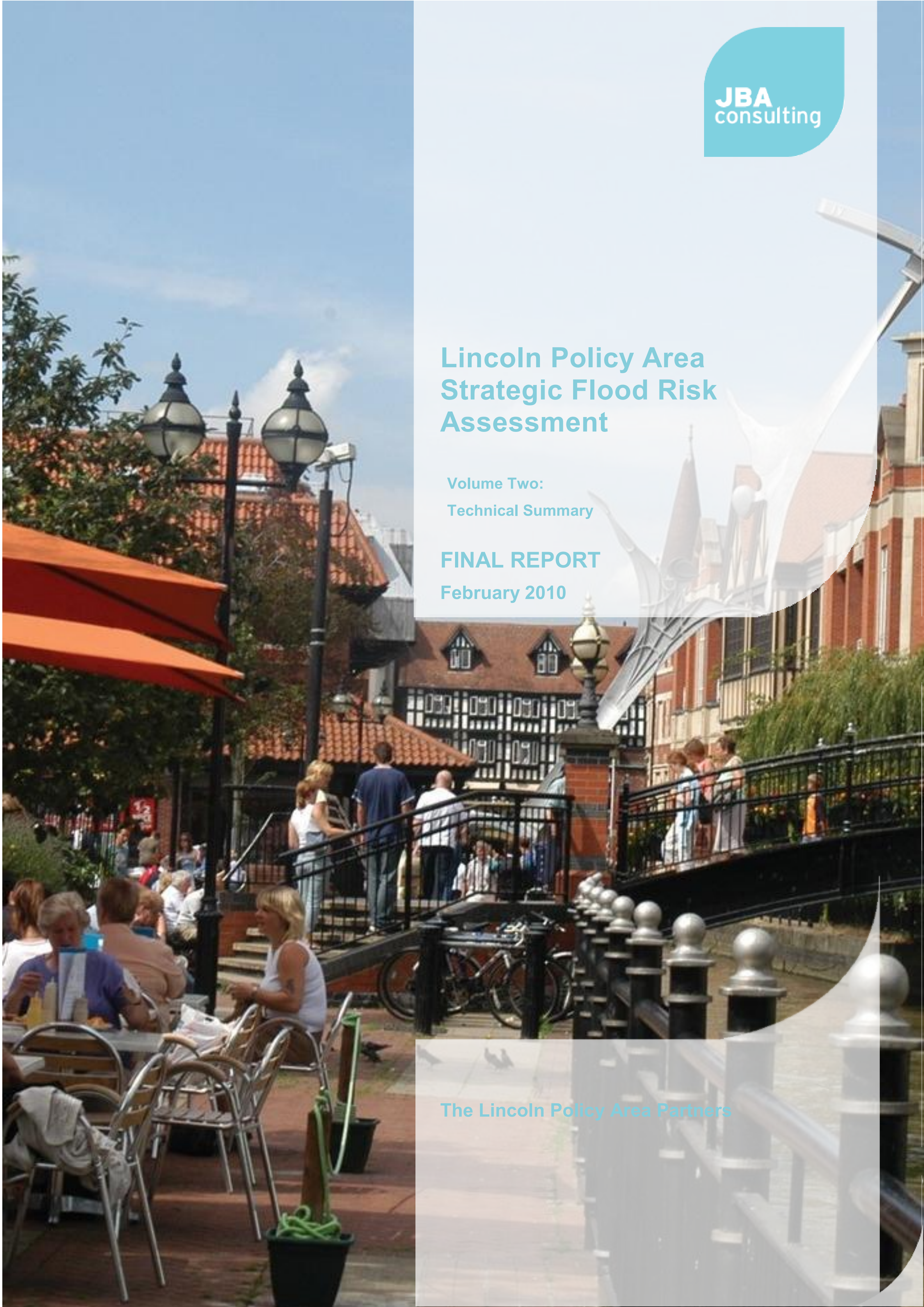

Lincoln Policy Area Strategic Flood Risk Assessment

Volume Two:

Technical Summary

FINAL REPORT

February 2010

The Lincoln Policy Area Partners

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Contract

This report describes work commissioned by The City of Lincoln Council, on behalf of The Lincoln Policy Area. The City of Lincoln Council 's representative for the contract was Toby Forbes-Turner. Matthew Hemsworth of JBA Consulting carried out this work.

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Purpose

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Acknowledgments

JBA would like to thank all those at Lincoln City Council, the Environment Agency and IDB's who provided information and data to support this project. Their assistance is gratefully acknowledged.

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Executive Summary

This report is a Strategic Flood Risk Assessment (SFRA) for The Lincoln Policy Area. It is a combined Level 1 and Level 2 SFRA that incorporates the requirements of a scoping study SFRA (Level 1) and increased scope SFRA (Level 2). This SFRA has been prepared in accordance with current best practice, Planning Policy Statement 25 Development and Flood Risk (PPS25) and updates the previous SFRA published in 2002.

The SFRA constitutes one of a number of planning tools that enables the local authority to select and develop sustainable site allocations away from areas of greatest vulnerability to flooding in Lincoln. The assessment does not focus on specific development sites. The report discusses the broad scale flood risk within the whole policy area, and also focuses in more detail in an extended area of the City of Lincoln including North Hykeham and the Western Growth Corridor (Figure 1-1). This allows for an informed decision to be taken when allocating future development sites. It sets out the procedure to be followed when assessing sites in the future. The SFRA will provide the local planning authorities with the necessary detailed information to make informed decisions when considering development and flood risk issues.

The SFRA is intended to be a “live” document, updated when appropriate to reflect changes in the area and as new information becomes available.

Relevant planning, policy and guidance documents have been taken into account in preparing this SFRA. The documents which have been reviewed include national, regional and local planning legislation, together with Environment Agency policy guidance.

A thorough review of existing information and the construction of new hydraulic models has identified the level of flood risk in the Lincoln Policy Area from fluvial (river flooding).

Consultation has been undertaken with the City of Lincoln Council, the Environment Agency, local Internal Drainage Boards (IDB), British Waterways and Anglian Water to assess the current flood risk from all sources.

The Environment Agency Flood Zone Maps are included in the SFRA. The Flood Zone Maps show indicative flood outlines based on a broadscale assessment of fluvial flood risk only and do not take into account the protection offered by any defences. There are three Flood Zones. Flood Zone 1 classifies areas with a low probability of flooding. Flood Zone 2 (1 in 1000yr) is considered suitable for water-compatible, less vulnerable, more vulnerable and essential infrastructure. Highly vulnerable development is only allowed where the Exception Test is passed. Flood Zone 3 is split in to 2 sections; Zone 3a represents areas with a high probability of flooding (ie 1 in 100yr) and Zone 3b represents the functional floodplain. This is normally defined by the 1 in 20 year flood outline where water is able to spill out of the river channel. In Lincoln 1 in 20 year flows remain in channel except for in specified washland areas designed to hold flood waters.

Hydraulic modelling has been undertaken for the level 2 SFRA within the City of Lincoln to establish more realistic indicative flood outlines in key areas that take into account defences and consider how flood water flows within a floodplain. This modelling (which includes allowances for climate change to 2108) calculates expected depths and velocities of flood water across the floodplain and allows consideration of the flood risk to people and properties. Modelled flood outlines also take in to account the effects of climate change.

The flood scenarios considered in the SFRA are 1 in 100 year with climate change and 1 in 1000 year with climate change annual chance flood events, which may also be expressed as 1%+cc and 0.1%+cc Annual Exceedance Probability (AEP) flood events.

An investigation has been carried out into the effect of defences on flood risk and the risk that remains behind them, for example by failure (due to breach) or overtopping. Purpose built, formal defences have been considered and also other features such as privately owned walls and road and rail embankments, which were not built specifically as flood defences, but which have an impact on the flow of flood water due to their elevated level.

The main flood risk within the Lincoln Policy Area is considered to be from fluvial flooding.

Following major flooding in 1947 and 1958, feasibility studies were undertaken in 1977 to investigate flood risk in Lincoln and possible flood alleviation schemes. As a result, a scheme was implemented, which consisted of two controlled washlands constructed upstream of Lincoln City Centre; one at the confluence of the River Witham and Brant, known as the Witham washlands (5km south of Lincoln), and the other on the River Till (7km to the north-west), which provide a 1 in 100-year level of flood protection. The washlands were created by building shallow embankments across the river valley, with control sluices in the rivers, which allow the amount of water in the washlands to be regulated. Pumping stations aid the final draining of the washlands. The scheme was completed in 1991.

Apart from the control gates at the washlands there are also automated control gates at Stamp End and at the upstream end of Sincil Dyke (Bargate Sluices). All of these control gates are used to keep water levels in Lincoln below critical levels, which were set taking account of existing defence levels. The water level in Lincoln is kept between 4.36m AOD and 5.7m AOD. A set of rules and criteria for the operation of the washlands exists. This is held by the Lincs Washlands Operating Team. The control gates at the washlands are operated manually based on levels and flows from telemetry sites upstream.

The present flood risk within the Lincoln Policy Area has been determined with reference to the Environment Agency's Flood Zone Map (FZM) 2009 and overtopping and breach analysis of the flood defences within the City of Lincoln.

Overtopping and Breach analyses have been undertaken showing the possible depths and hazard mapping has been undertaken (taking into account depth and velocity). Overtopping and Breach analyses have been carried out using JBA's in-house raster based 2-D model JFLOW, to enable the production of maps showing overtopping and breach extent. Maps and GIS layers have been provided.

The flood defence condition has also been summarised (in Volume 2) from information received from the Environment Agency. The condition of flood defences throughout Lincoln ranges from Good to Poor.

2D flood modelling within the 'extended' area of the City of Lincoln (including north Hykeham and the Western Growth corridor) for both the 100 year with climate change and 1000 year with climate change flood scenarios has shown that flood defences will overtop. Breach analysis of flood defences has shown flood water to extend over a large area of the existing low land within the City area. The areas to the Western side of the River Witham in Lincoln are at the greatest risk from flood defence failure.

The SFRA provides guidance relating to future development. It provides advice on any site-specific requirements for a Flood Risk Assessment within the different flood zones, and advises the local authorities on the use of the Exception Test, should the Sequential Test be passed.

Guidance for the local authorities on the future management of development with respect to flood risk has been given, relevant to the different flood zones and possible types of development.

In addition, an outline has been given of requirements for developers for Flood Risk Assessments, with supporting guidance on reducing flood risk and making development safe, including Sustainable Drainage Systems (SuDS) and flood mitigation measures. Advice is also given on environmental improvement opportunities and other issues to consider as part of a development proposal.

The SFRA is presented in four volumes: Volume 1 provides a non-technical summary of the SFRA process and findings, Volume 2 provides a technical summary of methods used to produce the SFRA, Volume 3 provides guidance for those using the SFRA and Volume 4 includes the mapped outputs of the SFRA.

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Abbreviations

AEP	Annual Exceedance Probability
AONB	Area of Outstanding Natural Beauty
CC	Climate Change
CFMP	Catchment Flood Management Plan
DEFRA	Department for the Environment, Food and Rural Affairs
EA	Environment Agency
FRA	Flood Risk Assessment
FZ	Flood Zone
Ha	Hectare
JBA	Jeremy Benn Associates Ltd
LDD	Local Development Document
LDF	Local Development Framework
LPA	Local Planning Authority
m AOD	Metres Above Ordnance Datum
MSfW	Making Space for Water
OS NGR	Ordnance Survey National Grid Reference
PPG25	Planning Policy Guidance Note 25
PPS25	Planning Policy Statement 25
RFRA	Regional Flood Risk Appraisal
SFRA	Strategic Flood Risk Assessment
SSSI	Site of Specific Scientific Interest
SuDS	Sustainable Drainage Systems

Definitions

Annual Exceedance Probability	e.g. 1% AEP	Refer to 'probability'.
Brownfield		Brownfield (sites or land) is a term in common usage that may be defined as 'development sites or land that has previously been developed'. Prior to PPS25, the term 'Brownfield' was used in Governmental Guidance and Statements, but in PPS25 has been replaced with 'Previously-developed land'. See 'Greenfield'.
Catchment Flood Management Plan	CFMP	A strategic planning tool through which the Environment Agency will seek to work with other key decision-makers within a river catchment to identify and agree policies for sustainable flood risk management.
Compensatory Storage		A floodplain (flood storage) area introduced to compensate for the loss of storage as a result of filling for development purposes.
Core Strategy	CS	This is the strategic vision of an area and is a central pillar of the Local Development Framework, comprising: A Vision, Strategic Objectives, a spatial land use strategy, core policies and a monitoring and implementation framework. The Core Strategy is a Development Plan Document which will determine overall patterns of future development, identifying broad locations where future growth will take place. All other Development Plan Documents should be in broad conformity with the Core Strategy Document The Core Strategy is a mandatory document, and a timetable for production is set out within the Local Development Scheme.
Defended Area		An area offered a degree of protection against flooding through the presence of a flood defence structure.
Development Plan Documents	DPDs	These documents have Development Plan Status and consequently form part of the statutory development plan for the area. A DPD will be subject to an independent examination. Typical documents that will have DPD status include the Core Strategy, Site-specific Allocations of Land, Proposals Map, and Area Actions Plans (where needed).
Environment Agency	EA	An executive non-departmental public body. It's principle aims are to protect and improve the environment and to promote sustainable development.
Exception Test		An integral part of the risk-based approach at the core of PPS25, the Exception Test is designed to allow for those exceptional circumstances when, for wider sustainability reasons, development not entirely compatible with the level of flood risk may be permitted. For the Exception Test to be passed, all three of its components must be fulfilled.
Flood Estimation Handbook	FEH	Provides current methodologies for estimation of flood flows for the UK.
Flood Hazard		A classification system developed by DEFRA/Environment Agency that gives an assessment of the hazard posed by a flood event at a given location. It is defined using the maximum modelled flood depth, velocity and a factor to allow for debris.
Floodplain		Any area of land over which water flows or is stored during a flood event or would flow but for the presence of defences.
Flood Risk Assessment	FRA	A detailed site-based investigation that is undertaken by the developer at planning application stage.

