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A GIS-based decision support methodology at local planning authority scale for the implementation of sustainable drainage

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A GIS-based decision support methodology at local planning authority scale for the implementation of sustainable drainage

By

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RESEARCH DECLARATION

I declare that this report is entirely my own work and that any use of the work of others has been appropriately acknowledged as in-text citations and compiled in the reference list. I also confirm that the project has been conducted in compliance with the University's research ethics policy.

Signed: F.Warwick Date: 12 September 2013

Abstract

Implementation of the Flood and Water Management Act (2010) will place increased responsibility on local planning authorities (LPAs) in England for planning approval and future maintenance of sustainable drainage (SUDS) installations. LPAs have limited experience in assessing SUDS, and there is a need for additional guidance to support decision making. A method was developed to analyse environmental and institutional characteristics of existing published datasets using a Geographical Information System (GIS), and to create maps indicating feasible locations for SUDS devices at the strategic scale of a full LPA area. The method was applied to an example study site: Coventry, UK, covering 98.7 km^2, of which 33% was impermeable, estimated from Ordnance Survey land cover. The method was reliant on the accuracy of the underlying datasets, although data uncertainties were identified, e.g. the incorrect classification of some land cover and lack of definition in private gardens. Construction of a framework allowed a structured approach to collection and presentation of information, and is a point of reference for other strategic scale investigations of SUDS feasibility. Feasibility maps were generated for SUDS in new developments, on both greenfield and previously developed land, and for retrofit of existing developments, across five main categories of SUDS: source control, infiltration, filtration, conveyance, and detention & retention. In new developments, source control, filtration and detention & retention SUDS were possible in 99% of Coventry, filtration SUDS in 95% and infiltration solutions 17%. The higher number of restrictions imposed on retrofit resulted in a smaller area where SUDS were feasible: source control 68%, infiltration 11%, filtration 64%, conveyance 57% and detention 79%. Soil impermeability and depth to water table were the principal spatial limitations on infiltration and detention SUDS in new developments. Water bodies imposed the small number of restrictions on source control, filtration and conveyance in new developments. Existing land cover was the main driver of feasible locations for retrofit. Smaller parcels of land were available for retrofit (median 35 m^2) than for new development (median 100 m^2). Private gardens occupied 23% of the city, forming a large part of suburban land cover. Large scale retrofit in these areas would necessitate convincing a significant number of individual landowners of the benefits of SUDS. Use of feasibility maps created using the method developed in this research might encourage more specific and earlier consideration of SUDS in the planning process. Retrofit feasibility maps, in conjunction with datasets identifying problem locations, would assist strategic reviews of SUDS options.

Keywords: GIS, Local Planning Authority, new development, planning, retrofit, SUDS

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Abbreviations

BGS	British Geological Survey
CCC	Coventry City Council
DCLG	Department of Communities and Local Government
Defra	Department of Environment, Food and Rural Affairs
DEM	Digital Elevation Model
DTM	Digital Terrain Model
EA	Environment Agency
FRA	Flood Risk Assessment
FWMA	Flood and Water Management Act 2010
FZ	Flood zone
GIA	Geographical Information Analysis
GIS	Geographical Information System
GLUD	Generalised land use database
LDF	Local Development Framework
LFRMS	Local Flood Risk Management Strategy
Lidar	Light detection and ranging
LLFA	Lead local flood authority
LPA	Local planning authority
NPPF	National Planning Policy Framework
OSMM	Ordnance Survey MasterMap
PDL	Previously developed land
PFRA	Preliminary Flood Risk assessment
PPS	Permeable paving systems
PPS25	Planning Policy Statement 25, Development and Flood Risk
SAAR	Standard Average Annual Rainfall
SAB	SUDS Approval Body
SFRA	Strategic Flood Risk Assessment
SPZ	Groundwater source protection zone
STW	Severn Trent Water
SUDS	Sustainable drainage systems
SWMP	Surface Water Management Plan
Vt	Treatment volume
WFD	Water Framework Directive

1 INTRODUCTION

1.1 BACKGROUND

Sustainable Drainage Systems (SUDS) have been proposed as a means of contributing to improved management of flooding and water pollution (Woods Ballard *et al.* 2007). The SUDS philosophy is to manage run-off in a way that mirrors natural drainage patterns, aiming for runoff at greenfield (undeveloped) rates, placing equal emphasis on water quality, water quantity and broader environmental, social and amenity impacts (Defra 2005a:4[1]; Woods Ballard *et al*. 2007:1.1) (Fig. 1.1). SUDS aim to treat storm-water runoff in a more sustainable manner than conventional drainage methods (RCEP 2007:75).

Fig. 1.1 The SUDS triangle places equal emphasis on water quality, water quantity and broader environmental, social and amenity impacts. Adapted from Wild *et al*. 2002:Fig. 1

There is increasing recognition of the potential value of sustainable drainage to manage flood risk (LGA 2011:24; Macmillan & Reich 2007:5-6; Middlesex University 2003:24,26; Sharma *et al*. 2008; Tait *et al*. 2008:85) and improve water quality (D'Arcy & Frost 2001; D'Arcy & Wild 2002:5; DTI 2006:40; Heal *et al.* 2009; SNIFFER 2004:4). Higher amenity and biodiversity value have been associated with some SUDS techniques (Charlesworth *et al.* 2003b; DCLG 2009:122; Heal 2010; Hyder Consulting 2004:22), and SUDS can also contribute to climate change mitigation and adaptation (Charlesworth 2010; Coventry City Council and Coventry Partnership 2012:31,37; Government Office for the West Midlands 2008:10,74,82), and water conservation, recycling and re-use (Charlesworth 2010;

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[1] References are presented as Author(s) and date. Where specific page numbers are cited, these are given after the date, separated by a colon

Domènech, & Saurí 2011). Their value in reducing flood risk has been recognised by government policy prescriptions such as the National Planning Policy Framework (NPPF, DCLG 2012), and provisions for widespread SUDS implementation in new developments arising from the Flood and Water Management Act (FWMA, Act of Parliament 2010). SUDS offer advantages over conventional drainage techniques.

The development planning process is the mechanism for controlling and promoting appropriate development in line with planning law. Implementation of sustainable drainage in new developments in England is managed using this process, by means of policies and plans at a number of levels, implemented by a variety of organisations (Fig. 1.2). There is no explicit national SUDS strategy in England, and SUDS are covered by a range of regulatory measures concerning flooding and water quality at both national and strategic levels. Legislation for improved surface water management using sustainable drainage in England was enacted in the FWMA (Act of Parliament 2010), but the relevant provisions have not yet come into force – see chapter 2.2. An underpinning set of National Standards for sustainable drainage systems (Defra 2011a) has been issued in draft form for comment, with consultation responses also published (Defra 2012), but no further update has been issued. This delay suggests that central government has not allocated the highest priority to implementing the SUDS measures in the FWMA. As a result, the existing regulatory guidance for SUDS in new developments still applies, specifically the NPPF (DCLG 2012:24), which gives priority to the appropriate use of SUDS for surface water management (point 103), supported by EA standing advice for flood risk assessments (2012) encouraging the use of SUDS. However, neither the NPPF nor the EA guidance defined the meaning of ‘appropriate’, and the NPPF does not mandate the use of SUDS.

At the strategic local authority level in England, a range of policies are in place to address different forms of flooding. The EA manages main river and coastal flooding, and has a national coordinating role. The FWMA and the Flood Risk Regulations (Act of Parliament 2009) assigned the role of lead local flood authority (LLFA) to unitary and upper tier councils. LLFAs were tasked with creating and applying a local flood risk management strategy (LFRMS) to coordinate local flood response for water bodies lying outside the remit of the EA, in particular flooding from surface runoff, groundwater, and ordinary watercourses (FWMA section 9). Local authorities also have to create a Surface Water Management Plan (SWMP, Defra 2010a:5), intended to enable cooperation between organisations to manage surface water in a local area over the longer term (Defra 2010a:72). SWMPs envisage a role for SUDS to support a more strategic approach to drainage planning across a wider area than individual site developments, and these plans should provide the detail to inform the LFRMS (Defra 2010a:xii).

The EA has the principal responsibility in England for addressing water quality issues, and employs a system of licensing and environmental permitting to manage point source pollution risks (EA 2013c:31). The NPPF directs that the planning system should contribute to preventing water pollution (DCLG 2012:26), but that its management and control should rest with the EA (DCLG 2012:29).

Implementation of new legislation on the ground, across the levels shown in Fig. 1.2, does not normally progress rapidly. For instance, the SUDS provisions in the FWMA, enacted in 2010, have not yet commenced. Local authorities could introduce their own local policies relating to SUDS without waiting for the FWMA, and a few have done so, such as Cambridge City Council (Wilson *et al*. 2009) and Islington London Borough (Robert Bray Associates and Islington Council 2010). The requirement for transitioning existing development plans to a local development framework was introduced in 2004, but Coventry, for example, has not yet replaced its Unitary Development Plan which was due to expire in 2011. Such delays can result in inconsistencies in approach. Uncertainties about the increased funding requirement for local authorities to adopt and maintain SUDS defined in the FWMA has engendered some uncertainty in local authorities as to the appropriate way to proceed in relation to SUDS implementation.

Developments in England are reviewed and approved through the planning process to ensure they comply with planning legislation. Larger developments often submit an outline planning application to gain consent in principle, followed by one or several detailed planning applications prior to the start of construction. Smaller developments may omit the outline application stage. Both stages may benefit from pre-application discussions between developer and planning officers in order to review the proposals and suggest how they may best comply with planning legislation and local policies, and reduce environmental impact (LGA 2006:iv). Constitution of SABs will add a further set of steps to existing approval processes, and Fig. 1.3 contains a draft outline of SAB approval process, adapted from Defra (2011b:23). This example shows SAB processes running in parallel with planning application approval, although other models may be developed such as design approval by the SAB prior to obtaining planning consent. The draft Defra process does not explain the role of SABs in conjunction with the separate stages of outline and detailed planning applications, nor the amount or type of detail to be supplied to the SAB at the outline planning stage.

Organisation	**Role**	**Development**	**Water**
EU Council & Parliament	Define international policy	**International**	**International** Water Framework Directive (2000/60/EC) Floods Directive (2007/60/EC)
National Government Departments	Define national policy	**National** National Planning Policy Framework Planning and Compulsory Purchase Act 2004	**National** Water Environment (WFD) (England and Wales) Regulations 2003 Flood Risk Regulations 2009 Flood and Water Management Act 2010
Regulatory Agencies	Define national strategy		National Flood and Coastal Erosion Risk Management Strategy
Regulatory Agencies	Define regional strategy	**Regional**	**Regional** River Basin Management Plans
Unitary Authority / Upper & Lower Tier Councils	Define local policy and strategy	**Strategic** Local Development Framework (Core Strategy, Adopted Proposals, Supplementary Planning Documents)	**Strategic** Local Flood Risk Management Strategy Surface Water Management Plan Strategic Flood Risk Assessment
Local Parish Councils / Neighbourhood Forums	Define neighbourhood strategy	**Neighbourhood** Localism Act 2011 Neighbourhood Plan	**Neighbourhood**
Developers	Develop using policies	**Area and Site** Outline Planning Application Detailed Planning Application Neighbourhood Development Order	**Area and Site** Site Flood Risk Assessment

Fig. 1.2 The emerging strategy and policy context for development in England, highlighting the relationship to surface water management. A hierarchy of organisations is related to their role and level in the policy and strategy making institutional structures. The Organisation column defines the bodies responsible for creating the policies / strategies / plans at that level. Examples of key development- and water-related policies and strategies are identified. The term ‘strategic’ for unitary and county/district council level is adopted from flood risk strategies developed at this planning level

Combined Planning and SAB Approval Process - draft

Fig. 1.3 Draft of combined Planning and SAB approval process. An overview of possible SAB processes is shown alongside planning approval processes. Adapted from Defra (2011b:23) and DCLG (2014)

The take-up of SUDS in England has been limited (Evans *et al.* 2008:113; Hyder Consulting 2004:3; White & Alarcon 2009:524), as without appropriate legislation a reluctance to implement SUDS remains (Defra 2012:2). Much of the increased research into more sustainable drainage in urban settings is not reflected in professional application and practice (Brown & Farrelly 2009:839; EA 2009d:iv). Possible reasons for this include: perceptions of problems relating to health and safety, cost, and difficulty; a lack of understanding of SUDS functionality; insufficient transparency concerning responsibilities amongst stakeholders; and legislative, adoption and maintenance issues (Brown & Farrelly 2009; Coulthard & Frostick 2010; Douglas *et al*. 2010; Ellis & Revitt 2010; Gill 2008; Pitt Review 2008; Todorovic *et al*. 2008; White & Alarcon 2009). These issues suggest a reluctance to adopt more sustainable water management practices (Farrelly & Brown 2011, Harries & Penning-Rowsell 2011), and several factors hamper non-traditional approaches to urban drainage (Balmforth *et al*. 2006b:15), including:

- the shortage of guidance for planning authorities on the types of SUDS appropriate for specific situations (D’Arcy & Wild 2003:7; EA 2009d:v; LGA 2012; Morrow & Doncaster 2007:6; SNIFFER 2006:12)
- lack of technical expertise in managing flood risk and drainage planning (Ellis *et al*. 2010:5)
- the consequent lack of experience in implementing SUDS (Gill 2008:26).

Local Planning Authorities (LPAs) have to address development planning at a strategic scale, and LLFAs need a coordinated strategic approach to managing surface water. Therefore, SUDS feasibility assessments should provide information at this scale. A focus on planning for SUDS at the individual site scale risks failing to identify risks and opportunities for wider. more joined up, approaches to surface water management. The need for different scales of assessment has been recognised by other decision framework approaches, e.g. Förster *et al*. 2004, and planning policy and guidance relating to water management in England utilises methodologies that cover different spatial scales (Fig. 1.2). In contrast to new developments, there is no existing or planned legislative driver for retrofit SUDS, which are implemented to address individual issues and enhance local environments (Digman *et al*. 2012), yet existing sites constitute the main component of the urban fabric, and have a more significant influence on water quantity and quality. Therefore assessments of SUDS feasibility must also consider the opportunities for retrofit.

The principal barriers to wider SUDS implementation in England are institutional and social (Ellis & Revitt 2010), such as organisational cooperation, complexity in ownership and maintenance, and public and developer acceptance of SUDS technologies. This result mirrors findings at an international level (Brown & Farrelly 2009). While not the only, or even the primary, factor hindering SUDS take-up in England, the lack of progress in implementing SUDS legislation in the FWMA has contributed to inertia in more sustainable stormwater management. The limited number of SUDS installations in England, the lack of guidance at the local authority level, and the resultant lack of awareness of SUDS, indicates a need for improved guidance to support local authority planning officers.

1.2 AIMS AND OBJECTIVES

With the implementation of schedule 3 of the FWMA, local planning authorities in England will be tasked with assessing, inspecting and maintaining SUDS installations, a role they have not previously undertaken. The overall goal of this study was to investigate options for provision of guidance about SUDS feasibility for the full extent of a local planning authority area, using the city of Coventry as a case study site. The target community of the outputs of this work were development planners, who are likely to play a key role in driving SUDS implementation, but have limited experience of these techniques. In order to communicate information, it is preferable to employ methods with which planners are familiar, and digital Geographical Information Systems (GIS) maps are already in routine operational use in planning departments. Therefore, development of a GIS-based methodology would not present an additional new technology barrier to understanding guidance. By working with Coventry City Council (CCC), this study intended to gain a greater understanding of the guidance needed, and to supply it in a form that was understandable at a practical working level.

1.2.1 Aims

The aims of this work are therefore to:

1. **Investigate the use of GIS to evaluate the feasibility of implementing and retrofitting sustainable drainage systems in an urban local authority area**
2. **Evaluate the creation and suitability of map-based recommendations of suitable SUDS devices for an urban local authority area.**

Aim 1 defines the context and provided structure and information for the work undertaken to achieve aim 2.

Availability and quality of data were important variables in developing the methodology. In order for the methodology to be transferrable to other organisations and stakeholders, information had to be readily available in an appropriate form, and its content also needed validity and relevance. The research undertook a critical and rigorous examination of the underlying datasets, the resulting outputs, and their potential usage. A more extensive set of information was employed, at a broader spatial scale, than had been used by previous work in this field. The research investigated how a substantial volume of information could be analysed across a relatively large area, yet be presented in a manner that was accessible. A novel methodology was created to distinguish new development and retrofit applications, and extended to consider their application to improve surface water management in England.

1.2.2 Objectives

The objectives supporting each aim are explained in more detail below. The numbering of the objectives relates them to the associated aim.

1a. Identify suitable evaluation techniques to determine SUDS feasibility in an urban environment in order to inform the choice of methods at the local authority strategic scale

Techniques such as multi-criteria analysis have been applied to support discussions between stakeholders in order to derive a mutually agreed set of decision criteria (e.g. Ellis *et al*. 2006), although these pre-suppose a group of stakeholders willing to hold negotiations. A number of studies have provided methods and frameworks for implementation of SUDS, with the aim of assisting decision-makers to select feasible options using straightforward assessment techniques. Studies such as SNIFFER (2006:28-31), Scholz (2006) and Stovin *et al*. (2007) have suggested generic decision-making tools that could support rapid feasibility assessment of retrofit SUDS. Methods with a GIS focus are reviewed in chapter 2. A pilot study was undertaken to evaluate techniques to determine the feasibility of SUDS implementation, in order to inform the choice of methods for the broader strategic, city-wide, scale.

1b. Construct a framework in order to evaluate suitable SUDS devices at the local authority strategic scale

Research into decision support tools for SUDS application in the UK has often focused on the smaller scale of individual projects (e.g. Scholz 2006, SNIFFER 2006, Viavattene *et al*. 2010), and future water management challenges may need a greater focus on understanding the extent and implications of a more widespread implementation of SUDS (Moore *et al*. 2012:276). The creation of a framework must be driven by the factors that impact SUDS implementation. Given the use of GIS as a means of analysing and communicating data, relevant factors needed a spatial attribute. Although urban planning is principally concerned with new developments, wider sustainability concerns, for instance about the impacts of climate change, have suggested that additional actions are needed to address drainage issues, and that retrofitting SUDS can play a role in adaptation (Charlesworth 2010), and solving existing performance issues (Stovin *et al*. 2007:1). Therefore the framework needed to address SUDS feasibility for both new developments and retrofit.

1c. Determine suitable SUDS devices for an urban local authority area

The intent of this objective was to evaluate whether particular SUDS devices were more appropriate in an urban local authority area than others. Detailed guidance about the attributes of SUDS devices has been provided by Woods Ballard *et al*. (2007) amongst others. The creation of a framework relevant to larger spatial scales requires a means of summarising these attributes, and placing them in the context of the characteristics of the entire local authority area.

2a. Develop and apply rules to generate maps showing feasible locations for suitable SUDS devices based on characteristics of the local authority area

For a local planning authority, it is helpful to identify which types of SUDS might be feasible at any location in their area, in order to undertake initial assessment of outline planning proposals and for evidence-based discussions with developers. Surface Water Management Planning guidance (Defra 2010b:41) suggested that SUDS implementation could be guided by maps of ground conditions affecting infiltration and storage. However, the few studies adopting this approach, e.g. Halcrow Group Limited (2008a) and Ipswich Borough Council (2007), have taken a restricted number of factors and types of SUDS devices into account. This research sought to ascertain whether the reasons for the shortage of examples was due to technical difficulties or lack of access to appropriate information by collecting a wide range of data to characterise the study area, and critically analysing the suitability of that data for generating feasibility maps. A set of general rules was developed to identify the factors influencing sustainable drainage feasibility at the local authority scale. These rules were agreed with stakeholders at a case study local authority, Coventry. The rules were tested by creating feasibility maps.

2b. Evaluate the suitability of the SUDS feasibility maps and the applicability of the approach

Dickie *et al*. (2010, chapter 4) provided high-level descriptive guidance on SUDS and a list of relevant questions and examples using planning terminology, and indicate devices for different development densities. However, the absence of infiltration SUDS in the guidance implies a focus on smaller scale developments. Specific guidance is important at the detailed design and planning application stages, as well as to understand later issues such as ongoing maintenance, but does not offer a straightforward introduction to planners for initial discussions with developers. Maps provide a means of communicating possible options, and can provide location-specific information.

2c. Assess potential additional applications of the SUDS feasibility maps

GIS-based maps of SUDS feasibility can be combined with additional spatial resources to address further questions. For example, if greater emphasis will be placed in future on retrofitting SUDS in order to address issues of water quality and quantity, then an understanding of the problem areas, the additional restrictions, and of the remaining potential locations, would help to speed up the steps of problem definition, identifying available data, and of detecting possible locations. While such projects can address discrete issues, they exist in a wider spatial context. Questions such as the extent of retrofit required to improve water quality across a whole catchment have still to be tackled.

1.3 DEFINITION OF KEY TERMS

This study addresses both new development and retrofit SUDS. New developments are those where new and / or replacement buildings and infrastructure are constructed, and this can take place on undeveloped, greenfield, sites, or by redevelopment of previously developed land, sometimes referred to as brownfield development. Retrofit SUDS are implemented by modifying an existing drainage system in order to improve water flow and quality (SNIFFER 2006:2; Stovin *et al*. 2007:1).

The phrase ‘conventional drainage’ is used to identify piped sewerage systems. The terms ‘drain’ and ‘sewer’ follow the definitions in the Water Industry Act (Act of Parliament 1991; Ashley *et al*. 2006:2). Drains are associated with one or more buildings in a single curtilage (the land area inside a property’s boundaries), whilst sewers serve buildings in more than one curtilage.

The abbreviation **SUDS** is used to mean Sustainable Drainage Systems. Some publications (e.g. Dickie *et al*. 2010; Digman *et al*. 2012) have preferred the abbreviation SuDS with a lower case ‘u’, to distinguish **Su**stainable **D**rainage **S**ystems from the earlier term SUDS (as used by Woods Ballard *et al*. 2007) indicating **S**ustainable **U**rban **D**rainage **S**ystems, on the basis that the techniques are also applicable outside urban areas. This author took the view that this debate is no longer current, and that the term SUDS implies the full range of devices and techniques rather than the location where they are implemented, and writing it in upper case defines the word as an abbreviation.

There is confusion in previous SUDS studies between land use and land cover, e.g. SNIFFER (2006:30). Land use is impossible to assess accurately from a map since it incorporates human intentions and non-continuous activities, i.e. the function of the land; land cover describes the physical nature or form and pattern of the land surface, without assigning function or use to the identified elements (Comber *et al*. 2004:3190; ODPM 2006:16; Prenzel 2004:284; Voogt & Oke 2003:373). This research is principally concerned with land cover, and did not consider in detail the use to which land was put. Where the term ‘land use’ appears, it refers specifically to the function of the land.

1.4 STRUCTURE OF THE THESIS

The thesis is organised as follows.

Chapter one gives a brief summary of the features and benefits of SUDS, and a short contextual background to the research, before setting out the aims and objectives of the research, and defining some key terms.

Chapter two provides initial background by outlining the changing regulatory background to management of the water environment and the implementation of SUDS in England. The majority of the chapter reviews previous work that has defined frameworks and methods for assessing SUDS feasibility.

Chapter three details the methods employed to obtain and analyse the data used in this study. The pilot study is covered in section 3.5, and section 3.6 explains the design of the strategic study, the data collection for which is covered in 3.7. The methods to generate maps are detailed in section 3.8, validation in 3.9 and techniques used to investigate further applications of the baseline feasibility map information are explained in section 3.10.

Chapter four presents the results for aim 1, by firstly summarising the results of the pilot study in section 4.2 (objective 1a), and then assessing how the information gained can be used to expand the spatial scope of the research to the wider strategic scale of the whole local planning authority area (section 4.3). Section 4.4 explains the development of a framework to evaluate suitable SUDS devices at the broader local authority strategic scale (objective 1b), and section 4.5 describes how suitable SUDS devices for an urban local authority area were determined (objective 1c).

Chapter five presents the results for aim 2. A set of maps was created using the framework explained in chapter four to show the location of suitable SUDS devices (objective 2a). These are covered in sections 5.2-5.7. The suitability of the SUDS feasibility maps and the applicability of the approach is considered in sections 5.8-5.10 (objective 2b). Further applications of the feasibility maps are demonstrated in sections 5.11-5.15 (objective 2c).

Chapter six discusses the results to consider the advantages and limitations of the approach taken by this research within the wider policy context (sections 6.1-6.3). Section 6.4 reviews the use of the feasibility maps to answer additional questions. The chapter ends with suggestions for future research that emerged from this study.

Chapter seven summarises the main findings of the thesis, and reviews the extent to which the aims and objectives were met.

2. LITERATURE REVIEW

2.1. INTRODUCTION

In order to establish the background within which this research project was undertaken, this literature review firstly considers the changing regulatory context in England (section 2.2), then assesses the methods used in previous studies of SUDS feasibility (sections 2.3-2.8), and wider-scale hydrology of urban areas (section 2.9). This literature review does not explore the problems associated with urban drainage in the UK, although a summary of SUDS characteristics, performance, and barriers to implementation was undertaken for the pilot phase, and is included in Appendix C.

2.2. THE STATE OF REGULATION

SUDS implementation in England has been hampered by complexities in the legislation and management of storm water (Douglas *et al*. 2010:113; Evans *et al*. 2008:52; House of Lords Science and Technology Committee 2006:99; Morrow 2008:2-3; Stovin *et al*. 2007:i). As outlined in chapter 1.2, SUDS implementation in England is currently covered by a range of regulatory measures concerning flooding and water quality at both national and strategic levels. Recent and impending changes to legislation in England have attempted to address some of the issues, with the result that flood risk and water management is currently in a state of flux, with a range of legislation and plans altering the landscape for national and local government bodies.

After the summer 2007 floods, the Pitt Review (2008) made 92 recommendations to improve responsiveness to flood risk, a number of which were addressed by the Flood and Water Management Act (FWMA, Act of Parliament 2010). In addition, the EU Floods Directive (EU 2007) was transposed into English law by the Flood Risk Regulations (Act of Parliament 2009), creating the role of lead local flood authority (LLFA), i.e. the top tier local authority, to determine areas of significant flood risk locally, and to prepare a preliminary flood risk assessment (PFRA), to be supplemented by flood hazard and risk maps and flood risk management plans before the end of 2015. In a separate exercise, Defra (2010a) issued guidance for the creation of Surface Water Management Plans (SWMPs) by local authorities to outline their strategy to manage flooding from sewers, drains, groundwater, and runoff from land, ordinary watercourses and ditches due to heavy rainfall, and to identify opportunities for SUDS.

To address issues of a lack of coordination in flood risk management, the FWMA defined the EA as the responsible body for national flood risk management strategy, in addition to their role in managing flooding from main rivers and coasts. The Flood Risk Regulations and the FWMA also established a duty of cooperation between agencies and a responsibility to provide information if requested. The LLFA was tasked with creating a local flood risk management strategy (LFRMS) to define the objectives, means and costs of managing local flood risk from surface runoff, ordinary watercourses and groundwater. It remains to be seen whether the production of three separate documents relating to local flood risk, the EU flood risk management plan, the SWMP and the LFRMS will “prevent duplication of work” (EU 2007, point 16), as desired by the EU Floods Directive.

The FWMA contained provisions (schedule 3) to make the use of SUDS mandatory in England. Measures in the FWMA directly relating to SUDS are listed in Table 2.1. Approving bodies defined by the Act have become known as SUDS Approval Bodies (SABs), and it will be the responsibility of local authorities to constitute these, and define suitable operational processes that integrate with existing planning regulations. However, SUDS measures in the FWMA have not yet come into force, with the next possible implementation date being October 2014. The associated draft SUDS National standards (Defra 2011a) gave rise to a number of questions and concerns, particularly in relation to processes and definitions (Defra 2012), and these have not yet been resolved.

Legal and regulatory barriers constitute an important difference between the limited implementation of SUDS in England compared to their wider application in Scotland. Scotland has taken a different path to SUDS implementation, and while the draft English legislation and associated guidance has adopted some of the features of the Scottish approach, there are notable differences. One key reason for the wider implementation of SUDS in Scotland is the timing of legislation. In Scotland the Water Environment and Water Services (Scotland) Act (WEWS, Act of the Scottish Parliament 2003) took the opportunity of transposing the Water Framework Directive (WFD, EU 2000) into Scottish Law to make the use of SUDS mandatory in new developments in order to address water quality issues due to diffuse pollution. Thus Scotland has gained 10 years’ more experience of implementing and regulating SUDS in comparison with England.

Table 2.1 SUDS provisions in the Flood and Water Management Act

Provision	Section
Removal of the right to connect to a public sewer	section 42
Publication of National standards for the design, construction, maintenance and operation of sustainable drainage	schedule 3 point 5
Constitution of Approving bodies by the unitary authority or county council	schedule 3 point 6
A requirement to obtain approval from the Approving body for construction of any building or structure that covers land affecting the ability of that land to absorb rainwater	schedule 3 point 7
Approval must be granted if the drainage system complies with the national standards	schedule 3 point 11
Applicants to provide a non-performance bond in case of failure to construct in accordance with the approval	schedule 3 point 12
An approving body must adopt approved drainage systems unless they drain a single property or publicly maintained roads	schedule 3 point 17-19
Adopted drainage systems must be maintained by the approving body according to the national standards	schedule 3 point 22

In Scotland, the benefits of a partnership approach between regulatory and commercial organisations (D’Arcy & Wild 2002:8), in conjunction with legislation, were recognised and have facilitated promotion and acceptance of SUDS solutions (RCEP 2007:75; SNIFFER 2006:3), and contributed to a greater level of SUDS implementation than in England. In England, this partnership approach has been encouraged by a duty of organisations to co-operate set out in the Flood Risk Regulations (Act of Parliament 2009, part 6).

English legislation is still oriented towards a hard-engineering pipe, drain, and sewer philosophy, rather than the wider range of available SUDS techniques (Defra 2005a:6). In English legislation, a sewer is defined as having a proper outfall to a watercourse, a public sewer, or in some circumstances an adopted highway drain (Defra 2005a:22), and a number of SUDS features lack this defined outfall, since their purpose is to infiltrate runoff, precluding adoption by the relevant Water Authority (Defra 2005a:14; DTI 2006:95). Scottish legislation, principally the Sewerage (Scotland) Act (Act of the Scottish Parliament 1968) defining the duties and powers of Scottish Water, was amended by the WEWS Act to identify references to sewers as including SUDS, a step that has not been taken in England.

Further differences apply between English and Scottish SUDS legislation, which are likely to influence the way that SUDS are implemented in the two jurisdictions (Table 2.2). Scottish legislation is on the whole more specific, and responsibilities are allocated to different organisations to those proposed in England.

In England, the FWMA assigns responsibility for approval and future maintenance of SUDS to the upper tier local authority in its role as SAB. In contrast, responsibility for operation and maintenance of defined SUDS in Scotland was assigned to the sole water and sewerage company, Scottish Water, by the WEWS Act (p.23). This may ultimately lead to differing standards and procedures across the different English local authorities.

Scottish legislation has assigned a much more precise definition to the meaning of ‘sustainable drainage systems’ than in the FWMA. The WEWS Act (section 33) clarifies that SUDS facilitate attenuation, settlement or treatment of surface water from two or more premises. It names specific devices that are considered to be SUDS: inlet structures, outlet structures, swales, constructed wetlands, ponds, filter trenches, attenuation tanks and detention basins, and clarifies that associated pipes and equipment are to be treated as part of the system. The FWMA does not explicitly clarify the meaning of SUDS, leaving that task to later ministerial regulation, although the early draft of the definition was that a sustainable drainage system was any drainage system not adopted by a sewerage undertaker (Defra 2011c:4), implying the need for precise construction standards to define what would be acceptable. Sewers for Scotland (Scottish Water 2007) gives specific construction standards for SUDS that Scottish Water will adopt, whereas the draft SUDS National standard (Defra 2011a) outline functional criteria that should be applied.

In Scotland, emphasis is placed on the role of SEPA to protect the water environment. CAR (2011) states for instance that “SEPA must impose such conditions as it considers necessary or expedient for the purposes of protection of the water environment” (p.7) indicating that protection of the water environment is paramount. In England, in contrast, the draft SUDS National Standards introduced the concept of affordability (Defra 2011a:6), limiting the need for compliance to the extent that construction should not be more expensive than an equivalent drainage design using conventional methods.

The WEWS Act (section 20 and schedule 2) allowed for regulation of ‘controlled activities’ that risked polluting, abstracting from or impounding water bodies, by means of general binding rules (GBRs) last updated in 2013 (Act of the Scottish Parliament 2013). GBRs 10 and 11 target pollution of surface water by runoff (diffuse pollution) and direct disposal of pollutants (point source pollution), and GBRs 18-24 control pollution due to agricultural and land management activities. SEPA (2014), as the regulator, has managed the potentially large workload that would be created of reviewing all potential sources of pollution by defining a hierarchy for approval of increasing levels of pollution risk. GBRs apply to specific low risk activities and are monitored initially through the planning system. Medium and higher risk activities require explicit registration and licensing, for which charges are made. This is a similar process to that employed by the EA (2009a) for Flood Risk Standing Advice in England, where small developments in low flood risk areas are provided with online guidance, while larger developments and those in higher flood risk zones must submit detailed applications which are reviewed through the planning system. The SAB process to address this same issue is not clearly defined by the FWMA, the National Standards, or by central government guidance, although it is proposed to phase in the role of SABs by initially focussing on larger developments (Defra 2012:6). In contrast to Scotland, there is no similar approach to using GBRs in England, although they could address some of the potential workload issues for SABs.

Table 2.2 Key differences between SUDS legislation in England and Scotland.

Element	**England**	**Scotland**
Regulator	SABs in each unitary / upper tier local authority	Scottish Environment Protection Agency (SEPA)
Design guidance	The draft SUDS National Standards (Defra 2011a) offered outline guidance on the volume and rate of runoff for the development site as a whole, and the number of treatment train components. More detailed supporting guidance (Defra 2011a:5) has not yet been issued	SUDS for Scotland (Water UK/WRc Plc 2007) provides detailed guidance about the specific types of SUDS that will be adopted, and their required design features
Adoptable public SUDS	SUDS covering more than one curtilage	SUDS, serving two or more premises, that are detention ponds, detention basins or underground storage located in public open space, and are designed to reduce runoff rates up to a 1 in 30-year event
Adoption, operation and maintenance organisation	SABs in each unitary / upper tier local authority	Scottish Water

The recent emphasis on flooding in English legislation has somewhat diverted attention from water quality actions under the Water Framework Directive 2000/60/EC (EU 2000), which aims to protect surface and groundwater from pollution. Accordingly, any discharge from SUDS structures directly into designated water bodies, e.g. Coventry’s main rivers the Sowe and Sherbourne, must not produce deterioration of aquatic ecosystems. Since SUDS features function as pollutant collectors (Wilson *et al*. 2005:223), questions have arisen as to their suitability to contribute to amenity and biodiversity goals (D’Arcy & Frost 2001:363), and ultimately to their designation as ‘sustainable’. Contaminants from urban run-off accumulate in SUDS infiltration devices (Heal *et al.* 2004:51; Wilson *et al*. 2005), and must be disposed of in accordance with waste legislation (Defra 2005a:12; Woods Ballard *et al*. 2007:2.21). However, in conventional sewerage systems, similar issues arise (Heal *et al.* 2004:51; Wilson *et al*. 2005:219), reflecting the presence of contaminants in the urban environment: pollutants and heavy metals accumulate in the sewage sludge generated in waste-water treatment plants; in separately sewered systems, pollutants may be delivered directly into watercourses by storm sewers. Targets that all water bodies should achieve good status by 2015 remain, and regional programmes such as the EA's Midlands Urban Rivers Community Initiative (Brewington 2012) are attempting to tackle diffuse pollution through projects such as the Coventry Brooks Plan (Warwickshire Wildlife Trust 2013), which has identified a series of measures including wider SUDS implementation to improve river quality locally.

As a result, planning authorities remain in some uncertainty because SUDS are expected to be prioritised, but there are no formalised adoption and maintenance procedures. Guidance in relation to SUDS feasibility will be required by the local planning authority (LPA), and the following sections review previous studies that have addressed how this could be achieved.

2.3. PREVIOUS STUDIES OF SUDS FEASIBILITY

A number of workers have attempted to develop methods for assessing SUDS feasibility that are appropriate for individual areas and / or at wider scales. A range of approaches has been adopted, summarised in Table 2.3. There have been some attempts to include or focus on water quantity and/or quality modelling, but the most frequently used method has been to utilise flowcharts or decision trees to define steps to reach a decision, or decision criteria to select appropriate SUDS devices in particular situations. Some approaches have employed Geographical Information systems (GIS) to collate, analyse and communicate information. An equal number of studies have focussed on either technical/ environmental influences on SUDS feasibility, or a mixture of technical and social/ institutional factors. The number of influencing factors ranged widely, from two to over 40. Whilst the SUDS triangle (Fig. 1.1) places equal emphasis on quantity, quality and amenity, few of the methods reviewed have addressed all three elements. Some of the studies have targeted individual problems locations, while others have attempted generic guidance, with the more structured approaches classifying themselves as frameworks due to a defined organisation of criteria or methods. These studies are reviewed in more detail according to the type of method adopted in sections 2.4–2.8.

No comprehensive frameworks or methods for assessment of SUDS amenity were found. Echols & Pennypacker (2008) presented a set of design methods that could contribute to amenity objectives, but did not explain how their success could be measured. In their definition of amenity Woods Ballard *et al*. (2007:3.13-3.15) focussed on safety concerns, with a brief mention of the need to incorporate visual impact and amenity benefit by maximising aesthetic appeal, but suggesting no means of measuring whether this has been achieved. Fowler *et al.* (2012) found a lack of agreement between authors on the meaning of amenity and how it can be assessed. Therefore, whilst the amenity value of SUDS is considered important, the lack of formal methods for evaluation necessitated its omission from the study.

Table 2.3 Comparison of SUDS feasibility studies. The target issues addressed are those identified by the SUDS triangle of quality (Qual), quantity (Qty), and amenity (Amy). Method identifies the principal techniques employed to support determination of appropriate SUDS features (Tsk= List of tasks, Flw= Flowchart, Dec= Decision chart/tree (w= using weightings), FHM= Flood / hydraulic model, WQM= Water quality model, Exp= Expert system, RA= Risk assessment, GIS= GIS). The 'type of factors' were technical (tech), e.g. water quantity and quality criteria, and institutional (Inst), where social and economic factors were considered. The number of factors in the assessment was not always clearly identifiable. Target issues in upper case were explicitly defined by the study, those in lower case were included but not explicitly identified

Study	**Method**								**Type of factors**		**No. of factors**	**Issues addressed**		
(Reference)	**Tsk**	**Flw**	**Dec**	**FHM**	**WQM**	**Exp**	**RA**	**GIS**	**Tech**	**Inst**		**Qual**	**Qty**	**Amy**
SEPA Diffuse Pollution Initiative (D'Arcy & Wild 2002)			x						x		8	**Y**		
Scottish Water SUDS Retrofit Research (Atkins Water 2004)				x			x		x	x	At least 10	**Y**		
Assessment of catchment area & soil type (Ellis *et al*. 2004b)			x						x		2	y	y	
Dunfermline SUDS Retrofit (Hyder Consulting 2004)			x						x		About 5	y	Y	
Ciria C609 (Wilson *et al*. 2004)			x (w)						x	x	About 23	Y	Y	Y
Scholz decision-support key (Scholz 2006)			x						x	x	9	y	y	
Scholz decision-support matrix (Scholz 2006)			x (w)						x		17	y	y	
Swan/Stovin hierarchical framework (SNIFFER 2006)			x						x		15	Y	Y	
Stormwater management information system (Becker *et al.* 2006)			x					x	x		15	y	Y	
Stormwater Management expert system (Jin *et al*. 2006)			x			x		x	x	x	At least 9	Y	Y	
Center for Watershed Protection (Schueler *et al*. 2007)		x							x	x	At least 30	Y	Y	Y
Map of locations for infiltration SUDS (Ipswich Borough Council 2007)								x	x		4	Y		
HR Wallingford Stormwater Storage (HR Wallingford 2008)			x	x					x	x	10	Y	Y	
SUDS guidance for Telford & Wrekin (Halcrow Group 2008a)		x						x	x		2	Y	Y	
Lower Irwell Valley IUD pilot (Doncaster *et al*. 2008)								x	x	x	4	Y	Y	
EPA SUSTAIN (Shoemaker *et al*. 2009)				x	x			x	x	x	12	Y	Y	
Treatment Train Assessment tool (Jefferies *et al*. 2009)			x (w)						x	x	4	Y		
Planning for SUDS C687 (Dickie *et al*. 2010)	x									x	About 5	Y	Y	Y
Sudsloc (Viavattene 2009)			x	x				x	x	x	At least 40	Y	Y	Y
Retrofitting to manage surface water C713 (Digman *et al*. 2012)		x							x	x	At least 14	Y	Y	Y
BGS Infiltration SUDS Map (Dearden and Price 2012)								x	x		Around 20	Y	Y	
GIS-based stormwater disconnection (Moore *et al*. 2012)			x	x				x	x		At least 7	Y	Y	

2.4. TASK LISTS

The methods listed in this section provided no formal structure for assessing SUDS feasibility.

2.4.1. Planning for SUDS (Ciria C687)

Dickie *et al*. (2010) provided guidance on greater integration of SUDS in the planning system on the assumption of rapid implementation of the FWMA (2010). The authors identified goals for master planning of development sites (Dickie *et al*. 2010:52-54) as:

- Identify important natural flow paths and possible sites for infiltration to shape the layout of the development
- Maximise permeable surfaces to minimise runoff
- Create multi-functional spaces by combining SUDS functionality with public realm open space
- Integrate SUDS with road layouts
- Cluster different land uses in order to manage pollution using SUDS management trains.

The guidance was presented in generic form, and used case studies to illustrate how requirements had been achieved in example projects. However, it relied on local development planners gathering relevant information and formulating their own plans, and provided only an outline for development planning using the steps listed above. It has been somewhat compromised by the rescinding of regional plans in 2011, the lack of consideration how SUDS Approval Bodies might operate in conjunction with other local planning procedures, and the delay in implementing the sections of the FWMA relating to SUDS, in particular the SUDS National Standards that it expected to take effect in 2011 (Dickie *et al*. 2010:2).

2.5. FLOWCHARTS

Flowchart-based methods imposed greater structure on the assessment methods by defining a sequence of tasks to be completed.

2.5.1. Center for Watershed Protection

The Center for Watershed Protection (Schueler *et al*. 2007:191-230) identified techniques to evaluate the potential for retrofit SUDS in urban environments. The method was less formalised than those found in other studies reviewed, comprising a set of assessment tasks (steps one to five in Fig. 2.1), which progressively built levels of detail. An initial scoping exercise is followed by desktop analysis of the study area, similar to the procedures followed by Atkins Water (2004). A field survey further assesses candidate sites, followed by collation of information to allow comparison. Finally, a multi-criteria decision approach is adopted to determine the highest priority candidate locations.

Fig. 2.1 Stormwater retrofitting process (summarised from Schueler *et al*. 2007:191-192)

The approach regarded levels of impermeability in the 45-60% range as relatively high for a catchment (Schueler *et al*. 2007:11), whereas such percentages may be low to moderate for UK urban areas, e.g. UK studies in Glasgow (69%, Singh *et al.* 2005:3), Livingston (87%, SNIFFER 2006:56), Merseyside (61%, Pauleit *et al*. 2005:301), and Sheffield (87.7%, Stovin *et al*. 2007:13). For catchments with a higher ratio of undeveloped areas, the analysis assumed a smaller quantity of larger SUDS features to be beneficial, so assessment was based on factors such as stormwater pond density, stream density, available area in stream corridors, and the extent of publicly owned land for implementing large storage devices. In more built-up areas, a greater quantity of smaller SUDS features was regarded as the most practical option, and feasibility was assessed by considering factors such as land cover and ownership, areas due for redevelopment, and the number of problem locations.

A substantial number of factors were included for evaluation, and field surveys were thought necessary to evaluate the entire area, implying either that relatively small geographical areas were addressed, substantial staff resources were available, or long timescales were acceptable. The value of using GIS systems was recognised as a tool for evaluation, but availability of suitable GIS data was assumed. Relevant GIS data from government sources is publicly available without cost in the USA, but this is not the case in the UK. In summary, the methodology contained a significant number of tasks requiring substantial effort, and was reliant on higher levels of data availability than are likely in the UK.

2.5.2. Retrofitting to manage surface water (Ciria C713)

Digman *et al*. (2012) defined a comprehensive framework for SUDS retrofit which built on the SNIFFER (2006) retrofit feasibility assessment and the Schueler *et al*. (2007) methodologies. Steps one, two and three of a six-step process (Fig. 2.2) addressed identification of retrofit potential. Within each heading, a series of steps gave practical suggestions and examples of the work to be undertaken. For instance, many of the example illustrations in chapter seven offered detailed design guidance and posed questions that were equally relevant for new developments. The approach relied on prior identification of needs, drivers and/or opportunities for retrofit (Digman *et al*. 2012:69), but did not propose a means of identifying those factors.

Fig. 2.2 Framework for retrofitting stormwater management measures (redrawn from Digman *et al*. 2012:38)

2.6. DECISION CHART/TREE STUDIES

Decision chart and decision tree approaches utilise structured choices to direct decision makers to select appropriate SUDS for the area under consideration. These focus more on the factors to consider and the decisions necessary to define feasible SUDS, and in general have imposed greater structure than the task list/ flowchart methods that were more oriented towards processes to be followed.

2.6.1. SEPA Diffuse Pollution Initiative

D'Arcy & Wild (2002:12-14; 2003) suggested decision trees to address pollution risks arising from industrial estates, contaminated land and brownfield sites as part of work for the SEPA Diffuse Pollution Initiative, to address water quality issues in Scotland. The work was focused on options to alleviate runoff into combined sewer systems, with roofs, roads and surface water drainage facilities judged to present the highest risk to water quality. Specifically, the decision chart for brownfield sites considered a range of SUDS options, using factors relating to soil type, perceived problem, and conformance to building regulations to determine suitable techniques from a range of nine SUDS devices.

2.6.2. Ellis *et al*. assessment of catchment area and soil type

Ellis *et al*. (2004b) aimed to ascertain the feasibility of seven SUDS devices based on catchment area and soil type (Fig. 2.3). Catchment size was used as an indicator of SUDS techniques, since some devices, *e.g.* wetlands, were considered to operate most effectively when collecting runoff from contributory areas in excess of 6 ha. Smaller devices such as swales, filter strips and permeable paving were regarded as more suitable for smaller catchments. Soil type was used to determine the associated infiltration rate, and thus suitability for rainwater infiltration or detention. The paper suggested the benefits that might accrue from SUDS implementation, but, unlike the Dunfermline study (Hyder Consulting 2004) did not consider whether additional technical or institutional factors may assist or hinder SUDS implementation.

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Fig. 2.3 Catchment area and soil type assessment of SUDS suitability (Ellis *et al*. 2004b:249)

2.6.3. Dunfermline SUDS Retrofit Case Study

The retrofit case study of Dunfermline (Hyder Consulting 2004) aimed to investigate the feasibility of removing surface water runoff from combined sewers at a specific location. The study classified land use into six categories: retail and business; health centres and hospitals; education and sports centres; transport and industry, residential, and roads; and then determined the extent of impermeable area, based on roof and paved sites, contributing to the sewer system for these six land use categories. A preference hierarchy was used to select those types of land use where SUDS were more likely to be feasible (Fig. 2.4). The hierarchy used was the 'surface type' component of the Swan/Stovin framework (Swan 2002; Stovin & Swan 2003 - see section 2.6.6), which defined that large impermeable surfaces belonging to a single landowner were likely to be more appropriate than individual household properties. A detailed hydraulic model was then created for each selected location to ascertain the potential effect of SUDS implementations. The study identified 10 additional factors that were important in determining SUDS feasibility, including environmental considerations such as soil, topography and groundwater, and institutional aspects of land ownership, traffic and community involvement, but did not evaluate these in detail.

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Fig. 2.4 Preference hierarchy used in Dunfermline SUDS retrofit study (Hyder Consulting 2004:9)

2.6.4. SUDS: Hydraulic, structural and water quality advice (CIRIA C609)

Wilson *et al.* (2004:269-276) proposed a 'coarse' decision-making tool to assist in defining suitable SUDS techniques for a specific site. Each of 13 SUDS techniques was scored on a scale of 1 (very poor / expensive) to 5 (very good / low cost) against approximately 23 factors covering:

- Water quantity control
- Water quality control
- Land use
- Physical site features
- Amenity and environmental value

- Economic value
- Maintenance burden.

Each factor also received a relative weighting of significance compared to the other factors considered; values of zero (not necessary), 1 (desirable) and 2 (essential) were proposed. Suggested scores and weightings were presented for each of the 13 SUDS techniques, although these could be altered by decision-makers. The methodology was based on the multi-criteria decision-making approach of Ellis *et al.* (2004a). Overall, it appeared more suited to evaluation of individual sites rather than whole catchments or wider urban areas.

2.6.5. Scholz's decision tools

Scholz (2006) proposed two methods for evaluating SUDS suitability. The first, a qualitative decision-support key (Fig. 2.5) was suggested for high-level identification of potential sites. The paper also proposed a more detailed decision-support matrix that evaluated 16 factors for each of 16 SUDS techniques in a similar manner to Wilson *et al.* (2004). Each of the 256 (16x16) 'treatments' was then weighted as to its relative importance. Resulting values were standardised to indicate whether a technique was highly suitable, good, satisfactory or unsuitable for a particular site. The matrix was specific to sites in Glasgow and Edinburgh, and threshold values and weightings might require changing for other locations outside lowland Scotland (Scholz 2006:119), although suggestions for such changes were not offered.

Fig. 2.5 Scholz’s (2006:120) Decision Support Key

2.6.6. Swan/Stovin hierarchical framework

The Swan/Stovin hierarchical framework (Swan 2002; Stovin & Swan 2003; updated in SNIFFER 2006:29) proposed a decision hierarchy aimed at rapid identification of retrofit opportunities, which has been recognised as useful by other workers, *e.g.* Atkins Water (2004:51), Hyder Consulting (2004) and Moore *et al*. (2012). The initial version was concerned with water quality issues, but the 2006 update (Fig. 2.6) was intended to address both water quality and flooding. A high level assessment attempts to determine practicality of implementation by considering different influencing factors:

- surface types, reviewing sewerage system layout, land ownership and land use (‘who’ and ‘what’)
- surface water management train options, assessing the most appropriate locations to provide water storage and treatment (‘where’)
- Mode of operation, technical methods to process runoff (‘how’).

Fig. 2.6 Swan/Stovin hierarchical framework (SNIFFER 2006:29)

The following explanations of the framework were offered in the SNIFFER (2006:29) report:

- separately sewered branches may be more easily diverted into site/regional controls;
- publicly-owned surfaces were preferred over private because of the higher likelihood of nearby land being available, and fewer stakeholders to be dealt with;
- disconnection of industrial/commercial premises may address the most significant sources of diffuse pollution, but may require suitable treatment to prevent contamination of groundwater or watercourses;
- disconnection of ‘clean’ sources may enable larger runoff volumes with low contamination risks to be removed from the system;
- Green roofs and porous car parks do not require additional land, and so are preferred above other operational techniques.

Swan’s original work (2002:166) specified that the factors should be evaluated in the sequence given above, although this clarity was no longer present in the updated SNIFFER (2006) framework. Nevertheless, this was the logical way to apply the methodology. Swan

(2002:148-151) also included cost as a fourth ‘stream’ in his original work, but its explicit consideration was removed from the updated version, as cost was considered to be a component of the three remaining hierarchies, to be used to differentiate potential options (SNIFFER 2006:30).

The SNIFFER guidance suggested that, where no suitable hydraulic model was available, a 'treatment volume' based on 12 mm of rainfall could be calculated to serve as a replacement indicator of excess runoff volume. However, this would only address problems associated with the polluted first flush of runoff, not the larger volumes that might result in flooding. In practice, the SNIFFER study evaluated water quantity issues by using hydraulic modelling, incorporating a number of assumptions. Although the methodology claimed to address both water quantity and quality issues, in practice much of the focus still appeared to be water quality.

In a similar manner to Ellis *et al.* (2004a) and Wilson *et al.* (2004:269-276), the SNIFFER method applied a multi-criteria decision approach to decide suitable SUDS options for a specific site. A set of 14 factors were grouped into economic, environmental, social and technical categories, which were applied to possible design options. The results were then ranked, the highest score being assigned to the best performing option, to enable decision makers to judge the most suitable scheme across all factors. The scheme that offered the most environmental benefits in the case study obtained the highest overall score, but it was also six times more expensive than the next option. This result highlighted the importance of assigning appropriate weightings to the various categories, since financial considerations are likely to be a major constraint on SUDS retrofit.

2.6.7. HR Wallingford Stormwater Assessment

The online UK SUDS assessment website (HR Wallingford 2008) provided tools for an initial site evaluation of the suitability of nine SUDS techniques. SUDS proposals were evaluated according to the following 10 criteria:

- Development type
- Drainage ownership
- Site size
- Soil type
- Land use
- Geographical location in the UK

- Groundwater
- Land contamination
- Aquifer vulnerability
- Water scarcity.

While all these factors were relevant to an assessment of SUDS feasibility, there was a risk that their values may not be known for smaller sites, or might exhibit some variability over wider spatial areas. The website also provided an assessment of the discharge rate limits and storage volumes required to achieve Environment Agency recommendations aimed at reducing the impact from surface water runoff by land developments. The assessment was based on hydrological parameters and calculations defined in Defra & Environment Agency (2007). Although the input parameters were relatively straightforward in hydrological terms, familiarity with their purpose and values was explained by reference to technical publications, which were unlikely to be known or accessible to those who were not regularly involved in hydrological or drainage calculations. This tool appeared more suited to evaluation of individual development sites rather than assessment of SUDS suitability over a larger urban catchment, and was explicitly limited to sites under 50 ha.

2.6.8. Treatment Train Assessment Tool

A SUDS Treatment Train Assessment Tool (STTAT, Jefferies *et al*. 2009) was developed to provide guidance to developers about regulatory requirements for SUDS in Scotland for water quality issues. It allocated scores to sensitivity of receiving water bodies, land use, and SUDS devices individually and in combination, and was one of the few feasibility methods to address treatment trains rather than individual SUDS devices. Scores were assigned to a treatment train considering four principal factors:

- pollutant removal performance of SUDS devices
- focus on individual pollutants
- ease & cost of maintenance
- long-term durability of the SUDS devices *in situ*.

2.7. MODELLING

The modelling studies considered are those which focussed on SUDS feasibility.

2.7.1. Scottish Water SUDS Retrofit Research

Scottish Water commissioned a study (Atkins Water 2004) to identify sites for rapid SUDS implementation in Ayrshire, assessing a county-wide area with multiple landowners. The resulting methodology was acknowledged to be project-specific with its focus on the impact of CSO spills on water quality. The report stressed the importance of information being readily available to undertake a desktop study. Recognising the restricted timescales available for decision-making, the methodology used weightings associated with six factors to determine schemes with fewer hindrances to implementation:

- Land owner agreement
- Consent processes
- Planning permission requirements
- Land procurement procedures
- Criminal record checks (required when working in schools)
- Public participation.

Areas of high impermeability were identified as a preliminary step, followed by a desk-top study using background maps to evaluate types of land cover and drainage characteristics. However, the study was reliant on existing hydraulic models of specific catchment sewerage systems to identify large areas of impervious land cover (Broad 2005:235), and such hydraulic models may not be readily available for other locations (SNIFFER 2006:23). A key conclusion was that areas with single landowners were more likely to offer potential for rapid SUDS implementation, as the timescales for negotiation would be reduced. However, if this approach resulted in identification of a limited number of sites, then objectives of significant water quality improvements were unlikely to be attained. The lack of awareness among individual landowners of how their drainage systems functioned was also noted.

2.7.2. EPA SUSTAIN

The USEPA’s System for Urban Stormwater Treatment and Analysis INtegration (SUSTAIN, Shoemaker *et al*. 2009; Shoemaker *et al*. 2011) was developed to support evaluation of impacts of SUDS implementation on hydrology and water quality using modelling at different spatial scales, and simulating the cost of different options, fronted by a GIS system (Fig. 2.7). Catering for 14 SUDS types, a key feature was the inclusion of different scales of evaluation from regional watershed planning (> 260 km^2), through mid-sized (25-260km^2) and smaller (2.6-25km^2) catchments to individual development sites (<2.6km^2). In order to avoid the computer resource issues associated with large datasets at the regional planning scale, a simplified functional categorisation of SUDS into four classes (on-site interception, on-site treatment, routing and attenuation, and regional storage and treatment) was employed. Catchment planning was undertaken for individual sub-catchments, and the results assumed to apply to other sub-catchments. The system required input of a DEM, land cover details, and stream routing, and was intended for technical users familiar with hydrological modelling techniques and technicalities.

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Fig. 2.7 Structure of the SUSTAIN system (Shoemaker *et al*. 2009:2.15). BMP (best management practice) is the equivalent of SUDS

2.8. GIS-BASED GUIDANCE

A number of studies have recognised the capabilities of GIS for assembling, managing and communicating information about SUDS feasibility.

2.8.1. Stormwater management information system

Becker *et al*. (2006) described a GIS-based system to evaluate the potential for disconnection from the public sewer system in an urbanised catchment in Germany. Two maps were constructed. The first map resulted from analysing aerial photographs to generate broad categories of land cover, based on building and location characteristics such as density of development and level of impermeability. Positive and negative attributes, such as proximity of permeable areas and number of land owners, were defined for each category, and resulted in a percentage disconnection potential for each land cover class. The second map depicted topography, geology, soil and groundwater attributes. These were the basis for determining suitable SUDS devices, for example using soil infiltration capacity. Each physical attribute was evaluated for a specific area, and the decisions combined to define suitable SUDS devices. By overlaying the two maps, the combined decisions could be seen for any selected location (Fig. 2.8). Including infiltration rates for SUDS infiltration devices allowed the potential impact on groundwater storage to be evaluated.

This study made use of the capabilities of GIS to support decision-making. A number of assumptions about data availability were included, which may not apply to the UK. The case study area was at risk from groundwater flooding, so the impact on previous decisions of adding new infiltration SUDS would require continual review.

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Fig. 2.8 Example GIS usage for stormwater disconnection (Becker *et al*. 2006:6)

2.8.2. Stormwater Management expert system

Jin *et al.* (2006) and Sieker *et al*. (2007) outlined an expert system developed to support planners in Germany when determining suitable locations for disconnection. This research appeared to build upon the work of Becker *et al*. (2006) described above. Information was collated and formed the input to a computer decision tree that incorporated the decision-making knowledge and procedures of experts in stormwater management. GIS-based maps were then generated (Fig. 2.9) which portrayed:

- appropriate SUDS techniques for specific areas
- impermeable areas that can be disconnected from the sewer system
- a qualitative assessment of how SUDS measures can contribute to hydrological aims.

Fig. 2.9 GIS presentation of the Stormwater Management expert system (Jin *et al*. 2006:8)

Expert systems are useful when dealing with complex, unstructured problems involving large amounts of data, as well as requiring practical experience and judgement. The SUDS techniques that were evaluated appeared to be limited to vegetated swale and infiltration devices.

2.8.3. Map of locations for infiltration SUDS

Ipswich Borough Council (2007:63) produced a map showing areas of the city suitable for infiltration SUDS (Fig. 2.10), demonstrating the level of information utilized by development planners. The underlying logic was based on four criteria: soil permeability, height of the water table, land contamination and groundwater source protection zones.

Fig. 2.10 Locations for infiltration SUDS (Ipswich Borough Council 2007)

2.8.4. SUDS guidance for Telford & Wrekin

The SUDS guidance maps produced for Telford & Wrekin's local development framework core strategy (Halcrow Group 2008a), depicted solely soil permeability characteristics and groundwater source protection zones (GWSPZs) (Fig. 2.11), although the study recognised that additional factors should have been taken into account. It was left to users to interpret the maps. 84% of Telford's land area was deemed unsuitable for infiltration SUDS, although the separate flowcharts identified possible SUDS devices for all combinations of soil type and GWSPZ (Fig. 2.12), and explicitly included a range of possible SUDS including source controls.

Fig. 2.11 Example SUDS guidance map for Telford (adapted from Halcrow Group 2008a)

Fig. 2.12 Example SUDS guidance flowchart (Halcrow Group 2008a)

2.8.5. Lower Irwell Valley Integrated Urban Drainage pilot

The Lower Irwell Valley Integrated Urban Drainage (IUD) pilot project in Salford (Doncaster *et al*. 2008) used readily available information to generate an advice map for planners that identified locations suitable for infiltration SUDS (Fig. 2.13). Factors used to derive the map were height above the river surface level, surface geology, fluvial flood zone extents, and areas at greater risk of sewer flooding, although additional reference information was shown. Factors not included but which were deemed relevant to SUDS advice maps were groundwater source protection zones, land contamination and underlying geology.

Fig. 2.13 Lower Irwell SUDS map (adapted from Doncaster *et al*. 2008)

2.8.6. Sudsloc tool

Similar to the EPA SUSTAIN tool (Shoemaker *et al*. 2009), Sudsloc was a GIS-based selection system integrated with 1D and 2D flood modelling software enabling identification of possible locations for a range of SUDS devices (about 16 types), and assessment of their hydraulic and pollutant removal potential (Ellis *et al*. 2012; Viavattene 2009; Viavattene *et al*. 2010) (Fig. 2.14). A significant number of factors could be evaluated, including:

- physical factors such as land cover (termed land use), soil type, depth to groundwater, slope and land contamination
- pollutant removal potential and
- multi-criteria analysis taking into account weighted scores for scientific, social, economic, operational and planning requirements.

The impact of installing SUDS on flooding at a site could be simulated (Viavattene *et al*. 2010:7). A further enhancement (Ellis *et al*. 2012) demonstrated the potential for using high-resolution ground-based Lidar (0.1-2cm vertical resolution) to provide more accurate flood models than airborne lidar (5-15cm vertical resolution). The finer resolution Lidar captured features such as kerb heights, and circumvented the problem of obstacles incorrectly recorded due to the Lidar light pulse encountering features such as bridges. The Sudsloc tool provided an advanced method of judging the impact of SUDS at a specific site at a relatively narrow scale using a wide range of criteria, although was reliant on capturing detailed data in a field survey.

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Fig. 2.14 Conceptual structure of the SUDSLOC tool (Ellis *et al*. 2012:544)

2.8.7. BGS Infiltration SUDS Map

Dearden and Price (2012) continued earlier work undertaken by the BGS (e.g. Lelliott *et al*. 2006; Royse *et al*. 2008:10) to develop a national map of locations suitable for infiltration SUDS based on geological characteristics. A four-step process (Fig. 2.15) determined:

- major constraints such as landslide risk
- drainage characteristics, e.g. permeability of geological layers
- ground instability
- pollutant attenuation capability

and presented the result as summary layers in a GIS highlighting the most significant design constraint at a particular location (Fig. 2.16). Due to the volume of information in the underlying databases, the resulting SUDS maps were created as separate layers rather than being dynamically generated.

Fig. 2.15 BGS Infiltration SUDS map methodology (Dearden and Price 2012:481)

Fig. 2.16 BGS Infiltration SUDS map example output (Dearden and Price 2012:482)

2.8.8. Moore *et al*. GIS-based stormwater disconnection

Recognising that many hydrological models used for SUDS selection were appropriate only at the individual site scale, Moore *et al*. (2012) constructed a means of evaluating SUDS retrofit options on a wider, master planning, scale using a GIS platform, and demonstrated its application in catchments up to 4.5km^2 (Fig. 2.17). Decision guidance from the Swan/Stovin hierarchical framework (SNIFFER 2006:29) was extended and a set of spatial rules applied to determine possible retrofit sites. Base data for the GIS analysis were taken solely from Ordnance Survey MasterMap (OSMM). Although the approach aimed to automate the process, a number of data selection decisions required manual intervention. The resulting source and site control SUDS options were then input to a hydraulic model of the catchment, making generic assumptions about runoff storage and attenuation properties of the different SUDS options, to determine their impact on CSO spill volumes. Results showed reductions ranging from 57% to 86%, demonstrating the benefits of wider scale SUDS implementation. Unlike the Sudsloc tool, there was no integration between the GIS system and the hydraulic model.

Fig. 2.17 Methodology to identify SUDS retrofit opportunities (Moore *et al*. 2012:278)

2.9. GIS-BASED HYDROLOGICAL STUDIES

Other studies have generally evaluated urban land cover for use in hydrological assessments using satellite and aerial imagery (Gill 2006:81). They provided information about data and methods which informed the current work, and relevant aspects are reviewed next.

