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Kings Lynn Ordinary Watercourses Study

Technical Note
October 2015

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Quality Management

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Contents

Figures

Tables

Appendices

1. Introduction

1.1 Background

The Kings Lynn and West Norfolk Settlements Surface Water Management Plan (SWMP) was completed in January 2012. The study assessed pluvial flood risk to 16 settlements across West Norfolk for a range of flood events. Due to project constraints, the flood risk associated with ordinary watercourses was not specifically assessed. Norfolk County Council commissioned Capita to undertake a more detailed assessment of flood risk from ordinary watercourses within Kings Lynn and its interaction with surface water flooding. The existing SWMP hydraulic models were updated to meet the requirements of this study.

This Technical Report provides an update to the assessment of flood risk flood risk from ordinary watercourses within Kings Lynn and its interaction with surface water flooding. It should be read in conjunction with the January 2012 Kings Lynn and West Norfolk Settlements SWMP Report. This report also comprises the surface water flood mitigation options assessment for Kings Lynn.

1.2 Project Aims and Work Areas

The purpose of the project is to determine the potential impact of ‘combined’ surface water and ordinary watercourse flooding. This report aims to provide Norfolk County Council (NCC) with supporting evidence on the feasibility of the development of potential flood risk management measures within the study area. The work scope below is broken into three Work Areas as requested by NCC.

Work Area 1 – Update SWMP Model and Run Specified Scenarios
This work area comprises of the following sub-tasks:

- Assessment of existing studies by Norfolk County Council and King’s Lynn IDB
- Model flood risk scenarios including asset failure and significant rainfall events
- Assess the impacts on people, properties and critical infrastructure
- Production of a Technical Note

Work Area 2 - Map, Measure and Assess ‘Critical Structures’ and Features
This work area comprises of the following sub-tasks:

- Site surveys of the watercourses and associated flood risk structures and features
- Mapping and detailing of structures and features associated with ordinary watercourses that have an effect on flood risk

Work Area 3 – Options Assessment
This work area comprises of the following sub-tasks:

- Options assessment of flood mitigation measures
- Develop Action Plan

2. SWMP Model Update

2.1 Modelling software

The model constructed for this study was simulated using the latest versions of ISIS and TUFLOW available at the time of the project start up (ISIS version 3. 7.0.110 and TUFLOW version 2013-12-AD-iDP). This will allow for use of the latest functionality available in each software package specifically the enhanced representation of soils infiltration. The mathematical solver for more recent versions of TUFLOW (as used for this study) also offers significant improvements in the stability of direct rainfall models.

2.2 Availability of existing models

2.2.1 SWMP TUFLOW models

Four 2D TUFLOW hydraulic models were constructed by Capita in 2012 to inform the SWMP study. The model named “Kings Lynn” covers the area of interest for this additional work and will be used to represent the 2D floodplain of a new model to be constructed for this study. Amendments and updates to certain model features are discussed in the subsequent sections of this document.

2.2.2 IDB studies

1D ISIS models of a number of the ordinary watercourses within Kings Lynn were commissioned by the Internal Drainage Board (IDB) in 2004 and 2009. These models were constructed for River Gaywood Strategic Review and for the Pierrepoint District Strategic Review and have been provided for use in this study. Table 2-1 below provides further details on these existing ISIS models. The model extents are shown in Figure 1-1.

Table 2-1: Existing ISIS models

Model Name	**Description**
River Gaywood and North Lynn ISIS model	The model has been has been developed by Hannah Reed (now part of PBA) in 2004 for the River Gaywood Strategic Review. The model includes River Gaywood (from the A149 to the tidal outfall into the River Great Ouse), Bawsey Drain (from Spring Lane to the tidal outfall into the River Great Ouse), Black Drain (from A149 to its confluence with the Bawsey Drain) and North Lynn Drain (from the culvert outlet north to Reid Way to the Tidal Outfall into the River Great Ouse, see Figure 1). The model has 961 nodes and since 2004 the model has been updated with recent survey data.
Pierrepoint ISIS model	The model has been developed by Hannah Reed (now part of PBA) in 2006 for the Pierrepoint District Strategic Review. The model includes Pierrepoint Drain (from north of Fair Green to its pumped outfall into the River Nar) and Middleton Stop Drain (from Station Road at Middleton Towers to its confluence with Pierrepoint Drain)-(see Figure 1). Model has 504 nodes and since 2006 the model has been updated for different development projects. The railway bridge on Middleton Stop Drain has not been modelled due to lack of survey data

2.3 Model extent

The existing extent of the 2D Kings Lynn SWMP TUFLOW model includes an area to the south that is not of interest as part of the Kings Lynn Ordinary Watercourse (KLOW) Study. This extent was trimmed as shown in Figure 1.1 in order to reduce model simulation times. The extent of the existing IDB's ISIS models remains same as shown in the Figure 1.1. More information about the modelling methodology can be found in Appendix A.

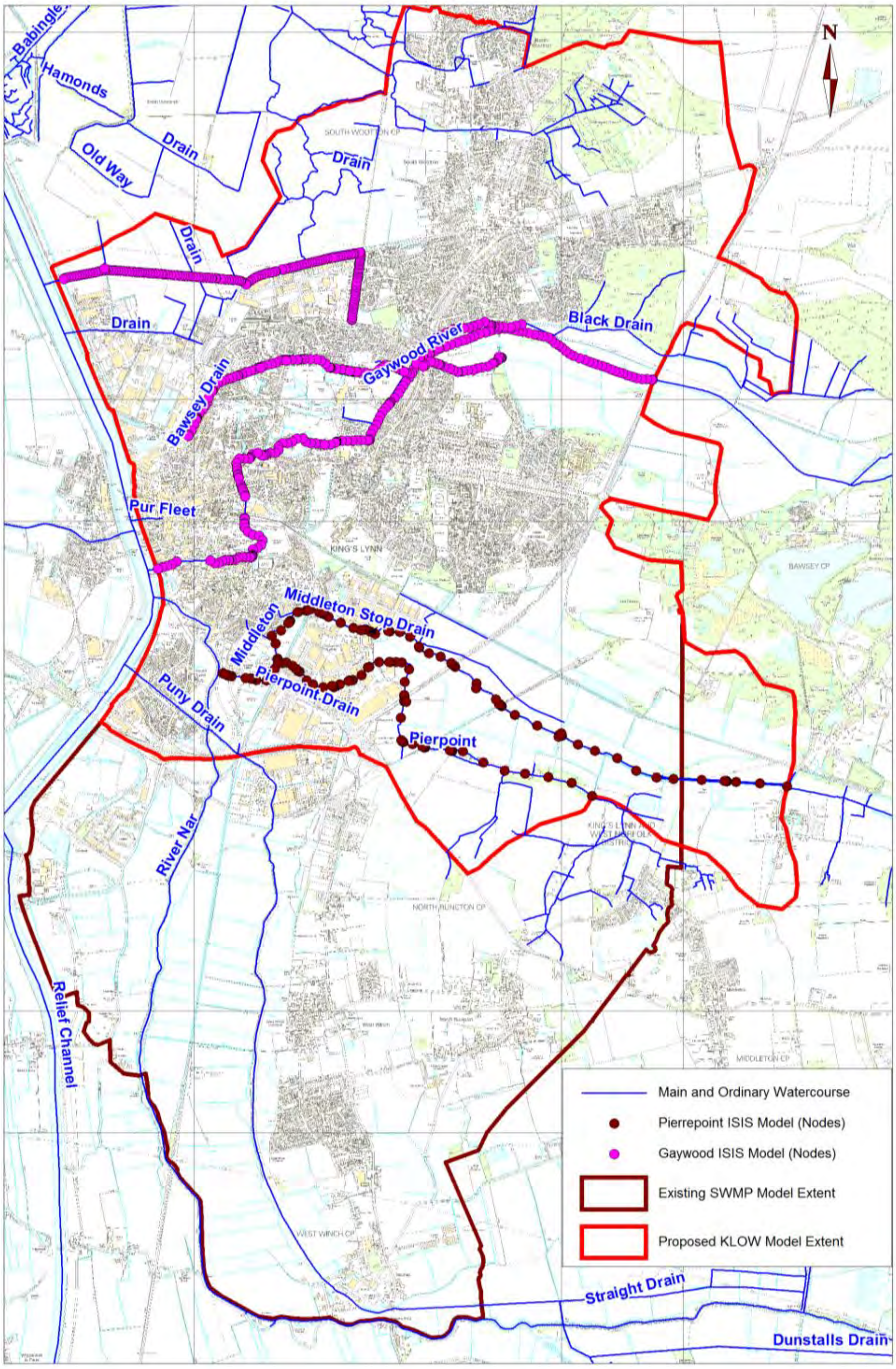


Figure 2-1: Model extents (existing SWMP and proposed KLOW model)

2.4 Additional survey requirements

A site walkover survey was carried out with stakeholders (NCC, Borough Council of Kings Lynn and West Norfolk (BCKLWN) and IDBs officials) on the 7th October 2014. During the site visit it was discussed that additional survey of the structures might not be required as most structures within the modelled reach have already been included in the existing IDB's ISIS models. The only structure not included in the existing model is the Railway Bridge on Middleton Stop Drain, (NGR562939, 319284). The Client (NCC) agreed and confirmed that no additional survey would be required for this project. The dimensions of the Railway Bridge on Middleton Stop Drain were measured during the site visit and the structure has been included in the KLOW model.

3. Baseline Assessment

3.1 Baseline Results

The detailed model built for this study provides an enhanced baseline representation of surface water flooding across the study area. Following the updates to the models (refer to Chapter 2 and Appendix A for more information), the baseline simulation was run to produce revised flood depth outputs for the area of interest. The model has been run for the following rainfall return periods:

- 3.3% Annual Exceedance Probability (AEP) (1 in 30 year);
- 1.33% AEP (1 in 75 year);
- 1% AEP (1 in 100 year)
- 1% AEP (1 in 100 year) including the effects of climate change; and
- 0.5% AEP (1 in 200 year).

The modelling outputs for the 100 year event are presented in Figure 3.1 below. Refer to Appendix D (Figures 1-5) for the other return periods.