Flood Risk Management		The introduction of mitigation measures (or options) to reduce the risk posed to property and life as a result of flooding. It is not just the application of physical flood defence measures.
Flood Zone 1	FZ1	This zone comprises land assessed as having a less than 1 in 1000 annual probability of river or sea flooding in any year (<0.1%).
Flood Zone 2	FZ2	This zone comprises land assessed as having between a 1 in 100 and 1 in 1000 annual probability of river flooding (1%-0.1%) or between a 1 in 200 and 1 in 1000 annual probability of sea flooding (0.5%-0.1%) in any year.
Flood Zone 3a	FZ3a	This zone comprises land assessed as having a 1 in 100 or greater annual probability of river flooding (>1%) or a 1 in 200 or greater annual probability of flooding from the sea (>0.5%) in any year.
Flood Zone 3b	FZ3b	This zone comprises land where water has to flow or be stored in times of flood. This is land which would flood with an annual probability of 1 in 20 (5%) or greater in any year or is designed to flood in an extreme (0.1%) flood.
Fluvial Flooding		Flooding caused by the overtopping of river or stream banks.
Formal Defence		A flood defence asset that is maintained by the Environment Agency.
Freeboard		A 'safety margin' to account for residual uncertainties in water level prediction and/or structural performance, expressed in mm.
Functional Floodplain		An area of land where water has to flow or be stored in times of (fluvial) flooding.
Greenfield		Greenfield (sites or land) is a term in common usage that may be defined as 'development sites or land that has not previously been developed'. Prior to PPS25 the term 'Greenfield' was used in Governmental Guidance and Statements, but in PPS25 has been replaced with 'Undeveloped land' See 'Brownfield'.
Informal Defence		A structure that provides a flood defence function, however is not owned nor maintained by the Environment Agency.
Internal Drainage Board	IDB	An Internal Drainage Board is a statutory body which provides flood protection and water level management services
ISIS		1-Dimensional hydraulic modelling software used to demonstrate flow within river channels
JFLOW		Proprietary 2-Dimensional hydraulic modelling software package developed by JBA, which demonstrates overland flow in floodplains
Local Development Framework	LDF	The Local Development Framework is made up of a series of documents that together will form part of the Development Plan. Broadly, Local Development Framework documents fall into two categories: - Development Plan Documents - Supplementary Planning Documents.

Local Development Scheme	LDS	A Local Development Scheme is a public statement of the Council programme for the preparation of Local Development Documents which will form the Local Development Framework.
Local Planning Authority	LPA	Local authority with responsibility for determining whether proposed developments are approved or otherwise.
Main River		A watercourse designated as such by DEFRA that is regulated and maintained by the Environment Agency using their permissive powers.
Measure		A deliverable solution that will assist in the effective management (reduction) of risk to property and life as a result of flooding, e.g. flood storage, raised defence, effective development control and preparedness, and flood warning.
Mitigation		The management (reduction) of flood risk.
Option		Refer to 'measure'.
PAG2		Project Appraisal Guidance (PAG) 2 (Strategic Planning) outlines the DEFRA requirements against which the Environment Agency must demonstrate that they are managing flood risk in a strategic (catchment wide) manner.
Probability	e.g. 1%	A measure of the chance that an event will occur. The probability of an event is typically defined as the relative frequency of occurrence of that event, out of all possible events. Probability can be expressed as a fraction, percentage or a decimal. For example, the probability of obtaining a six with the shake of a fair die is 1/6, 16% or 0.166. Probability is often expressed with reference to a time period, for example, annual exceedance probability. For example, a 1% AEP event is an event with a 1% chance of occurring or being exceeded in any one year.
Proposals Map		This is an Ordnance Survey based map that spatially illustrates policies and proposals within LDDs. The Proposals Map will show planning policy designations and land allocations identified within DPDs, statutory land use and landscape designations and other land and area based designations. It will form part of the statutory development plan.
Residual Risk		The risk that inherently remains after implementation of a flood mitigation measure (option).
Return Period	e.g. 1 in 100-Year	The expected (mean) time (usually in years) between the exceedance of a particular extreme threshold. Return period is traditionally used to express the frequency of occurrence of an event, although it is often misunderstood as being a probability of occurrence.
Risk		The threat to property and life as a result of flooding, expressed as a function of probability (that an event will occur) and consequence (as a result of the event occurring).
Sequential Flood Risk Test	SFRT	The assessment and 'categorisation' of flood risk on a catchment-wide basis in accordance with PPS25.
Site Specific Allocations Development Plan Document		A mandatory document, the Allocations Development Plan Document is a high priority item for preparation, details of which are provided in the Local Development Scheme. Prepared in conformity with the Core Strategy, once approved, the Allocations Document will identify sites for development as part of

		the delivery of the overall planning strategy for the area.
Standard of Protection	SoP	The return period to which properties are protected against flooding
Strategic Flood Risk Assessment	SFRA	The assessment of flood risk on a catchment-wide basis for proposed development in a District
Strategic Flood Risk Management	SFRM	Considers the management of flood risk on a catchment-wide basis, the primary objective being to ensure that the recommended flood risk management 'measures' are sustainable and cost effective
Supplementary Planning Documents	SPD	Supplementary Planning Documents, or SPD, support DPDs in that they may cover a range of issues, both thematic and site specific. Examples of SPDs may be design guidance or development briefs. SPDs may expand policy or provide further detail to policies in a DPD. They will not be subject to independent examination.
Sustainable Drainage Systems	SuDS	Current 'best practice' for new development that seeks to minimise the impact upon the localised drainage regime, e.g. through the use of pervious areas within a development to reduce the quantity of runoff from the development.
TUFLOW		2-Dimensional hydraulic modelling software package with links to ISIS, which demonstrates overland flow in floodplains
Uncertainty		A reflection of the (lack of) accuracy or confidence that is considered attributable to a predicted water level or (modelled) flood extent.
Washlands		Areas which are not susceptible to flooding in a 20 year flood event and hence not classified as Flood Zone 3b, but are considered of vital importance as floodplains and should therefore be treated as functional floodplain
Windfall Sites		Sites that become available for development unexpectedly and are not included in a planning authority's development plan as allocated land.

1 Introduction

1.1 Background

JBA Consulting was commissioned in November 2008 by The City of Lincoln Council to undertake a review of the existing Strategic Flood Risk Assessment (SFRA) for the Lincoln Policy Area and update it in accordance with current best practice, Planning Policy Statement 25 Development and Flood Risk (PPS25)i. The supporting guidance, "Development and Flood Risk: A Practice Guide", The East Midlands Regional Flood Risk Appraisal, the Lincoln Integrated Urban Drainage Pilot Study and the Lincoln Water Cycle Study have also been referred to

The SFRA will assist the Local Planning Authority (LPA) to make the spatial planning decisions required to inform their Local Development Framework (LDF).

The SFRA is a planning tool that enables the Local Planning Authority (LPA) to select and develop sustainable allocations away from the highest flood risk areas. This report sets out the procedure to be followed when assessing sites for development in the future.

The SFRA should be treated as a 'dynamic' document that is periodically reviewed as the policy area changes or if further information becomes available to provide a better understanding of flood risk. The SFRA should be updated when changes are made to policies or strategy reports relating to flood risk or if conditions change that impact on the nature of flood risk in the Lincoln Policy Area, for example the presence and characteristics of flood defences, flood defence schemes or significant development in the district. When the Environment Agency Flood Zone outlines are updated, they should be incorporated into the SFRA.

Building on information already available, a Level 1 SFRA has been produced for the Lincoln Policy Area and a Level 2 SFRA has been produced for the City of Lincoln.

1.2 Format of the SFRA and Key Outputs

The Lincoln Policy Area SFRA has been broken down into four separate volumes:

Volume 1: Non - Technical Summary

Volume 2: Technical Summary

Volume 3: Guidance for Planners and Developers

Volume 4: Maps

1.3 Scope and Objectives

The SFRA involves a two step approach to the assessment of flood risk:

- Utilising existing available information, a broad scale assessment of flood risk to identify sites at risk from flooding across the whole Lincoln Policy Area (Level One Assessment of Flood risk); and
- An assessment of flood risk that is based upon more detailed river modelling. This includes consideration of flood risk management measures, such as flood defences, that may be present and the flood risk posed should such defences fail (breach) or be exceeded (overtopped) by extreme flooding (Level Two Assessment of Flood Risk).

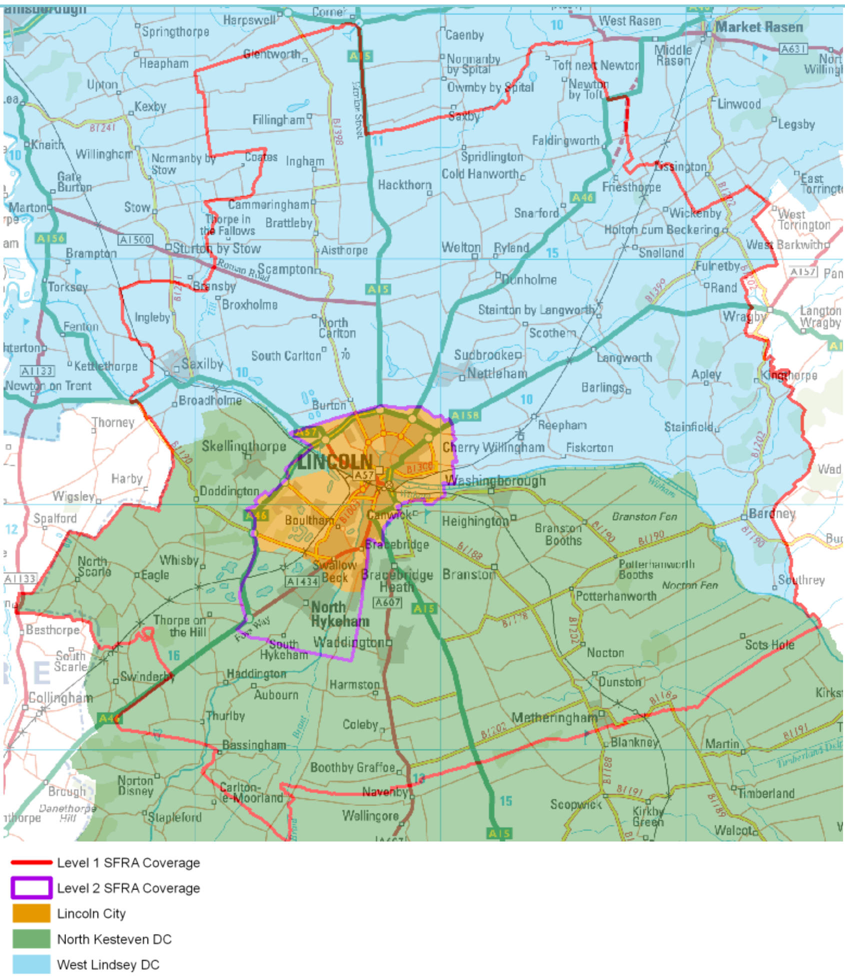
Current Government policy requires local authorities to demonstrate that due regard has been given to the issue of flood risk as part of the planning process. It also requires that flood risk is managed in an effective and sustainable manner and where new development is exceptionally necessary in flood risk areas, the policy aim is to make it safe without increasing flood risk elsewhere. Where possible flood risks should be reduced overall.