2.9.1. Satellite and aerial imagery

Studies such as Elgy (2001), Pauleit *et al*. (2005), Wentz *et al*. (2006) and Pauleit & Duhme (2000) have employed satellite and aerial imagery in visible and infrared bands to determine the impact of changing land use / land cover on hydrology. Pauleit *et al*. (2005) visually assigned a land cover category to the central point of 625 20m^2 grids, and manual assessment of imagery was often needed (similarly by Pauleit & Duhme 2000; Wentz *et al*. 2006), resulting in a labour-intensive exercise or a loss of accuracy. Elgy (2001), for example, attempted to determine whether a range of automated image classifiers could improve land cover categorisation in a case study in Birmingham, UK, concluding that the best method resulted in an overall accuracy of 71%. In areas of greater land cover diversity such as urban sites, detailed photographs and ground observations were needed to resolve difficulties in characterising land cover (e.g. Wentz *et al*. 2006:344).

In one of the more extensive studies of a full local planning authority area, Gill *et al*. (2007) determined runoff from Greater Manchester (1300 km^2) taking into account density of development and soil infiltration characteristics. Land use, rather than land cover, was determined from 0.25m resolution aerial photographs digitised in ArcGIS. Nine classes of land use in urban areas were estimated by interpreting aerial photographs at 400 random points within each of 29 subsidiary categories. Residential areas were divided into high, medium and low density, based on visual interpretation (Gill *et al*. 2008:213). The study also determined the impact of adding and removing green infrastructure under changing climate conditions by modelling runoff using the curve number approach employed in the USA (e.g. USDA 1986; USEPA 2000:9), with equation variables of land cover, precipitation, antecedent moisture conditions, and soil type (Fig. 2.18).

Fig. 2.18 Surface runoff in Greater Manchester based on land cover from classified imagery, evaluating differing climate scenarios (Gill *et al*. 2007:125)

At the broader regional scale, Mitchell *et al*. (2001:86) combined data from a range of published sources to map nonpoint source urban diffuse pollution hazards in the R. Aire basin, Yorkshire (2,057 km^2), although the land cover resolution of individual cells was relatively coarse (200 m^2). At a yet broader scale covering several local planning authorities, Butler *et al*. (2006) developed a GIS-based decision support system to assist in selecting and prioritising developments in regional land use planning. The evaluation was based on a range of environmental, social and economic sustainability criteria, with emphasis towards water management. The approach relied on a coarsened raster map resolution for the individual criteria, appropriate given the size of the example study area (3,517 km^2), but which would not be useful in dealing with specific locations. The raster cell resolution was not specified, although seemed from inspection of an example image to be about 0.5 km^2 per cell. The work relied on new software development using fuzzy logic programming to generate results. A multi-criteria analysis approach was adopted in order to facilitate agreement between decision makers on the inclusion and appropriate weighting applied to the different criteria.

These studies revealed the need for a coarsened resolution when employing raster satellite or aerial imagery at the broader scale of assessment due to the large volume of data, and the difficulties of assigning detailed and accurate land cover classes using such methods.

2.9.2. Aerial imagery combined with OSMM

Other studies have attempted to address these issues of relatively coarse classification by combining raster imagery with vector polygons such as those provided by OSMM. Prisloe *et al*. (2000) used classified aerial photographs to determine impermeability coefficients for three urbanised towns in Connecticut (Fig. 2.19). However, when compared with GIS-based planimetric data such as OSMM, the photographic method under- or over-estimated actual impermeability by up to 35%. Furthermore, roads were completely excluded from the study due to classification difficulties.

Fig. 2.19 Comparison of land cover impermeability from classified images (predicted) with GIS planimetric data (actual) for three towns in Connecticut (Prisloe *et al*. 2000:10)

In north-west England, the North West Green Infrastructure Unit (2009) manually classified OSMM polygons into 19 target classes using the characteristics available in the MasterMap dataset, in conjunction with aerial photography and other digital maps of open space, to identify potential green infrastructure sites. In a similar study for the West Midlands, TEP (2007) provided examples of applications of green infrastructure mapping and planning using GIS technology, while Perry & Nawaz (2008) compared aerial photographs against OSMM data using ArcGIS, to determine changing garden impermeability in a 1.16 km^2 suburban area of Leeds. Palmer & Shan (2002) also demonstrated that a combination of manual and automated methods was required to generate acceptable land cover classification in a heterogeneous 1.2 km^2 urban area in Baltimore, Maryland.

These studies used aerial imagery to generate alternative classifications of planimetric polygon data such as OSMM, showing that a mix of methods was required to generate appropriate land cover information from raw data.

2.10. SUMMARY OF EXISTING DECISION-SUPPORT METHODOLOGIES

Methodologies for determining SUDS feasibility have been developed over a number of years, and some have benefited from the advances and knowledge of previous workers. There was, however, no single consistent approach across existing methods for assessing SUDS feasibility, as shown in Table 2.3. Few aim to address all three aspects of the SUDS triangle: water quantity, quality and amenity value. Earlier UK studies favoured decision charts in order to provide structure to the complexity of data collection and analysis, and to the different stages of assessment. More recent work has placed greater emphasis on GIS and modelling as a means of manipulating complex data and communicating it in an understandable form. However, the application of computer-based decision-making and decision-support techniques, providing some automation of data presentation and processing, risks being tied in to specific technologies, and may demand some level of expertise on the part of the system users. At the broader scale of an LPA, the development planning process involves coordinating a range of inputs at different scales from numerous sources, and obtaining agreement, or at least acceptance, from multiple stakeholders about the future direction of development in the planning area (Gilmour & Blackwood 2006), and benefits from clearly portrayed guidance in order to support decision-making.

A number of existing studies have attempted to define a framework for assessing SUDS feasibility. Some have focused on the technical attributes of SUDS as a basis to arrive at a decision on feasibility, while others have seen value in including institutional and social factors. There was no clear consensus (Table 2.3) on the individual factors to be assessed, the number of factors, the most appropriate methods to employ, nor the approaches to take when not all the required data was available. A common conclusion from previous studies was the recognition that additional criteria needed to be taken into account, with limitations of time and data availability likely to have been the main reasons preventing their inclusion. It was not clear whether the increased time and complexity involved in evaluating additional factors would result in greater clarity of the outcome. Indeed, little evidence was found concerning the practical effectiveness of many of the decision-making methods for development planning. Furthermore, no single technique has been recommended above others, has gained consensus, or has achieved *de facto* pre-eminence in use (Hurley *et al*. 2008:28).

Most methods for SUDS feasibility assessment in the UK have focused on evaluating feasibility for individual sites. The few authors attempting to map SUDS feasibility at the strategic LPA scale have placed emphasis on infiltration solutions. SUDS comprise a wider range of techniques than infiltration alone, so one goal of the current research was to demonstrate the feasibility of the whole range of SUDS techniques in a local planning authority area. Since no clear methodological approach emerged from the review of existing techniques, a pilot study was undertaken to gain a clearer view of the application and performance of techniques to define feasible SUDS for a retrofit site. The pilot study was undertaken in 2007-08, and only the decision-making tools available at the time of the pilot study were evaluated. The methods adopted for the pilot study are briefly described in chapter three, and the results summarised in chapter four, with full details given in Appendix C. Section 4.3 reviews whether techniques which are appropriate at the site level remain so when applied to broader scale assessments of SUDS suitability The next chapter describes the methods utilised for both the pilot study and at the wider city scale.

3 METHODOLOGY

3.1 OVERALL OUTLINE

This chapter explains the methodology adopted for the research to address the aims and objectives defined in chapter 1. Table 3.1 identifies sections in this chapter that explain the methods associated with each objective. It also points forward to the relevant sections in the results chapters.

Table 3.1 Summary of Methods and Results section for each objective

Objective	Methodology section	Results section
1a. Identify suitable evaluation techniques to determine SUDS feasibility in an urban environment in order to inform the choice of methods at the local authority strategic scale	3.5	4.2-4.3
1b. Construct a framework in order to evaluate suitable SUDS devices at the local authority strategic scale	3.6.1-3.6.2	4.4
1c. Determine suitable SUDS devices for an urban local authority area	3.6.3-3.6.4, 3.7	4.5
2a. Develop and apply rules to generate maps showing feasible locations for suitable SUDS devices based on characteristics of the local authority area	3.8	5.2-5.7
2b. Evaluate the suitability of the SUDS feasibility maps and the applicability of the approach	3.9	5.8-5.10
2c. Assess potential additional applications of the SUDS feasibility maps	3.10	5.11-5.14

3.2 RESEARCH AREA

Coventry (1^{o}46' W, 50^{o}04' N), a city of approximately 315,700 inhabitants (Coventry City Council (CCC) 2011c:1), was the case study site for this research. It is located on the eastern edge of the West Midlands conurbation in central England, UK. The study area of the city of Coventry (Fig. 3.1) was that delimited by the government local planning authority (LPA) boundary, covering 98.65 km^2. Coventry has been occupied since Saxon times, and since the early 19th century had a history of skilled artisan trades such as ribbon weaving and watchmaking, developed into a centre for bicycle manufacture in the latter part of the 19th century, leading to motor cycle and car manufacture becoming major industries in the 20th century (Stephens 1969). The city covered about 10 km^2 in the early 20th century, expanding rapidly to around 65 km^2 in the late 1930s to accommodate the growing population (Stephens 1969).

Most of Coventry lies below 100 m above Ordnance Datum (AOD), grading from 165 m in the north-west to 63 m AOD in the south-east, in the R. Sowe valley (Fig. 3.1). The north-east of the city is generally flat, while the north-west and west are more undulating. The underlying geology is sedimentary, with Carboniferous sandstone, siltstone and conglomerate in the west and centre, and Triassic mudstone in the east (BGS 2008b). Superficial deposits comprise relatively porous glacial sand and gravel in the lower Sowe valley, and less permeable glacial till principally in the east and centre of the city. Soils range from free-draining loams (30% of LPA area), slowly permeable loams and clays (26%), clays with impeded drainage (41%), and high groundwater floodplains (2%) (NSRI 2010; Soil Environment Services 2008). Annual rainfall is 670 mm (Bablake Weather Station 2013).

Based on Ordnance Survey mapping (Edina 2009), the largest land cover component in Coventry was greenspace (Fig. 3.2), although much of this was situated in the northwest (Fig. 3.3). The mixed land cover of gardens occupied 22%, predominantly in the suburbs. Buildings covered 12%, with concentrations indicating commercial and industrial zones. Paved areas, including roads and rail tracks, occupied 19%, although these features do not emerge clearly on Fig. 3.3 due to their linear nature. Only 1% of the city was open water. Unclassified land undergoing redevelopment accounted for a further 1%.

Fig. 3.1 Key locations and characteristics in Coventry. The location of the city centre, the pilot study site, and Canley, used to evaluate the feasibility map approach, are indicated. Main roads and rivers are shown for reference. Fluvial water quality reflects the Water Framework Directive (WFD) measures. Data sources: Edina 2009, EA 2010b, CCC 2012b

Fig. 3.2 Land cover distribution in Coventry. Data source: OSMM (Edina 2009)

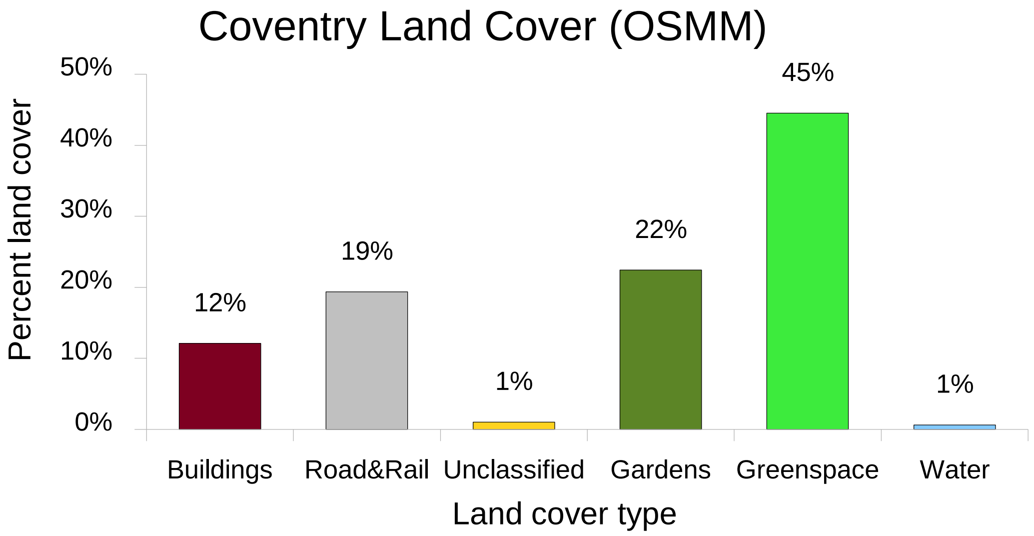

Fig. 3.3 Summary of land cover in Coventry based on the OSMM classification

Coventry is well served by a mixture of storm and combined sewers to drain surface water, but no detailed records for public or private drainage covering the full city area were obtained. Visual assessment of an overview plan of the public sewer system (Jacobs Gibb 2008:23) indicated that over 50% of Coventry was served by combined sewers, with storm sewers more prevalent in the eastern and western suburbs.

Coventry’s position at the head of two tributaries of the Warwickshire Avon in the Severn river basin district has meant that it has not been subject to extensive fluvial flooding in the past. There has however been a history of relatively frequent small-scale flooding affecting a limited number of properties. A total of 774 flood events were identified in the period 1910-2009, of which 436 occurred during 1980-2009, mean 14.5 events per year. Six locations in the city were assessed as at high risk of surface water flooding (CCC 2011b:2).

The water quality of Coventry's three main rivers, the R. Sowe, R. Sherbourne and Canley Brook (Fig. 3.1), was forecast to fail to achieve the 'good' standard required by the Water Framework Directive (WFD) by 2015 (EA 2010b; EA 2014). The ‘poor’ rating assigned to the rivers Sherbourne and Sowe was determined by the biological measure. The moderate rating of the Canley Brook was driven by phosphate. The lower reaches of the R. Sowe failed to meet the WFD chemical quality standard due to the presence of tributyltin pollution. No significant change in water quality status was predicted by the EA before 2015, except to remove the source of tributyltin pollution affecting the R. Sowe. Groundwater quality was poor under the west and centre of Coventry (72% of the LPA area), and 98% of the city was included in a surface water nitrate vulnerable zone (EA 2013b).

Further details of the data used to characterise Coventry are provided in section 3.7, and the full characterisation dataset is contained in appendix D. Coventry, is a unitary authority. In the absence of an approved and adopted Local Development Framework under the *Planning and Compulsory Purchase Act* (Act of Parliament 2004), the Coventry Unitary Development Plan 1996-2011 (CCC 2001) defined policies and proposals for the development and use of land. In the Unitary Development Plan, food risk was to be managed following procedures in national planning policy (now the annex to the NPPF), and surface water by the use of SUDS for “source control” (CCC 2001:38).

Coventry was selected as the research site due to a number of factors. Local authority personnel, both elected officials and council officers, were enthusiastic to investigate the potential role for SUDS in the city, but had little experience of their implementation. Coventry’s LDF core strategy was well developed at the start of the research period, and underwent examination in public by the Planning Inspectorate in late 2009. Coventry had identified a role for SUDS in addressing flooding (CCC 2008b:52), adapting to climate change (Coventry City Council and Coventry Partnership 2012:31,37), and the draft local development framework core strategy (CCC 2009) proposed that developments in the city should use SUDS techniques. Access to data and resources was provided by the local authority planning, drainage and sustainability departments. The proximity of the researcher to Council offices led to ease of access, and Council officers were happy to cooperate.

The LPA boundary area was relatively compact (98.65 km^2), and population density was 32.1 residents per hectare (rank 107 / 154 English tier 1 authorities), based on 2011 population census data (ESRC 2014). 81% of tier 1 authorities in England lay with one standard deviation of Coventry’s population density, and 62% within one standard deviation of its area (Coventry ranked 61 / 154). Coventry was therefore not unique as a study location, and it provided distinct advantages in terms of access to stakeholders directly interested in the research.

3.3 GIS TOOLS AND METHODS

This research uses a Geographical Information System (GIS) based methodological approach to determining SUDS feasibility. Map outputs were produced by means of Geographic Information Analysis (GIA), a computer-assisted spatial analysis technique using a GIS, founded on the concept that the location of objects and events is critical to an understanding of problems (Longley *et al.* 2005:4,316-317). GIS was utilised to record, collate, communicate and analyse spatial data. The coordinated database was constructed by importing and editing data using the ArcGIS geographical information system (ESRI 2005-2010). The data were coordinated using the British National Grid 1936 spatial referencing system. GIS analysis was undertaken using embedded structured query language (SQL) statements, for the most part in ArcGIS software, although some analyses were performed in Quantum GIS (QGIS, 2012). Processing of some data obtained from Coventry City Council was carried out in MapInfo (Pitney Bowes 2003). Standard GIS functionality was used, with no bespoke development. A summary of the principal GIA functions referred to in the process diagrams is given in Table 3.2.

Table 3.2 Standard GIS analysis functions utilised (ESRI 2010)

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Geographical outputs were represented in map form. The use of GIS ensured that the maps were scaleable, and could be viewed at differing resolutions from the full city area down to individual development and regeneration sites. Local government bodies in England have access to detailed computer-based maps of the areas for which they are responsible. Combining the SUDS feasibility maps with existing map resources available to local government was intended to support rapid familiarity with the meaning of the SUDS data and its spatial relationship to known information. Conventions used in the GIA process diagrams are shown in Fig. 3.4.

Fig. 3.4 Colour and shape conventions used in the GIA process diagrams. Adapted from Eastman (2001)

3.4 ETHICAL APPROVAL

Ethical approval was sought, obtained and followed for this research according to Coventry University's research procedures. The forms are provided in Appendix B.

3.5 PILOT FEASIBILITY STUDY

Objective 1a was to identify suitable evaluation techniques to determine SUDS feasibility in an urban environment in order to inform the choice of methods at the local authority strategic scale. This was undertaken by means of a pilot study of a smaller area to apply a range of available techniques and evaluate their effectiveness. The pilot study also investigated the feasibility of retrofitting SUDS to Coventry University's inner-city campus, which was undertaken at the same time. The methods explained here concentrate on meeting objective 1a. More details of the pilot study, and its assessment of SUDS retrofit feasibility, are contained in Appendix C.

3.5.1 Scope

Coventry University's Estates Dept. requested an assessment of the feasibility of retrofitting sustainable drainage on the University's inner-city campus, driven initially by the flooding of a number of university buildings during heavy rainfall in summer 2006. Sustainable drainage was suggested as a possible means of mitigating future flooding. The pilot study took place in 2007-08. The study area covered 13.3 ha (33 acres), incorporating buildings used for teaching and administration (Fig. 3.5).

At the time of the pilot study, guidance on retrofitting SUDS to existing sites was regarded as incomplete and not generally applicable (Atkins Water 2004:1; SNIFFER 2006:12). Much of the existing resource base addressed questions to be answered once the decision to implement SUDS has been taken (SNIFFER 2006:17), but did not consider the preceding feasibility assessment stage. The purpose of a feasibility study is to ascertain the value of SUDS and the role they can play at a specific site (Claytor 1998:212; SNIFFER 2006:17-28). Previous SUDS retrofit feasibility studies in the UK have addressed water quality issues, *e.g.* Atkins Water (2004); Broad (2005); Hyder Consulting (2004); and Stovin *et al*. (2007:4-5), but little attention had been paid to retrofit for water quantity issues. Larger institutions such as Coventry University were considered to offer effective locations for SUDS implementation, due to their ability to reach and implement decisions relating to their own property (Atkins Water 2004:i; SNIFFER 2006:16; Stovin *et al*. 2007). A goal of the pilot was to highlight key issues at a type of site that was considered among the more suitable for retrofit SUDS.

Fig. 3.5 Pilot research site context of Coventry University campus in Coventry city centre. Campus land cover in colour. Sites evaluated for potential SUDS attenuation (see 3.5.5.2) are shown: 1) Armstrong Siddeley (AS) sub-catchment; 2) buildings for green roof implementation in yellow. Data sources: EA, Edina (2009)

3.5.2 Process

Seven steps were undertaken to assess the suitability of Coventry University's inner-city campus for retrofit SUDS, and to determine

- which techniques were appropriate to select feasible SUDS devices

- which SUDS evaluation techniques were suitable in urban environments.

An initial data collection exercise was carried out, followed by evaluation of five separate approaches, and finally a review of the applicability of the approaches (Table 3.3). The method employed for each step is explained in the remainder of section 3.5.

3.5.3 Data Collection

The pilot feasibility assessment comprised principally a desk study, although some fieldwork was necessary to gather baseline information. Table 3.4 identifies data necessary to determine SUDS feasibility at the pilot site, together with its intended and actual source and availability. Similar to the experience of previous studies (*e.g.* Schueler & Kitchell 2005:A2; SNIFFER 2006:50; Stovin *et al*. 2007) not all data was available in a suitable form, necessitating some alternative approaches. Field surveys were considered necessary to provide details of land cover, an insight into land use, a view of localised precipitation, infiltration and runoff patterns, and topography.

Table 3.3 Activities undertaken to assess feasibility of retrofit SUDS on Coventry University's inner city campus.

Activity	Main data used	Analysis to identify potential sites for SUDS	Method Section
Data collection	Characteristics of pilot study site		3.5.3, 3.5.4.1
Problem locations - Water Quality	Quality of local watercourses, locations of surface water sewers disposing runoff into watercourses	Assess where SUDS could be of benefit	3.5.4.2
Problem locations - Water Quantity	Recent sites of flooding, Lidar Digital Elevation Model	Develop GIS-based hydrological model to identify runoff flow paths and sites of water accumulation after rainfall; validate model using known flood locations	3.5.4.3
Flood risk	Fluvial flood risk maps	Evaluate and compare maps	3.5.4.4
Hydrological assessment	Sub-catchment impermeability characteristics. Design storm data. Hydrological equations	Determine runoff rate and volume, and resulting storage requirements for sub-catchments. Compare results of different methods	3.5.4.5
SUDS decision support tools	SUDS feasibility assessment techniques	Evaluate suitability of proposed SUDS techniques and compare results	3.5.5.1
Evaluate retrofit SUDS suitability for pilot site	Characteristics of SUDS devices. Results of evaluations in pilot study	Recommendations of suitable SUDS devices and retrofit implementation locations	3.5.5.2

3.5.4 Data Analysis

This section explains the methods used to analyse data.

3.5.4.1 Land cover

Land cover classifications were compared between:

- Ordnance Survey digital MasterMap data (OSMM, EDINA 2008)
- the Generalised Land Use Database (GLUD), itself adapted from Ordnance Survey digital MasterMap data (DCLG 2007c)
- an additional dataset, correcting MasterMap using input from a field survey, to provide a more accurate representation of actual land cover.

The third dataset was created because inspection of OSMM data revealed inaccuracies in land-cover of the campus, *e.g.* one missing building, four buildings with incorrect outlines, and missing surface differentiation between vegetated and paved areas.

Table 3.5 lists the specific categories from each dataset that were compared. The proportion of land-cover class and sub-class was determined for each dataset, by sub-catchment and for the full study area (Figs. 3.6 & 3.7).

Table 3.4 Information required for the feasibility study, its planned source, and information obtained

Data type	Planned Source	Available?	Actual Source	Comment
Topography	Ordnance Survey, field survey	Partially	Environment Agency (2008a), field survey	OSMM contained a limited number of spot heights for the campus area. The OS Landform Digital Terrain Model data provided 10m resolution, but the Environment Agency Light detection and ranging (Lidar) data (EA 2008a) was the best obtainable, and was used to determine pilot site topography. Image resolution was 1m horizontally, and approximately 15cm vertically (Gallay 2008:158). Some field survey work was undertaken to assess topographical drainage patterns.
Land-use, land-cover	Ordnance Survey, aerial imagery	Partially	Land-cover from Ordnance Survey (Edina 2008), DCLG, field survey	Aerial imagery was insufficiently clear
Precipitation	Met Office, field survey	Yes	Daily records from local Met Office weather station (Bablake Weather Station 2013)	
Sewer locations	Severn Trent, Coventry University, City Council, field survey	Partially	Public sewer locations - Severn Trent (2007); University sewer, manhole and drain locations - paper-based 'as designed' drawings were available for 10 of 24 buildings; Field Survey	Public sewers, paper-based records supplied by Severn Trent Water (2007); 'As designed' building drawings did not reflect subsequent changes. No information was available for inter-building spaces. Additional survey work and desk research was undertaken to locate manhole and downpipe locations

Data type	Planned Source	Available?	Actual Source	Comment
Drainage (hydraulic) characteristics	Severn Trent, Coventry University, City Council, field survey	No	No hydraulic drainage network or model relating to the university campus was available	Problems with non-availability and inaccuracy of hydraulic models have been encountered by other SUDS feasibility studies, e.g. SNIFFER (2006:50); Stovin *et al*. (2007:8, 18, 24)
Existing underground services	Coventry University	No	The University held limited drawings of existing underground services	Drawings had not been maintained and were not guaranteed to be current
Geology	British Geological Survey (BGS)	Yes	BGS (2008a), Old (1988:7), CCC (2008:11)	
Soil	Soil Survey of England and Wales (SSEW)	Partially	SSEW (1963,1983), NERC 1975), field survey	Infiltration tests were performed at four locations to obtain an overview of soil permeability across the campus
Watercourses and flood zones	Environment Agency		EA 2008c, CCC (2008b), Edina (2008), Hyde (2006), Historic Coventry (2008)	Data were manually transcribed into GIS.
Groundwater	Environment Agency, BGS	Partially	EA (2008b, 2010b), CCC (2008b:54)	Groundwater source protection zones were available from EA. No information about current groundwater levels was available
Examples of flood damage	Coventry University	Partially	University, only for one day in 2006. Records unavailable for earlier years	Updated information may have been available in an archive, but the university's filing system was not conducive to its retrieval without significant effort
Water quality	Environment Agency	Yes	EA (2007g)	

Data type	Planned Source	Available?	Actual Source	Comment
Planning constraints and covenants	Coventry University, City Council, national and regional planning guidelines	Yes	CCC (2007), Informal information provided by the University’s Estates Dept.	
Land Contamination	City Council	No		No publicly available records for the pilot site
Sub-catchment boundaries	Field Survey	Yes	Field Survey	Boundaries representing topographically related areas
University development plans	Coventry University	Yes	Coventry University	

Table 3.5 Land cover classes utilised in the three classification datasets, and their assignment to the categories used in this study

Dataset **Category**	**MasterMap**	**GLUD**	**Modified MasterMap**
Buildings	Buildings	Domestic buildings Non-domestic buildings	Roof
Paved areas	Roads Tracks And Paths	Roads Paths Other (largely hardstanding)	Paving
Vegetated areas	Land	Greenspace Domestic gardens	Vegetation
Surface water	Water	Water	Water

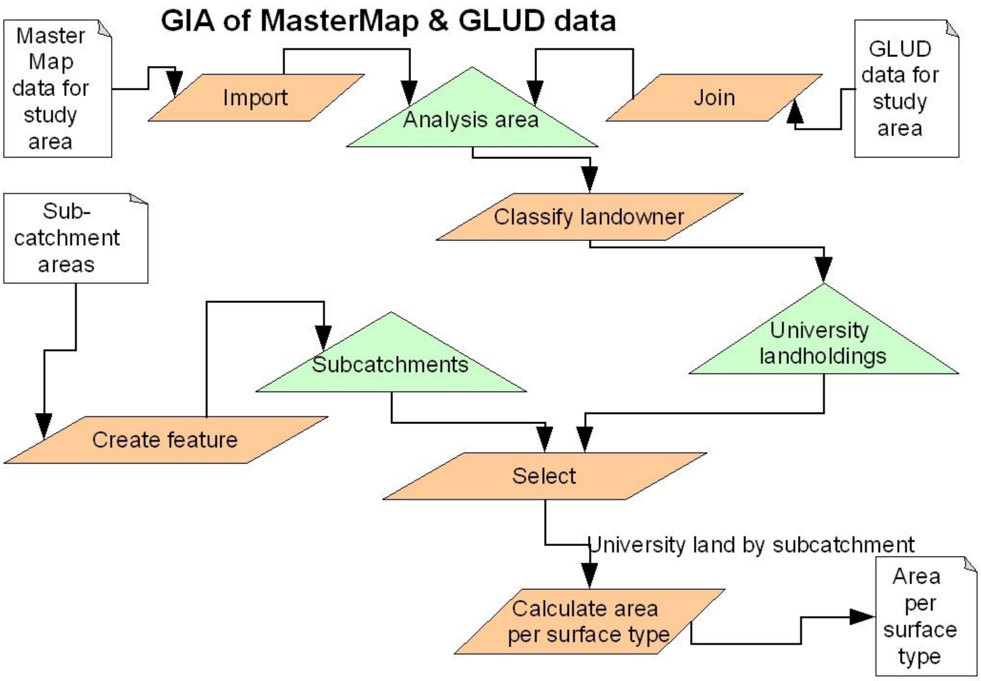


Fig. 3.6 Process in ArcGIS to determine land cover types using OSMM and GLUD data. University-owned land and sub-catchments manually identified based on field survey

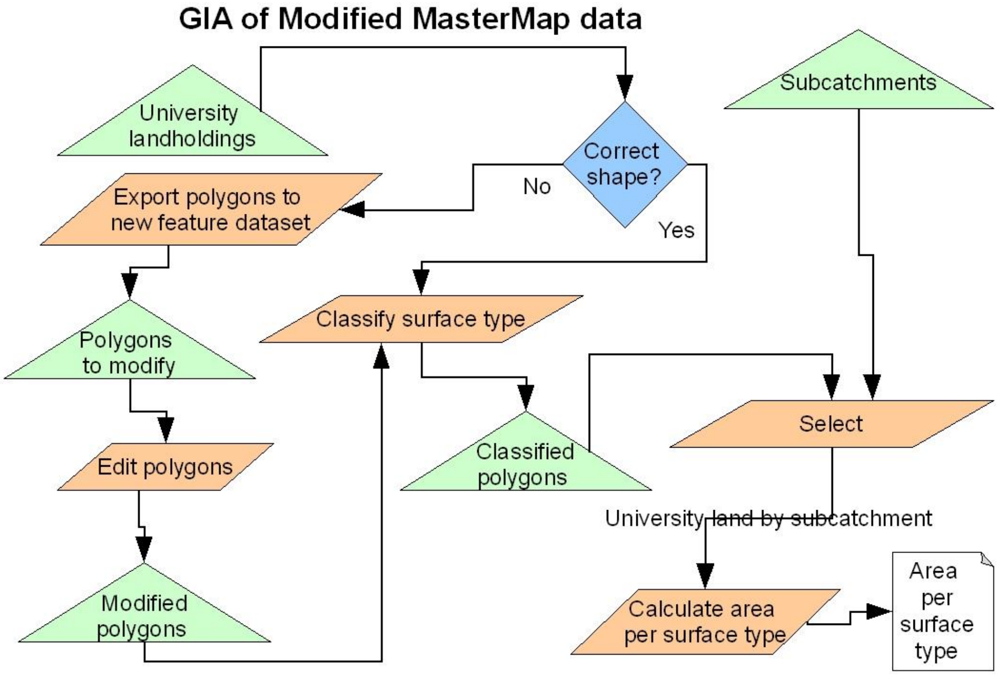


Fig. 3.7 Process in ArcGIS to modify OSMM data to reflect field survey, and to determine land cover types. Where land cover variation was identified between the MasterMap representation and the field survey, polygons were adjusted to reflect actual land cover. Both modified and unmodified polygons were assigned a land cover category.

The Modified MasterMap dataset was treated as a sufficiently accurate representation of the study area. The surface area of each surface type in the OSMM and GLUD datasets was compared to the Modified MasterMap dataset in order to determine their accuracy. Inaccuracies in representing land cover type in raw MasterMap and GLUD were quantified as a percentage of the associated modified MasterMap category using equation 3.1

$$Eld = (Ald - Alm) / Alm * 100 \qquad \text{(Eqn.3.1)}$$

where:

Eld = Classification error in land cover type between specified dataset and modified MasterMap (%)

Ald = Area of land cover type in comparison dataset (raw MasterMap or GLUD) (m^2)

Alm = Area of land cover type in modified MasterMap dataset (m^2).

Sub-catchment impermeability percentages, required for the hydrological calculations, were determined from the surface area of each land cover class within each sub-catchment.

3.5.4.2 Water Quality

Water quality of the R. Sherbourne running near the campus was determined as per Table 3.4. The location of surface water sewers on campus disposing to the river was reviewed to ascertain possible sites to improve runoff quality.

3.5.4.3 GIS hydrological modelling

GIS hydrological modelling was undertaken to identify runoff flow paths and sites of water accumulation after rainfall in order to identify beneficial sites for retrofitting SUDS. Airborne Lidar data (EA 2008a) offered higher-resolution topographical data compared to Ordnance Survey sources. The data collection missions were commissioned by the EA (2008a) and flown in March 2005, reducing the effect of tree cover obscuring other surfaces. The study area was contained within two 2x2 km tiles. The study area topography was taken directly from the digital terrain bare-earth model supplied with the Environment Agency Lidar dataset. No validation was undertaken to assess whether the algorithms used by the EA to remove building cover from the original Lidar data were correct. Other studies (e.g. Balmforth & Dibben 2006; FRMRC 2007; Telford & Wrekin Council 2008) have utilised Lidar data to represent surfaces in flooding models.

Fig. 3.8 outlines the process employed to analyse the Lidar data using standard ArcGIS hydrology functions. A Digital Elevation Model (DEM), containing building elevations and surface topography, was the input used to generate flow accumulation raster images, indicating locations of runoff accumulation. Flow was transferred between cells using the rolling ball technique. The ArcGIS hydrology tools were unable to generate results for the Lidar data at the resolution and spatial scale supplied, so the 1m horizontal resolution needed to be coarsened to 10 m in order to generate output (for details see Appendix C). Unexpected changes of measurement in the Lidar dataset, called sinks, may represent genuine ground depressions or instrument recording errors in the dataset supplied, so the extent, and depth of sinks was evaluated. Fig. 3.9 reveals a regular pattern of sinks deeper than 34 mm, suggesting that these were artefacts of the data collection, rather than genuine ground depressions. Flow accumulations both with and without sinks were produced to compare differences. The proximity of flow accumulation to locations flooded in 2006 was examined to judge the utility of the ArcGIS hydrology functions in an urban environment.

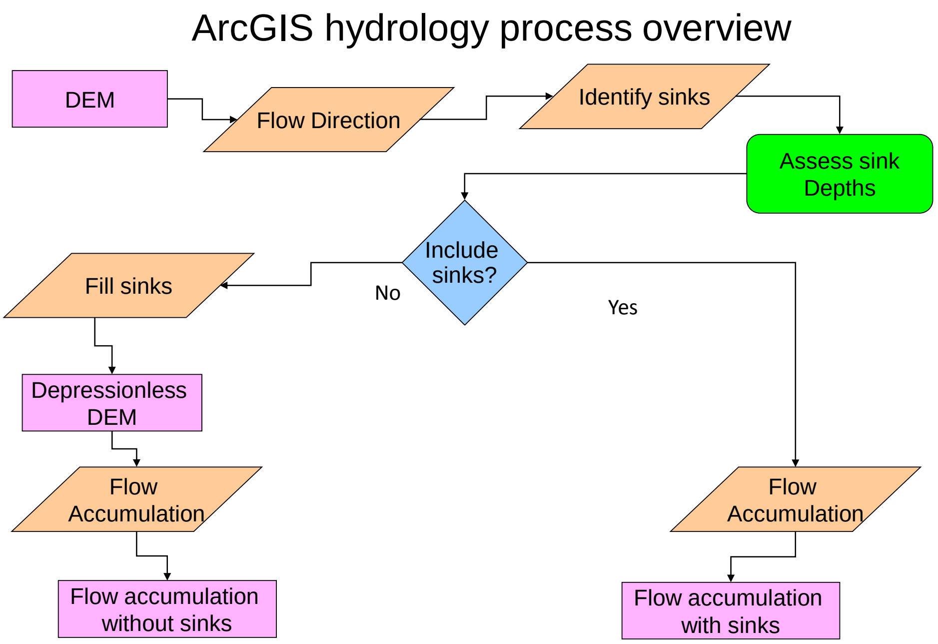
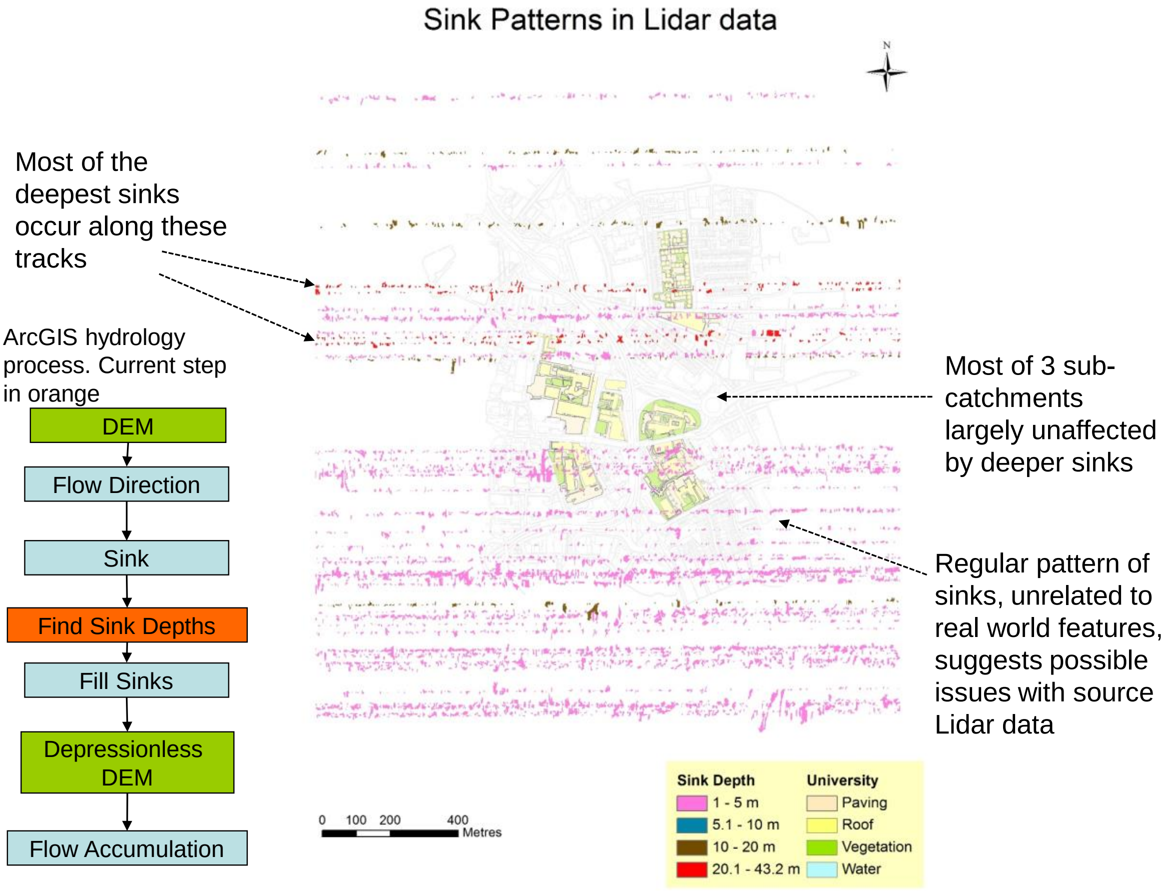


Fig. 3.8 ArcGIS hydrology process overview



Most of the deepest sinks occur along these tracks

Most of 3 sub-catchments largely unaffected by deeper sinks

Regular pattern of sinks, unrelated to real world features, suggests possible issues with source Lidar data

Fig. 3.9 Sink locations in central Coventry in the Lidar dataset

3.5.4.4 Flood Risk Evaluation

100-year and 1000-year river flood risk maps from the EA (2008c) and the Strategic Flood Risk Assessment (SFRA, CCC 2008b), were compared to University locations to determine areas of fluvial flood risk. The SFRA contained a revised river flood risk map based on more detailed hydraulic modelling than was available in the EA published maps**.**

3.5.4.5 Hydrology

Using site characteristics determined in the previous sections, precipitation, runoff and storage requirements were calculated for each sub-catchment. Hydrological equations were based on published sources of information specified in the sub-sections below. The overall process followed to evaluate the hydrology of the pilot area is illustrated in Fig. 3.10.

Fig. 3.10. Hydrological factors evaluated. White box = process. Yellow box = associated data. Based on procedures in Balmforth *et al*. (2006a:74); Defra & EA (2007:11); Woods Ballard *et al*. (2007:4.3)

3.5.4.5.1 Precipitation

Precipitation influences the volume of runoff from a land surface. Ideally, site-specific precipitation data should be used as input to runoff and storage calculations, but these were unavailable, so catchment hydrological characteristics based on UK historical records were substituted. Individual hydrological equations employed either annual rainfall totals or rainfall depths for specific storm return periods.

3.5.4.5.2 Annual rainfall

No precipitation records were available for the campus or for central Coventry, but daily actual data were acquired from Bablake Weather Station (2013), the nearest Met Office weather station to the research site, approximately 1.3 km northwest of the campus. Precipitation values for a range of periods from the full available record, 1870-2012, were compared with each other and with mean annual rainfall data estimated by HR Wallingford (2008) to determine a suitable annual precipitation value for runoff and storage equations.

3.5.4.5.3 Return periods

Central Coventry is potentially at risk from drainage, overland and river flooding. In order to protect against flood risks, developments must be designed to handle storm events of particular magnitudes. Recommendations for the use of return periods in evaluation of flood risk in England were (Defra & EA 2007:xiv; Woods Ballard *et al*. 2007:3.2-3.4):

- River flooding: 1 in 100 year flood zone, representing the distinction between medium and high risk of river flooding (DCLG 2010:23)
- Drainage flooding: 1 in 30 year event for the site, reflecting the criteria set by the Sewers for Adoption guidelines (Water UK/WRc Plc 2006:29; Woods Ballard *et al*. 2007:3.17)
- Overland flow: 1 in 100 year 1 hour storm (Woods Ballard *et al*. 2007:3.3).

In addition, a 1 in 1-year storm represents relatively frequent events that may cause morphological changes to a receiving watercourse, such as increased erosion (Woods Ballard *et al*. 2007:3.5). These rainfall return periods were used in the calculation of storage requirements.

3.5.4.5.4 Design Storms

Daily rainfall records may be suitable for estimating the total runoff generated by a storm event, but are insufficiently precise for predicting peak runoff volumes (Shaver *et al*. 2007:2.24). However, this more detailed information was unavailable for the study area. Design storm data is in common use for flood studies (Woods Ballard *et al*. 2007:4.10), so the evaluation relied on generic design storm data for the selected return periods. Generic data were determined from statistical evaluations of similar sites in order to determine appropriate rainfall depths, and were obtained for the study area from Dales & Reed (1989), Defra & EA (2007) and NERC (1975).

The Flood Studies Report (FSR, NERC 1975) determined a 2-day rainfall depth of 50 mm for a 5-year return period. Dales & Reed (1989:19) identified regional variations in rainfall patterns, and, using a 67-year period of record (1915-1981), estimated a mean 1-day annual maximum rainfall for the Warwickshire Avon catchment as 32.6 mm. Both methods provided growth curves to extrapolate rainfall depths for additional return periods, and FSR also supplied formulae to extrapolate alternative durations. The NERC rainfall figures were revised to reflect more recent rainfall depths in the Flood Estimation Handbook (FEH) (Defra & EA 2007). For the study area, the NERC 1941-1970 rainfall depths were estimated to be 90% of 1961-1990 rainfall. 24-hour rainfall depths were calculated using the Dales & Reed, NERC and revised NERC methods. In addition, 6-hour rainfall depths were calculated using the NERC and revised NERC methods in order to determine rainfall for the ‘critical flood duration’, which defines the length of time for a storm to generate the greatest flood rate or volume (Woods Ballard *et al*. 2007:4.2). Critical durations for the study area were determined using a table of critical durations and maps of rainfall ratios in Defra & EA (2007:16) – see Table 3.7.

A 6-hour, 100-year event was used as the basis for calculating long-term storage requirements, as recommended by Woods Ballard *et al*. (2007:3.7). For Coventry, the 100 year 6-hour rainfall depth was 63 mm (Defra & EA 2007:48).

Climate change may result in changes to the pattern of rainfall in future. Variations predicted as a result of climate change from PPS25 (DCLG 2010:16) are listed in Table 3.6. Given the potential lifetime for SUDS features on campus, the 2025 to 2055 increase of 10% in rainfall intensity was used.

Table 3.6 Recommended national precautionary sensitivity ranges for peak rainfall intensities and peak river flows due to climate change. Source: DCLG 2010:16

Parameter	**1990 to 2025**	**2025 to 2055**	**2055 to 2085**	**2085 to 2115**
Peak rainfall intensity	+5%	+10%	+20%	+30%
Peak river flow	+10%	+20%	+20%	+20%

3.5.4.5.5 Runoff

Procedures for determining runoff rates and volumes were obtained from Balmforth *et al*. (2006a:228-240), Defra & EA (2007), SNIFFER (2006:62) and Woods Ballard *et al*. (2007:3.1-4.36). Hydrological calculations are based on parameters driven largely by a site’s location in the UK. Hydrological parameters for each sub-catchment were determined according to guidelines in Defra & EA (2007:10-20) and Woods Ballard *et al*. (2007:4.3-4.24), based on the Flood Studies report procedure (Woods Ballard *et al*. 2007:4.10) (Table 3.7). These values were used in calculation of runoff and required storage volumes.

Recommendations for new developments are to maintain runoff rates and volumes at greenfield levels. Where a site is already developed, but further changes are proposed, then contemporary guidelines recommended that runoff should be restricted to current rates at least, and preferably reduced (DCLG 2009:130; Defra & EA 2007:xiii). Greenfield and developed runoff rates and volumes were calculated in order to determine the maximum volume that should be discharged from a site (Defra & EA 2007:4; Woods Ballard *et al*. 2007:4.7). Some methods differentiate summer and winter rainfall profiles. Summer profiles have higher intensities and are recommended for sizing conveyance systems, while winter profiles generate more runoff and so are recommended for sizing storage systems (Woods Ballard *et al*. 2007:4.10). Where the methods took these seasonal effects into account parameters, these were evaluated. For the pilot study, greenfield runoff rates were used as the ideal target figures to be achieved.

Table 3.7 Hydrological parameter values used in rainfall, runoff and storage requirement calculations. Parameter abbreviations used in equations (*cf*. Appendix J) are listed. Source: Defra & EA (2007)

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3.5.4.5.6 Runoff Rates

The runoff rates calculated were (Defra & EA 2007):

- Mean annual flood flow rate (Qbar), equivalent to a return period of approximately 2.3 years (Defra & EA 2007:xi)
- Greenfield runoff rate for 1-, 30-, and 100-year events.

Two methods were used to determine greenfield runoff volumes, both derived from Flood Studies Supplementary Report 16 (cited in Woods Ballard *et al*. 2007:4.7-4.9):

- Fixed percentage runoff
- Variable percentage runoff, for summer and winter rainfall profiles.

The methods used to determine developed runoff volumes (Woods Ballard *et al*. 2007) were:

- Fixed Wallingford Procedure, for summer and winter rainfall profiles
- Variable Wallingford Procedure.

The mean difference between greenfield and developed runoff volumes was calculated in order to assess required storage volumes.

Peak developed runoff rates were calculated for each sub-catchment using the Modified Rational Method (Butler & Davies 2004; Woods Ballard *et al*. 2007:4.13-4.14), utilising the 100-year rainfall figure (63 mm).

Discharge limits for each sub-catchment were taken from HR Wallingford (2008), who based calculations on Marshall & Bayliss (1994). Limits were determined where long-term storage was both feasible and impractical. Where provision of long-term storage is feasible, higher discharge rates from developed areas are allowed since the long-term storage facilities attenuate some of the additional runoff. Where long-term storage is not feasible, then lower discharge rates, equal to the Mean Annual Flood (QBar), are required in order to achieve an equivalent runoff rate reduction (HR Wallingford 2008). The reduction in runoff rate necessary to achieve greenfield conditions was calculated as the difference between the winter peak runoff rate and the discharge limit assuming no long-term storage.

The relevant equations for the above methods are presented in Appendix J.

3.5.4.5.7 Storage Requirements

Storage volumes are largely dependent on the volume of runoff generated by a storm event. Procedures for assessing appropriate attenuation and storage volumes were obtained from Balmforth *et al*. (2006a:228-240), Defra & EA (2007), SNIFFER (2006:62) and Woods Ballard *et al*. (2007:3.1-4.36).

Four types of storage are required to manage different effects of runoff (HR Wallingford 2008; Wood Ballard *et al*. 2007) (Table 3.8). Storage volumes were determined using equations in Defra & EA (2007), HR Wallingford (2008), SNIFFER (2006), and Woods Ballard *et al*. (2007). These are discussed in more detail below, and summarised in Table 3.9. Where values were calculated manually, the specific equations are provided in Appendix J. The storage volumes determined using the online SUDS assessment website (HR Wallingford

2008) employed, according to the documentation, the same equations for treatment, attenuation and long-term storage defined in Defra & EA (2007). A value for interception storage was also supplied by HR Wallingford, but no equation was defined.

Interception volumes were determined using 5mm (HR Wallingford 2008; Woods Ballard *et al*. 2007:3.11) and 7.5 mm as the mean of the minimum 5 mm and maximum 10 mm recommended by Woods Ballard *et al*. (2007:3.11). No interception storage equation was provided by Defra & EA. Treatment volumes (Vt) were calculated using 12 mm (SNIFFER 2006:78) and 15 mm (Woods Ballard *et al*. 2007:4.24) precipitation over the impermeable area. Defra & EA (2007:18) proposed 1Vt as a minimum requirement, and 4Vt was considered to offer an ideal treatment volume by SNIFFER (2006:78). In practice, even impermeable areas will retain and infiltrate some water, e.g. through cracks between paving and depressions on roofs. Guidelines in Defra & EA (2007:xvi) stated that impermeable areas should be treated as 100% impervious to generate a more conservative estimate during initial assessment, and this guideline was followed in all manual calculations for interception and treatment storage. In contrast, HR Wallingford used 80% runoff from impermeable areas in its Vt calculation.

Attenuation storage volumes were determined using the Defra & EA (2007) and HR Wallingford (2008) methodologies. HR Wallingford generated two values for attenuation storage, one assuming that long-term storage was also available, the second that conditions for long-term storage were unsuitable. Both were applicable to a 100 year event. The Defra & EA calculations produced values for 1-, 30- and 100-year return periods. For comparison with the HR Wallingford combined attenuation and longterm storage for 100-year return period, an equivalent volume was determined using Defra & EA data, although this option was not suggested in their documentation. In theory, the equations utilised by the HR Wallingford methodology were the same as those in Defra & EA. A climate change factor of +10% (Table 3.6) was applied to both methods.

Table 3.8. Objectives of the different types of runoff storage. Sources: HR Wallingford 2008; Wood Ballard *et al*. 2007:

Long-term storage volumes were determined using the Defra & EA (2007), HR Wallingford (2008) and Woods Ballard *et al*. (2007) methodologies. In all methods, the long-term storage volume was calculated as a function of the developed runoff volume less the greenfield runoff volume for a 100-year, 6-hour event, equivalent to 63 mm of rainfall. HR Wallingford based their equation on the soil percentage runoff factor, and assumed 100% runoff from impermeable surfaces and 0% from pervious areas. Woods Ballard *et al*. (2007:4.22-4.23) proposed that a factor of 80% could be applied to runoff from impermeable areas to take account of a level of retention and infiltration. The same authors (2007:4.22) suggested, as a simple alternative, that 60 m^3 ha^{-1} could be used for soil type 4 areas for an initial assessment, based on 80% runoff and 70% impermeability.

Where soil conditions are unsuited to infiltration, long-term storage is unlikely to be feasible (HR Wallingford 2008), so attenuation volumes must be increased accordingly. Combined attenuation and long-term storage volumes were determined from the Defra & EA (2007), and HR Wallingford (2008) methodologies.

The total storage volume required was determined by accumulating the calculated interception, treatment, attenuation and long-term storage values for the HR Wallingford, Defra & EA and Woods Ballard *et al.* methodologies. Where multiple storage types are calculated, some storage types may duplicate volumes already provided. Rules for removal of duplication were supplied by HR Wallingford and Woods Ballard *et al*., but not by Defra & EA. The rules are summarised in Table 3.10. These rules were used in the calculation of total storage volumes using the three methods listed. Where no explicit rules for removal of duplicated volumes was given, no values were treated as duplicates of other results. The 1-year and 30-year volumes were only calculated by the Defra & EA procedure. These included attenuation and treatment volumes, as no interception storage equation was provided, and long-term storage was only determined for the 100-year return period.

To determine the total storage requirement for each sub-catchment, equation 3.2 was applied:

$$R_j = I + (T-I) + A_j \qquad \text{(Eqn.3.2)}$$

where

R_j = Total storage requirement for period (m^3)

j = period (1, 30, 100 years)

I = Interception volume (m^3)

T = Treatment volume (m^3)

A = Attenuation volume (m^3).

Table 3.9 Summary of storage volumes calculated in this analysis. A dash indicates that no value or equation was used from the methodology in question. Sources as per table headings

Storage volume type	**Defra & EA (2007)**	**HR Wallingford (2008)**	**SNIFFER (2006)**	**Woods Ballard *et al.* (2007:3.17)**
Interception	-	5 mm of rainfall (value supplied by online tool)	-	5 mm, 7.5 mm
Treatment	Treatment volume	15 mm of rainfall, 80% runoff	12 mm (1Vt), 48 mm (4Vt)	15 mm
Attenuation	1-year, 30-year, 100-year	long-term storage available, long-term storage unavailable. (Both for a 100-year event)	-	-
Long-term	100-year event	100-year event, 100% runoff	-	100-year event, 80% runoff, Soil type 4 (60 m^3 ha^{-1})
Combined Attenuation & Long-term	Combined Attenuation & Long-term, 100-year event	Combined Attenuation & Long-term, 100-year event	-	-
Total	1-year, 30-year, 100-year	100-year event	-	100-year event

Table 3.10 Rules for removal of duplicated storage volumes when multiple storage types are implemented. Sources as per table headings

Storage Type	HR Wallingford (2008)	Defra & EA (2007)	Woods Ballard *et al*. (2007:3.17)
Interception	No reduction	No rule provided	No reduction
Treatment	Subtract interception storage	No rule specified	No reduction
Attenuation	No reduction	No rule specified	Subtract interception storage and long-term storage
Long-term	Subtract interception storage	No rule specified	No reduction

3.5.4.6 SUDS feasibility assessment tools

Six SUDS feasibility evaluation methodologies, available at the time of the pilot study, were assessed to ascertain their suitability for recommending SUDS techniques for Coventry University's inner-city campus:

- Swan/Stovin hierarchical framework (SNIFFER 2006)
- Scholz decision tools – two separate techniques (Scholz 2006)
- SEPA Diffuse Pollution Initiative (D'Arcy & Wild 2002, 2003)
- HR Wallingford Stormwater Storage Assessment (HR Wallingford 2008)
- Ellis *et al*. (2004b) assessment of catchment area and soil type.

The methods employed by each are described in chapter two.

3.5.5 Evaluation

3.5.5.1 Evaluation of techniques used

The analyses described in section 3.5.4 were used to generate an assessment of the SUDS techniques that were potentially feasible in specific locations. Given the characteristics of the pilot site, the suitability of individual SUDS devices (from Woods Ballard *et al*. 2007) across the city centre campus was reviewed. Detailed knowledge acquired during field work was useful for this exercise.

The performance of the SUDS feasibility tools was scored in relation to their proposals for retrofit and implementation in new developments. A simple weighted scoring mechanism was applied of recommendations against possible SUDS options of each device in each sub-catchment (suitable = one, limited implementation options = 0.25). For retrofit, a number of sub-catchment characteristics were assessed against the derived score to judge the most effective at predicting the likely number of retrofit SUDS options. New developments were judged to have no determining institutional or environmental limitations.

The SUDS devices evaluated were those proposed by the six decision methodologies assessed in the pilot study. A three-stage process was followed to determine a score foe each methodology:

1. Suitable devices were identified as those which could be implemented in the inner city pilot site based on characteristics defined in Woods Ballard *et al.* (2007); unsuitable devices were those whose use was limited by land availability or soil infiltration characteristics
2. The devices proposed by each decision methodology were compared with the device suitability derived in stage one. SUDS devices that were proposed and suitable were allocated a 'suitable' score. SUDS devices that were proposed but were not suitable were allocated an 'unsuitable' score
3. A total percentage was calculated using Eqn. 3.3. Unsuitable proposals were deducted from the total score since they were likely to be ineffective, but would have cost time, effort, space and money to implement.

(Eqn. 3.3)

$$\frac{\left(\sum(Ss)-\sum(Su)\right)}{\sum(Sp)}$$

where:

Ss = suitable devices

Su = unsuitable devices

Sp = all possible devices.

3.5.5.2 Determination of feasible SUDS solutions

Not all SUDS techniques are suitable for all sites (Woods Ballard *et al.* 2007:5.1), so detailed investigation of the specific environment proposed for retrofit is necessary to determine feasibility. While detailed technical assessments are required when designing sustainable drainage systems, more straightforward, readily understandable techniques are necessary to evaluate initial feasibility and to support high-level decision-making.

3.5.5.2.1 Examples of SUDS feasibility assessment

The extent to which flooding problems could be addressed by SUDS installations and calculated storage volumes could be achieved in these locations was assessed by investigating two examples in more detail.

Example one reviewed the technical potential for retrofitting SUDS in the least impermeable Armstrong Siddeley (AS) sub-catchment in the pilot study area (indicated on Fig. 3.5). Each surface type was evaluated in the light of the possible SUDS devices from the pilot site analysis. Storage volumes calculated for the proposed options were compared to the storage requirement (section 3.5.4.5.7).

Example two was an evaluation of retrofitting extensive green roofs in all sub-catchments. The evaluated buildings are shown on Fig. 3.5. Rainfall storage capability, based on implementation using 50% of the present roof cover, assuming 30% attenuation and a minimal 15cm substrate depth was calculated using Eqn. 3.4.

$$Vol_s = ((Ar/2) * Ds) * AS \qquad \text{(Eqn.3.4)}$$

where

Vol_s = Rainwater storage (m^3)

Ar = Roof area (m^2)

Ds = Substrate Depth (m) = 0.15 m

AS = attenuation storage (%) = 30%.

The results were compared with the total storage volume required for the sub-catchment (section 3.5.4.5.7), adjusted by the roof area of the sub-catchment.

3.6 DESIGN OF THE STRATEGIC STUDY

This section covers methods for the design of the city-wide study. It is closely linked to sections 4.4-4.5, which show the results of applying the methods, and explain the reasons why particular choices were made. Sections 3.6-3.10 describe the methods used to collect and analyse data for the strategic scale study. Section 3.6 explains the overall design approach, and section 3.7 the data collection methods. The process used to generate SUDS feasibility maps is covered in section 3.8, while section 3.9 defines the map validation procedures, and section 3.10 explains additional applications of the SUDS feasibility maps.

3.6.1 Process

The process to create the SUDS guidance maps for Coventry is outlined in Table 3.11, and identifies the sections in which the methods for individual steps are described. Although presented as a sequential process, in practice a number of iterations occurred to refine the data collected and develop the rules and methods.

Table 3.11 Steps in the map creation process

Step	**Activity**	**Methodology section**
1. Define SUDS groupings	Functional groupings of SUDS devices were compiled from reference information	3.6.3
2. Identify influencing factors	Factors driving SUDS feasibility in an urbanised local government area were evaluated to determine the types of SUDS suitable in particular location	3.6.4 Table 3.13
3. Allocate influencing factors to SUDS groupings	Factors identified in step two were allocated to the SUDS groupings defined in step one	3.6.4 Table 3.13
4. Define rules for influencing factors	A set of decision criteria (rules) were created for each of the attributes listed in Table 3.13. For example, different rock types were assessed in relation to their capacity for infiltration or detention of runoff	3.6.4 Table 3.14
5. Determine spatial distribution of influencing factors	A data source was identified for each factor and the dataset was obtained. The spatial distribution of each attribute was then determined and the data were coordinated in a GIS system	3.7
6. Agree rules for influencing factors	The rules were agreed with local government, environmental regulators and the responsible water utility, all of whom had knowledge of the local authority area in question.	3.9.1
7. Apply rules to each SUDS grouping	Each item of geographical data was coded so that the rules could be applied spatially. The spatial relationships between attributes from step three were analysed using GIS, in order to determine appropriate locations for the different types of SUDS for new development and retrofit sites. The full set of layers for each factor was then combined to determine suitable sites based on all factors	3.8
8. Present outputs in map form	The resulting geographical outputs were represented in map form	3.8

3.6.2 Construction of an evaluation framework

The framework to evaluate suitable SUDS devices at the local authority strategic scale (objective 1b) was created out of a review of the literature about factors influencing SUDS feasibility, prioritising those factors relevant to strategic development planning. The details are in section 5.4.

3.6.3 Identification of suitable SUDS devices

The outcomes of the pilot study and the literature review were used to determine suitable SUDS devices for an urban local authority area (objective 1c). Functional groupings of SUDS devices (Table 3.12) were adapted from Woods Ballard *et al*. (2007).

Table 3.12 Overview of SUDS device groupings (Sources: Charlesworth *et al*. 2013:537-538; Woods Ballard *et al*. 2007)

SUDS device grouping	**Function**	**Examples SUDS Devices**
Infiltration	Runoff storage and infiltration into the ground to recharge groundwater	Soakaway Infiltration basin Infiltration trench
Detention and retention	Basins with temporary or permanent storage of runoff. Removal of pollutants to improve water quality	Detention basin Retention basin Pond Wetland
Filtration	Slow down flow and treat runoff to remove pollutants	Sand filter Filter strip Filter trench Bioretention device
Conveyance	Channels that convey runoff. Can also store and infiltrate water into the ground	Swale Rill
Source Control	Slow down, store and treat runoff at locations close to where rain has fallen. Water can be released gradually or utilised for non-potable purposes.	Green Roof Rainwater harvesting Permeable paving Sub-surface storage Trees Rain garden Disconnected downpipe

3.6.4 Influencing factors

Influencing factors were identified from sources described in chapter two and from the pilot study, to some extent based on data availability, and are listed in column one of Table 3.13. The relationship between each factor and each SUDS grouping is identified in Table 3.13. Table 3.14 shows the characteristics of each influencing factor in relation to their suitability for SUDS implementation. Individual influencing factors were characterised either as fixed, i.e. varying over relatively long timescales, or variable, representing those that may alter over a shorter term. Fixed physical (environmental) factors included geology, soil, topography and the presence of water above and below ground. Fixed anthropogenic (human-induced) factors were related to definitions of groundwater protection near extraction boreholes, plus known and potential sites of groundwater contamination risk. Variable factors such as existing land cover and planning regulations may impact SUDS implementation over shorter timescales.

3.7 DATA COLLECTION

3.7.1 Overview of characteristics included in the city-wide study

Data were obtained from a number of sources, prioritising those sources and level of detail that were readily available to local government at zero or low cost. In some instances, more detailed information could have been obtained with significantly greater effort and / or higher cost, e.g. by undertaking field surveys or purchasing information from other organisations, but these higher cost options were not appropriate for the target organisations. The types of data used in the city-wide study are listed in Table 3.15. Methods used to collect and analyse the data are described in this section where additional explanation is necessary. No information was obtained about underground services such as gas and electricity supply.

