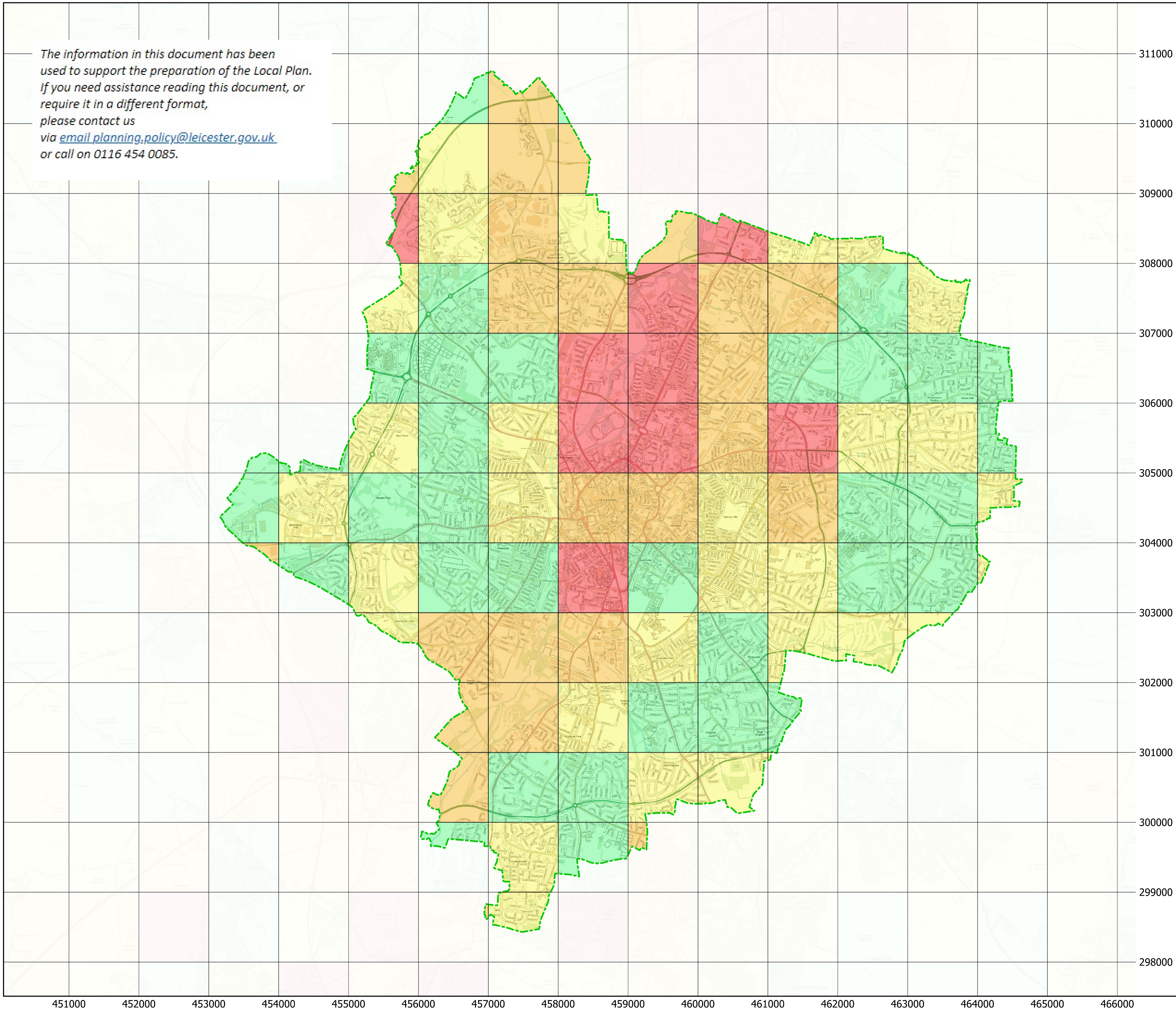
The information in this document has been used to support the preparation of the Local Plan. If you need assistance reading this document, or require it in a different format, please contact us via [email planning.policy@leicester.gov.uk](mailto:planning.policy@leicester.gov.uk) or call on 0116 454 0085.



Leicester City Council

Strategic Flood Risk Assessment 2022

Drawing Title

Areas Susceptible to Groundwater Flooding

Map Number:

Scale: 1:50000 @A3

0 500 1,000 1,500 2,000 m

LEGEND

Leicester administrative boundary

Areas Susceptible to Groundwater Flooding

- < 25%
- >= 25% <50%
- >= 50% <75%
- >= 75%

Notes

The Areas Suceptible to Groundwater Flooding Maps are a nationalscale dataset that is not suitable for the assessment of risk at the level of individual planning applications. The maps do not take into account areas where groundwater is likely to pond or flow but simply consider where groundwater might emerge. Hazard is represented by one of four area catergories showing the proportion of each 1km square that is susceptible to groundwater flood emergence.

More detailed data may be available from other sources including the British Geological Survey.

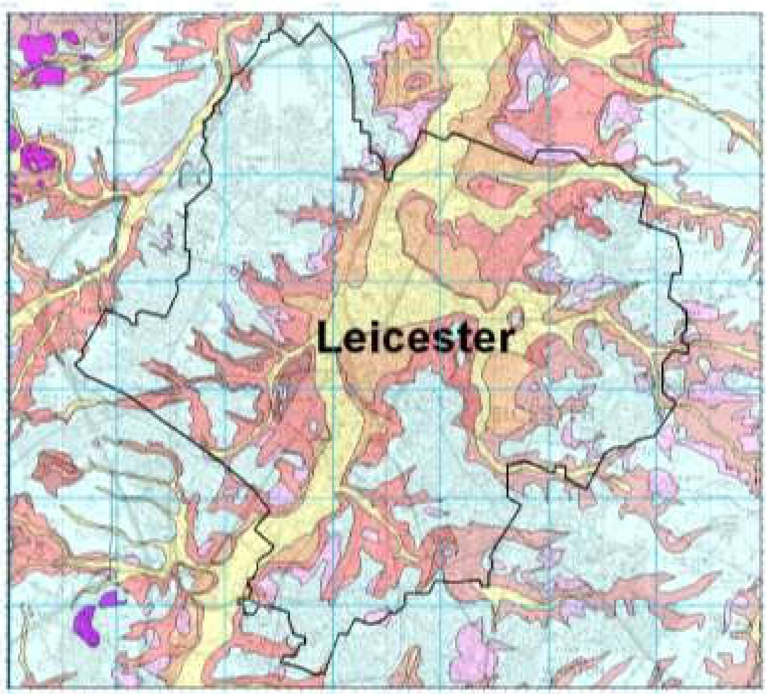
URS

Leicester Surface Water Management Plan

Part 1 – Surface Water Management Plan

Appendix A - Intermediate Assessment of Groundwater Flooding Susceptibility

Phase 2
September 2011



Prepared for

Leicester City Council

Revision Schedule

Appendix A – Intermediate Assessment of Groundwater Flooding Susceptibility
September 2011

REVISION SCHEDULE					
Rev	**Date**	**Details**	**Prepared by**	**Reviewed by**	**Approved by**
01	March 2011	Draft Report	**Trevor Muten** Principal Hydrogeologist	**Stephen Cox** Senior Hydrogeologist	
02	March 2011	Final Report	**Trevor Muten** Principal Hydrogeologist	**Stephen Cox** Senior Hydrogeologist	**Jane Sladen** Technical Director
03	September 2011	Final Report v2	**Stephen Cox** Senior Hydrogeologist	**Jane Sladen** Technical Director	**Jane Sladen** Technical Director

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Abbreviations

ACRONYM	DEFINITION
BGS	British Geological Survey
DEFRA	Department for Environment, Fisheries and Rural Affairs
EA	Environment Agency
LCC	Leicester City Council
LiDAR	Light Detection and Ranging
ST	Severn Trent Water
SUDS	Sustainable Drainage Systems
SWMP	Surface Water Management Plan

Glossary

TERM	DEFINITION
Aquiclude	Formations that may be sufficiently porous to hold water, but do not allow water to move through them.
Aquifer	Layers of rock sufficiently porous to hold water and permeable enough to allow water to flow through them in quantities that are suitable for water supply.
Aquitard	Formations that permit water to move through them, but at much lower rates than through the adjoining aquifers.
Climate Change	Long term variations in global temperature and weather patterns, caused by natural and human actions.
Flood defence	Infrastructure used to protect an area against floods, such as floodwalls and embankments; they are designed to a specific standard of protection (design standard).
Floods and Water Management Act	Legislation constituting part of the UK Government's response to Sir Michael Pitt's Report on the Summer 2007 floods, the aim of which is to help protect ourselves better from flooding, to manage water more sustainably and to improve services to the public.
Fluvial flooding	Flooding by a river or a watercourse.
Groundwater	Water that is underground. For the purposes of this study, it refers to water in the saturated zone below the water table.
Pluvial Flooding	Flooding as a result of high intensity rainfall when water is ponding or flowing over the ground surface before it enters the underground drainage network or watercourse, or cannot enter it because the network is full to capacity.
Risk	The product of the probability and consequence of the occurrence of an event.
Sewer flooding	Flooding caused by a blockage, undercapacity or overflowing of a sewer or urban drainage system.
Sustainable Drainage Systems	Methods of management practices and control structures that are designed to drain surface water in a more sustainable manner than some conventional techniques. The current study refers to the 'infiltration' category of sustainable drainage systems e.g. soakaways, permeable paving.

