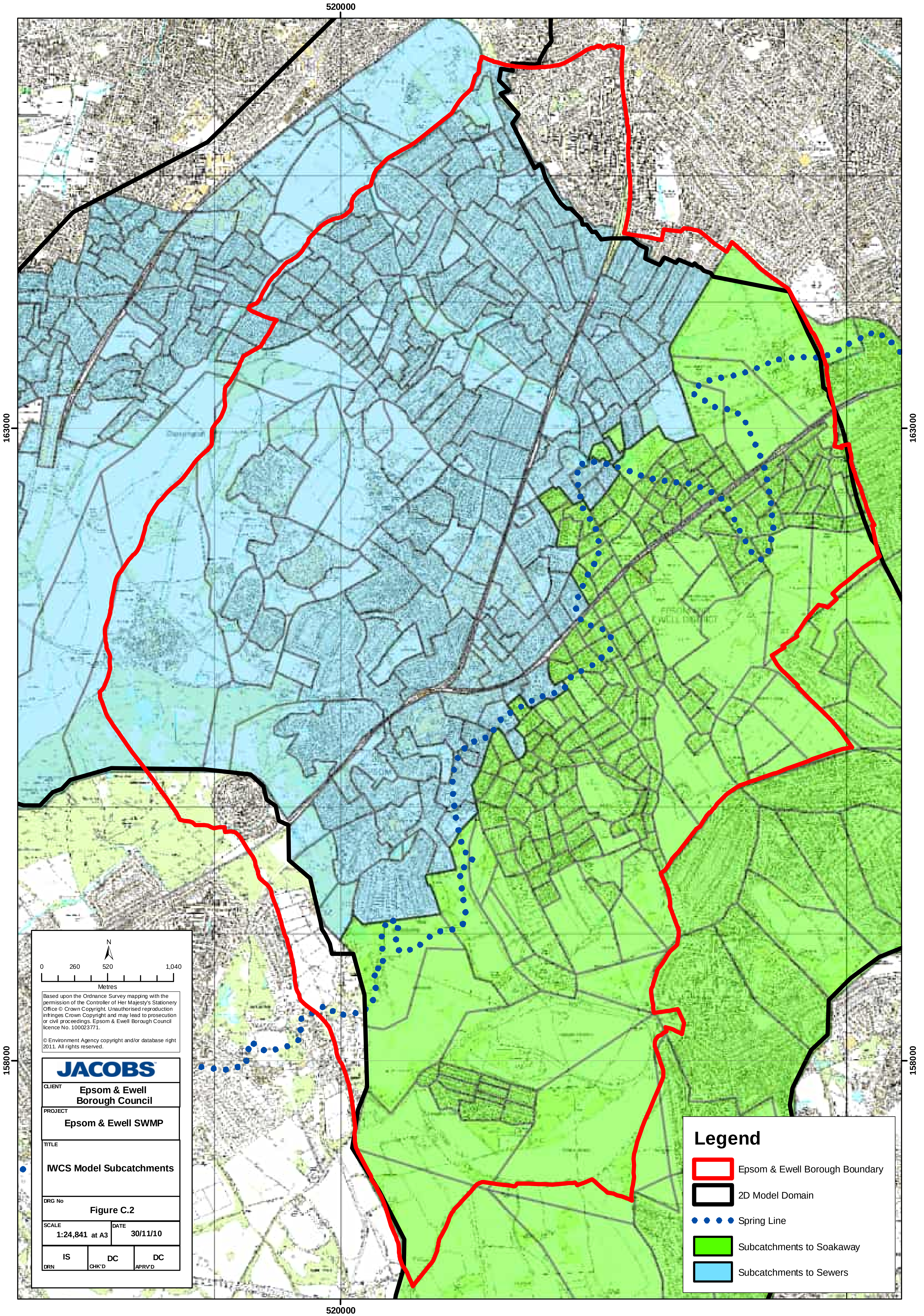
JACOBS
CLIENT
Epsom & Ewell Borough Council
PROJECT
Epsom & Ewell SWMP
TITLE
The Primary Drainage Systems in the Borough
DRG No
Figure 1.2
SCALE
1:25,524 at A3
DATE
30/11/10
IS
DRN
DC
CHK'D
DC
APRV'D
Legend
Epsom & Ewell Boundary
Spring Line
Surface Water Gravity Network
Soakaways