The overall objective for this SFRA is to provide sufficient information for the application of the Sequential Test and to identify whether application of the Exception Test is likely to be necessary. It involves a broad scale assessment of flood risk to identify sites at flood risk from fluvial and other sources of flooding, utilising existing available information. In addition to this, the SFRA will allow the Lincoln Policy Area to:

- prepare appropriate policies for the management of flood risk within the policy area;
- inform the sustainability appraisal so that flood risk is taken into account when considering options and in the preparation of strategic land use policies;
- identify the level of detail required for site-specific Flood Risk Assessments (FRA) in particular locations, and
- enable the policy area to determine the acceptability of flood risk in relation to emergency planning capability.

1.4 Policy Area

Figure 1-1: Policy Area



The City of Lincoln is located within a ridge in the Lincolnshire Heights, a north – south limestone ridge, through which the River Witham flows. The River Witham and the River Brant flow north towards Lincoln, with the River Brant joining the River Witham to the south of Lincoln. The River Till joins with the Fossdyke Canal to the north west of Lincoln. The Fossdyke Canal then continues to flow south east towards Lincoln City Centre. The Boultham Catchwater flows towards Lincoln from the west. The Fossdyke and Boultham Catchwater join with the River Witham in the centre of Lincoln. The Sincil Dyke acts as a relief channel for the River Witham in Lincoln. The Sincil Dyke then becomes the South Delph and this and the River Witham flow out of Lincoln in an easterly direction.

The catchment areas for the rivers flowing through Lincoln are primarily large, rural catchments, of 600km2 and 200km2 for the River Witham and Fossdyke Canal, respectively.

Due to the development of the low-lying areas adjacent to the watercourses, Lincoln is at increasing risk of flooding. Approximately 20% of Lincoln's 100,000 population lives in areas at risk from flooding. High flood risk areas also include the majority of Lincoln's industrial buildings and approximately half of Lincoln's commercial property.

In 1977, following major flooding in 1947 and 1958, feasibility studies were undertaken to investigate flood risk in Lincoln and possible flood alleviation schemes. As a result, a scheme was implemented, which consisted of two controlled washlands constructed upstream of Lincoln City Centre; one at the confluence of the River Witham and Brant, known as the Witham washlands (5km south of Lincoln), and the other on the River Till (7km to the north-west), which provide a 1 in 100-year level of flood protection. The washlands were created by building shallow embankments across the river valley, with control sluices in the rivers, which allow the amount of water in the washlands to be regulated. Pumping stations aid the final draining of the washlands. The scheme was completed in 1991.

1.5 Main Sources of flooding

The main flood risk within the Lincoln Policy Area is from fluvial flooding from the River Witham, River Till and the Fossdyke Canal.

The present flood risk within the Lincoln Policy Area has been determined with reference to the Environment Agency's Flood Zone Map (FZM) 2009 and overtopping and breach analysis of the flood defences within the City of Lincoln.

Flooding from the River Trent has also been considered. The Environment Agency consider the River Trent influence to extend to the western side of the A46 Lincoln Bypass. The Environment Agency Lower Trent Strategy has shown that a breach of the River Trent flood defence at Torksey would allow flows to be concentrated along the Fossdyke canal towards Lincoln, however the Environment Agency do no consider this to be a risk to Lincoln as floodplains to the western side of the A46 / Lincoln bypass will accommodate floodwaters.

Overtopping and Breach analyses have been undertaken showing the possible flood depths. Hazard mapping has also been undertaken (taking into account depth and velocity. Overtopping and Breach analyses have been carried out using JBA's in-house raster based 2-D model JFLOW, to enable the production of maps showing overtopping and breach extent.

2D flood modelling within the 'extended' area of the City of Lincoln for both the 100 year with climate change and 1000 year with climate change flood scenarios has shown that flood defences will overtop. Breach analysis of flood defences has shown flood water to extend over a large area of the existing low land within the City area.

In some cases within Lincoln it was found that the maximum possible breach outline (derived from the 100 year + cc and 1000 year +cc flooding scenarios) extended beyond flood zones 2 and 3. As a result it is recommended that the local authorities within the policy area restrict development within these areas. It is recommended that the sequential approach be applied to flood zone one in this instance. A flood risk assessment will need to be submitted in accordance with Annex E of PPS 25.

1.6 Other Sources of Flooding

Other sources of flooding can include surface water run off, blocked sewers and groundwater flooding. These are detailed further in Volume 4.

1.7 Updating the SFRA

The SFRA is intended to be a "live" document, updated when appropriate to reflect changes in the area and as new information becomes available. It is recommended that the SFRA is reviewed annually in liaison with the Environment Agency. If changes are required the SFRA should be updated accordingly.

The following areas should be subject to a future review in order to ensure the most up to date information is being used:

- Environment Agency Flood Zones Maps - these are updated periodically by the Environment Agency
- OS Background Mapping - These are updated periodically by Ordnance Survey
- PPS25 Practice Guidance Updates and Flooding Policy - A consultation is currently taking place into proposed amendments to Planning Policy Statement 25 (PPS25). The SFRA should be updated accordingly if the proposed amendments are brought in to force.
- Climate Change Predictions - Predictions for this SFRA are based on current guidance. Any future reviews of the SFRA should consult the Environment Agency to ensure the most up to date predictions are being used.

2 Data Sources

2.1 Data Collection

Figure 2-1 lists the data that was made available/obtained for the Lincoln SFRA. A critical phase in the project delivery is the collection and review of existing information. This data comprises of known or perceived flood risk issues within the district, development pressures and constraints and current policy governing development within flood risk affected areas. The majority of this data has been recorded and included in the GIS data layers used to undertake the assessment.

Figure 2-1: Data availability for use in the Lincoln SFRA

Data Type	Use within SFRA
OS 10k Basemap	Flood Risk Mapping
OS Mastermap	Flood Risk Mapping
Flood Zone Map	Initial Flood Zone delineation
Main river map	Flood Risk Mapping
National Flood and Coastal Defence Database (NFCDD) data	Locate defended and undefended locations
LiDAR Digital Elevation Model	Flood Risk Mapping
Breach and Overtopping Hydrographs	Flood Risk Mapping
River Withern Catchment Flood Management Plan	Background information
The East Midlands Plan	Background information, flood risk
Lincoln Water Cycle Study	Background information, flood risk
Lincoln Integrated Urban Drainage Study	Background information, flood risk
Surface Water Maps	Flood Risk Mapping

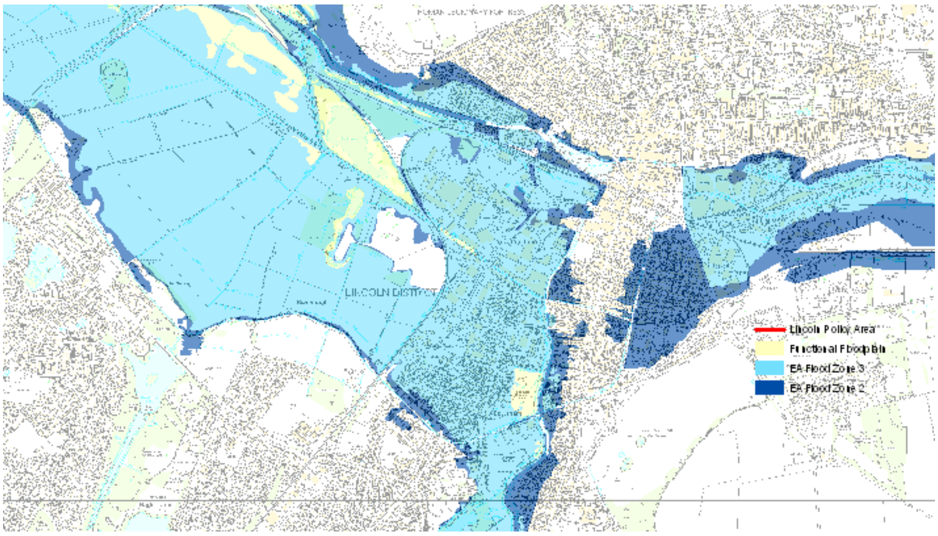
2.2 Flood Zone Map

The Environment Agency Flood Zone Map shows the areas at risk from extreme events from river flooding. The Flood Zone maps were prepared using a methodology based on the national digital terrain model (NEXTMap), derived river flows (Flood Estimation Handbook (FEH)) and two dimensional flood routing. The theoretically derived Flood Zone extents have been adjusted in some locations where the results are inconsistent with historical flooding extents, more detailed flood mapping studies are available or where there are known errors in the digital terrain model.

The Environment Agency Flood Zone maps are precautionary in that they do not take account of flood defences and, therefore, represent a worst-case extent of flooding. The actual extent of flooding within the Lincoln Policy Area is mitigated to some degree by flood defences along the River Witham, Fossdyke Canal and Boultham Catchwater. It should be noted that the Flood Zone Maps (without climate change) are based on broadscale modelling and only cover watercourses with catchments greater than 3 km2 in size, therefore flood risk associated with smaller watercourses is not shown. The most recent revision of the Environment Agency Flood Zone Map has been used to delineate Flood Zones in the Lincoln Policy Area and the full maps are included in Volume 4.

Flood Zone Maps including the expected future effects of climate change are not currently available, however it is expected that the extent of the Flood Zone outlines will increase over time. A comparison is shown below of the current extents of Flood Zone 3 and the expected approximate outline of Flood Zone 3 in the future (based on the current Flood Zone 2 outline). When the Flood Zone Maps with climate change are available they should be added to this SFRA.

Figure 2-2: Example of Environment Agency Flood Zone Two and Three Map



2.3 Flood Defences

The Environment Agency Flood Zone Maps do not take account of the presence of flood defences. PPS25 states that defended areas (i.e. those areas that are protected to some degree against flooding by the presence of a formalised flood defence) are still at risk of flooding, and therefore sites within these areas must be assessed with respect to the adequacy of the defences.

An extract from the Environment Agency's National Flood and Coastal Defence Database (NFCDD) has been supplied and provides information about existing defences in the area, as well as categorising them by type and providing information on who owns and maintains them. All of the formal flood defences present in Lincoln are man made and have been constructed to a design standard return period of 1 in 100 years (1% AEP).

Internal Drainage Board (IDB) maintained watercourses assist in the removal of storm water from low lying areas behind Environment Agency maintained flood defences on the River Witham and the Fossdyke Canal. Pumping stations operated by the IDB's aid in removing this water, and thus reducing flood risk.