1 Introduction

1.1 Groundwater Flooding

1.1.1 Groundwater flooding occurs as a result of water rising up from the underlying aquifer or from water flowing from springs. This tends to occur after long periods of sustained high rainfall, and the areas at most risk are often low-lying where the water table is more likely to be at shallow depth. Groundwater flooding is known to occur in areas underlain by major aquifers, although increasingly it is also being associated with more localised floodplain sands and gravels.

1.1.2 Groundwater flooding tends to occur sporadically in both location and time, and because of the more gradual movement and drainage of water, tends to last longer than fluvial, pluvial or sewer flooding. When groundwater flooding occurs, basements and tunnels can flood, buried services may be damaged, and storm sewers may become ineffective, exacerbating the risk of surface water flooding. Groundwater flooding can also lead to the inundation of farmland, roads, commercial, residential and amenity areas.

1.1.3 It is also important to consider the impact of groundwater level conditions on other types of flooding e.g. fluvial, pluvial and sewer. High groundwater level conditions may not lead to widespread groundwater flooding. However, they have the potential to exacerbate the risk of pluvial and fluvial flooding by reducing rainfall infiltration capacity, and to increase the risk of sewer flooding through sewer / groundwater interactions.

1.1.4 The need to improve the management of groundwater flood risk in the UK was identified through Defra's Making Space for Water strategy. The review of the July 2007 floods undertaken by Sir Michael Pitt highlighted that at the time no organisation had responsibility for groundwater flooding. The Flood and Water Management Act identified new statutory responsibilities for managing groundwater flood risk, in addition to other sources of flooding and has a significant component which addresses groundwater flooding.

1.2 The Current Report

1.2.1 Leicester City Council has commissioned URS Environment and Infrastructure (UK) Ltd ("URS") to complete their Surface Water Management Plan (SWMP). A SWMP is a plan which outlines the preferred surface water management strategy in a given location. In this context surface water flooding describes flooding from sewers, drains, groundwater, and run-off from land, small water courses and ditches that occurs as a result of heavy rainfall (DEFRA, March 2010).

1.2.2 The current report provides a detailed assessment of groundwater flooding susceptibility as part of the SWMP Phase 2, and provides recommendations for Phase 3. The following sections outline the geology and hydrogeology in the Leicester City Council (LCC) administrative area. From this analysis:

- Potential groundwater flooding mechanisms are identified;
- Evidence for groundwater flooding is discussed;
- Areas susceptible to groundwater flooding are recognised; and
- Recommendations are provided for further investigation.

2 Topography, Geology and Hydrogeology

2.1 Topography and Hydrology

2.1.1 The River Soar, which has a catchment area of 1,384 km^2, is a major right bank tributary of the River Trent. It rises near Hinkley in Leicestershire and flows northeast to Leicester where it is joined from the east by the River Sence.

2.1.2 The River Soar flows northwards within the LCC administrative area, with ground levels along the river on the southern boundary of the Leicester City administrative area at 60 maOD to 50 maOD on the northern boundary. Away from the River Soar, the ground elevation rises to above 86 maOD in Braunstone Park to the west of the city, and rising to 93 maOD at the Leicester Golf Club west-southwest of the city centre. There are a number of surface water courses – all tributaries of the River Sour - within the LCC administrative area. The main tributaries of the River Soar in the LCC administrative area are the Melton Brook, Braunstone Brook, Saffron Brook and Bushby Brook; all are shown on Figure 1 and described further below. The Grand Union Canal also passes through the city centre, alongside the River Soar.

2.1.3 The River Soar is maintained by the Environment Agency (EA) (URS Scott Wilson, January 2011), although the City Council's parks department is responsible for the section through Abbey Park and the recreational area on the flood plain at Watermead Bridge. British Waterways have responsibility for the Grand Union Canal and navigable sections of the River Soar through Leicester. The River Soar flows south to north though the City Council area towards Watermead County Park.

2.1.4 Following a severe flood event in 1968, major flood defences were installed, including large diameter flood relief pipes to swiftly divert flood waters down river, away from the city. These measures have protected most residential areas of the city from flooding since their installation.

2.1.5 The route of the River Soar is geologically controlled, flowing along the line of the Soar Fault south of Leicester. The River Soar is heavily modified, with its navigable sections effectively forming connecting reaches of the Grand Union Canal as it passes through Leicester City. It is diverted into a second channel upstream of Frog Island for historic navigation reasons; rejoining the river at the lock and weir structures beside the National Space Centre.

2.1.6 The River Sence is a major tributary of the River Soar, which flows westward from west of Illstone on the Hill some 15 km from Leicester City Centre, into the River Soar south of Leicester City administrative area. The Grand Union Canal runs parallel with the course of the River Sence until turning north southwest of Glen Parva, close to the confluence of the River Sence with the River Soar.

2.1.7 The Lubbesthorpe Brook flows into the River Soar at Kings Lock, immediately upstream of Leicester City's south-westerly administrative boundary. A minor tributary – the River Biam – flows to the west of the sports ground, and meets the River Soar above the Lock and Weir at the point where the Grand Union Canal meets the River Soar.

2.1.8 The Braunstone Brook, and its tributary the Gilrose Brook, is a watercourse to the west of Leicester City centre, which rises in the vicinity of the Kirby Fields Industrial Estate and flows east towards Braunstone Park mainly via an underground culvert. The brook re-emerges as an open channel (referred to as 'the Pool', as identified on Figure 1) and flows along the southern side of the park in a south easterly direction before a pronounced change of direction to flow north east. The Braunstone Brook is culverted, flowing northward through residential areas prior to its confluence with the River Soar to the southwest of Frog Island. There is evidence to suggest that the section of the Brook downstream of Braunstone Park historically may have been re-routed from its natural course towards the River Soar.

2.1.9 The Western Park Brook is an urban drain flowing eastward from Western Park, under and through the Western Park residential area, into the Braunstone Brook. It is noted that this water course is not shown in the detailed river network (Figure 1) provided by the EA.

2.1.10 The Saffron Brook, and its tributary, the Wash Brook, rise from springs flowing from the Lias east of Oadby, flowing north-westward draining the south-eastern areas of Leicester City before flowing into the Grand Union Canal, south of the railway crossing. The Wash and Saffron Brooks are predominately, or extremely, urbanised catchments with substantive channel modification. The linear mostly piped Queens Road Brook flows into the Saffron Brook east of the Railway at Knighton Fields.

2.1.11 The Holbrook is mainly in a culvert, flowing westward from Oadby through South Knighton, before discharging into the Wash Brook via a culvert and pipe.

2.1.12 The Bushby Brook catchment drains a substantive area of eastern Leicester, and is dominantly an urbanised catchment, with substantive modification. The Bushby Brook rises to the west of Houghton on the Hill, flowing eastwards to Thurnby; where the Thurnby Brook joins the Bushby Brook. The upper catchment of the Bushby Brook is moderately urbanised and dominated by clay and limestone deposits; whereas the lower Bushby Brook catchment is extremely urbanised, totally dominated by the conurbation of Leicester.

2.1.13 The Evington Brook rises from springs east of Leicester City, flowing westward through the city centre and joining the Bushby Brook. The Willow Brook forms the confluence of the Bushby Brook and the Evington Brook. Downsteam of this confluence, the Portwey Brook flows into the Willow Brook. All these sections of urban stream are heavily modified and culverted.

2.1.14 North of the Bushby Brook, the Melton Brook rises as springs in a relatively rural area northeast of Leicester City centre. From its source, the Melton Brook flows westwards past Old Ingarsby, Keyham and the medieval village of Hamilton before entering the city of Leicester at Barkbythorpe Road. The brook finally flows into the River Soar in Rushey Mead beside the foot bridge south of the A563. JBA (2004) established the total area of the Bushby Catchment as 19.4 km^2. The upper 15 km^2 of the catchment is defined as being moderately sloped and essentially rural above Barkbythorpe Road. The lower 4 km^2 of the catchment between Barkbythorpe Road and the River Soar is dominated by extensive urbanisation and channel modification.

2.1.15 The Thurmaston Parish Dyke is a linear culvert or drain, effectively forming a drainage channel from the railway at Thumastone to the Grand Union Canal at Watermead County Park.

2.2 Geology

2.2.1 Figures 2 and 3 provide bedrock and superficial geological information, respectively, for the LCC administrative area and the surrounding area from the BGS 1:50,000 scale geological series. Figure 4 provides a generalised geological cross section for the study area showing both superficial (Figure 4A) and bedrock (Figure 4B) deposits; these are used to improve the conceptual understanding of the area. The BGS 1:10,000 scale geological series exists for the east of Leicester, should a more detailed geological assessment be required. However, 111 borehole logs and water wells were obtained from the BGS to provide local data (see Figure 3). These help to identify the variable geological conditions that may be encountered by new development, and water strike information can be used to inform the assessment of groundwater flooding susceptibility and the suitability for infiltration SUDS.

Bedrock Geology

2.2.2 The bedrock geology of the area comprises broadly the Middle to Upper Triassic Mercia Mudstone Group to the West of Leicester and the Lower Jurassic Lias Group to the East of Leicester; with a thin layer of the Rhaetian Penarth Group deposits between. The line of the River Soar approximates the boundary between the older Mercia Mudstone to the west, and the younger Lias Group to the east. This reflects the structural control, as the River Soar flows along the line of the Soar Fault[1] south of Leicester City, joining the line of other major faults to the north of the city.

2.2.3 The Mercia Mudstone Group in Leicestershire is divided into five Formations, with the youngest forming the bedrock to the east of the River Soar, with the bedrock formation aging with distance westward from Leicester. These are not shown on the BGS digital data, although they can be observed on the BGS paper map.