Table 3.13 Cross-tabulation of data sources and their use in SUDS themes. Groupings of SUDS devices (column headings) are outlined in Table 3.12

	Infiltration	**Detention**	**Filtration**	**Conveyance**	**Source Control**	**Potential implementation sites**	**Beneficial implementation sites**
Physical							
Fixed factors							
Bedrock geology	x	x					
Superficial geology	x	x					
Water bodies	x	x	x	x	x	x	x
Fluvial flood zones	x		x			x	
Soil drainage type	x	x					
Topography	x	x					
Water Table	x	x					
Anthropogenic							
Fixed factors							
Waste and landfill sites	x						
Sites of current and former industrial usage	x						
Historical flood locations							x
Surface and ground water quality assessments	x	x					x
Variable factors							
Land cover	x	x	x	x	x	x	x
Planning constraints				x	x	x	
Land ownership						x	
Sewer locations							x

Table 3.14 Characteristics of influencing factors listing the specific attributes applicable to Coventry

	Infiltration			**Detention**			**Filtration**	**Conveyance**	**Source Control**	**Potential implementation locations**			**Beneficial implementation locations**
Factor	**Infiltration not possible**	**Infiltration possible**	**Infiltration needs investigation**	**Less suitable**	**More suitable**	**Engineered more suitable**	**Restrictions**	**Restrictions**	**Less suitable**	**Implementation restricted**	**Increased complexity of implementation**	**Higher probability of implementation**	
Physical													
Fixed factors													
Bedrock geology	Mudstone, siltstone and sandstone	Siltstone and sandstone; sandstone and conglomerate			Mudstone, siltstone and sandstone except below glacial sand and gravel								
Superficial geology	Till deposits overlying mudstone and sandstone; till deposits overlying sandstone and conglomerate	Glacial sand and gravel; till deposits overlying siltstone and sandstone		Glacial sand and gravel		Glacial sand and gravel							
Water bodies	Water bodies			Water bodies			Water bodies	Water bodies	Water bodies	Water bodies			Near watercourses
Fluvial flood zones	Fluvial flood zone 2 & 3	Fluvial flood zone 1					Fluvial flood zone 3			Fluvial flood zone 3	Fluvial flood zone 2	Fluvial flood zone 1	

Factor	**Infiltration**			**Detention**			**Filtration**	**Conveyance**	**Source Control**	**Potential implementation locations**			**Beneficial implementation locations**
	Infiltration not possible	**Infiltration possible**	**Infiltration needs investigation**	**Less suitable**	**More suitable**	**Engineered more suitable**	**Restrictions**	**Restrictions**	**Less suitable**	**Implementation restricted**	**Increased complexity of implementation**	**Higher probability of implementation**	
Soil drainage type	Impeded drainage; high groundwater	Slowly permeable, Free draining		Free draining; Slowly permeable, high groundwater	Impeded drainage	Free draining; Slowly permeable							
Topography	Steeper terrain (>= 5% slope)	Level or gently sloping terrain (< 5% slope)		Steeper terrain (>= 5% slope)	Level or gently sloping terrain (< 5% slope)	Steeper terrain (>= 5% slope)							
Water Table	High water table (<=4m)	Intermediate and deep water table (>4m) (replaces >10m), Fairly high water table (4-10m)		Very high water table (<0m)	Water table not close to surface (>4m)	High water table (<4m)							
Anthropogenic													
Fixed factors													
Waste and landfill sites	Current and historical waste and landfill sites surrounded by a 250m buffer												

	Infiltration			**Detention**			**Filtration**	**Conveyance**	**Source Control**	**Potential implementation locations**			**Beneficial implementation locations**
Factor	**Infiltration not possible**	**Infiltration possible**	**Infiltration needs investigation**	**Less suitable**	**More suitable**	**Engineered more suitable**	**Restrictions**	**Restrictions**	**Less suitable**	**Implementation restricted**	**Increased complexity of implementation**	**Higher probability of implementation**	
Sites of current and former industrial usage		Where contamination from industrial usage is unlikely	Where contamination from industrial usage may be present										
Groundwater SPZs 1 and 2	Where contamination is present; runoff from major roads	Where contamination from industrial usage and from main road runoff is unlikely											
Surface and ground water quality assessments	At sites where trichloroethene (TCE) concentrations exceed drinking water standards (10 $\mu g\ l^{-1}$) s			At sites where trichloroethene (TCE) concentrations exceed drinking water standards (10 $\mu g\ l^{-1}$)		At sites where trichloroethene (TCE) concentrations exceed drinking water standards (10 $\mu g\ l^{-1}$)							Watercourses not achieving ‘good’ status’; Surface and groundwater nitrate vulnerable zones; Groundwater reservoirs requiring recharge
Historical flood locations													Flood locations 1980-2009
Variable factors													

Factor	Infiltration			Detention			Filtration	Conveyance	Source Control	Potential implementation locations			Beneficial implementation locations
	Infiltration not possible	Infiltration possible	Infiltration needs investigation	Less suitable	More suitable	Engineered more suitable	Restrictions	Restrictions	Less suitable	Implementation restricted	Increased complexity of implementation	Higher probability of implementation	
Land cover	Existing road and rail carriageways, existing buildings (with 5m buffer)	Greenspace; gardens, unclassified, non-road paving		Buildings, road carriageways	Greenspace, gardens, paving except road carriageways	Greenspace, gardens, paving except road carriageways	Buildings, rail and roads	Road carriageways, railway tracks, buildings, gardens	Road carriageways, railway tracks, greenspace further than 20m away from existing buildings, built structures	main road carriageways (motorway, A and B roads)	Gardens, Existing large roofs with sufficient surrounding greenspace or paving	Greenspace, unclassified land	Near roads (highway drains), near impermeable front gardens
Planning constraints								Listed buildings, scheduled monuments	Listed buildings, scheduled monuments	Listed buildings, scheduled monuments	SSSIs, Nature conservation and wildlife sites, conservation areas	Parks, Within regeneration and development zones; employment and housing development areas	
Land ownership												Local authority, housing associations	
Sewer locations													Where surface sewers feed into combined sewers

Table 3.15 Data used for the city-wide study. The Appendix number containing more detail about the collected data is listed in the final column.

Data type	Data	Relevance / Reason for inclusion	Source	Appendix
Land cover	Ordnance Survey Mastermap (OSMM) polygons as at September 2009 (1:1,250)	Land cover	Edina (2009)	D.1
Boundaries	Area covered by local planning authority	Limits of study area	Edina (2009)	D.1
Topography	1m vector contour lines	Direction of flow and Slope	CCC	D.2
Aerial photography	True colour aerial images of study area, 10 cm resolution (status 2007)	Assess accuracy of OSMM	Geoperspectives 2009	D.1
House types	Key Statistics Table 16, Household Spaces and Accommodation Types (2001 census)	Assess accuracy of OSMM	ESRC Census Programme 2010	D.1
Geology	Bedrock & superficial geology (1:625,000, status 2008)	Infiltration characteristics	BGS 2003 & 2008b	D.3
Groundwater	Groundwater aquifers and source protection zones, boreholes	Groundwater resources and areas of possible contamination	BGS 2009, BGS 2013a, EA 2010b, EA 2013a	D.4
Depth to water table	Depth to water table	Suitability for infiltration	Modelled - see section 3.7.3	D.4
Precipitation	Monthly precipitation 1870-2012	Local rainfall patterns	Bablake Weather Station 2013	D.5
Watercourses	Rivers and streams	Water quality and areas influencing SUDS implementation	See Table 3.17	D.6

Data type	Data	Relevance / Reason for inclusion	Source	Appendix
Fluvial flood zones	Zones for main rivers and modelled sections of two ordinary watercourses: Hall Brook & Springfield Brook	Areas at risk of fluvial flooding, areas influencing SUDS implementation	EA	D.6
Surface water flood risk	Draft risk maps (not for reproduction)	Comparison with known flood events	EA	D.6
Soil	Soilscapes dataset (1:250,000)	Soil impermeability	NSRI 2010; Defra & Environment Agency 2007; Soil Environment Services 2008	D.7
Contaminated sites	Locations of known contamination	Influences on SUDS implementation	Besien & Pearson 2007:5, 33-34	D.9
Historical flood events	Flood locations 1910-2009	Locations at risk of flooding that may benefit from sustainable drainage	See Table 3.18	D.8
Fluvial water quality	WFD assessments of water quality for river stretches	Locations where sustainable drainage might improve water quality	EA 2010b	D.9
Nitrate vulnerable zones (NVZ)	Surface and groundwater NVZs	Locations at risk of pollution	EA 2013b	D.9
Sites of current and former industrial usage	Generalised representation of industrial sites (status 2009)	Areas of potential land contamination that may be unsuitable for infiltration	CCC (see section 3.7.6)	D.10

Data type	Data	Relevance / Reason for inclusion	Source	Appendix
Sewer and drain locations and characteristics	Sewerage network, Surface water sewers disposing into combined sewers	Areas that may benefit from SUDS; the extent to which properties dispose of water to sewers	Jacobs Gibb 2008, Severn Trent Water	D.11
Major roads and adopted highways	Roads maintained by Highways Agency and local authority	Identification of roads suitable for permeable paving	CCC	D.1
Planning constraints and covenants	SSSIs (status 2010), local nature reserves (status 2006), conservation areas, strategic parks, archaeological sites, scheduled monuments, listed buildings, waste and landfill sites	Possible restrictions on using sustainable drainage	CCC, English Heritage 2007, Natural England 2010	D.12
Land ownership	Land owned by local authority (status 2012) and largest housing association (status 2010)	Large landowners may have sites where sustainable drainage can be more easily implemented	CCC	D.13
Development Zones	Prioritisation of land use changes in regeneration zones	Increased likelihood of SUDS implementation	CCC 2012a, 2012b	D.14

3.7.2 Land cover

Six simplified land cover categories, similar to those of Elgy (2001), were derived for this study from the OSMM classification, and defined as either permeable or impermeable (Table 3.16). The full translation table is in Appendix F. It was not possible to separate impermeable from permeable road/paving surfaces, and all occurrences of road, rail and paving were assumed to be impermeable. Unclassified areas represented, for the most part, former industrial sites that had been cleared and were awaiting or undergoing redevelopment.

Table 3.16. Permeability status of simplified land cover classes

Class	**Permeability**
Buildings	Impermeable
Road&Rail	Impermeable
Unclassified	Impermeable
Gardens	Permeable
Greenspace	Permeable
Water	Permeable

3.7.2.1 Gardens

Gardens could contain more than one surface type, and presented the main challenge to identification of land cover, as a division into paved and vegetated areas, or into front and rear gardens, was not identifiable for the most part from the OSMM classification. A further analysis of garden land cover was undertaken from a visual assessment of aerial photographs (GeoPerspectives 2009), for a random sample of 59 house + garden plots in Coventry – see Appendix F, section F1.4, for details of the selection and classification process. Within the land cover defined as ‘garden’ from the OSMM dataset, new polygons were digitised to represent the different categories of land cover using the classes: buildings, paving and vegetation. None of the analysed gardens contained water as an identifiable land cover. The house type (detached, semi-detached and terraced) associated with each garden was also identified in order to assess differences in garden size per house type.

Garden sizes were smallest for terraced houses (mean 99.5 m^2, median 86.1 m^2), and largest for detached houses (mean 513.8 m^2, median 325.4 m^2). Detached gardens contained the largest permeable area (mean 325.1 m^2), followed by semi-detached (mean 224.7 m^2), with terraced gardens (mean 68.5 m^2) having the smallest permeable area (Fig. 3.11). In percentage terms however, a different pattern emerged. Detached house owners had covered a greater proportion of gardens with impermeable surfaces (36.7%), terraced gardens were less impermeable (31.2%), and semi-detached gardens the least impermeable (26.9%). Appendix D, section D.1.2, gives more details of the statistical analysis of garden land cover from the image dataset.

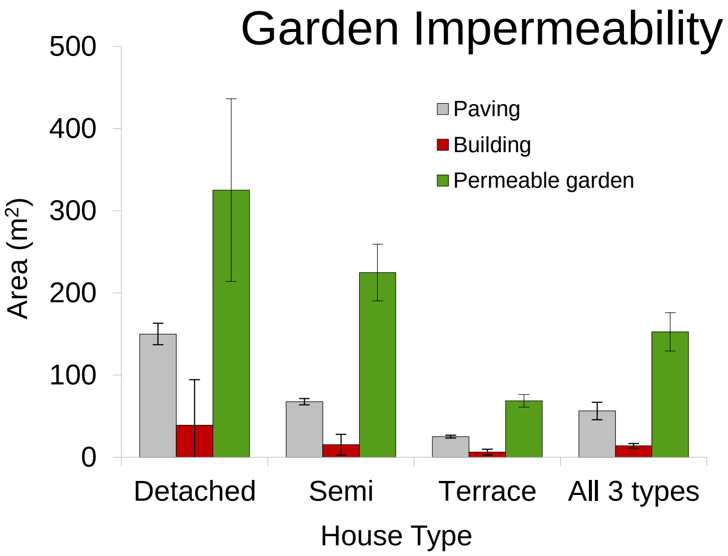


Fig. 3.11 Garden impermeability, showing land cover within the different house types (n=59). Error bars = standard error.

If the OSMM land cover percentages (Fig. 3.3) were adjusted by the garden land cover percentages to reflect the cover in gardens, then Coventry's land cover would differ in some respects from that resulting from Ordnance Survey (Fig. 3.12). Road and rail increased to cover 25.3% of the city, and buildings increased to 13.6%. Gardens declined to 15.7% of land cover, although this figure now represented solely the vegetated element of gardens. Greenspace remained the largest single land cover category, but paved areas (road and rail) replaced gardens as the second largest land cover in areal terms.

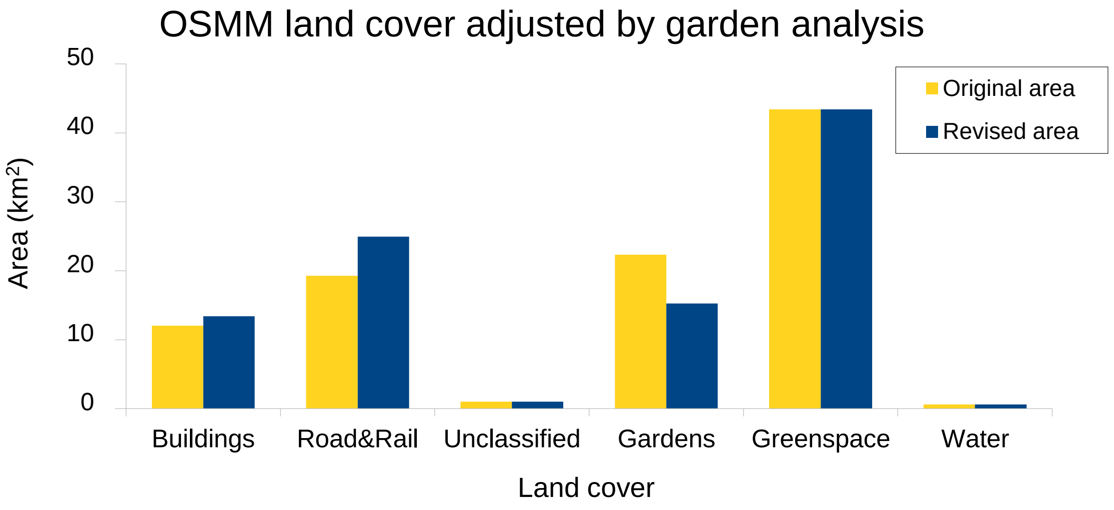


Fig. 3.12 Coventry's land cover after application of garden analysis to the classified OSMM dataset.

Separate polygons in OSMM were commonly used to represent front and rear gardens of the same property. A relationship between garden polygons and land ownership was calculated according to proportions of house types in Coventry determined from the 2001 census (ESRC Census Programme 2010). Roughly 1.85 garden polygons were equivalent to the garden land cover associated with each building.

The area of potentially impermeable front gardens in Coventry was selected according to the following characteristics:

- Minimum size: 12 m^2 as the typical area suitable for car parking (Hill *et al*. 2005:37)
- Maximum size: 57m^2, calculated as the mean of Coventry's mean front garden area from the sample garden analysis, 58.9 m^2, and London's mean front garden size, 56 m^2 (Smith *et al.* 2011:10). These smaller front gardens have less space in which to attenuate runoff by other means when a permeable surface is not used.
- within 5 m of a road.

3.7.2.2 Large Roofs

Large roofs were OSMM buildings with an area over 200 m^2 (Swan 2002:162). Large roofs were assumed to be flat rather than pitched.

3.7.3 Depth to Water Table

A sample of 125 BGS borehole records (BGS 2013a) were mapped, ranging in date from 1881 to 2005, but no realistic depth to groundwater map could be generated from these records. A time series of data, fortnightly measurements from 1974 to 1984, were available from only a single site, with a range of 2.64 m during this period. Available data on depth to groundwater were therefore treated as unreliable, a situation experienced by other researchers, e.g. Ball *et al*. (2004:19); Lelliott *et al*. (2006:299); and Rutter *et al*. (2006:19). Under these circumstances, an assumption was made that river levels equate broadly to the water table surface (Ball *et al*. 2004:19).

Depth to water table was determined in ArcGIS using the process depicted in Fig. 3.13. Groundwater height was assumed to be coincident with watercourse height (Ball *et al*. 2004:19), as rivers in Coventry are largely groundwater fed (EA 2006b:37). In summary, spot heights for multiple points along all watercourses within and surrounding the city were used to interpolate a water table height value for all locations, based on a 60 m x 60 m grid, using algorithms based on Hutchinson (1989). The difference between the land surface height from a digital terrain model (DTM) determined from 1 m contour lines, and the water table height, produced a depth to water table raster, which was converted to vector format with integer values for depths, and clipped to the city boundary. More details of the process are in Appendix F3.

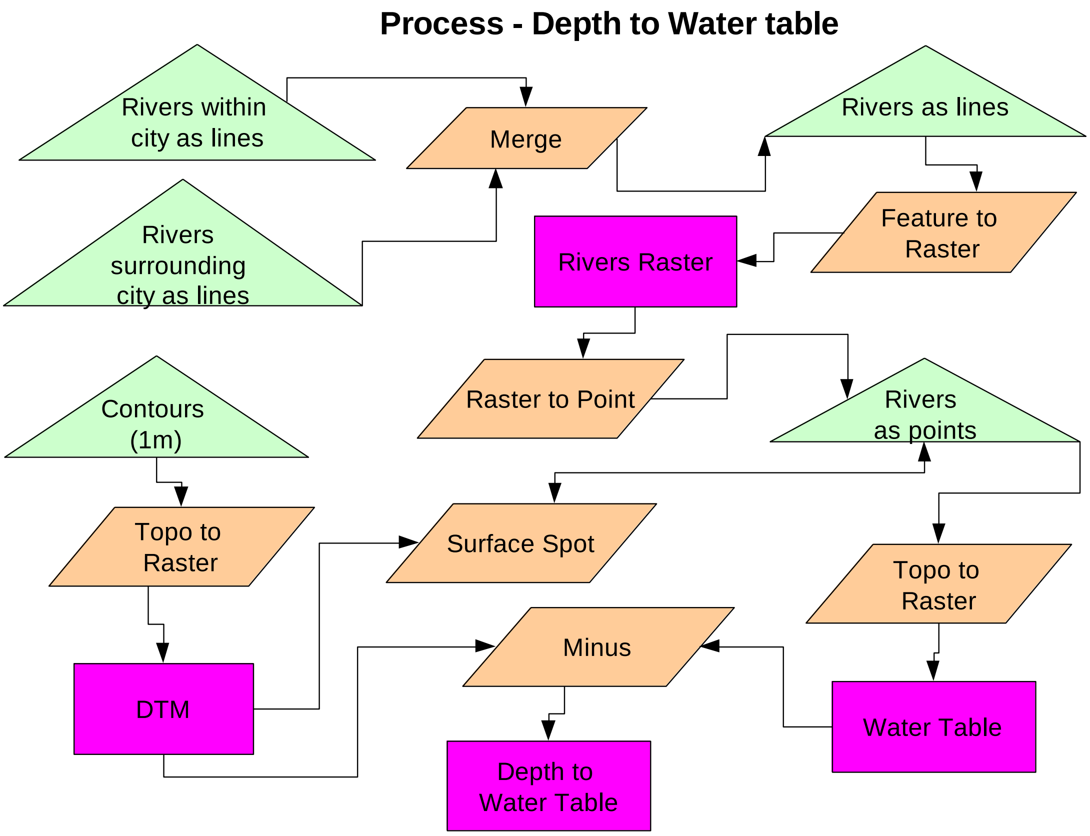


Fig. 3.13. Process in ArcGIS to determine depth to water table.

3.7.4 Water bodies

No single source of water body information was found. A composite water body dataset was created manually in ArcGIS using information compiled from several sources (Table 3.17). Duplicate features were removed.

Table 3.17 Sources of water body information

Type	Data source	Comment
Main river lines	EA	
Main river culverts	EA	River defences categorised as 'culverted channel'
Minor rivers	CCC 2008b	From Level 1 SFRA
Culverted ordinary watercourses	CCC	The precise location of these features could not be verified from OSMM or field survey.
OSMM linear surface water features not corresponding to previously determined watercourses	OSMM (Edina 2009)	
Probable culverts	Manually created	Where notional lines could be surmised to join open water features
Additional watercourses	CCC 2008b	SFRA minor rivers not in OSMM. These may in some instances run in culvert or underground
Canal	OSMM (Edina 2009)	
Marsh	OSMM (Edina 2009)	
Lakes and larger ponds	OSMM (Edina 2009)	‘Water’ features with (Area / Length) < 7 (because non-linear water bodies had a lower ratio of area to length)

3.7.5 Historical flood events

The pattern of historical flood events may indicate locations that would benefit from the attenuation properties of some SUDS devices. Details of flood events in the city over a 100-year period were collected from sources identified in Table 3.18. Floods were considered to occur when excess water caused significant disruption to everyday events. Thus, for example, ingress of water into buildings constituted property flooding, and significant standing water that prevented passage of traffic equated to road flooding. Approval to utilise more precise information on the location of historical sewer flooding and sewer flood risk (the DG5 register) was not obtained from the water management company, Severn Trent Water.

Table 3.18. Sources of historical flood event information used in this study. Publicly available information is labelled as 'public' status. Information not in the public domain is labelled 'restricted'

Source	**Status**	**Contents**	**Reference**
Council Flood Study (2002-03)	restricted	Councillors' records of flood events reported to them	CCC internal records
Council Local Climate Impact Profile	restricted	Press survey covering 1999-2008	CCC internal records
Coventry Strategic Flood Risk Assessment	public	Canal breach 1978; higher level postcodes affected by sewer flooding	CCC (2008b)
Coventry University records (2006)	restricted	University buildings affected by flooding in 2006	Coventry University internal records
Undergraduate Research project	public	Flood events 1900-2000	Swaine (2002)
Coventry Telegraph	public	Flood events 1950-2009	Local Press archives held by the History Centre at the Herbert Museum
Council flood records	restricted	Properties affected by flooding from the 1950s to 1989	CCC internal records
Council flood correspondence	restricted	Properties affected by flooding in the 1990s	CCC internal records
Coventry Highway flood records	restricted	Roads affected by recent flooding	CCC internal records
EA historic flood records 1997	restricted	Fluvial flood locations 1900-1993	CCC internal records
EA historic flood records 2010	restricted	Fluvial flood locations 1998-1999	EA records
Council Multi-Agency Flood Plan (2009)	restricted	Surface water flood locations in 2000-2008	CCC internal records
Water resource Growth Point Study	public	Locations at risk of sewer flooding based on projected changes to the sewer network to handle expanded housing development of the city to 2026	Jacobs Gibb Ltd (2008)

For each occurrence of flooding in the city, the following data, where available, were recorded:

- Date of occurrence
- Location
- Current postcode of location
- Cause, classified into river, sewer, canal, overland and groundwater
- Impact, classified into property, garden, road, and greenspace
- Number of properties and gardens impacted
- Source of data
- Additional comments relating to accuracy of information.

Events in approximately the same location, to within 100 to 200 m of each other on the same date, were amalgamated into a single 'location event'. Location events occurring on the same date were mapped only once to avoid duplication. For the purposes of this study, the term 'rivers' encompassed main rivers, ordinary watercourses and drainage ditches, 'sewers' included public surface and foul water sewers, private drains, and highway drains. The use of these terms in this study does not imply ownership of assets or responsibility for the relevant causes.

Flood location events were analysed over the full 100-year period. Significant sewer enhancement and capacity extension works were carried out in the 1960s through to the early 1980s to solve existing sewer flooding problems in the city. Therefore, events were also analysed over the last three full decades, 1980-2009.

Spatial analysis of impacts and causes was carried out in ArcGIS using density estimation as the preferred GIS technique for evaluating the spatial relationship of discrete points (Longley *et al*. 2005:337-338). The relative likelihood of flooding at a specific location was determined using the kernel density function, with input parameters: points within 300 m radius of each other were related, flood locations represented by 35 m^2 cells, and the 'population' weighting of each point equal to 1 since each point represented a single location event. Given the potential uncertainties surrounding exact locations in some cases, and the concern not to identify specific properties, cells smaller than 35 m^2 corresponded too precisely to individual locations. Cells larger than 35 m^2 and a search radius over 300 m gave the impression that larger areas of the city were affected than was actually the case.

In order to assess possible changes in the causes of flooding, the number of flood events within 100 m of flood zone 2 for main rivers, and 100 m of ordinary watercourses, was compared for the periods 1910-1979 and 1980-2009. Spearman's rank and Pearson’s product moment correlations were used to investigate the relationship between flood locations and the initial release of EA maps of susceptibility to surface water flooding (EA 2009c). Analysis of temporal changes in flood frequency, and the relationship between monthly precipitation and flood events, was undertaken using Pearson correlation.

The cause of flooding for some location events was not always certain. Where more than one possible or probable cause was determined, the weighting was split equally among causes in the analysis. Location events frequently had multiple impacts. In order to allocate them to a single category, the hierarchy: property --> garden --> road --> greenspace was used.

3.7.6 Sites of current and former industrial usage

Promoting SUDS infiltration solutions on contaminated land risks mobilising and transmitting pollutants to groundwater stores. Work undertaken by the city council's Environmental Protection Dept. over a 4-year period prior to this study had mapped sites of current and previous industrial usage to assist in responding to enquiries about sites that might require remediation of land contamination. This GIS-based dataset was made available to the research study, but because of its commercially sensitive nature, the city council did not wish the detailed dataset to be made public. It was agreed that a generalised version of the map could indicate the principal areas of current and former industrial usage, avoiding precise delimitation of individual sites – the process is explained in Appendix F2. The contents of this generalised map were agreed with the Environmental Protection Dept. (Appendix B).

3.7.7 Evaluation of Uncertainty

Uncertainties and sources associated with the datasets used in this study were identified during the data collection and initial analysis process. These are described in section 6.2. The accuracy of the OSMM land cover dataset was assessed using a confusion matrix (Elgy 2001:292; Longley *et al*. 2005:138-139). The observations of actual land cover were taken from the pilot field survey of Coventry University’s inner-city campus. The land cover class of all polygons undertaken during the pilot were compared with the land cover class determined from the set of rules applied to OSMM (Appendix F Table F.13). The two statistics derived from the confusion matrix were the percentage correctly classified, and the kappa index, which takes into account polygons that might have been correctly classified by chance. The kappa index was determined using Eqn 3.5.

$$k=\frac{\sum_{i=1}^{n} p_{ij}-((\sum_{i=1}^{n} c_{it}c_{jt})/c_g)}{c_g-((\sum_{i=1}^{n} c_{it}c_{jt})/c_g)} \qquad \text{(Eqn 3.5)}$$

where

k = kappa index (percentage)

p = correctly classified cell

c = cell position in table

i = row number

j = column number

n = number of classes

t = total

g = grand total.

3.8 GENERATION OF SUDS FEASIBILITY MAPS

This section explains the rules and processes used to generate maps showing feasible locations for suitable SUDS devices based on characteristics of the local authority area (objective 2a). Section 3.8.1 summarises the approach, with details for each of the five SUDS groupings in sections 3.8.2-3.8.6.

3.8.1 Rule definition Overview

For each dataset, the component attributes were identified and spatially located in the GIS. The example in Fig. 3.14 illustrates the components of datasets.

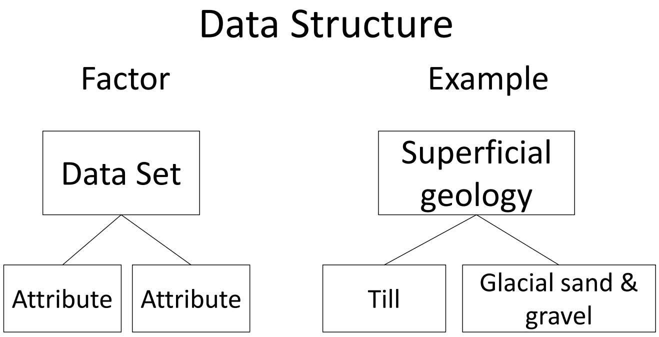


Fig. 3.14 Overview of data structure naming

Each sub-section is structured to firstly list the data sets and attributes employed for each SUDS type in a table or series of tables. The process diagrams show how these were processed to create the SUDS location maps. The tables define a set of 'if ... then ...' conditions, for example, bedrock geology from Table 3.19:

```
If bedrock geology = 'Mudstone, siltstone and sandstone'
    then define area as 'impermeable'
else
if bedrock geology = 'Siltstone and sandstone' or 'sandstone and conglomerate'
    then define area as 'permeable'.
```

The sub-process for geological characteristics in relation to detention SUDS, is illustrated in Fig. 3.15. Rules indicating permeability and impermeability of underlying rock deposits were applied independently to the geology dataset, to derive areas with greater and lesser potential for detention. Areas that are less suitable cannot also be more suitable in the same physical space, so overlaps between the two datasets were removed. The resulting area indicates the locations that are more suitable for detention SUDS based on geological criteria. The same process was performed for the other applicable factors listed in Table 3.14. The full set of layers was then combined to determine suitable detention and retention sites based on all factors.

The diagrams in sections 3.8.2-3.8.6.define the precise process employed to create each map. The diagrams inputs are generally to left and top, outputs generally in bottom right.

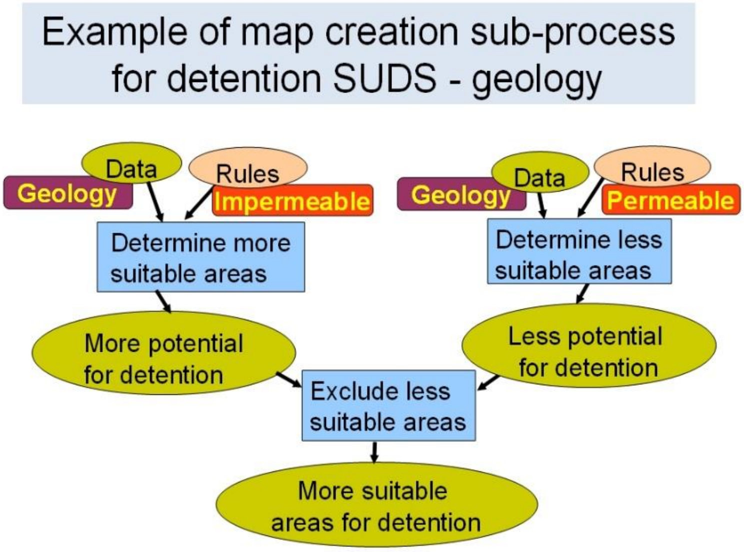


Fig. 3.15 Example of the map creation sub-process in the GIS system using geological data for the detention SUDS map. More and less suitable areas were determined independently, and their geographical overlaps were then removed.

3.8.2 Locations suitable for infiltration SUDS

Locations suitable for infiltration SUDS were determined from fixed physical influences (Table 3.19) and from fixed and variable anthropogenic influences (Table 3.20). Fig. 3.16 summarises the GIS process to determine areas suitable for infiltration from Tables 3.22 and 3.23. Fluvial flood zones were considered unsuitable for infiltration, as they were already locations for accumulation of flood waters.

The Highways Agency (2006:11.14) reviewed infiltration solutions for use with major roads in relation to groundwater source protection zones (SPZs) and aquifers. On the basis that road runoff is potentially contaminated, they concluded that infiltration of runoff in SPZs 1 and 2 was inappropriate due to the risk of polluting groundwater at the borehole protected by the SPZ, advising that runoff should be directed to surface water, and consequently areas near SPZ 1 and 2 were considered unsuitable for infiltration (Table 3.20). This approach will effectively transfer the pollution to other surface locations, but protect groundwater at the source of pollution. In contrast, CCC's Highway drainage strategy (2008c:11.7) was to ensure that polluted runoff is not directed to watercourses.

Table 3.19 Classification of physical factors influencing infiltration. Attributes in columns to the left take precedence over attributes in columns further right. Figure numbers indicate where the GIS process is described

Data Type	Impermeable	Permeable
Fixed factors	**Fig. 3.17**	**Fig. 3.18**
Bedrock geology	Mudstone, siltstone and sandstone	Siltstone and sandstone; sandstone and conglomerate
Superficial geology	Till deposits overlying mudstone and sandstone; till deposits overlying sandstone and conglomerate	Glacial sand and gravel; till deposits overlying siltstone and sandstone
Water bodies	Water bodies	
Fluvial flood zones	Fluvial flood zone 2 & 3	Fluvial flood zone 1
Soil drainage type	Impeded drainage; high groundwater	Slowly permeable, Free draining
Topography	Steeper terrain (>= 5% slope)	Level or gently sloping terrain (< 5% slope)
Water Table	High water table (<=4 m)	Intermediate and deep water table (>4 m)
Variable factors		
None		

Table 3.20 Classification of anthropogenic factors influencing infiltration. Attributes in columns to the left take precedence over attributes in columns further right. Figure numbers indicate where the GIS process is described

Data Type	Infiltration not possible	Infiltration possible	Infiltration requires investigation
Fixed factors	**Fig. 3.19**	**Fig. 3.21**	**Fig. 3.19**
Sites of current and former industrial usage		Where contamination from industrial usage is unlikely	Where contamination from industrial usage may be present
Waste and landfill sites	Current and historical waste and landfill sites surrounded by a 250 m buffer		
Groundwater SPZs 1 and 2	Where contamination is present; runoff from major roads	Where contamination from main road runoff is unlikely	Where contamination from main road runoff is unlikely
Known groundwater contamination sites	At sites where trichloroethene (TCE) concentrations exceed drinking water standards (10 µg l^{-1}), surrounded by a 250 m buffer		
Variable factors	**Fig. 3.20**	**Fig. 3.22**	**Fig. 3.20**
Land cover	Existing road and rail carriageways, existing buildings (plus 5 m buffer)	Greenspace; gardens, unclassified, non-road paving	

3.8.2.1 GIS process – physical factors

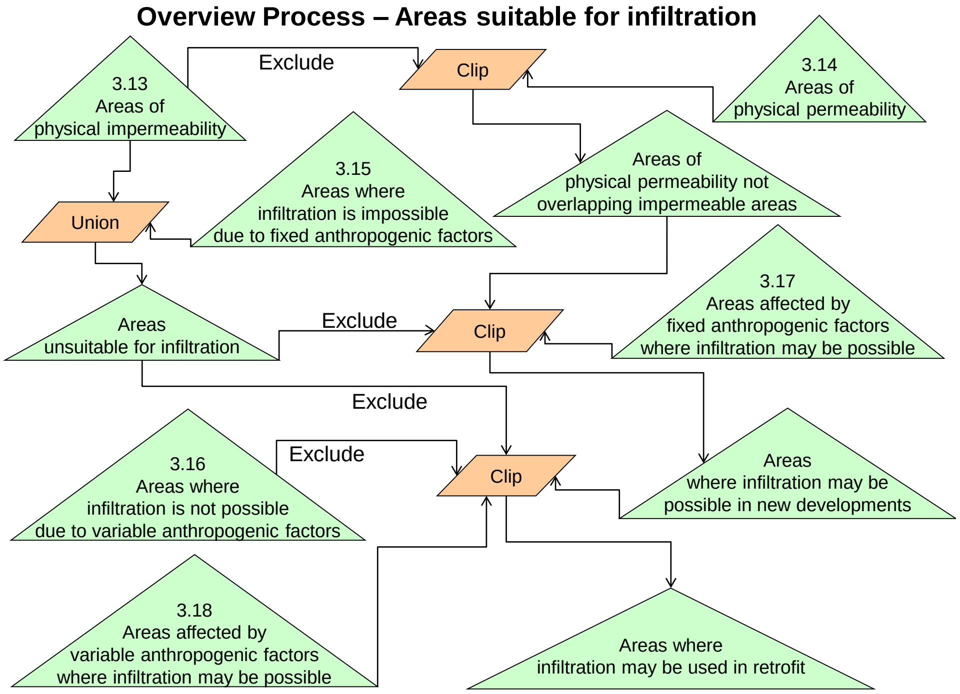


Fig. 3.16. Process in ArcGIS to create areas suitable for infiltration. The numbers refer to related figures explaining how subordinate outputs were generated.

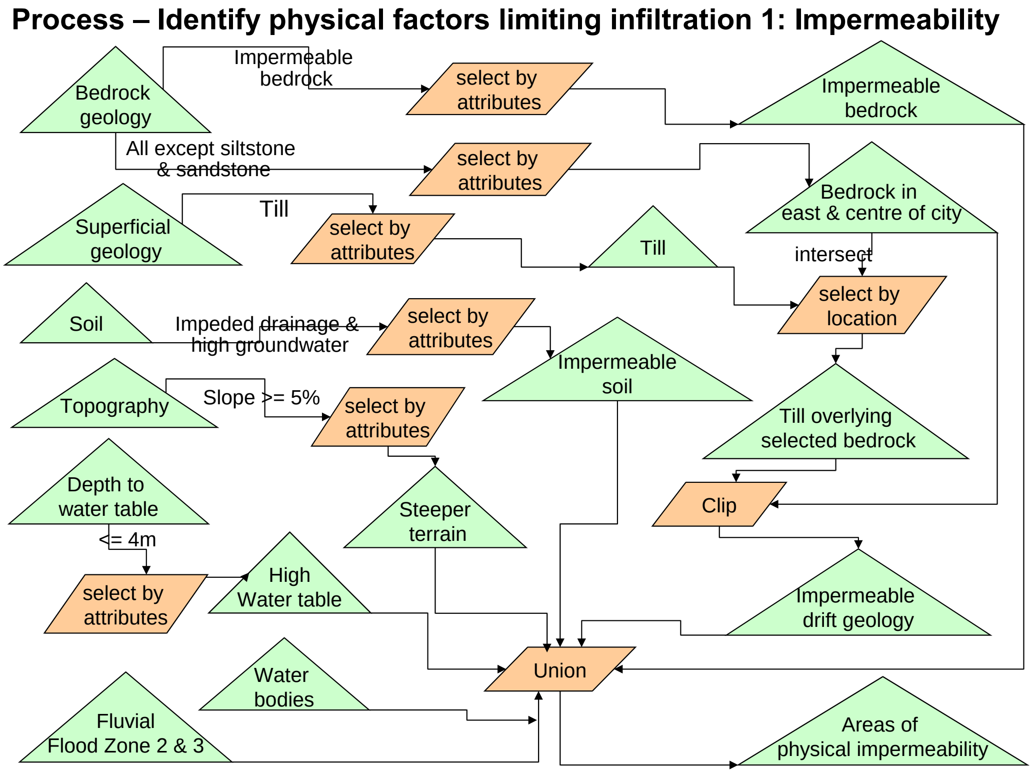


Fig. 3.17. Process in ArcGIS to determine physical factors influencing impermeability

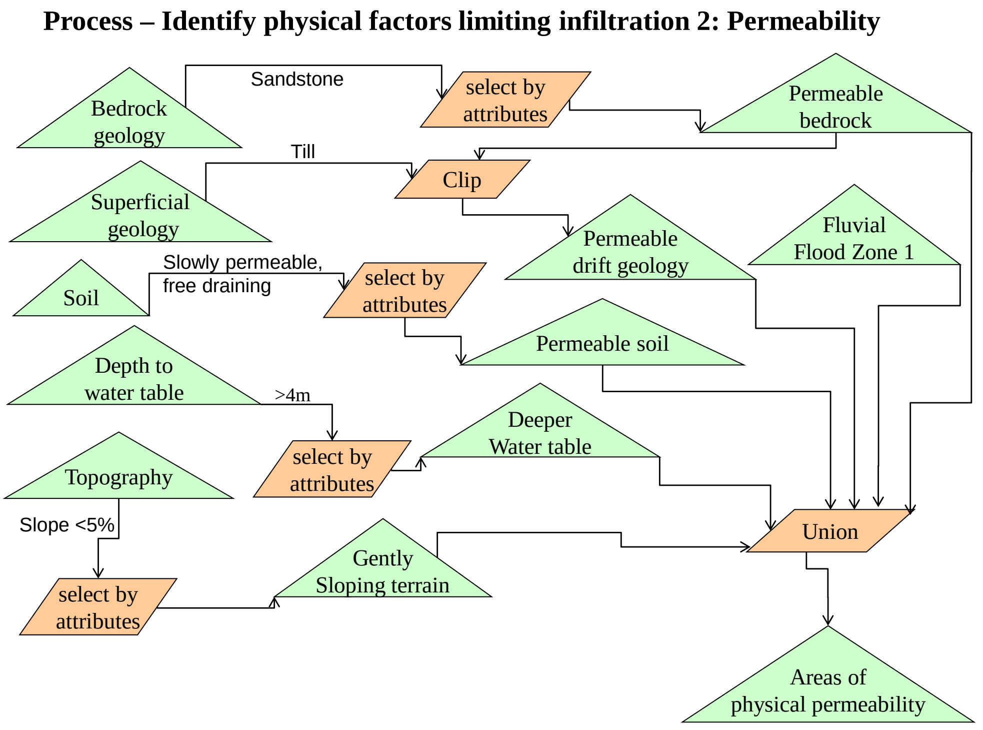


Fig. 3.18. Process in ArcGIS to determine physical factors influencing permeability

3.8.2.2 GIS process – anthropogenic factors

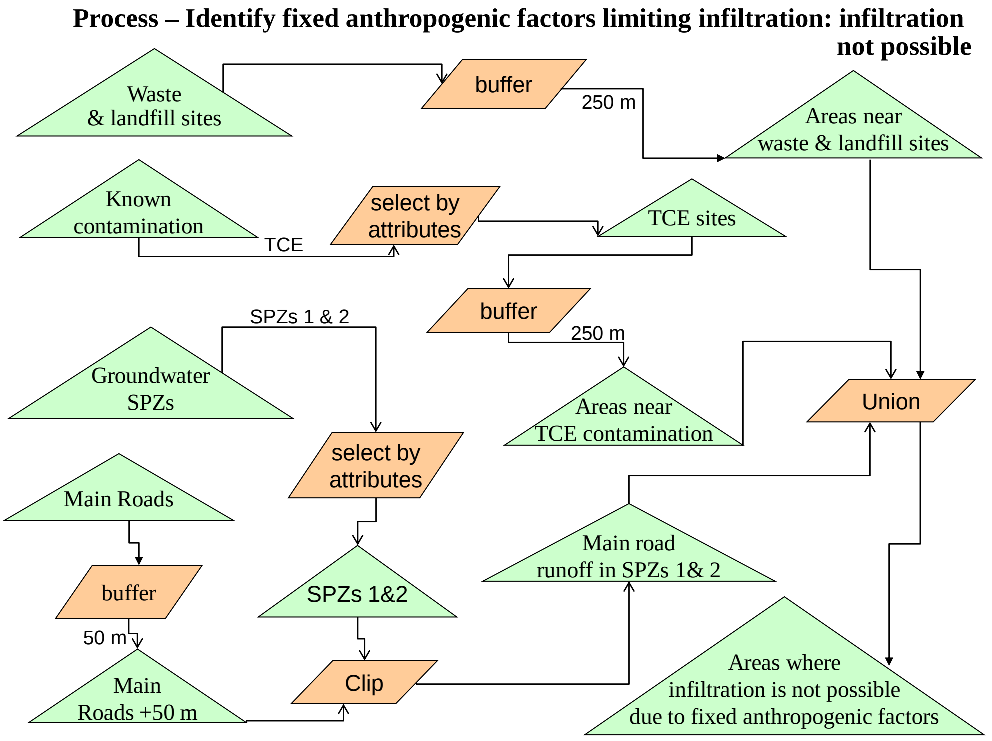


Fig. 3.19. Process in ArcGIS to determine fixed anthropogenic factors rendering infiltration impossible. SPZ = source protection zone. TCE = trichloroethene

Process – Identify variable anthropogenic factors limiting infiltration: infiltration not possible

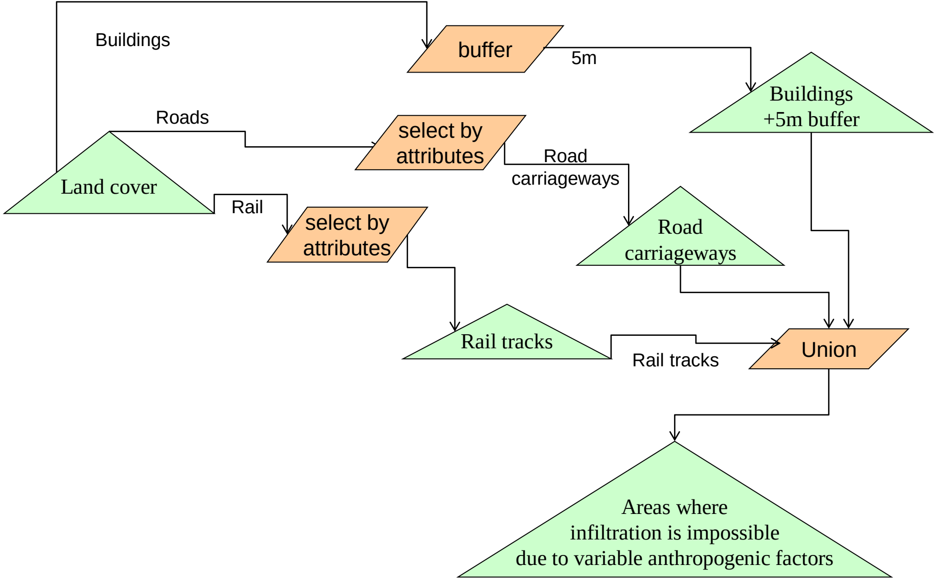


Fig. 3.20. Process in ArcGIS to determine variable anthropogenic factors rendering infiltration impossible. A 5m buffer around buildings reflects building regulations (ODPM 2002)

Process – Identify fixed anthropogenic factors influencing infiltration: infiltration possible

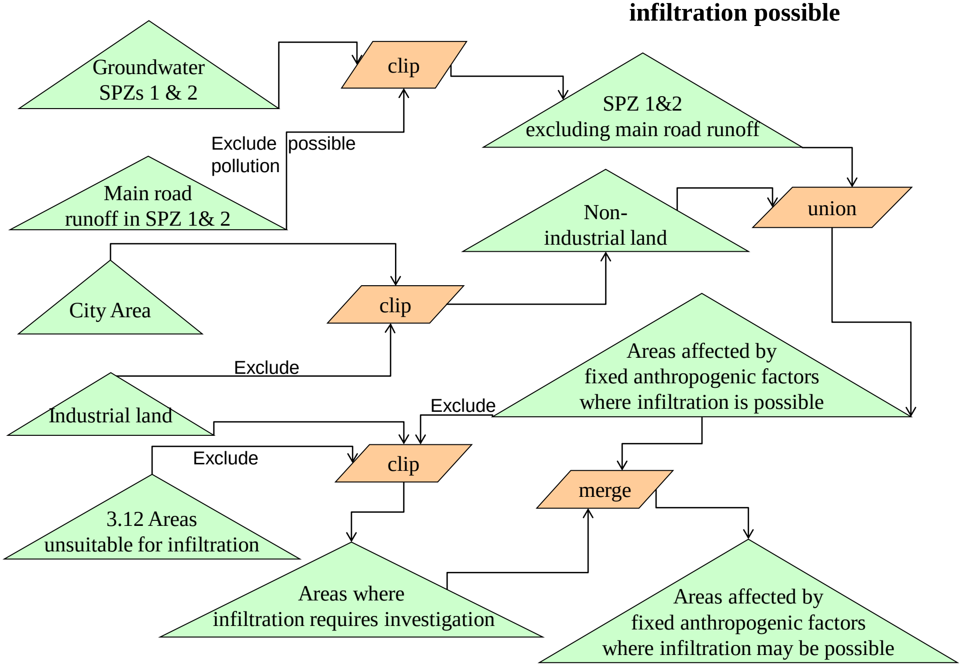


Fig. 3.21 Process in ArcGIS to determine fixed anthropogenic factors rendering infiltration possible

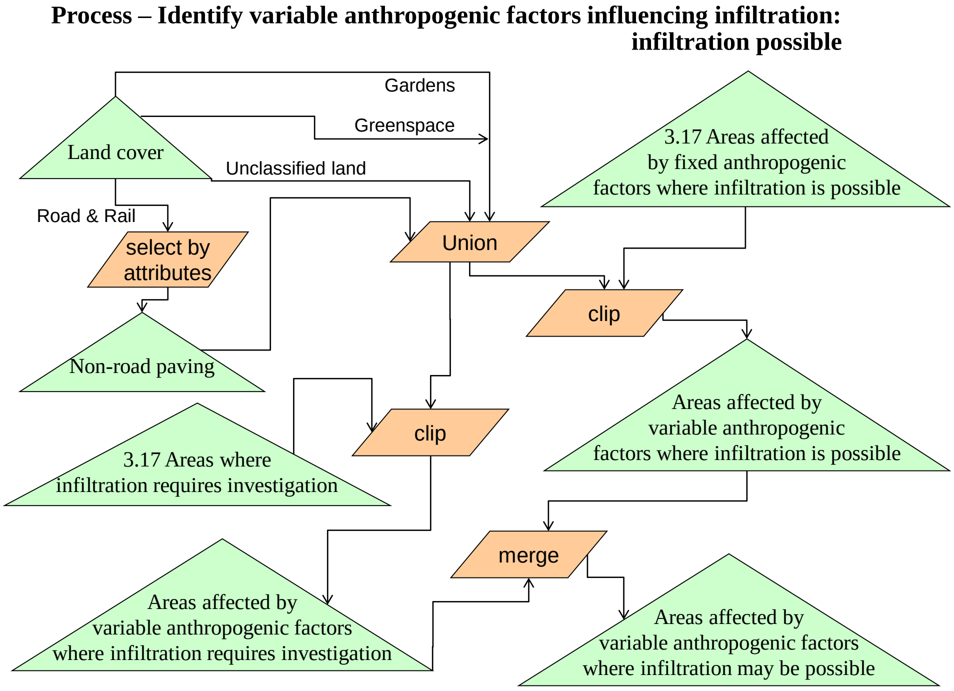


Fig. 3.22 Process in ArcGIS to determine variable anthropogenic factors rendering infiltration possible

3.8.3 Locations suitable for detention and retention SUDS

Locations suitable for detention and retention SUDS were determined from Table 3.21. Fig. 3.23 summarises the GIS process to determine areas suitable for detention and retention SUDS in new developments, and Fig. 3.24 shows the process for retrofit. Two separate areas for detention and retention SUDS were determined, referred to as vegetated and engineered. Vegetated detention and retention SUDS are those where conditions are suitable for installing vegetation-based, ‘soft’ devices above-ground with relative ease. Engineered detention and retention SUDS reflect the increased difficulty of installing a vegetated device in areas where conditions are less suitable. Implementation of engineered SUDS in these locations is likely to necessitate more design work and result in potentially higher cost. Engineered solutions might require, for example, the use of liners in ponds, landscaping techniques to increase retention capacity, or installation of underground storage.

Table 3.21 Classification of factors influencing detention and retention. Attributes in columns to the left take precedence over attributes in columns further right. Figure numbers indicate where the GIS process is described

Data Type	**Unsuitable**	**Vegetated Less suitable**	**Vegetated More suitable**	**Engineered more suitable**
Fixed factors	**Fig. 3.25**	**Fig. 3.26**	**Fig. 3.27**	**Fig. 3.28**
Bedrock geology			Mudstone, siltstone and sandstone except below glacial sand and gravel	
Superficial geology		Glacial sand and gravel		Glacial sand and gravel
Water bodies	Water bodies			
Soil drainage type		Free draining; Slowly permeable, high groundwater	Impeded drainage	Free draining; Slowly permeable
Topography		Steeper terrain (>= 5% slope)	Level or gently sloping terrain (< 5% slope)	Steeper terrain (>= 5% slope)
Water Table		Very high water table (<= 0 m below surface)	Water table not close to surface (>4 m below surface)	High water table (<4 m below surface)
Known groundwater contamination sites		At sites where trichloroethene (TCE) concentrations exceed drinking water standards (10 μg l^{-1}), surrounded by a 250 m buffer		At sites where trichloroethene (TCE) concentrations exceed drinking water standards (10 μg l^{-1}), surrounded by a 250 m buffer
Variable factors		**Fig. 3.29**	**Fig. 3.30**	**Fig. 3.31**
Land cover		Buildings, road carriageways and structures	Greenspace, gardens, paving except road carriageways and structures	Greenspace, gardens, paving except road carriageways and structures

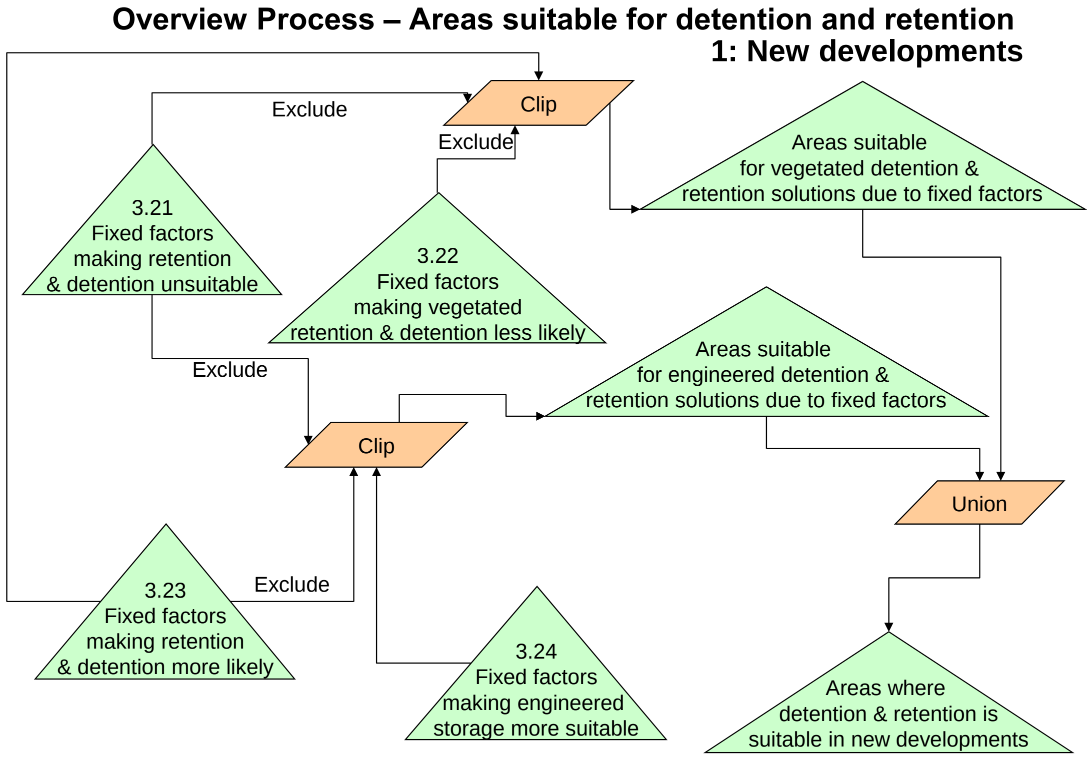


Fig. 3.23 Overview Process in ArcGIS to identify areas suitable for detention and retention in new developments. The numbers refer to related figures explaining how subordinate outputs were generated.

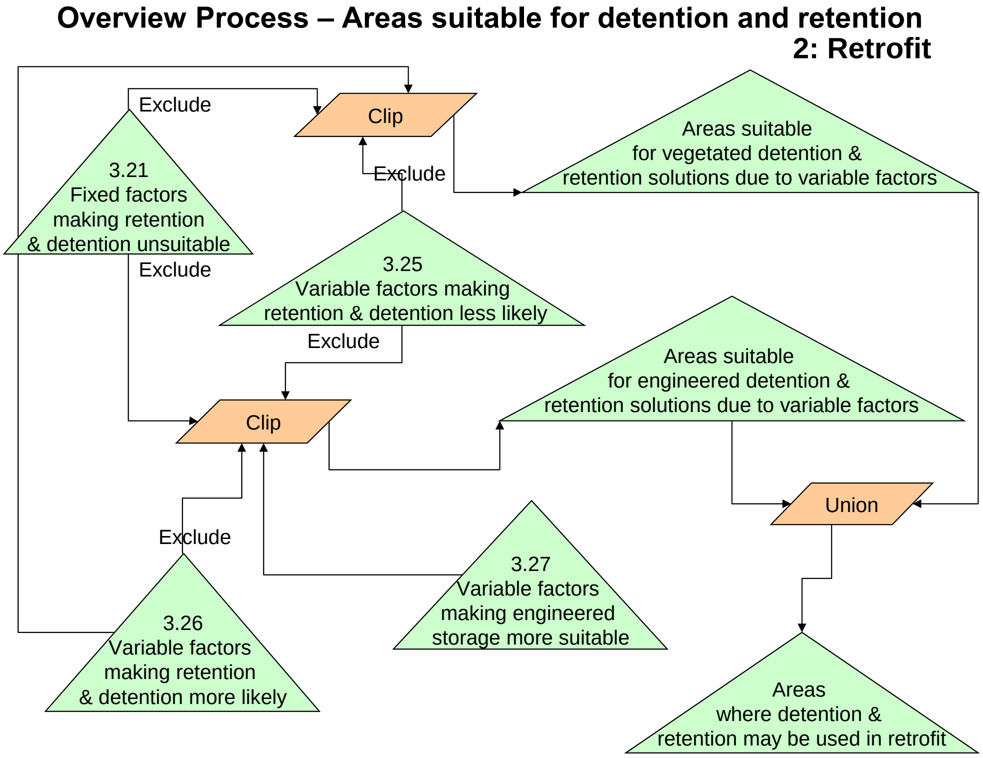


Fig. 3.24 Overview Process in ArcGIS to create areas suitable for detention and retention for retrofit. The numbers refer to related figures explaining how subordinate outputs were generated.

3.8.3.1 GIS process – fixed factors

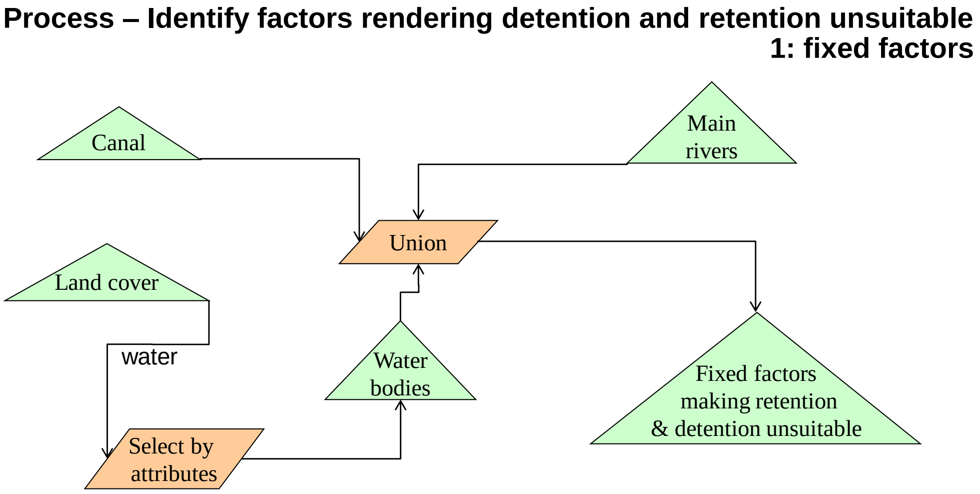


Fig. 3.25 Process in ArcGIS to determine locations where detention and retention are unsuitable.