Figure 2-3: Maintained Flood Defences within Lincoln

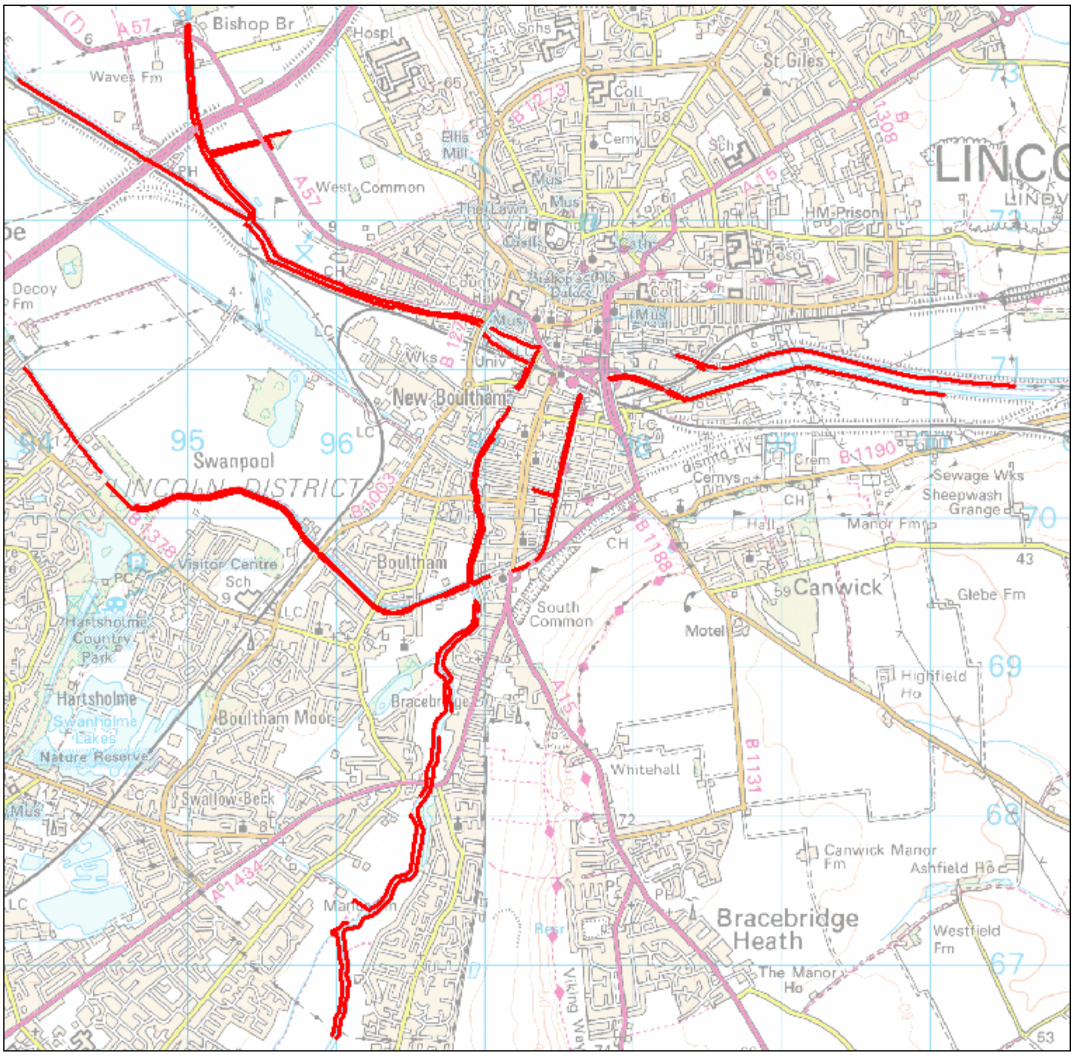


Figure 2-4: Lincoln Defence Details

Grid Ref	Defence Type	Maintainer	Design Standard (years)	Bank
SK9361573261	raised defence (man-made)	Environment Agency	100	left
SK9420772728	raised defence (man-made)	Environment Agency	100	left
SK9478772371	raised defence (man-made)	local authority	100	left
SK9479072370	raised defence (man-made)	Environment Agency	100	left
SK9486272332	raised defence (man-made)	Environment Agency	100	left
SK9487474129	raised defence (man-made)	Environment Agency	100	right
SK9488872318	raised defence (man-made)	Environment Agency	100	left
SK9505872702	raised defence (man-made)	Environment Agency	100	left
SK9504872182	raised defence (man-made)	Environment Agency	100	right

Grid Ref	Defence Type	Maintainer	Design Standard (years)	Bank
SK9505672579	raised defence (man-made)	Environment Agency	100	right
SK9505872702	raised defence (man-made)	local authority	100	left
SK9509172581	raised defence (man-made)	Environment Agency	100	left
SK9509172581	raised defence (man-made)	Environment Agency	100	left
SK9547372531	raised defence (man-made)	Environment Agency	100	right
SK9547372531	raised defence (man-made)	Environment Agency	100	left
SK9541372011	raised defence (man-made)	internal drainage board	100	left
SK9552072552	raised defence (man-made)	Environment Agency	100	right
SK9553172550	raised defence (man-made)	Environment Agency	100	left
SK9568972601	raised defence (man-made)	Environment Agency	100	right
SK9556672485	raised defence (man-made)	Environment Agency	100	left
SK9646871407	raised defence (man-made)	Environment Agency	100	right
SK9639071415	raised defence (man-made)	Environment Agency	100	right
SK9649471422	raised defence (man-made)	Environment Agency	100	left
SK9545971910	raised defence (man-made)	private	100	right
SK9646871430	raised defence (man-made)	Environment Agency	100	left
SK9644071435	raised defence (man-made)	Environment Agency	100	left
SK9643971436	raised defence (man-made)	Environment Agency	100	left
SK9611571533	raised defence (man-made)	Environment Agency	100	left
SK9608871542	raised defence (man-made)	Environment Agency	100	left
SK9604671560	raised defence (man-made)	Environment Agency	100	left
SK9543871989	raised defence (man-made)	Environment Agency	100	left
SK9734671152	raised defence (man-made)	Environment Agency	100	left
SK9704871273	raised defence (man-made)	Environment Agency	100	left
SK9706171175	raised defence (man-made)	private	100	right
SK9704771186	raised defence (man-made)	private	100	right
SK9700771225	raised defence (man-made)	private	100	right
SK9700771225	raised defence (man-made)	private	100	right
SK9699771230	raised defence (man-made)	private	100	right
SK9703671278	raised defence (man-made)	Environment Agency	100	left
SK9691171311	raised defence (man-made)	private	100	right
SK9691171311	raised defence (man-made)	private	100	right
SK9696471331	raised defence (man-made)	private	100	left
SK9693671339	raised defence (man-made)	local authority	100	left

Grid Ref	Defence Type	Maintainer	Design Standard (years)	Bank
SK9647771402	raised defence (man-made)	Environment Agency	100	right
SK9679871380	raised defence (man-made)	Environment Agency	100	left
SK9659071394	raised defence (man-made)	Environment Agency	100	left
SK9657271397	raised defence (man-made)	Environment Agency	100	left
SK9653971411	raised defence (man-made)	Environment Agency	100	left
SK9831070823	raised defence (man-made)	Environment Agency	100	left
SK9783870932	raised defence (man-made)	Environment Agency	100	right
SK9722470868	raised defence (man-made)	private	100	right
SK9783570944	raised defence (man-made)	Environment Agency	100	left
SK9721170876	raised defence (man-made)	Environment Agency	100	left
SK9725070936	raised defence (man-made)	private	100	left
SK9725570945	raised defence (man-made)	private	100	left
SK9726770980	raised defence (man-made)	private	100	left
SK9730671021	raised defence (man-made)	private	100	right
SK9726171059	raised defence (man-made)	private	100	right
SK9707071169	raised defence (man-made)	private	100	right
SK9828871098	raised defence (man-made)	Environment Agency	100	left
SK9841271059	raised defence (man-made)	Environment Agency	100	left
SK9888270955	raised defence (man-made)	Environment Agency	100	right
SK9845771038	raised defence (man-made)	Environment Agency	100	left
SK9844971019	raised defence (man-made)	Environment Agency	100	right
SK9845771015	raised defence (man-made)	private	100	right
SK9847171006	raised defence (man-made)	Environment Agency	100	right
SK9847771032	raised defence (man-made)	private	100	left
SK9847771032	raised defence (man-made)	Environment Agency	100	left
SK9861371014	raised defence (man-made)	private	100	left
SK9861371014	raised defence (man-made)	Environment Agency	100	left
SK9918371124	raised defence (man-made)	Environment Agency	100	left
SK9888270955	raised defence (man-made)	Environment Agency	100	right
SK9918371124	raised defence (man-made)	Environment Agency	100	left
SK9992970949	raised defence (man-made)	Environment Agency	100	left
SK9998770942	raised defence (man-made)	Environment Agency	100	left
TF0034670912	raised defence (man-made)	Environment Agency	100	left
TF0034670912	raised defence (man-made)	Environment Agency	100	left

Grid Ref	Defence Type	Maintainer	Design Standard (years)	Bank
TF0068470884	raised defence (man-made)	Environment Agency	100	left
SK9747170120	raised defence (man-made)	Environment Agency	100	right
SK9746470160	raised defence (man-made)	Environment Agency	100	left
SK9692770281	raised defence (man-made)	Environment Agency	100	left
SK9694170285	raised defence (man-made)	Environment Agency	100	right
SK9694870342	raised defence (man-made)	private	100	right
SK9695470358	raised defence (man-made)	Environment Agency	100	right
SK9695770374	raised defence (man-made)	Environment Agency	100	right
SK9696270397	raised defence (man-made)	Environment Agency	100	right
SK9702070491	raised defence (man-made)	Environment Agency	100	right
SK9711770658	raised defence (man-made)	private	100	right
SK9714270707	raised defence (man-made)	private	100	right
SK9760570725	raised defence (man-made)	Environment Agency	100	left
SK9761470727	raised defence (man-made)	Environment Agency	100	right
SK9832070807	raised defence (man-made)	Environment Agency	100	right
SK9833070813	raised defence (man-made)	Environment Agency	100	left
SK9830070816	raised defence (man-made)	Environment Agency	100	right
SK9446070234	raised defence (man-made)	Environment Agency	100	right
SK9579669864	raised defence (man-made)	Environment Agency	100	left
SK9574269956	raised defence (man-made)	Environment Agency	100	left
SK9464470081	raised defence (man-made)	Environment Agency	100	left
SK9441470309	raised defence (man-made)	private	100	left
SK9379671179	raised defence (man-made)	Environment Agency	100	left
SK9687069554	raised defence (man-made)	Environment Agency	100	left
SK9734169722	raised defence (man-made)	Environment Agency	100	right
SK9694769781	raised defence (man-made)	Environment Agency	100	right
SK9698769943	raised defence (man-made)	Environment Agency	100	right
SK9745670057	raised defence (man-made)	Environment Agency	100	right
SK9745670057	raised defence (man-made)	Environment Agency	100	right
SK9695470107	raised defence (man-made)	Environment Agency	100	right
SK9693570109	raised defence (man-made)	Environment Agency	100	left
SK9695470130	raised defence (man-made)	Environment Agency	100	right
SK9693570131	raised defence (man-made)	Environment Agency	100	left
SK9744670156	raised defence (man-made)	Environment Agency	100	right

Grid Ref	Defence Type	Maintainer	Design Standard (years)	Bank
SK9732170194	raised defence (man-made)	Environment Agency	100	right
SK9744770160	raised defence (man-made)	Environment Agency	100	left
SK9695170160	raised defence (man-made)	Environment Agency	100	right
SK9693170231	raised defence (man-made)	Environment Agency	100	right
SK9693270242	raised defence (man-made)	Environment Agency	100	right
SK9686169219	raised defence (man-made)	Environment Agency	100	right
SK9691769571	raised defence (man-made)	Environment Agency	100	right
SK9695369583	raised defence (man-made)	Environment Agency	100	left
SK9692169557	raised defence (man-made)	Environment Agency	100	right
SK9695169420	raised defence (man-made)	Environment Agency	100	right
SK9694869330	raised defence (man-made)	Environment Agency	100	right
SK9695069380	raised defence (man-made)	Environment Agency	100	right
SK9695369583	raised defence (man-made)	Environment Agency	100	left
SK9699369599	raised defence (man-made)	Environment Agency	100	left
SK9719469656	raised defence (man-made)	Environment Agency	100	left
SK9719569656	raised defence (man-made)	private	100	left
SK9726369678	raised defence (man-made)	private	100	left
SK9556065174	raised defence (man-made)	Environment Agency	100	left
SK9588466283	raised defence (man-made)	Environment Agency	100	right
SK9589769763	raised defence (man-made)	Environment Agency	100	left
SK9607667287	raised defence (man-made)	Environment Agency	100	left
SK9599769652	raised defence (man-made)	Environment Agency	100	right
SK9611267432	raised defence (man-made)	Environment Agency	100	left
SK9623669418	raised defence (man-made)	Environment Agency	100	right
SK9623969417	raised defence (man-made)	Environment Agency	100	right
SK9626669397	raised defence (man-made)	Environment Agency	100	right
SK9656367961	raised defence (man-made)	Environment Agency	100	right
SK9663368195	raised defence (man-made)	Environment Agency	100	right
SK9660068201	raised defence (man-made)	private	100	left
SK9660068201	raised defence (man-made)	Environment Agency	100	left
SK9660568263	raised defence (man-made)	Environment Agency	100	left
SK9660768235	raised defence (man-made)	Environment Agency	100	left
SK9663368195	raised defence (man-made)	Environment Agency	100	right
SK9692569420	raised defence (man-made)	Environment Agency	100	left

Grid Ref	Defence Type	Maintainer	Design Standard (years)	Bank
SK9671669032	raised defence (man-made)	Environment Agency	100	right
SK9671769035	raised defence (man-made)	Environment Agency	100	right
SK9672468997	raised defence (man-made)	Environment Agency	100	right
SK9672569484	raised defence (man-made)	Environment Agency	100	right
SK9677068709	raised defence (man-made)	Environment Agency	100	right
SK9685869218	raised defence (man-made)	Environment Agency	100	right

2.4 Condition of flood Defences

The condition of existing flood defences is an important consideration for local authority planners when allocating new development. PPS 25 considers that defended areas (i.e. those areas that are protected to some degree against flooding by the presence of a formalised flood defence) are still at risk of flooding, and therefore sites within these areas must be assessed with respect to the adequacy of the defences.