2.2.4 At the base of the Mercia Mudstone is the Sneinton Formation, with a thickness of up to 90 metres, is an interbedded reddish brown mudstone, siltstone and buff-grey fine- to medium-grained sandstone, with micaceous, pebbly beds in the lower half. The basal beds of the Sneinton Formation tend to have a lower gypsum content than the beds above, and whilst still dominated by mudstones and marls it often has slightly coarser sandstones and pebble beds towards the unconformable contact with the underlying Sherwood Sandstone Group beneath.

2.2.5 Above the Sneinton Formation is the Gunthorpe Formation, which is red-brown mudstone, with subordinate to greenish-grey dolomitic siltstone and fine-grained sandstone, where gypsum veins and nodules are common. The Gunthorpe Formation is up to 70 to 80 metres thick, and forms the bedrock west of approximately 9 km northwest of Leicester City centre.

2.2.6 The Edwalton Formation sits above the Gunthorpe Formation and is red-brown to grey-green mudstone gypsiferous mudstone with green-grey dolomitic siltstones and sandstones. The Edwalton Formation is between 40-50 metres thick, and forms the bedrock of the north-western boundary of Leicester City administrative area.

2.2.7 The upper part of the Edwalton Formation is the Holygate Sandstone Member (now referred to as the Arden Sandstone Formation, as shown on Figure 2), which is a 10 to 15 metre thick grey, interbedded sandstone, forming the bedrock of the Western Park District of Leicester.

2.2.8 Above the Edwalton Formation is the Cropwell Bishop Formation, which is a red-brown or grey-green gypsiferous mudstone with beds of green-grey dolomitic siltstones, sandstones and gypsum. The Cropwell Bishop Formation is 40 to 50 metres thick and forms the bedrock in the western side of Leicester City.

[1] It is noted that the Soar Fault and the majority of other faults in the area are only shown on the BGS paper map, not the digital version supplied for Figures 2 and 3.

2.2.9 The Penarth Group is a thin succession of 5 to 6 metre thick grey-green mudstone of the Blue Anchor Formation with 3 to 4 metres thickness of dark, organic-rich mudstones of the Westbury Formation with fine-grained tea-green marls of the Lilistock Formation marking the base of the Lias above. The sediments represent a variety of shallow marine, lagoonal and near-shore environments, reflecting the early stages of submergence of the land surface at the early stages of the shallow seas of the Lower Jurassic. The Penarth Group separates the Mercia Mudstone from the Lias Group above, forming thin bedrock deposits outcropping in a south-southwest to north-northeast strip to the east side of the centre of Leicester City. Although a fairly minor formation, these units of the Penarth Group form the bedrock for significant areas of Leicester City area; notably, for example, Spinny Hills is an outlier of the Cotham Member of the Westbury Formation.

2.2.10 The Lias Group of eastern Leicestershire and Leicester City east of the River Soar comprises of (from oldest to youngest and forming bedrock from west to east) the Blue Lias Formation; the Charmouth Mudstone Formation; the Dyrham Formation; the Marlstone Rock Formation; and the Whitby Mudstone Formation.

2.2.11 The Blue Lias Formation is brown to blue grey mudstone, locally fissile, interbedded with pale grey argillaceous limestone. The Blue Lias Formation has a thickness ranging from 55 to 120 metres thick. This is the dominant bedrock for the south-eastern and eastern areas of Leicester City administrative area.

2.2.12 The Charmouth Mudstone Formation is a grey limestone with occasional limestone beds, and locally ferruginous, phosphatic and sideritic nodules. The Charmouth Mudstone Formation is up to 105 to 180 metres thick.

2.2.13 The Dyrham Formation is a grey micaceous siltstone with beds of sandstone above the Charmouth Formation, and has a thickness of about 15 metres. Above this is the Marlstone Rock Formation (1 to 9 metres thick), which is a ferruginous ooidal limestone and iron grainstone; and above this, the Whitby Mudstone Formation which is a grey mudstone, with locally ferruginous sporadic limestone beds. The Whitby Formation forms a thickness of 40 to 50 metres. The Dyrham Formation and above form the bedrock to the east of Leicestershire, beyond the LCC administrative area. They are mentioned in this report as some springs flowing west lead to the drainage through Leicester. However, this is not seen as dominant; and therefore not a focus of this report.

Superficial Geology

2.2.14 The superficial geology of the Leicester City area consists of Alluvium, River Terrace Deposits, and Glacio-Fluvial Deposits.

2.2.15 The Alluvium forms the bed and flood plain of the River Soar and its tributaries through the centre of Leicester. It comprises of brown and grey clay, silt, sand and gravel, locally rich in organic material.

2.2.16 The River Terrace Deposits are associated with the historic position of the River Soar, and comprise brown gravels and flinty gravels locally with head and organic rich silts and clays. The main deposits are named; notably the Birstall Member, the Wanlip Member and the Syston Member in the south and southeast through the centre to the north of the LCC administrative area.

2.2.17 Along the valleys of the tributaries flowing from the east, there are pockets of Valley Deposits or Colluvium, mainly brown claying silts and sands. These deposits are found particularly along the valleys of the River Soar tributaries flowing through Evington, and Humberstone, for example.

2.2.18 To the east of the city centre, generally at higher elevation than the Valley Deposits, and in interfluves, are areas of Glacio-Fluvial deposits. These are undifferentiated brown to red-brown sand and gravels. Discrete areas of these deposits are particularly noted in Stoughton, Evington, Bushby, Hamilton and Barkby Thorpe areas of Leicester City.

2.2.19 To the east and west of the River Soar Valley and its tributaries, and their associated deposits much of the land area is covered by the Oadby Member Till, which is a grey to yellow brown Lias rich till, with clasts that include flint, chalk and Jurassic rocks. It is part of the Wolston Formation (Catt et al., 2006).

2.2.20 To the east of Leicester, beyond the Leicester City administrative boundary, are the reddish-brown Bytham Sands and Gravel Formation, containing Trias-derived vein quartz and quartzite pebbles.

2.3 Hydrogeology

2.3.1 The hydrogeological significance of the various geological units within the study area is provided in Table 1. The range of permeability likely to be encountered for each geological unit is also incorporated in Table 1, based on the BGS permeability data (Figures 6).

Table 1: Geological Units in the Study Area and their Hydrogeological Significance

Geological Units		**Permeability (based on BGS permeability map)**	**Hydrogeological Significance**
Superficial Geology	Alluvium	High to very low	Variable (but probably an aquitard)
	River Terrace Deposits (sand and gravel)	Very high to high	Secondary aquifer
	Valley Deposits	Moderate to very low	Variable (probably an aquitard but may locally form a secondary aquifer)
	Glacio-Fluvial Deposits	Moderate to very low	Variable (probably an aquitard but may locally form a secondary aquifer)
Bedrock Geology	Lias Group	Moderate to very low	Some Aquifer units – notably the Blue Lias; with the clays and fine silts typically forming Aquiclude layers, with local Aquitard layers and a small number of layers forming a secondary aquifer supporting small scale abstraction
	Penarth Group	Low to very low	Aquitard and secondary aquifer
	Mercia Mudstone Group	Low to very low	Aquiclude (predominantly) with local Aquitard layers and a small number of layers forming a secondary aquifer supporting small scale abstraction

'Aquifer' - allows significant groundwater movement (see Glossary)
'Aquitard' - allows some groundwater movement (see Glossary)
'Aquiclude' - does not allow groundwater movement (see Glossary)
'N/A' not available

Bedrock Geology

2.3.2 The BGS has designated the Mercia Mudstone Group as a non-aquifer due to the general poor ability to store and transmit significant quantities of water. It is regarded as predominantly impermeable, with some layers forming a poor aquifer, used locally for minor abstraction for small scale agricultural and domestic supply purposes.

2.3.3 The EA class the Mercia Mudstone Group in the Leicester area as a 'Secondary B' aquifer - predominantly lower permeability layers which may store and yield limited amounts of groundwater in thin permeable horizons, forming water-bearing horizons within the former non-aquifers.

2.3.4 The Sneinton Formation, at the lower part of the Mercia Mudstone Group, often forms an aquifer, forming numerous small springs along its outcrop in Nottinghamshire. However, this is outside the study area. The other horizons of the Mercia Mudstone Group are not characterised as aquifers.

2.3.5 The physical properties for secondary aquifers in England and Wales (Jones et al., 2000) suggests that hydrogeological investigations specific to the Mercia Mudstone Group has not been undertaken; generally assessed in relation to the Sherwood Sandstone aquifer below.

2.3.6 The Penarth Group is predominantly mudstone, and therefore regarded as an aquitard. Thin beds of silts and fine sands do allow some groundwater movement. As the Penarth Group outcrop runs south-southwest to north-northeast through the eastern side of Leicester City Centre, many of the tributaries flowing from the Lias springs to the east of Leicester flow across the Penarth Group outcrop. These thin beds, therefore, may have a minor hydrogeological affect on perched water tables associated with the Alluvium and the River Terrace Deposits; nonetheless, they are not developed as a groundwater resource.

2.3.7 The Lias Group has a variable lithology, and therefore variable hydraulic properties. The Blue Lias is classified by the EA as a Secondary Aquifer. The groundwater flow within the Blue Lias is controlled by its lithology and bedding, with a series of small springs to the east of Leicester, forming the tributaries of the River Soar that flow through the city.