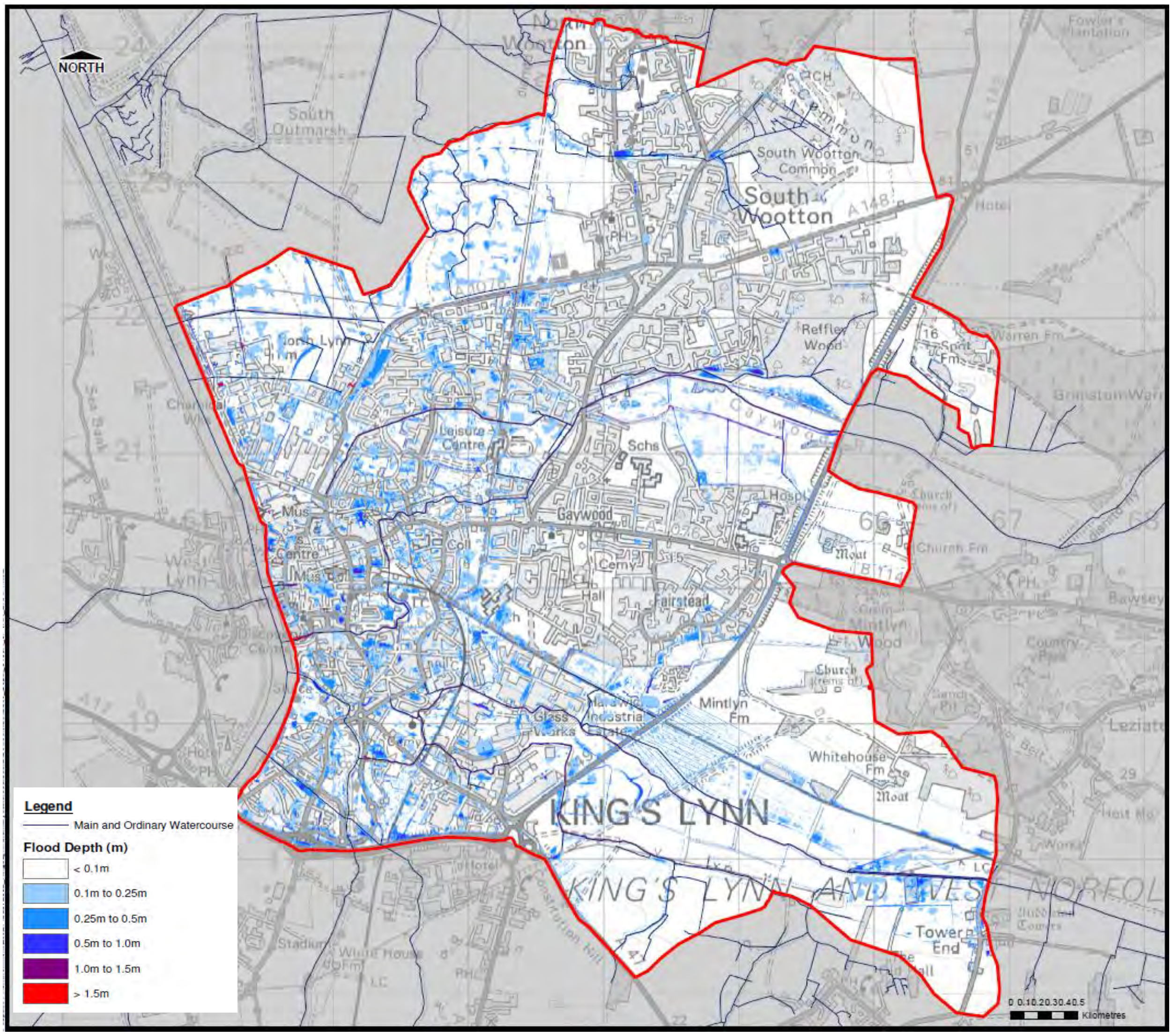


Figure 3-1: Baseline results (1 in 100 year event - pluvial)

In order to assess the fluvial impact in the area the baseline model was also run with fluvial inflow only (no rainfall was applied). The model results for the 1 in 100 year fluvial event are presented in Figure 3.2. Refer to Figures 6-10 in Appendix D for the remaining return periods.

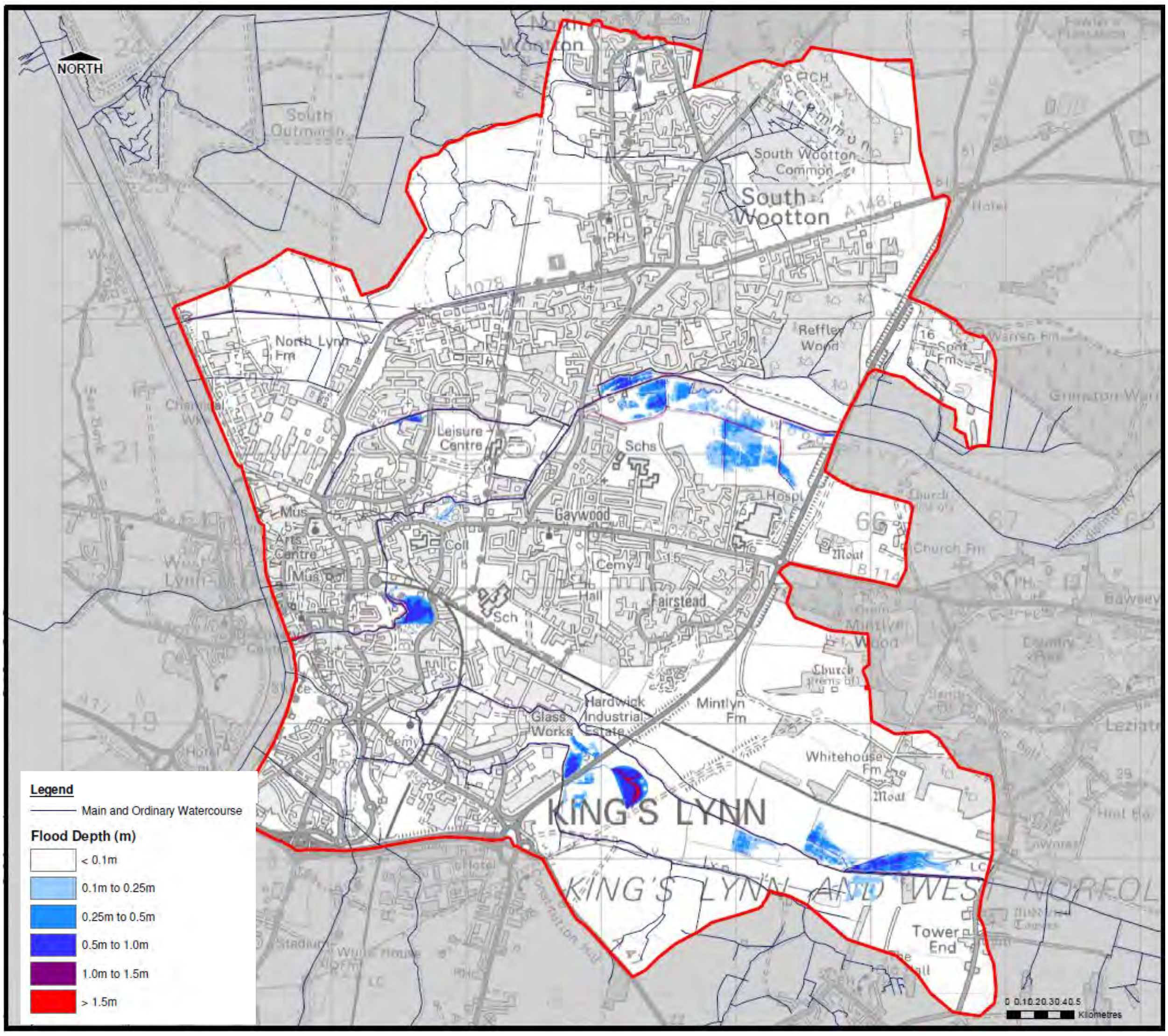


Figure 3-2: Baseline results (1 in 100 year event - fluvial)

The pluvial model shows more severe flooding within the area of interest therefore these outputs were used to identify the Critical Drainage Catchments (CDCs) and the recommended appraisal options, which are described in the sections below.

A Blockage scenario was run for some key structures in the area of interest. However, the model results of this scenario did not show any significant increase in flooding within the study area (refer to Appendix D for the model results of the Blockage scenario – Figures 11-22).

3.2 Critical Drainage Catchments

The results of this modelling have been used to identify Local Flood Risk Zones (LFRZs) where surface water flooding affects properties, businesses and/or infrastructure. Those areas identified to be at more significant risk have been delineated into Critical Drainage Catchments (CDCs) representing one or more LFRZs as well as the contributing catchment area and features that influence the predicted flood extent.

Within the study area, twelve (12) final CDCs have been identified which have discussed and agreed with NCC, and are presented in Figure 3.3. The dominant mechanisms for flooding can be broadly divided into the following categories:

- Topographical low lying areas – are more susceptible to surface water flooding particularly where obstructions impede flow; and
- Topographical low points – areas which are at topographical low points throughout the Borough (predominantly from basement properties) which result in small, discrete areas of deep surface water ponding.