The location and condition of all flood defences is provided by the Environment Agency via the National Fluvial and Coastal Defence Database (NFCDD).

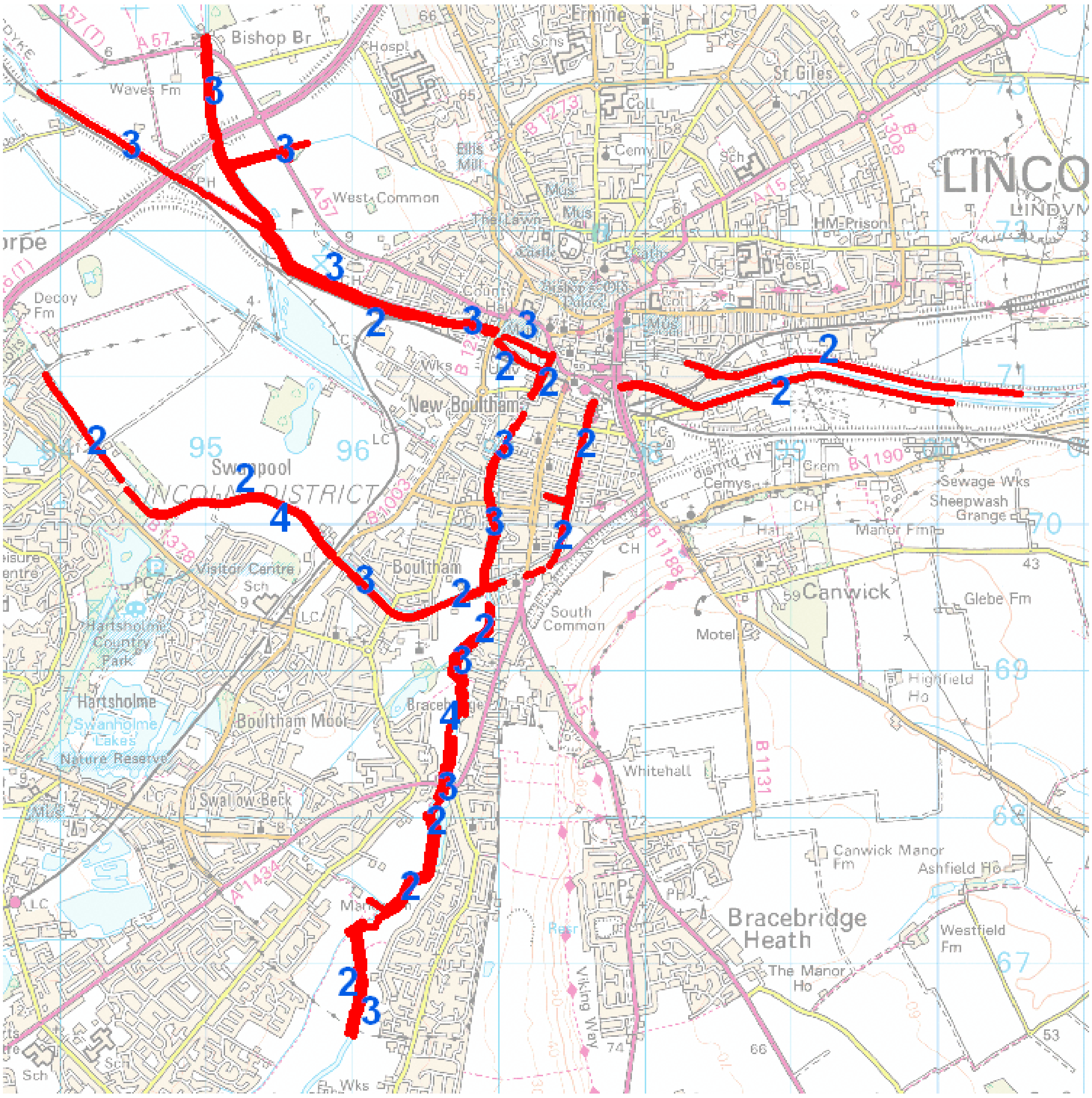
The condition of existing defences is provided in the form of a 'rating' (1 to 5), and is a reflection of any signs of 'obvious' structural problems. The condition rating is determined on the basis of visual inspection, focussing on obvious signs of structural defect (e.g. slippage, cracking, poor maintenance), designed to inform the maintenance programme. A summary of the NFCDD condition rating allocations is shown in Figure 2-5 below.

Figure 2-5: NFCDD Condition Ratings for Flood Defences

Condition Rating	Condition	Condition Description
1	Very Good	Fully serviceable.
2	Good	Minor defects.
3	Fair	Some cause for concern. Requires careful monitoring.
4	Poor	Structurally unsound now or in the future.
5	Very Poor	Completely failed and derelict.

The condition of existing flood defences and whether they will continue to be maintained and/or improved in the future, is an issue than needs to be considered as part of the risk based sequential approach and in the light of this, whether proposed land allocations are appropriate and sustainable. In addition, detailed FRAs will need to explore the condition of defences thoroughly, especially where these defences are informal and contain a wide variation of condition grades.

Figure 2-6: Overview of Lincoln Defence conditions



2.5 Hydraulic Modelling

Flood defence overtopping and flood defence breach analysis has been carried out for within the extended area of Lincoln. The Environment Agency supplied JBA with breach and overtopping hydrographs for specified locations (See Volume 4) within Lincoln for the purpose of this SFRA. The supplied hydrographs were used to undertake 2D modelling. Overtopping and Breach analyses have been carried out using JBA's in-house raster based 2-D model JFLOW, to enable the production of maps showing overtopping and breach extent.

2.6 Topographical Data

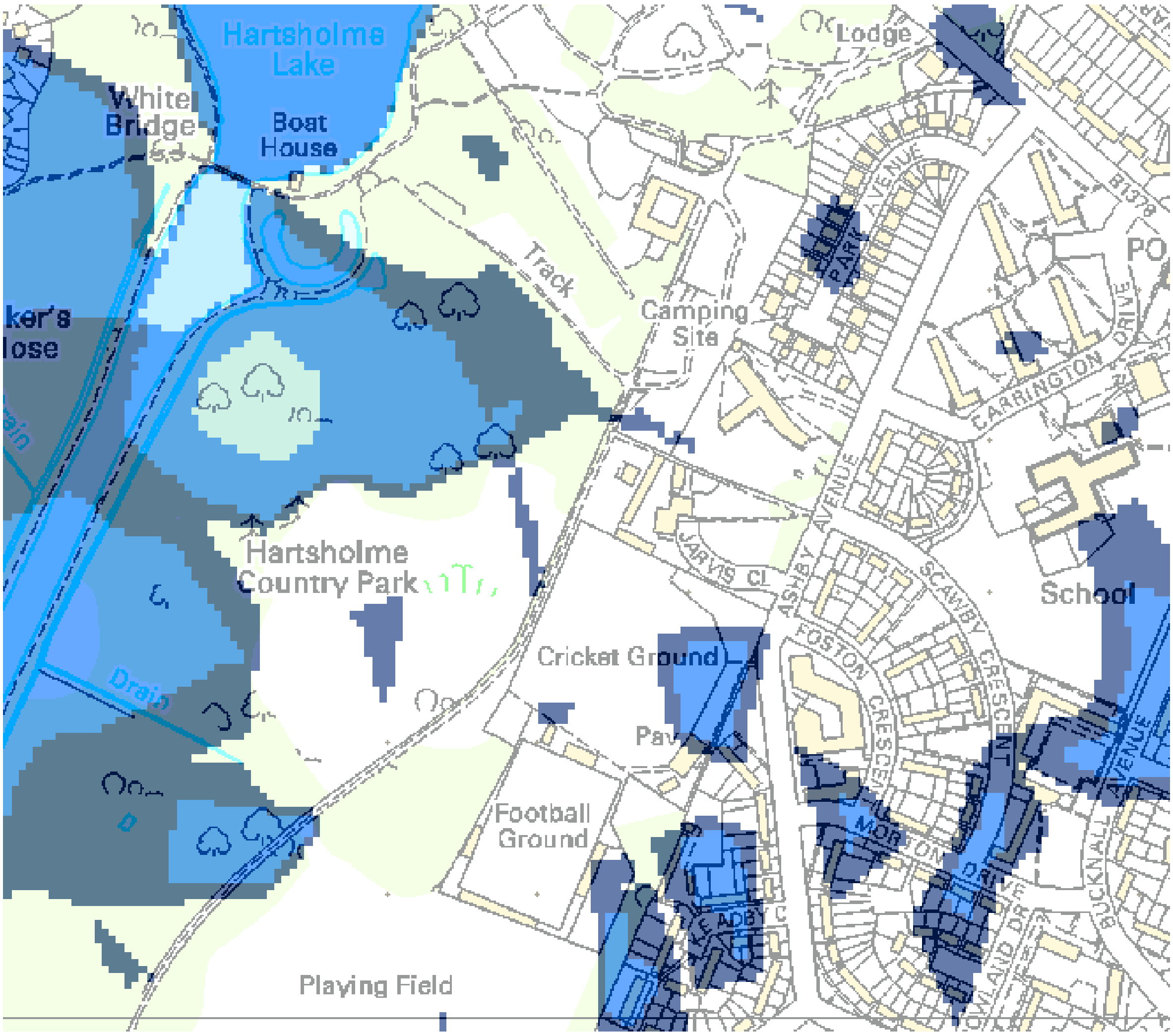
The essential dataset required for flood modelling and mapping is a ground model or Digital Elevation Model (DEM). The main source of DEM data for Lincoln is LiDAR (Light Detection and Ranging) data. LiDAR data was supplied by the environment Agency at 2m resolution in ASCII format. Filtered LiDAR was used for the modelling in this SFRA.

The filtered LiDAR data was trimmed to remove land outside the policy area boundary that was not required for this study.

The null values (holes in the LiDAR or areas of no data) were filled using data interpolation. The LiDAR survey records the top of bridges and embankments.

2.7 Non Fluvial Flood Risk

Figure 2-7: Surface Water Flooding



These maps show indicative flooding caused by surface water run off during an extreme (1 in 200 year) rainfall event, assuming sewer networks are full to capacity. The surface water flooding is categorised according to its depth and associated risk. The maps also highlight areas where instances of sewer flooding have been recorded. The maps should be used to inform Flood Risk Assessments.

2.8 History of Flooding

Several notable instances of fluvial flooding have occurred in the River Witham catchment during the past 100 years

Figure 2-8: Historical Flooding

Date	Flooding Details
March 1947	Flooding of Lincoln from the River Witham
July 1958	of Lincoln and surrounding areas from the River Witham, Fossdyke Canal, River Brant and River Till due to the failure of defences
December 1960	Flooding at Hykeham due to failure of defences
February 1977	Flooding in Lincoln from Heighington Beck, River Witham and River Brant
April 1981	Flooding in Lincoln, Cherry Willingham, Fiskerton, Stainfield, Langworth, Bullington, Fulsby from Barlings Eau and River Witham due to defences overtopping.
October 1993	Flooding in Swinethorpe, Cherry Willingham, Fiskerton, Sudbrooke, Scothern, Snarford, Stainford, Langworth, Friesthorpe from Barlings Eau, Boultham Catchwater Drain and the River Witham due to defences overtopping
November 2000	Flooding in Langworth from local beck. Flooding at several rural locations around Lincoln from the River Witham and River Till. Defences did not fail. Lincoln Washland scheme operated for the first time.
Summer 2007	Flooding in Lincoln and the surrounding area as a result of intense rainfall. Defences in Lincoln did not fail. Washlands to the North and South of the City were opened and reached 15 per cent full (Witham Reservoir) and 85 per cent full (Till reservoir), providing protection for Lincoln.
January 2008	Washlands partially filled providing protection for Lincoln

2.9 Limitations of Background Information

The data used in the SFRA is limited in some aspects and it is important that these limitations are considered.

The Environment Agency's Flood Zone maps are based on generalised river modelling only and are limited by way of not including all minor watercourse floodplains or the effects of any defences. The Flood Zone maps are produced from a national mapping project and provide flood zone mapping from the points where river catchments reach an area of $3km^2$. Therefore, for any site (including those below 1ha) adjacent to an unmapped watercourse, a site-specific FRA will be required to establish the true floodplain extent and flood risk to the development site.

Where there is no reference to localised flooding issues at a site, this does not necessarily mean that there are none; records may not have been available to inform this SFRA.