Superficial Geology

2.3.8 Alluvium and River Terrace Gravel deposits along the course of the River Soar and associated tributaries are classed as Secondary Aquifer by the EA.

2.3.9 The Valley Deposits and Glacio-Fluvial Deposits are also included in the Secondary Aquifer classification.

2.3.10 Because all of the superficial deposits in the Leicester area have a broad range of grain size, the sands and gravels allow effective groundwater movement and groundwater yields, therefore forming secondary aquifer units. However, the clays and silts retard groundwater flow, forming aquitards. Perched water tables and small springs and seepage faces are common in the superficial deposits of Leicester City area. These aquifer units tend to be small and localised, with a small storage capacity. Springs flow after sustained and heavy rainfall – usually in the winter, filling up these aquifer units to overflowing.

2.3.11 Furthermore, the Alluvium is in hydraulic connectivity with the River Soar; and the River Terrace Deposits have the potential to be hydraulically connected with the River Soar flood plain and associated lakes north of the city – such as Watermead County Park. The groundwater level in the Alluvium, therefore, will be a reflection of the water level of the River Soar, and the amount of sustained and heavy rainfall.

2.3.12 Notably, the Oadby Member Till, the Glacial Deposits away from the deposits associated with the river valley and its tributaries cover a substantial area of the catchment. Many of the spring flows feeding the tributaries that flow through Leicester City centre are associated with these silty clays and the respective bedrock beneath.

Groundwater Levels

Bedrock Geology

2.3.13 The EA does not monitor groundwater levels within LCC administrative area. As a consequence, limited groundwater level information is available for this area. Groundwater level data were also requested from the water supply company, Severn Trent Water (ST). However, they do not have any abstraction or observation boreholes in the Leicester area.

2.3.14 Water level information has been obtained from a small number of borehole drilling logs held by the British Geological Survey. Because of this sparse data, it cannot be determined whether these water levels are representative for the Leicester area or controlled by localised constraints. One groundwater level has been identified in the bedrock beneath Leicester City centre, at between 25 and 29 m below ground level (bgl); although no information is available about the long term range in groundwater level fluctuation.

Superficial Geology

2.3.15 The EA does not monitor groundwater levels in the superficial deposits of the LCC administrative area. However, borehole logs have been collated from the BGS and a number of these provide some details of groundwater levels. The boreholes were drilled in different years and so groundwater contours cannot be constructed, although comments on groundwater levels can provide an indication of depth to groundwater.

2.3.16 However, BGS borehole logs indicate that there may be some localised perching of the water table in the Alluvium and River Terrace Deposits; partly controlled by the water level in the River Soar and Grand Union Canal. The groundwater table has generally a greater depth in the bedrock geology aquifers. It is stressed, however, that this is based on the limited available data.

2.3.17 Borehole logs show water table levels in Leicester City have been observed between 3.7 m bgl in Syston Street, 6.6 m bgl at Sanvey Gate and 8.3 m bgl at Waring Street.

Water Supply Abstractions

2.3.18 There are no major groundwater abstractions in the Leicester City area; such that no part of the area is delimited as a Source Protection Zone by the EA.

2.3.19 However, there are a small number of minor groundwater abstractions from the superficial and Blue Lias Formations used for domestic, minor agricultural, industrial and ground source heating purposes. This abstraction will only have a minor impact on the water balance.

2.3.20 The River Soar and its tributaries Water Resources Management Unit have a CAMS status of 'Water Available', such that water is likely to be available at all flows including low flows, although restrictions may apply.

Artificial Groundwater Recharge

2.3.21 Water mains leakage data for the administrative area of LCC were requested from ST. Unfortunately the water company does not assess leakage estimates at this level of detail. However, for the area of the East Midlands served by ST, the reported leakage level for 2010 was over 180 Ml/d (ST, June 2010), with a planned decrease to approximately 152 Ml/d by 2027. It would be possible to estimate leakage in the Leicester City administrative area by apportioning total leakage for the East Midlands area based on population estimates. This has not been undertaken, but the method could be used in future investigations if a water balance assessment is required.

Surface Water / Groundwater Interactions

2.3.22 Groundwater to surface water interactions are primarily within the Alluvium and River Terrace Deposits. This has been partly restrained by the modification associated with the Grand Union Canal and historic modification of surface water courses notably the culverting of the urban tributaries of the River Soar.

2.3.23 The development of the Watermead Country Park and other water storage on the flood plain of the River Soar has locally enhanced recharge to the Alluvium and thin aquifer units beneath. These are downstream of the city centre, and do not have a control on water levels further south.

2.3.24 Because many of the small urban tributaries flowing to the River Soar from the east, through Leicester City centre, are spring fed, their base flow during the summer months tend to decline and are very low due to the small volumes of natural groundwater storage in the superficial deposit aquifers and Blue Lias beds present in the area. However, they may also be low owing to limited hydraulic connectivity with the superficial geology aquifers resulting from the river channel modifications. Without groundwater level data for the superficial geology aquifers, it is not possible to gain an understanding of the relationship between surface water and groundwater.

3 Assessment of Groundwater Flooding Susceptibility

3.1 Groundwater Flooding Mechanisms

3.1.1 Based on the current hydrogeological conceptual understanding, there is potential for groundwater flooding in the LCC administrative area. There are five key groundwater flooding mechanisms that may exist:

- **Superficial aquifers along the course of the River Soar (and the associated Grand Union Canal present within the Flood Plain of the River Soar):** groundwater flooding may be associated with Alluvium deposits and the sand and gravel River Terrace Gravels deposits where they are in hydraulic continuity with surface water courses. Stream levels may rise following high rainfall events but still remain "in-bank", and this can trigger a rise in groundwater levels in the associated superficial deposits. The properties at risk from this type of groundwater flooding are probably limited to those with basements / cellars, which have been constructed within the superficial deposits. Within the UK, houses with cellars / basements were largely built within the Victorian era and into the early 1900s. Therefore, the developed areas with properties of this period are more likely to comprise properties with cellars / basements.

- **Superficial aquifers in various locations:** a second mechanism for groundwater flooding is also associated with River Terrace Deposits (gravel and sand) and sand lenses within the Valley Deposits and Glacio-Fluvial deposits along the tributaries of the River Soar flowing through Leicester City area that occurs where they are not hydraulically connected to surface water courses. Perched groundwater tables can exist within these deposits, developed through a combination of natural rainfall recharge and artificial recharge e.g. leaking water mains. The properties at risk from this type of groundwater flooding are probably limited to those with basements / cellars; and in close proximity to the course of the urban tributaries of the River Soar.

- **Springs from the Blue Lias feeding tributaries of the River Soar that flow east to west through LCC administrative area (the Saffron Brook, the Evington Brook, the Holbrook, the Wash Brook, the Bushby Brook, the Willow Brook, the Portwey Brook, the Melton Brook and the Thurmaston Parish Dyke):** a third mechanism for groundwater flooding could occur when rainfall recharges the perched water tables within the lenticular water bearing sand lenses within the Lias. These aquifer layers are separated by considerably less permeable clay and silt layers. As the water table rises, springs and seepages may flow at their outcrop. This mechanism is illustrated in Figure 5. The properties at risk from this type of groundwater flooding are probably limited to those with basements / cellars in close proximity to the spring fed tributaries to the east of Leicester.

- **Springs from the Mercia Mudstone Formation to the south and southwest of LCC administrative area (the Braunstone Brook, and its tributary the Gilrose Brook, and the Western Park Brook):** the thin aquifer units of the Mercia Mudstone Group on the west side of the River Soar overtop and form springs at the head of these minor tributaries. Rainfall recharges the lenses of sandstones in the Mercia Mudstone, which release their storage as springs and seepages at their outcrop when the perched water table rises. This mechanism is similar to that controlling the springs flowing from the perched water table and aquifer horizons of the Lias, and the mechanism is illustrated in Figure 5.

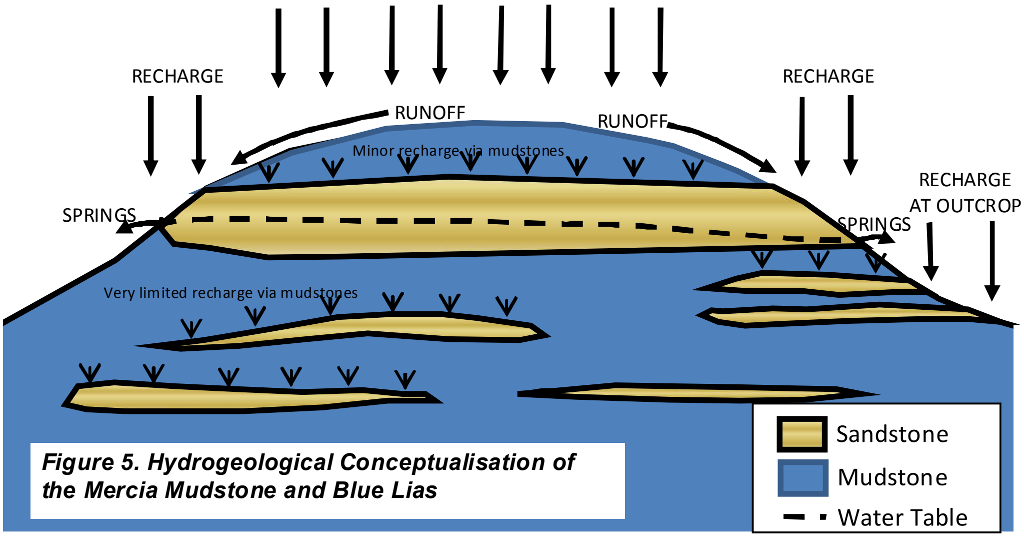

Figure 5. Hydrogeological Conceptualisation of the Mercia Mudstone and Blue Lias

- **Made ground in various locations:** a final mechanism for groundwater flooding may occur where the ground has been artificially modified to a significant degree. If this 'made ground' is of substantial thickness and permeability, then a shallow perched water table may exist. This could potentially result in groundwater flooding at properties with basements, or may equally be considered a drainage issue. Areas mapped by the BGS as containing made ground deposits are found both on the superficial deposits and directly on the bedrock and may either form a continuous aquifer with respective aquifer horizons, or provide a low permeability cap constraining recharge to and seepage from such horizons, depending on the composition of the made ground[2].