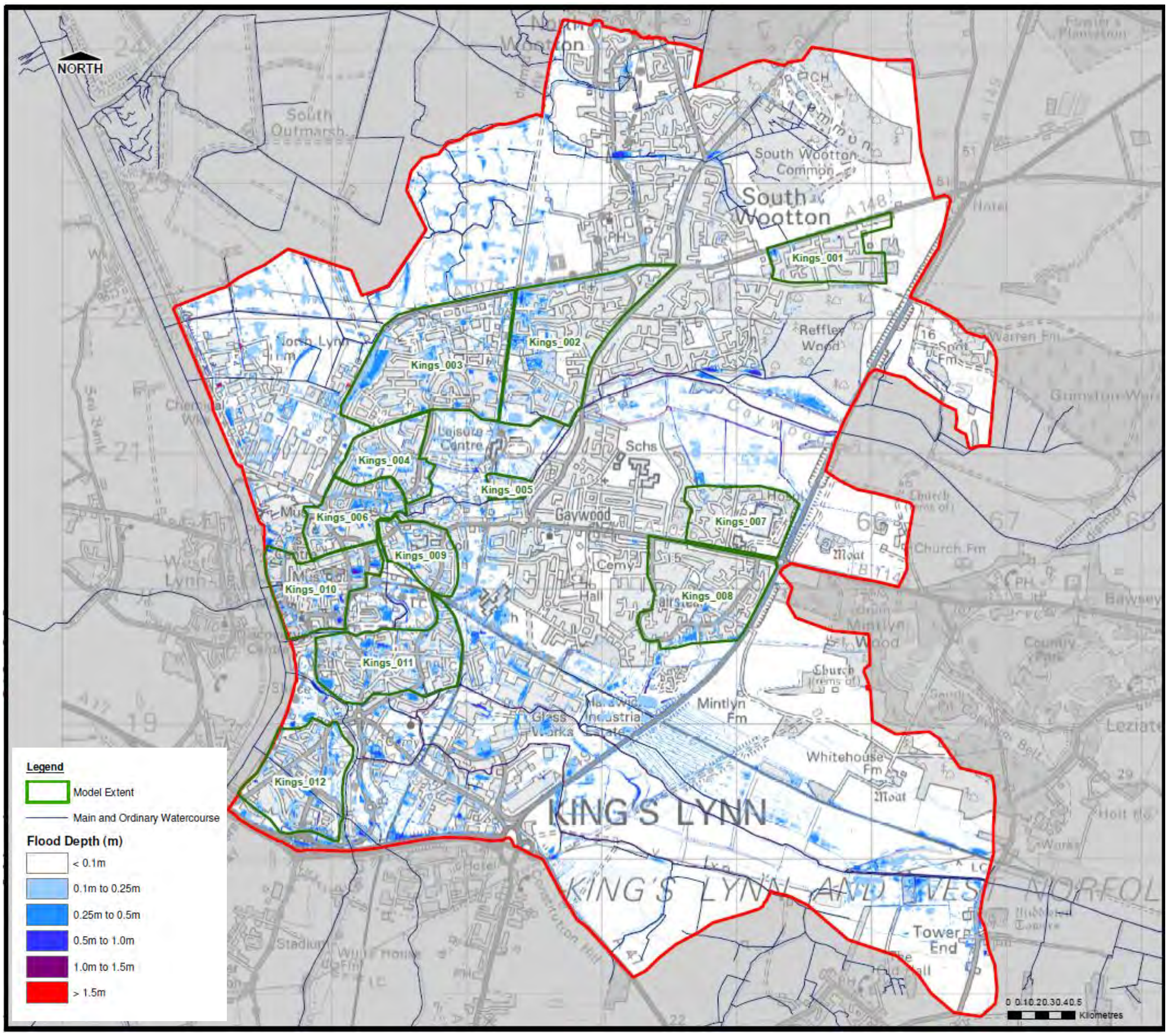


Figure 3-3: Critical Drainage Catchments.

3.3 Baseline Damage Assessment

A damage assessment was undertaken based on the Environment Agency's Flood and Coastal Erosion Risk Management Appraisal Guidance (FCERM-AG) and the Multi Coloured Manual (Middlesex, 2014). The methodology for the damage assessment is outlined in Appendix B.

The hydraulic modelling has estimated the following properties at risk of flooding under each flood event.

Table 3-1: Properties at risk (baseline model)

CDCs	30yr	75yr	100yr	100yrCC	200yr
Kings_001	0	4	6	14	13
Kings_002	18	85	112	202	180
Kings_003	48	101	116	179	160
Kings_004	10	27	28	60	55
Kings_005	2	2	3	5	5
Kings_006	58	98	111	141	132
Kings_007	5	7	7	9	9
Kings_008	4	9	16	50	42
Kings_009	35	54	59	96	85
Kings_010	98	138	143	188	172
Kings_011	57	102	128	241	223
Kings_012	65	98	114	184	164
Out Side	50	81	96	179	154
Total	450	806	939	1548	1394

Expected damage data has been scaled up over the appraisal time period by multiplying the expected annual average damage by 100 years. These were then discounted; discounting is an adjustment which reduces the size of future values to represent, within the appraisal, the preference of society to receive benefits sooner. Discounting is an obligation set out in the Treasury Green Book which influences the expenditure of Grant in Aid to projects with more rapid outcomes. The sum of discounted benefits over the appraisal period is the Present Value Benefits; these are presented in the table below.

Table 3-2: Baseline damages

CDCs	Damage (PVd – Present Value damage) (£)
CDC 01	876,408
CDC 02	3,381,574
CDC 03	2,877,150
CDC 04	1,056,465
CDC 05	147,666
CDC 06	2,233,713
CDC 07	523,659
CDC 08	2,346,919
CDC 09	1,437,247
CDC 10	3,238,672
CDC 11	3,978,479
CDC 12	2,510,125

4. Option Assessment

4.1 Option Identification

A long list of potential flood risk management options for alleviating flooding in the area was developed with reference to the baseline modelling results and knowledge of the study area. The following potential options were discussed with Norfolk County Council during a Progress Meeting (18th March 2015):

<u>Source Measures</u>

- SUDS – Small Scale (Green roofs, rain gardens, permeable paving, soakaways)
- SUDS – Large Scale (Wetlands, ponds, detention basins) - SUDL

<u>Pathway Measures</u>

- Increase drainage capacity (more gullies, bigger pipes, more pipes)
- Separation of sewers
- Managed overland flows
- Improved land management practices

<u>Receptor Measures</u>

- Property level protection (PLP)
- Temporary defence raising
- Resilience and resistance
- Planning policy changes
- Improved emergency response
- Raise Kerbing (RAK)

4.2 Option Selection

From this list above, four of the most suitable options for the area were then selected and included in the hydraulic modelling to provide supporting information for the final choice of options. These four options are:

1. Large Scale SUDS (SUDL) – Ponds and detention basins;
2. Small Scale SUDS (SUDS) – Permeable Pavement;
3. Raise Kerbing (RAK); and
4. Property level Protection (PLP).

In the 3rd progress meeting on 29th April 2015 the model results of the above four options (for all the CDCs) were presented and discussed with the Steering group. Following the progress meeting (April 2015) the Steering group selected a combined option for five of the CDCs. The selected options to be taken forward for assessment are:

- CDC 02: Infiltration Basins and Pond.
- CDC 03: Small infiltration Basins.
- CDC 04: Infiltration Basin off Raby Avenue.
- CDC 06: Infiltration Basin in Loke Park.
- CDC 12: Infiltration Basins.

It was agreed that options would not be selected for the rest CDCs either because there were too few properties benefiting from them to justify works or because there was little space for Sustainable Urban Drainage Systems (SUDS) features.

Further information on the option model results can be found in Figures 23-26 on Appendix D.

4.3 Option Appraisal

All five shortlisted options mentioned above were considered to be technically feasible and progressed for appraisal. Options were packaged together per CDC to form the 'Combined Option' for each individual CDC, as recommended by the client. Although we would usually appraise a number of competing options within the appraisal, in this case, the combined option was judged by the client as the only option which would provide a significant enough reduction in flood risk to make investment worthwhile. Therefore the options appraisal will only consider the combined options as listed in section 4.2.

The table below shows the number of properties which are expected to experience flooding from a 1 in 100 event (moderate), 1 in 30 event (significant) and 1 in 20 event (very significant) under the Do Nothing and the Combined Option Scenarios for each CDC.

Table 4-1: Number of flooded properties

	Baseline Scenario	Mod	Sig	V. Sig	Combined Option	Mod	Sig	V. Sig
CDC 02	20% Most Deprived	0	0	0	20% Most Deprived	0	0	0
	40% Most Deprived	191	81	34	40% Most Deprived	176	56	28
	60% Least Deprived	25	6	4	60% Least Deprived	23	6	4
	Baseline Scenario	Mod	Sig	V. Sig	**Combined Option**	Mod	Sig	V. Sig
CDC 03	20% Most Deprived	184	102	33	20% Most Deprived	170	92	31
	40% Most Deprived	0	0	0	40% Most Deprived	0	0	0
	60% Least Deprived	0	0	0	60% Least Deprived	0	0	0
	Baseline Scenario	Mod	Sig	V. Sig	**Combined Option**	Mod	Sig	V. Sig
CDC 04	20% Most Deprived	61	29	12	20% Most Deprived	61	29	12
	40% Most Deprived	19	4	3	40% Most Deprived	19	4	3
	60% Least Deprived	0	0	0	60% Least Deprived	0	0	0
	Baseline Scenario	Mod	Sig	V. Sig	**Combined Option**	Mod	Sig	V. Sig
CDC 06	20% Most Deprived	69	51	13	20% Most Deprived	68	51	13
	40% Most Deprived	92	59	17	40% Most Deprived	58	51	17
	60% Least Deprived	0	0	0	60% Least Deprived	0	0	0
	Baseline Scenario	Mod	Sig	V. Sig	**Combined Option**	Mod	Sig	V. Sig
CDC 12	20% Most Deprived	103	56	14	20% Most Deprived	95	51	17
	40% Most Deprived	89	44	16	40% Most Deprived	80	43	14
	60% Least Deprived	0	0	0	60% Least Deprived	0	0	0

Note: Indices of Deprivation are produced by Communities and Local Government (CLG) to measure deprivation for every Lower Layer Super Output Area (LSOA) and local authority area in England. 32,482 LSOAs are ranked according to how deprived they are relative to each other.

Assumptions and limitations

The appraisal considered the costs and impacts of options over 100 year timeframe (years 0-99). The base year (year 0) is 2015. All previous prices were uplifted to present day prices and inflation has not been included within forecasts. All future costs and benefits are discounted using the Treasury Social Time Preference rate which is 3.5% for years 0-29, 3% from years 30-74 and 2.5% for years 75-99.

When assessing the costs to implement a scheme, all costs were considered including not only construction costs but also those to promote, design and maintain the scheme. In addition to this, an "optimism bias" was applied to cost evaluations. The optimism bias takes into consideration any potential under estimations of cost that might be made during the early assessment of a scheme and therefore allows for a more conservative and potentially more pragmatic cost assessment. The unit costs and associated assumptions are outlined in Appendix C.

Costs were then inputted into the Defra Appraisal Spreadsheet relating to the year they were expected to be spent. The Defra Appraisal Spreadsheet calculated net present value over the 100 year lifetime of the appraisal, using the Treasury social time preference rate. This rate is 3.5% in years 0 to 30, 3% from years 31 to 75 and 2.5% from year 76 to 99. Discounting is an adjustment used in appraisal to reflect the preference of society to receive benefits (flood risk damage reduction) sooner and pay costs later.

4.4 Option Damage Assessment

A damage assessment was undertaken for the shortlisted options. The methodology for the damage assessment is outlined in Appendix B.

Benefits

Modelling has estimated the following properties at risk of flooding under each flood event.