JACOBS

CLIENT	Epsom & Ewell Borough Council
PROJECT	Epsom & Ewell SWMP
TITLE	IWCS Drainage Scheme
DRG No	Figure C.1
SCALE	1:24,841 at A3
DATE	30/11/10
DRN	DC
CHK'D	JS
APRV'D	DC



520000
163000
158000
N
0
260
520
1,040
Metres
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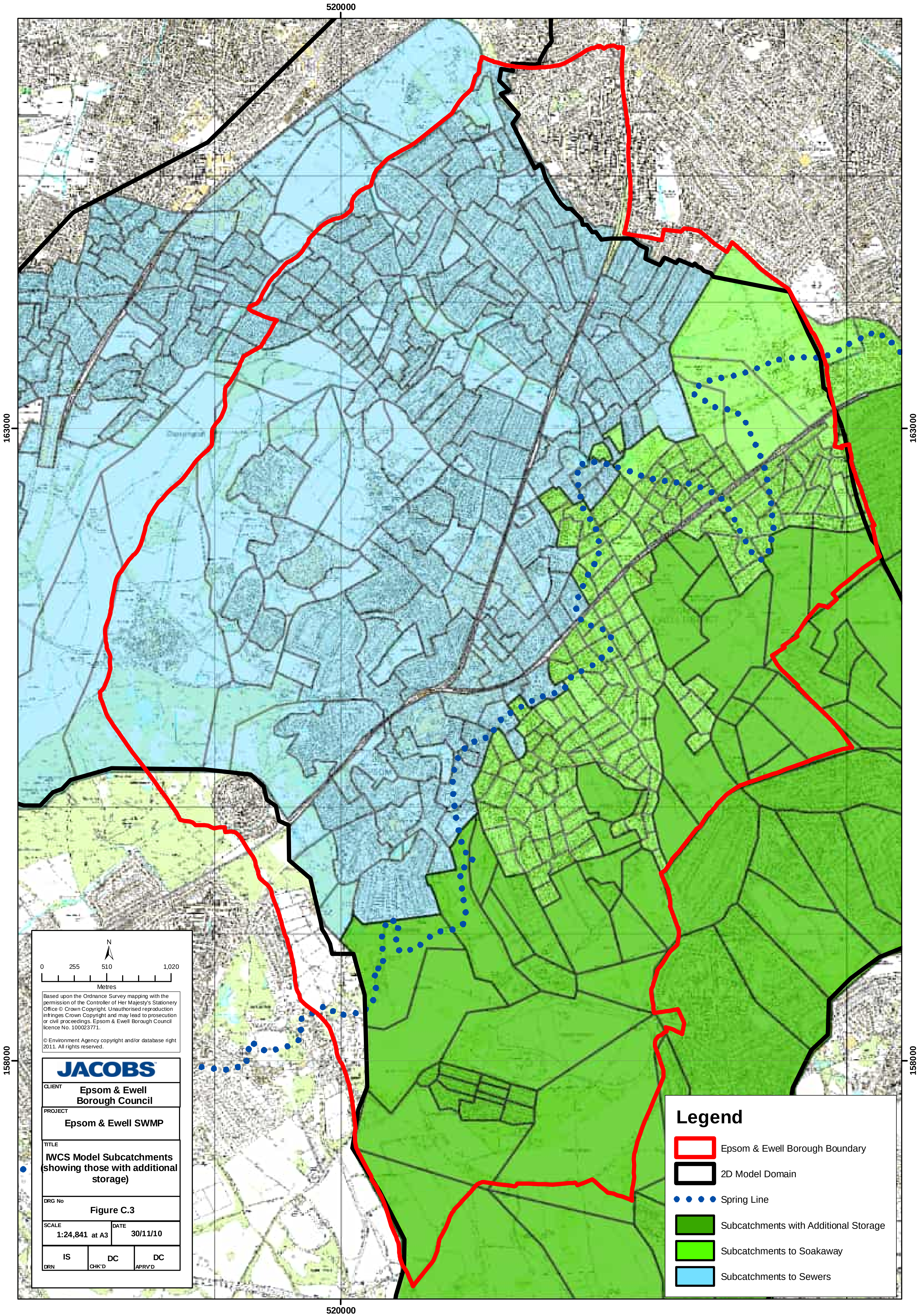
CLIENT
Epsom & Ewell Borough Council
PROJECT
Epsom & Ewell SWMP
TITLE
IWCS Model Subcatchments
DRG No
Figure C.2
SCALE
1:24,841 at A3
DATE
30/11/10
IS
DRN
DC
CHK'D
DC
APRV'D
Legend
Epsom & Ewell Borough Boundary
2D Model Domain
Spring Line
Subcatchments to Soakaway
Subcatchments to Sewers