3.2 Evidence of Groundwater Flooding

3.2.1 No groundwater flooding incidents within the study area have been reported to the EA. Figure 6 shows the reported historic flood incidents recorded by LCC and flood incidents reported by Fire and Rescue. However, these do not distinguish between groundwater, fluvial or pluvial flooding incidents. It is possible that some of these incidents are groundwater flooding events or related to water table rise or spring flows. However, there is insufficient information from the data to distinguish groundwater flooding from pluvial or fluvial flooding events.

3.3 Groundwater Flooding Susceptibility Datasets

3.3.1 The BGS has produced a data set showing areas susceptible to groundwater flooding on the basis of geological and hydrogeological conditions. The high and very high susceptibility bands are shown on Figure 6. The BGS data indicates that susceptibility to groundwater flooding is very high to high in some areas where Alluvium and River Terrace Deposits are present at surface; notably along the River Soar and its tributaries that flow through Leicester City. The Alluvium has been classified as having low minimum permeability (although Alluvium may have

[2] It is noted that significantly larger areas are mapped as made ground on the BGS paper map, but not the digital data supplied for Figure 3.

more permeable sands and gravels), whilst the River Terrace Deposits have very high minimum permeability.

3.3.2 In general, it is thought that the approximate areas identified by the BGS as being susceptible to groundwater flooding, are, as expected. However, it is possible that the various susceptibility categories from 'very high' to 'very low' may not be accurate given the poor availability of groundwater level data to the BGS; the EA does not monitor superficial or bedrock groundwater levels for the study area. Nonetheless, it is possible to compare the BGS susceptibility to groundwater flooding data with the locations of general flooding incidents on Figure 6. This indicates the groundwater conditions may have contributed to a number of the historic flooding incidents within the Leicester City area.

3.3.3 Finally, those areas identified by the BGS as having no susceptibility to groundwater flooding could still be affected where groundwater springs / seepages form minor flows and ponding over impermeable strata. This mechanism may have resulted in the regular ponding of water observed adjacent to the River Soar, at the edges of its flood plain, where it is possible that groundwater seepages from the River Terrace Deposits seep onto the relatively low permeable Alluvium. Likewise, flows in the ephemeral springs feeding the headwaters of the tributaries to the east and to the west of Leicester may lead to localised groundwater flooding.

3.4 Importance of Long Term Groundwater Level Monitoring

3.4.1 Groundwater flow direction, depth to groundwater, topography and the degree of artificial influence in the subsurface (e.g. leaking water mains or groundwater abstractions) play an important role when considering the susceptibly of an area to groundwater flooding. Unfortunately groundwater level data for the superficial aquifers is limited to recorded water strikes or rest water levels on BGS borehole logs, which only provide groundwater levels at one location and for one point in time. Without long term groundwater monitoring, it is not possible to derive groundwater level contours, or understand maximum seasonal fluctuations. Therefore it is not possible to provide a detailed assessment of groundwater flood risk or provide detailed advice on suitability for infiltration SUDS.

3.4.2 It is not sufficient to rely on the work undertaken by developers through the planning application process, unless long term monitoring (several years) is one of the conditions when granting planning permission. Groundwater levels are often only measured once, or, at most, for a number of weeks. It would be advisable for the Council, in combination with the EA, to begin long term monitoring of superficial aquifer groundwater levels. This data would also be useful for understanding groundwater / surface water interactions, which is important when considering the design of fluvial flood defences.

3.4.3 It is also important to understand how changing policies relating to infiltration SUDS can impact groundwater levels. For instance, historic development was limited by the flood plain of the River Soar and associated alluvium and terrace deposits. These areas have subsequently been developed and natural recharge to the aquifer will have reduced, possibly leading to a lowering of groundwater levels if not balanced by an increase in artificial recharge through leaking pipes. The introduction of infiltration SUDS (e.g. soakaways) may slowly reverse this process, leading to a subsequent rise in groundwater levels. This could prevent soakaways from operating and the reduction in unsaturated zone thickness may not be acceptable to the EA owing to its responsibilities under the Water Framework Directive (see Section 4).

3.4.4 Long term groundwater level monitoring (Figure 6a) is required to support decision making with respect to future land development and future co-ordinated investments to reduce the risk and informing the assessment of suitability for infiltration SUDS. Finally, once sufficient data has been collected, it may be suitable to develop a groundwater level warning system using the observation borehole network.

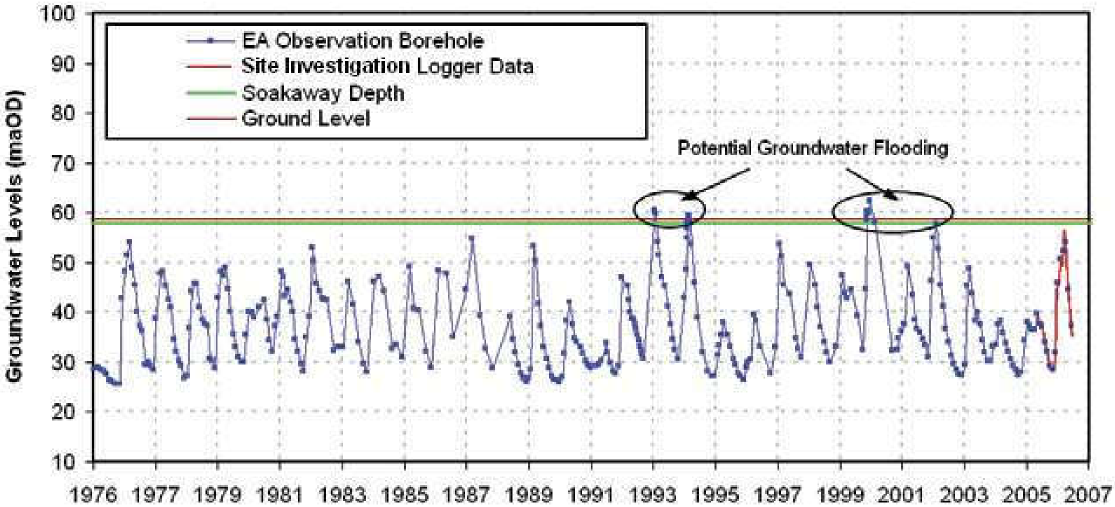

Figure 6a: Schematic demonstrating the importance of long term groundwater level monitoring

4 Water Framework Directive and Infiltration SUDS

4.1.1 The Water Framework Directive approach to implementing its various environmental objectives is based on River Basin Management Plans (RBMP). These documents were published by the EA in December 2009 and they outline measures that are required by all sectors impacting the water environment. The Humber RBMP is considered within the current study since infiltration SUDS have the potential to impact the water quality and water quantity status of aquifers.

4.1.2 The current quantitative assessment for the Soar groundwater unit (GB40402G990600) is 'good' and the current quality assessment is 'good'. It is also noted there are no water dependent Sites of Special Scientific Interest (SSSI) within the Leicester City administrative area. Gipsy Lane Pit SSSI is located in the northeast part of the study area, although its status is related to geological interest and is therefore not pertinent to the current study.

4.2 Infiltration SUDS Suitability

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

4.2.2 EA guidance on infiltration SUDS is available on their website at: http://www.environment-agency.gov.uk/business/sectors/36998.aspx. This should be considered by developers and their contractors, and by LCC when approving or rejecting planning applications. Infiltration SUDS are suitable where aquifers exist, so long as contamination is not introduced to the aquifers, particularly where there are sensitive groundwater receptors, such as licensed groundwater abstractions.

Key Water Level Considerations (Figure 6)

4.2.3 The areas that may be suitable for infiltration SUDS exist where there is a combination of high ground and permeable geology. However, consideration should be given to the impact of increased infiltration SUDS on properties further down gradient. An increase in infiltration / groundwater recharge will lead to an increase in groundwater levels, thereby increasing the susceptibility to groundwater flooding at a down gradient location. This type of analysis is beyond the scope of the current report.

4.2.4 It is important to be aware of groundwater level conditions at a potential development site. As many of the permeable deposits are River Terrace Deposits associated with surface water courses, it will be important to understand the degree of hydraulic continuity between groundwater and surface water. Maximum likely groundwater levels should be assessed, to confirm that soakaways will continue to function even during prolonged wet conditions.

Key Geological Considerations (Figure 7)

4.2.5 The infiltration SUDS suitability assessment shown on Figure 7 is based on permeability data obtained from the BGS. It shows that for much of the Leicester City area the potential for infiltration SUDS is restricted i.e. probably unsuitable where high infiltration rates are required, although there may exist potential for low infiltration rate SUDS in conjunction with attenuation SUDS. In addition, some areas along the course of the River Soar and its urban tributaries will require enhanced site investigation and assessment prior to establishing their suitability for high infiltration rate SUDS.