Table 4-2: Number of flooded properties for the baseline and combined option

	Flood event				
CDC 02 - Residential	Q30	Q75	Q100	Q200	Q100CC
Baseline	18	85	115	186	213
Combined Option	16	61	81	156	197
CDC 02 - Non residential	Q30	Q75	Q100	Q200	Q100CC
Baseline	0	0	0	0	0
Combined Option	0	0	0	0	0

	Flood event				
CDC 03 - Residential	Q30	Q75	Q100	Q200	Q100CC
Baseline	48	102	116	160	179
Combined Option	44	92	109	150	165
CDC 03 - Non residential	Q30	Q75	Q100	Q200	Q100CC
Baseline	0	0	2	2	2
Combined Option	0	0	2	2	2
CDC 04 - Residential	Q30	Q75	Q100	Q200	Q100CC
Baseline	9	29	30	59	64
Combined Option	9	29	30	59	64
CDC 04 - Non residential	Q30	Q75	Q100	Q200	Q100CC
Baseline	2	2	2	8	8
Combined Option	2	2	2	8	8
CDC 06 - Residential	Q30	Q75	Q100	Q200	Q100CC
Baseline	52	94	112	131	140
Combined Option	52	86	94	129	132
CDC 06 - Non residential	Q30	Q75	Q100	Q200	Q100CC
Baseline	2	4	4	6	7
Combined Option	2	4	4	6	7
CDC 12 - Residential	Q30	Q75	Q100	Q200	Q100CC
Baseline	59	92	108	158	182
Combined Option	59	86	101	145	165
CDC 12 - Non residential	Q30	Q75	Q100	Q200	Q100CC
Baseline	0	0	0	0	0
Combined Option	0	0	0	0	0

Expected damage data has been scaled up over the appraisal time period by multiplying the expected annual average damage by 100 years. These were then discounted; discounting is an adjustment which reduces the size of future values to represent, within appraisal, the preference of society to receive benefits sooner. Discounting is an obligation set out in the Treasury Green Book which influences the expenditure of Grant in Aid to projects with more rapid outcomes. The sum of discounted benefits over the appraisal period is the Present Value Benefits; these are presented in the table below.

Table 4-3: Damages avoided compared to the baseline

	Damage (PVd) (£)	**Damage Avoided (£)**	**Benefits (PVb) (£)**
CDC 02 – Combined Option	3,042,833	338,741	338,741
CDC 03 – Combined Option	2,792,812	84,339	84,339
CDC 04 – Combined Option	1,056,465	0	0
CDC 06 – Combined Option	2,055,489	178,225	178,225
CDC 12 – Combined Option	2,439,120	71,005	71,005

The damage avoided as a result of the options developed is greatest in CDC 02, followed by CDC 06 and then CDC 03 and 12. We still expect to see damages from flooding; this is because the options reduce the depth of flooding, but many of the properties are still likely to be flooded but less frequently and to lower depths.

The results of this assessment are shown in the table below. Present Value Costs are the total discounted costs of implementing the chosen flood protection scheme. Present Value Damages are the total discounted damages caused by the effects of flooding. The Net Present Value is the Present Value Benefits (Damages Avoided) less Present Value Costs. The benefit cost ratio is calculated as Present Value Benefits divided by Present Value Costs. Where the Net Present Value is greater than £0 and Benefit Cost Ratio is greater than 1; benefits exceed costs.

Table 4-4: Benefit cost assessment

CDC	PV costs (£)	PV benefits (£)	Average benefit cost ratio (BCR)
02	12,385,798	338,741	0.03
03	7,647,441	84,339	0.01
04	1,286,254	0	0.00
06	1,694,393	178,225	0.11
12	5,248,082	71,005	0.01

The combined option in each CDC has a benefit cost ratio of less than 1. Although the combined option are beneficial in most of the CDCs, the benefit cost ratio is less than 1, meaning that spending more budget on the combined option would not achieve higher benefits per extra pound spent.

5. Action Plan

5.1 Structure and Content

An Action Plan has been developed to outline a range of recommended measures that should be undertaken to manage surface water within Kings Lynn more effectively. It outlines the responsibilities and implications of both structural and non-structural options and details the methods, timescale and responsibility of each proposed action.

Within the Action Plan there are details of general measures that could be implemented across Kings Lynn as well as more specific measures based on the options assessment. The general actions are non-structural and encourage improved surface water management through planning policy and public education and awareness.

The Action Plan should be read in conjunction with details referenced within relevant sections of this document. The Action Plan is included in Appendix E of this report. This is a DRAFT document and it will be revised following client's review.

This Action Plan is a simple summary spreadsheet that has been formulated by reviewing the modelling outputs in order to create a useful set of actions relating to the management and investigation of surface water flooding going forward. It is the intention that the Action Plan is a live document, maintained and regularly updated as actions are progressed and investigated. New actions may be identified by the LLFA, or may be required by changing legislation and guidance over time.

6. Conclusions and Recommendations

6.1 Conclusions

This report comprises the surface water flood mitigation options assessment for Kings Lynn.

As part of the assessment the existing SWMP hydraulic models were updated to incorporate all latest features of the software used. The model constructed for this study was simulated using the latest versions of ISIS and TUFLOW. This allowed for use of the latest functionality available in each software package specifically enhanced representation of soils infiltration.

A pluvial and a fluvial model was run for the area of interest in order to identify the impacts the pluvial and fluvial flood events will have in the study area. Assessment of the model results identified that the pluvial model produces more severe flooding in the Kings Lynn area. Therefore, the pluvial model was used as the baseline model for this study.

Asset failure scenarios for the key structures were also run. The model results indicated that this scenario does not produce any significant changes in flood depth.

Critical Drainage Catchments (CDCs) were identified based on the baseline results. Twelve CDCs were identified in the Kings Lynn area. Following consultation with NCC combined options were developed for five of them.

A damage assessment was performed for the baseline model as well as the combined options. The damage avoided as a result of the options developed is greatest in CDC 02, followed by CDC 06 and then CDC 03 and 12. Damages will still be expected from flooding; this is because the options reduce the depth of flooding, but many of the properties are still likely to be flooded, but less frequently and to lower depths.

The results of this assessment show that the combination of the options chosen to be used in each CDC has a benefit cost ratio of less than 1 for each CDC.

6.2 Recommendations

The updated model used for this study does not include the drainage network. Inclusion of the pipe network in the model might refine the model results for the area of interest.

Action could be taken in order to reduce flood risk within the CDCs. Below are a series of recommendations to further reduce the risk of surface water flooding in the area:

- As part of highways improvement programme include an additional construction task of installing additional gullies or alternative drainage systems to reduce standing water depth and duration.
- Include at least one 'at source' SuDS measure to all proposed developments across the catchment.

- Proposed ‘brownfield’ redevelopments are required to reduce post-development runoff rates for events up to and including the 1 in 100 year return period event with an allowance for climate change. (Refer to Action Plan in Appendix E for more information).

- Focus attention on the maintenance of gully pots in the CDCs which are considered to be high risk.

Appendix A : Detailed Modelling

The Kings Lynn and West Norfolk Settlements SWMP was completed in January 2012. The study assessed pluvial flood risk to 16 settlements across West Norfolk for a range of flood events. Due to project constraints, the flood risk associated with ordinary watercourses was not specifically assessed. Norfolk County Council have commissioned Capita to undertake a more detailed assessment of flood risk from ordinary watercourses within Kings Lynn and its interaction with surface water flooding.

A.1 Model Extent

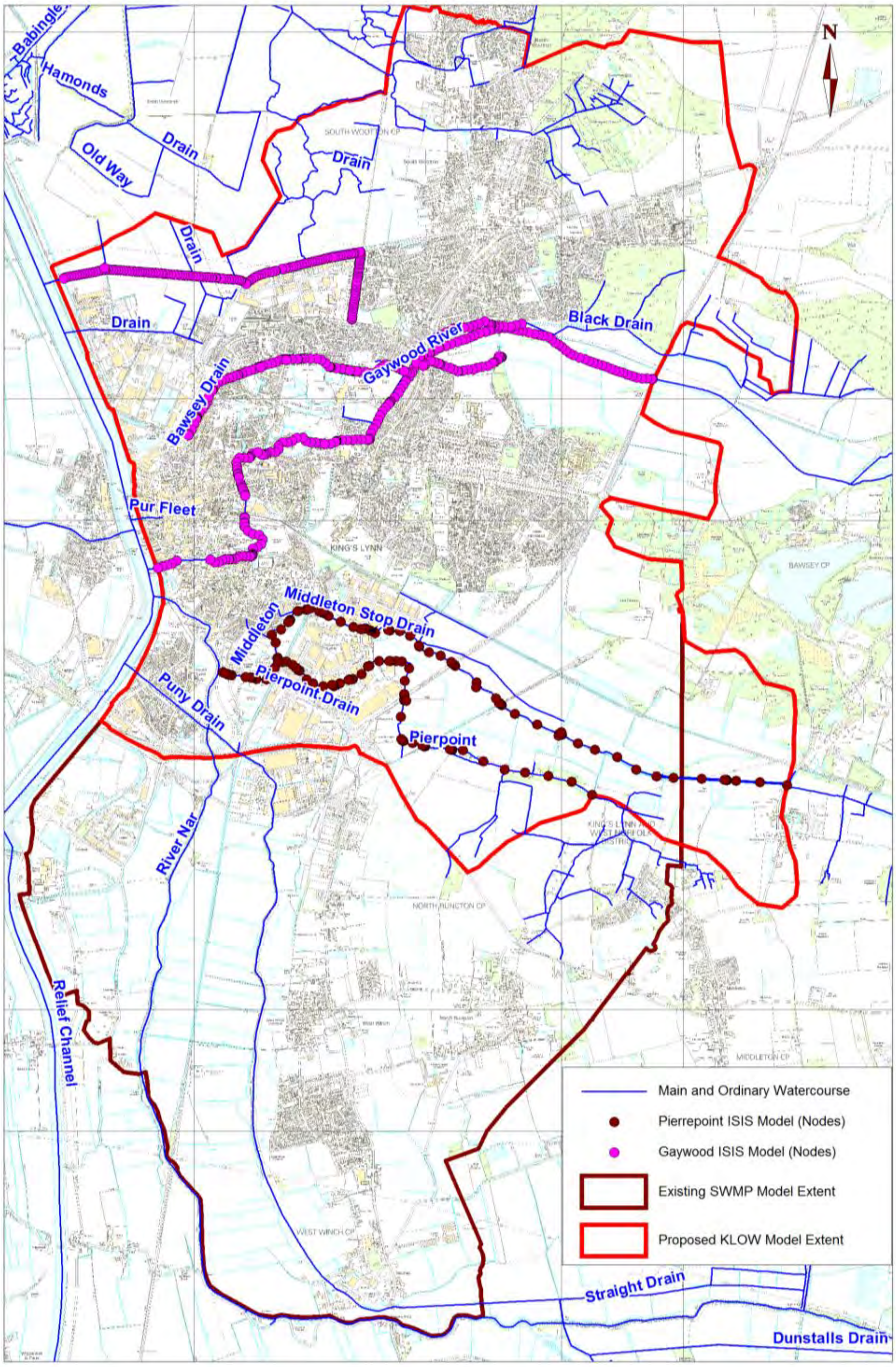
Four 2D TUFLOW hydraulic models were constructed by Capita to inform the SWMP study. The models named “Kings Lynn” covers the area of interest for this additional work and have been used to represent the 2D floodplain of a new combined model to be constructed for this study. Amendments and updates to certain model features are discussed in the subsequent sections of this appendix.