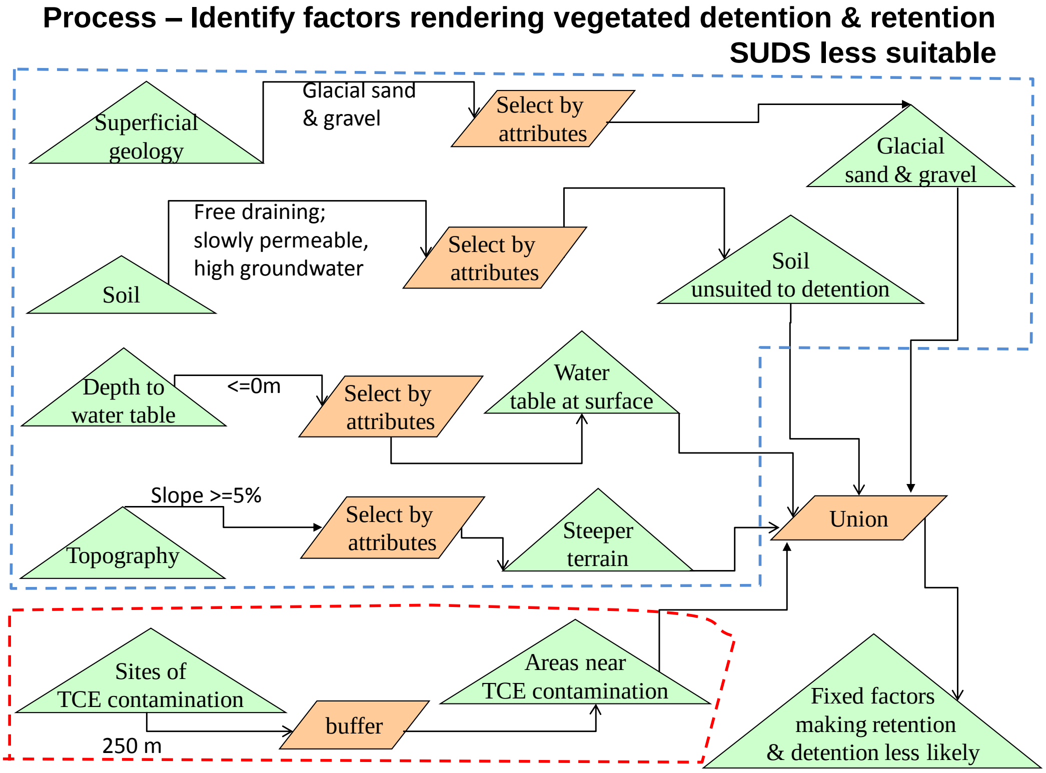


Fig. 3.26 Process in ArcGIS to determine locations where vegetated detention and retention are less suitable. Fixed factors are shown inside the blue dashed outline, variable factors inside the red dashed TCE = trichloroethene

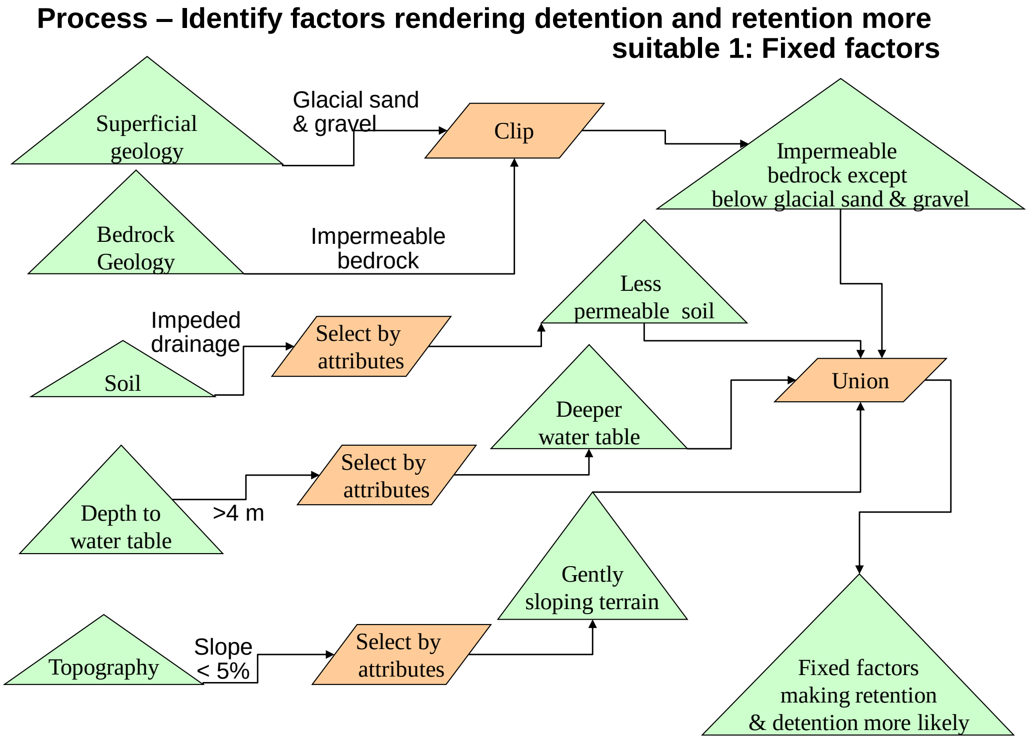


Fig. 3.27 Process in ArcGIS to determine locations where vegetated detention and retention solutions are more suitable

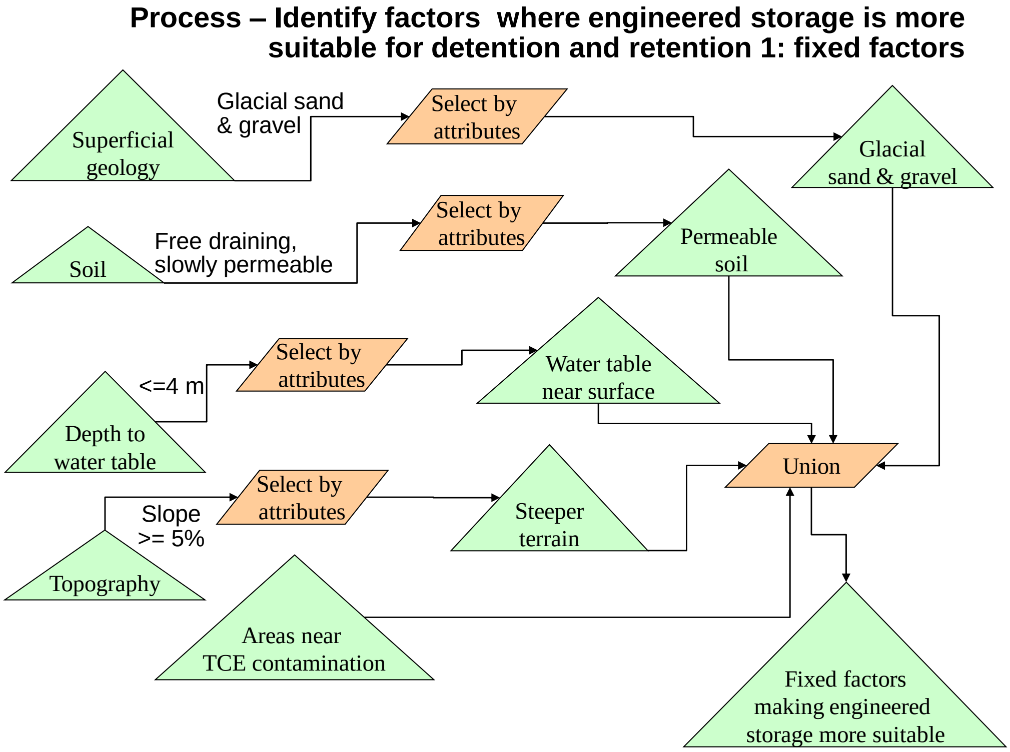
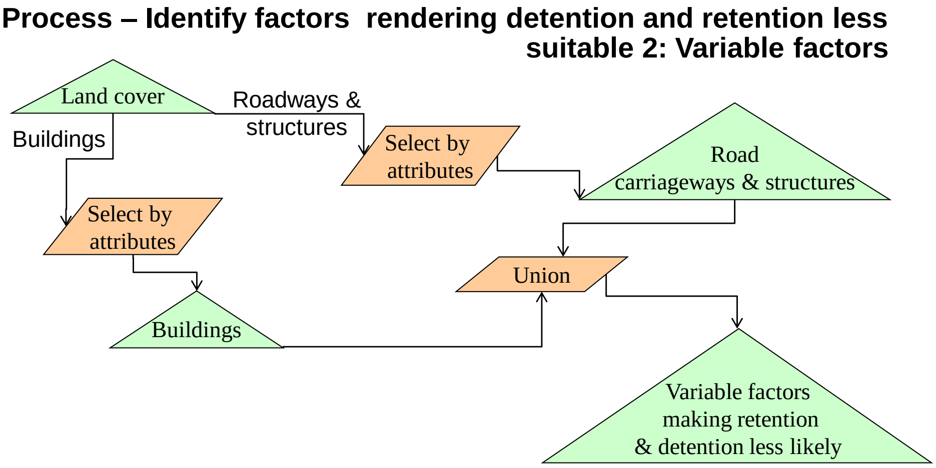


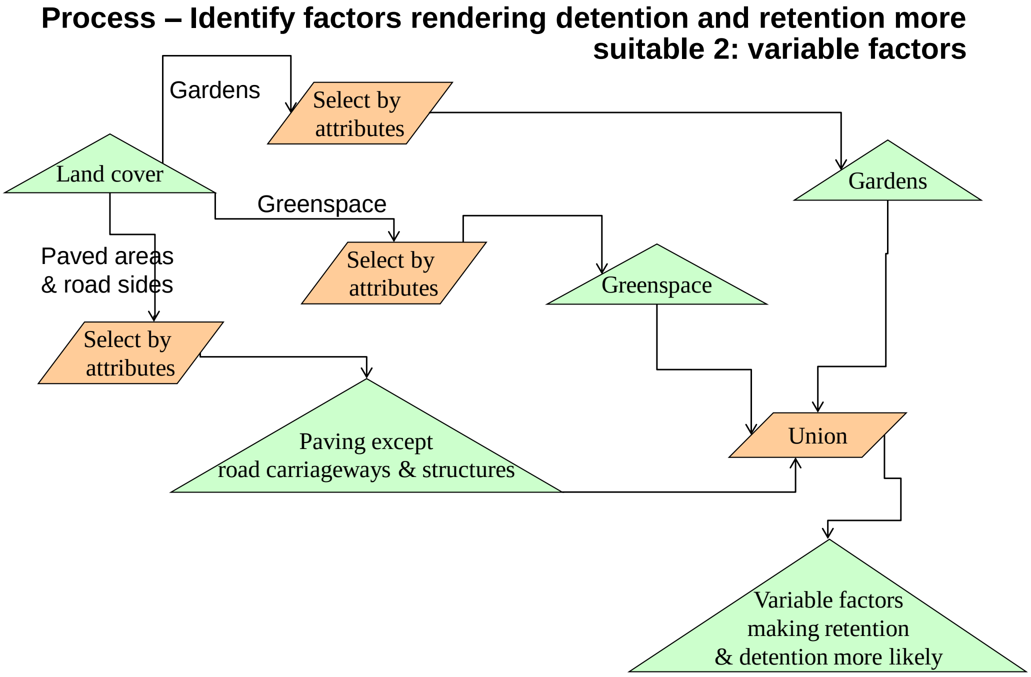
Fig. 3.28 Process in ArcGIS to determine fixed factor locations where engineered storage is more suitable for detention and retention

3.8.3.2 GIS process – variable factors



Process – Identify factors rendering detention and retention less suitable 2: Variable factors

Fig. 3.29 Process in ArcGIS to determine locations where detention and retention are less suitable. Paved structures are features such as elevated walkways



Process – Identify factors rendering detention and retention more suitable 2: variable factors

Fig. 3.30 Process in ArcGIS to determine variable factors influencing locations where detention and retention are more suitable

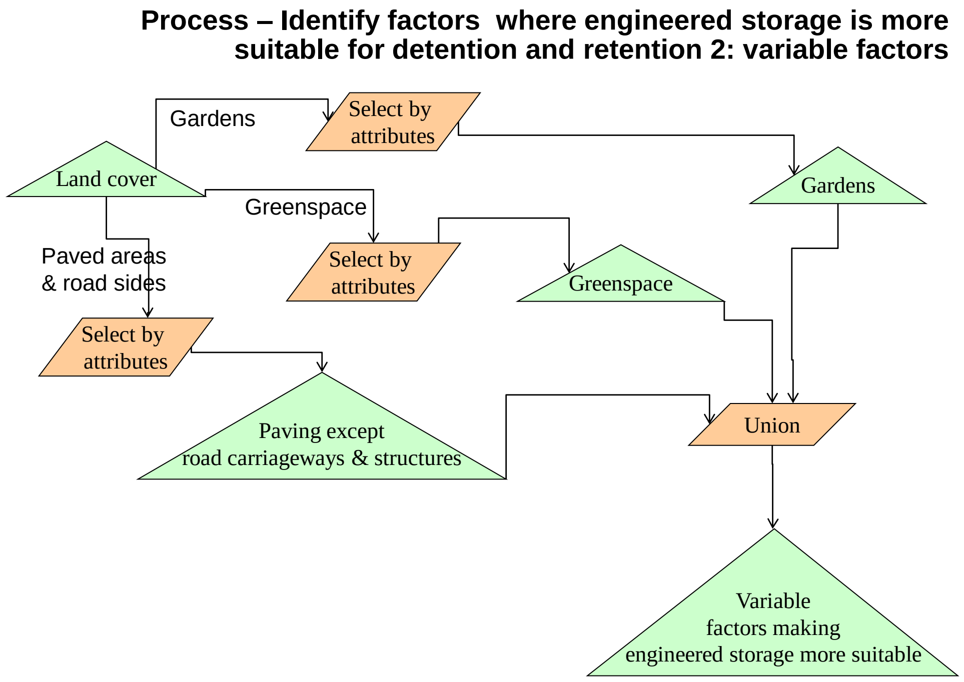


Fig. 3.31 Process in ArcGIS to determine variable factor locations where engineered storage is more suitable for detention and retention

3.8.4 Locations suitable for source control SUDS

Locations suitable for source control SUDS were determined from influences shown in Table 3.22, which also indicates the relevant figures showing the GIS processes.

Table 3.22 Classification of factors influencing locations suitable for source control SUDS. Built structures are features such as bridges and elevated walkways. Figure numbers indicate where the GIS process is shown

Data Type	**Less suitable**
Fixed factors	**Fig. 3.32**
Water bodies	Water bodies
Variable factors	**Fig. 3.33**
Planning constraints	Listed buildings, scheduled monuments
Land cover	Railway tracks, greenspace further than 20 m from existing buildings, built structures, road carriageways of non-minor roads

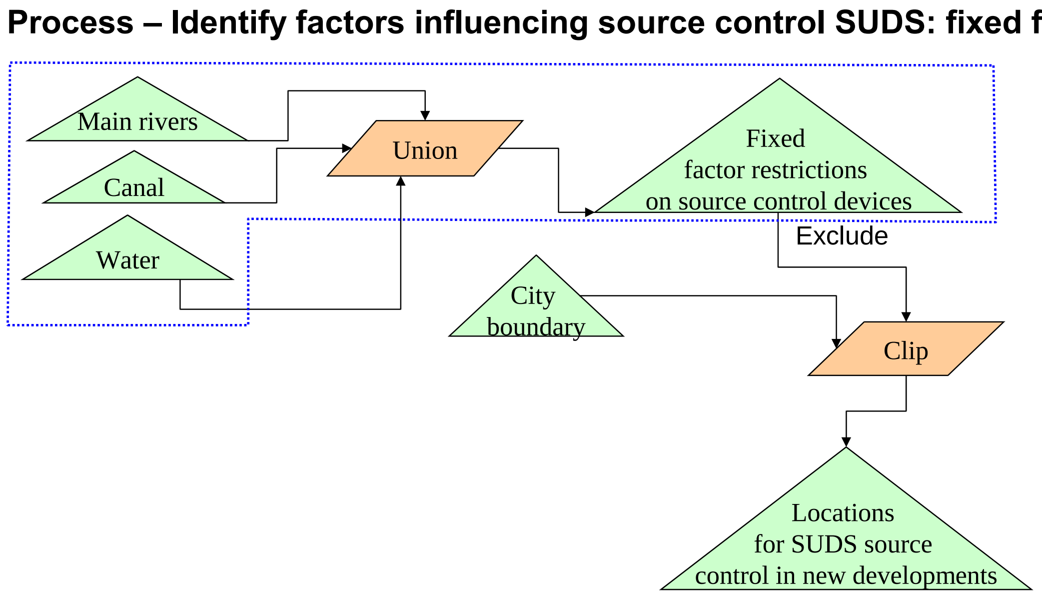


Fig. 3.32 Process in ArcGIS to identify fixed factors influencing source control SUDS

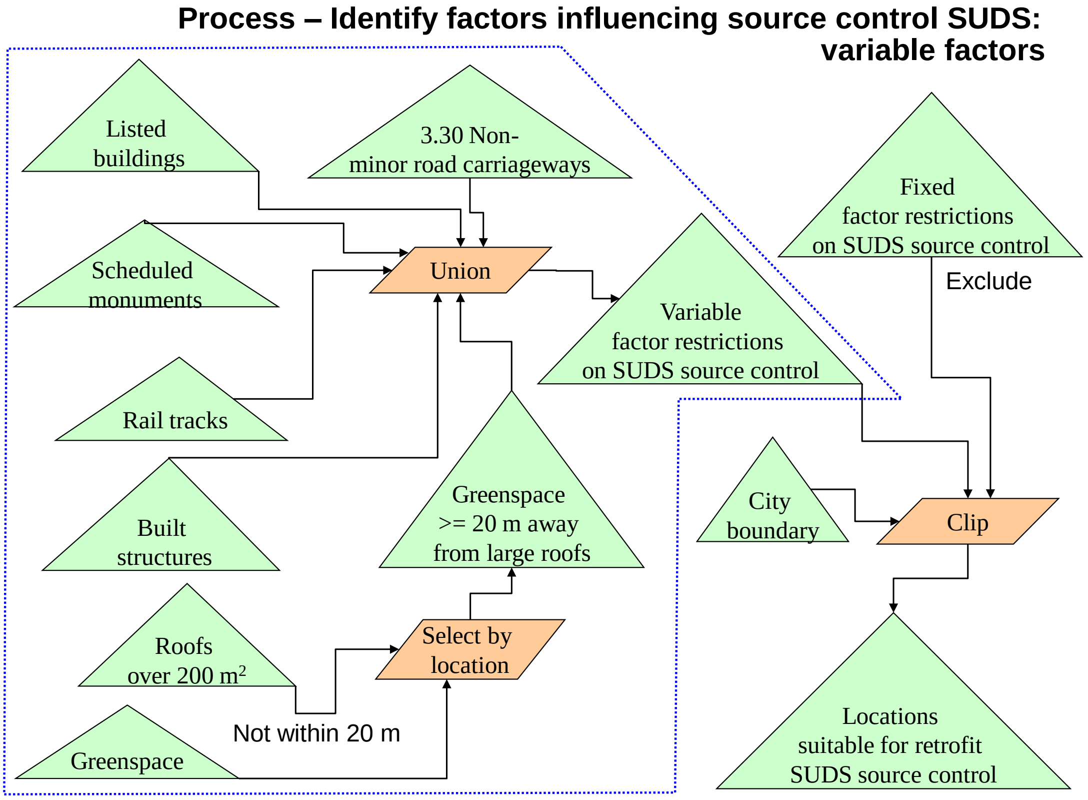


Fig. 3.33 Process in ArcGIS to identify variable factors influencing source control SUDS. Road carriageways were determined in the separate Fig. 3.34

Permeable paving is currently considered unsuitable for heavily trafficked roads (Knapton *et al*. 2002), but may be appropriate for minor roads. Identification of such roads required several processing steps (Fig. 3.34). Motorway, A- and B-road layers were line layers, and did not precisely follow the path of the OSMM roads, so a 20 m buffer around all OS road carriageways was used to identify those that were not near major roads, and were thus taken to be smaller roads potentially suitable for permeable paving. The next step excluded larger roads not present in the formal definition of A and B roads, by selecting the carriageways of roads adopted by CCC, omitting features such as road verges and footpaths, and roads with names suggesting major thoroughfares, resulting in a layer of adopted minor roads. These adopted minor roads were then matched with road carriageways defined in OSMM, and those over 700 m were discarded as having an increased likelihood of being sections of longer main roads. Road carriageways in OSMM that were not part of the minor road carriageways layer were extracted as non-minor road carriageways. Unadopted roads, absent from the adopted roads layer, were retained from the OSMM layer, as these were likely to be smaller and estate roads.

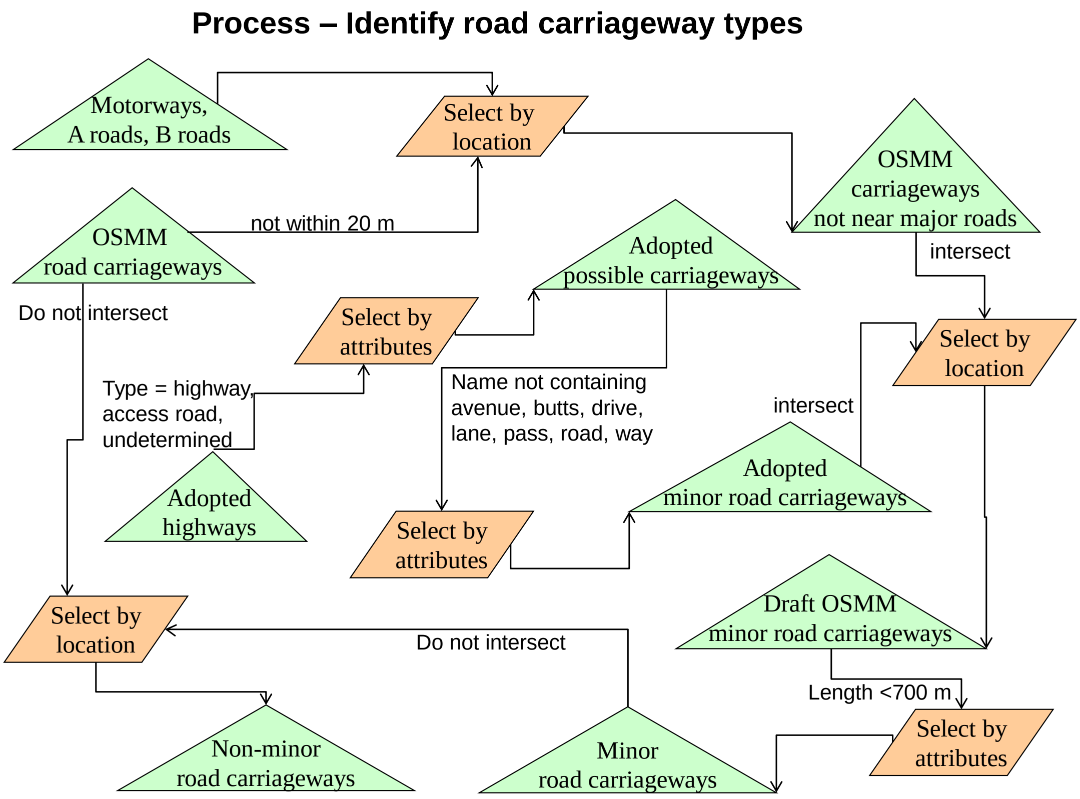


Fig. 3.34 Process in ArcGIS to identify major and minor road carriageways

3.8.5 Locations suitable for filtration SUDS

Table 3.23 identifies the rules used to determine locations suitable for filtration SUDS. Fig. 3.35 outlines the GIS process to identify suitable areas. No filtration was allowed in FZ3 in case flooding might remobilise contaminants. Vegetated road verges were classified as greenspace, so were not included in the roads category.

Table 3.23 Classification of factors restricting locations suitable for filtration SUDS. All other factors pose no significant restriction on the use of filtration SUDS.

Data Type	Restrictions
Fixed factors	**Fig. 3.35**
Water bodies	Water bodies
Flood zones	Fluvial flood zone 3
Variable factors	**Fig. 3.35**
Land cover	Buildings, rail and roads

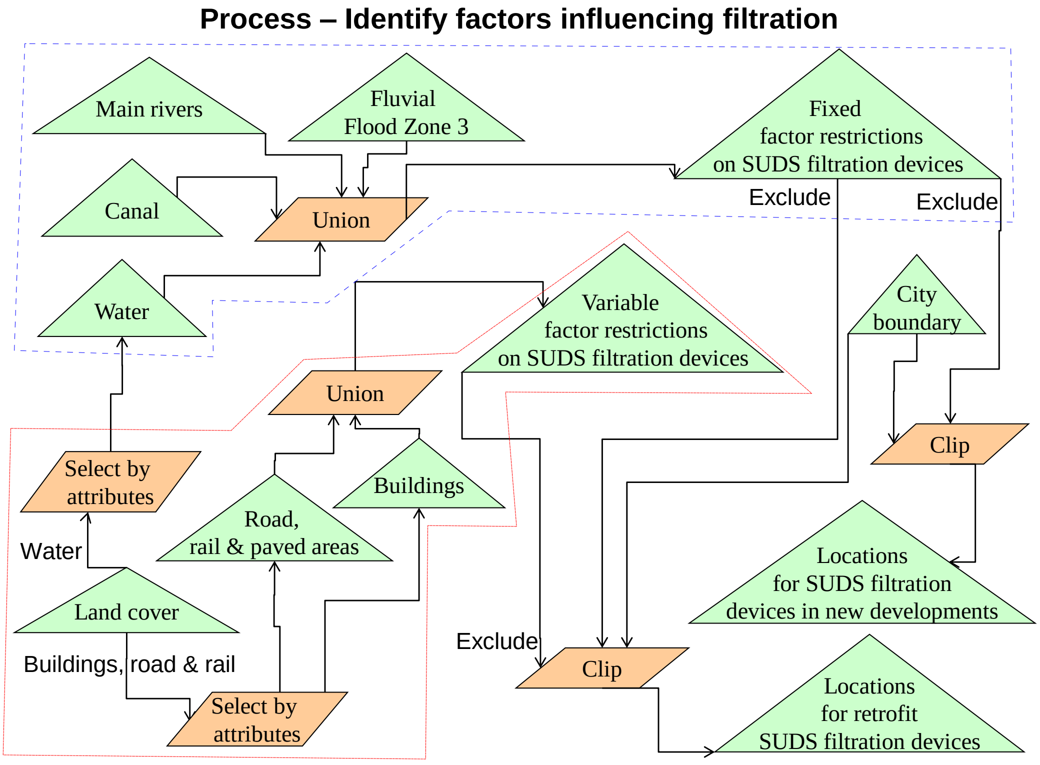


Fig. 3.35 Process in ArcGIS to identify factors restricting filtration. Fixed factors are shown inside the blue dashed outline, variable factors inside the red dashed outline.

3.8.6 Locations suitable for conveyance SUDS

Table 3.24 identifies the rules used to determine locations suitable for conveyance SUDS. Fig. 3.36 outlines the GIS process to identify suitable areas. In contrast to filtration, conveyance was considered possible in FZ3 because any contaminants present are already being transported, and if flooding occurs in FZ3, some pollution arising from SUDS devices may be the least of the contamination concerns.

Table 3.24 Classification of factors restricting locations suitable for conveyance SUDS

Data Type	Restrictions
Fixed factors	**Fig. 3.36**
Water bodies	Water bodies
Variable factors	**Fig. 3.36**
Planning constraints	Listed buildings, scheduled monuments
Land cover	Buildings, existing road carriageways, rail, gardens

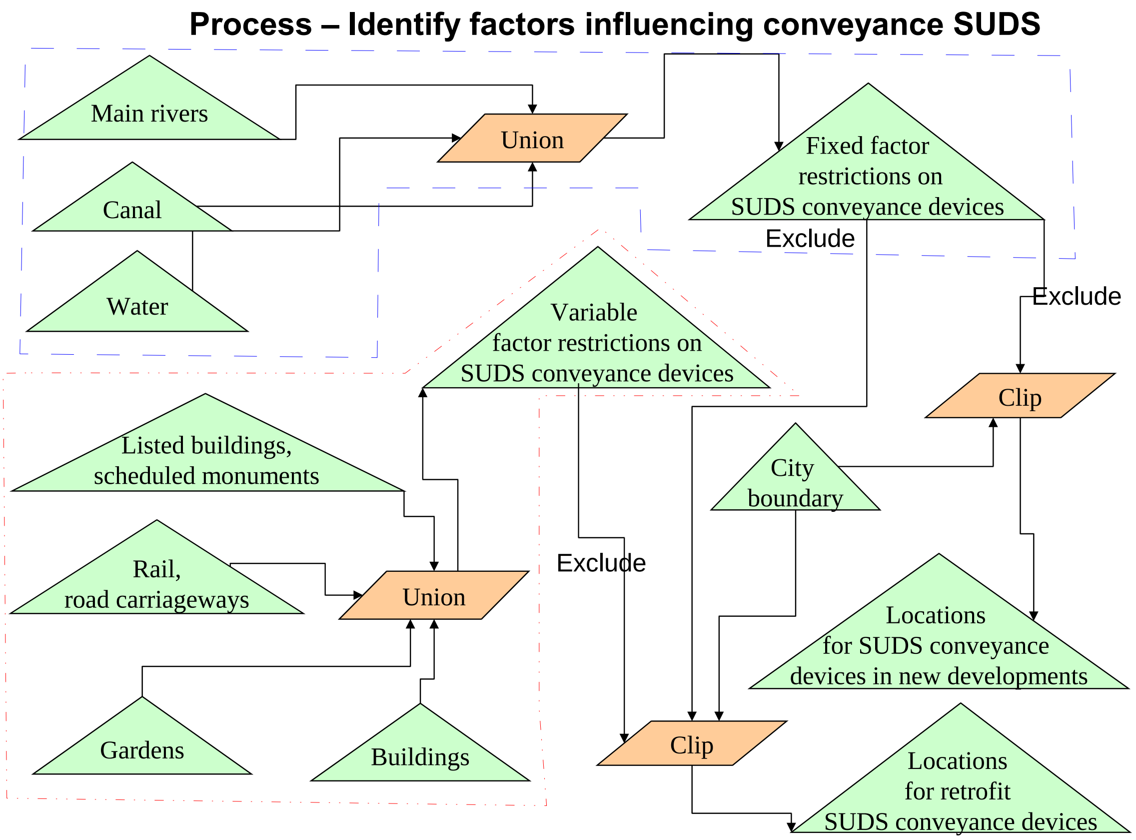


Fig. 3.36 Process in ArcGIS to identify factors restricting conveyance. Fixed factors are shown inside the blue dashed outline, variable factors inside the red dashed outline.

3.9 VALIDATION

Objective 2b, to evaluate the suitability of the recommended SUDS devices and the applicability of the approach, was undertaken using a stakeholder validation exercise, and comparison of feasibility map recommendations with more detailed studies of SUDS implementation in Coventry.

3.9.1 Stakeholder Validation

A range of stakeholders were consulted to validate the SUDS feasibility maps for both new development and retrofit, as well as the high level decision charts. Most of the stakeholder consultations took place in July 2011, with final comments received by the end of December 2011. A summary of all comments and feedback was sent to all consultees in April 2012. Table 3.25 lists the organisations consulted, with the number of respondents from each, although individual respondents are not identified in order to follow ethics practice of preserving anonymity since no respondent specifically asked to be named. The overall response rate was 46%, relatively high for a consultation exercise, although consultees were specifically targeted because of their knowledge and interest in the subject, and most of the respondents had prior awareness of the research.

Consultees were provided with draft copies of the SUDS feasibility maps for new development and retrofit for the entire LPA area, together with a copy of the rules used to create the maps. A more detailed set of maps was also supplied, showing the Canley regeneration area (see Fig. 3.1) for which an outline planning application had been submitted. These more detailed maps allowed stakeholders to assess the impact of the SUDS feasibility proposals in conjunction with current land cover. Maps were provided in hard copy so that they could be annotated. Consultees were also given a hard copy of the SUDS decision charts, which presented images of possible SUDS devices for eight urban development types covering housing, commercial and industrial sites, transportation infrastructure and recreational areas, and indicating SUDS devices that might be suitable in smaller, medium-sized and larger developments (see Appendix I) . A brief explanation of the maps and charts was given prior to asking for comments.

Table 3.25 Stakeholder consultees and respondents. In the 'Invited' column, the numbers in parentheses after the department name indicates the number of consultees from that department

Organisation	Invited to respond	Number of respondents	Response rate
Coventry City Council	Development planning (2), Planning control (2), Development control (1), Highways (1), Highways Drainage (2), Sustainability (1), City councillors (3), Planning and Transportation management (2)	6	43%
Environment Agency	Flood Mapping and Management (4)	2	50%
Severn Trent Water	(2)	1	50%
Coventry University	Supervisory team (3), SUDS applied research group members (3)	3	50%
Total	26	12	46%

3.9.2 Development scale use of SUDS feasibility maps

Validation of the proposals was undertaken using two sites:

- Canley Regeneration zone for new development SUDS
- Coventry University Armstrong Siddeley sub-catchment for retrofit SUDS.

New development recommendations were compared with other studies of the location by Halcrow Group Ltd (2008b), Lashford *et al*. (2014), Nicholls Colton Geotechnical (2012) and RPS Planning and Development (2012). Retrofit recommendations were compared to the pilot site outcome for the sub-catchment.

3.10 APPLICATION OF MAPS

Objective 2c, to assess potential additional applications of the SUDS feasibility maps, is addressed in the sections below. Section 3.10.1 explains the methods to derive potential locations for SUDS implementation. Sections 3.10.2-3.10.3 address the use of two types of land cover, while section 3.10.4 explains the factors included as potential drivers of SUDS implementation

3.10.1 Locations where SUDS may be implemented

Table 3.26 identifies the rules used to select locations where SUDS were more likely to be implemented. Greenbelt land was considered a possible additional planning constraint under increased complexity of implementation, but was not included as the National Planning Policy Framework (DCLG 2012:19) specifically stated that the existence of greenbelt land should not increase complexity. SUDS in conservation areas would need to be in keeping with the area and therefore the possible range of SUDS features was likely to be limited.

The difference in area between polygons for new development and retrofit were compared using single factor ANOVA.

Table 3.26 Indicators of locations where SUDS may be implemented. Figure numbers indicate where the GIS process is described.

Data type	**Implementation restricted**	**Increased complexity of implementation**	**Higher probability of implementation**
Fixed factors	**Fig. 3.37**	**Fig. 3.38**	**Fig. 3.39**
Watercourses & fluvial flood zones	Existing water bodies, fluvial flood zone 3	Fluvial flood zone 2	Fluvial flood zone 1
Variable factors	**Fig. 3.40**	**Fig. 3.41**	**Fig3.42**
Planning constraints & covenants	Listed buildings, scheduled ancient monuments	SSSIs, conservation areas, nature conservation and wildlife sites	Parks
Land ownership			Local authority, housing associations
Development zones			Within regeneration and development zones; employment and housing development areas
Land cover	Main road carriageways (motorway, A and B roads)	Gardens, Buildings	New and existing greenspace, unclassified land

3.10.1.1 GIS process – fixed factors

Process – Identify locations for SUDS: Restrictions on implementation – fixed factors

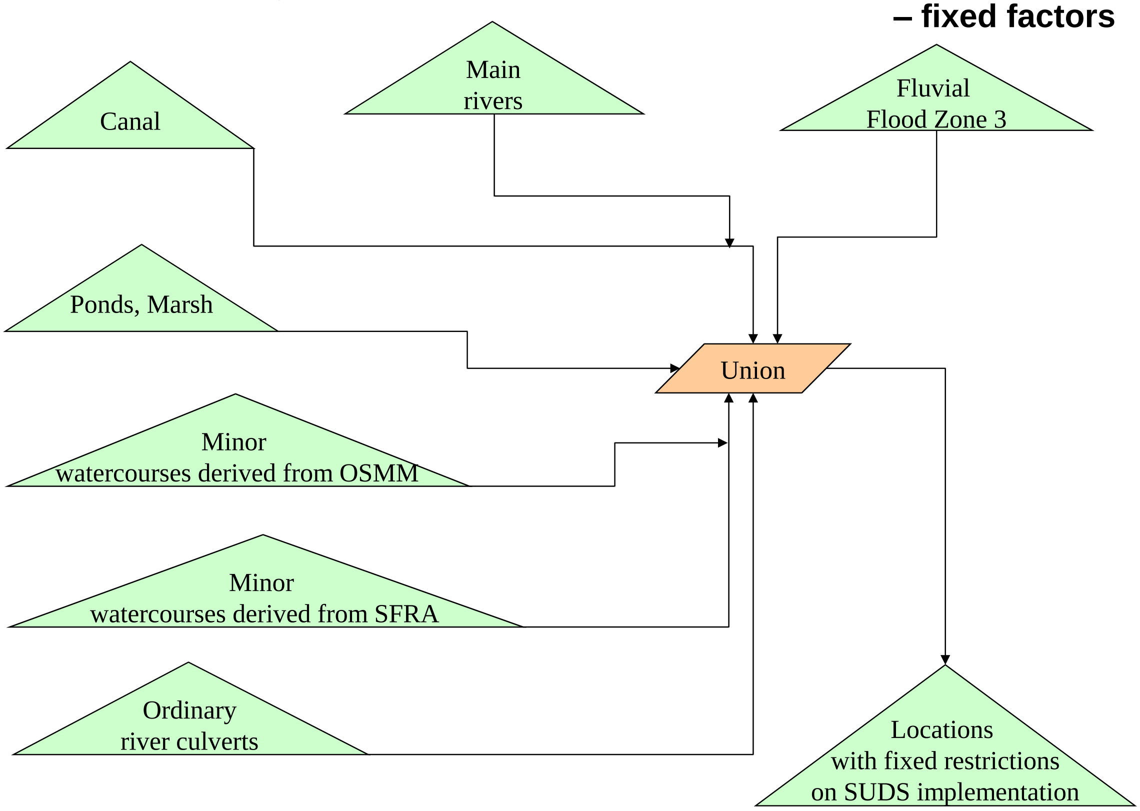


Fig. 3.37 Process in ArcGIS to determine locations with restrictions on SUDS implementation: fixed factors

Process – Identify locations for SUDS: Increased complexity of implementation – fixed factors

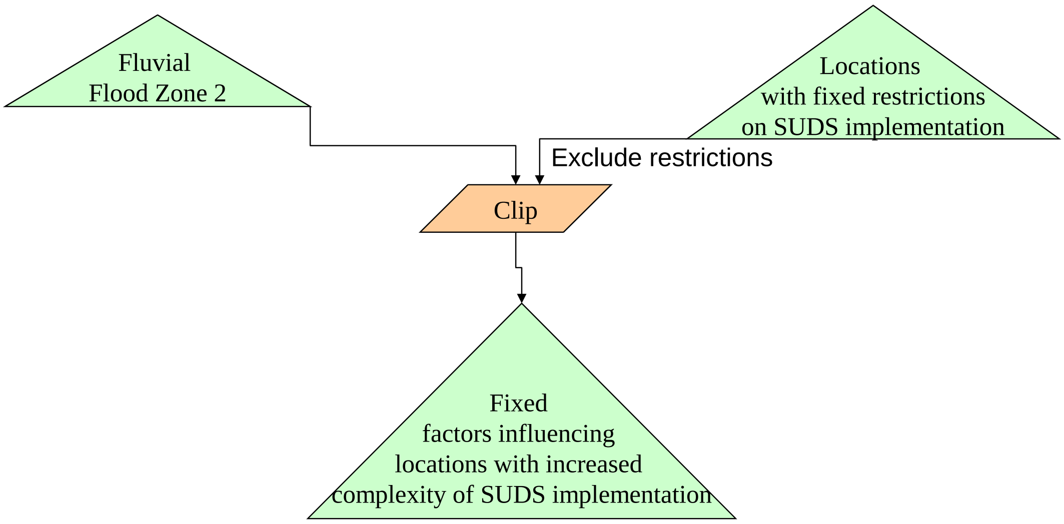


Fig. 3.38 Process in ArcGIS to determine locations with more complex SUDS implementations: fixed factors

Process– Identify locations for SUDS: higher probability of implementation - New developments

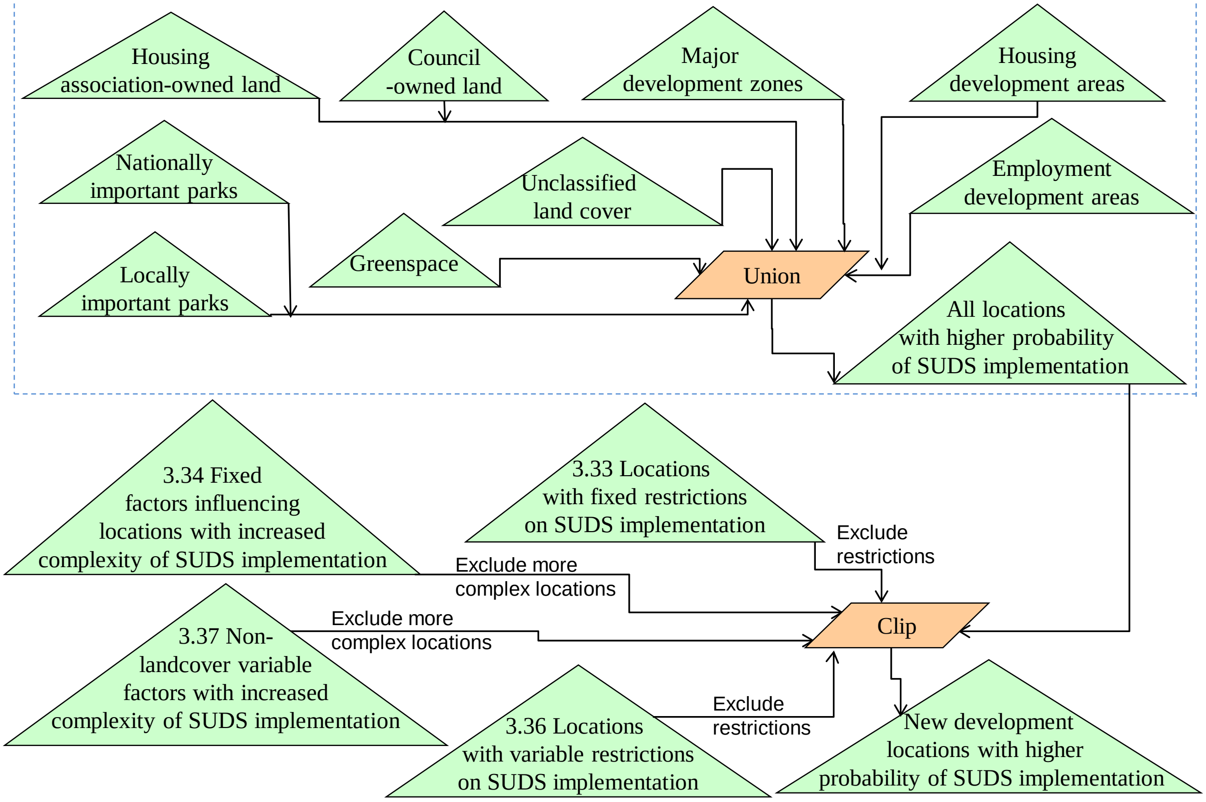


Fig. 3.39 Process in ArcGIS to determine locations with higher probability of SUDS implementation in new developments. The numbers refer to related figures explaining how subordinate outputs were generated.

3.10.1.2 GIS process – variable factors

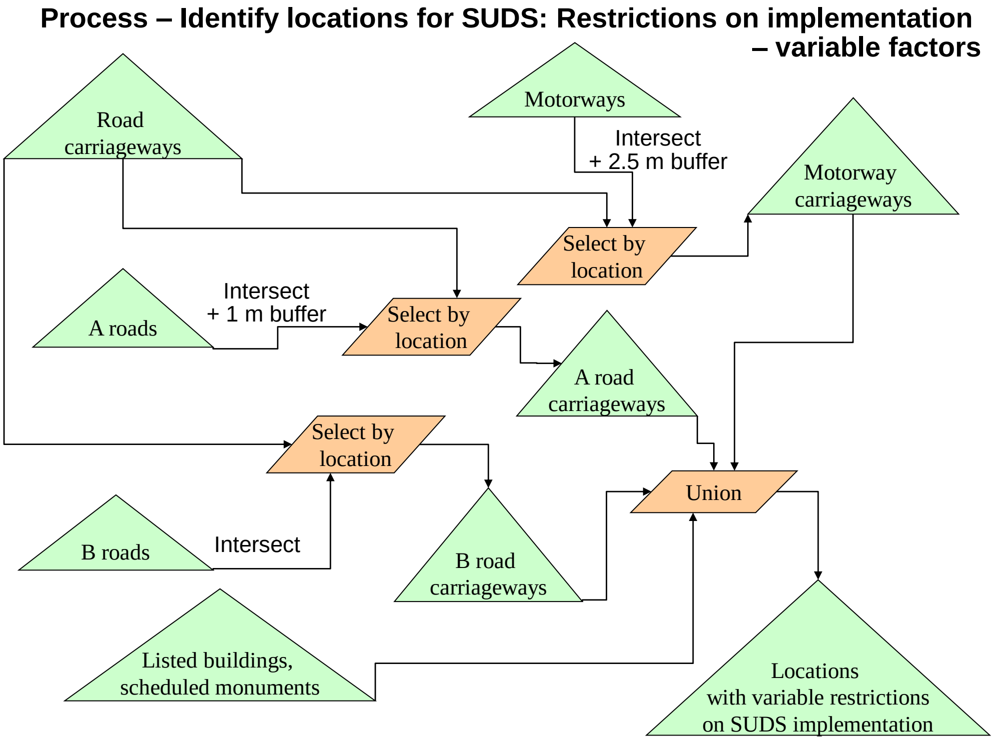


Fig. 3.40 Process in ArcGIS to determine locations with restrictions on SUDS implementation: variable factors

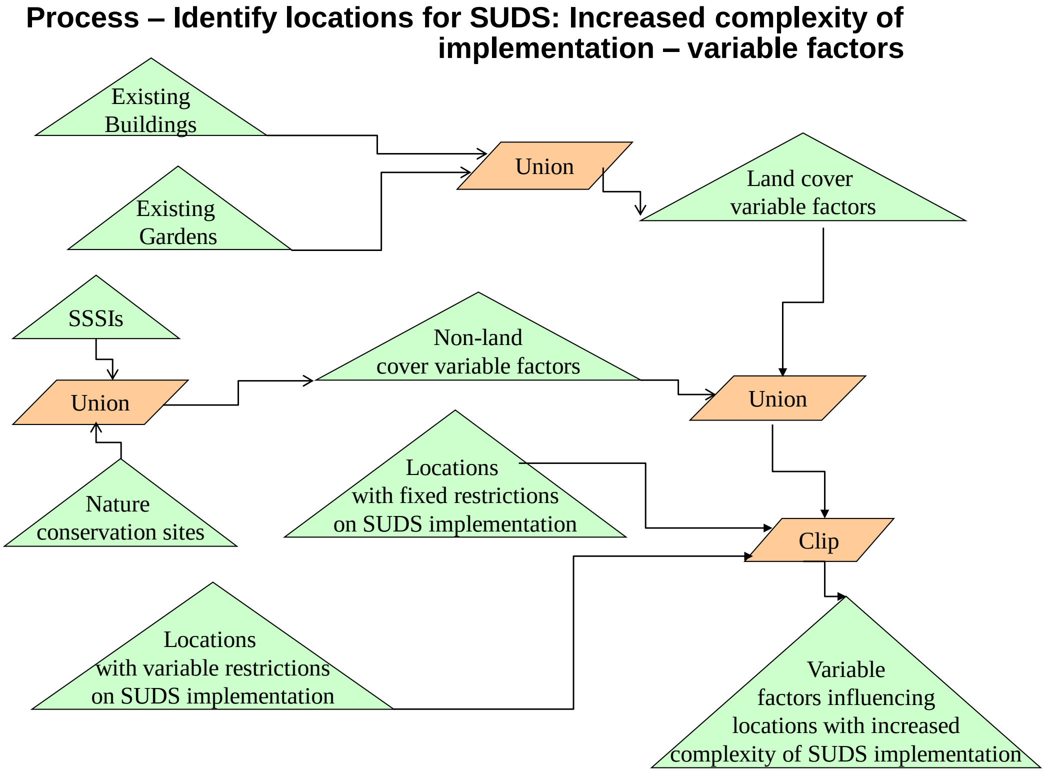


Fig. 3.41 Process in ArcGIS to determine locations with more complex SUDS implementations: variable factors

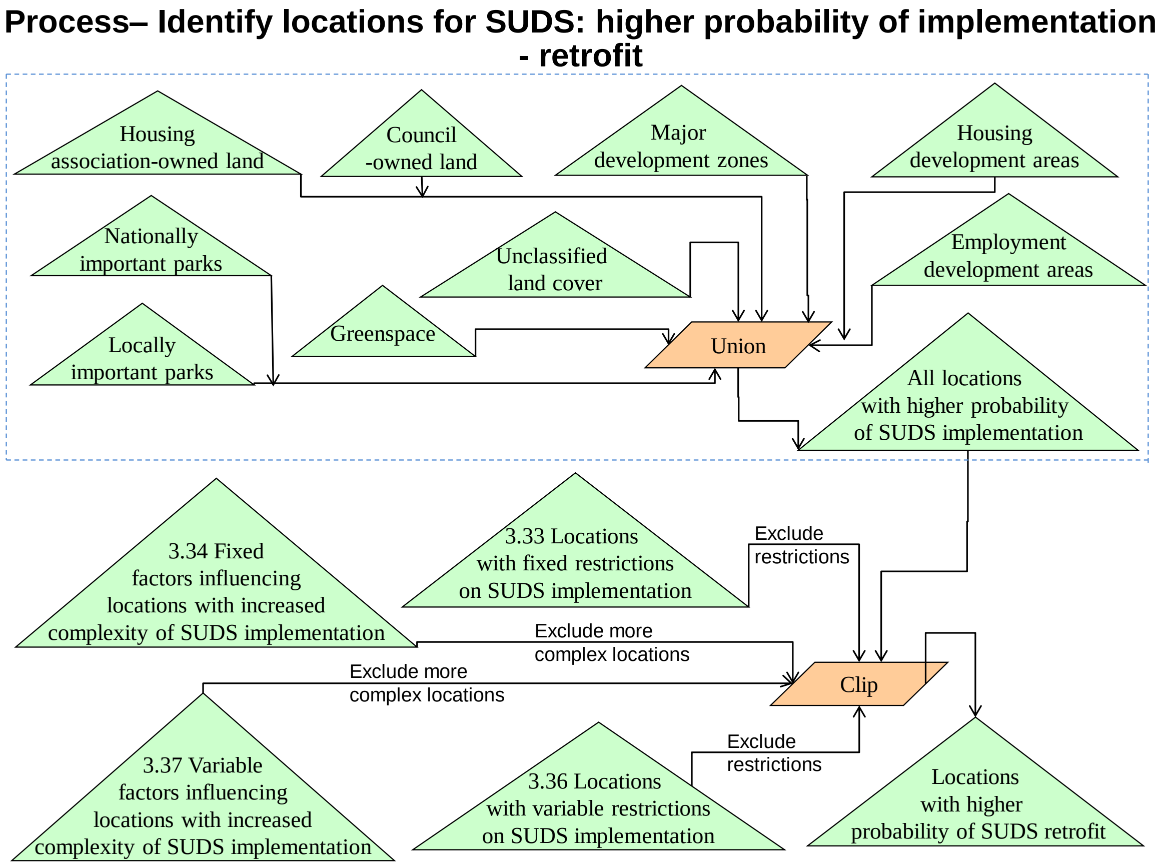


Fig. 3.42 Process in ArcGIS to determine locations with higher probability of SUDS implementation for retrofit. The numbers refer to related figures explaining how subordinate outputs were generated.

3.10.2 Large roofs

The Swan/Stovin hierarchical framework (Stovin *et al*. 2007:19; Swan 2002:89) asserted that large roofs were preferred locations for SUDS retrofit because sufficient areas of land exist nearby that are suitable for infiltration or detention of runoff. A process was designed to assess the extent to which there were areas of suitable land of sufficient size near to large roofs in Coventry. Large roofs were those over 200 m^2 (Swan 2002:162), and verification of buildings in Coventry suggested this was an appropriate figure, although some larger house roofs exceeded this size. Large roof sizes in Coventry ranged from 200 m^2 to 61,911 m^2, and a range of attenuation device sizes would be required accordingly. Therefore, large roofs were allocated to a range of class sizes (Table 3.27), each of which was analysed separately before combining into a final result.

Existing greenspace was deemed to be the most suitable land for attenuation of runoff from large roofs, except for greenspace allocated to railways. In the absence of sufficient greenspace, paved areas might also be suitable for installation of permeable paving and, if necessary, underground storage. However, areas of road and associated paved verges were treated as unsuitable, due to the complexities of installation and maintenance. Therefore only non-road paving was taken into account when determining suitable land for large roofs. Gardens were also considered unsuitable as large roof attenuation facilities, since these were linked to private property ownership, largely domestic dwellings. Paving was treated as a lower priority than greenspace due to the additional complexity and expense of installing sustainable drainage devices in such sites.

The area of land required for attenuation of runoff from the building footprint was calculated according to Eqn.3.6. Design storm data were taken from NERC (1975) amended by an FEH rainfall factor of 0.9 (Table 3.7). Three design storm rainfall depths were considered:

- Treatment volume of 15 mm, to handle the majority of polluted runoff
- 30-year 6-hour
- 100-year, 24-hour.

If paved areas were used to attenuate runoff, then in theory the impermeable area of the paving must also be taken into account. However, since the land requirement R was under 10% of the roof area A in all cases, even for the 100-year design storm, no further allowance was made for paved attenuation.

$$R = \frac{AP}{D} \qquad \text{(Eqn.3.6)}$$

where

R = Land requirement (m^2)

A = baseline roof area (m^2), the upper member of the range for each class in Table 3.27

P = Rainfall depth (m)

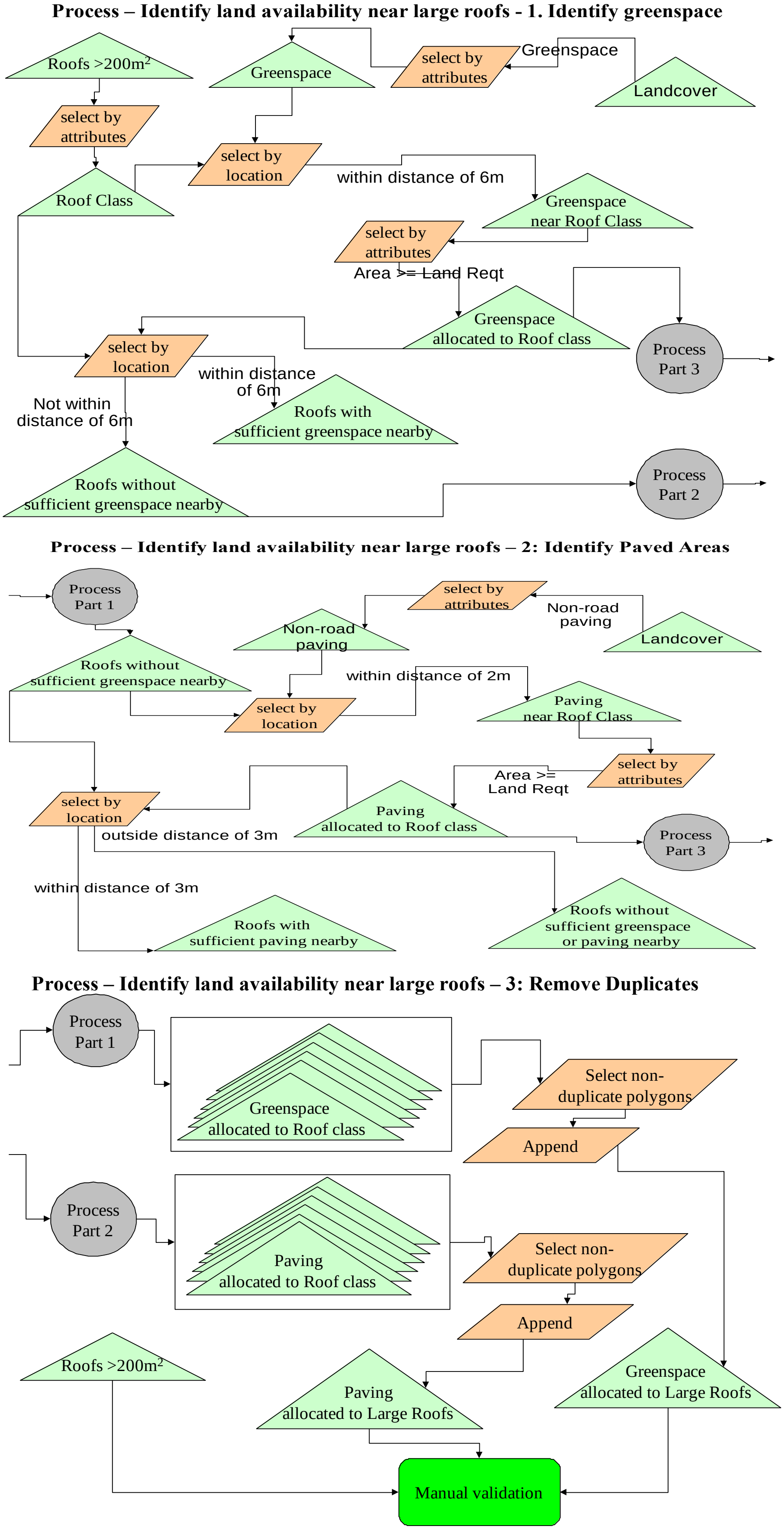
D = storage depth (m), 0.5 m assumed

AP is equivalent to storage volume (m^3).

Table 3.27 Size classes and parameters for analysis of large roofs. The land requirement was determined according to Eqn.3.6, and indicates the area (m^2) required to attenuate the runoff volume for the three defined scenarios

	----------------- Land requirement (m^2) ----------------------		
Design storm	**Treatment volume (Vt) (15 mm rainfall)**	**30yr-6hr design storm (50 mm rainfall)**	**100yr-24hr design storm (90 mm rainfall)**
Roof Size Class (m^2)			
200-500	15	50	90
501-1000	30	100	180
1001-1500	45	150	270
1501-2000	60	200	360
2001-5000	150	500	900
5001-10000	300	1000	1800
10001-62000	750	2500	4500

Having determined the land requirement for each roof class and rainfall event, the ArcGIS process in Fig. 3.43 was followed to determine the large roofs in each class, and to allocate them to suitably sized areas of greenspace or paving where possible. The proximity of land areas was taken as 6 m for greenspace and 2 m for paving, which was determined by experimentation. As greenspace and paving polygons might have been assigned to more than one roof class, duplicate polygons were removed when composite greenspace and paving datasets were created for each rainfall event scenario. A manual validation exercise was performed to ensure that there was still sufficient attenuation capacity in the combined datasets.



Process – Identify land availability near large roofs - 1. Identify greenspace

Process – Identify land availability near large roofs – 2: Identify Paved Areas

Process – Identify land availability near large roofs – 3: Remove Duplicates

Fig. 3.43 Process to identify land availability near large roofs in ArcGIS. For definition of roof classes and land requirements, see Table 3.27 and associated explanation

3.10.3 Paved areas for retrofit SUDS

In dense urban environments, there may be insufficient greenspace to provide vegetated infiltration or detention SUDS. Fig. 3.44 shows the process to select areas where permeable paving may be installed, or which may be converted to greenspace.

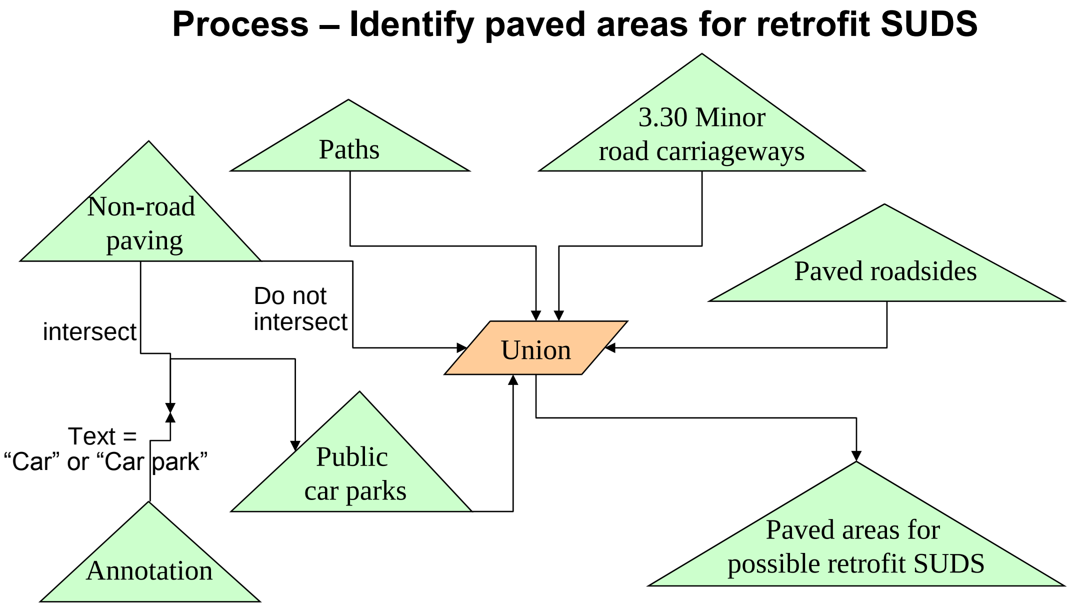


Fig. 3.44 Process in ArcGIS to identify paved areas for retrofit SUDS. Road carriageways were determined in the separate Fig. 3.34

3.10.4 Locations that may benefit from SUDS

3.10.4.1 Identification of locations

The factors defining areas where SUDS may be beneficial are identified in Table 3.28.

Table 3.28 Indicators of locations that may benefit from SUDS. Figure numbers indicate where the GIS process is shown

Data type	**Water Quality**	**Water Quantity**
Fixed factors	**Fig. 3.45**	**Fig. 3.46**
Water bodies	Near (within *x* m of) watercourses (caters for surface water sewers to some extent)	Groundwater reservoirs requiring recharge
Historical flood events		Locations at greater risk of flooding
Water quality assessments	Watercourses not achieving ‘good’ status’; Surface and groundwater nitrate vulnerable zones	
Sewer and drain locations and characteristics	Surface sewer outfalls; combined sewer overflows	Where surface sewers feed into combined sewers
Variable factors	**Fig. 3.47**	**Fig. 3.47**
Land cover	Near roads (to handle highway runoff), near impermeable front gardens	Near roads (to handle highway runoff), near impermeable front gardens

Process – Identify beneficial locations for SUDS: water quality fixed factors

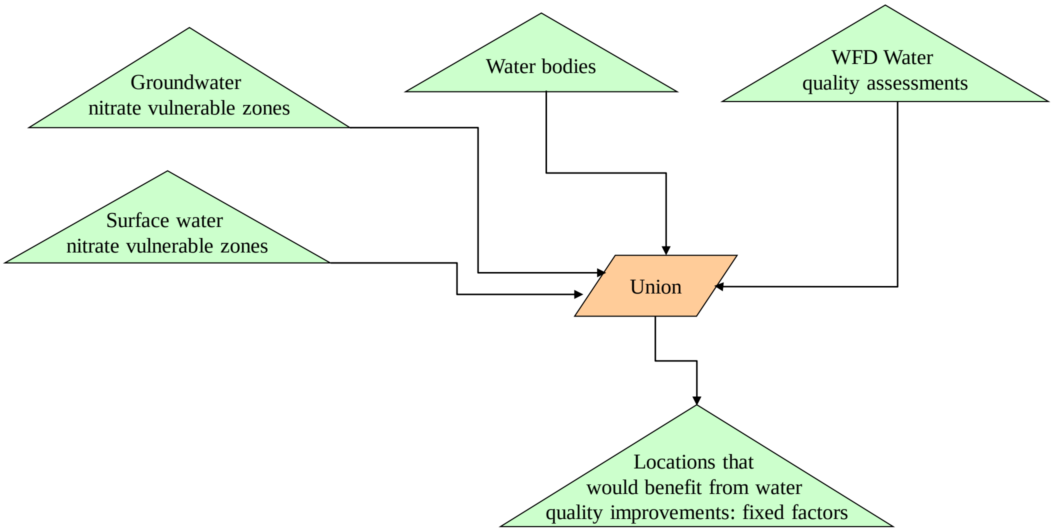


Fig. 3.45 Process in ArcGIS to identify fixed water quality factors influencing beneficial locations for SUDS

Process – Identify beneficial locations for SUDS: water quantity fixed factors

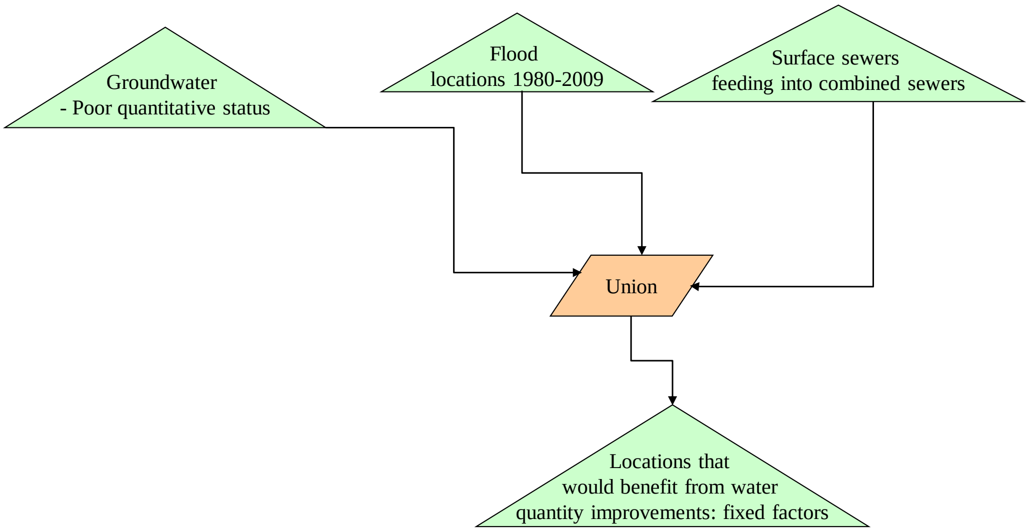


Fig. 3.46 Process in ArcGIS to identify fixed water quantity factors influencing beneficial locations for SUDS

Process – Identify beneficial locations for SUDS: variable factors

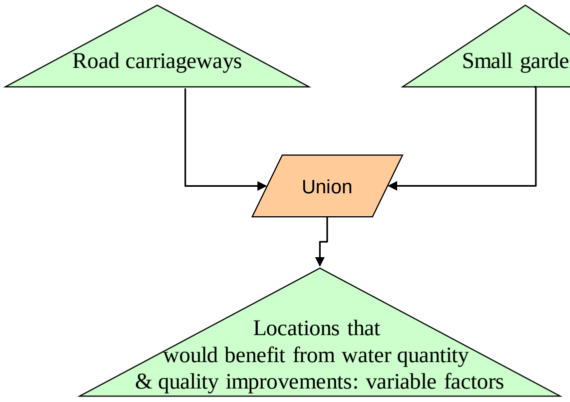


Fig. 3.47 Process in ArcGIS to identify variable factors influencing beneficial locations for SUDS

3.10.4.2 Investigation of locations

To examine their potential use as input to project-based investigations of SUDS implementation, the available SUDS options near problem locations were compared with land cover to evaluate possible solutions.

To assess restrictions on the scale of SUDS implementation, the area of land available for each SUDS grouping was calculated based on nominated buffer distances from the problem site. Fig. 3.48 shows a generic example of the process using infiltration SUDS. Outputs for retrofit and new build source control, detention and infiltration SUDS were created in relation to sites of historical flooding and water quality.

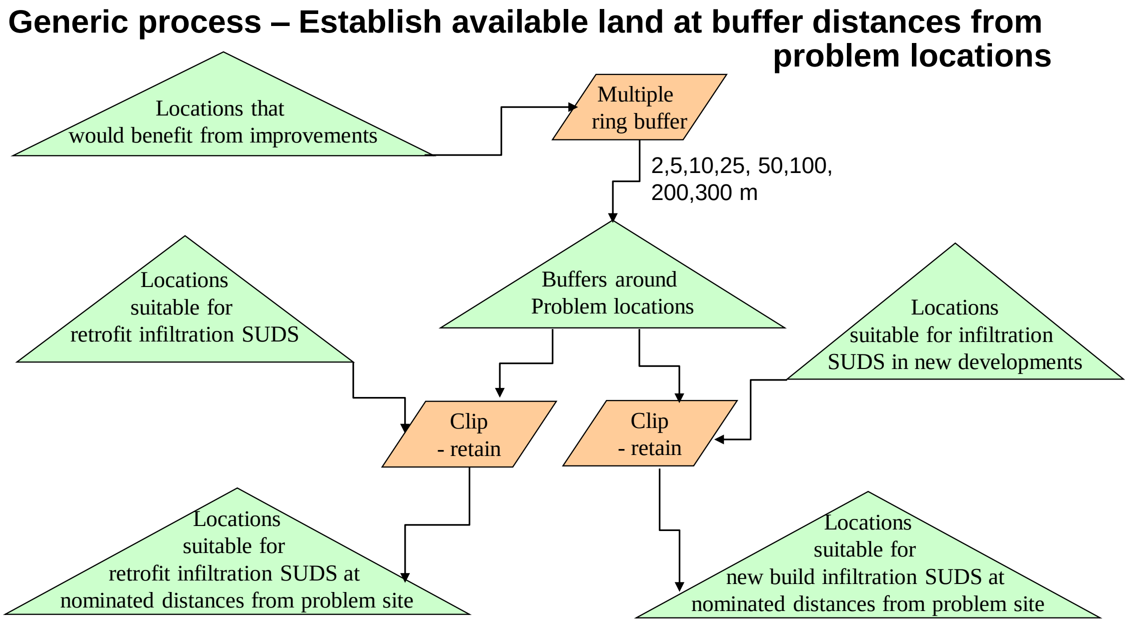


Fig. 3.48 Generic process – Establish available space at buffer distances from problem locations

3.11 SUMMARY

This chapter has explained the methods used to collect and analyse information. The results of the analysis are presented in chapter four for aim 1, and chapter five for aim 2.