4.2.6 Following a review of the BGS data, no part of Leicester City administrative area has been immediately identified as potentially suitable for high infiltration rate SUDS. However, it is noted that this is a high level assessment and only forms an approximate guide to infiltration SUDS suitability; a site investigation is required to confirm local conditions.

Key Water Quality Considerations (Figure 7)

4.2.7 Infiltration SUDS should be located away from areas of historic landfill (as identified in Figure 7) and areas of known contamination or risk of contamination, where possible, to ensure that the drainage does not re-mobilise latent contamination or exacerbate the risk to groundwater quality and possible receptors, such as abstractors, springs and rivers. A preliminary groundwater risk assessment should be included with the planning application.

4.2.8 Restrictions on the use of infiltration SUDS apply to those areas within Source Protection Zones (SPZ). Developers must ensure that their proposed drainage designs comply with the available EA guidance. However, at present there are no SPZ defined within the Leicester City administrative area.

5 Conclusions and Recommendations

5.1 Conclusions

5.1.1 The following conclusions can be drawn from the current study:

- The superficial deposits form a small perched aquifer over the bedrock aquiclude across much of the central, southern and northern districts of LCC administrative area. In addition, the localised Valley Deposits and possibly the Glacio-fluvial deposits will behave as aquifers in localised areas. The EA and LCC do not currently monitor groundwater levels in the superficial deposits.
- A limited number of borehole logs have been obtained from the BGS. These indicate that the Aluminium and River Terrace Deposits are water bearing and the groundwater table has been observed between around 3.5 and 8.5 m below ground level, No information is available regarding the range of water level fluctuation within the Leicester City area.
- A number of potential groundwater flooding mechanisms have been identified. Of significance are those flooding mechanisms associated with the superficial aquifers and their hydraulic continuity with surface water courses. Properties at most risk are those with basements / cellars.
- No groundwater flooding incidents within the study area have been reported to the Environmental Agency. Figure 6 shows the reported historic flood incidents recorded by LCC and flood incidents reported by Fire and Rescue. However, these do not distinguish between groundwater, fluvial or pluvial flooding incidents. It is possible that some of these incidents are groundwater flooding events or related to water table rise or spring flows. However, there is insufficient information from the data to distinguish groundwater flooding from pluvial or fluvial flooding events.
- The BGS has produced a data set showing areas susceptible to groundwater flooding on the basis of geological and hydrogeological conditions. The map indicates that susceptibility to groundwater flooding is very high to high in some areas where Alluvium and River Terrace Deposits are present at surface; along the course of the River Soar, and its flood plain, and along the course of the spring fed tributaries flowing from the east and the west, though the Leicester City administrative area.
- Without long term groundwater monitoring, it is not possible to derive groundwater level contours or understand maximum seasonal fluctuations and potential climate change impacts. Therefore, at this stage, it is not possible to provide a detailed assessment of groundwater flood risk or provide detailed advice on suitability for infiltration SUDS.

5.2 Recommendations

5.2.1 The following recommendations are made based on the current report:

- Information on foul sewer leakage and groundwater infiltration could be obtained from ST, if available, to help understand the water balance for the area;
- Review site investigation reports held by LCC, to identify whether groundwater level data is held within them. This could be used to enhance the assessment of groundwater flooding susceptibility and infiltration SUDS suitability.

- The areas identified as being susceptible to groundwater flooding should be compared with those areas identified as being susceptible to other sources of flooding e.g. fluvial and pluvial. An integrated understanding of flood risk will be gained through this exercise;
- As the historic flooding recorded by LCC, and Fire and Rescue, do not distinguish between groundwater, fluvial or pluvial flooding incidents, further evaluation of these events is required to establish which of the reported historic flood events are a result of groundwater flooding rather than fluvial or pluvial flooding.
- The impact of infiltration SUDS on water quality and quantity with respect to the Water Framework Directive should be considered further within future investigations including those undertaken by developers;
- Monitoring boreholes should be installed in the Alluvium and River Terrace Deposits, fitted with automatic level recording equipment for a period of one year and water quality sampling undertaken. At this point a review of the monitoring network should be undertaken and an update on infiltration SUDS guidance provided;
- The proposed monitoring boreholes may assist the EA with water quality and quantity assessments for the next River Basin Management Plan. Therefore, site selection should be agreed with the EA and the necessity for water quality monitoring agreed; and
- Construction of a numerical groundwater model for the Alluvium and River Terrace Deposits, and a detailed conceptual model for the minor aquifers affecting flow to the spring-fed tributaries to the West and East of Leicester should be considered, following at least 3 years of groundwater level monitoring that has been undertaken. The model could then be used as a tool for assessing the impact of infiltration SUDS on the aquifer or for modelling water management options.

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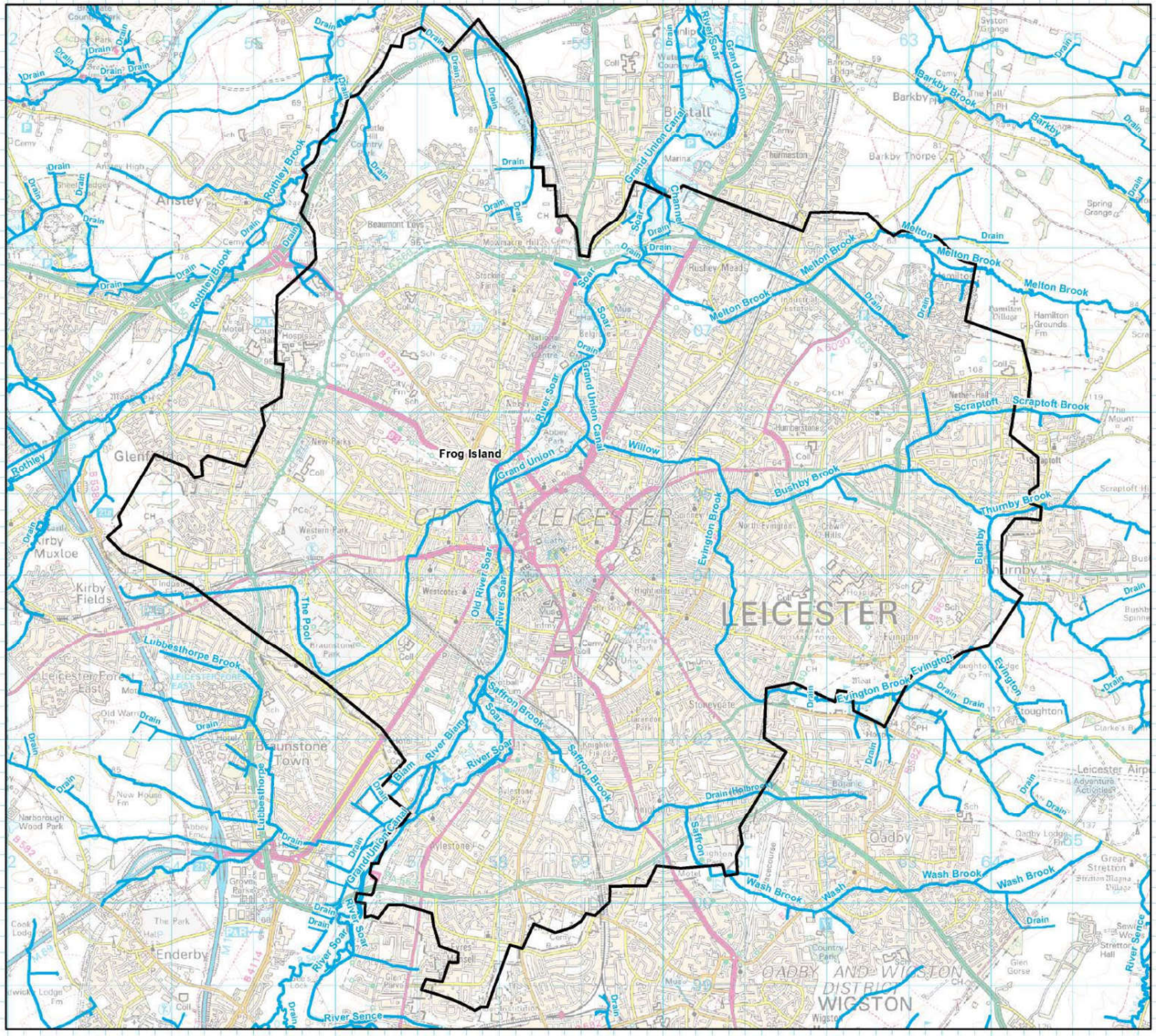