The existing extent of the 2D Kings Lynn SWMP TUFLOW model includes an area to the south that is not of interest as part of the Kings Lynn Ordinary Watercourse (KLOW) Study. This extent was trimmed as shown in Figure A-1 in order to reduce model simulation times. However the extent of the 2D model was extended further to the east to incorporate the upstream reach of the Middleton Stop Drain.

1D ISIS models, produced in 2004 and 2009, of a number of the ordinary watercourses within Kings Lynn were provided by. These models were constructed for River Gaywood Strategic Review and for the Pierrepoint District Strategic Review. Following a review of the existing ISIS models, the vertical datum was amended from “South Level Datum” to “Ordnance Datum Newyln” in order to make the 1D (ISIS) and 2D (TUFLOW) domains consistent. This was done by subtracting 100m from all model node elevations. The extent of the existing IDB’s ISIS models remains same as in the shown in the Figure A-1.

The new Kings Lynn Ordinary Watercourse (KLOW) Study model has been developed by combining the amended 1D ISIS models (from the IDBs) and the updated Kings Lynn 2D model.

Figure A-1: Model extents (existing SWMP and revised KLOW model boundaries)



A.2 Topography

The floodplain ground levels in the existing TUFLOW model have been based on 1m and 2m resolution LiDAR data flow in 2011. A check of the Environment Agency's Geomatics website[1] has shown that there have been no updates to this dataset since. The existing LiDAR data has therefore been retained for use in this study.

Following the review of ISIS models it was identified that the existing model (Gaywood River Model) did not include the more recent survey data, which was collected by Brandon surveys for the Bawsey Drain in 2013 and the right bank of the River Gaywood in July 2014.

A.3 Model updates

The following modifications and updates have been applied to the exiting ISIS and 2D model for the purposes of this study:

- Following a review of the existing ISIS models, the vertical datum was amended from "South Level Datum" to "Ordnance Datum Newyln" in order to make the 1D (ISIS) and 2D (TUFLOW) domains consistent. This was done by subtracting 100m from all model node elevations.
- Gaywood River model has been updated with cross section data from the Brandon surveys for Bawsey Drain in 2013
- The existing Railway Bridge on Middleton Stop Drain has been included in the model. The dimensions of the Railway Bridge were measured during the site visit
- 2d Zsh layers that raises watercourses to bankful in the existing SWMP model has been reviewed / checked and removed from the model for ordinary watercourses (as watercourses are modelled using ISIS)
- The representation of the left and right bank of the River Gaywood has been improved using July 2014 survey data.
- Improved representation of existing structures, where required. For example, in the existing IDB ISIS model the Broad Walk Bridge was modelled as two separate orifice units (9m apart) at BRU_0832 and BRU_0823 using the upstream and downstream openings of the bridge respectively. The Broad Walk Bridge has been represented in the KLOW model as an orifice unit at node BRU_0827,as per survey drawings using the dimension of the downstream face of the bridge since it has the minimum bore area. The node levels and distance between GWD_0832 to GWD_0804 also has been adjusted based on survey data.
- River channel cross sections were truncated, where required, as the floodplains have been represented within the 2D TUFLOW domain.

[1] https://www.geomatics-group.co.uk/GeoCMS/Homepage.aspx

- Removal of all reservoir units and associated spill units as the floodplains are now represented in the 2D domain.
- Interpolated sections were added, where required, in order to improve model stability.
- Panel markers were added to river channel sections, where required, in order to improve the conveyance calculations.

A.4 Structures

The majority of the structures located along the modelled sections of the watercourses were included in the existing ISIS models. The review of the existing ISIS models has identified that the Railway Bridge on Middleton Stop Drain (562939 319284) has not been included in the Pierrepoint ISIS model. This structure has been included in the ISIS model based on the site walkover survey.

A number of pipes (crossing the watercourses) have been deleted from the model where they were tending to create poor convergence, but there was no discernible change in head over the structures.

The Kings Lynn IDB are currently in the process of constructing a new attenuation pond at Queen Elizabeth Way as part of the 'Pierrepoint Scheme' (as detailed in the attached drawing reference C-205124/200 Rev P16). The attenuation pond is currently under construction and has been represented in the existing ISIS (1D) model. The attenuation pond has been represented in the 2D based on the construction drawings (C-205124/200-Rev-P16).

The review of the existing ISIS models also identified that flapped outfalls/gates from River Gaywood, Bawsey Drain and North Lynn Drain have been modelled using sluice gates, and the pumped outlet from the North Lynn Drain modelled as pump unit with automated operation with following operation rules:

The River Gaywood Sluice operating rules are defined to open the sluice gate to a height of 1.71m when the upstream water level is greater than the downstream water level.

The North Lynn Drain Sluice operating rules are defined to open the sluice gate to a height of 1.063m when the upstream water level is greater than the downstream water level.

The Bawsey Drain Sluice operating rules are defined to open the sluice gate to a height of 1.595m when the upstream water level is greater than the downstream water level.

Again for the Pierrepoint Model, the outfall to the River Nar from the watercourses has been modelled as three pumps in parallel, with data drawn from pump curves and IDB operation rules.

All above structure operation rules has been reviewed and modified/adjusted to fit with NewLyn Datum.

A.5 Model Software Version

The model has been simulated with the latest versions of both ISIS and TUFLOW (ISIS version 3. 7.0.110 and TUFLOW version 2013-12-AD-iDP) to make use of additional functionality and improved stability for direct rainfall models. Changes to the mathematical solver in TUFLOW will allow for the model time-step to be increased resulting in a significant reduction in model simulation time. Changes to default settings in either software package may result in changes to the model results.

A.6 Model Boundaries

A.6.1 *Model Inflow*

The hydrological report for the Gaywood River was reviewed and inflows for the Gaywood River, North Lynn, Bawsey and Black Drains generated.

No hydrology report or ISIS inflow boundaries were available for the Pierrepoint Model and the previous study recommended re-estimating flow boundaries using updated methods (since the FEH rainfall-runoff method has been superseded by the Revitalised Flood Hydrograph method) and data. Therefore, additional hydrological calculations have been carried out for the Pierrepoint and Middleton Stop Drains to derive inflows for the ISIS model.

A review of the direct rainfall from the SWMP model and inflows estimated from the ISIS models was carried out to ensure the flood risk is represented as accurately as possible and the fluvial flood risk is not over estimated and included from both approaches. The inflows applied to the model consisted of a combination of point inflows applied to the watercourses and rainfall hyetographs applied to the entirety of the 2D model extent. The point inflows represent runoff from the upper parts of the catchment that are not explicitly modelled.

The existing Kings Lynn SWMP model has been simulated with hydrological inflows based on a storm duration of 3.4hrs. The existing IDB's ISIS model has been simulated with hydrological inflows based on a storm duration of 26.1hrs. As agreed with the NCC, the fluvial and pluvial scenarios have been simulated separately (as the critical storm durations are so different) as shown below:

- Pluvial scenarios- with a critical storm duration of 3.4hrs
- Fluvial scenarios- with a critical storm duration of 26.1hrs

Further details on the hydrology changes can be found Appendix F – Flood Estimation Proforma.

A.6.2 *Downstream Boundaries*

The ordinary watercourses in the study area outfall to the tidally influenced River Great Ouse. The downstream boundary of the Gaywood ISIS model represents a spring tide estimated by extrapolating between known tidal curves at Hammonds Drain and Freebridge. The downstream boundary of the existing Pierrepoint ISIS model has been set as a constant level of River Nar. For this study the downstream boundaries remain the same as the existing IDB's ISIS model.

The tide curves were adjusted so that the peaks were synchronised.

A 2D tidal boundary is not required due to the presence of defences along the eastern boundary of the River Great Ouse.

A.7 Infiltration

The current SWMP model utilises runoff coefficients to represent the soils infiltration. Each land use is assigned a coefficient and the amount of rainfall applied to the model is adjusted according to the specified coefficient. Following the release of the 2012 version of TUFLOW, the Green-Ampt method was made available to represent soils infiltration. This method is more advanced than the use of runoff coefficients as it varies the rate of infiltration over time based on a number of soil characteristics.

The new KLOW 1D-2D model has included representation of soils infiltration using the Green-Ampt method. The classification of soils across the study area are based on data supplied by BGS as well as Cranfield University's Soils capes website. Infiltration has been applied across all permeable land uses in the study area only.

A.8 Representation of the Drainage Network

The TUFLOW models previously constructed for the SWMP study did not include an explicit representation of the drainage network. Instead a 3mm/hr loss was applied to impervious surfaces for some of the SWMP modelled area, to represent available storage within the drainage network. However, this loss was not included in the SWMP model for the Kings Lynn area to represent tide locking of the drainage network. This assumption was also retained for this KLOW study.

Appendix B : Methodology for the Damage Assessment

This comprised of the following steps:

1. Building polygons as defined in the OS MasterMap data were used (© Crown copyright and database rights 2015 Ordnance Survey 100019340).
2. Properties were given a ‘Multicoloured Manual (MCM) code’ based upon their use.
3. All buildings under 25m^2 were assumed not to be residential or commercial properties (e.g. shed) and were removed from the analysis.
4. All properties ‘wet’ to less than 10cm were assumed to experience rain runoff but not surface water flooding. (Note that all properties in the model were ‘wet’ because they received rainfall so this assumption was used to separate properties getting wet and properties being flooded).
5. The average flood depth for each property was determined using the modelled depth outputs for the baseline and combined options, for a range of return periods (2, 30, 75, 100, 100 + climate change, 200 design flood events).
6. Using the Multicoloured Manual depth-damage data for short duration floods with no prior warning, a cost was associated with each flooding depth for each property.
7. Damage costs were set up to be capped at the value of the property (average values of flats, terraced, semi-detached and detached homes were sourced from www.home.co.uk), adjusted by the distributional impacts factor (which increases/decreases this price to account for social grade). Note that damages for properties in this appraisal did not reach the cost of the relevant property over the 100 year time horizon and therefore no capping was undertaken.
8. As well as including damage costs for residential and non-residential properties, damages to vehicles, and emergency services were included. These were based upon a factor of property damages, as advised in the MultiColoured Manual.
9. These damages (by event) were entered into the Defra Appraisal Spreadsheet. Damages for the baseline and combined options were totalled for each return period and were used to calculate the average annual damage, based on the summary of repeated damage calculated for the lifetime of the scheme.
10. The losses due to flood damage were calculated by discounting the damage values (using the Social Preference Rate, as outlined in Treasury Green Book supplementary guidance) to calculate the Present Value damages.
11. The high level cost estimates were assumed to be the initial capital outlay and a maintenance cost of 2.5% of the capital cost applied for every year of the scheme lifetime The present value cost was calculated using the Social Preference Rate, as outlined in Treasury Green Book supplementary guidance.
12. The cost difference between the baseline and combined option costs and damages avoided were used to generate an approximate net present value and cost benefit ratio result.