520000
163000
158000
N
0
255
510
1,020
Metres
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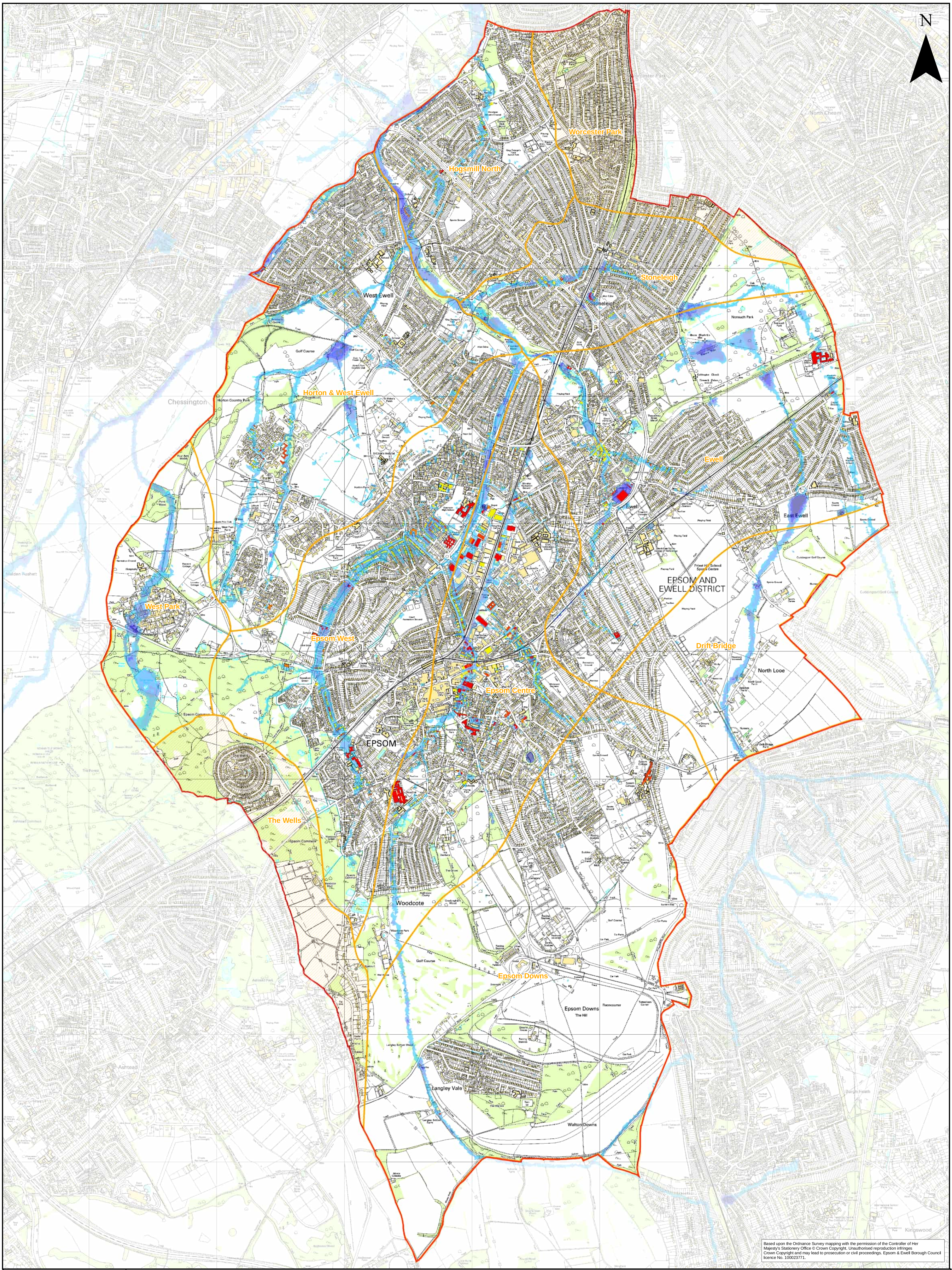
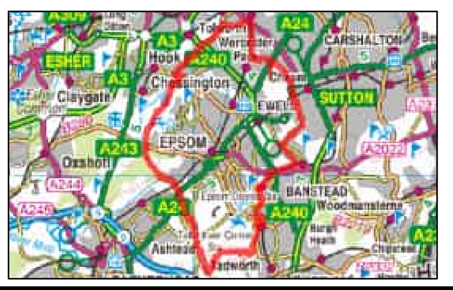
JACOBS
CLIENT
Epsom & Ewell Borough Council
PROJECT
Epsom & Ewell SWMP
TITLE
IWCS Model Subcatchments (showing those with additional storage)
DRG No
Figure C.3
SCALE
1:24,841 at A3
DATE
30/11/10
IS
DRN
DC
CHK'D
DC
APRV'D
Legend
Epsom & Ewell Borough Boundary
2D Model Domain
Spring Line
Subcatchments with Additional Storage
Subcatchments to Soakaway
Subcatchments to Sewers