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0 0.5 1 2 3 Kilometers

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Legend

Leicester City Council

Detailed River Network

River

Drain

NOTES

Drawing Status: FINAL

Job Title: **Leicester City Council Surface Water Management Plan**

Drawing Title: **Topography and Hydrology**

Scale at A3: 1:50,000

Drawn by	Date	Approved	Date
Trevor Muten	22/03/11	Stephen Cox	22/03/11

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FIGURE 1

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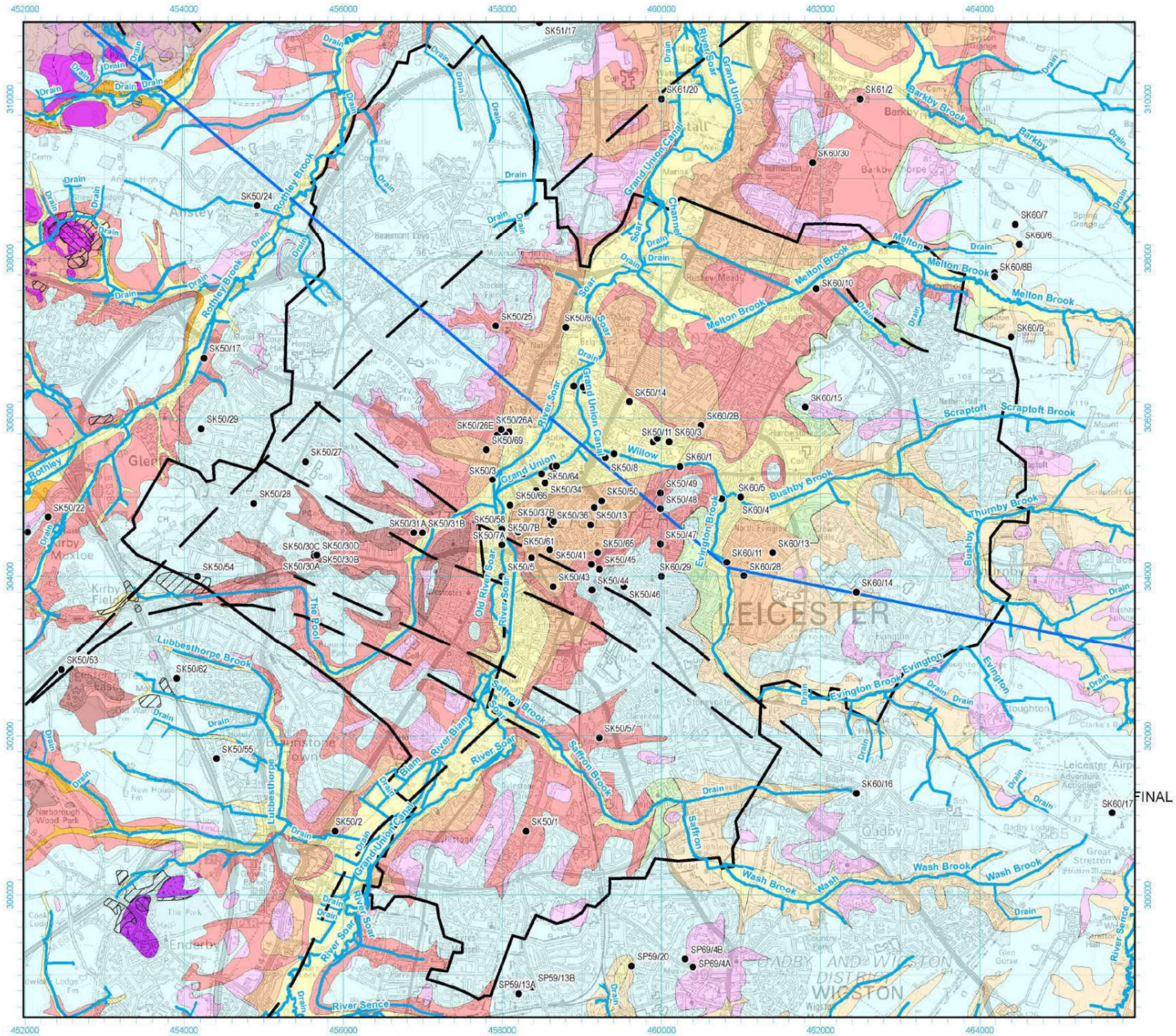

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Legend

- Leicester City Council
- Geological Cross Section [see Figure 4]
- Geological Fault
- BGS Water Wells

Artificial Geology

- Made Ground
- Worked Ground (open)

Superficial Geology

- Alluvium
- Glaciofluvial Deposits, Middle Pleistocene
- Head (Undifferentiated)
- River Terrace Deposits, 1
- River Terrace Deposits (Undifferentiated)
- Till, Middle Pleistocene

Bedrock Geology

- Blue Lias & Charmouth Mudstone Formations
- Penarth Group
- Mercia Mudstone Group
- Arden Sandstone Formation
- Mountsorrel Complex
- Beacon Hill Formation
- Swithland Formation
- Hanging Rocks Formation
- Bradgate Formation
- Sliding Stone Slump Breccia Member
- Stable Pit Member
- South Charnwood Diorites
- South Leicestershire Diorite Complex

Drawing Status: FINAL

Job Title:
Leicester City Council
Surface Water Management Plan

Drawing Title:
Geological Map
Bedrock and Superficial Geology

Scale at A3: 1:50,000

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FIGURE 3

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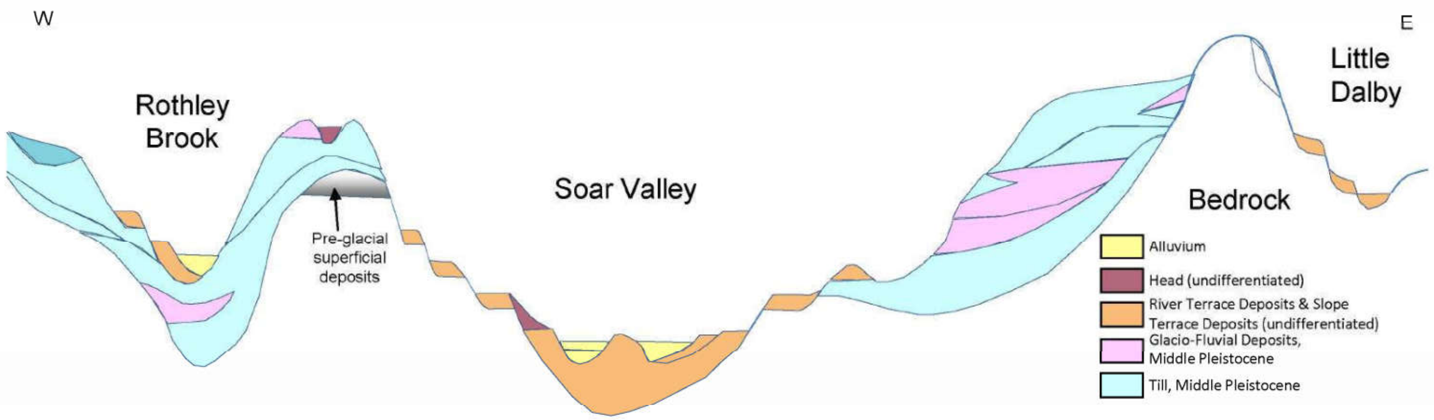
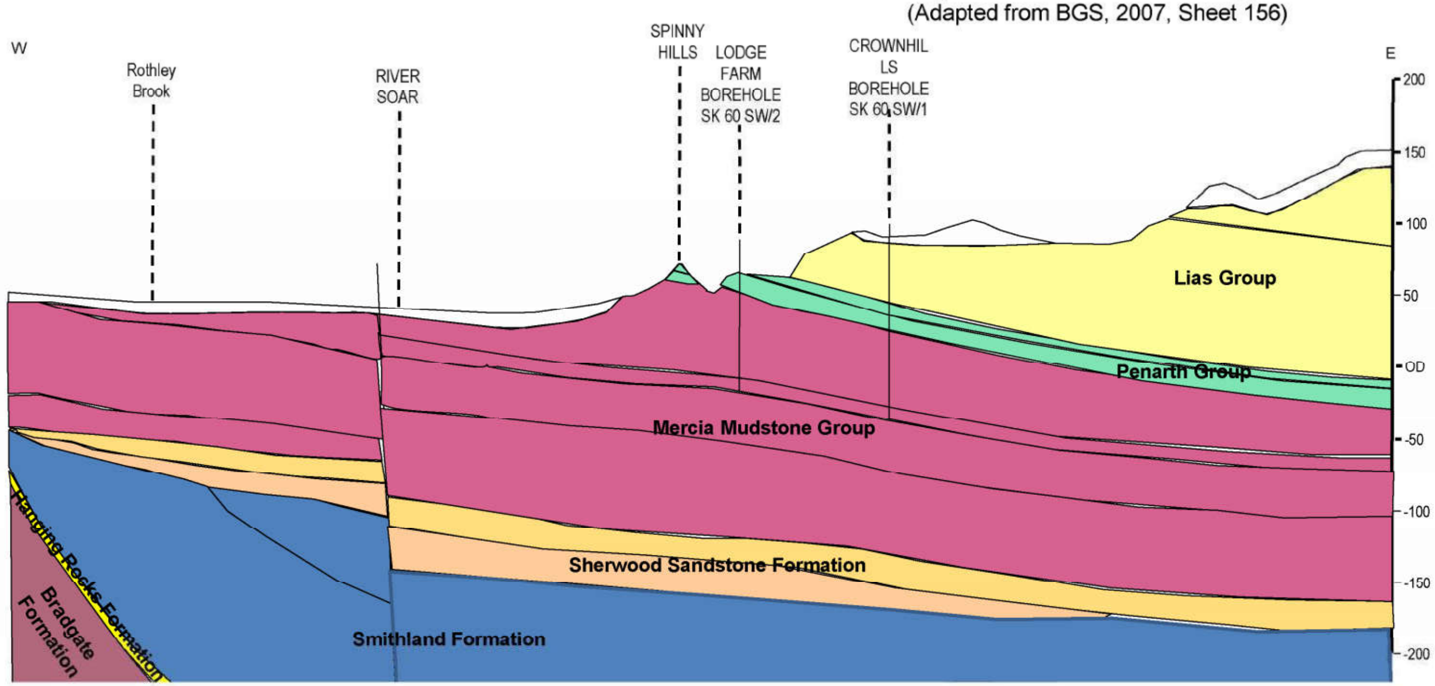