It is assumed that all combined options will last for 100 years.

Direct damages to properties is the loss caused to both residential and non residential property owners and residents as a result of inundation of the property during a flood event, allowing for damage to the building fabric and structure, and leading to damage of fixtures and fittings, furniture and loss of personal effects or stock.

Emergency service costs are the costs associated with the response of the emergency services during flood events, including police, fire and ambulance services, as well as local authority emergency response teams and the response of the Environment Agency.

Research into the costs to emergency services of flood events has shown that the cost is dictated by the density of settlements in the affected area, with a flood in a highly densely populated area leading to a cost represented by an uplift factor of 5.6% on property damages, while a flood in a less densely populated area will lead to a cost better represented by an uplift factor of 10.7% on property damages. We have used the 5.6% uplift in this appraisal.

Evacuation and Temporary Accommodation costs are the costs associated with short term emergency evacuation of residents during a flood event and providing them with accommodation following a flood event whilst properties are cleaned, repaired and generally made fit for habitation again.

Vehicle Damages are the costs associated with damages to cars and other vehicles in residential areas due to flood inundation. It is estimated that there are 1.15 average vehicles per household in the UK, with an average value of these being £3,100. Therefore, a value of £3,600 is taken per property at which the flood depth exceeds 0.35m above ground level, estimated to be the average depth at which vehicle damage will occur.

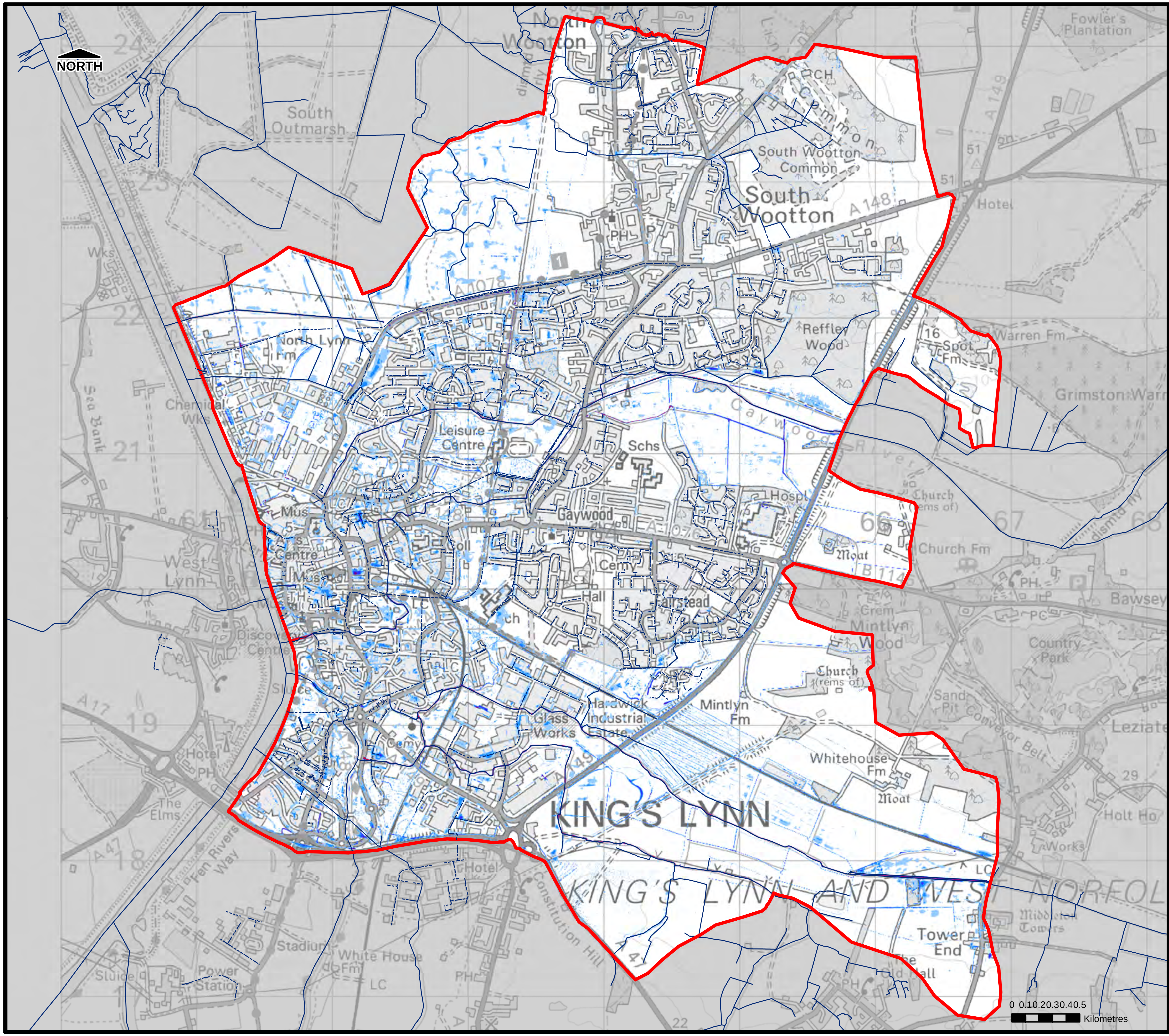
Appendix C : Unit Cost per Option

Description	Unit Type	Unit Measure	Unit Rate (base year prices)	Unit Rate (2014 prices)	Source	Quantity (approx)	Cost (rounded)	Design Fee (15% of Construction Cost)	General Preliminaries (40% of Construction Cost)	TOTAL CAPITAL COSTS (inc. Oncost etc.)	Maintenance cost per annum*	CDC	Assumptions
Pond	Ponds and wetlands	m³ Detention Volume	£33.00	£38.40	CIRIA SuDS manual	20,736.59	£796,000	£119,400	£318,400	£1,233,800	£30,845	2	Volume Calculated from difference modelled DEM_Z difference grids
Pond excavation	Excavation	Volume of excavation m³	£4.04	£4.48	Spons	20,736.59	£93,000	£13,950	£37,200	£144,150	£0	2	As Above
Disposal of excavation material	Landfill Non hazardous gate fee only (m3)	Volume of excavation m³	£33.64	£34.22	WRAP gate fees report (2013)	20,736.59	£709,519	£106,428	£283,808	£1,099,754	£0	2	
Add pipe Connected to the pond	Increase capacity in drainage system	m length of box culvert	£0.00	£1,200.00	EA FRM Estimating Guide Appendix B	211	£253,000	£37,950	£101,200	£392,150	£9,804	2	Circular culvert d= 0.5 211m long (pipes assumed to have d=0.8 since this is the smallest in the table. Note: EA advise not to use costs for circular pipes. Circular pipes are likely to be cheaper 'off the shelf' compared to box culverts, therefore these costs are likely to be conservative.)
Culvert excavation	Excavation	Volume of excavation m³	£4.04	£4.48	Spons	41	£180	£27	£72	£279	£0	2	As above (A=0.2m2 L=211m)
Disposal of excavation material	Landfill Non hazardous gate fee only (m3)	Volume of excavation m³	£33.64	£34.22	WRAP gate fees report (2013)	41	£1,403	£210	£561	£2,174	£0	2	
Infiltration Practice (Detention Basins)	Infiltration Practice	per m³ Stored Volume	£89.13	£106.96	CIRIA SuDS Manual (2007)	13912.17	£1,488,000	£223,200	£595,200	£2,306,400	£57,660	2	Assumed 1.5m deep (total area of Infiltration Basins = 9275 m2)
Infiltration Practice (Detention Basins)	Infiltration Practice	per m³ Stored Volume	£89.13	£106.96	CIRIA SuDS Manual (2007)	17347.67	£1,855,000	£278,250	£742,000	£2,875,250	£71,881	3	Assumed 1.5m deep (total area of Infiltration Basins = 11565 m2)
Infiltration Practice (Detention Basins)	Infiltration Practice	per m³ Stored Volume	£89.13	£106.96	CIRIA SuDS Manual (2007)	2917.92	£312,000	£46,800	£124,800	£483,600	£12,090	4	Assumed 1.5m deep (total area of Infiltration Basins = 1945 m2)

Description	Unit Type	Unit Measure	Unit Rate (base year prices)	Unit Rate (2014 prices)	Source	Quantity (approx)	Cost (rounded)	Design Fee (15% of Construction Cost)	General Preliminaries (40% of Construction Cost)	TOTAL CAPITAL COSTS (inc. Oncost etc.)	Maintenance cost per annum*	CDC	Assumptions
Infiltration Practice (Detention Basins)	Infiltration Practice	per m³ Stored Volume	£89.13	£106.96	CIRIA SuDS Manual (2007)	3842.12	£411,000	£61,650	£164,400	£637,050	£15,926	6	Assumed 1.5m deep (total area of Infiltration Basins = 2561m2)
Infiltration Practice (Detention Basins)	Infiltration Practice	per m³ Stored Volume	£89.13	£106.96	CIRIA SuDS Manual (2007)	11906.49	£1,273,000	£190,950	£509,200	£1,973,150	£49,329	12	Assumed 1.5m deep (total area of Infiltration Basins = 7938 m2)

The unit cost for each of the SuDS practices have been derived from available cost data, including the CIRIA SuDS Manual (2007) and EA FRM Estimating Guide as explained above. However, the costs of the actual schemes could be lower or higher depending on individual site circumstances.