4 PILOT SITE EVALUATION

4.1 INTRODUCTION

This chapter summarises the results of the pilot site investigation to identify suitable evaluation techniques to determine SUDS feasibility in an urban environment in support of objective 1a (section 4.2). It then considers the applicability of the pilot outcomes (section 4.3) to the wider strategic scale of an LPA area. Section 4.4 explains the construction of a framework to evaluate suitable SUDS devices at the local authority strategic scale, and evaluates which SUDS devices would be suitable for an urban local authority area (objective 1c, section 4.5).

4.2 PILOT SITE INVESTIGATION

The pilot study investigated techniques for assessing SUDS feasibility, using the example of Coventry University's inner city campus to assess retrofit options in existing sites. Key characteristics of the six sub-catchments evaluated in the pilot study are summarised in Table 4.1. Previous instances of flooding of University buildings had caused disruption and financial loss, and sustainable drainage installations were suggested as a means of mitigating future flooding. Water quantity concerns were thus the initial drivers of the pilot study, whilst bearing in mind that water quality and amenity issues might emerge during the investigation. General principles for SUDS implementation in new developments were identified by simplifying consideration of the factors associated with the increased complexity of retrofit. Only those factors with implications for the wider city-scale study are reported in this chapter. Full details of the pilot site investigation are given in Appendix C for reference.

Stages in the pilot process were summarised in Table 3.3, and the main outcomes are listed in Table 4.2, using the same headings. Brief explanatory comments for each heading are given in the rest of section 4.2.

Table 4.1 Key characteristics of the pilot study sub-catchments

Sub-catchment	**Abbreviation**	**Area (ha)**	**Impermeability (%)**	**Building Area (% of sub-catchment)**	**No. of flooded locations on 18 Aug. 2006**	**Runoff to local watercourse**
Armstrong Siddeley	AS	1.62	56.4	35.2	0	Yes
Frederick Lanchester Library	FL	2.89	81.0	37.4	0	Yes
George Eliot	GE	3.05	90.7	44.3	6	Limited
Graham Sutherland	GS	1.19	80.1	55.5	0	Limited
John Laing	JL	1.89	84.6	47.2	1	No
Singer	SI	2.70	81.2	39.3	0	Yes
Full Pilot Study Site	-	13.33	80.7	42.1	7	Yes

Table 4.2 Summary of pilot site conclusions. The final column refers to sections containing brief additional considerations and illustrative figures and tables

Activity	**Main findings**	**Methodological and data issues**	**Section**
Data collection	Inaccuracies identified in the OSMM dataset: one building missing, incorrect representation of four buildings, and inadequate differentiation of paved and vegetated areas	Field survey undertaken to validate land cover (four weeks effort). The total absolute areal variation of 66.3% for OSMM compared to the field survey largely reflected the lack of discrimination between paving and vegetation in OSMM using the defined classification scheme	4.2.1 Table 4.3
	Data availability and uncertainty	Missing and out of date records relating to University infrastructure Absence of historical records about flooding incidents Lack of access to third-party data regarded as commercially confidential Inadequate spatial and topographic detail in published maps Lack of clarity about the relationship between precipitation rates and local flooding Absence of detailed information about flood risk from overland flow and sewer flooding	
Problem locations - Water Quality	Poor water quality in river receiving runoff from study site (EA's GQA biology score = poor, phosphates = high). Four sub-catchments disposed of water to river, so scope for treating runoff	Lack of information about private drains feeding the public sewer system. No drivers for University to improve runoff quality	4.2.2 Fig. 4.1

Activity	Main findings	Methodological and data issues	Section
Problem locations - Water Quantity	Seven buildings flooded on 7 August 2006	Floods occurred in the two most impermeable sub-catchments, so reduced scope for SUDS	4.2.3.1 Fig. 4.2
	ArcGIS hydrological modelling identified flow channels, but not known flood sites, when using both sinks filled and unfilled methods	Input airborne Lidar data resolution too coarse. ArcGIS hydrology functions required further coarsening of resolution due to spatial extent of coverage. Lack of standard functionality to address representation issues such as bridges treated as dams	4.2.3.2 Fig. 4.3
Flood risk	No buildings within the 100-year fluvial flood plain, but four lay within the 1000-year zone	Flood risk maps considered only fluvial flooding. Flood zones differed between EA (2008c) and SFRA (CCC 2008b). Flood zones did not follow current watercourse channels in places, perhaps due to historical re-engineering. Impact of culverts on flood risk unclear	4.2.4 Fig. 4.4

Activity	Main findings	Methodological and data issues	Section
Hydrological assessment	**Design values** Greenfield runoff rate 4.59 l s^{-1} ha^{-1}, so first 11.6 mm of rainfall expected to infiltrate For the five most impermeable sub-catchments, a 34-38-fold reduction in runoff rate was required to meet discharge limits. Additional runoff from development in the most impermeable sub-catchment was 537 m^3 (100-year, 6-hour event)	Developed runoff volumes varied depending on model used (maximum 8% difference between highest and lowest) and sub-catchment impermeability percentage	4.2.5 Fig. 4.5
	Storage Requirements Values for interception (5 mm), treatment (15 mm), attenuation and long-term storage (based on HR Wallingford (2008) for 100-year event) were determined, with higher storage requirements in the more impermeable sub-catchments. Long-term storage not considered feasible in pilot site due to infiltration characteristics	Variability in results (maximum 73% difference) for all types of storage, due to differing hydrological equations and assumptions between methods, led to uncertainty about appropriate values to use. Equations appeared to be influenced differently by higher impermeability levels	4.2.5.2 Fig. 4.6 Table 4.4
	Sub-catchment impermeable area was the best predictor of storage volume requirements ($r^2 >= 0.99$)	Limited number of sub-catchments assessed	4.2.5.2 Table 4.5

Activity	Main findings	Methodological and data issues	Section
SUDS decision support tools	Permeable paving was the most commonly suggested source control, and swales the most frequently proposed site control feature. The Swan/Stovin hierarchical framework (SNIFFER 2006) and HR Wallingford (2008) generated recommendations that were understandable and transparent. Results from some other tools were questionable	Despite the same catchment characteristics being used as input to all the tools, and the same potential range of SUDS techniques being available, a wide range of alternative solutions was proposed. Some methods included a limited set of SUDS techniques, appeared too focused on the individual circumstances of their own study sites and were less generally applicable. All could be improved by indicating how SUDS techniques could be linked in a management train.	4.2.6 Table 4.7
	The HR Wallingford (2008) methodology generated the most appropriate proposals for SUDS in new developments on the pilot site	Most tools evaluated a limited range of factors or included fewer possible SUDS devices	Table 4.8
Evaluation of retrofit SUDS suitability for pilot site	Most SUDS devices were suitable for the pilot study site. Permeable paving, underground storage, and bio-retention features were more generally applicable than other techniques. Infiltration devices were less appropriate due to poor site infiltration characteristics. Large ponds and wetlands were not feasible due to lack of space		4.2.7 Table 4.6

Activity	Main findings	Methodological and data issues	Section
	The least impermeable sub-catchment (56%) offered scope for the greatest number of techniques A detention basin and feeder swales, permeable paving with underground storage in 50% of the existing paved area, 50% green roofs, and bioretention features could be retrofitted to meet the 100-year interception, treatment and storage requirement		Fig. 4.7
	The implementation of extensive green roofs across the campus could provide a noticeable attenuation of runoff volumes from the roofs. Green roofs could attenuate the full Vt and interception volumes, preventing runoff from all small rainfall events. Alternatively, they could store the majority (for AS sub-catchment, all) of the 1-year runoff volume falling on the roofs in each sub-catchment	Roofs cover only part of the campus surface, and so cannot attenuate precipitation falling on other surfaces.	Table 4.9

4.2.1 Data collection

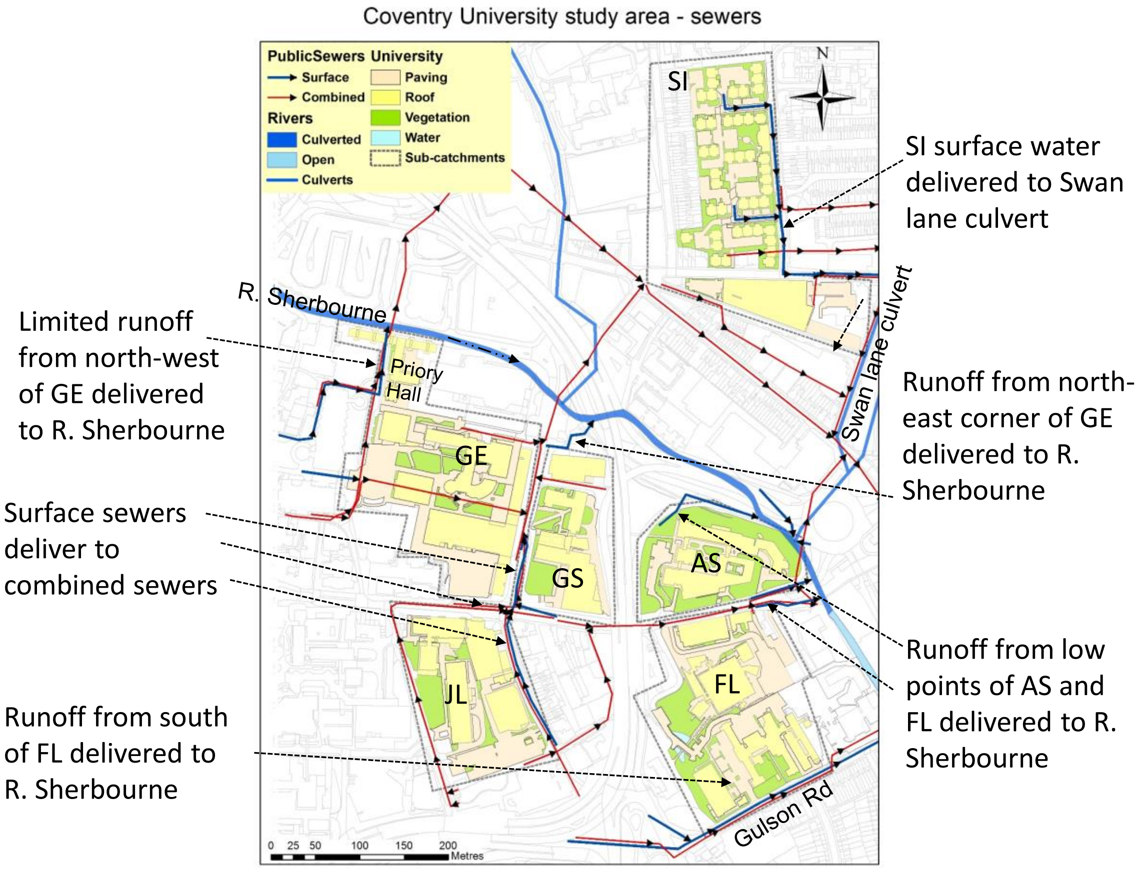
The pilot exercise revealed some of the difficulties in obtaining reliable estimates of land cover in urban environments from sources that are widely accepted as accurate (Table 4.3). The total absolute variation of 66.3% for raw MasterMap compared to modified MasterMap reflected principally the lack of discrimination between paving and vegetation. Since the Generalised Land Use Database (GLUD, DCLG 2007) dataset was a re-classification of the raw MasterMap but used the same base entities, errors in building representation in raw MasterMap were also present in GLUD.

Table 4.3 Percentage areal variation between land cover classifications for each land cover class of University-owned property in the pilot study: modified MasterMap resulted from the field survey, supplied (raw) MasterMap and GLUD. Column two gives the land cover proportion for each class in modified MasterMap. Columns three and four present the percentage variation within each class for raw MasterMap and GLUD compared to the field survey

Land cover type	**Modified MasterMap land cover (%)**	**Raw MasterMap variation (%)**	**GLUD variation (%)**
Buildings	42.1	-0.7	-1.7
Paved areas	38.6	-32.5 (1)	-3.6
Vegetated areas	19.1	+33.1 (1)	+1.0
Surface water	0.2	0	0
Unclassified	0.0	0	+4.3
Total variation		**66.3**	**10.6**

4.2.2 Problem locations - Water Quality

Runoff from the campus entered the R. Sherbourne via surface water sewers, located in the Singer, Armstrong Siddeley sub-catchments, the Priory Hall end of the GE sub-catchment, and the southern (Gulson Rd) end of the Library sub-catchment (Fig. 4.1).



Limited runoff from north-west of GE delivered to R. Sherbourne

Surface sewers deliver to combined sewers

Runoff from south of FL delivered to R. Sherbourne

SI surface water delivered to Swan lane culvert

Runoff from north-east corner of GE delivered to R. Sherbourne

Runoff from low points of AS and FL delivered to R. Sherbourne

Fig. 4.1 Public sewers near Coventry University city centre campus. Four sub-catchments disposed of water to R. Sherbourne; the stretch shown had GQA scores for biology = E (poor) and phosphates = 4 (high) (EA 2007). Sub-catchment abbreviations: AS=Armstrong Siddeley; FL=Lanchester Library; GE=George Eliot; GS=Graham Sutherland; JL=John Laing; SI=Singer.

4.2.3 Problem locations - Water Quantity

4.2.3.1 Flood locations

The University suffered flooding of buildings in seven locations on 18 August 2006 as a result of surface water flooding (Fig. 4.2). These locations might benefit from runoff reduction SUDS.

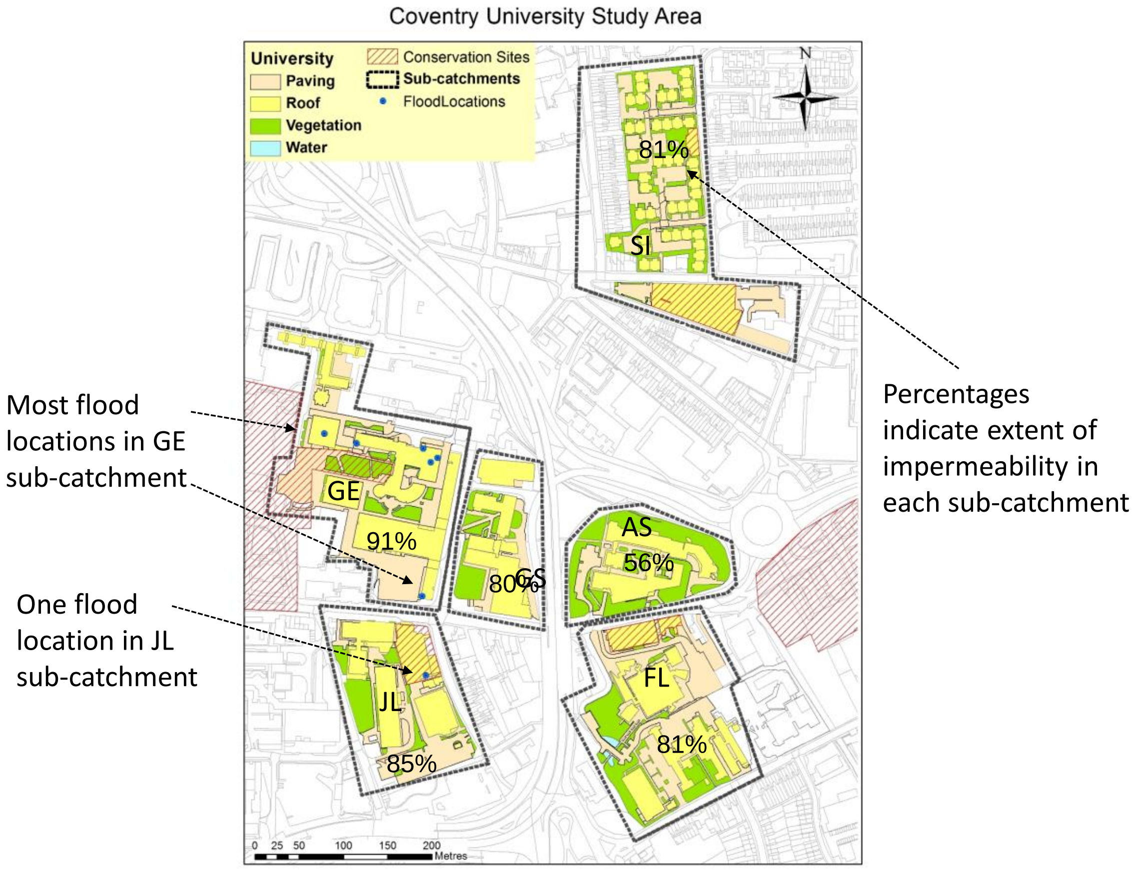


Fig. 4.2 Flood locations on Coventry University campus on 18 August 2006 due to surface water runoff. Flood locations were in the two most impermeable sub-catchments. Sub-catchment abbreviations as per Fig.4.1

4.2.3.2 GIS hydrological modelling

ArcGIS hydrological modelling (ESRI 2006) was undertaken to identify runoff flow paths and sites of water accumulation after rainfall. Fig. 4.3 depicts the runoff flowpaths and areas of flow accumulation for the western section of the pilot area.

GIS modelling using Lidar data did not provide sufficiently specific indication of the locations of known flood events in an urban area, and these techniques are probably more effective in rural areas with more homogenous land cover. Balmforth & Dibben (2006:5) considered Lidar to offer the most precise representation of topography of the available data sources, but the impact of factors such as abrupt, albeit relatively small, changes in surface level is not always captured due to the resolution of the dataset, although this factor can be important in detailed flood risk evaluation (Ellis *et al*. 2012). Telford & Wrekin Council (2008) concluded that GIS Slope analysis of a 3m resolution Lidar dataset gave a valuable initial view of flowpaths, but did not indicate flow depths, and that a finer resolution Lidar, with a hydrological modelling package, was needed for a more accurate assessment, but required higher cost and effort. In the pilot study, a relative view of flow depths was achieved with 10m resolution data, although the overall accuracy of the result was questionable.

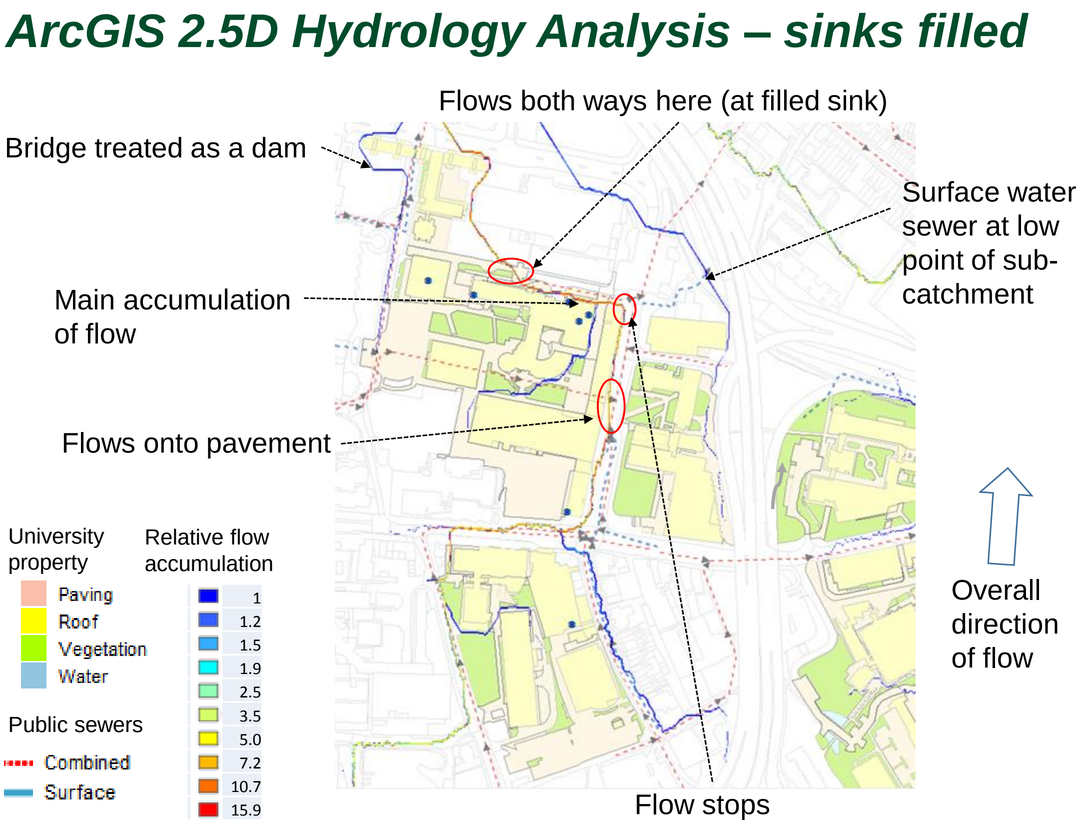


Fig. 4.3 Hydrological analysis output for the western section of the pilot area, where runoff accumulation flows were larger. Runoff, once it reached road carriageways, ran down road gullies. Some flow accumulation passed near three of the seven flooded locations, but flow paths ignored some real-world features. Sinks in the input Lidar data were filled before running the model, as recommended by ESRI. Non-University features outlined in grey.

4.2.4 Flood risk

EA fluvial flood maps (EA 2008c) and the Coventry level 1 SFRA (CCC 2008b) showed boundaries for 100- and 1000-year river floods, assuming that no flood defences were in place. Fig. 4.4 compares the flood plain definitions from these two sources. No buildings were within the 100-year flood plain, but four lay within the 1000-year risk zone. The SFRA 1000-year boundary covered a larger area than the equivalent EA 1000-year limit, so more university buildings were categorised at risk using SFRA modelling. There was some disparity between the precise route of watercourses and the associated flood risk boundaries, which may reflect anthropogenic re-engineering of river channels over time.

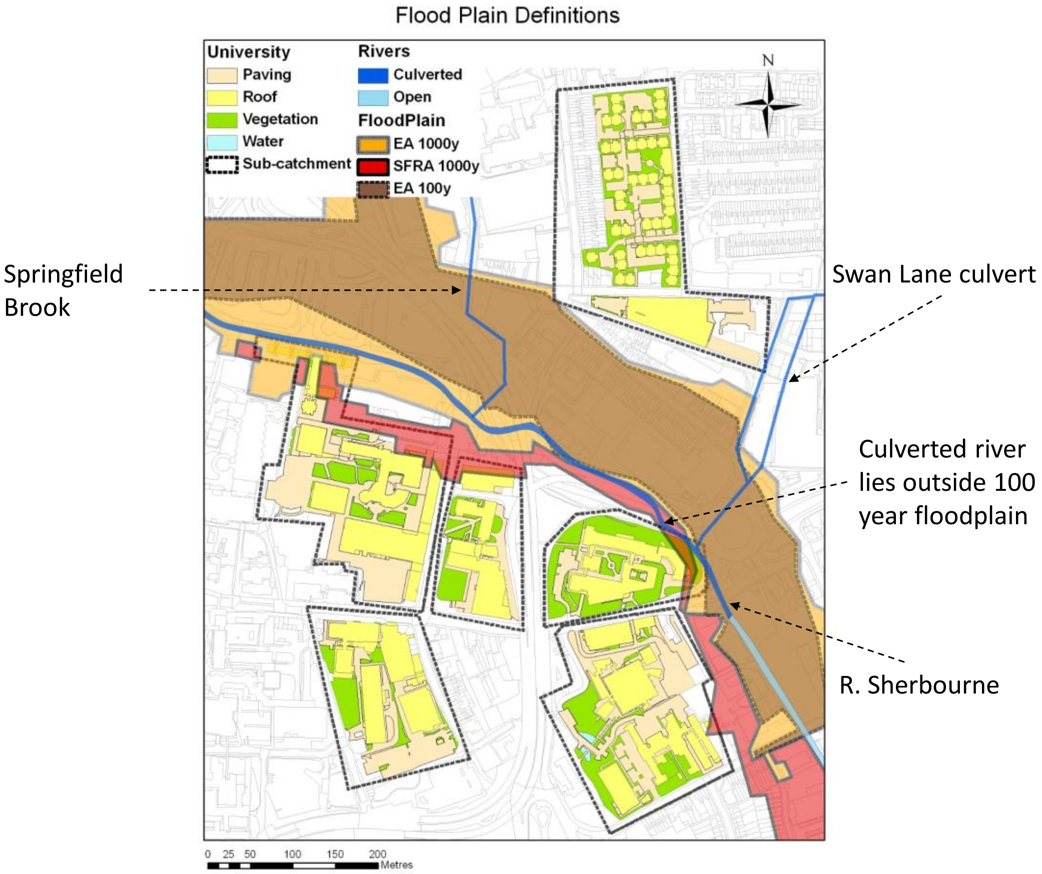


Fig. 4.4 Comparison of flood risk from the River Sherbourne according to EA and SFRA maps. Only zones impacting the campus are shown. For the SFRA 1000-year zone, only areas additional to the EA 1000-year zone are depicted. Data sources: CCC 2008b; EA 2008c

4.2.5 Hydrological assessment

This section summarises results of the hydrological investigation for runoff and storage requirements. Sub-catchment impermeability was a significant driver of SUDS feasibility in this research in determining the runoff and storage volume requirements, but the results obtained varied depending on the methods and equations used.

4.2.5.1 Runoff

If retrofits aimed to achieve the greenfield runoff rate of 4.59 $l\ s^{-1}\ ha^{-1}$, then a 34-38 times reduction was necessary to meet discharge limits for the five most impermeable sub-catchments, and 25 times for the most permeable Armstrong Siddeley sub-catchment (Fig. 4.5).

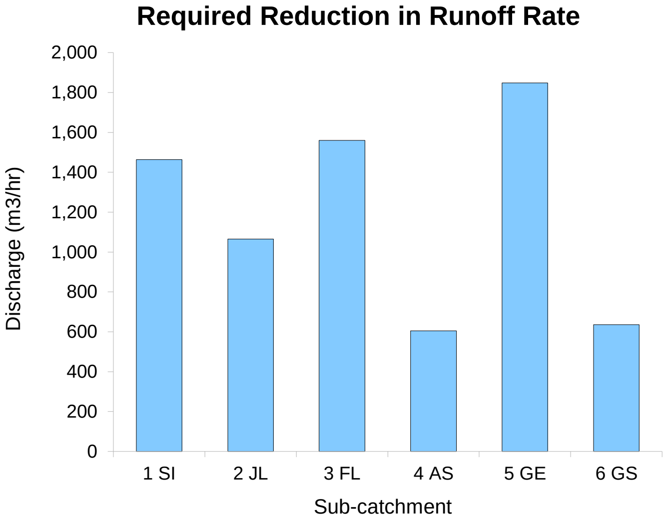
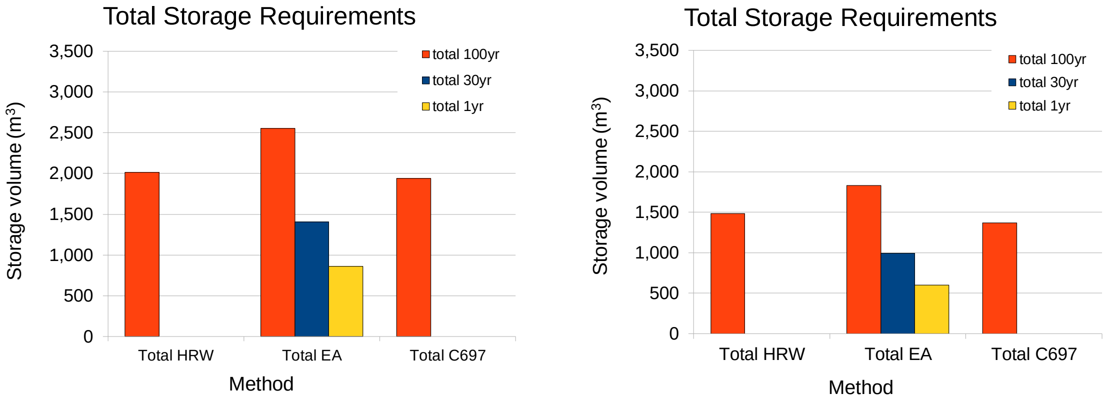


Fig. 4.5 Reduction in runoff rate necessary to achieve greenfield conditions, for each sub-catchment, calculated as the difference between the winter peak runoff rate and the discharge limit assuming no long-term storage

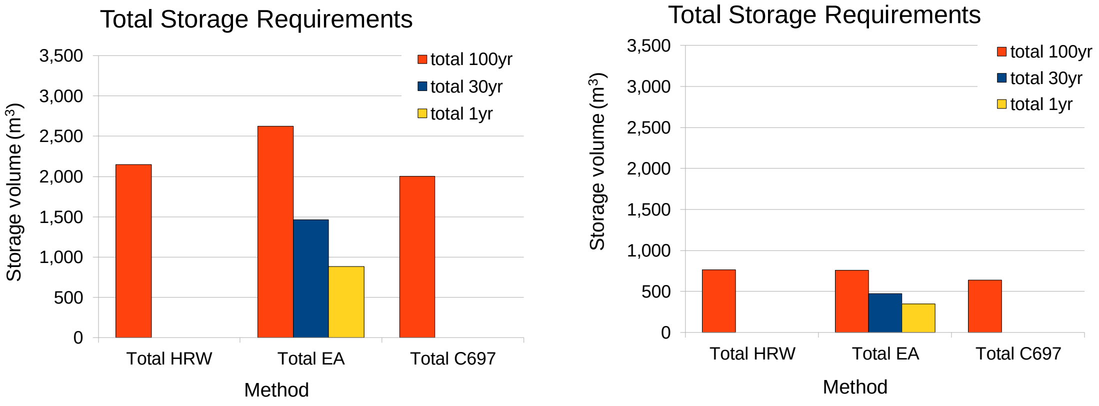
4.2.5.2 Storage Requirements

The total storage volume required for each sub-catchment in order to attenuate a 100-year 6-hour event flood is shown in Fig. 4.6. The greatest storage volume was required in the most impermeable GE sub-catchment, and the least in the most permeable AS sub-catchment. There was broad agreement between the values calculated using the HR Wallingford (2008) and Woods Ballard *et al*. (2007) methodologies for the 100-year return period, with a maximum 10% difference between these two methods across the more impermeable sub-catchments, and 19% in AS. In the five less permeable sub-catchments, the Defra & EA (2007) totals exceeded the HR Wallingford values by 21-32%. In the Armstrong Siddeley sub-catchment, only 1% difference separated the Defra & EA total from the HR Wallingford value.

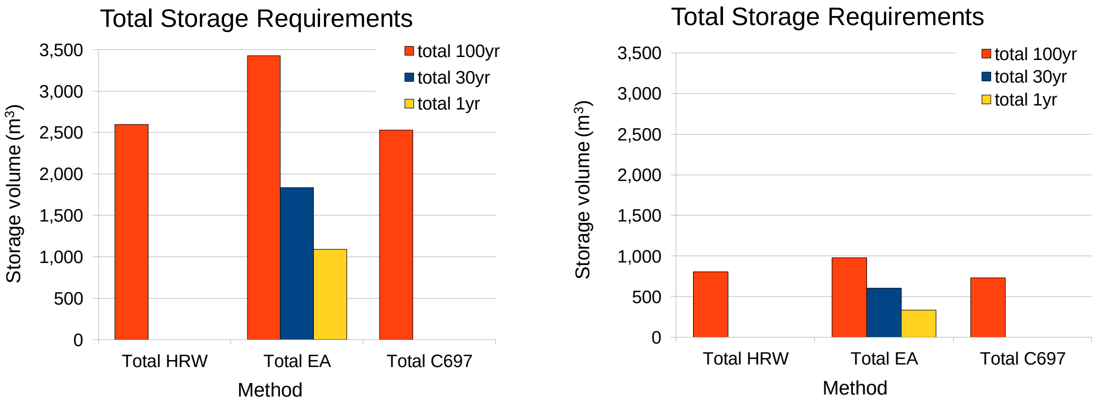
Only the Defra & EA methodology generated 1-year and 30-year totals. The 30-year total was 61-63% of the 100-year total for four sub-catchments (SI, JL, FL and GE); in the smallest sub-catchment, GS, it was 71%, and for the most permeable, AS, 55%. The 1-year total was 26-28% of the 100-year total for five sub-catchments, with AS slightly higher at 31%.



Singer **John Laing**



Lanchester Library **Armstrong Siddeley**



George Eliot **Graham Sutherland**

Fig. 4.6 Total storage volumes for each sub-catchment. Categories: HRW values from HR Wallingford (2008) methodology; EA values for 1-, 30- and 100-year return periods from the Defra & Environment Agency (2007) methodology; C697 values from Woods Ballard *et al*. (2007) methodology. Same scale on y-axis for all sub-catchments.

The most apparent outcome of the storage requirement investigation was the variability across values obtained using the different methods. Consequently, each storage type was assessed to determine a relevant value before calculating the total storage volume requirement per sub-catchment (Table 4.4). The 100-year total storage volume according to the HR Wallingford method was within 19% of the Woods Ballard *et al.* figure in all sub-catchments. The difference between the total storage volume requirements determined using the HR Wallingford methodology compared to the Defra & EA methods for the five more impermeable sub-catchments ranged from 21-32%, while the difference between the Woods Ballard *et al.* and Defra & EA methods lay between 31-35%. The difference between methods in the more permeable AS sub-catchment was -1% and 18% respectively. The Defra & EA volumes appeared to over-estimate the total storage volume due to the absence of rules concerning the extent to which volumes were duplicated among storage types. Based on the r^2 value of a linear trend, sub-catchment impermeable area was the best predictor of storage volume requirements (Table 4.5). There was no relationship between sub-catchment permeable area and storage volume.

Table 4.4 Summary of storage volumes derived using the hydrological assessment methodologies. Total storage = Interception + Treatment + relevant Attenuation value. Treatment volume excludes the interception value. These volumes were used in evaluation of storage requirements in the pilot study. All volumes in m^3.

Sub-catchment	**1 SI**	**2 JL**	**3 FL**	**4 AS**	**5 GE**	**6 GS**
Area (ha)	2.70	1.89	2.89	1.62	3.05	1.19
Storage Type						
Interception	110	80	117	46	138	47
Treatment	219	160	234	91	277	95
Attenuation 1-year	446	300	440	154	581	151
Attenuation 30-year	991	693	1,021	276	1,326	420
Attenuation 100-year	1,751	1,289	1,868	653	2,263	693
Total 1-year requirement	775	540	791	291	996	293
Total 30-year requirement	1,320	933	1,372	413	1,741	562
Total 100-year requirement	2,080	1,529	2,219	790	2,678	835

Table 4.5 Relationship between sub-catchment characteristics and storage volume requirements (r^2 - square of Pearson's product moment correlation co-efficient - linear trend)

Characteristic	1-year	30-year	100-year
Percentage impermeability	0.48	0.56	0.50
Sub-catchment area	0.93	0.89	0.93
Sub-catchment impermeable area	1.00	0.99	1.00
Sub-catchment permeable area	0.02	0.05	0.02

4.2.6 SUDS decision support tools

The suitability of a range of SUDS devices at Coventry University is summarised in Table 4.6. The devices included were those proposed by the six decision methodologies evaluated in the pilot study. Most devices were, in practice, suitable for the inner city site, the restrictions being those of land take for wetlands, and poor infiltration characteristics. Results from the six decision-support methods evaluated to determine their recommendations for SUDS techniques in the pilot study area are summarised in Table 4.7, which shows a lack of agreement about the most appropriate devices for this inner-city site. Permeable paving and swales were the most frequently identified techniques.

Table 4.6 Suitability of SUDS devices at Coventry University. Descriptions taken from Woods Ballard *et al*. (2007).

Table 4.7 Summary of techniques proposed by applying the existing methodologies, based on the particular circumstances of the pilot site. Key to methodologies: D'Arcy = D'Arcy & Wild (2003); Ellis = Ellis *et al*. (2004b); HRW = HR Wallingford (2008); Scholz A = Scholz (2006) decision-support key; Scholz B = Scholz (2006) decision-making matrix; Swan = Swan/Stovin hierarchical framework (SNIFFER 2006)

Sub-catchment	**1 SI**	**2 JL**	**3 FL**	**4 AS**	**5 GE**	**6 GS**
SUDS feature	**Singer**	**John Laing**	**Library**	**A.Siddeley**	**George Eliot**	**G.Sutherland**
Source controls	Swan	Swan	Swan	Swan	Swan	Swan
Green roof	HRW	HRW	HRW Swan	HRW	HRW Swan	HRW Swan
Rainwater harvesting	HRW Swan	HRW	HRW Swan	HRW	HRW Swan	HRW
Permeable paving	HRW Swan D'Arcy	HRW Swan D'Arcy	HRW Swan D'Arcy	HRW Swan D'Arcy	HRW Swan D'Arcy	HRW D'Arcy
Site controls				Swan		
Filter strip	Scholz B				Scholz B	
Infiltration devices	Scholz B	Scholz B	Scholz B	Scholz B	Scholz B	
Detention basin	D'Arcy	D'Arcy	D'Arcy	Swan D'Arcy	D'Arcy	D'Arcy
Pond	Scholz B	Scholz B	Scholz B	Scholz B	Scholz B	Scholz B
Swales	HRW D'Arcy Ellis	HRW D'Arcy	HRW D'Arcy Ellis	HRW Scholz B D'Arcy	HRW D'Arcy Ellis	HRW D'Arcy
Swale with pond	Scholz B				Scholz B	
Small vegetated bio-retention features	HRW Swan	HRW Swan	HRW	HRW Swan	HRW	HRW
Underground storage	Scholz A Scholz B	Scholz A Scholz B	Scholz A Scholz B	Scholz A Scholz B	Scholz A Scholz B	Scholz A Scholz B

Colour key to number of times proposed: 🟩 3 🟧 2 🟨 1 ⬜ 0

Table 4.8 shows the number of times each methodology identified appropriate SUDS, evaluating each sub-catchment separately, in comparison to the suitability defined in column ‘Suitable for University’ in Table 4.6. SUDS devices that were proposed by each decision methodology and were defined as suitable in Table 4.6 were allocated a ‘suitable’ score. SUDS devices that were proposed but were not suitable were allocated an ‘unsuitable’ score. Unsuitable proposals were deducted from the total score since they were likely to be ineffective, but would have cost time, effort, space and money to implement. HR Wallingford (2008) was the only method to achieve a score for practical suggestions across all types of SUDS exceeding 50%. Evaluation techniques that included source controls identified a higher proportion of appropriate SUDS devices.

Table 4.8 Efficacy of existing methodologies for new build SUDS proposals, determined from the number of times that appropriate techniques were proposed, reduced by inappropriate SUDS. See Table 4.7 for key to methodologies

Methodology	Source Control	Site Control	All SUDS
D'Arcy	33%	28%	30%
Ellis	0%	10%	6%
HRW	100%	34%	60%
Scholz A	0%	21%	13%
Scholz B	0%	3%	2%
Swan	61%	14%	32%

4.2.7 Retrofit SUDS suitability for the pilot site

4.2.7.1 Applicability of SUDS devices to Coventry University campus

Existing tools proposed a wide range of SUDS devices (Table 4.7), and their suitability at Coventry University is summarised in Table 4.6. Detailed design would be necessary to confirm any proposals.

4.2.7.2 Potential locations for retrofit SUDS

4.2.7.2.1 Example One – Sub-catchment

The least impermeable sub-catchment, Armstrong Siddeley (56.4%), offered scope for retrofitting the greatest number of SUDS techniques. The 1.62 ha sub-catchment was characterised by some noticeable gradients (3.6% overall drop) and also by topographical variability. Existing permeable area slightly exceeded 7,000 m^2, while paving covered approximately 3,400 m^2.

Filter strips would be most beneficial to receive runoff from car parking areas (points 1 - 3 on Fig. 4.7). However, the topographical gradient at points 1 and 2 was away from existing vegetated areas, and installation of new 6 m wide filter strips was unlikely as it would remove parking spaces. The grass strip downslope from car park 3 (point 8) was not wide enough to contain a 6m filter strip unless the access pavement were removed (point 9).

A detention basin was only practicable at point 4, to capture roof runoff from the Armstrong Siddeley building. Landscaping work would be required. Electrical cabling ran underground to the William Lyons building through this area, so a more detailed survey would be needed to ensure land usage compatibility. A small detention basin was considered at point 5 to capture roof runoff from the Jaguar building. Part of the grassed area was subject to water logging (point 6), indicating poor infiltration capability. However, health and safety concerns were raised by the Estates Dept. that standing water could dislodge kerbing stones and cause a trip hazard.

Small swales (point 7) might replace the small concrete open drainage channel to the west of Armstrong Siddeley, and could convey water to the detention basin. Assuming effective depths of 40 cm for both detention basin and feeder swales, 119% of the 1-year attenuation storage requirement (346 m^3) could be achieved, equal to 44% of the 100-year requirement.

If a high volume of rainfall were to fill the detention basin, excess water would run off down-slope, as happens without a detention basin. The soil type was not conducive to infiltration, although some water would percolate into the ground surface. Evaporation will account for some dispersal, but relying on infiltration alone, water in the full detention basin and swales would take weeks to drain down, leading to water logging and effectively turning the detention basin into a retention basin. Recommendations are that half the storage should empty within 24 hours to cater for a further rainfall event (Kellagher 2004b:180). Installing an outlet to release water at low flow rates to the drainage system would require additional infrastructure. This would achieve the goal of runoff rate reduction, but would make a minimal contribution to reduction of runoff volume.

Permeable paving could meet the total 100-year rainfall storage requirement by converting 50% of the existing paved area to permeable paving, and providing aggregate with sufficient void space, or underground storage devices, to a depth of approximately 0.5 m. Underground storage is less preferable than vegetated SUDS as it possesses limited biodiversity/amenity value and provides little treatment (HR Wallingford 2008; Schueler *et al*. 2007:15), although overlying permeable paving has the capability to deal with pollution arising from car parking areas (Newman *et al*. 2004), so would be a feasible option for points 1, 2 and 3 (Fig. 4.7). However, the steeper gradient on the car park at point 1 (around 7%) suggested points 2 and 3 as easier installation sites. The possibility of linking underground storage with a detention basin would be hampered by the site layout, with the AS and WL buildings dividing the two locations. Stored water might be utilised for grounds maintenance, as at the time of the pilot the University did not employ rainwater harvesting techniques on the inner-city campus for any purpose. Installing swales, a detention basin and permeable paving with associated underground storage in half of the existing paved area would meet the 100-year attenuation volume requirement, effectively returning the sub-catchment to greenfield runoff rates.

Existing shrub beds (point 10) could be converted into bio-retention features by replacement of some elements of the lowest brick course with inlet structures. Even this small measure, assuming a 10 cm infiltration depth, would deliver the 5 mm interception volume requirement for the whole sub-catchment.

Although the University's Estates Dept. had concerns about the extent of possible remedial preparation work, green roofs could be installed on all buildings in the sub-catchment (point 11) in order to contribute to treatment volume requirements. All had flat roofs, and were of older construction date, thus more likely to have the required structural strength. A later campus building, the Lanchester Library constructed in 2000, had the capability to support a green roof (Charlesworth *et al*. 2013). If 50% of the available roof surface in the AS sub-catchment were occupied by an extensive green roof, with a 15 cm substrate depth and 30% void space, 94% of the combined interception and treatment volume from 15 mm of rainfall could be attained (141% of the treatment volume). The Swan/Stovin hierarchical framework highlighted the value of using large roofs as surfaces for SUDS retrofit. However, Schueler *et al*. (2007:129) considered that large non-residential roofs were likely to be less cost-effective than bioretention devices, water butts and simple disconnection, although these options would offer fewer attenuation opportunities than green roofs due to the building and landscape configuration in the sub-catchment.

The presence of few external downpipes resulted in limited opportunities for rainwater harvesting and downpipe disconnection in the sub-catchment (point 12). If used as a stormwater attenuation facility, the storage tank would require emptying before a significant rainfall event to ensure full design criteria were achieved. The practicalities of managing this operationally on a large campus reliant on maintenance staff being permanently available made its implementation improbable.

In summary, installation of a detention basin and feeder swales, permeable paving with underground storage for 50% of the existing paved area, green roofs covering 50% of the flat roofs, and bioretention features, if suitably configured, could meet 100% of interception storage requirements, 141% of the treatment volume, and 144% of the 100-year runoff storage requirement for the Armstrong Siddeley sub-catchment. Although a fully vegetated SUDS management train would be an ideal solution to address water quality, quantity and amenity issues, in terms of retrofit in a densely developed urban environment, a mixed solution of sustainable and conventional drainage, incorporating underground storage, would offer a means of addressing the issues currently associated with surface water management in England.

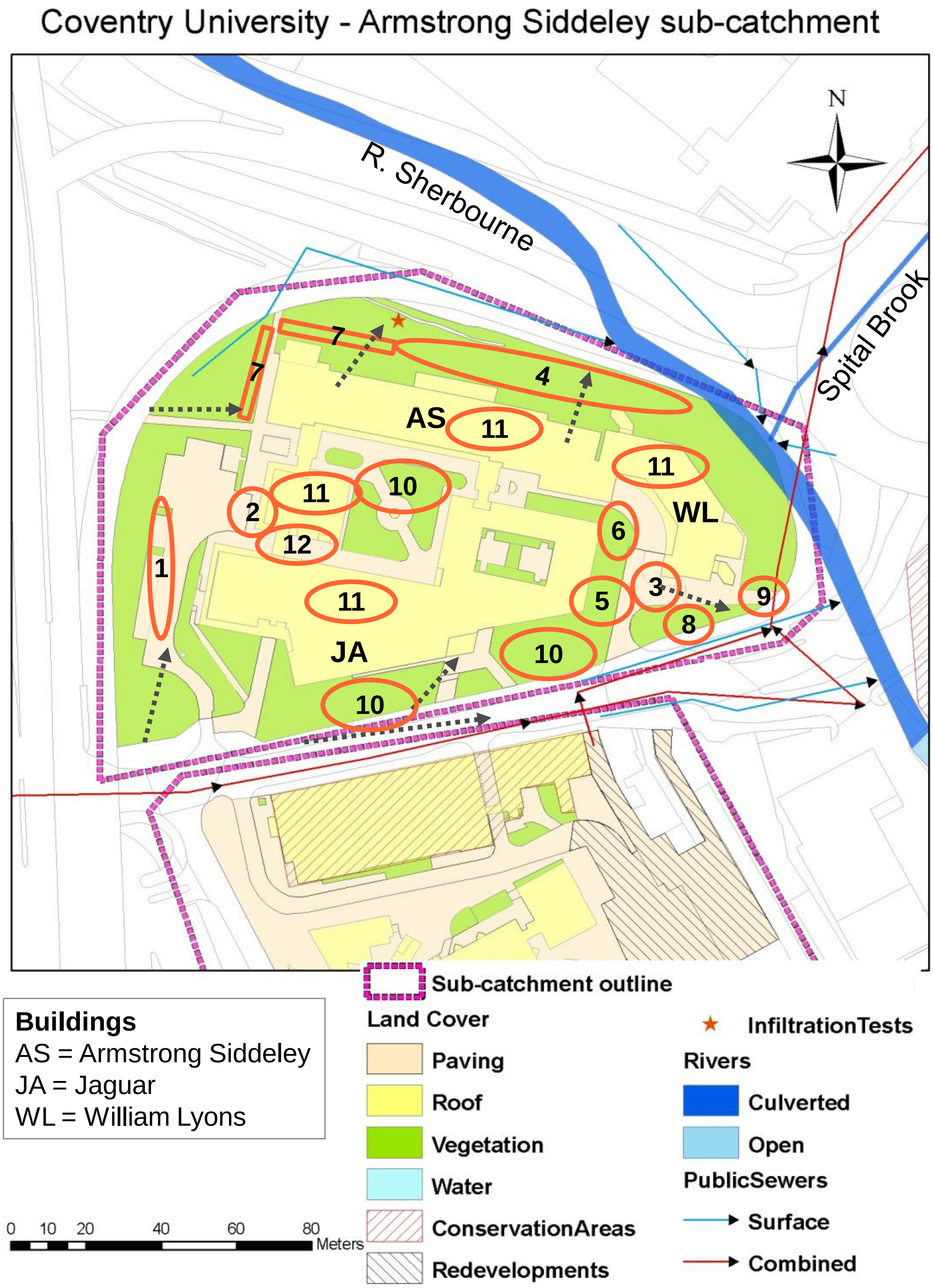


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Fig. 4.7 Armstrong Siddeley sub-catchment showing feasibility of SUDS features. Dark dashed arrows indicate the drainage direction at key locations. Point locations: 1) car parking area; 2) car parking area, potential for permeable paving; 3) car parking area, potential for permeable paving; 4) possible detention basin; 5) possible small detention basin; 6) grassed area subject to water logging; 7) small swales; 8) grass strip downslope from car park 3; 9) access pavement; 10) Existing shrub beds with potential for conversion to bio-retention features; 11) possible green roof installations; 12) downpipe. For discussion of marked points, see text.

4.2.7.2.2 Example Two - Green Roofs

The implementation of extensive green roofs across the campus could provide a noticeable attenuation of runoff volumes (Table 4.9).

Table 4.9 Potential impact of large-scale green roof implementation on runoff attenuation. The volume of rainwater stored by green roofs is based on a substrate depth of 15 cm and an assumption of 30% attenuation. Green roofs were assumed to cover 50% of actual roof area. The sub-catchment volume requirements for return periods were taken from Table 4.4

Sub-catchment	**1 SI**	**2 JL**	**3 FL**	**4 AS**	**5 GE**	**6 GS**
Area (ha)	2.7	1.89	2.89	1.62	3.05	1.19
Roof area (ha)	1.06	0.89	1.08	0.57	1.35	0.66
Percentage roof surface in sub-catchment	39.3%	47.2%	37.4%	35.2%	44.3%	55.5%
Green roof rainwater storage (m^3)	478	401	486	256	607	296
Percentage of 5mm Interception	554%	532%	556%	798%	496%	562%
Percentage of 15mm Vt + interception	185%	177%	185%	266%	165%	187%
Percentage of 1-year requirement	78%	79%	82%	125%	69%	91%
Percentage of 30-year requirement	46%	46%	47%	88%	39%	47%
Percentage of 100-year requirement	29%	28%	29%	46%	26%	32%

4.2.8 Summary of pilot site investigation

Based on the limited set of flood events available, surface water flooding and overland flow posed greater risk than fluvial flooding to Coventry University’s city centre campus. In urban areas of high impermeability such as this, where soil conditions are largely unsuitable for infiltration, a range of techniques exists to reduce runoff and surface water flood risk. Some techniques are easier to implement and more cost-effective than others, and a reduction in runoff rate was easier to achieve than lower runoff volume. Temporary detention of rainwater was achievable, but permanent infiltration of rainwater was not. Features that integrate into the existing landscape, such as bio-retention areas and permeable paving, were more likely to be perceived as acceptable. Retrofit of SUDS on Coventry University inner-city campus was shown to be technically feasible, and could contribute to reduced flood risk on and off campus, and improve local river water quality. Flood prevention measures might provide financial justification for SUDS retrofit at Coventry University, although economic analysis of the SUDS installation in the pilot study would be the subject of a separate study.

4.3 EXPANDING THE SPATIAL SCOPE

Whilst the pilot site of Coventry University's inner city campus covered 0.13 km^2, the full study area comprised the local authority area of the city of Coventry, covering 98.65 km^2, an increase in spatial area of approximately 740 times. Consequently techniques that may be appropriate for SUDS evaluation in specific locations may be less suitable across the whole city. This section reviews the applicability of the pilot outcomes for use at the LPA scale.

4.3.1 Pilot study methodology

The pilot phase evaluated the use of several techniques to assess potential for SUDS in an inner-city site, and Table 4.10 summarises their applicability at the broader scale. Apart from identifying the need for relevant data, none of the evaluation techniques assessed for the smaller scale of the pilot study were immediately useful. The decision chart feasibility assessment tools were less apparently applicable at the broader scale. The use of GIS to collate, analyse and visualise information was the principal technique taken forward to the strategic scale study.

4.3.2 Pilot study data

The majority of data types available for the pilot study was also available for the full study, albeit sometimes from different sources. The three principal differences are summarised below.

4.3.2.1 Land cover

For the pilot study, a field survey validation of OSMM, and the resulting modification of the baseline Ordnance Survey dataset (‘modified OSMM’), provided the most accurate characterisation of land cover. Shuster *et al*. (2005:270) suggest that an element of field investigation to validate land cover is always required, irrespective of data source. However, at the wider scale of the city, a detailed ground survey would be impractical. For the pilot study, the GLUD (DCLG 2007) land cover classification proved the most accurate without a detailed survey, and value of GLUD at the broader scale had been identified in other studies (e.g. Bibby 2009:S5; Ellis *et al*. 2011:1; TEP 2007:4), so GLUD land cover classes for the whole city were requested from DCLG. However, a hardware failure on the DCLG server rendered the relevant data unavailable for a critical period of nine months in 2009. DCLG could give no forecast of future availability, nor suggest an alternative source for retrieving the data. As a result, a revised land-use / land cover (LULC) classification was developed using the characteristics present in the OSMM dataset (section 3.7.2).

Some prior work on utilisation of MasterMap to assess urban flood risk (*e.g.* Diaz-Nieto *et al*. 2008:4) has accepted that OS land cover classifications are sufficiently accurate, while others (*e.g.* Viavattene *et al*. 2008:7) recognised the need to supplement OSMM with airborne photography such as Google Earth to provide adequate clarification of land cover. These results contrast with the work undertaken in the pilot study, where neither the MasterMap dataset nor satellite/aerial photography were sufficiently accurate at this scale.

4.3.2.2 Topography

Topography of the pilot site was determined from 1m resolution Lidar data. However, the size of the database (30 Mb) for a relatively small spatial area (5.6 km^2) rendered this detailed resolution difficult to process in ArcGIS v9.1 (ESRI 2006). Hydrological modelling trials in the pilot phase failed to produce any results until the resolution was coarsened to 10 m. For the larger city area, using the 1m resolution Lidar data with ArcGIS was considered impractical. As an alternative, a set of 10 m contour lines was sourced from CCC, and converted to a digital terrain model.

4.3.2.3 Sewer and drain locations and characteristics

Information on private and public drainage configurations would assist in determining appropriate locations for SUDS facilities. SUDS could help to address weaknesses in the current sewer layout and provide additional protection to deal with problems of water quality and quantity. In the pilot phase, the University's records of their private drainage system were inadequate for a detailed assessment, and insufficient time was available to undertake a detailed survey. Collecting information about drainage layouts from private landowners, assuming that such information existed, would require an excessive time commitment. Severn Trent Water made available a paper copy of the public sewer system layout surrounding the pilot site, but did not provide this data for the whole city.

Table 4.10 Applicability of pilot study techniques to wider strategic scale

Feasibility assessment technique in pilot study	**Applicability to strategic scale study**	**Major gaps**	**Notes**
Data collection	Identification and collection of relevant data		Availability dependent on individual datasets
Problem locations – water quality	Indicate locations where SUDS may be of benefit	Location of ‘public’ [sic] and private drainage systems unknown or unavailable	
Problem locations – water quantity	Indicate locations where SUDS may be of benefit	Lack of historical records	
GIS hydrological modelling		Known flood locations not accurately predicted	
Fluvial flood risk maps	Indicate locations where SUDS may be implemented	Only main rivers and some stretches of critical ordinary watercourses modelled	Discrepancy between EA and SFRA flood risk maps resolved after pilot phase. EA flood risk maps updated
Hydrological assessment of SUDS devices	Not applicable	The approaches used were designed for application with individual projects.	HR Wallingford (2008) tool restricted to 50ha. Defra & EA (2007) advised use of FEH procedures for developments larger than 200ha
SUDS decision support tools	GIS-based approaches useful in collating and visualising data	SUDS feasibility assessment tools evaluated in the pilot study applicable to individual developments	

4.3.3 Planning scale

Since LPAs have to address planning at a strategic scale, then arguably SUDS feasibility assessments are also required at this scale, in order to mirror the hierarchical approaches used in governmental surface water strategies. The need for different scales of assessment has been recognised by other decision framework approaches. For example, planning policy and guidance relating to water management in England utilises methodologies that cover different spatial scales. Prior to the introduction of the NPPF (DCLG 2012), Planning Policy Statement 25, Development and Flood Risk (DCLG 2010), defined a flood risk appraisal hierarchy from regional risk, through strategic assessments by local planning authorities, to site-specific assessments. Although regional assessments were abolished by the current government (Act of Parliament 2011:103) as being unaccountable (DCLG 2011:11), the need for neighbouring local authorities to cooperate on cross-boundary environmental issues such as flooding was recognised (DCLG 2011:14). Regional evaluations are employed in the Flood Risk Regulations (Act of Parliament 2009). Both EPA's SUSTAIN model (Shoemaker *et al*. 2009) in the USA and the European DayWater project (Förster *et al*. 2004) identified the need for decision-making at multiple spatial scales. Similarly, the Environment Agency's Water Framework Directive implementation approach (EA 2006c:14) encompasses river basin management planning by region, then, at a more detailed scale, Flood Management Plans and Abstraction Management Strategies for catchments within each river basin, through to local plans for each water body within the catchment.

In contrast, the SUDS decision-making tools evaluated in the pilot study addressed only the site scale. Since the pilot phase, more attention has been paid to feasibility assessment approaches that consider the broader scale, e.g. Moore *et al*. (2012); Shoemaker *et al*. (2009), and SWMP guidance identified possible benefits of applying a strategic approach to drainage planning across a wider area than individual site developments (Defra 2010a:xii), but the concept of a strategic-level SUDS assessment was not considered in the FWMA.

Applying lessons from the Lower Irwell SUDS mapping (Doncaster *et al*. 2008), the Defra SWMP guidance (Defra 2010b:42) suggested SUDS implementation could be guided by maps of ground conditions affecting infiltration and storage. However, the delay in producing SWMPs (section 2.2) has resulted in limited response to this advice. For a local planning authority, it is helpful to be able to identify which types of SUDS might be feasible at any location in their area, in order to undertake initial assessment of outline planning proposals and for evidence-based discussions with developers. A goal of the study was therefore to evaluate whether information could be derived from sources that are readily accessible to LPAs to generate a map of potential sites for SUDS feasibility to provide guidance for planners in discussions with developers. If greater emphasis will be placed in future on retrofitting SUDS in order to address issues of water quality and quantity, then an understanding of problem areas, additional restrictions, and the remaining potential locations, would help to speed up the steps identified in retrofit methodologies such as Claytor (1998:213), Schueler *et al*. (2007:191-232), and SNIFFER (2006:Fig. 5) of problem definition, identifying available data, and identifying feasible locations.

To date a number of studies, summarised in Table 2.3, have used GIS techniques to identify location suitable for land-use / land-cover (LULC) planning, and to determine the impact of LULC on hydrology. However, few authors have attempted to map SUDS feasibility at the strategic or regional scale in the UK, and they have emphasised infiltration solutions, based on a limited number of datasets. SUDS comprise a wider range of techniques than infiltration alone, so the feasibility of the whole range of SUDS techniques in a local planning authority area also needs to be portrayed in order to guide planners in relation to suitable SUDS techniques in areas under their jurisdiction.

4.4 FRAMEWORK TO CREATE SUDS GUIDANCE MAPS

Objective 1b was to construct a framework in order to evaluate suitable SUDS devices at the local authority strategic scale. Although one purpose of a framework is to support decision-making by enabling discussion between a range of stakeholders (Hurley *et al*. 2007:57), in this study the role of the framework was to establish a structure for considering which factors influence SUDS implementation at the strategic scale, and how they are related. This step occurs before stakeholder discussions are held.

The key determinands used in the framework were defined to be:

- Development Type
- Development Size
- Type of SUDS device
- Type of influencing factor, *e.g*. physical/environmental or anthropogenic/social drivers
- Likelihood of change in influencing factor (termed fixed or variable).

These are discussed in more detail below. There is more scope for SUDS implementation in new developments than when retrofitting, when a greater number of restrictions limits options, so the type of development influences SUDS feasibility. The size of the area affects which SUDS devices can be employed. While source controls require only limited space, features such as ponds and constructed wetlands occupy larger areas in order to operate effectively (Ellis *et al*. 2004b). In dense developments or existing sites where retrofit is investigated, the layout of built structures such as roads and houses will influence options for and placement of SUDS devices (Dickie *et al*. 2010). SUDS devices possess differing functions for managing water quantity and water quality issues, and therefore appropriate SUDS devices need to be selected for the problem being addressed, and the location in which it is addressed. SUDS are impacted by the characteristics of the environment in which they are placed, and a range of factors can influence SUDS selection and utilisation. These factors can vary over time, so it is relevant to understand the likelihood of change over the SUDS lifetime.

4.4.1 Structure of the theoretical framework

A 5-dimensional array was constructed to create a theoretical structure to show the relationship between the determinands and to build a framework to place factors influencing the feasibility of SUDS in a defined context (Fig. 4.8). Each intersection of the first three determinands, portrayed as a green box, gives rise to a set of conditions that may vary in relation to the influences on the potential for SUDS. To determine those influences, rules need to be applied, shown as a breakout box, where the types of influencing factor must be identified, in this instance classified as physical such as geology or anthropogenic such as land contamination. The likelihood of change in those factors is categorised as fixed where they are relatively stable over longer periods of time, such as soil type, and variable for those factors which may change over shorter timescales, such as land cover.

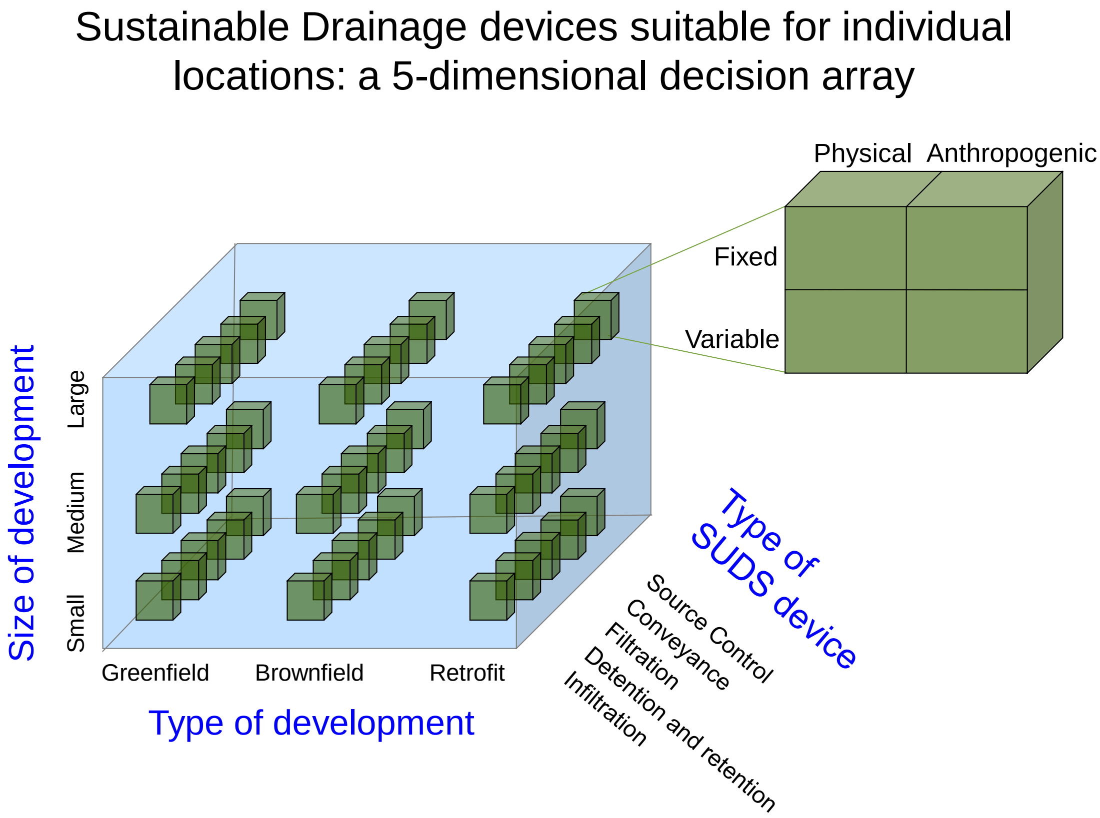

Fig. 4.8 Theoretical framework to identify locations for SUDS based on type and size of development

The framework in Fig. 4.8 does not consider the SUDS management train, nor the more specific nature of the development to be undertaken, and these are taken into account in an alternative representation in Fig. 4.9. Although the visual representation of Fig. 4.9 appears more complex, the only element that has changed is the number of components on the x-axis, which comprises eight land uses rather than three development types. The number of components in the management train is a function of the type of land use and the size of the development.