Legend

Drainage Areas	Annual Average Damages	Maximum Depth (m) 0.5% (1:200 year)
Within model domain	£1 - £500	<0.1m
Outside model domain (The Wells)	£501 - £1,000	0.1 - 0.25m
Outside model domain (Worcester Park)	£1,001 - £2,000	0.25 - 0.5m
	£2,001 - £5,000	0.5 - 1.0m
	>£5,001	1.0 - 1.5m
		>1.5m

Drawing Title

Baseline Economic Damage Assessment

Drawing Number

Figure I.1

0 0.5 1 2 Kilometers

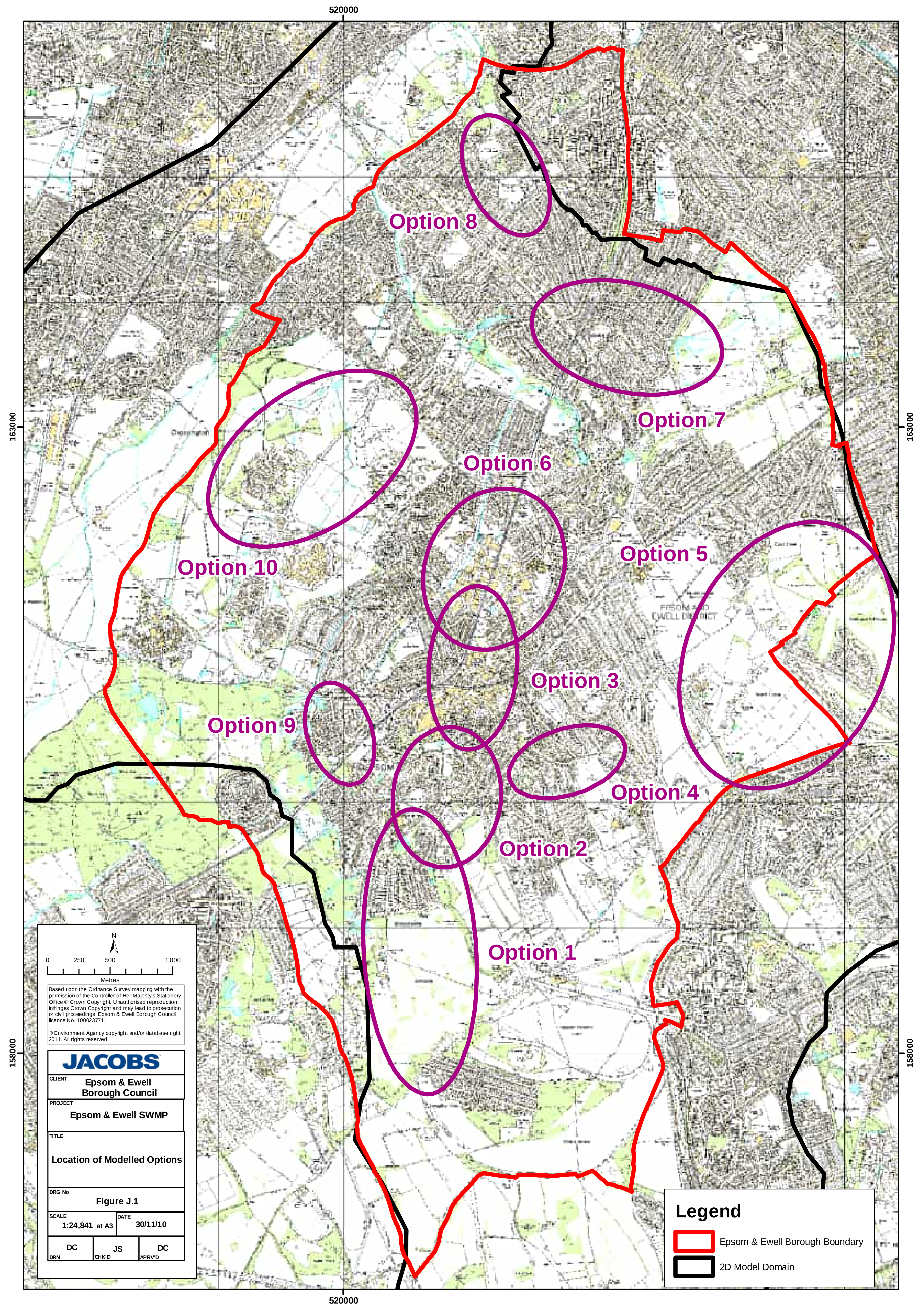
Epsom & Ewell SWMP

EPSOM & EWELL BOROUGH COUNCIL

JACOBS

1180 Eskdale Road, Winnersh, Wokingham, RG41 5TU

Produced	DC	Apr 2011
Checked	VW	Apr 2011
Approved	DC	Apr 2011


520000
Option 8
Option 7
Option 6
Option 10
Option 5
Option 3
Option 9
Option 4
Option 2
Option 1
EPSOM AND EWELL DISTRICT
163000
158000
N
0
250
500
1,000
Metres
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JACOBS
CLIENT
Epsom & Ewell Borough Council
PROJECT
Epsom & Ewell SWMP
TITLE
Location of Modelled Options
DRG No
Figure J.1
SCALE
1:24,841 at A3
DATE
30/11/10
DC
DRN
JS
CHK'D
DC
APRV'D
Legend
Epsom & Ewell Borough Boundary
2D Model Domain