Appendix D : Figures



THIS DRAWING MAY BE USED ONLY FOR THE PURPOSE INTENDED

Legend

- Main and Ordinary Watercourse
- Model Extent
- CDC Boundary
- Sewer- Surface and Combined

Flood Depth (m)

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

King's Lynn Ordinary Watercourse Flood Investigation

Scale at A3	Date	Drawn by	Approved by
1:27,000	July 2015	G. Athanasia	M. Mamun

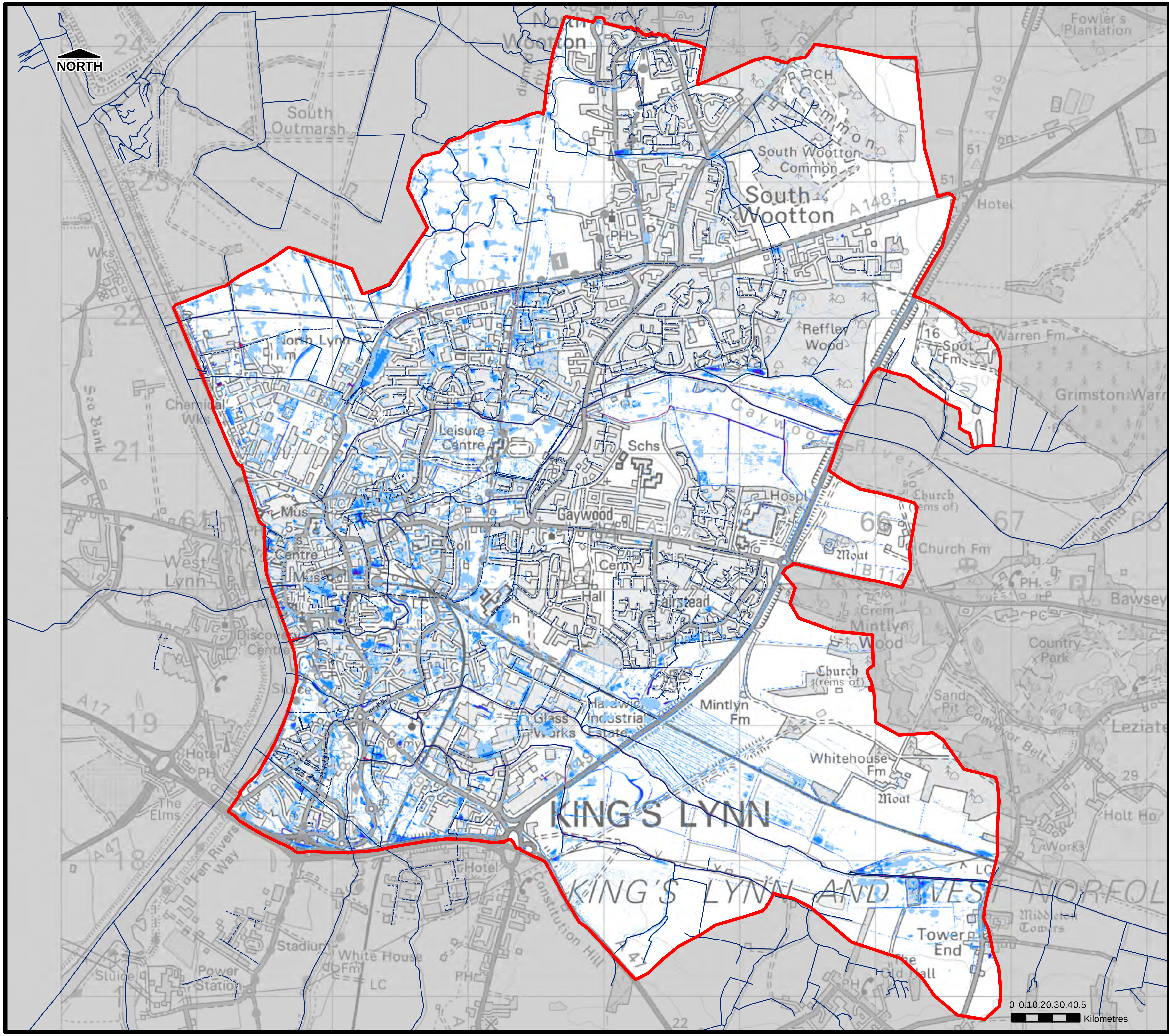
DRAFT
Flood Depth
1 in 30yr, 3.4hr duration

Consultant

CAPITA

Capita
Level 4
65 Gresham Street
EC2V 7NQ

FIGURE 1



THIS DRAWING MAY BE USED ONLY FOR THE PURPOSE INTENDED

Legend

- Main and Ordinary Watercourse
- Model Extent
- CDC Boundary
- Sewer- Surface and Combined

Flood Depth (m)

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

King's Lynn Ordinary Watercourse Flood Investigation

Scale at A3	Date	Drawn by	Approved by
1:27,000	July 2015	G. Athanasia	M. Mamun

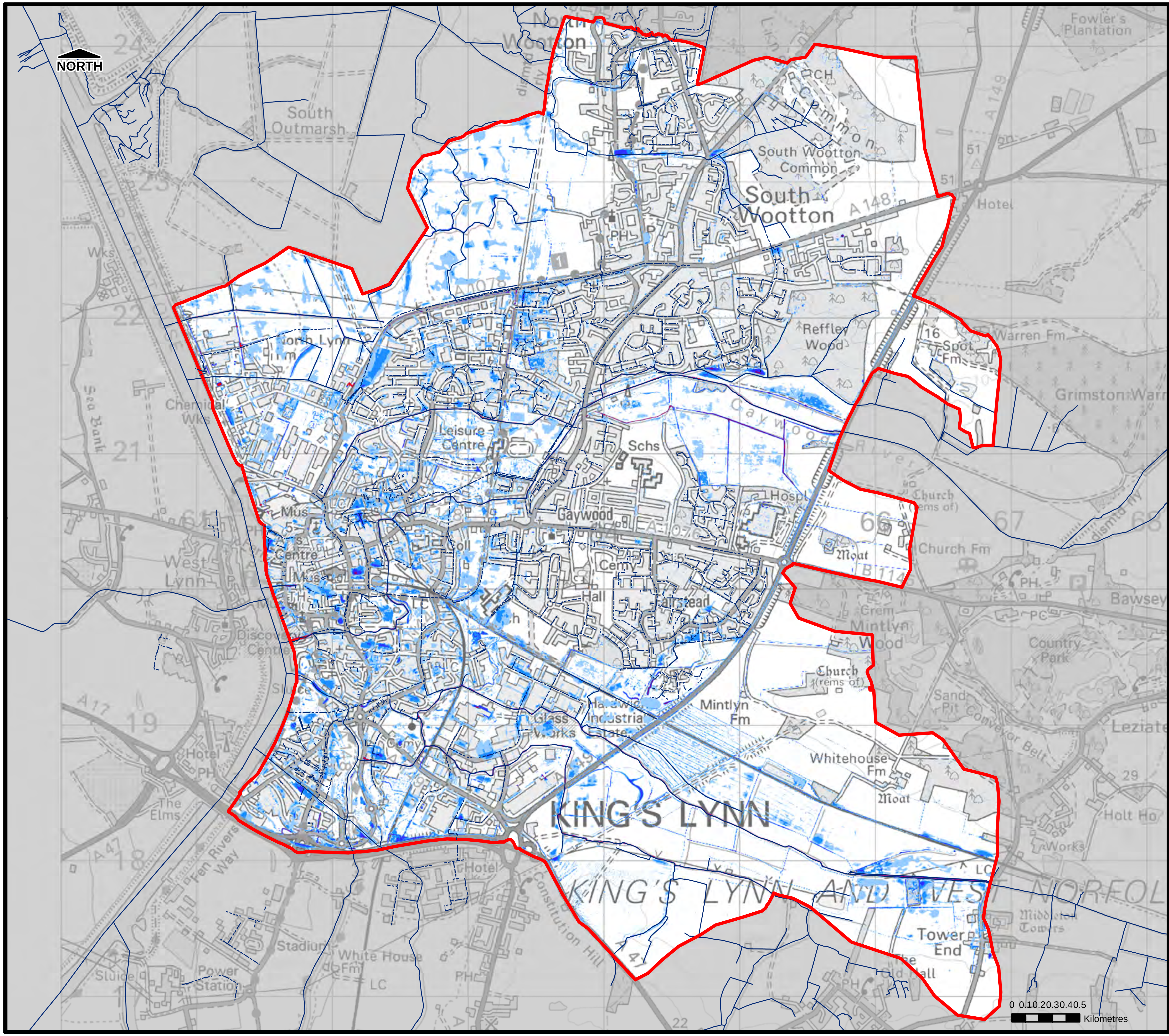
DRAFT
Flood Depth
1 in 75yr, 3.4hr duration

Consultant

CAPITA

Capita
Level 4
65 Gresham Street
EC2V 7NQ

FIGURE 2



Legend

- Main and Ordinary Watercourse
- Model Extent
- CDC Boundary
- Sewer- Surface and Combined

Flood Depth (m)

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

King's Lynn Ordinary Watercourse Flood Investigation

Scale at A3	Date	Drawn by	Approved by
1:27,000	July 2015	G. Athanasia	M. Mamun

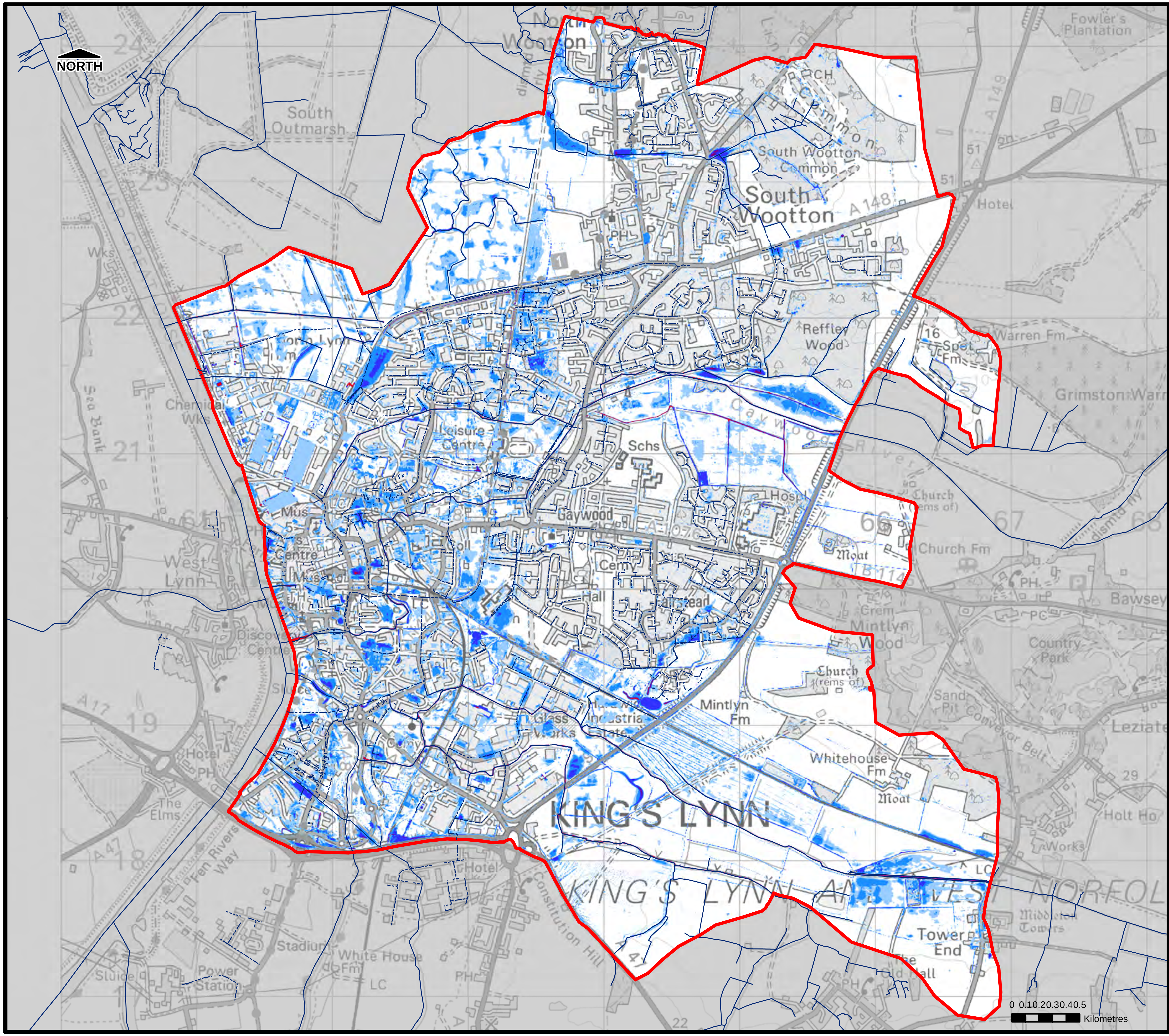
DRAFT
Flood Depth
1 in 100yr, 3.4hr duration