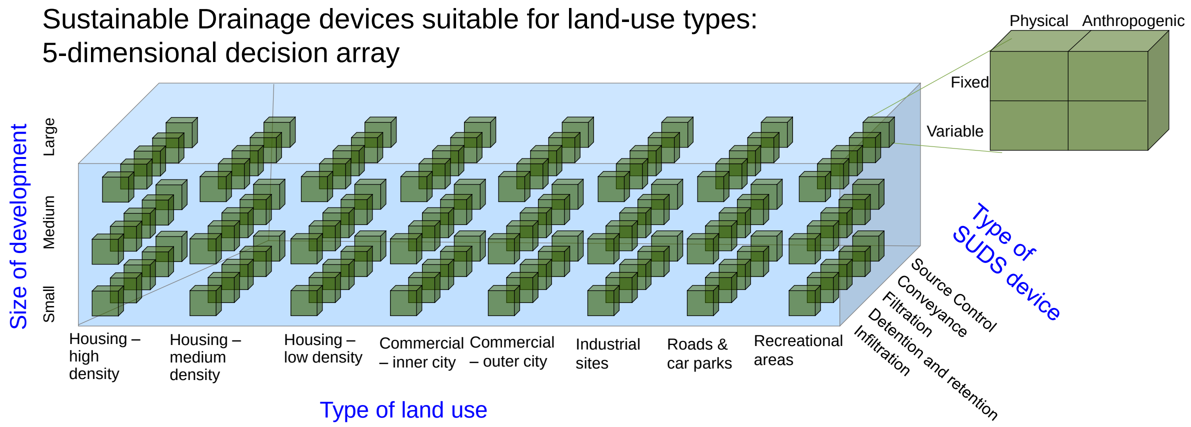

Fig. 4.9 Theoretical framework to identify locations for SUDS based on land use and size of development. The type of land use is from Table 4.13

4.4.2 Implementing the Framework

Figs. 4.8 & 4.9 represent a theoretical view of the framework. If Fig. 4.8 were to be represented in this form in a GIS system, then a set of decisions would be required for each box, so 180 (3x5x3x2x2) sets of possible options would need to be constructed. For Fig. 4.9, 480 sets of options would be required. Whilst possible, this would require a significant effort to build, and would not result in an easily understandable presentation for the end user. However, a number of simplifications were possible in order to transpose the theory into a working model resulting in a set of GIS-based maps to identify locations for feasible SUDS. The sequence numbers in the list below represent the stages in Fig. 4.10.

1. The initial simplification was to combine SUDS devices with similar functionality together into the five groupings defined in Table 4.11.

2. From Fig. 4.8, the type of development could be represented by whether the factors were fixed or variable. New developments, whether on greenfield or previously developed land, were not considered to be constrained by current land use, so equated to fixed factors. Conversely, retrofit needed to take into account both fixed and variable factors. The set of physical and anthropogenic factors influencing each SUDS type were determined. For some SUDS types, not all combinations were present, for example variable factors tended to be anthropogenic rather than physical – see the detail in Table 3.14.

3. The spatial extent of each factor was calculated based on its characteristics, for instance permeable versus impermeable bedrock geology, resulting in a set of GIS

layers for each combination of SUDS type and fixed and variable factors, represented by the image in Fig. 4.10.

4. Inclusion and exclusion rules were applied to each set of layers from step three to create a separate new development and retrofit layer for each of the five SUDS types, 10 layers in total.
5. Appropriate SUDS for different sizes of development were then allocated as a column (field) in each layer. The SUDS devices appropriate to each size and type of land use (Fig. 4.9) could also be included as additional fields.
6. The required number of management train components for each land use type could also be included as additional fields.

This procedure reduced the number of output GIS layers to a manageable total of 10, rather than the large numbers in the theoretical model.

The next chapter presents illustrative maps showing the spatial extent of influencing factors, and the SUDS location maps resulting from application of the framework.

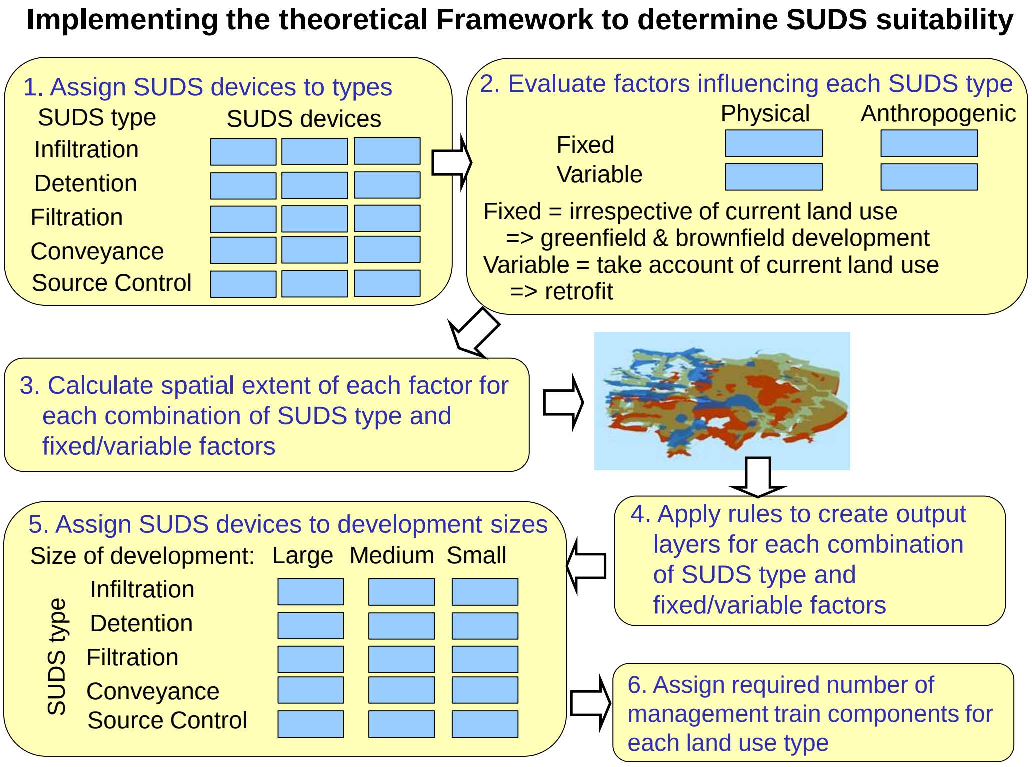

Fig. 4.10 Major steps to transform the theoretical framework to a set of GIS-based maps

4.5 SUITABILITY OF SUSTAINABLE DRAINAGE DEVICES

4.5.1 SUDS device groups

Objective 1c was to determine suitable SUDS devices for an urban local authority area. Table 4.6 showed that most SUDS devices were feasible even in the densely urbanised setting of the pilot site (mean impermeability 81%). Infiltration devices were not suitable due to the underlying ground conditions, nor were features with greater land take such as constructed wetlands. However, such SUDS devices might validly be used in a different location in Coventry. Therefore, no SUDS devices were regarded as inherently unsuitable in urban settings. Rather, their suitability derives from the underlying conditions found in the physical or social environment. Therefore, in order to establish which SUDS devices were feasible in specific sites, these practical restrictions must be taken into account, e.g. infiltration is not appropriate in all circumstances, some locations may benefit more than others due to existing issues.

At the broader spatial scale, Shoemaker *et al*. (2009) and Moore *et al*. (2012) have grouped SUDS into simplified functional categories to avoid problems associated with large datasets. SNIFFER (2004:4) concluded that the hydrological performance of SUDS devices was similar within categories of source, site and regional controls. Sustainable drainage devices were grouped into five over-arching categories according to functionality (Table 4.11), and individual sustainable drainage devices were allocated to these groups using a schema adapted from Woods Ballard *et al*. (2007:5.4). Devices were also classified based on their suitability for ranges of development size. The sizes indicated are only guideline values. The 1 ha boundary reflected the EA's (2009a) flood risk standing advice.

4.5.2 Generation of SUDS guidance maps

The process to derive SUDS guidance maps from the starting point of the SUDS groupings is summarised in Fig. 4.11. The detailed methodology is explained in sections 3.6-3.8, with an overview in Table 3.11. The decision to retain the detail in chapter three, rather than present it here, was made because subsequent methods rely on the detail, particularly in Table 3.14.

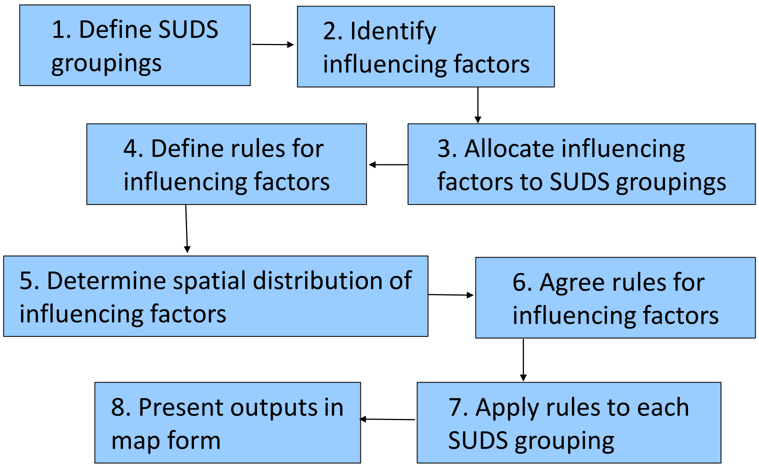

Fig. 4.11 Process to create SUDS guidance maps

Authors such as SNIFFER (2006:50) have identified relevant data to determine suitable SUDS, and Table 3.15 lists the datasets used for the strategic scale study. Table 3.13 develops an association between datasets and SUDS device groupings, while Table 3.14 shows in detail how the attributes of the individual factors were related to their influence on specific SUDS groupings, and identifies the specific threshold values applicable in Coventry. As recognised by Ellis *et al*. (2004a:256), most of the influencing criteria were physical constraints. At this strategic scale, rules were based on a number of simplifications with the potential to affect results, and this is considered in section 6.2. Where choices were made, a relatively conservative approach was taken to the inclusion of possible locations for SUDS. The resultant maps needed to be evidence-based, in order to possess credibility with stakeholders.

Table 4.11 Allocation of sustainable drainage devices to SUDS device groupings according to function and differing sizes of development. The primary role column indicates SUDS whose principal function is defined by the grouping, while secondary role lists other devices performing this function. The last three columns identify suitability in different sizes of development. Adapted from Woods Ballard *et al*. (2007:5.4)

SUDS device grouping	**SUDS Devices – primary role**	**SUDS Devices – secondary role**	**Small (<1 ha)**	**Medium (1-5 ha)**	**Large (>5 ha)**
Infiltration	Soakaway		X	X	X
	Infiltration basin			X	X
	Infiltration trench		X	X	X
		Swale		X	X
Detention and retention	Detention basin			X	X
	Retention basin			X	X
	Pond			X	X
	Wetland				X

SUDS device grouping	SUDS Devices – primary role	SUDS Devices – secondary role	Small (<1 ha)	Medium (1-5 ha)	Large (>5 ha)
		Sub-surface storage	X	X	X
		Rainwater harvesting	X	X	X
		Bioretention device	X	X	X
		Swale	X	X	X
Filtration	Sand filter		X	X	X
	Filter strip		X	X	X
	Filter trench		X	X	X
	Bioretention device		X	X	X
		Detention basin		X	X
		Retention basin	X	X	X
		Pond		X	X
		Wetland			X
		Swale	X	X	X
		Permeable paving	X	X	X
Conveyance	Swale		X	X	X
	Rill		X	X	X
Source Control	Green Roof		X	X	X
	Rainwater harvesting		X	X	X
	Permeable paving		X	X	X
	Sub-surface storage		X	X	X
	Trees		X	X	X
	Rain garden		X	X	X
	Disconnected downpipe		X	X	X
		Soakaway	X	X	X
		Infiltration trench	X	X	X
		Bioretention device	X	X	X

It was also necessary to consider the restrictions placed on implementation of specific SUDS devices which would preclude their use. Table 4.12 depicts an example high-level evaluation matrix (Ellis *et al*. 2004a:256) to identify factors that influence the use of individual SUDS techniques. In terms of the theoretical framework, Table 4.12 operates at the level of the breakout box shown in Figs. 4.8 and 4.9. Some factors, such as those in the final five columns, were not readily mappable at the strategic scale. This study did not take the same view as Table 4.12 for the criteria in red text. While agreeing that detention and retention basins and constructed wetlands were not restricted by gradient, more design input was likely to be needed to cope with steeper slopes, and so in this situation these structures were allocated to the engineered detention category. For grass swales and porous paving, several factors were regarded as precluding SUDS use by Ellis *et al*. (2004a). In Coventry these conclusions were seen as overly restrictive, and could be overcome with careful design. The factors considered in Table 4.12 are at a fairly detailed level appropriate for discussion about individual sites, but at LPA scale a higher level of factors was defined, as explained in sections 4.3-4.4.

Table 4.12 SUDS restrictions evaluation matrix. Cell shading indicates the view of Ellis *et al*. (2004a): green = generally not a restriction; white = restriction can be overcome with careful site design; orange = may preclude SUDS use. Text indicates the view of the current study: Y = generally not a restriction; N = may preclude SUDS use; 0 = restriction can be overcome with careful site design compared to the original recommendations Text in black indicates a common view between the two studies. Red text indicates where a different judgement was made for the Coventry study. Adapted from Ellis *et al*.

(2004a:Table 4) and Middlesex University (2003:Fig. 3.1)

4.5.3 The management train

The performance of SUDS, particularly in terms of water quality, will also be influenced by the type and number of devices, thus the definition of a management train to propose the required number of SUDS in particular settings was necessary. It was problematic to define the precise components of a SUDS management train in the context of map-based guidance, since the train will depend on the particular solution chosen for each development. Woods Ballard *et al*. (2007:3.12) proposed that different numbers of components are required depending on the type of development being served and receiving water sensitivity. These proposals rely on gross sediment loads being pre-screened to prevent them from reaching the first element of the train. A range of different development land uses was compiled, similar to those in Digman *et al*. (2012), and the number of treatment train components assigned according to size and type of land use – more details are given in Appendix I. Early versions of these SUDS decision support charts were reviewed with stakeholders.

Woods Ballard *et al*. (2007:3.12) specified only the minimum number of components for a relatively small 2 ha development, so their text comment relating to larger developments has been interpreted for Table 4.13 to cater for the higher pollution risks associated with larger or riskier sites. The number of treatment train components is not dependent on SUDS device types, rather on the nature of potential site pollution, so could not be included in Table 4.11.

Table 4.13 Minimum number of treatment train components depending on type of land use. Numbers assume that gross sediment loads are prevented from reaching the train. Adapted from Woods Ballard *et al*. (2007:3.12).

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5 RESULTS OF THE STRATEGIC SCALE INVESTIGATION

5.1 INTRODUCTION

This chapter addresses aim 2, to create and evaluate map-based recommendations of suitable SUDS devices for an urban local authority area. Sections 5.2-5.7 show the maps of suitable SUDS, based on the characteristics of a local authority area, using the example of the city of Coventry, created using the rules defined in section 3.8 (objective 2a). Sections 5.8-5.10 evaluate the suitability of the SUDS feasibility maps and the applicability of the approach (objective 2b). Sections 5.11-5.14 assess further potential applications of the SUDS feasibility maps (objective 2c). Sections 5.2-5.6 first present maps of influencing factors driving the feasible locations. Finally, two maps were created for each the five SUDS groupings, portraying locations for a) new developments on greenfield sites and previously developed land, and b) retrofit.

5.2 LOCATIONS SUITABLE FOR INFILTRATION SUDS

More factors influenced infiltration than the other SUDS groupings. Tables 3.19 and 3.20 identified the influences on SUDS infiltration solutions. Three stages of evaluation are represented as maps in this section:

- Physical factors influencing infiltration SUDS
- Anthropogenic factors influencing infiltration SUDS
- SUDS location maps.

Table 5.1 summarises the relationships between the maps presented in this section.

Table 5.1. Summary of figures for influencing factors and SUDS location maps for Infiltration, with the associated methodology

Influencing factors - Physical	**impermeable**	**permeable**
Fixed factors	Areas of physical impermeability	Areas of physical permeability not overlapping impermeable areas
Map figure	5.1	5.2
Methodology figure	3.17	3.18

Influencing factors - Anthropogenic	**Infiltration not possible**	**Infiltration possible**	**Infiltration requires investigation**
Fixed factors	Areas where infiltration is impossible due to fixed anthropogenic factors	Areas affected by fixed anthropogenic factors where infiltration is possible	Areas affected by fixed anthropogenic factors where infiltration requires investigation
Map figure	5.3	5.4	5.4
Methodology figure	3.19	3.21	3.21
Variable factors	Areas where infiltration is not possible due to variable anthropogenic factors	Areas affected by variable anthropogenic factors where infiltration is possible	Areas affected by variable anthropogenic factors where infiltration requires investigation
Map figure	5.5	5.6	5.6
Methodology figure	3.20	3.22	3.22

SUDS location maps	**New Developments**	**Retrofit**
	Areas where infiltration may be possible	Areas where infiltration may be used
Map figure	5.9	5.10
Methodology figure	3.16	3.16

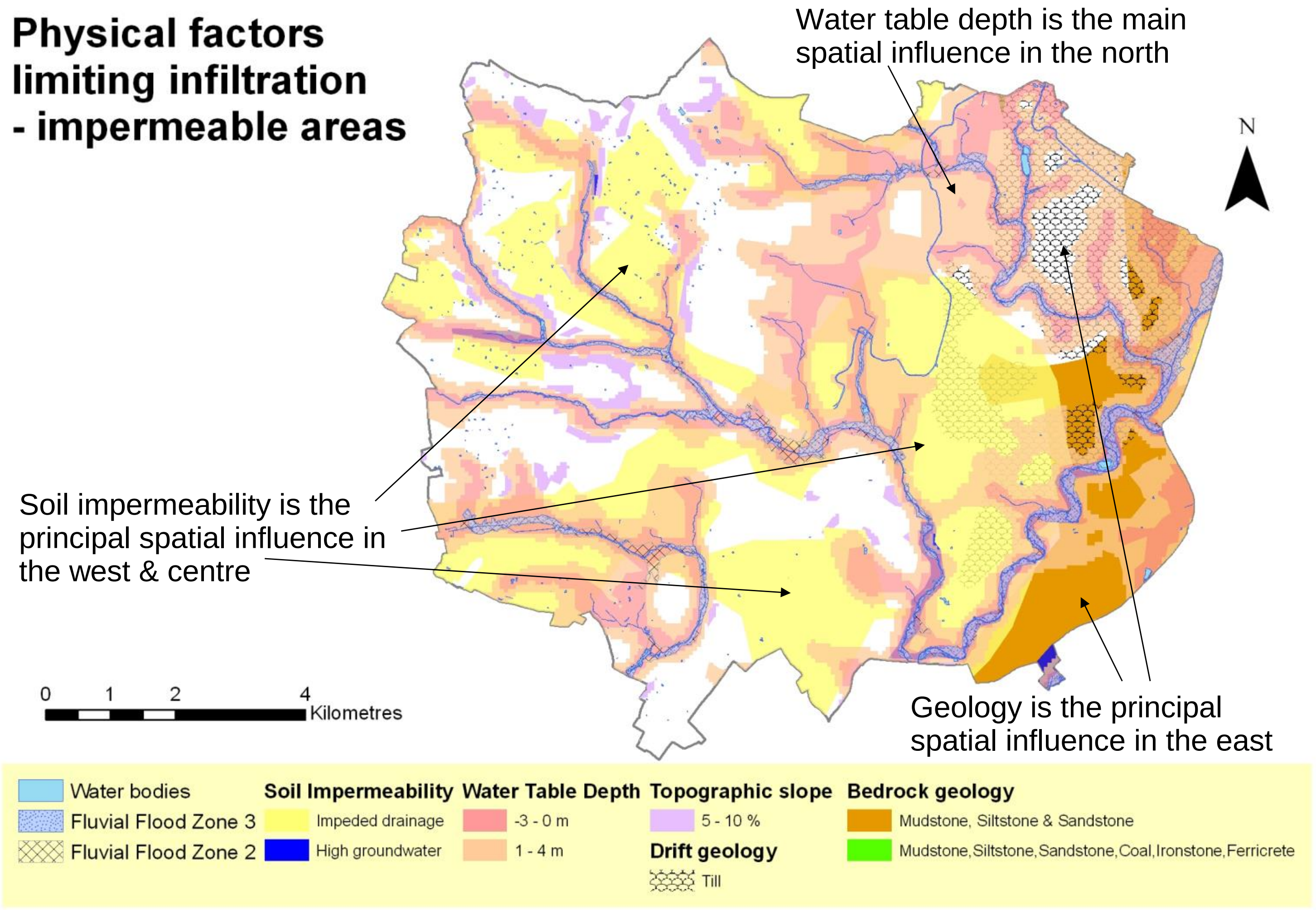
5.2.1 Physical factors influencing infiltration

Combining the factors from Table 3.19 resulted in a definition of the spatial location of areas that were:

- impermeable and therefore unsuited to SUDS infiltration solutions (Fig. 5.1)
- permeable and therefore suitable for SUDS infiltration solutions (Fig. 5.2).

Based on the assessment of physical factors, the majority of Coventry (83%) was unsuited to infiltration solutions (Fig. 5.1). In the east, bedrock and surface geology were the main spatial limitations, while in the north a shallow water table depth reduced the potential for infiltration SUDS. In the west and centre, soil impermeability was the main limiting factor. Rivers, streams and fluvial flood zones are accounted for by depth to water table.

SUDS infiltration solutions would be effective in a limited part of Coventry (17%), largely in the western half of the city (Fig. 5.2). No single factor emerged as a primary spatial influence.



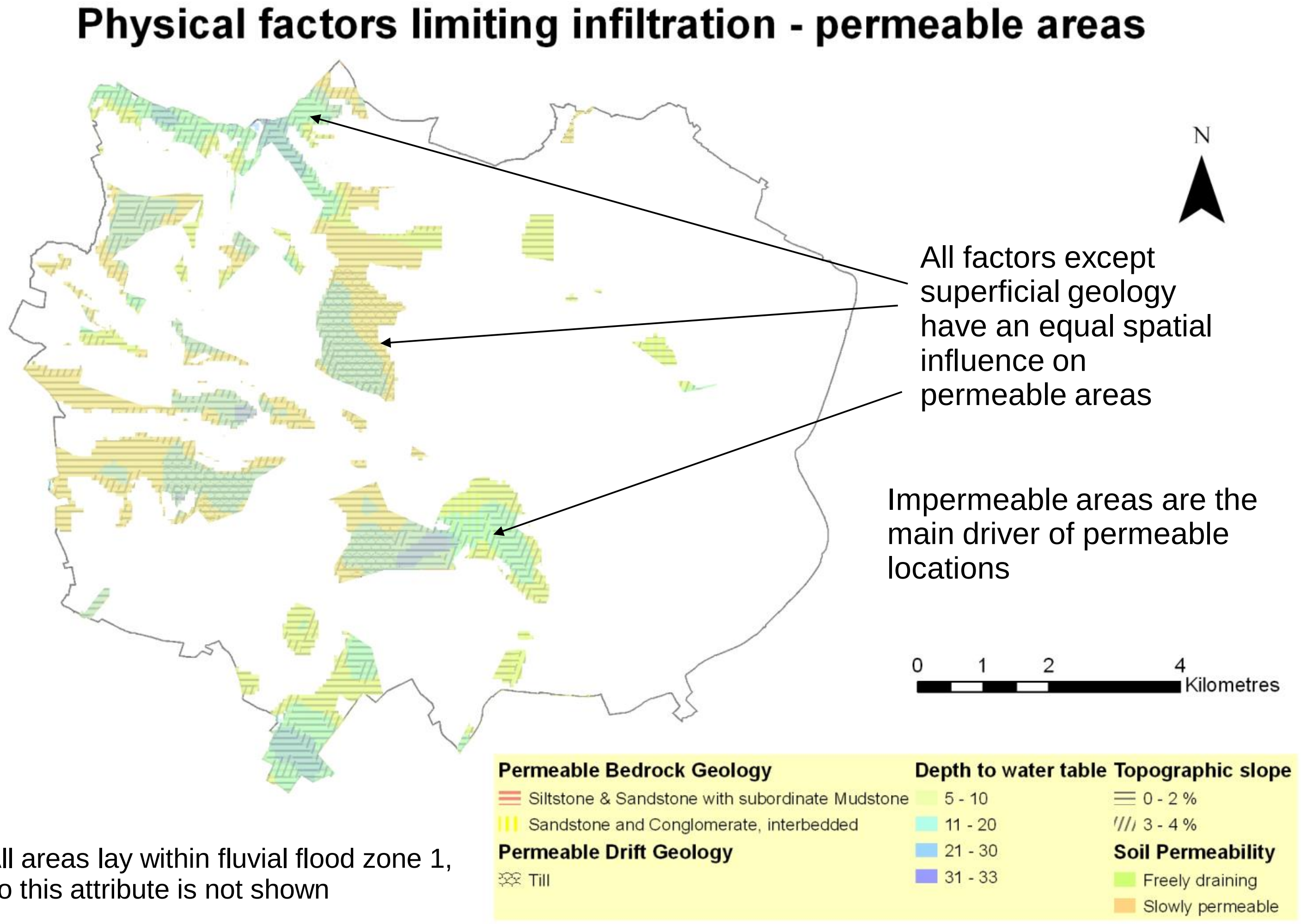
Physical factors limiting infiltration - impermeable areas

Water table depth is the main spatial influence in the north

Soil impermeability is the principal spatial influence in the west & centre

Geology is the principal spatial influence in the east

Fig. 5.1 Impermeable areas in Coventry resulting from physical factors limiting infiltration



All factors except superficial geology have an equal spatial influence on permeable areas

Impermeable areas are the main driver of permeable locations

All areas lay within fluvial flood zone 1, so this attribute is not shown

Fig. 5.2 Permeable areas in Coventry resulting from physical factors limiting infiltration. Areas that overlap with impermeable areas are excluded.

5.2.2 Anthropogenic factors influencing infiltration

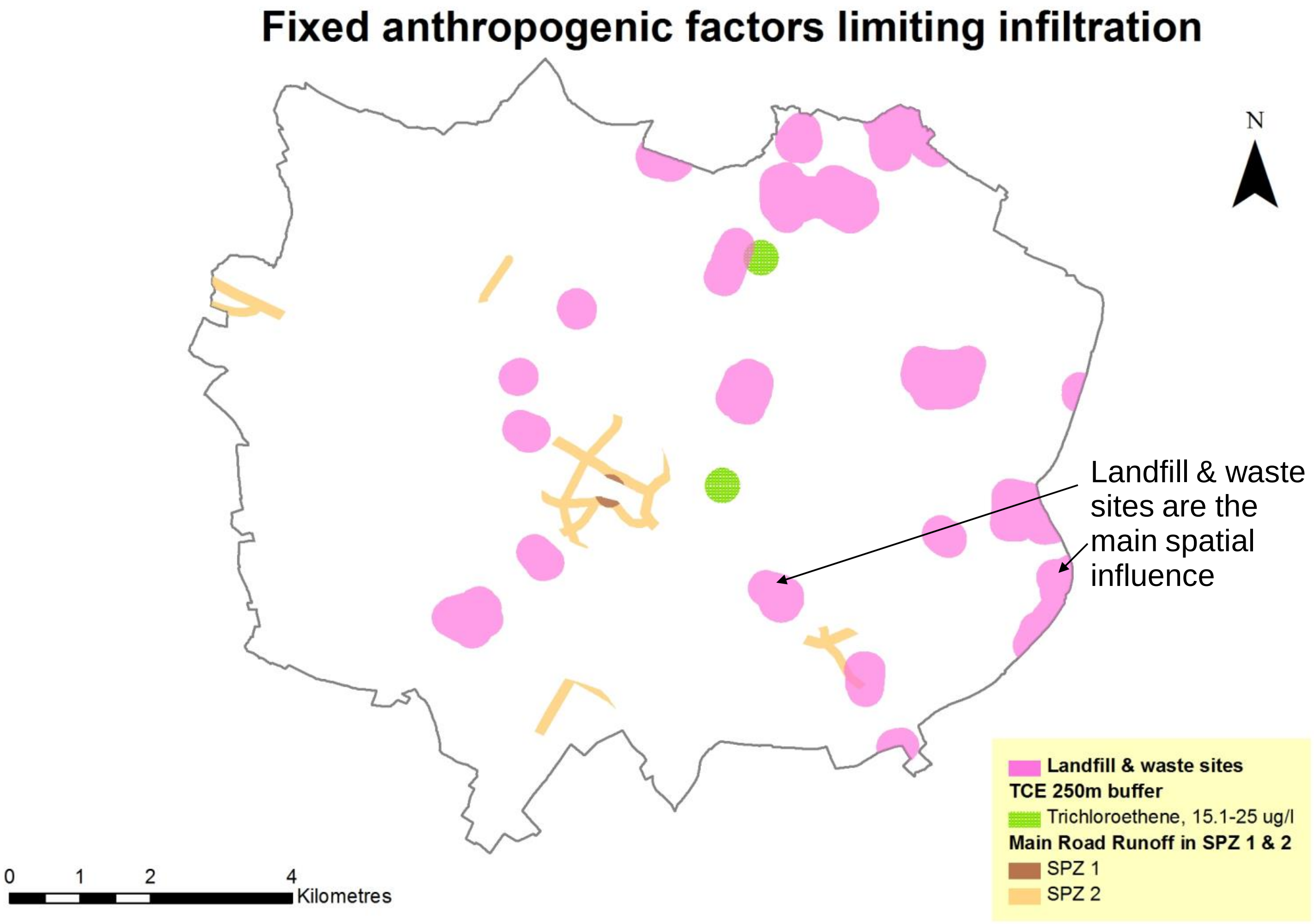
Combining the factors from Table 3. 20 resulted in a definition of the spatial location of areas where:

- SUDS infiltration solutions could not be implemented (Fig. 5.3 and Fig. 5.5)
- SUDS infiltration solutions are possible, although investigation into potential contamination may be necessary (Fig. 5.4 and Fig. 5.6).

Based on the assessment of fixed anthropogenic factors, 11% of Coventry was unsuited to infiltration solutions (Fig. 5.3). Current and former landfill and waste sites were the main spatial influence, located in the eastern and central areas. Variable anthropogenic influences inhibited infiltration in about 66% of Coventry's land area (Fig. 5.5), with buildings the main limiting factor throughout much of the city.

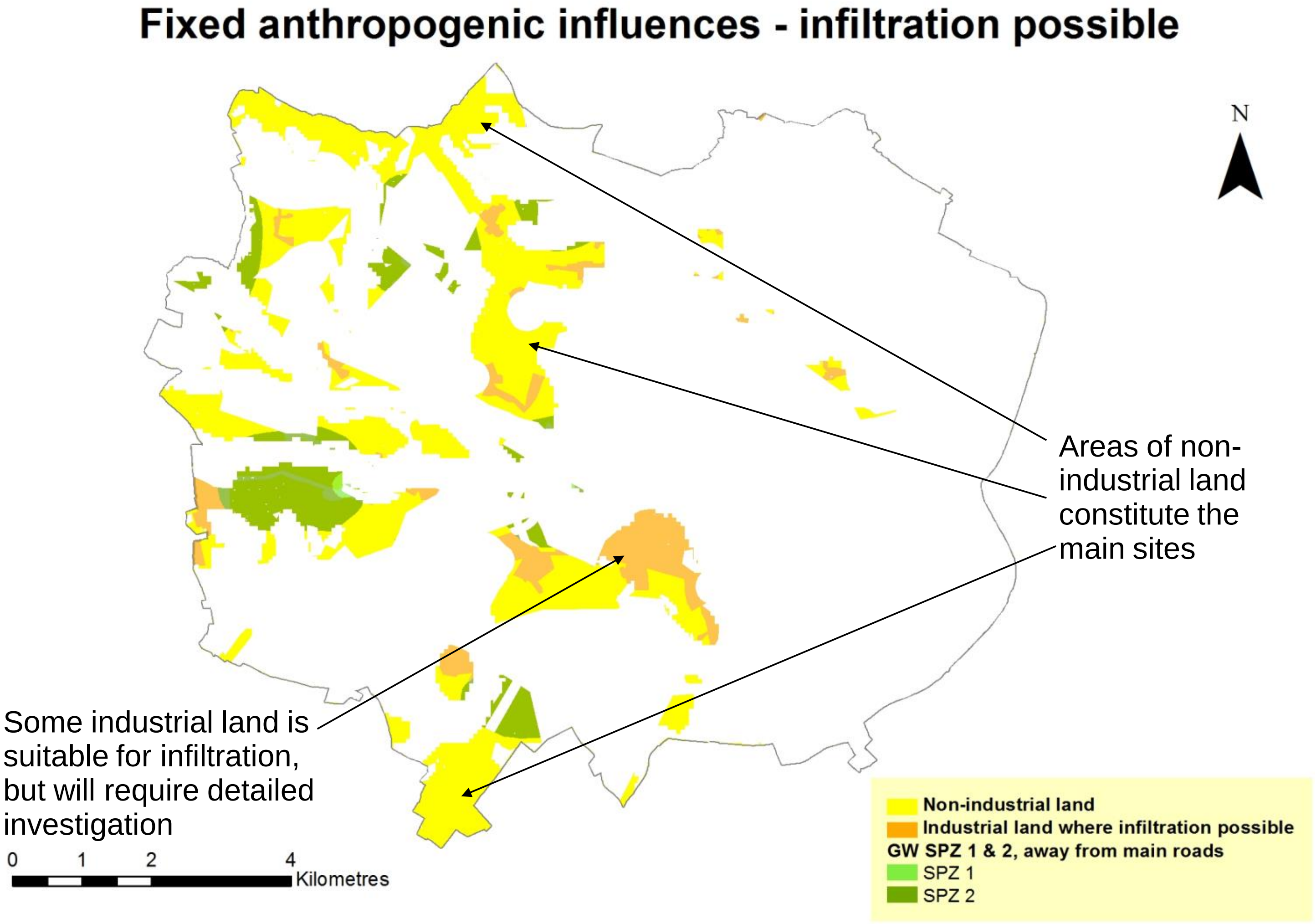
Excluding fixed physical and anthropogenic limitations, infiltration was possible in 14.4% of Coventry (Fig. 5.4), principally on land that has not been used for industrial or manufacturing purposes in the past. In addition, infiltration may be possible on previously developed industrial land (2.5% of the city), but more detailed site investigation of soil conditions will be necessary before deciding whether infiltration is appropriate.

Additional limitations (Fig. 5.5) restricted the locations available for retrofit (Fig. 5.6) to 10.6% of the city’s land area. Much of this land was greenspace in the west and south, with very little suitable space in the east and north. 1.3% of the available sites were former industrial land, requiring further investigation to determine feasibility for retrofit infiltration.



Landfill & waste sites are the main spatial influence

Fig. 5.3 Areas in Coventry where fixed anthropogenic factors render infiltration inadvisable. SPZ = Groundwater Source Protection Zone. TCE = trichloroethene



Areas of non-industrial land constitute the main sites

Some industrial land is suitable for infiltration, but will require detailed investigation

Fig. 5.4 Areas in Coventry where fixed anthropogenic factors render infiltration possible, although in some areas investigation of potential contamination may be required. Areas where infiltration was not possible are excluded.

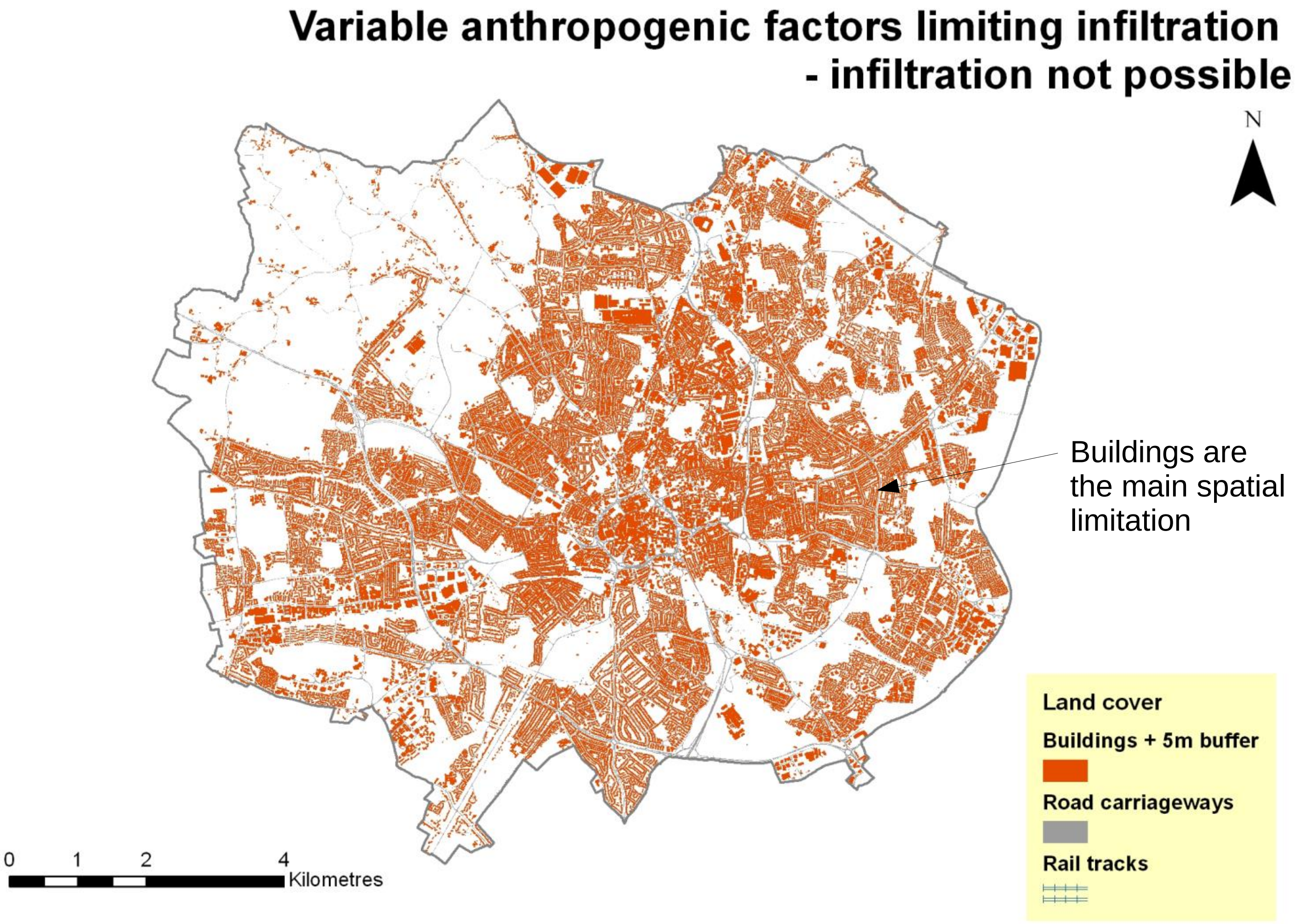
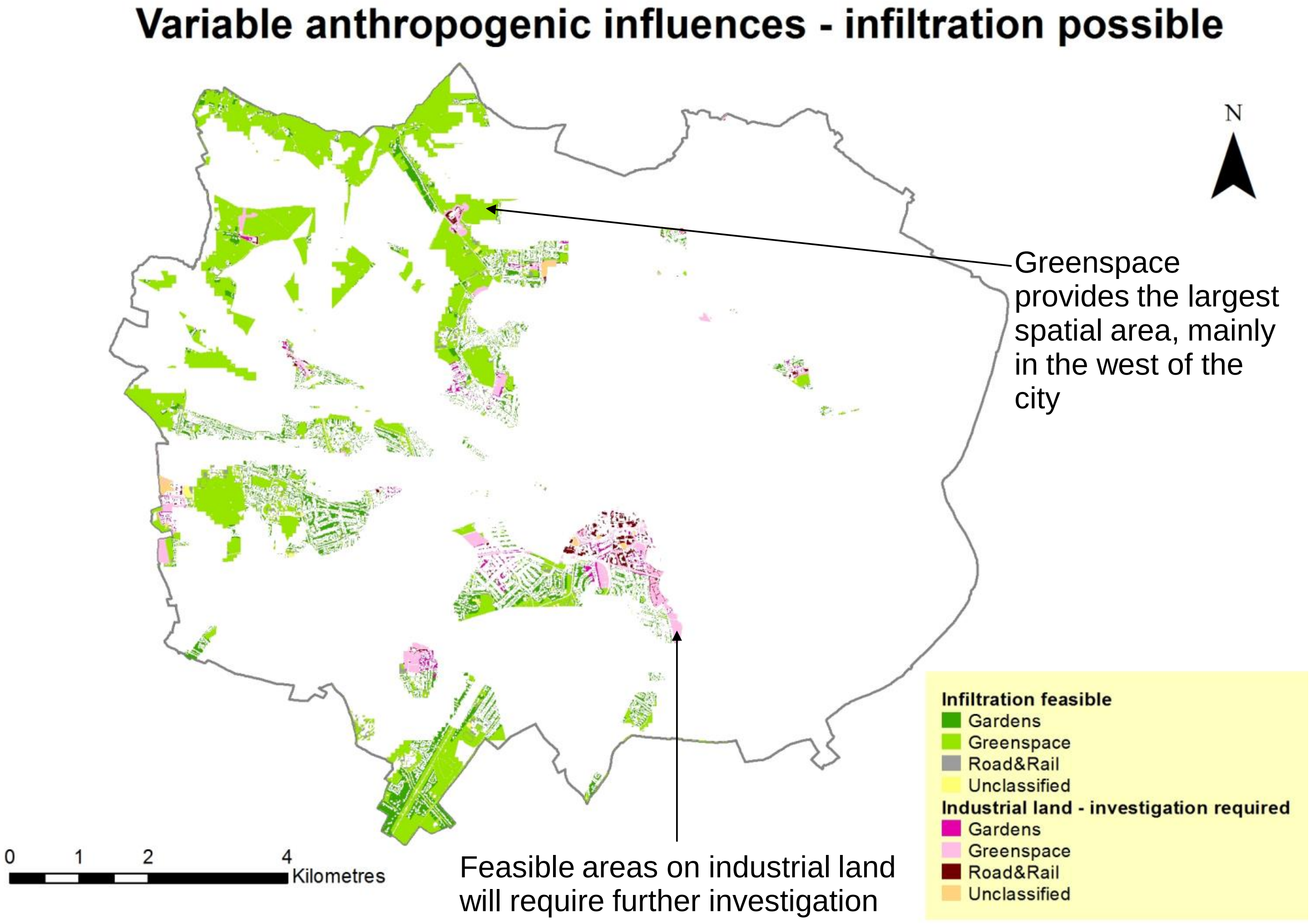


Fig. 5.5 Areas in Coventry where variable anthropogenic factors render infiltration impossible. Brighter colours indicate higher building density.



Greenspace provides the largest spatial area, mainly in the west of the city

Feasible areas on industrial land will require further investigation

Fig. 5.6 Areas in Coventry where variable anthropogenic factors render infiltration possible. Areas where infiltration was not possible are excluded.

5.2.3 SUDS infiltration feasibility maps

Combining the physical and anthropogenic influences on SUDS implementation resulted in overview maps of locations where:

- infiltration SUDS can be implemented in new developments (Fig. 5.9)
- infiltration SUDS may be retrofitted (Fig. 5.10).

Combining fixed physical impermeability factors (Fig. 5.1) and anthropogenic factors preventing infiltration (Fig. 5.3) resulted in a restricted area of Coventry (16.7 km^2, 17%) where infiltration SUDS would be possible in new developments (Fig. 5.7). Taking into account the additional restrictions placed on SUDS retrofit (Fig. 5.8), 10.6% of Coventry is suitable for retrofit infiltration.

Fig. 5.9 gives an overview at the city scale of locations suitable for infiltration in new developments. SUDS infiltration solutions would be effective in a limited part of Coventry (17.0%), largely in the western half of the city (Fig. 5.9). 47.9% of potential infiltration locations occupy greenspace, and 39.6% occur on greenbelt land (Fig. 5.11). Therefore, a focus on reusing previously developed land would further reduce the potential for infiltration SUDS in new developments. Almost all sites requiring further investigation prior to infiltration (97%) were outside the greenbelt (Fig. 5.11).

Compared to infiltration potential in new developments, the greater restrictions placed on retrofit reduce the available area to 7.8 km^2 (7.9% of the city), a reduction of 37% compared to new development sites (Fig. 5.10). Most of the locations (74%) available for retrofit infiltration were situated towards the perimeter of the planning authority area, with sites in the inner suburbs and centre more fragmented.

Given the limited scope for infiltration solutions, large-scale stormwater attenuation will be reliant on storage retention and detention SUDS to manage runoff in the event of heavy rainfall – see section 5.3.

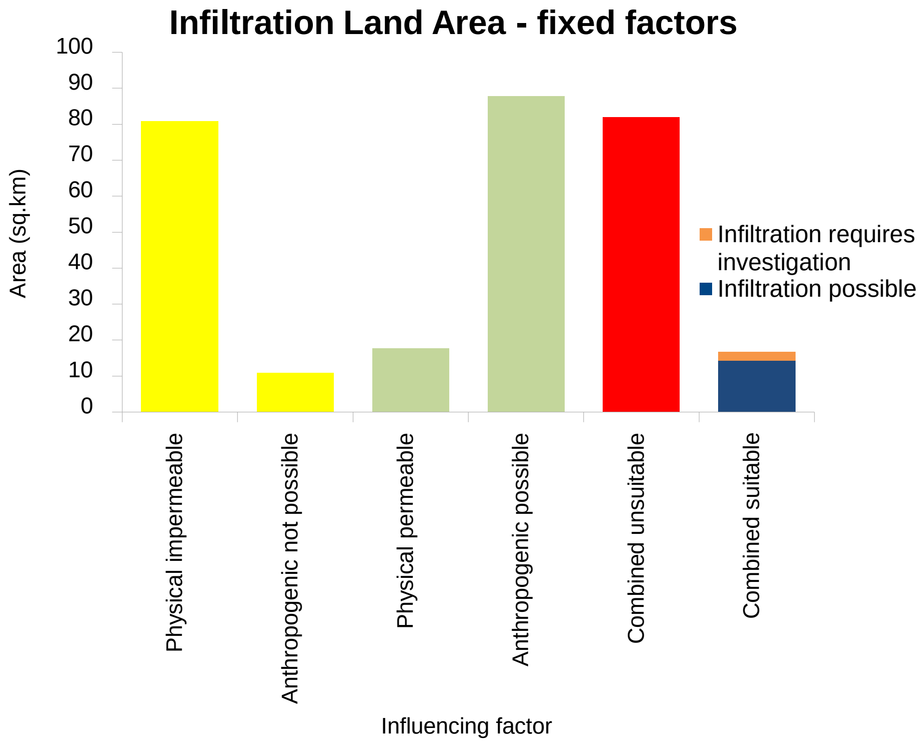


Fig. 5.7 Infiltration land area in relation to fixed factor influences on infiltration. Anthropogenic factors limit suitable locations to 88% of Coventry, although physical factors restrict suitable land area to 18% of the city. When the two sets of influences are combined spatially, 17% of the land area is suitable for infiltration SUDS. Of this 17%, 2.5% of the city area would require further investigation due to previous use as industrial land

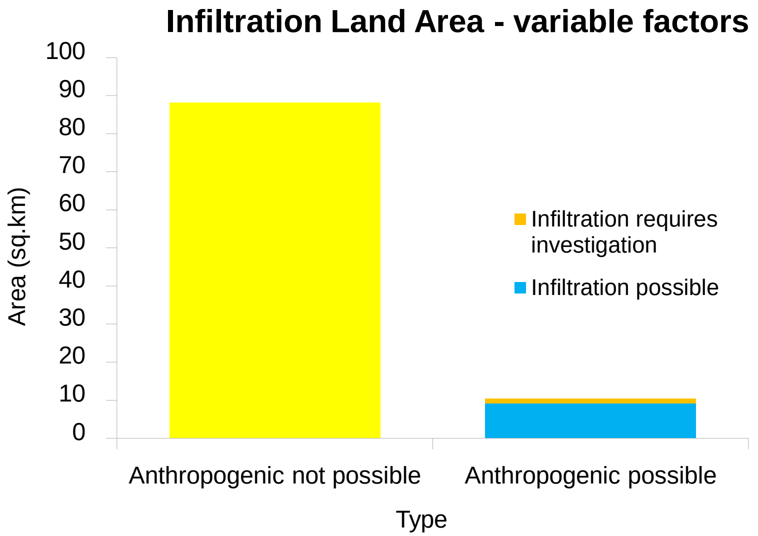
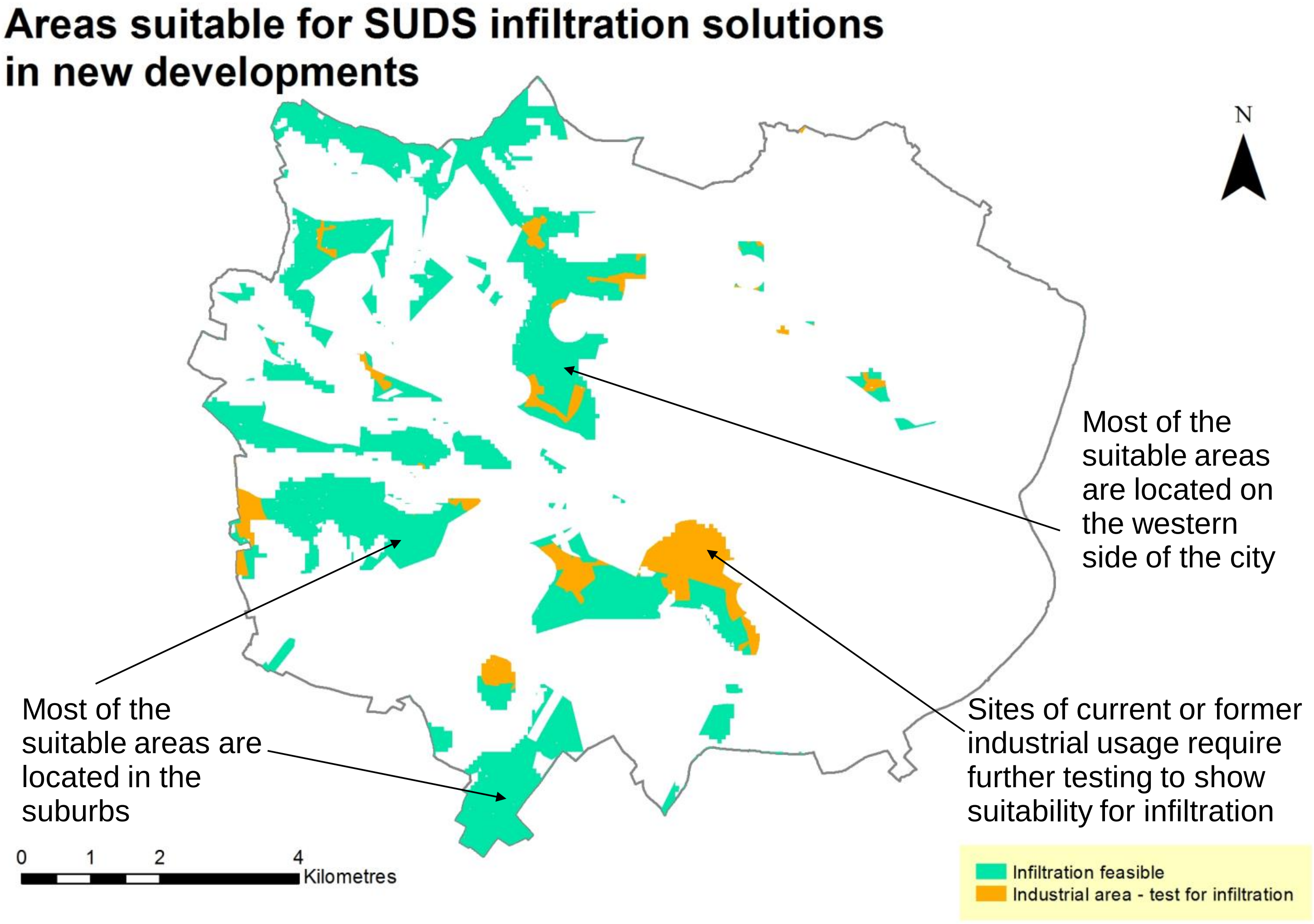


Fig. 5.8 Infiltration land area – variable factors. Fixed factors (Fig. 5.7) restrict SUDS infiltration solutions in much of the city. Retrofit infiltration SUDS are possible in 10.6% of Coventry

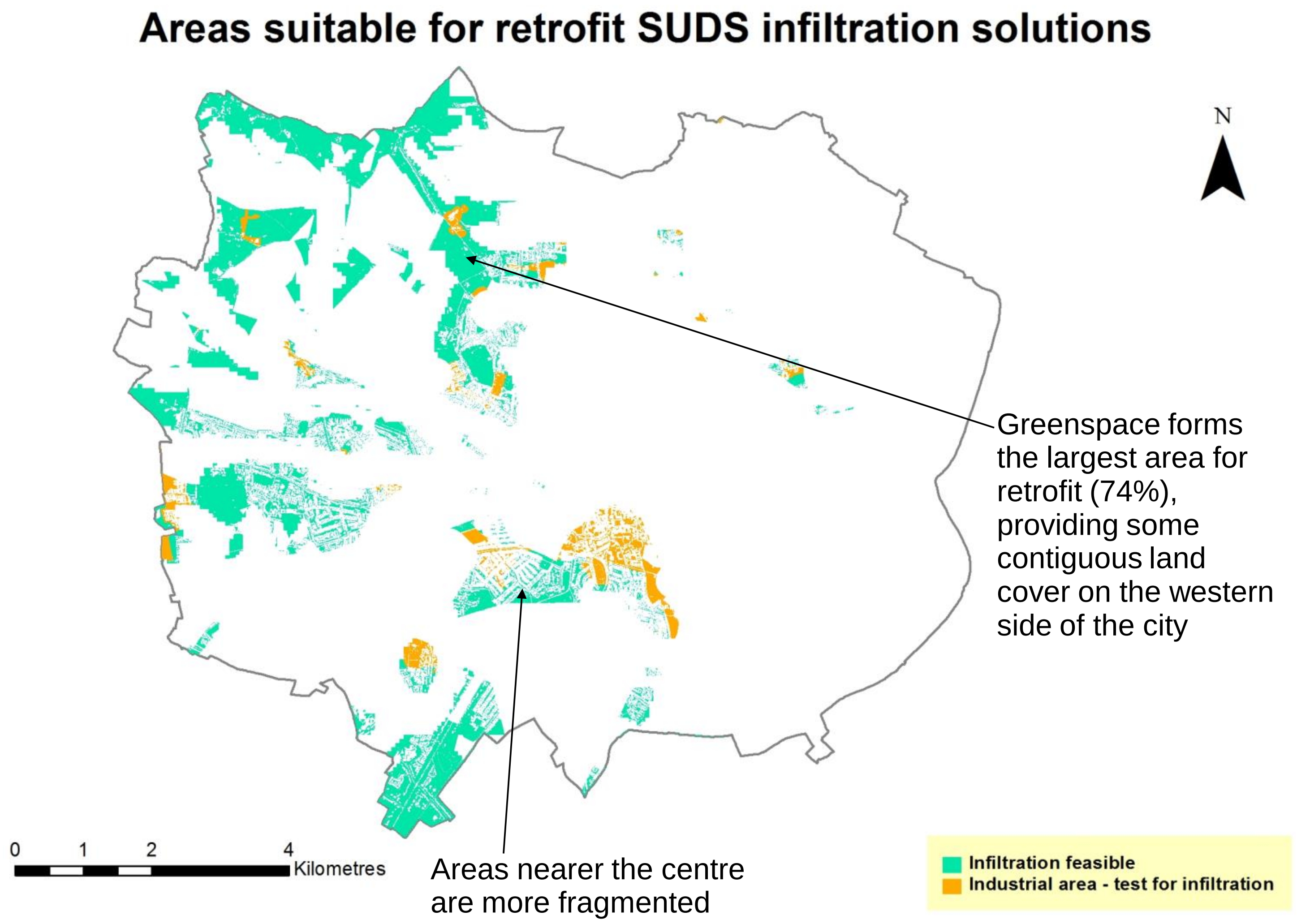


Most of the suitable areas are located on the western side of the city

Most of the suitable areas are located in the suburbs

Sites of current or former industrial usage require further testing to show suitability for infiltration

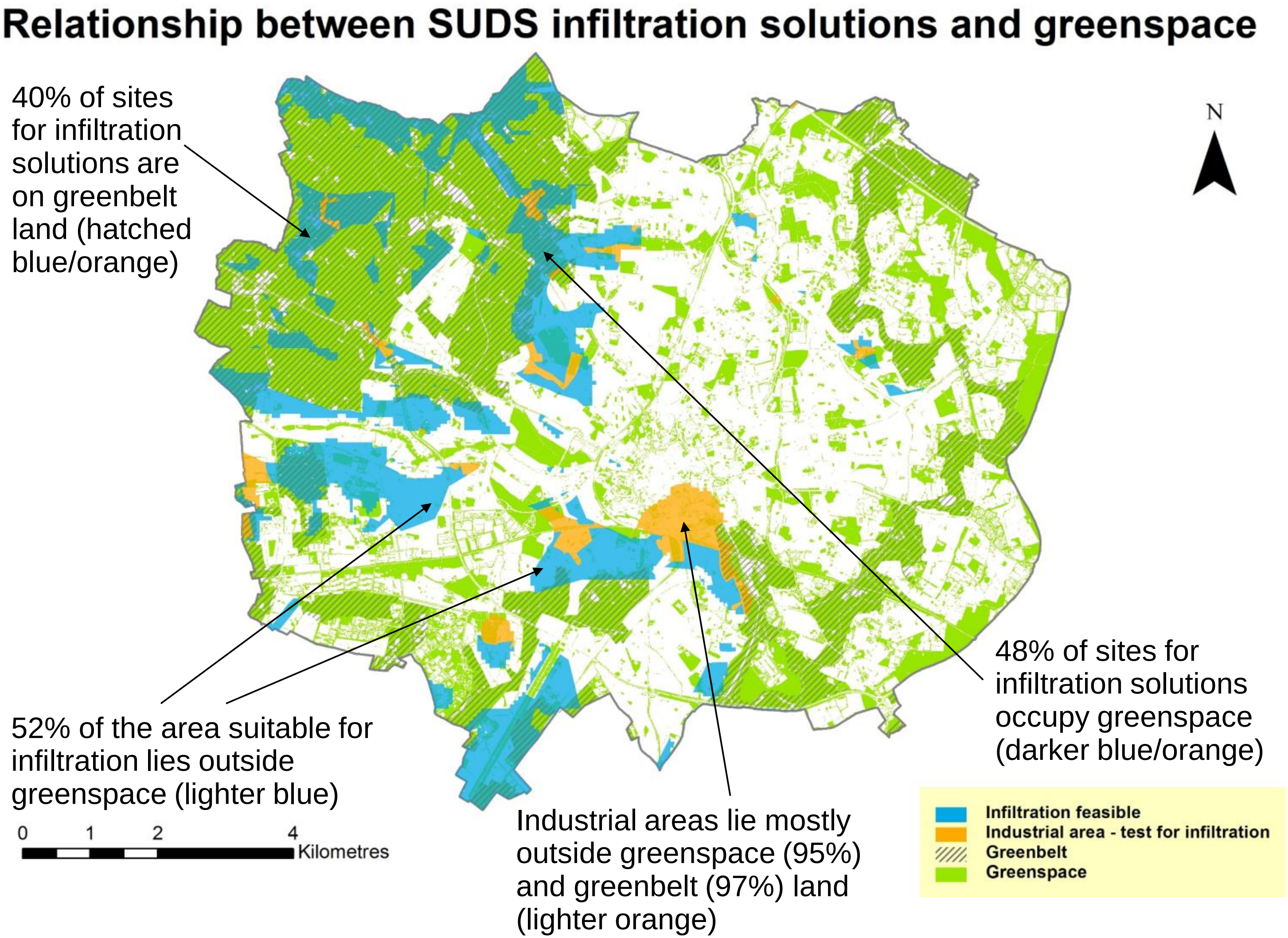
Fig. 5.9 Areas suitable for SUDS infiltration solutions in new developments in Coventry.



Greenspace forms the largest area for retrofit (74%), providing some contiguous land cover on the western side of the city

Areas nearer the centre are more fragmented

Fig. 5.10 Areas suitable for retrofit SUDS infiltration solutions



40% of sites for infiltration solutions are on greenbelt land (hatched blue/orange)

48% of sites for infiltration solutions occupy greenspace (darker blue/orange)

52% of the area suitable for infiltration lies outside greenspace (lighter blue)

Industrial areas lie mostly outside greenspace (95%) and greenbelt (97%) land (lighter orange)

Fig. 5.11 Spatial relationship between SUDS infiltration solutions and greenspace in new developments.

5.3 LOCATIONS SUITABLE FOR DETENTION AND RETENTION SUDS

Given the limited capacity for infiltration SUDS in Coventry (section 5.2), greater reliance must be placed on detention and retention SUDS in order to provide stormwater attenuation. The factors influencing detention and retention SUDS were defined in Table 3.21. In contrast to infiltration, detention solutions operate more effectively where conditions tend towards impermeability.

Four stages of evaluation are represented as maps in this section, summarised in Table 5.2:

- Unsuitable locations for detention and retention SUDS
- Factors influencing suitable locations for detention and retention SUDS in new developments
- Factors influencing suitable locations for retrofit detention and retention SUDS
- SUDS location maps.

Table 5.2. Summary of figures for maps of influencing factors and SUDS locations for Detention & Retention SUDS, with the associated methodology

Influencing factors	**Detention unsuitable**	**Vegetated detention less suitable**	**Vegetated detention more suitable**	**Engineered detention more suitable**
Fixed factors	Areas where detention & retention is not possible	Areas where vegetated detention & retention is less likely	Areas where vegetated detention & retention is more likely	Areas more suited to engineered detention & retention
Map figure	5.12	5.13	5.14	5.15
Methodology figure	3.25	3.26	3.27	3.28
Variable factors	Areas where detention & retention is not possible	Areas where vegetated detention & retention is less likely	Areas where vegetated detention & retention is more likely	Areas more suited to engineered detention & retention
Map figure	5.12	5.16	5.17	5.18
Methodology figure	3.25	3.29	3.30	3.31

SUDS location maps	**New Developments**	**Retrofit**
	Areas where detention & retention are possible	Areas where detention & retention may be used
Map figure	5.19	5.20
Methodology figure	3.23	3.24

5.3.1 Unsuitable locations

Existing water bodies were treated as unsuitable locations for detention and retention SUDS (Fig. 5.12) due to the risk of introducing additional pollution into what should in theory be an uncontaminated pond, lake, stream or canal; these features occupied 0.75% of the city’s area (Fig. 5.21). These factors applied to both new development and retrofit SUDS.

5.3.2 Locations for detention and retention SUDS in new developments

For their ease of implementation, future maintenance and amenity benefits, above-ground vegetated detention and retention SUDS were to be preferred over underground retention devices.

There were a number of additional limitations on the implementation of vegetated detention and retention SUDS (Fig. 5.13). Free draining and slowly permeable soil were treated as unsuited to retaining runoff due to the likelihood of infiltration, while high groundwater was also excluded because of the difficulties of storage where the water table was very close to the surface. In spatial terms these occupied 67.8% of Coventry (Fig. 5.21), with much of the eastern side of the city excluded. The principal restrictions were areas of permeable soil that would not retain water, and zones with shallow depth to groundwater where the existing water table might reduce the design capacity of newly constructed SUDS.