Limitations of the existing river modelling studies used in the report should be acknowledged due to the nature of flood risk mapping, estimation of catchments and hydrology. Watercourse surveys, changes since the studies, new developments, additional structures and constraints, seasonal variations in the roughness of watercourse channels due to growth of vegetation and maintenance of the channel will all have an effect on the flood risk.

Limitations associated with the use of LiDAR data must be acknowledged. LiDAR is more accurate on flat ground, but the degree of accuracy decreases substantially for vegetated and built up areas. Inaccuracies are reduced by a process of filtering. It is essential to cross reference against surveyed level information where this is available and against Ordnance Survey and site visits to allow for flow routes under bridges or embankments which would not be picked up by the aerial surveys.

3 Hydraulic Modelling

3.1 Overview

The purpose of the modelling of breaches and overtopping is to show the likely degree of flood hazard (in terms of flood depths and Flood Hazard Rating) within the Flood Zone areas and for planning purposes to derive a delineation of residual risk that can be used by local authorities and developers within the policy area and developers.

For the Lincoln SFRA, JBA has carried out detailed hydraulic modelling to identify the residual risk using 2d JFLOW modelling.

An appraisal of the effect of any failure of flood defences, whether formal defences maintained by the EA or informal defences, in order to establish areas of residual risk, rapid inundation and low-lying areas. Within Lincoln, new maps have been produced based on 2d modelling carried out for this SFRA. Two flood scenarios have been modelled:

- 100 year with climate change flood scenario
- 1000 year with climate change flood scenario

3.2 Overtopping and Breach Locations

The Environment Agency supplied JBA with overtopping and breach hydrographs for specified locations (Figure 3-1 and Figure 3-1) within Lincoln for the purpose of this SFRA. Locations were supplied for the river Witham, Fossdyke and boultham catchwater Drain. The supplied hydrographs were used to undertake further 2D modelling.

Figure 3-1: Overtopping Locations

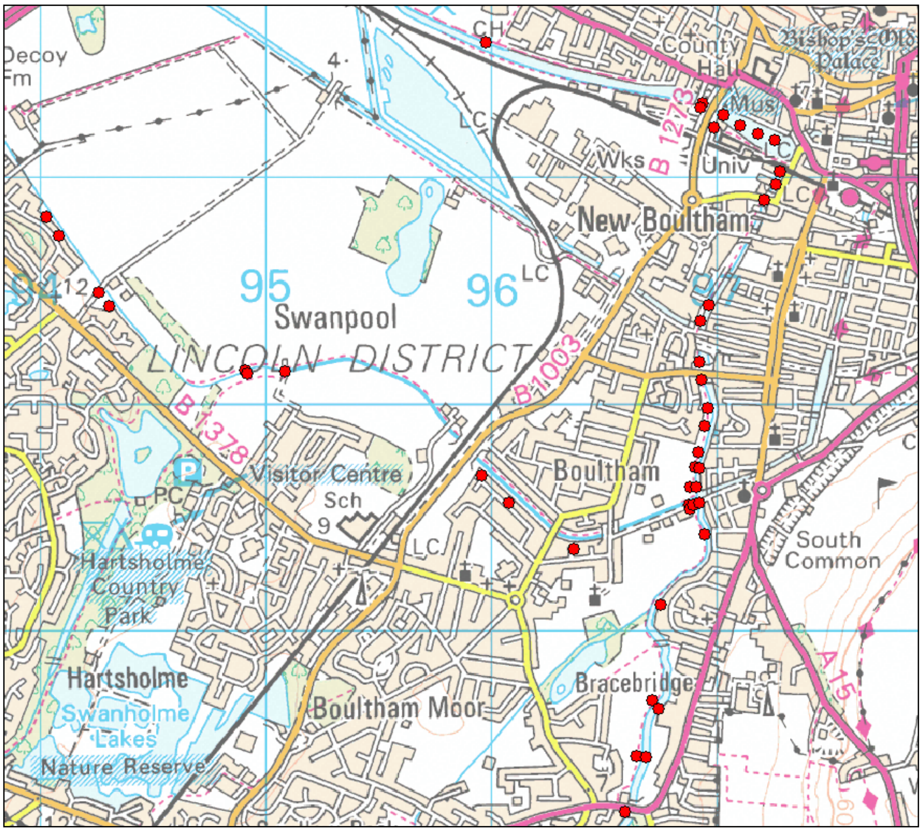
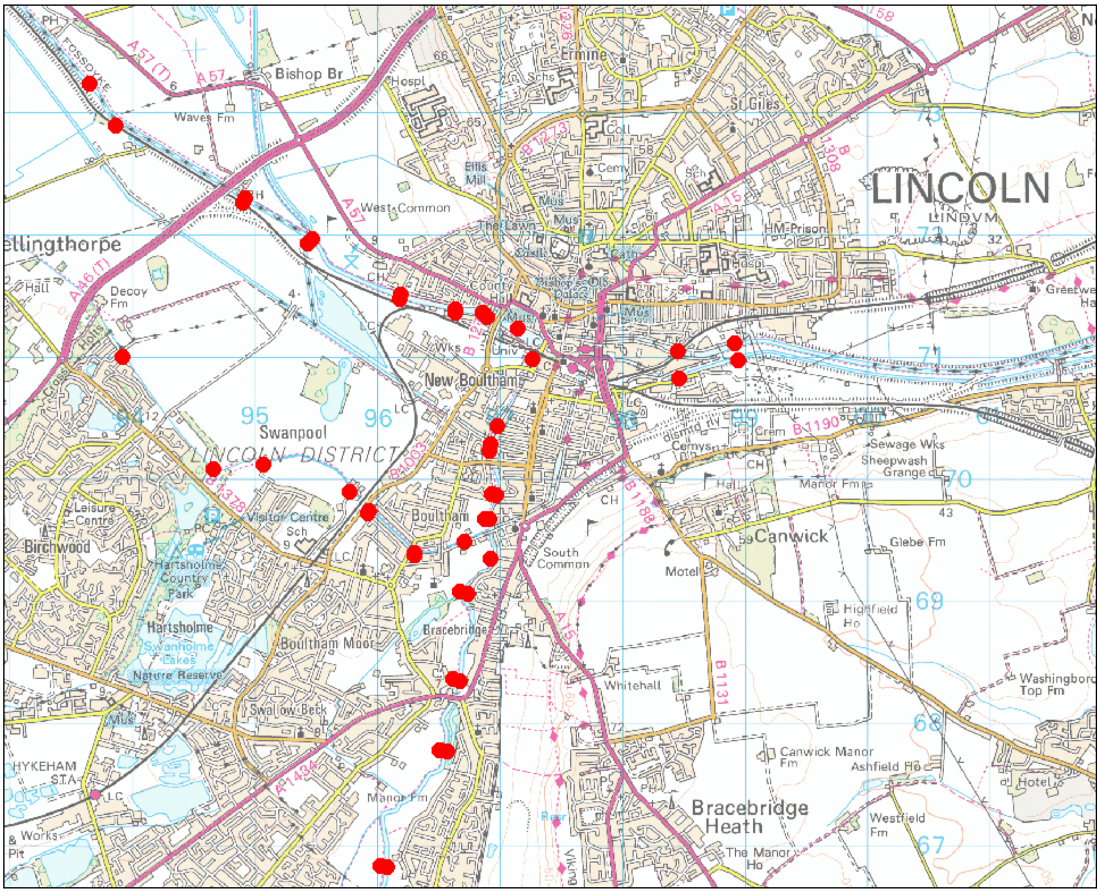


Figure 3-2: Breach locations



3.3 Modelling Software - JFLOW

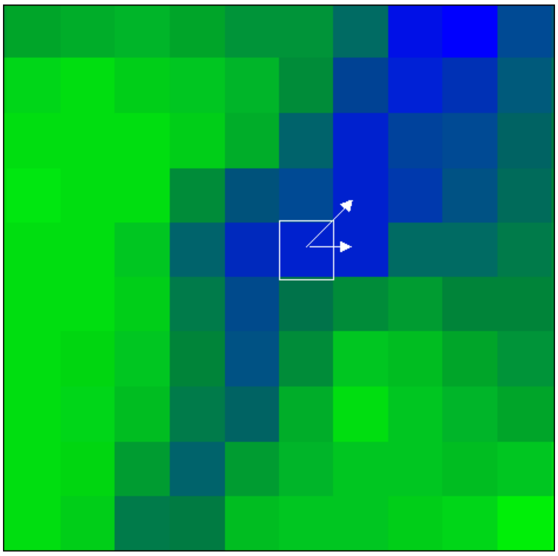
2D JFLOW v7.0 modelling software was used to simulate overtopping and breaching of flood defences within Lincoln. This required the input of a Digital Elevation Model (DEM) and flow hydrographs for each overtopping point.

3.3.1 JFLOW Physical Principles

Basic principles

The methodology is a raster-based approach, driven by an underlying Digital Elevation Model (DEM) such as that shown in Figure 3-1: Overtopping Locations. Each cell has a ground level and water depth. Water can move to surrounding cells where the water level is lower, driven by gravity. Water will pond in low spots until the water level is high enough to spill. The velocity of movement depends on water surface slope and surface roughness.

Figure 3-3: Example Digital Elevation Model



The above points describe the basic principles of the model. The two underlying physical principles are that mass is conserved within each cell and that the fluxes of water between the cells arise from a balance between the water surface slope and the resistance to flow due to friction.

Mass Conservation

Each grid cell is treated as a small storage area. Mass conservation is applied to each grid cell. In finite volume form this can be written as:

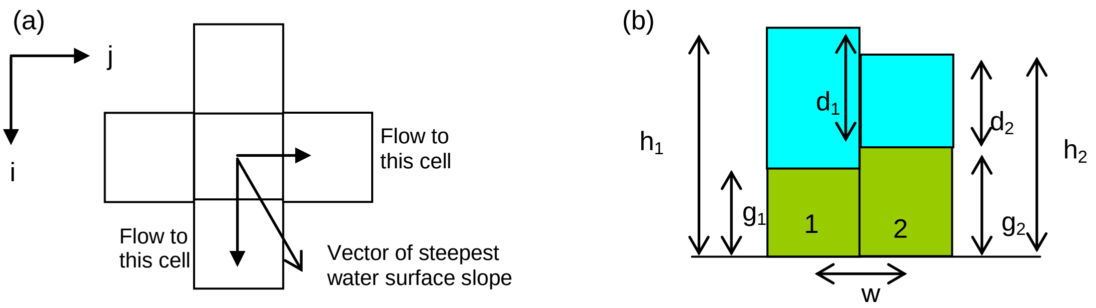
$$\Delta h = \frac{\sum Q_{in}}{A} \Delta t \qquad [1]$$

where Δh is the change in water surface elevation or depth in the cell, ΣQin is the sum of all the fluxes from surrounding cells (fluxes leaving a cell are negative), A is the cell area and Δt is the time-step.

Flux between cells

Consider a gridcell, and the four cells adjacent to it The two orthogonal directions of the grid cells are called i and j. The direction of the steepest water surface slope is determined by comparing the water level in the source cell with those in the four adjacent cells. Adjacent cells with water levels higher than the source cell are not included. The slope (S) is calculated by the vector sum of the slopes in each orthogonal direction (Si and Sj) which is given by the difference in water level between the cells divided by the distance between the cell centres (the grid width).

Figure 3-4: Flow Between Floodplain Nodes



The depths of flow in each direction (di, dj) are calculated as the water level in the source cell above the highest of the two ground levels 2b). This recognises that local low points may occur in a complex DEM in which the depth of water may be deep, but the effective depth of flow to adjacent cells is much less. The effective depth of flow in the direction of the steepest slope is calculated using a weighted mean of the flow depths in each direction, such that for flow at 45° to the grid direction the effective depth is the arithmetic mean of the two flow depths, but if is flow aligned with one of the grid directions the effective depth is equal to the depth for that direction. The flow in the direction of the steepest slope is calculated using Manning's equation:

$$Q = \frac{wd^{1.67}S^{0.5}}{n}$$

where $S^2 = S_i^{\,2} + S_j^{\,2}$

in which $S_i = \frac{h_{i,j} - h_{i\pm1,j}}{w}$, and $S_j = \frac{h_{i,j} - h_{i,j\pm1}}{w}$

and $d = \frac{d_i S_i^{\,2} + d_j S_j^{\,2}}{S^2}$

in which $d_i = h_{i,j} - \max(g_{i,j}, g_{i\pm1,j})$ and $d_j = h_{i,j} - \max(g_{i,j}, g_{i,j\pm1})$ [3]

where h is water level, g is ground level and d is depth.