Figure 4A: Superficial Geological Section (Schematic)
(Adapted from BGS, 2007, Sheet 156)

Figure 4B: Bedrock Geological Section
(Adapted from BGS, 2007, Sheet 156)



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Job Title: **Leicester City Council Surface Water Management Plan**

Drawing Title: **Geological Cross Sections Bedrock and Superficial Geology**

Scale at A3

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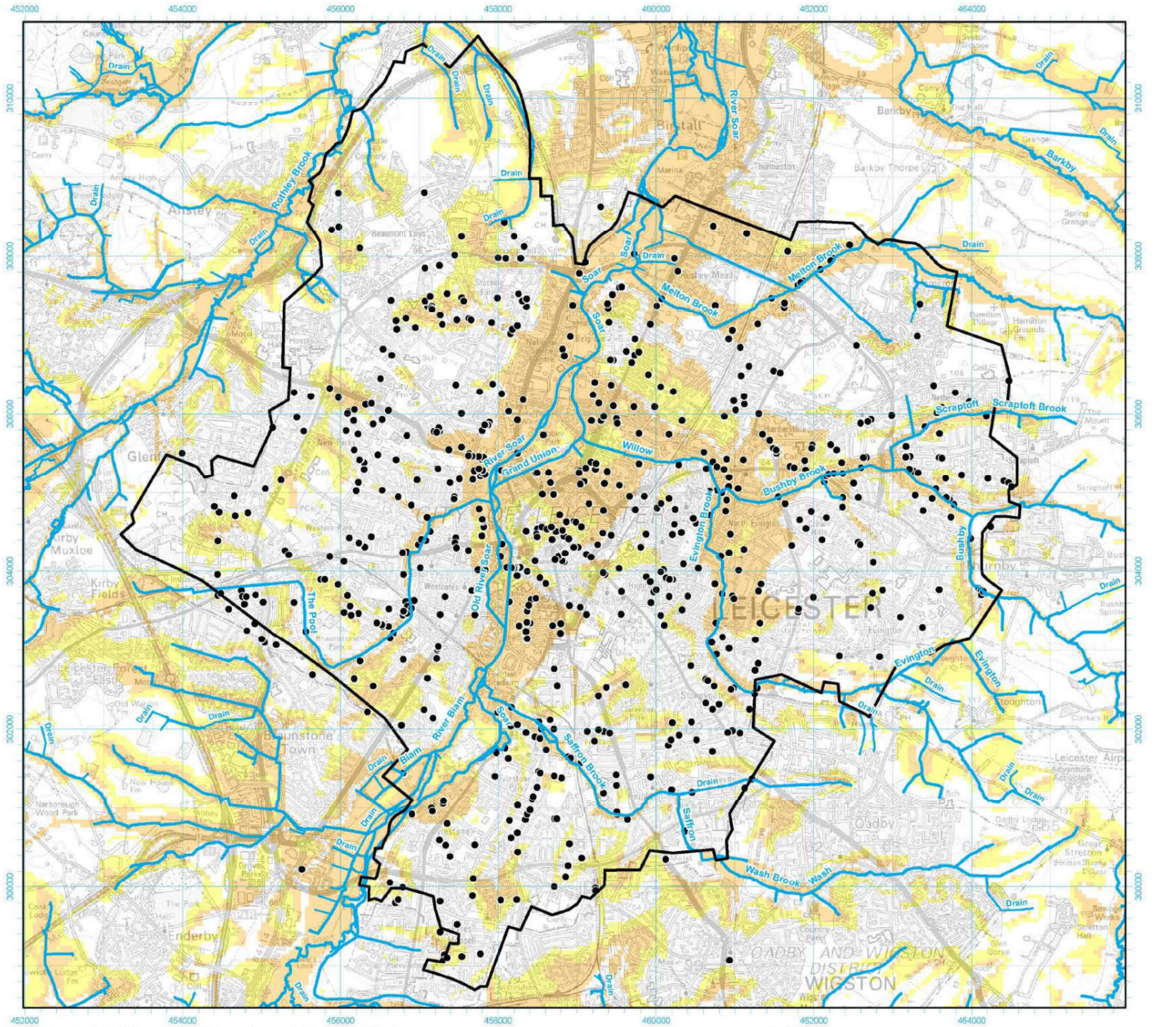

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Notes:

This map forms an approximate guide to areas that may be susceptible to groundwater flooding. However, for all new developments, site investigation is required to confirm local groundwater levels and therefore risk of groundwater flooding.

Drawing Status			
FINAL			
Job Title: Leicester City Council Surface Water Management Plan			
Drawing Title: BGS Groundwater Flooding Susceptibility Map			
Scale at A3: 1:50,000			
Drawn by: Trevor Muten	Date: 22/03/11	Approved: Stephen Cox	Date: 22/03/11

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FIGURE 6

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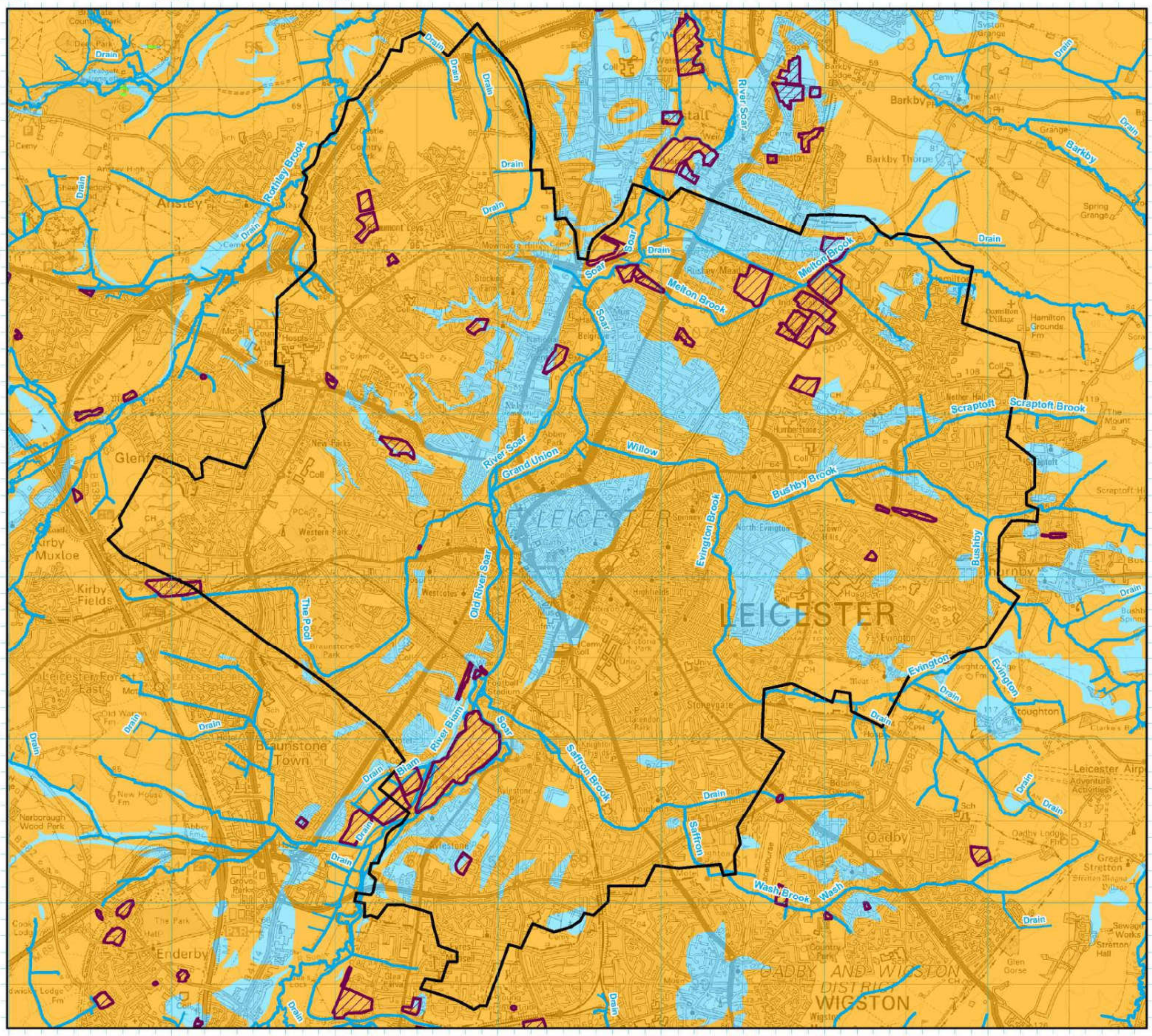

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Legend

- Leicester City Council
- Historic Landfill

Infiltration SUDS Suitability

- Infiltration SUDS potentially suitable
- Restricted Potential for Infiltration SUDS
- Enhanced site investigation required

Notes:

This map forms an approximate guide to permeability. However, for all new developments, site investigation is required to confirm local permeabilities and infiltration rates.

Areas identified as having 'restricted potential' for infiltration SUDS are probably unsuitable where high infiltration rates are required. However, it is possible that low iniltration rate SUDS can be used in conjunction with attenuation SUDS.

Where historic landfill sites exist, infiltration SUDS techniques may not be suitable, as they have the potential to mobilise contamination.

Drawing Status: FINAL v2

Job Title: **Leicester City Council Surface Water Management Plan**

Drawing Title: **Infiltration SUDS Suitability Map Including Historic Landfills**

Scale at A3		1:50,000	
Drawn by	Date	Approved	Date
Trevor Muten	22/03/11	Stephen Cox	10/08/11

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