Locations that remained after excluding unsuitable sites (Figs. 5.12 & 5.13) are presented in Fig. 5.14. Soil permeability had the largest spatial influence on the suitable locations for detention and retention SUDS, which covered 32.3% of Coventry (Fig. 5.21). The principal appropriate locations for vegetated detention and retention SUDS were situated in the eastern suburbs away from the perimeter, and in the northwest and southwest.

In locations where implementation of vegetated detention and retention SUDS was not straightforward, alternative detention solutions would be needed. In these situations, more attention, effort, and potentially expense, would be required to design and install appropriate detention SUDS. The fixed factors influencing these engineered SUDS are shown in Fig. 5.15. For example, in the north, east and west, free draining and slowly permeable soil are not conducive to retention of water, so lined basins might be needed. Along water courses, the water table was assumed to be high, so raised landscaping to create detention / retention basins could be an option. Deculverting, if used in conjunction with techniques such as reinstatement of stream meanders and new offline wetlands, could attenuate flow rate and provide some treatment. Alternatively, underground storage might be used where vegetated detention SUDS were not a possibility, although they would be more difficult to maintain, and would offer little in the way of amenity.

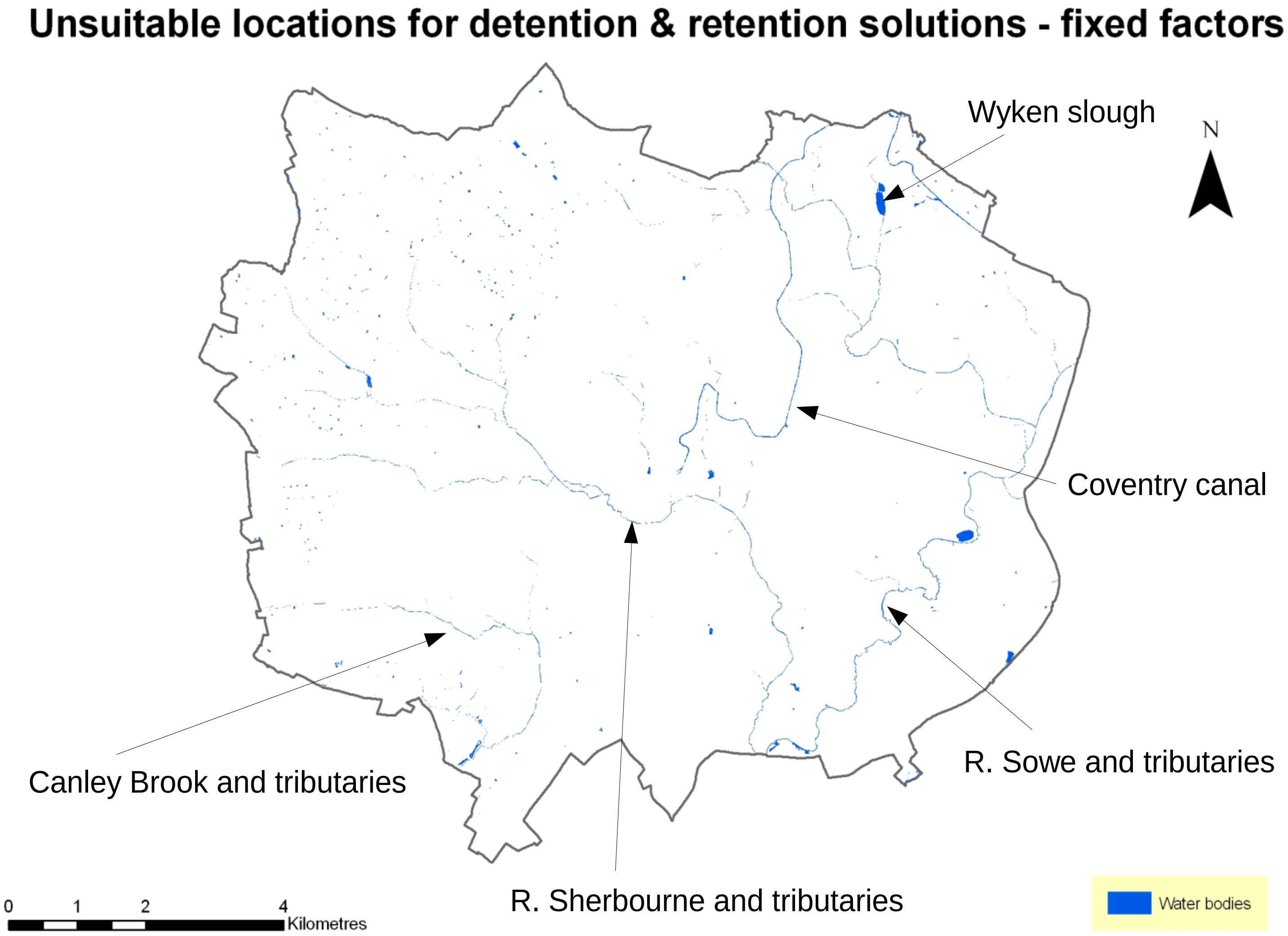
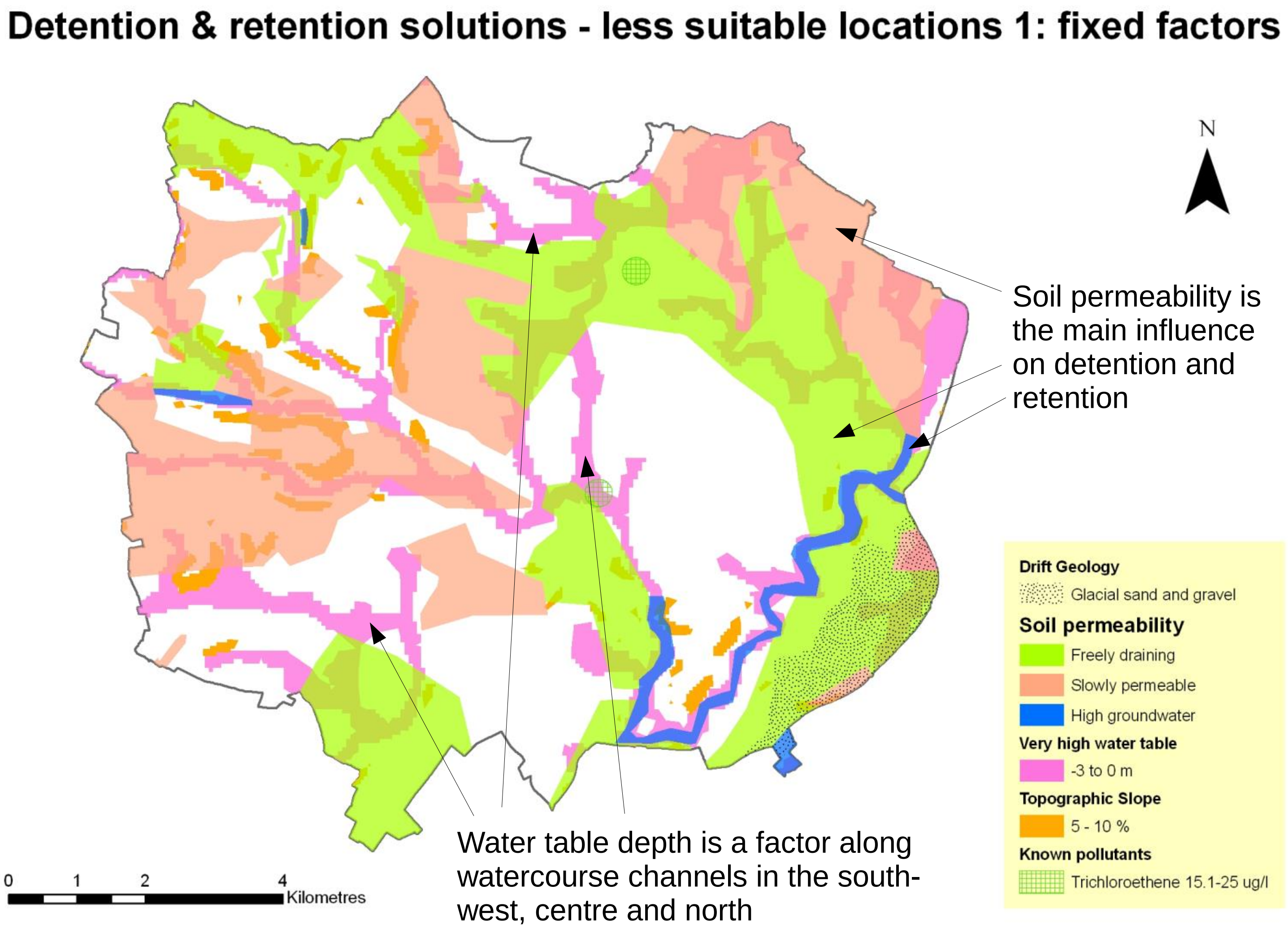


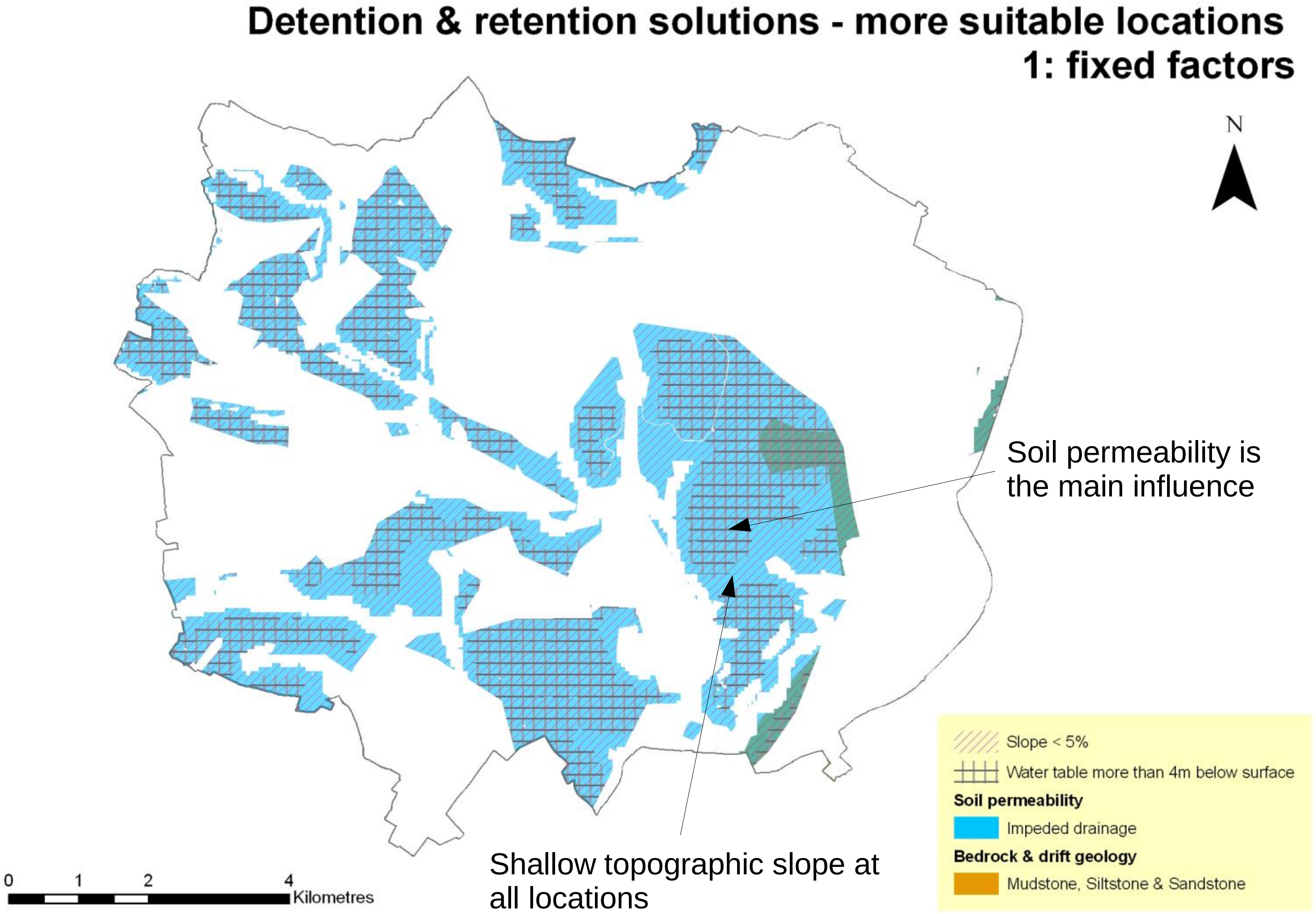
Fig. 5.12 Unsuitable locations for detention and retention solutions. The restrictions apply to both fixed and variable factors



Soil permeability is the main influence on detention and retention

Water table depth is a factor along watercourse channels in the south-west, centre and north

Fig. 5.13 Areas less suitable for vegetated detention and retention solutions: fixed factors. Areas near trichloroethene (TCE) contamination are fixed anthropogenic factors; all other datasets are fixed physical factors

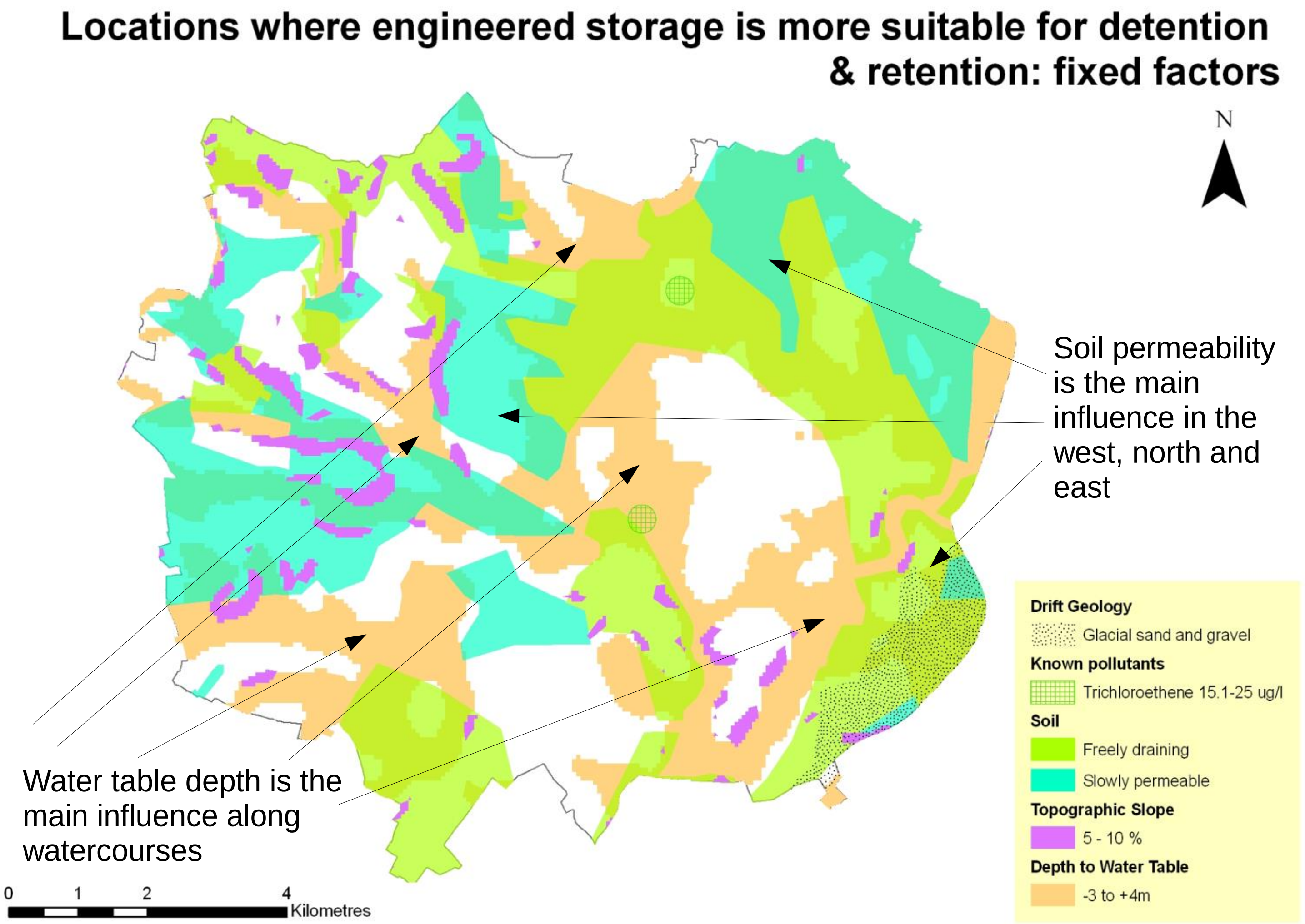


Detention & retention solutions - more suitable locations
1: fixed factors

Soil permeability is the main influence

Shallow topographic slope at all locations

Fig. 5.14 Areas more suitable for vegetated detention and retention solutions: fixed factors



Soil permeability is the main influence in the west, north and east

Water table depth is the main influence along watercourses

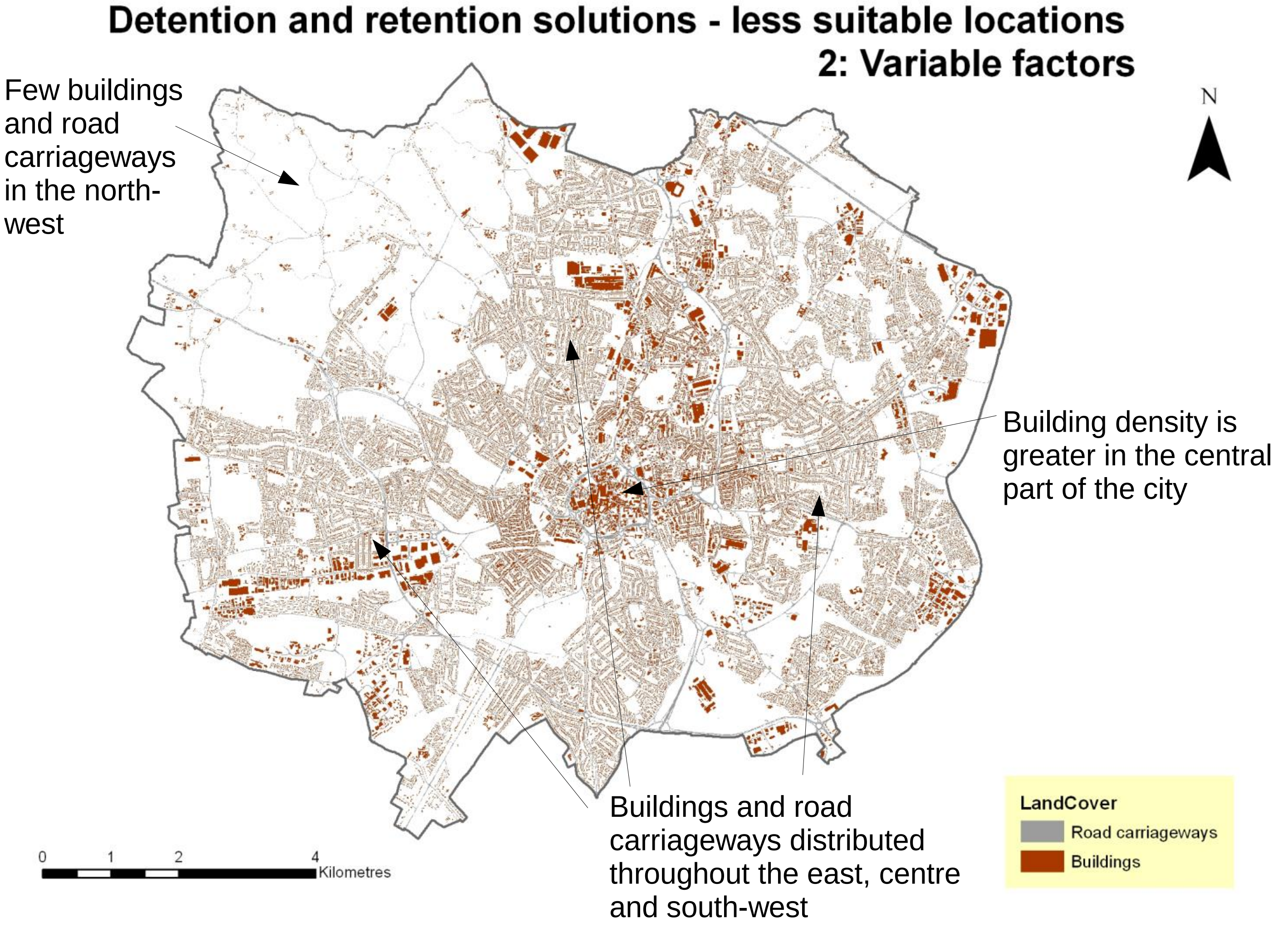
Fig. 5.15 Locations where engineered storage is more suitable for detention and retention: fixed factors.

5.3.3 Locations for retrofit detention and retention SUDS

Variable factors limiting detention and retention SUDS, existing buildings and road carriageways, are shown in Fig. 5.16. These features are spread across the local planning authority area, covering 19.6% (Fig. 5.22), but are denser in the centre and in the main commercial developments along main roads. Fewer restrictions occur in the less developed northwest.

Variable factors further limited the areas suitable for retrofitting detention and retention SUDS to 25.3% of the city, and these are shown in Fig. 5.17. Roadsides occurred throughout, as did greenspace, suitable for larger scale vegetated detention and retention facilities, which covered 12.6% of Coventry, and was available throughout the city. The northwest contained the largest contiguous area of greenspace. Existing gardens constituted a significant proportion (31.7%) of available retrofit sites for vegetated detention and retention.

In the areas suitable for retrofitting engineered detention and retention solutions (Fig. 5.18), greenspace constituted the main component (31% of Coventry), predominantly in the north-west and south-west. Gardens formed the majority of locations in the north and west, while roads were the main land cover in the central area.



Few buildings and road carriageways in the north-west

Building density is greater in the central part of the city

Buildings and road carriageways distributed throughout the east, centre and south-west

Fig. 5.16 Areas less suitable for detention and retention solutions: variable factors

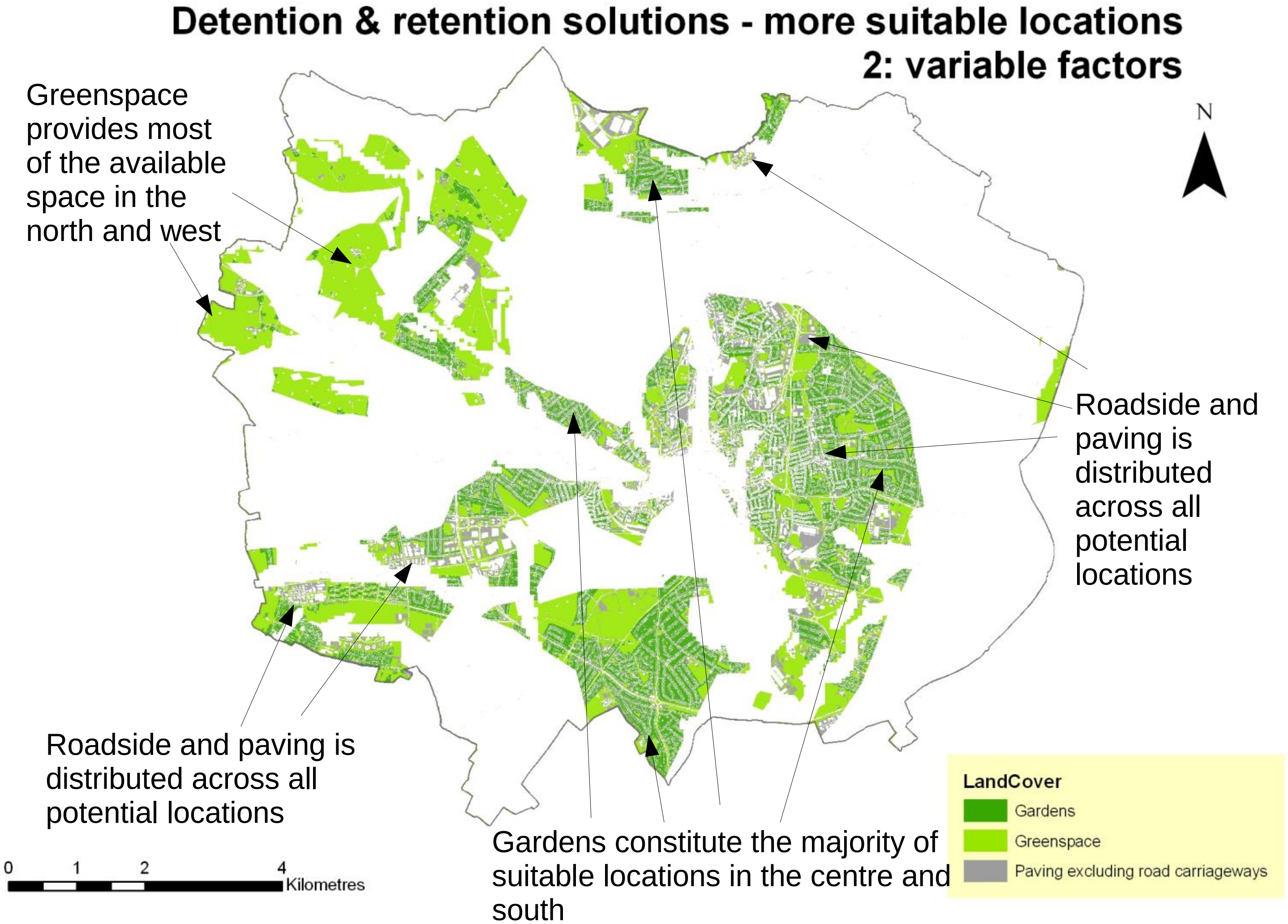
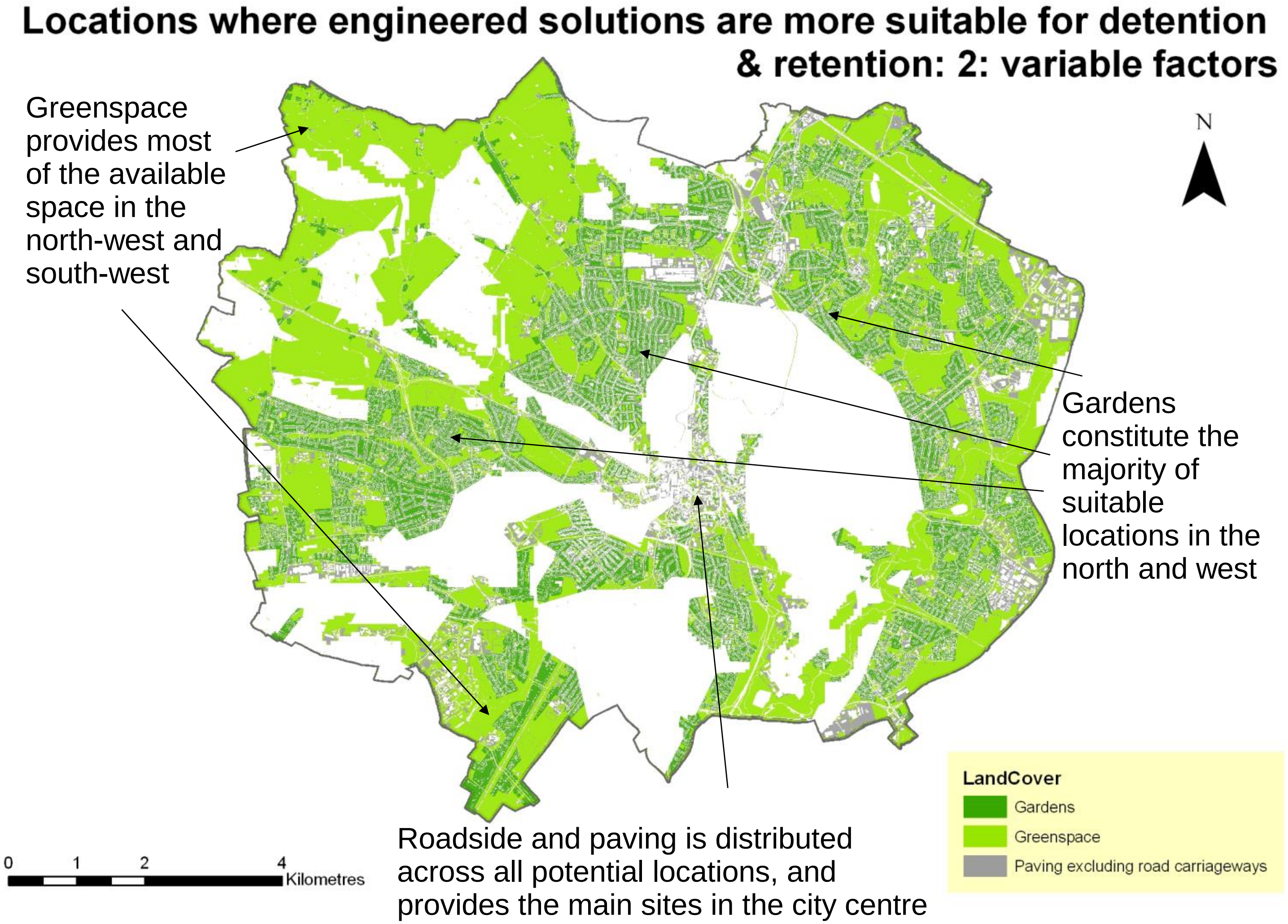


Fig. 5.17 Areas more suitable for vegetated detention and retention solutions: variable factors



Greenspace provides most of the available space in the north-west and south-west

Gardens constitute the majority of suitable locations in the north and west

Roadside and paving is distributed across all potential locations, and provides the main sites in the city centre

Fig. 5.18 Locations where engineered storage is more suitable for detention and retention: variable factors

5.3.4 SUDS detention and retention feasibility maps

Combining the factors outlined in this section, Fig. 5.19 summarises the locations suitable for detention and retention SUDS in new developments. Most of the city (99.25%) is suitable for detention and retention SUDS in new developments. Ideally, above ground vegetated SUDS solutions would be employed for ease of implementation and maintenance, but a number of factors restricted this approach, resulting in 32.3% of the city offering suitable sites for vegetated detention and retention SUDS (Fig. 5.21). These vegetated solutions were more likely in the centre, northwest and around the city perimeter (Fig. 5.19). Engineered detention and retention SUDS in new developments were more likely to be required in the east, west and north (Fig. 5.19), in areas occupying 67.0% of Coventry (Fig. 5.21).

Additional restrictions limited the areas available for retrofit detention and retention SUDS (Fig. 5.20) to 78.7% of the city. At 24.8% (Fig. 5.22), the area available for retrofit vegetated SUDS was 7.8% lower than in new developments (Fig. 5.21). Engineered SUDS were suitable for retrofitting in 53.9% of Coventry, 13.1% less than in new developments.

Engineered detention and retention SUDS were regarded as less preferable than vegetated detention solutions. Fig. 5.23 shows that, in 25.3% of the area requiring engineered storage, infiltration solutions were also feasible, and should be used in preference, reducing reliance on engineered solutions.

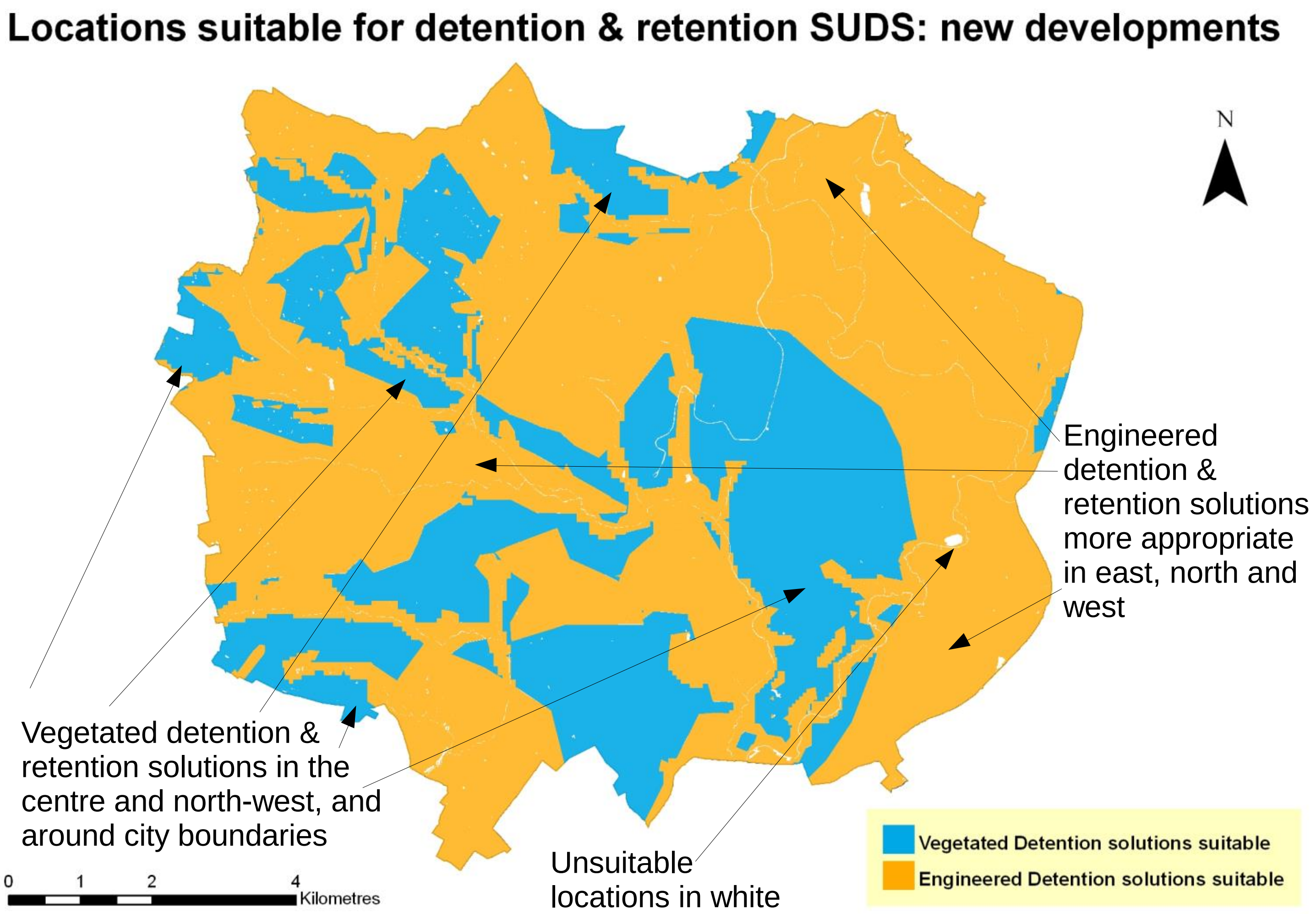
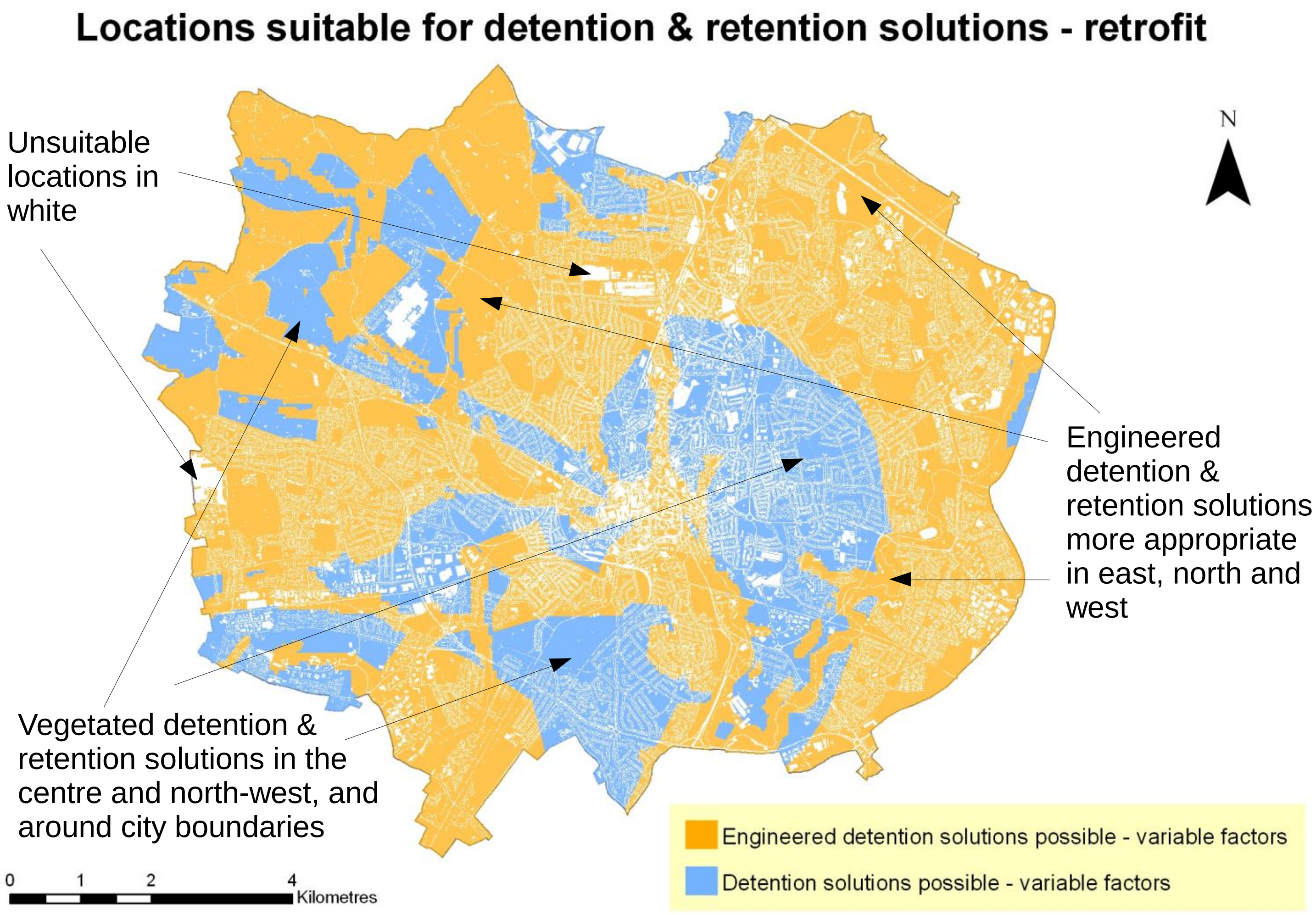


Fig. 5.19 Locations suitable for detention and retention SUDS in new developments. Areas in blue represent potential above ground vegetated storage, while areas in light brown are more likely to require engineered solutions



Locations suitable for detention & retention solutions - retrofit

Unsuitable locations in white

Engineered detention & retention solutions more appropriate in east, north and west

Vegetated detention & retention solutions in the centre and north-west, and around city boundaries

Fig. 5.20 Locations suitable for retrofit detention and retention SUDS. Areas in blue represent potential above ground solutions, while areas in light brown are more likely to require engineered solutions

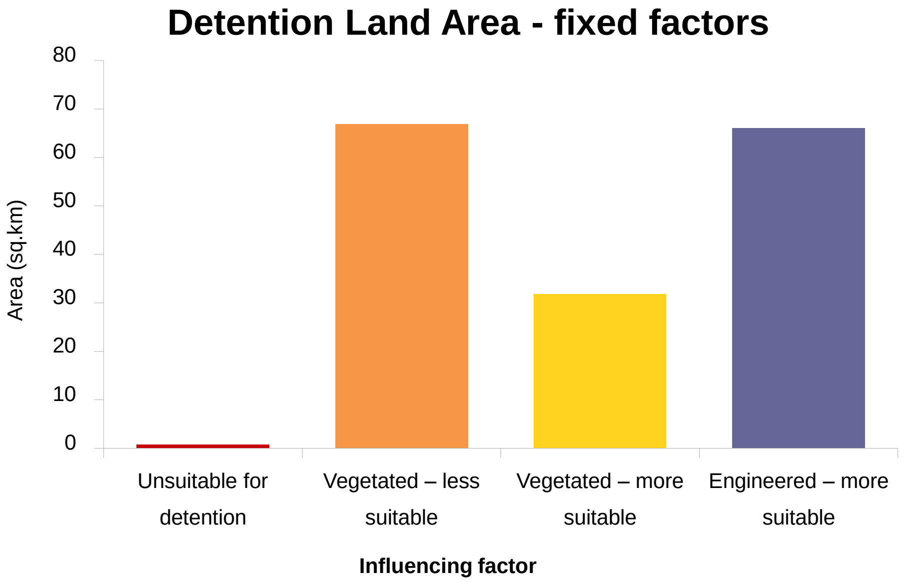


Fig. 5.21 Detention and retention land area – fixed factors. Unsuitable areas occupy 0.75% of Coventry's land area. Less suitable locations for vegetated detention and retention SUDS take up 68% of the city, leaving 32% as appropriate locations for detention and retention SUDS in new developments. Engineered storage is required for 67% of the LPA land area.

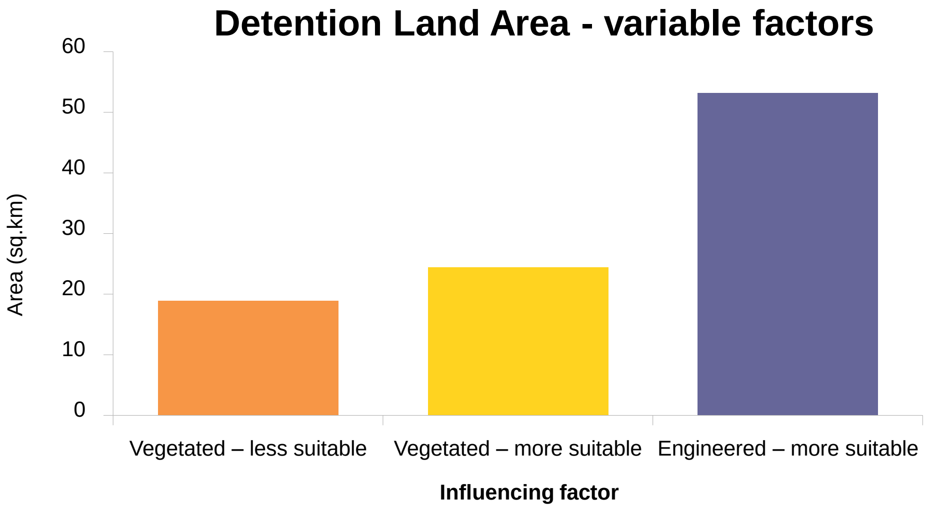


Fig. 5.22 Detention and retention land area – variable factors. Less suitable locations for vegetated detention and retention solutions occupy 20% of Coventry's land area. Appropriate locations for retrofit detention and retention SUDS take up 25% of the city. Engineered storage is required for 55% of the LPA land area.

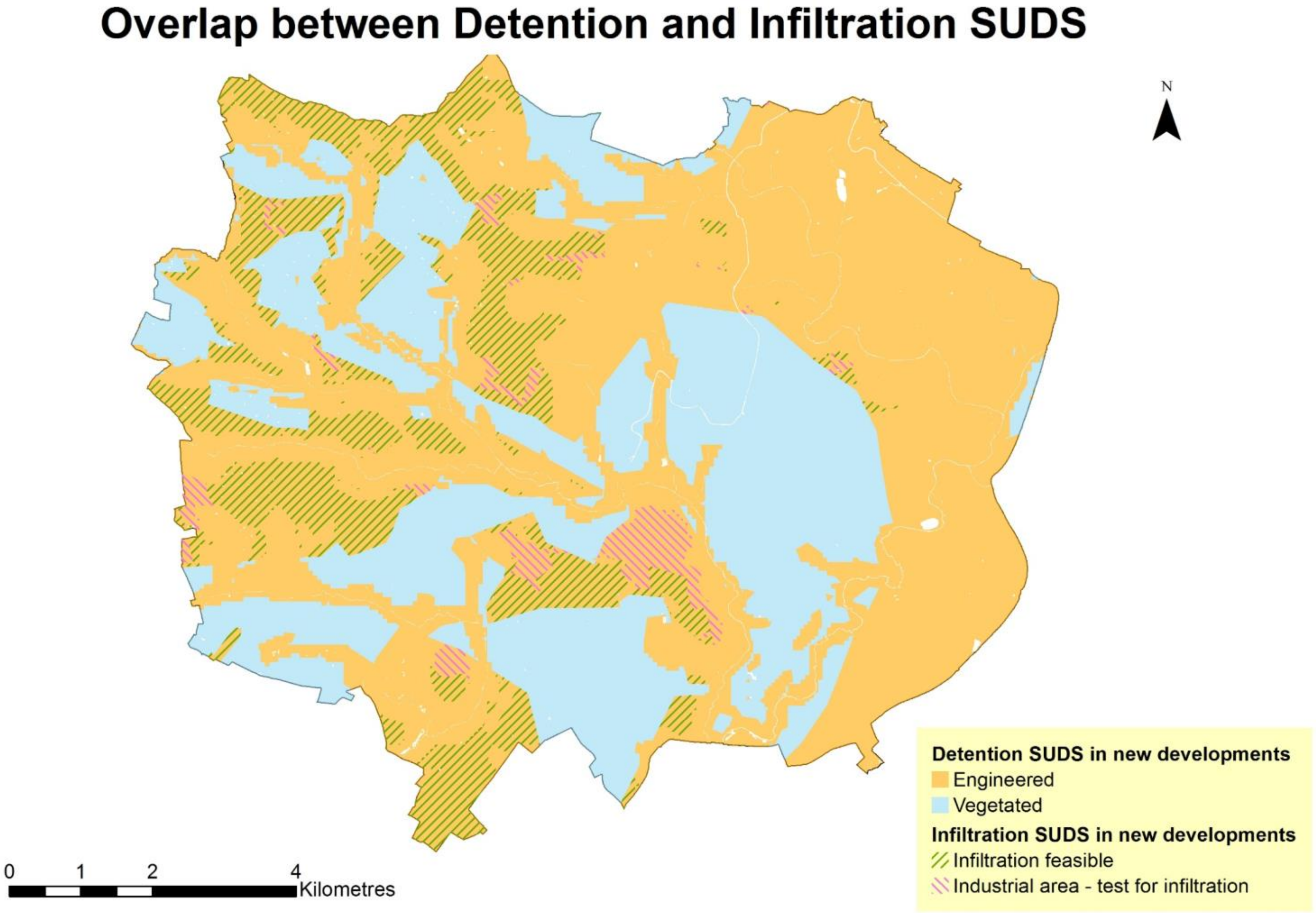


Fig. 5.23 Overlap between Detention and Infiltration SUDS in new developments

5.3.5 Retrofit land cover

The areas of different types of land cover in Coventry available for retrofit detention and retention SUDS are summarised in table 5.3. Greenspace formed the largest component (56%), with gardens 29% and paved areas 15%.

Table 5.3 Retrofit detention land cover. The two final columns represent the area owned by Coventry City Council and Whitefriars Housing

	Vegetated detention area (km^2)	**Engineered detention area (km^2)**	**Total detention area (km^2)**	**Vegetated detention in public ownership (km^2)**	**Engineered detention in public ownership (km^2)**
Greenspace	12.4	31.0	43.4	6.35	20.51
Gardens	7.8	14.5	22.3	1.74	4.50
Roads & paved areas	4.3	7.7	12.0	2.23	5.06
Total	24.5	53.2	77.7	10.32	30.07

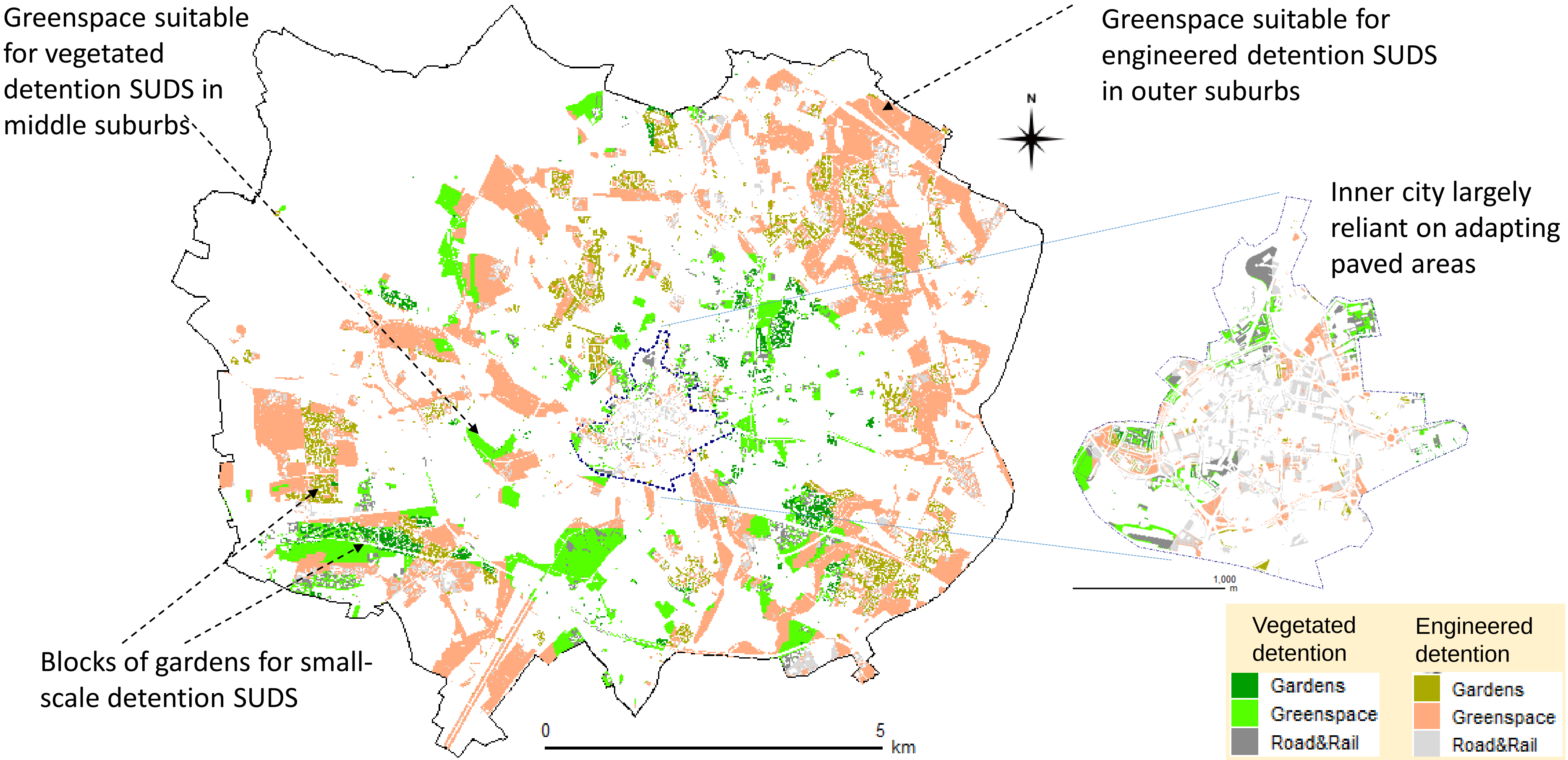
Greenspace, suitable for larger scale vegetated detention and retention facilities, covered 44% of Coventry (31% engineered, 13% vegetated), and was available throughout the city. The northwest contained the largest contiguous area of greenspace, but presented relatively few practical opportunities for retrofitting detention SUDS, as it was the least developed part of the conurbation, and was also in the upper reaches of the R. Sherbourne catchment. Therefore fluvial flood plain detention would be of limited value, and there would be limited runoff generated above greenfield rates from impermeable surfaces. 62% of suitable greenspace was in public ownership, principally located in the middle and outer suburbs (Fig. 5.24).

Existing gardens constituted a significant proportion (31.7%) of available retrofit sites for vegetated detention and retention. Based on the relationship between garden polygons in OSMM and house dwellings in the 2001 census (ESRC Census Programme 2010), then

41,236 individual gardens were available for retrofitting vegetated detention SUDS such as rain gardens. In the areas suitable for retrofitting engineered detention and retention solutions, 66,613 individual gardens were available. 28,000 gardens (27% by area) were in public ownership, 8,100 in vegetated and 19,900 in engineered detention areas. Gardens offered a significant area for retrofit, but each installation would of itself only offer scope for small devices, representing a significant challenge due to the distributed ownership of this resource.

Roads and paved areas constituted 15% of detention land cover overall, of which 5% was in areas suitable for vegetated detention. Roadsides might be appropriate for linear and small-scale SUDS, potentially as a means of storing and treating runoff before it entered highway drains. Non-road paving could be converted to vegetation in suitable areas. Landscaped or hard-engineered detention features could also be implemented, but given the relatively restricted one-quarter of Coventry available for retrofit vegetated detention and retention SUDS, opportunities might better be sought to maximise such features rather than retaining hard landscaping. Roadsides and non-road paving provided 7.8% of Coventry’s land cover in the areas suitable for engineered detention, but in the central area were the main potential sites, reflecting the more built-up nature of the city centre (Fig. 5.24).

Retrofit Detention and Retention land cover in public ownership



Greenspace suitable for vegetated detention SUDS in middle suburbs

Greenspace suitable for engineered detention SUDS in outer suburbs

Inner city largely reliant on adapting paved areas

Blocks of gardens for small-scale detention SUDS

Fig. 5.24 Retrofit Detention and Retention land cover in public ownership

5.4 LOCATIONS SUITABLE FOR SOURCE CONTROL SUDS

Table 3.22 identified the factors driving the feasibility of source control SUDS. Table 5.4 summarises the relationships between the maps presented in this section. There were few fixed factor limitations on the use of source control SUDS in new developments (Fig. 5.25). Existing constraints and practical considerations, however, presented further restrictions (31.4% of the city) on locations for source control retrofit (Fig. 5.26), distributed throughout Coventry.

Table 5.4. Summary of figures for maps of influencing factors and SUDS locations for Source Control SUDS, with the associated methodology

Influencing factors	**Source Control**
Fixed factors	Areas where Source Control is less suitable
Map figure	5.25
Methodology figure	3.32
Variable factors	Areas where Source Control is less suitable
Map figure	5.26
Methodology figure	3.33

SUDS location maps	**New Developments**	**Retrofit**
	Areas where Source Control is possible	Areas where Source Control is possible
Map figure	5.27	5.28
Methodology figure	3.32	333

Fig. 5.27 shows the resulting map of locations where source control SUDS were feasible in new developments; 99.3% of the land area was suitable (Fig. 5.29). The reduced area available for retrofit is indicated in Fig. 5.28, 67.8% of the city (Fig. 5.29). Opportunities existed for retrofitting source control SUDS in much of the city, including the most densely developed areas.

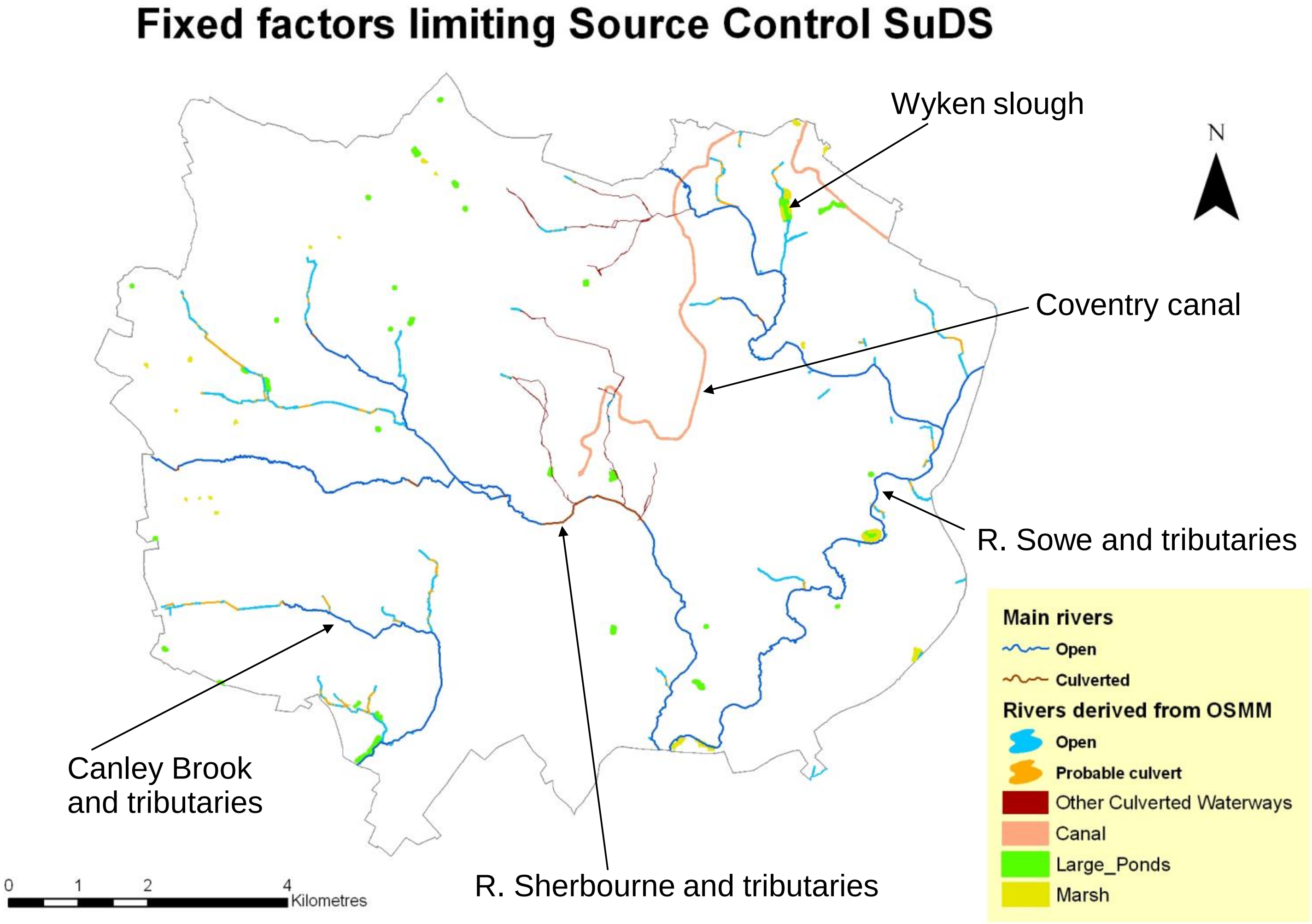
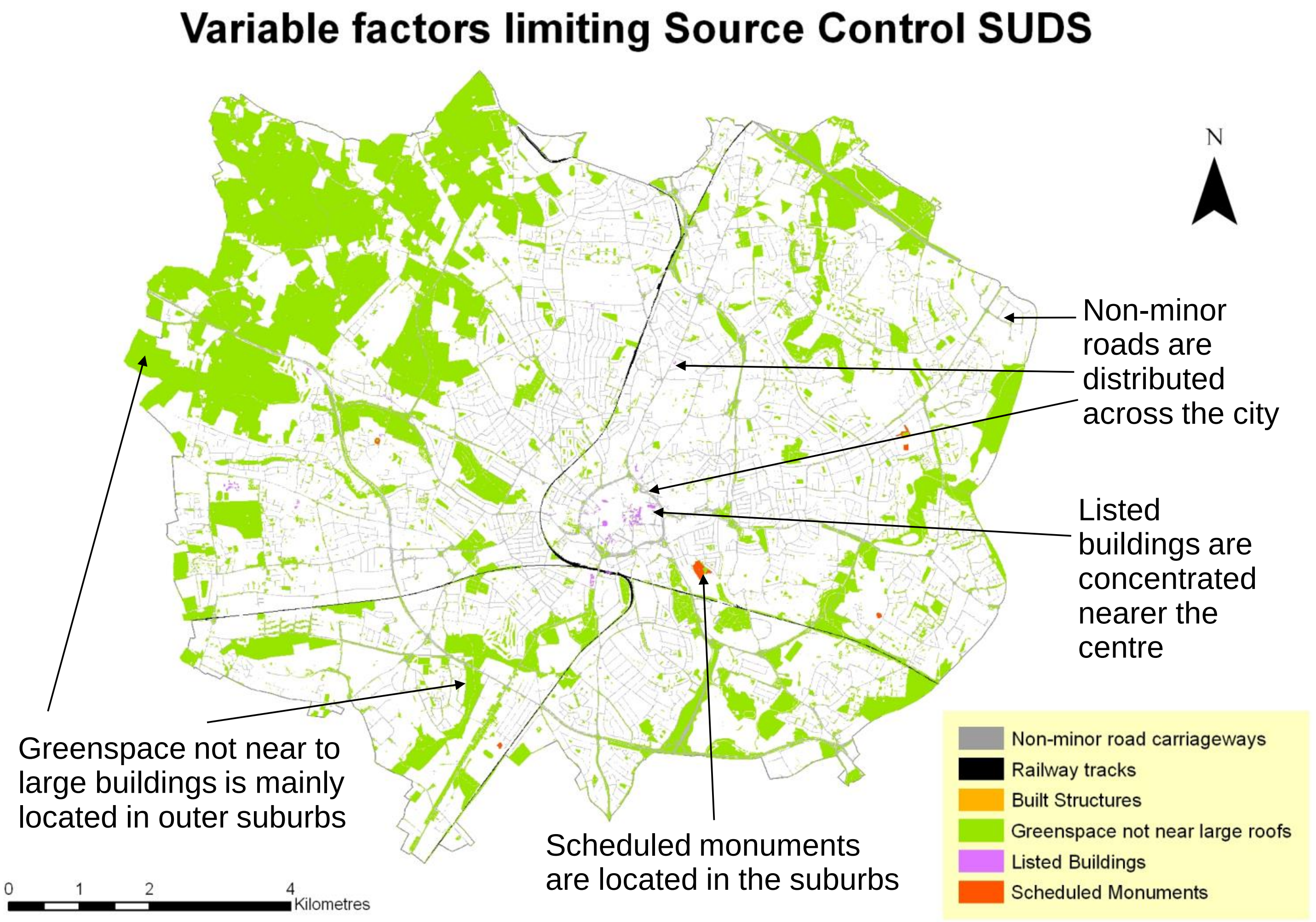


Fig. 5.25 Fixed factors limiting source control SUDS. These are the same as fixed factors limiting conveyance SUDS (Fig. 5.35)



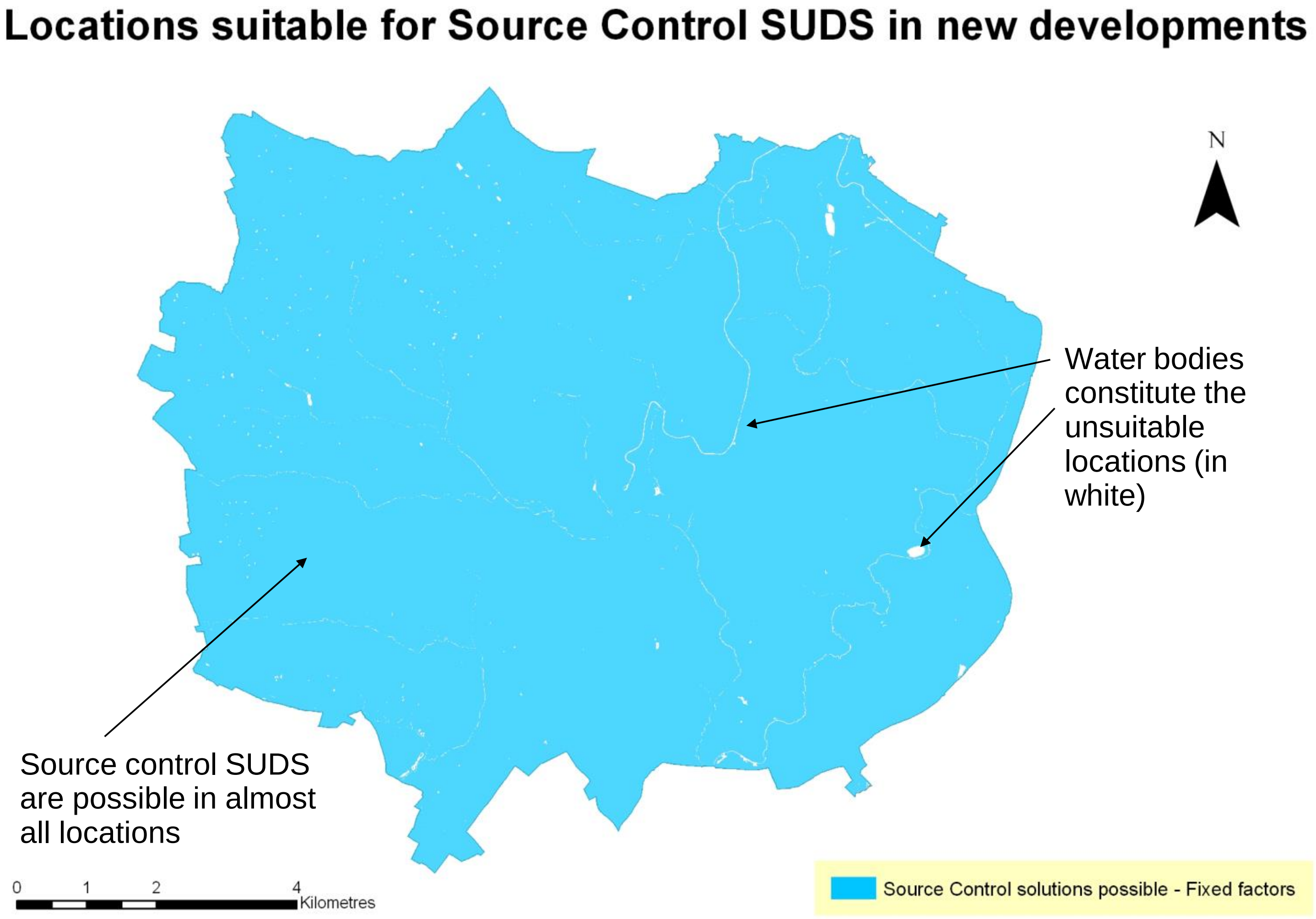
Non-minor roads are distributed across the city

Listed buildings are concentrated nearer the centre

Greenspace not near to large buildings is mainly located in outer suburbs

Scheduled monuments are located in the suburbs

Fig. 5.26 Variable factors limiting Source Control SUDS. Built structures are features such as elevated walkways. Utilisation of greenspace that is not near to large buildings would require construction of additional infrastructure, so was excluded

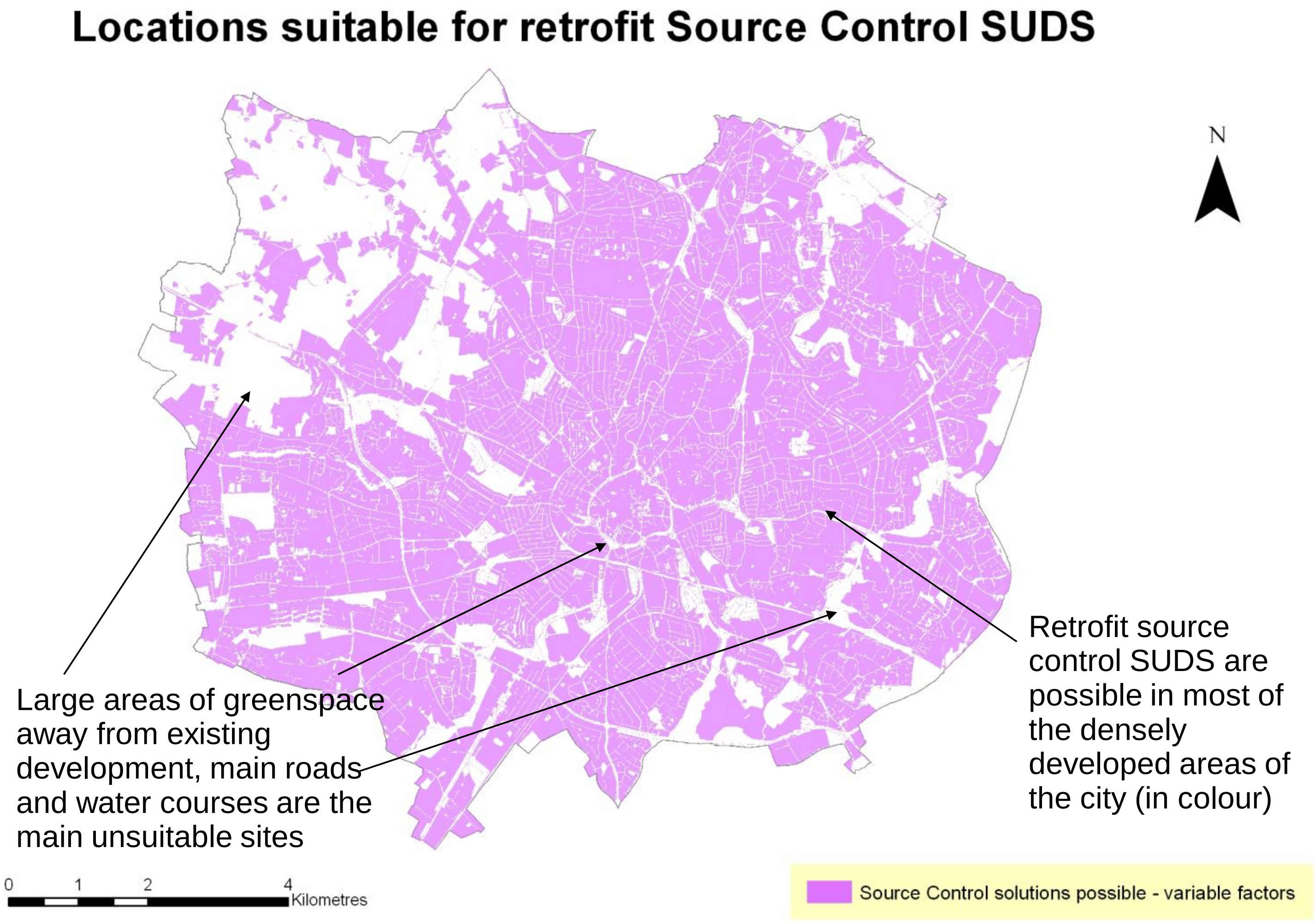


Locations suitable for Source Control SUDS in new developments

Water bodies constitute the unsuitable locations (in white)

Source control SUDS are possible in almost all locations

Fig. 5.27 Locations suitable for Source Control SUDS in new developments. Solutions can be implemented in the coloured areas



Large areas of greenspace away from existing development, main roads and water courses are the main unsuitable sites

Retrofit source control SUDS are possible in most of the densely developed areas of the city (in colour)

Fig. 5.28 Locations suitable for retrofit Source Control SUDS. Solutions can be implemented in the coloured areas

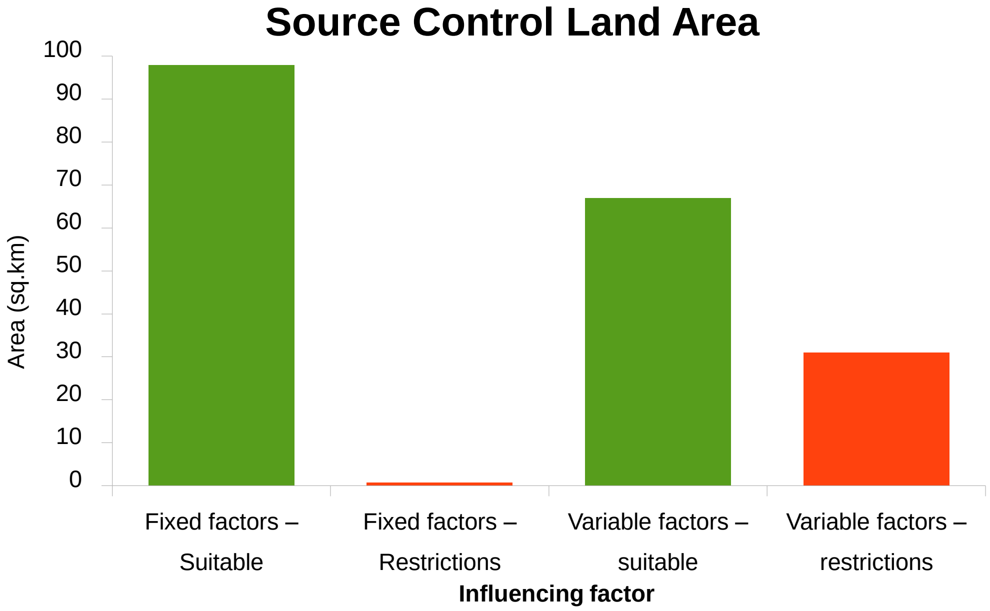


Fig. 5.29 Source Control land area. 99.25% of Coventry's land area is suitable for source control SUDS in new developments. Retrofit source control SUDS can be implemented in 67.8% of the city.