The flow vector can be resolved in each of the 2 orthogonal (i and j) directions of the grid, giving possible flow to up to 2 of the adjacent cells. This gives a discretised version of the two-dimensional diffusion wave equations,

$$Q_i = Q\frac{S_i}{S} = \frac{wd^{1.67}S_i}{nS^{0.5}} = \frac{wd^{1.67}\left(\dfrac{h_{i,j}-h_{i\pm1,j}}{w}\right)}{n\left[\left(\dfrac{h_{i,j}-h_{i\pm1,j}}{w}\right)^2+\left(\dfrac{h_{i,j}-h_{i,j\pm1}}{w}\right)^2\right]^{\frac{1}{4}}}$$

$$Q_j = Q\frac{S_j}{S} = \frac{wd^{1.67}S_j}{nS^{0.5}} = \frac{wd^{1.67}\left(\dfrac{h_{i,j}-h_{i,j\pm1}}{w}\right)}{n\left[\left(\dfrac{h_{i,j}-h_{i\pm1,j}}{w}\right)^2+\left(\dfrac{h_{i,j}-h_{i,j\pm1}}{w}\right)^2\right]^{\frac{1}{4}}}$$

$$\text{and } v = \frac{Q}{wd},\ v_i = \frac{Q_i}{wd} \text{ and } v_j = \frac{Q_j}{wd} \qquad [4]$$

where v is the velocity of the flow.

These equations can be derived from the two-dimensional shallow water equations as follows:

The momentum equation in the Shallow Water Equations is given by:

$$\frac{D\underline{V}}{Dt} + (\underline{V}.\underline{\nabla})\underline{V} + g\underline{\nabla}(z_o + d) + \frac{n^2 g\underline{V}|\underline{V}|}{d^{4/3}} = 0 \qquad [5]$$

where $\underline{V}$ is the depth averaged velocity vector, t is time, zo is the bed elevation, d is the flow depth and n is Manning's n. The first step is to make a diffusion wave approximation by ignoring the acceleration (also known as convection/advection) terms, which are the first two terms on the left of [5]. This is assuming that the temporal acceleration within a time step is negligible and that the spatial accelerations or inertial terms are also negligible. In other words, the flow is being driven by the balance between water surface slope and bottom resistance. A normal depth assumption would also ignore the variable d in the third term. However, we set $z_o + d = h$, where d is water depth, and divide through by g, [5] becomes:

$$\underline{V}|\underline{V}| = -\frac{d^{4/3}}{n^2}\underline{\nabla}(h) \qquad [6]$$

Equation [6] can be rearranged to solve for the modulus of $\underline{V}$ (i.e. velocity magnitude) through:

$$|\underline{V}| = -\frac{d^{2/3}}{n}|\underline{\nabla}(h)|^{1/2} \qquad [7]$$

Substitution of [7] into [6] and rearranging gives:

$$\underline{V} = \frac{d^{2/3}}{n}\frac{\underline{\nabla}(h)}{|\underline{\nabla}(h)|^{1/2}} \qquad [8]$$

Given that $\underline{Q} = wd\underline{V}$, where $\underline{Q}$ is vector discharge and w is the grid spacing,

$$\underline{Q} = \frac{wd^{5/3}}{n} \frac{\underline{\nabla}(h)}{\left|\underline{\nabla}(h)\right|^{1/2}} \qquad [9]$$

This is a two-dimensional flow vector, which when resolved into the two orthogonal grid directions, i and j, and discretised using a central differencing scheme for the cell face, gives

$$Q_i = \frac{wd^{5/3}\left(\frac{h_{i,j} - h_{i\pm1,j}}{w}\right)}{n\left[\left(\frac{h_{i,j} - h_{i\pm1,j}}{w}\right)^2 + \left(\frac{h_{i,j} - h_{i,j\pm1}}{w}\right)^2\right]^{1/4}} \qquad [10a]$$

$$Q_j = \frac{wd^{5/3}\left(\frac{h_{i,j} - h_{i,j\pm1}}{w}\right)}{n\left[\left(\frac{h_{i,j} - h_{i\pm1,j}}{w}\right)^2 + \left(\frac{h_{i,j} - h_{i,j\pm1}}{w}\right)^2\right]^{1/4}} \qquad [10b]$$

which are the equations in JFLOW [Equation 4].

The loss of the momentum terms will not be significant if these terms are small anyway. This is likely to be the case for shallow, topographically driven flow. The water surface within each cell is assumed to be flat but this is a function of the discretisation and not of the form of the equations used. This assumption is not dissimilar to some finite volume codes. The generally small size of the grid cells used in most applications (1-10m wide) mean that this is not a significant limitation except around sharp discontinuities, such as shock waves or bores, which are in any case smoothed out by the diffusion wave approximation.

3.3.2 JFLOW Calculation Schemes

Basic Principles

There are two schemes used to solve the basic diffusion wave equations [1] and [10]. Both are explicit, which means that as the solution marches forward in time it is important for model stability that the maximum time step should be set such that any surface disturbances do not grow uncontrollably and cause the solution to break down.

The two approaches are:

1. A Courant Number based solution with additional smoothing to suppress oscillations
2. A Rigorous Time Step solution based on controlling oscillations directly

Courant Number time step control

The Courant Number is used to set a condition in which any surface disturbance should not propagate beyond the boundaries of a single grid cell within one time step. It is a feature of explicit solution schemes of the shallow water equations. In JFLOW, a Courant Number limitation is applied with respect to the wave celerity√(gd) such that

$$C = \frac{w}{\Delta t\sqrt{gd}} \qquad [11]$$

where d is depth, g is acceleration due to gravity, Δt is time step and w is cell size. For stability of explicit computations $C \le 1$. To ensure this criterion is met, the next time step is calculated based on the depths at the end of the previous step

$$\Delta t = \frac{w}{\sqrt{gd}} \qquad [12]$$

For example, for a depth of 1m, celerity of 0.5m/s and a grid size of 10m, Equation [12] gives a time step of 2.8s. However, some instability (oscillations in water surface from one iteration to the next) are still manifest in certain situations (where depth generally greater than 2m) so a further adjustment of the time step has been built in to help model stability in these situations so that if necessary, the time step is further decreased to keep oscillations within a pre-set tolerance. In regions of severe oscillation, an additional smoothing algorithm can be used to reduce oscillations in the water surface whilst maintaining mass conservation.

Rigorous Time Step

The RTS (Rigorous Time Step) was introduced in JFLOW7. It reduces the time step such that no oscillation occurs in the water surface profile. However, from a practical point of view this can place an unnecessarily strict constraint and give rise to very long run-times. In recognition of this fact, a relaxed RTS time step is also available as an option where the user selects the level of vertical oscillation that is acceptable.

3.3.3 Software Version

Structure

In JFLOW the diffusion wave equations are solved with a relatively simple explicit scheme. The basic procedure is as follows:

- **For each cell,**
  - calculate the discharge from the cell Q along the line of steepest water surface slope as a function of water surface elevations, depths and roughness
  - resolve the flux rates into their orthogonal components qi and qj according to equation [4]
  - calculate a time step condition for the cell

- **Find the largest acceptable time step for the grid**

- **For each cell,**
  - compute the net flux into or out of the cell
  - compute the corresponding change in depth based on the net flux and the current time step
  - update the depth and water surface elevation

Steps 1 and 3 provide opportunities to exploit the parallelism of the GPU because essentially the same calculation has to be applied to every cell in the grid in each case. Rather than writing these operations as loops, we have therefore written kernel programs that apply the hydraulic calculations to every grid cell, with many cells being computed simultaneously in parallel. When loaded onto the GPU, the hardware takes care of streaming the data grids through these kernels in the most efficient way.

The time step control in JFLOW-GPU is based on physical reasoning and is very similar to the RTS time step in the x86 JFLOW codes. Oscillations can appear in the water surface as numerical artefacts if Δt in Equation [1] is too large and in extreme cases these may cause cells to dry out completely. The oscillations appear first in regions where the inter-cell flux rates are high, that is where ΔQin is large and hence the change in water surface elevation in a single step will be large. The time step is therefore calculated by specifying the maximum allowable change in water surface elevation in any calculation step and finding a value of Δt that satisfies this condition, given the prevailing inter cell flux rates.

This approach allows the user to decide on the amount of water surface oscillation that is acceptable in a given simulation and accordingly to make the time step condition more relaxed or more strict. This is a useful feature of the scheme because the time step may often be controlled by large fluxes that develop in a very few locations within the model grid. In many cases, it is possible to tolerate controlled instabilities at those locations without contaminating the rest of the grid. By doing this, the model can use a longer time step and hence take less time to complete the simulation.

Boundary Conditions

The options for boundary conditions in JFLOW-GPU are slightly less flexible than in JFLOW-x86. Inflows can be specified as points or as a cross-section inflow. There is a limit to the number of simultaneous inflows (currently 30 points). Level boundaries are not available. For the Lincoln SFRA Polylines were used to disperse water across a channel section evenly.

Water is either allowed to flow off the edges of the calculation grid as a weir flow, or is kept within the grid by artificial ‘glass walls’.

Deployment

JFLOW-GPU is typically run as a console application suitable for batch processing. In this configuration it uses an Access database to supply inflow and control data and fetches ground elevations from an Arc SDE server.

JFLOW-GPU can also be made available as an alternative calculation engine within the JFLOW7 front end application, although not all of the functionality offered by the x86 code is available.

3.4 Flow Hydrographs

Hydrographs were supplied by the Environment Agency for overtopping and breaching locations for both the 100 year +cc and 1000 year +cc flood scenarios.

3.5 Breach and Overtopping Dimensions

2D modelling has been undertaken in accordance with current EA guidance.

Breach widths have been set to:

- 40m for Earth banks
- 20m for Hard banks

The flow hydrographs used begin one hour before the peak level.

3.6 Overtopping Depth Maps

Flood depth maps have been created for both the 100 year with climate change and the 1000 year with climate change scenarios. These maps are intended to inform the sequential and exception tests, in particular to understanding future flood effects as a result of climate change. Examples of the maps are shown below:

Figure 3-5: Overtopping Flood Depth Map

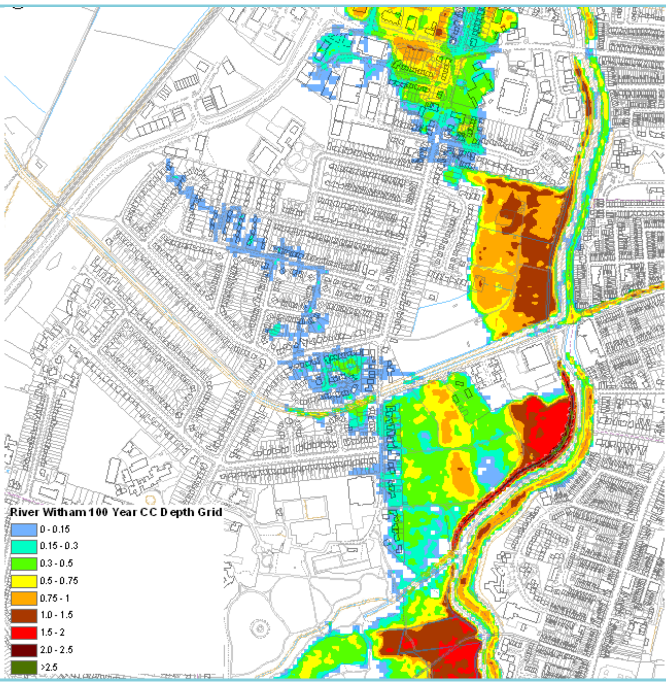
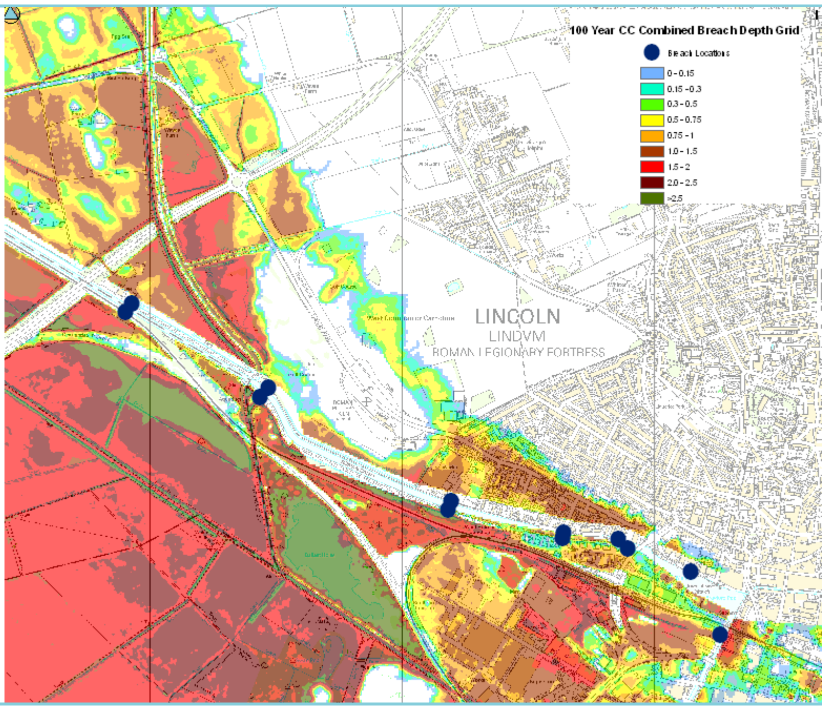


Figure 3-6: Breaching Flood Depth Map



3.7 Flood Hazard Mapping

3.7.1 Overview

With the aim of allowing application of the Sequential Test, the flood depth and velocity data derived from the flood defence breach and overtopping modelling is used to produce a map of flood hazard. It was agreed with the Environment Agency that flood hazard was to be mapped according to the methodology given in the DEFRA report FD2320. This methodology was clarified and affirmed in the Supplementary Note published in May 2008.