Consultant

CAPITA

Capita
Level 4
65 Gresham Street
EC2V 7NQ

FIGURE 3



Legend

- Main and Ordinary Watercourse
- Model Extent
- CDC Boundary
- Sewer- Surface and Combined

Flood Depth (m)

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

King's Lynn
Ordinary Watercourse Flood Investigation

Scale at A3	Date	Drawn by	Approved by
1:27,000	July 2015	G. Athanasia	M. Mamun

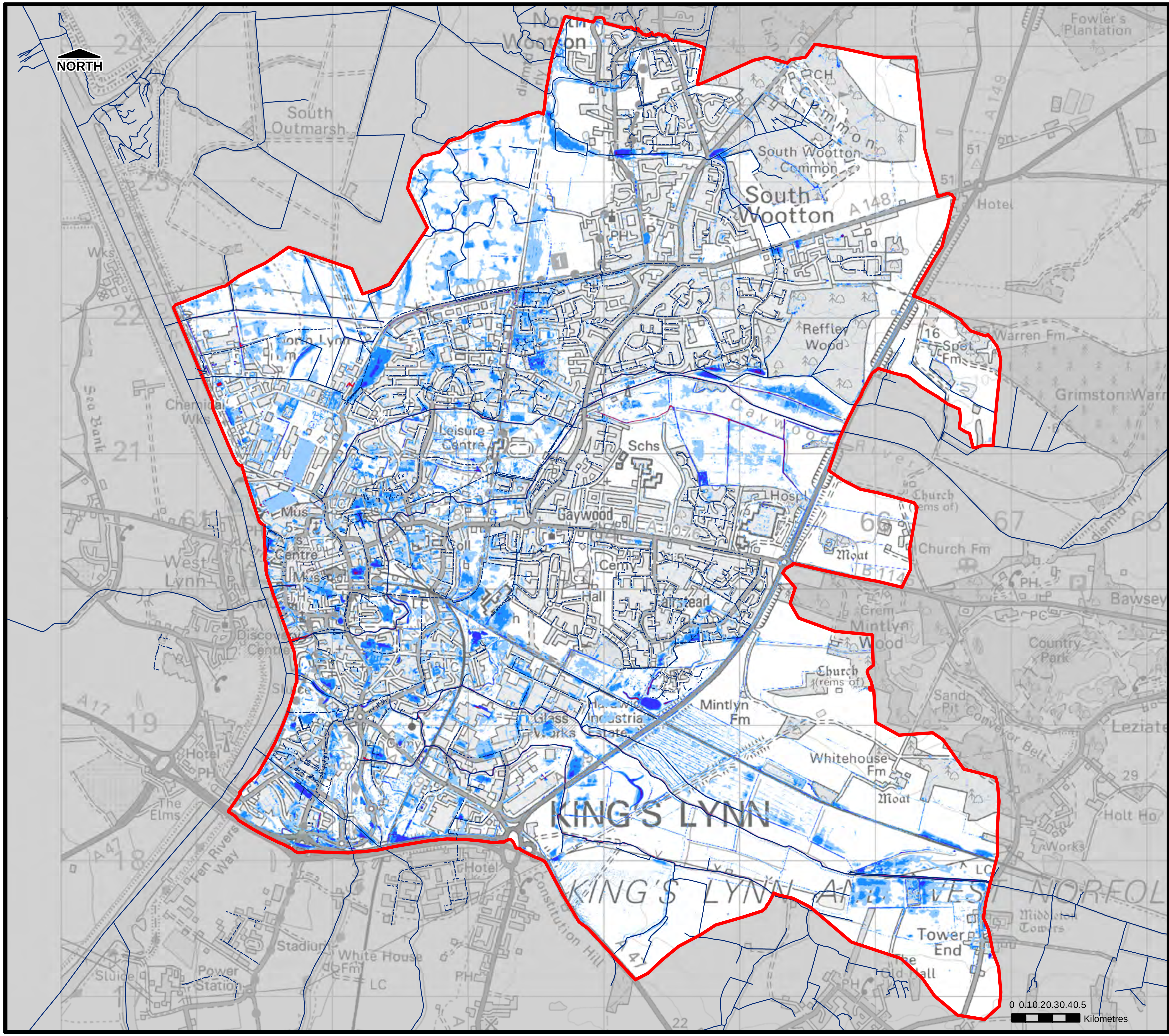
DRAFT
Flood Depth
1 in 100yr CC, 3.4hr duration

Consultant

CAPITA

Capita
Level 4
65 Gresham Street
EC2V 7NQ

FIGURE 4



THIS DRAWING MAY BE USED ONLY FOR THE PURPOSE INTENDED

Legend

- Main and Ordinary Watercourse
- Model Extent
- CDC Boundary
- Sewer- Surface and Combined

Flood Depth (m)

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

King's Lynn Ordinary Watercourse Flood Investigation

Scale at A3	Date	Drawn by	Approved by
1:27,000	July 2015	G. Athanasia	M. Mamun

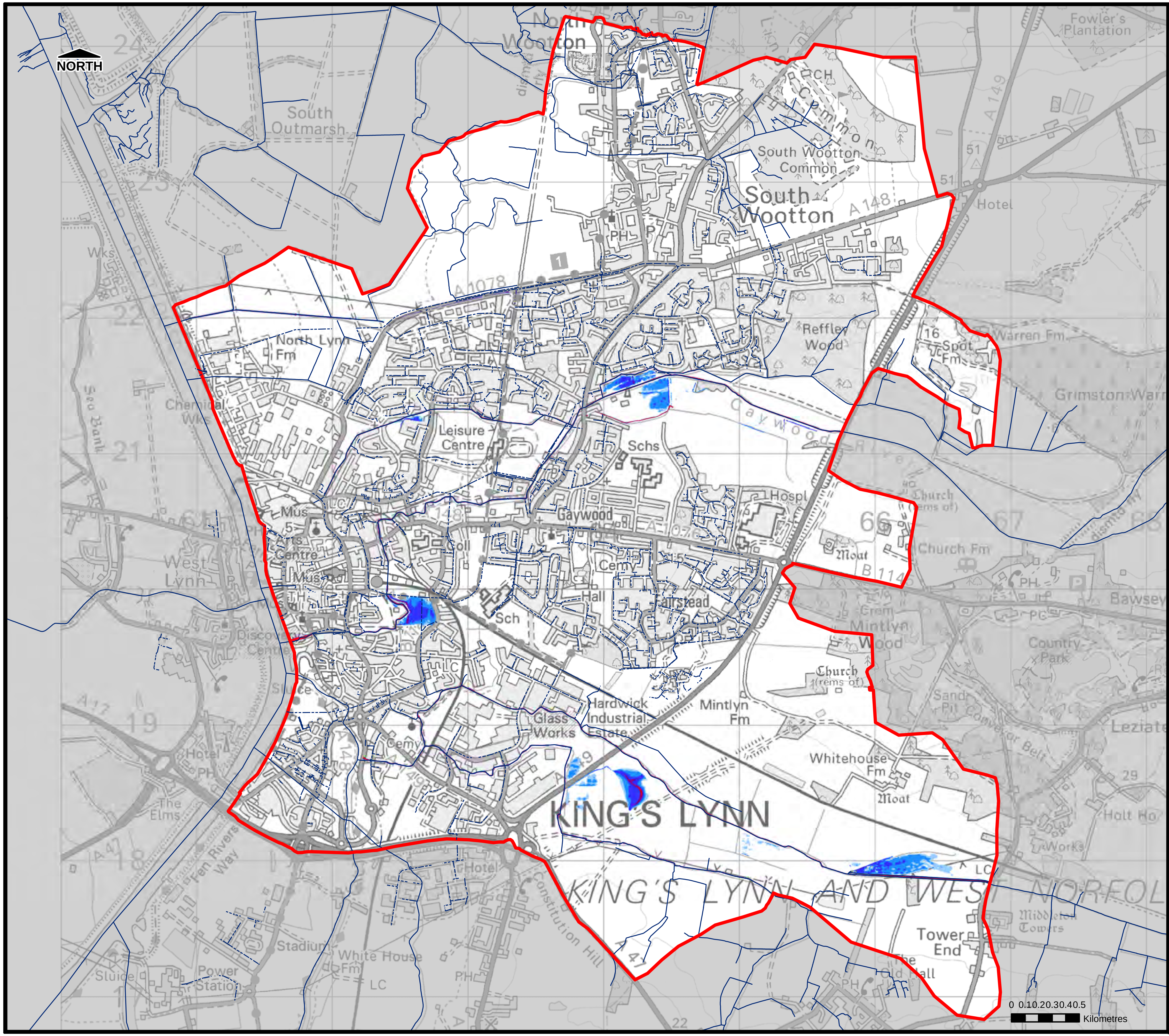
DRAFT
Flood Depth
1 in 200yr, 3.4hr duration

Consultant

CAPITA

Capita
Level 4
65 Gresham Street
EC2V 7NQ

FIGURE 5



THIS DRAWING MAY BE USED ONLY FOR THE PURPOSE INTENDED

Legend

- Main and Ordinary Watercourse
- Model Extent
- CDC Boundary
- Sewer- Surface and Combined

Flood Depth (m)

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

King's Lynn Ordinary Watercourse Flood Investigation

Scale at A3	Date	Drawn by	Approved by
1:27,000	July 2015	G. Athanasia	M. Mamun

DRAFT
Flood Depth, Fluvial Flow
1 in 30yr, 26.1hr duration

Consultant

CAPITA

Capita
Level 4
65 Gresham Street
EC2V 7NQ

FIGURE 6