The flood hazard rating was developed to make it easier to define the level of risk to people from flooding in order to help plan responses. The formula below provides a means to calculate the flood hazard rating for every grid cell in the Digital Terrain Model. The Hazard Rating is based on flood depth, velocity and a value to allow for likely debris during flood. The flood hazard rating is calculated using the equation:

Hazard Rating = d × (v + 0.5) + DF

d is depth (m)

v is velocity (m/s)

DF is the debris factor with a value of 0.5 or 1.

The velocity component of the flood hazard rating includes an adjustment factor of 0.5. The DEFRA Flood Risks to People research project identified that an adjustment factor of 0.5 was required in order to reflect the wide variation in velocity in the degree of associated hazardii.

Where maximum flood depth at any grid cell is less than or equal to 0.25m, a DF of 0.5 is applied and where the maximum flood depth is greater than 0.25m, a DF of 1 is applied. This method of applying debris factors is discussed in the Supplementary Note on mapping flood hazard and is considered most appropriate for urban areas. Figure 3-7 depicts a matrix of flood hazard ratings, based on the maximum modelled flood depth, velocity and debris factor.

Figure 3-7:Flood hazard rating Matrix

Flood Hazard Rating = d × (v + 0.5) + DF Depth of Flooding d (m)													
Velocity	DF = 0.5				DF = 1								
v (m/s)	0.05	0.10	0.20	0.25	0.30	0.40	0.50	0.60	0.80	1.00	1.50	2.00	2.50
0	0.53	0.55	0.60	0.63	1.15	1.20	1.25	1.30	1.40	1.50	1.75	2.00	2.25
0.1	0.53	0.56	0.62	0.65	1.18	1.24	1.30	1.36	1.48	1.60	1.90	2.20	2.50
0.3	0.54	0.58	0.65	0.69	1.24	1.32	1.40	1.48	1.64	1.80	2.20	2.60	3.00
0.5	0.55	0.60	0.70	0.75	1.30	1.40	1.50	1.60	1.80	2.00	2.50	3.00	3.50
1	0.58	0.65	0.80	0.88	1.45	1.60	1.75	1.90	2.20	2.50	3.25	4.00	4.75
1.5	0.60	0.70	0.90	1.00	1.60	1.80	2.00	2.20	2.60	3.00	4.00	5.00	6.00
2	0.63	0.75	1.00	1.13	1.75	2.00	2.25	2.50	3.00	3.50	4.75	6.00	7.25
2.5	0.65	0.80	1.10	1.25	1.90	2.20	2.50	2.80	3.40	4.00	5.50	7.00	8.50
3	0.68	0.85	1.20	1.38	2.05	2.40	2.75	3.10	3.80	4.50	6.25	8.00	9.75
3.5	0.70	0.90	1.30	1.50	2.20	2.60	3.00	3.40	4.20	5.00	7.00	9.00	11.00
4	0.73	0.95	1.40	1.63	2.35	2.80	3.25	3.70	4.60	5.50	7.75	10.00	12.25
4.5	0.75	1.00	1.50	1.75	2.50	3.00	3.50	4.00	5.00	6.00	8.50	11.00	13.50
5	0.78	1.10	1.60	1.88	2.65	3.20	3.75	4.30	5.40	6.50	9.25	12.00	14.75

Once a Flood Hazard Rating has been calculated, it is categorised, as shown in

Figure 3-8. Maps of the flood hazard for each breach and overtopping simulations modelled are shown in Section 10.

Figure 3-8: Flood Hazard Rating Classification

Flood Hazard Rating	Colour Code	Classification
Less than 0.75		Very Low Hazard – Caution
0.75 to 1.25		Danger For Some – Includes children, the elderly and the infirm
1.25 to 2.0		Danger For Most – Includes the general public
More than 2.0		Danger For All – Includes the emergency services

3.7.2 Hazard mapping

The following maps are examples of flood hazard maps which are contained within Volume 4

Figure 3-9: Overtopping Flood Hazard Map

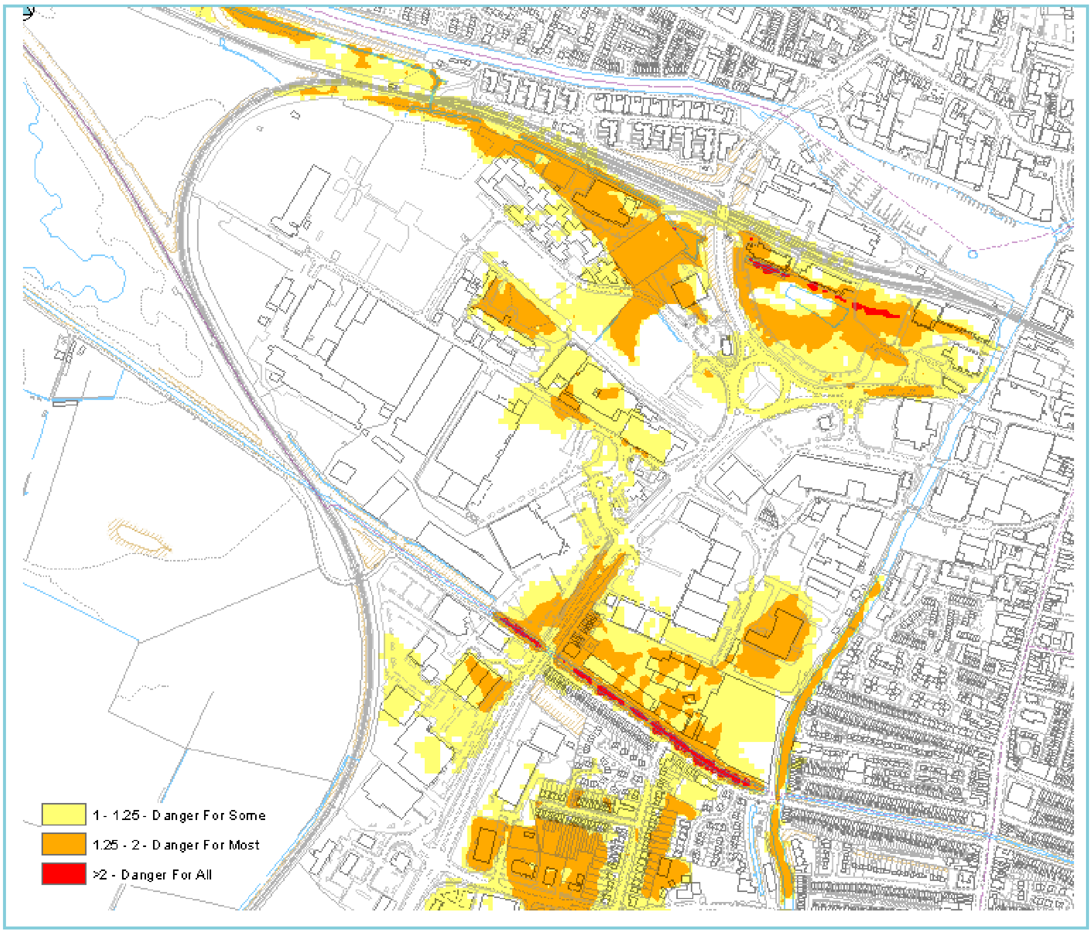
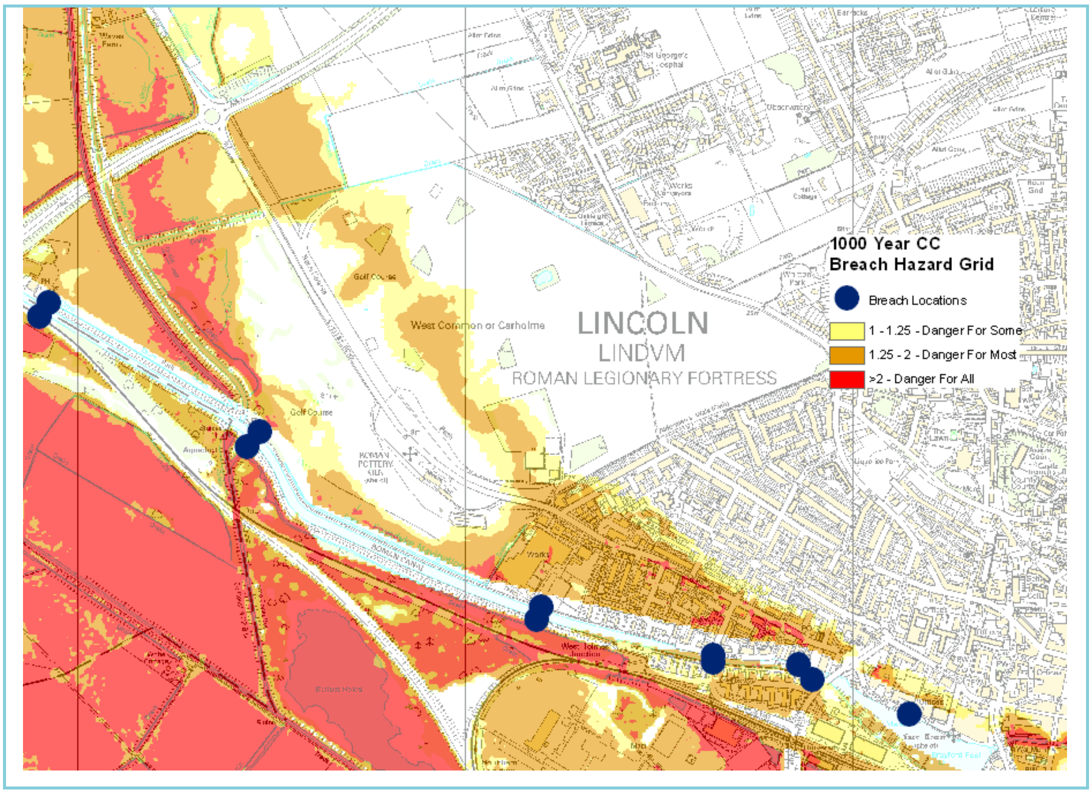


Figure 3-10: Breaching Flood Hazard Map



4 Summary of Flood Risk within the Lincoln Policy Area

A thorough review of existing information and new more detailed flood modelling work has identified the level of flood risk within the Lincoln Policy Area. This is summarised below:

Table 4-1: Summary of Flood Risk within the policy area

Source of Flooding	Potential			Comments
	High	Med	Low	
Fluvial Flooding (Rivers)	X			Fluvial flood risk is high within the policy area. The urban areas of Lincoln have significant flood protection. With the effects of climate change the flood defences will be overtopped above the 100 year with climate change scenario causing significant flooding to South Western areas of the city. A breach / failure of a flood defence would have a significant effect on the city and would cause widespread flooding.
Pluvial Flooding (Drainage)		X		It is expected that during moderate rainfall events the drainage system capacity is likely to be exceeded in some areas and further development in these areas will exacerbate this problem.
Surface Water Run-off		X		The overall risk to the district remains moderate due to the topography. Surface Water flood maps have been provided in Volume 4 detailing the effects of a 1 in 200 tear chance rainfall event assuming all sewer systems are full to capacity. The flood outlines which have been provided highlight areas where water could collect and thus highlights the need for further consideration during development planning
Groundwater			X	The risk of groundwater flooding is low

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