5.5 LOCATIONS SUITABLE FOR FILTRATION SUDS

Table 3.23 identified the factors driving the feasibility of filtration SUDS. Table 5.5 summarises the relationships between the maps presented in this section.

Table 5.5. Summary of figures for maps of influencing factors and SUDS locations for Filtration SUDS, with the associated methodology

Influencing factors	**Filtration**
Fixed factors	Areas where Filtration SUDS are less suitable
Map figure	5.30
Methodology figure	3.35
Variable factors	Areas where Filtration SUDS are less suitable
Map figure	5.31
Methodology figure	3.35

SUDS location maps	**New Developments**	**Retrofit**
	Areas where Filtration SUDS are possible	Areas where Filtration SUDS are possible
Map figure	5.32	5.33
Methodology figure	3.35	3.35

There were few fixed limitations on the use of filtration SUDS in new developments (Fig. 5.30). The main intention of these devices is to capture pollutants on the surface, so below ground factors such as geology and groundwater were not taken into account. Sites of existing contamination were not regarded as limitations, since the presence of filtration devices should not permit onward transmission of pollutants, either on the surface or to groundwater. Consequently, only existing water bodies and adjoining areas (fluvial flood zone 3) were treated as limitations in new developments because of the risk of pollutants being delivered to watercourses during heavy rainfall. In contrast, existing development presented many additional restrictions (31.5% of the city) on locations for retrofit filtration (Fig. 5.31), with buildings and roads distributed throughout much of the city except for the northwest.

Fig. 5.32 shows the resulting map of feasible locations for filtration SUDS in new developments; 95.4% of the land area was suitable (Fig. 5.34). The reduced area available for retrofit is indicated in Fig. 5.33, 64.0% of the city (Fig. 5.34). The suburbs have the greatest potential for retrofit filtration SUDS, while the central area, the north-east, and industrial and commercial zones in the northern and western corridors have limited space.

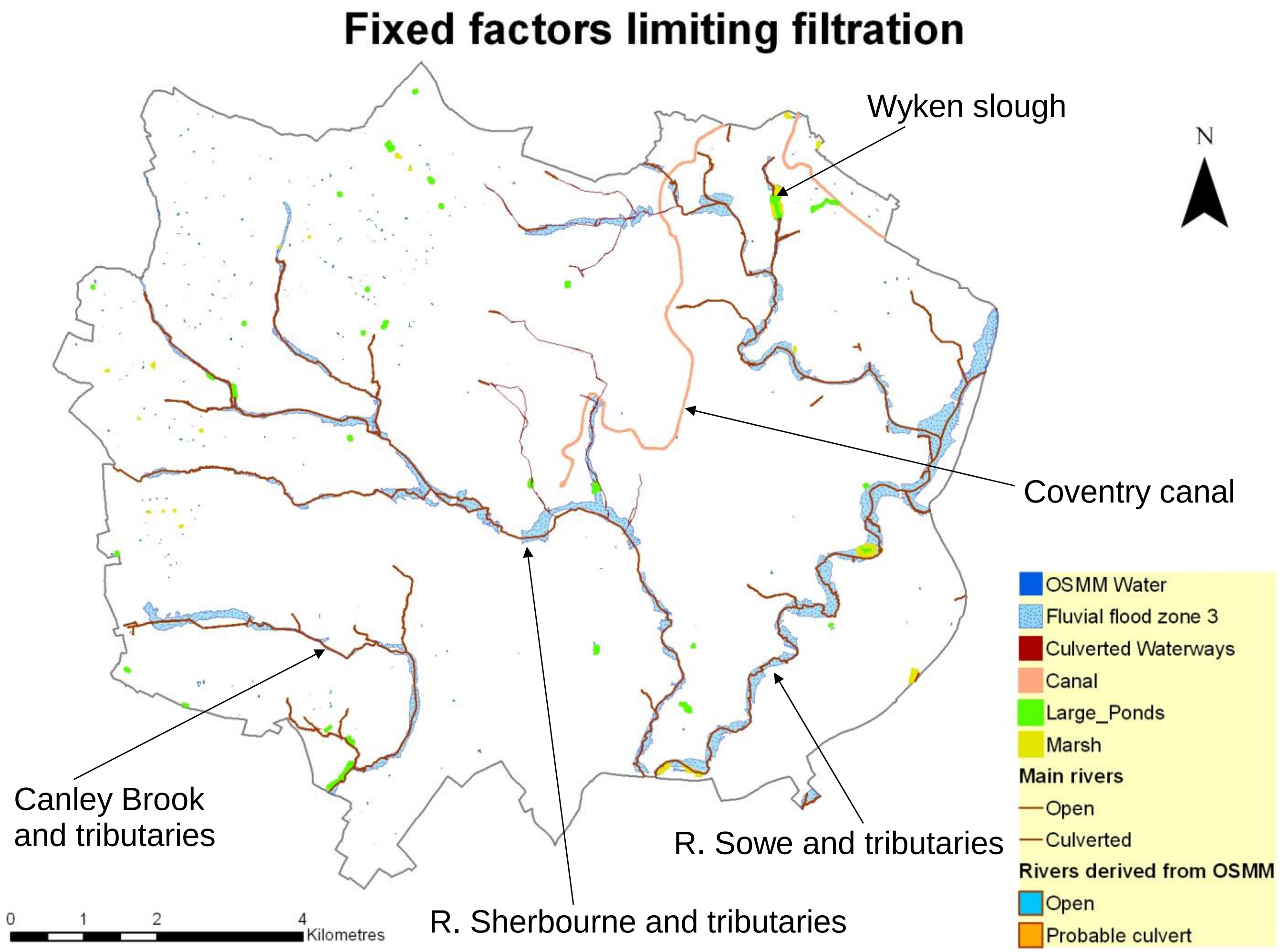
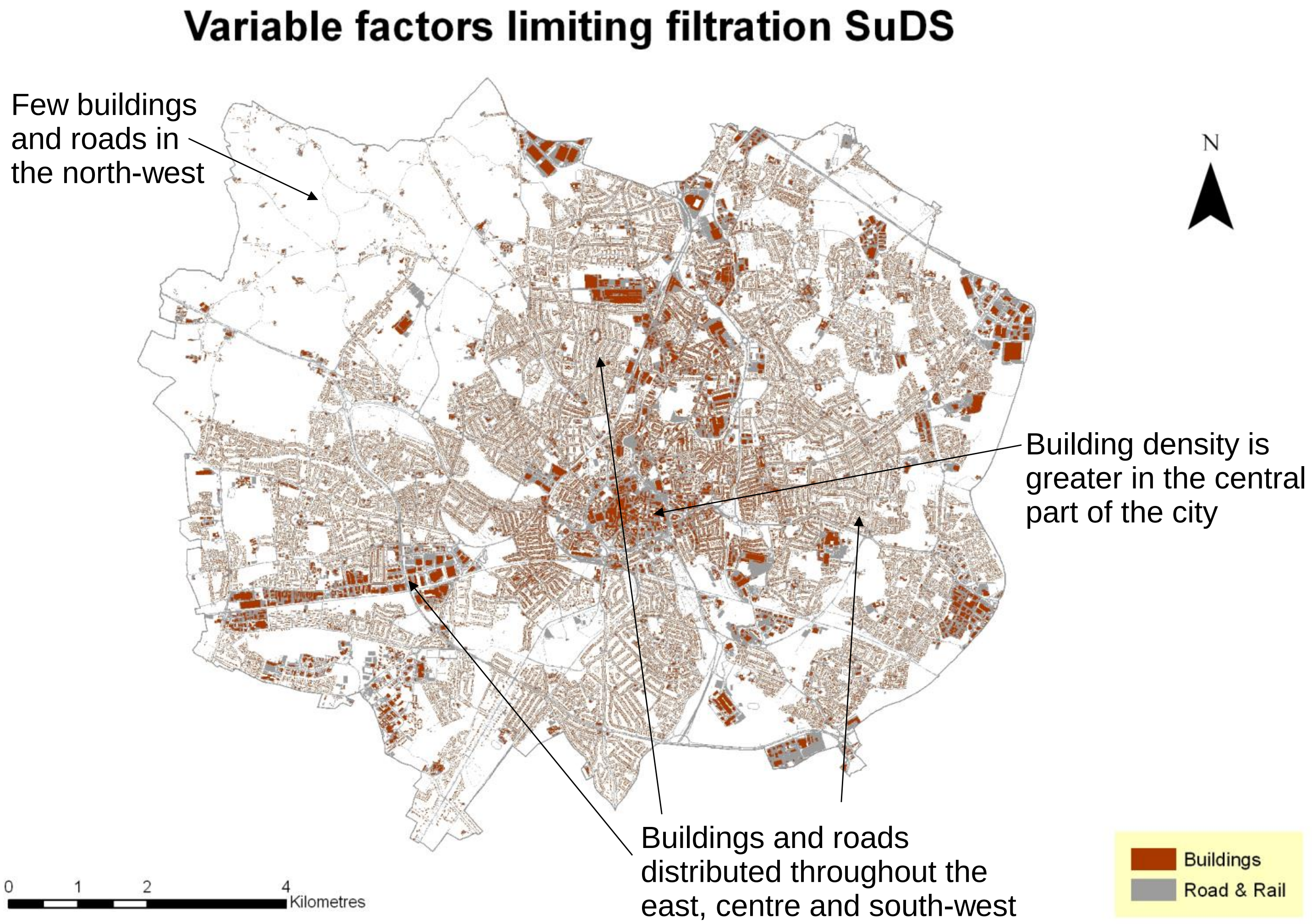


Fig. 5.30 Fixed factors limiting filtration SUDS

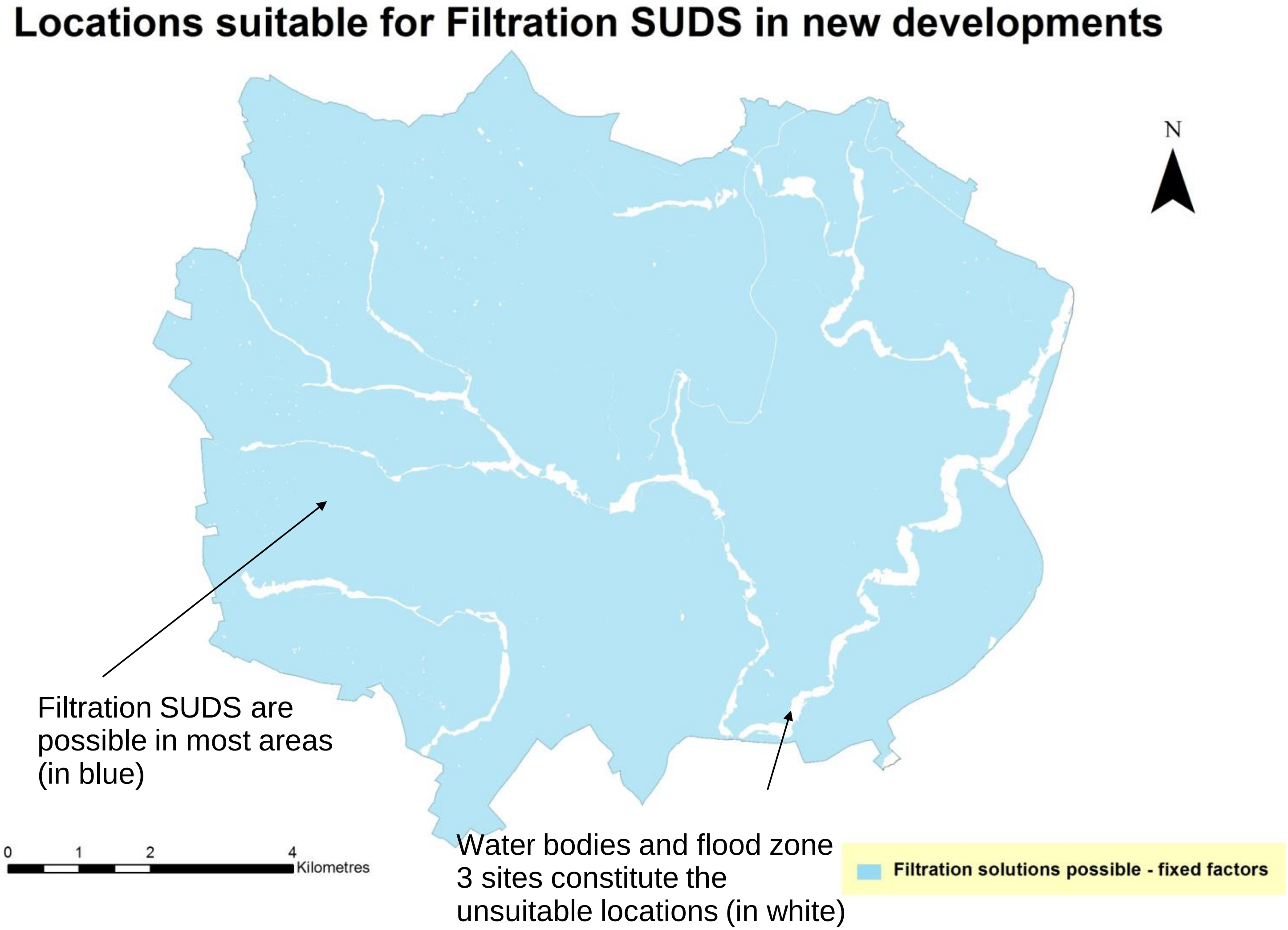


Few buildings and roads in the north-west

Building density is greater in the central part of the city

Buildings and roads distributed throughout the east, centre and south-west

Fig. 5.31 Variable factors limiting filtration SUDS. Vegetated road verges are not included in the road and rail category



Filtration SUDS are possible in most areas (in blue)

Water bodies and flood zone 3 sites constitute the unsuitable locations (in white)

Fig. 5.32 Locations suitable for Filtration SUDS in new developments. Solutions can be implemented in the coloured areas

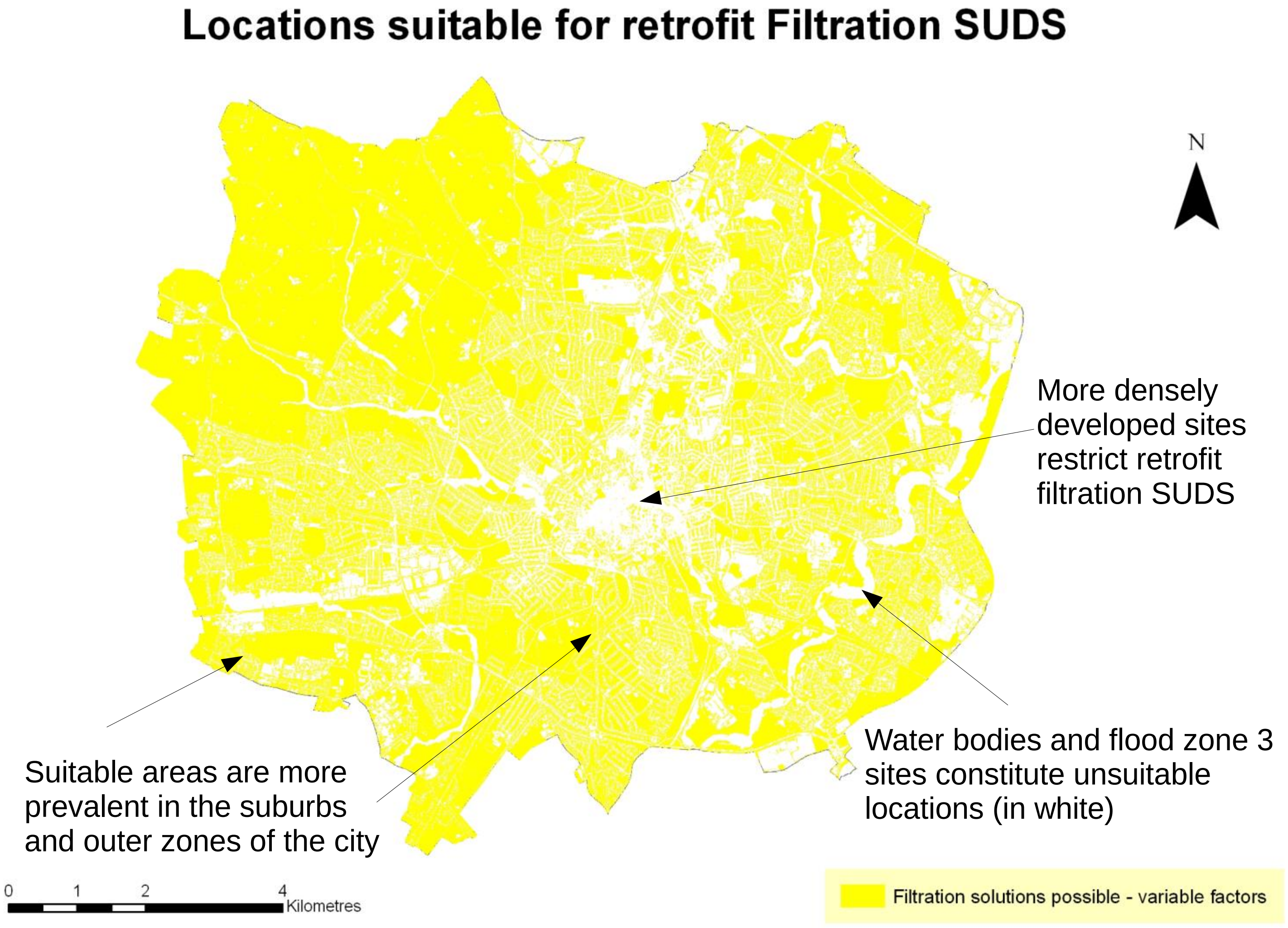


Fig. 5.33 Locations suitable for retrofit Filtration SUDS. Solutions can be implemented in the coloured areas

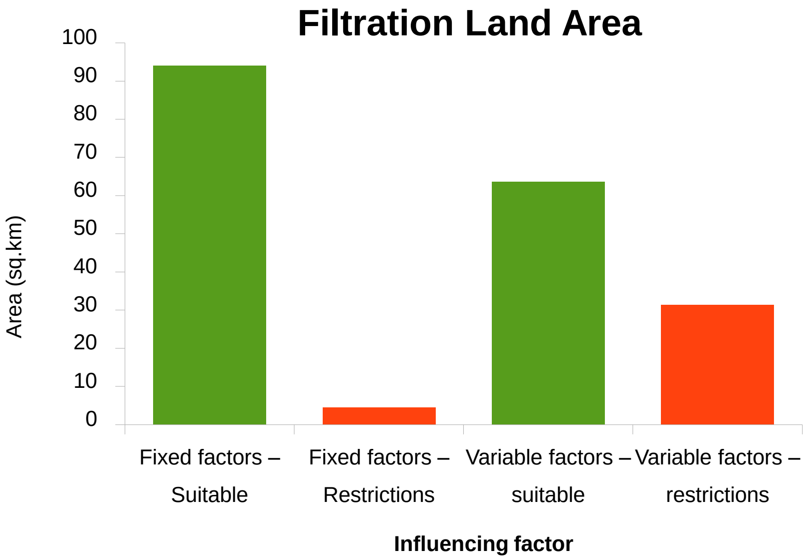


Fig. 5.34 Filtration land area. Unsuitable areas due to fixed factors occupy 4.6% of Coventry's land area, leaving 95.4% as appropriate locations for filtration SUDS in new developments. Variable factors eliminate 31.5% of the land area for retrofit. Taking fixed factor restrictions into account, 64.0% of Coventry is suitable for retrofit filtration SUDS.

5.6 LOCATIONS SUITABLE FOR CONVEYANCE SUDS

Table 3.24 identified the factors driving the feasibility of conveyance SUDS. Table 5.6 summarises the relationships between the maps presented in this section.

Table 5.6. Summary of figures for maps of influencing factors and SUDS locations for Conveyance SUDS, with the associated methodology

Influencing factors	**Conveyance**
Fixed factors	Areas where Conveyance SUDS are less suitable
Map figure	5.35
Methodology figure	3.36
Variable factors	Areas where Conveyance SUDS are less suitable
Map figure	5.36
Methodology figure	3.36

SUDS location maps	**New Developments**	**Retrofit**
	Areas where Conveyance SUDS are possible	Areas where Conveyance SUDS are possible
Map figure	5.37	5.38
Methodology figure	3.36	3.36

There were few fixed factor limitations on the use of conveyance SUDS in new developments (Fig. 5.35). Existing development, however, presented significant additional restrictions (43.0% of the city) on locations for conveyance SUDS (Fig. 5.36), distributed throughout the majority of the city except for the northwest greenbelt. Fig. 5.37 shows the resulting map of feasible locations for conveyance SUDS in new developments; 99.3% of the land area was suitable (Fig. 5.39). The reduced area available for retrofit is indicated in Fig. 5.38, 57.1% of the city (Fig. 5.39). There were fewer opportunities for retrofitting conveyance SUDS in the centre and densely developed inner suburbs, the locations with potentially the greatest requirement. More space was available in the outer suburbs around the perimeter.

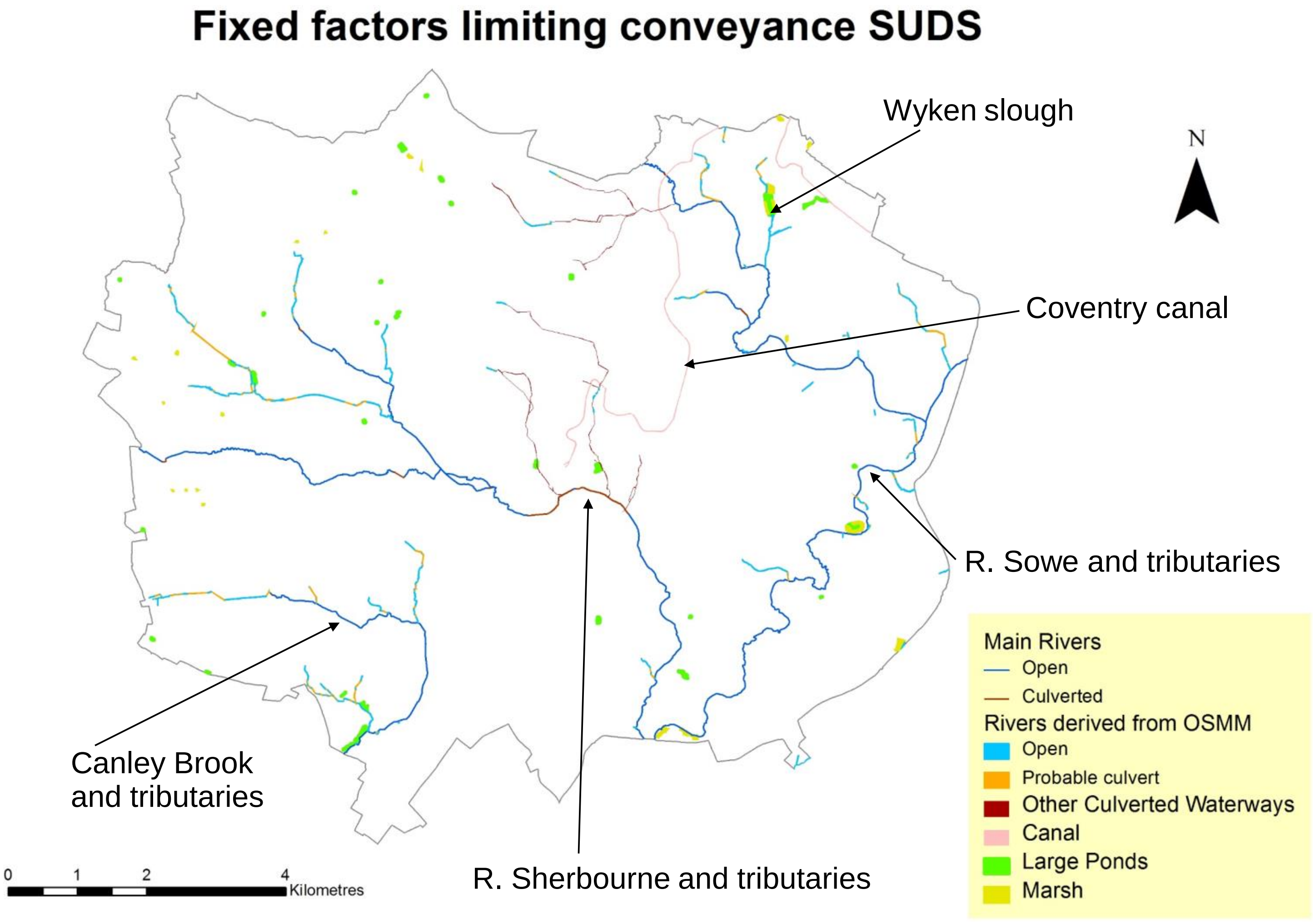


Fig. 5.35 Fixed factors limiting conveyance SUDS

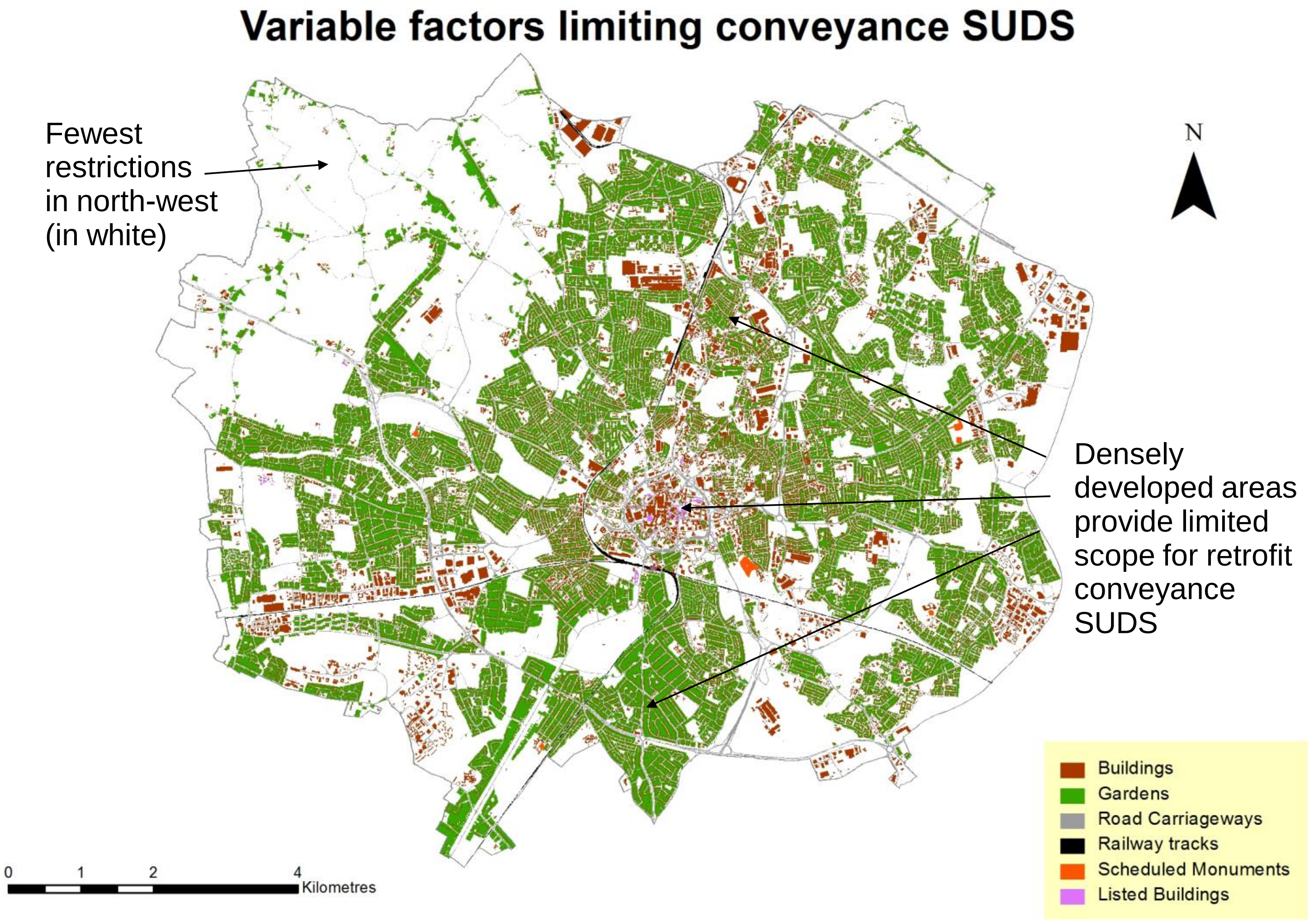
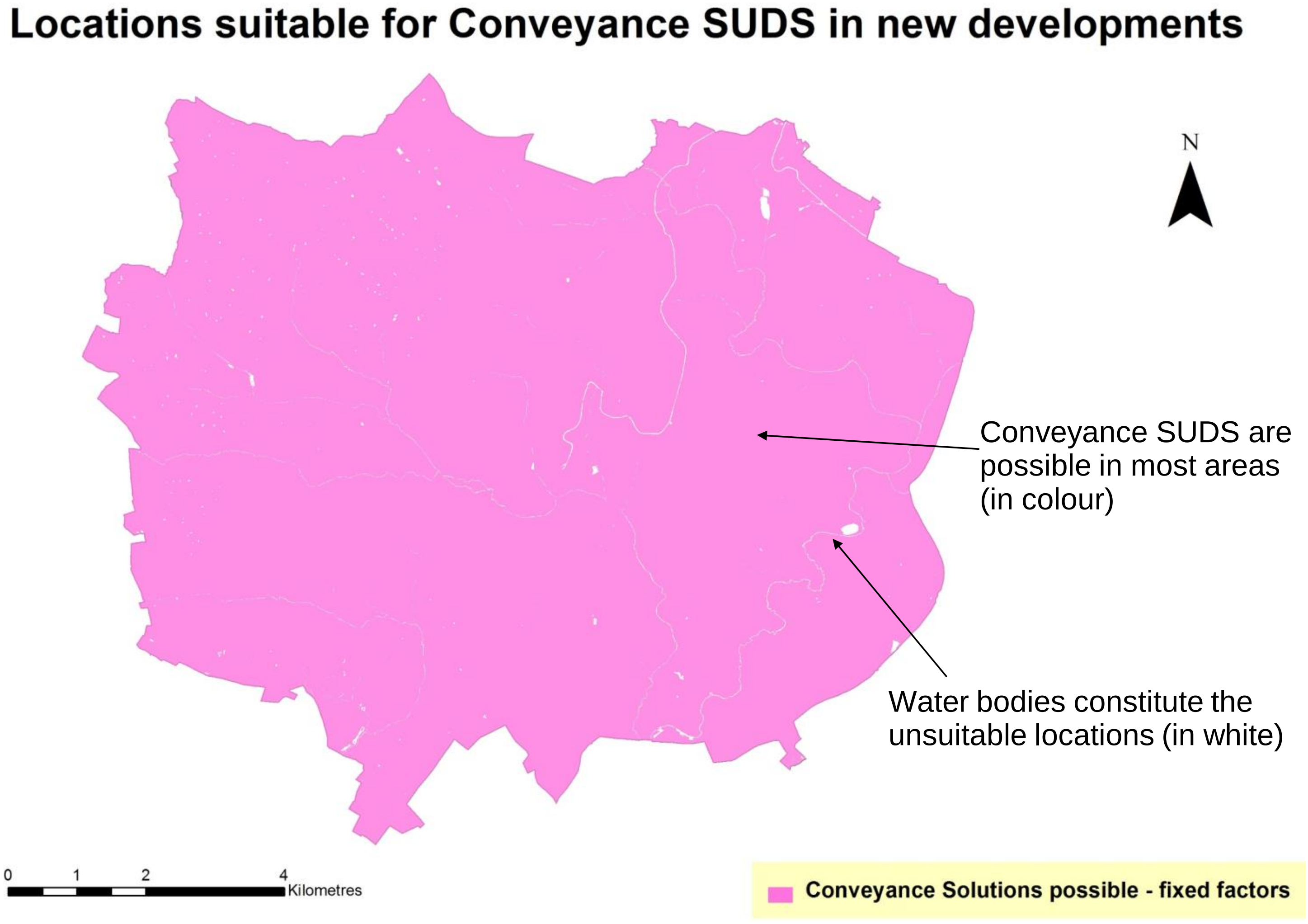


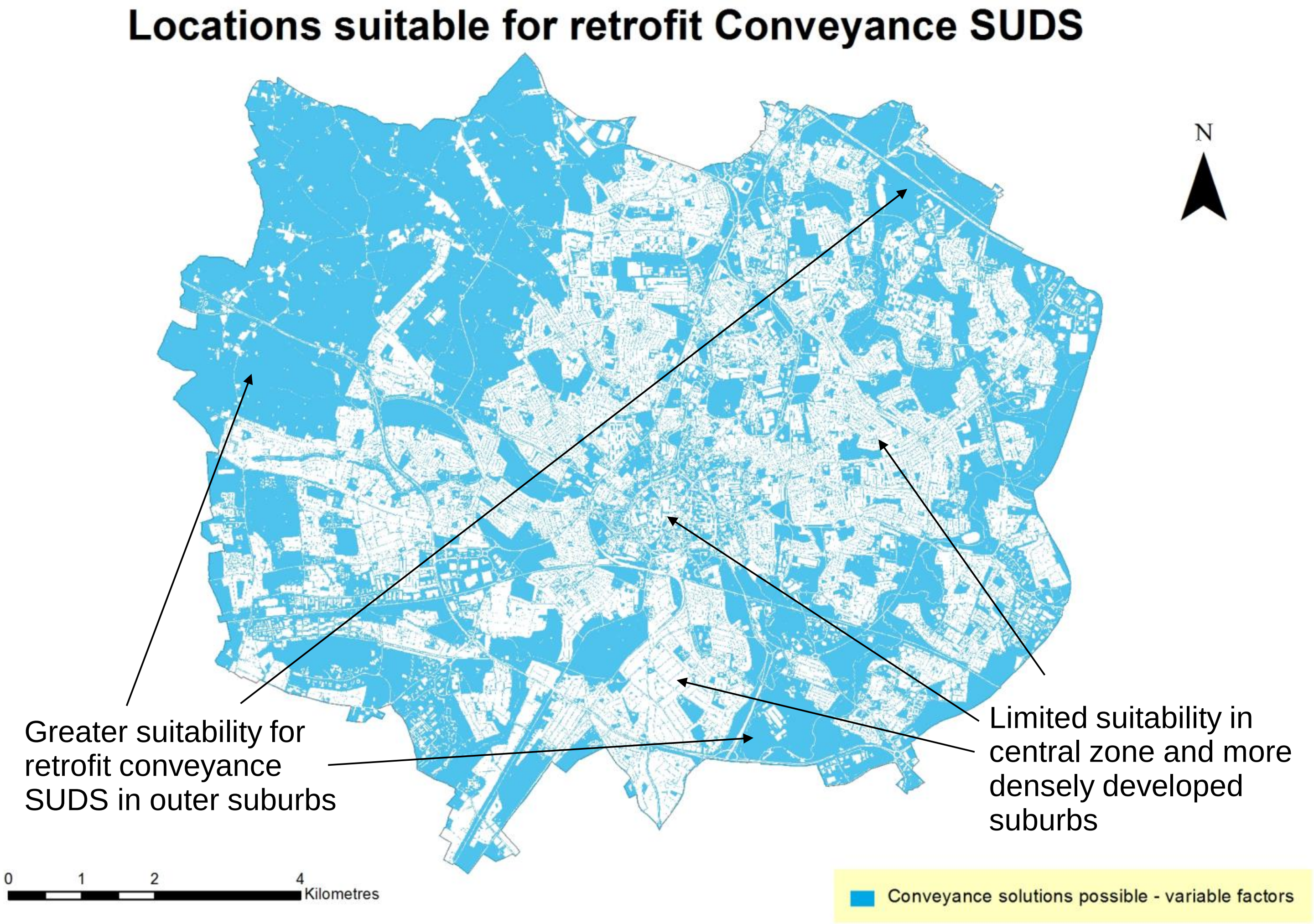
Fig. 5.36 Variable factors limiting conveyance SUDS



Conveyance SUDS are possible in most areas (in colour)

Water bodies constitute the unsuitable locations (in white)

Fig. 5.37 Locations suitable for Conveyance SUDS in new developments. Solutions can be implemented in the coloured areas



Greater suitability for retrofit conveyance SUDS in outer suburbs

Limited suitability in central zone and more densely developed suburbs

Fig. 5.38 Locations suitable for retrofit Conveyance SUDS. Solutions can be implemented in the coloured areas

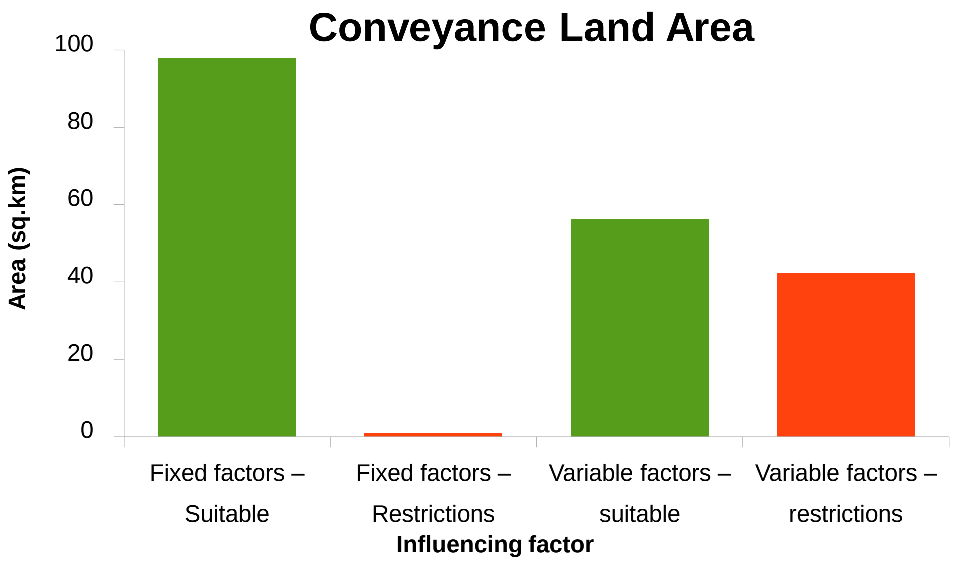


Fig. 5.39 Conveyance land area. 99.25% of Coventry's land area is suitable for conveyance SUDS in new developments. For retrofit SUDS, 57.1% of the city was suitable.

5.7 COMPARISON OF AREAS FOR SUDS IN NEW DEVELOPMENTS AND RETROFIT

The relative spatial area covered by each of the SUDS types in new development and retrofit sites is shown in Fig. 5.40. For SUDS in new developments, areas available for detention, conveyance and source control solutions exceeded 99%, while the area for filtration SUDS was over 95%. There was however limited space suitable for infiltration solutions in new developments, just under 17% of the city's land area. Land area available for retrofit was smaller due to the limitations imposed by existing structures such as buildings and roads (Fig. 5.40). Retrofit detention and retention solutions were possible in 78.7% of the city. Filtration and source control retrofit SUDS were possible in around a third of Coventry, and conveyance in 45%. Infiltration SUDS were possible in 10.6% of the city's land surface, with 1.3% requiring further investigation for possible contamination.

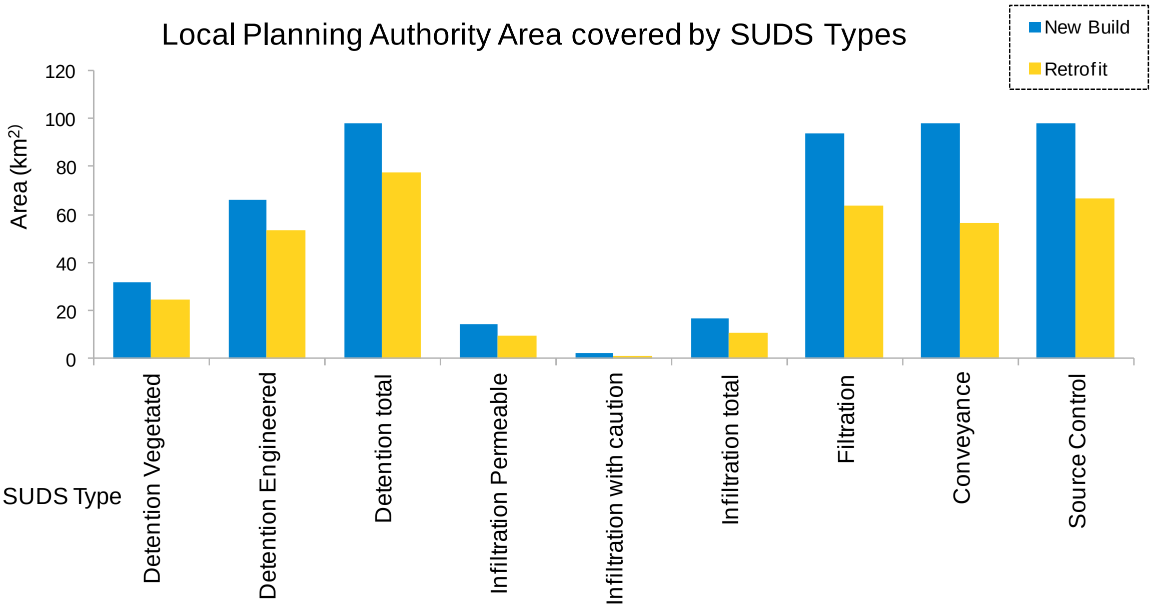


Fig. 5.40 LPA Area covered by SUDS types. For each SUDS type the columns distinguish the areas for New Build and Retrofit. The 'Detention total' columns sum the data from the two component categories 'Detention vegetated' and 'Detention Engineered'. The ‘Infiltration total’ columns sum the data from the two component categories ‘Infiltration permeable’ and ‘Infiltration with caution’.

Detention and retention SUDS exhibited a lower reduction in area available for retrofit compared to the area for new developments, compared to the mean reduction of 32.4%, whereas all other SUDS types were at or above the mean (Fig. 5.41). The greatest percentage difference between new build and retrofit areas was for infiltration SUDS requiring further investigation (-49.1%). These locations were situated in previously developed land where buildings and roads (Fig. 5.5) constituted significant limitations, symptomatic of earlier redevelopment. The second largest percentage reduction was for conveyance SUDS, where the existing land cover and other restrictions reduced available land by 42.5%, due to the unavailability of privately owned gardens for transporting runoff.

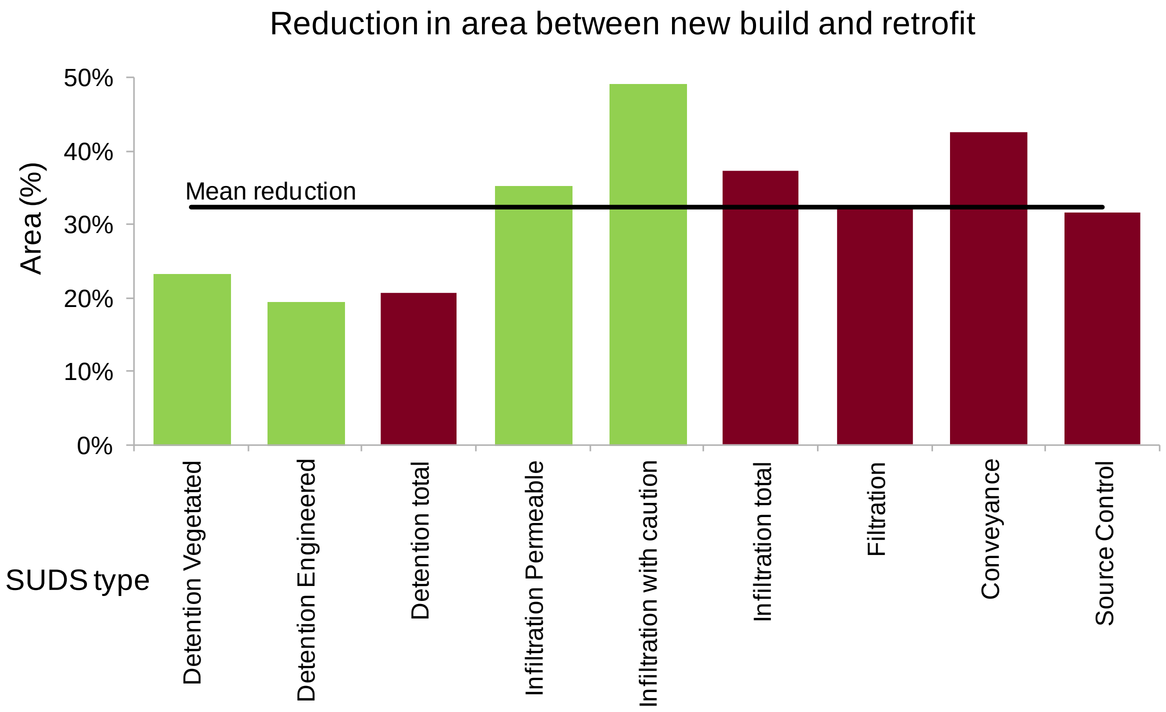


Fig. 5.41 Reduction in spatial area between new build and retrofit. The difference between spatial areas available for new build compared to areas available for retrofit for each SUDS type was calculated using the area available for new build SUDS as the denominator. The 'Detention total' column sums the data from the two component categories 'Detention vegetated' and 'Detention Engineered'. The ‘Infiltration total’ column sums the data from the two component categories ‘Infiltration permeable’ and ‘Infiltration with caution’.

5.8 STAKEHOLDER VALIDATION OF SUDS MAPS

This section explains the stakeholder validation of draft maps in support of objective 2b, to evaluate the suitability of the SUDS feasibility maps and the applicability of the approach. Stakeholders from Coventry City Council, the Environment Agency, Severn Trent Water and Coventry University were consulted for comments on draft versions of the SUDS new development and retrofit maps. A summary of the consultee comments, the responses given, and the changes made to the SUDS maps is provided in Table 5.7 for the new development maps, and in Table 5.8 for the retrofit maps. The detailed document issued to stakeholders is included in Appendix G. As a result of the comments, a number of adjustments were made to the maps, and these changes are incorporated in the versions presented in this document. A notable feature of the comments was the greater quantity and depth of responses to the new build maps (nine) as opposed to the retrofit maps (five). This may have reflected the interests of the consultees, who were mostly involved in the current planning process, which focuses on new development.

Amendments were made to the infiltration maps to cater for climate change. Retrofit conveyance was originally shown as possible in private gardens, but was removed as a result of comments. Options such as the reprofiling of floodplains to increase storage capacity were valuable. However, suggestions that detention and filtration were not possible on privately owned land were not incorporated in the final version of the maps.

Consultees had differing views on whether the detention and retention maps should separate vegetated and engineered solutions, or whether a single extent should be shown. The argument given in favour of showing a single extent was that the separation effectively prejudged the possible solutions a developer might propose, and that it would be better to suggest a hierarchy of solutions, from more to less preferred, alongside a single extent. The argument in favour of separating solutions was that analysis had already identified locations where detention and retention SUDS were likely to be more problematic, and so this information could be made available to planners. However, overall both sides agreed that above ground solutions were to be encouraged rather than underground storage. From the point of view of this work, the more detailed level of analysis was retained, as it would be possible to remove detail at a later stage, but not to add it.

Stakeholders were also asked to comment on a draft set of decision support charts depicting suitable SUDS devices for the range of development land uses shown in Fig. 4.9.

A summary of the comments is presented in Table 5.9. The charts (updated versions of which are included in Appendix I) were employed to gather comments on the type of SUDS suitable for particular styles and sizes of development to inform allocation of SUDS devices to development size (Table 4.11). The issues and comments emerging from the decision charts were substantially the same as those from the SUDS feasibility maps (Tables 5.7 and 5.8). No further changes were necessary to the SUDS feasibility maps as a result of feedback received on the decision support charts.

Table 5.7 Summary of stakeholder comments on new development SUDS maps. The Comment column contains stakeholder views. The Issue column explains the underlying issues. The Outcome indicates changes made to the SUDS maps and / or responses given

SUDS Type	Comment	Issue	Outcome
Detention & retention	1. The division into above and below ground solutions is inflexible. It would be better to show one colour on the map and provide guidance to indicate a hierarchy of above then below ground solutions.	1. The draft detention and retention map differentiated: a) locations suitable for 'detention solutions' where above ground, vegetated solutions can be implemented fairly readily using landscaping techniques b) 'engineered detention solutions', where physical characteristics and/or historical land use make above ground vegetated solutions less suitable, and where more thought may need to be given to appropriate SUDS solutions. It was suggested that below ground solutions may be needed in such locations. The terminology used to explain this difference was not clear.	1. The intention underlying the map was that above ground, vegetated solutions, are preferable to below ground solutions, as the latter may require additional maintenance effort, causing increased disruption in the future. To encourage above ground storage, the definition of the two categories was reworded to emphasise the 'engineered' rather than the 'underground' aspects of the engineered storage locations (see also point 2 next). It was considered valuable to retain presentation of two separate categories on the map for information purposes. The suggestion of the need for a hierarchy indicated that the maps should be used in conjunction with planning guidance.

SUDS Type	Comment	Issue	Outcome
Detention & retention	2. Why not use overground storage, especially in the floodplain? Land could be re-profiled to increase storage in case of large and / or frequent events.	2. Explanation of draft maps implied that engineered detention was limited to below ground storage.	2. The definition of the two categories on the SUDS detention map was reworded to emphasise the 'engineered' rather than the 'underground' aspects of the engineered storage locations. This approach is in line with 'water-compatible development' defined in the Technical Guidance to the National Planning Policy Framework (DCLG 2012: Table 2).
Detention & retention	3. There are risks with engineered solutions in the floodplain, which may influence performance and require inspection.	3. Maps could provide more information about factors that should be considered in decision-making.	3. These high-level maps were not intended to replace more detailed planning guidance. Attempting to include all possible information risked making the maps unwieldy in operation.

SUDS Type	Comment	Issue	Outcome
Detention & retention	4. Engineered detention is not appropriate in private gardens	4. Maintenance of engineered detention SUDS might be considered the responsibility of local government or flood risk bodies.	4. This may be true for large devices under 'public' management, but a means of encouraging householder responsibility for stormwater management at the small scale is needed, so it may be possible for small devices to be installed in new developments, for instance in conjunction with rainwater harvesting techniques. Communicating information on the impact of development on flood risk and water quality may also be useful as a means of educating householders in management of stormwater on their properties. This should be a policy or a detailed planning decision, rather than a map recommendation of what might be possible.
Infiltration	1. Exclude Flood Zone two in order to take into account climate change allowance	1. Only fluvial flood zone three was defined as unsuitable for infiltration in the draft infiltration map	1. Both new development and retrofit infiltration maps were updated.

SUDS Type	Comment	Issue	Outcome
Infiltration	2. Why is the definition of a high water table set at 4 m? 2 m should be adequate	2. Uncertainty about depth to water table and its impact on SUDS devices	2. Measurements of the water table in Coventry were not available, so a simulation was created using a British Geological Survey procedure (Fig. 3.13). Because of the lack of accurate data about existing groundwater levels, the BRE 365 (Soakaway Design) suggestion that a 3 m soakaway depth is acceptable, and Environment Agency guidance of a minimum 1 m depth between the base of infiltration devices and the water table, the 4 m depth was used for safety.
Filtration	1. Private gardens are unsuitable due to maintenance, policing and enforcement considerations	1. Maintenance of filtration SUDS might be considered the responsibility of local government or flood risk bodies	1. Although large-scale filtration is unsuitable in private gardens, householders could take individual responsibility for the run-off from their premises. This should be handled as a policy issue. Better water management by householders could be encouraged by alternative charging mechanisms for stormwater management in conjunction with implementation of SUDS measures by the Flood and Water Management Act (Act of Parliament 2010)

SUDS Type	**Comment**	**Issue**	**Outcome**
Conveyance	No comments		
Source Control	No comments		

Table 5.8 Summary of stakeholder comments on retrofit SUDS maps. The Comment column contains stakeholder views. The Issue column explains the underlying issues. The Outcome indicates changes made to the SUDS maps and / or responses given

SUDS type	**Comment**	**Issue**	**Outcome**
Detention & retention	1. Not suitable in private gardens, unless there are exceptional circumstances	1. Maintenance of detention SUDS might be considered the responsibility of local government or flood risk bodies	1. This may be true for large SUDS devices under 'public' management, but a means of encouraging householder responsibility for stormwater management at small scale is needed
Infiltration	No comments		
Filtration	1. Not suitable in private gardens	1. Maintenance of filtration SUDS might be considered the responsibility of local government or flood risk bodies	1. This may be true for large SUDS devices under 'public' management, but a means of encouraging householder responsibility for stormwater management at small scale is needed

SUDS type	**Comment**	**Issue**	**Outcome**
Conveyance	1. Suitable for public open spaces only, not in private gardens	1. Maintenance of conveyance SUDS might be considered the responsibility of local government or flood risk bodies	1. Conveyance SUDS are a means of transporting water, therefore any interruption to their operation would be detrimental and potentially have wider impacts than other types of SUDS. Therefore, due to practical considerations of maintenance and definitions of responsibility, the retrofit conveyance maps were updated to remove conveyance as an option in existing private gardens
Source Control	1. Sub-surface storage is not appropriate in private gardens	1. Concerns about inappropriate installation and use of sub-surface storage, and of responsibilities for maintenance	1. This may be the case for large SUDS devices under 'public' management, but if there is sufficient space in a garden, it should be possible to include storage facilities that will not affect building foundations

Table 5.9 Summary of stakeholder comments on SUDS decision charts. The Comment column contains stakeholder views. The Response column indicates changes made to the SUDS decision charts and / or responses given

Decision Chart	**Comment**	**Response**
Housing - terraced	1. There is no need to differentiate house types; the scale of development is the important factor	1. Scale of development will influence the range of SUDS implementation options, with larger schemes having more scope to design in appropriate solutions. However, even small-scale developments should implement some form of stormwater management. The space available for SUDS will be influenced by the density of development and therefore there is a need to differentiate housing densities. Consequently, the three 'house type' charts were renamed to high, medium, and low density rather than terraced, semi-detached and detached, based on the densities employed in Coventry City Council's Strategic Housing Land Availability Assessment (SHLAA) September 2011 Review (CCC 2011a, section 4.23). This terminology should be meaningful as the primary use is for planning purposes. The scale of development was already reflected in the x-axis options.
Housing - terraced	2. Swales, filter strips, detention basins and underground storage are not appropriate for private gardens	2. Swales – although these are not appropriate for private gardens, there will still be a need to convey stormwater in housing developments on ‘public land’, and thus there is a role for swales. Filter strips, detention basins and underground storage – as discussed for new development and retrofit maps (Tables 5.7 and 5.8) these should be an option, in order to encourage householder engagement with and individual responsibility for stormwater management

Decision Chart	Comment	Response
Housing – semi-detached	1. Swales, detention basins and underground storage are not appropriate for private gardens	1. Swales – although these are not appropriate for private gardens, there will still be a need to convey stormwater in housing developments on 'public land', and thus there is a role for swales. Detention basins and underground storage – as discussed for new development and retrofit maps (Tables 5.7 and 5.8) these should be an option, in order to encourage householder engagement with and individual responsibility for stormwater management.
Housing – semi-detached	2. Ponds are acceptable in public open space	2. This was already reflected in the charts
Housing – detached	1. Underground storage should not be used	1. Although using above ground storage is preferable, circumstances may dictate that there are no suitable alternative options. Underground storage could be integrated into a rainwater harvesting facility.
Housing – detached	2. Swales, bioretention, filter strips, ponds, detention basins and wetlands are all OK in public open space	2. These were already reflected in the charts

Decision Chart	**Comment**	**Response**
Commercial inner-city	1. The city centre is a special case as all water is discharged into R. Sherbourne, so not clear that conveyance is required	1. Not all runoff in the city centre is currently discharged into the R. Sherbourne. However, it is desirable to discharge treated runoff into the river, and consequently a means of conveyance is necessary. Rather than vegetated swales, engineered rills may be preferable in this setting, and a number of the decision charts were updated to include this option.
Commercial inner-city	2. Commercial inner-city developments need more soft landscaping and open space	2. Rain gardens, detention (but not retention) basins, bioretention devices and small infiltration areas could all be used if suitably designed to take into account high pedestrian traffic volumes. Grassed areas could be landscaped to form detention basins, but will temporarily hold standing water that will drain down over a period of, say, 24 hours – this needs to be managed in an inner-city environment. It is valuable to encourage soft landscaping and open space in the inner city, but this is a policy rather than a SUDS mapping issue.
Commercial outer-city with parking	No comments	

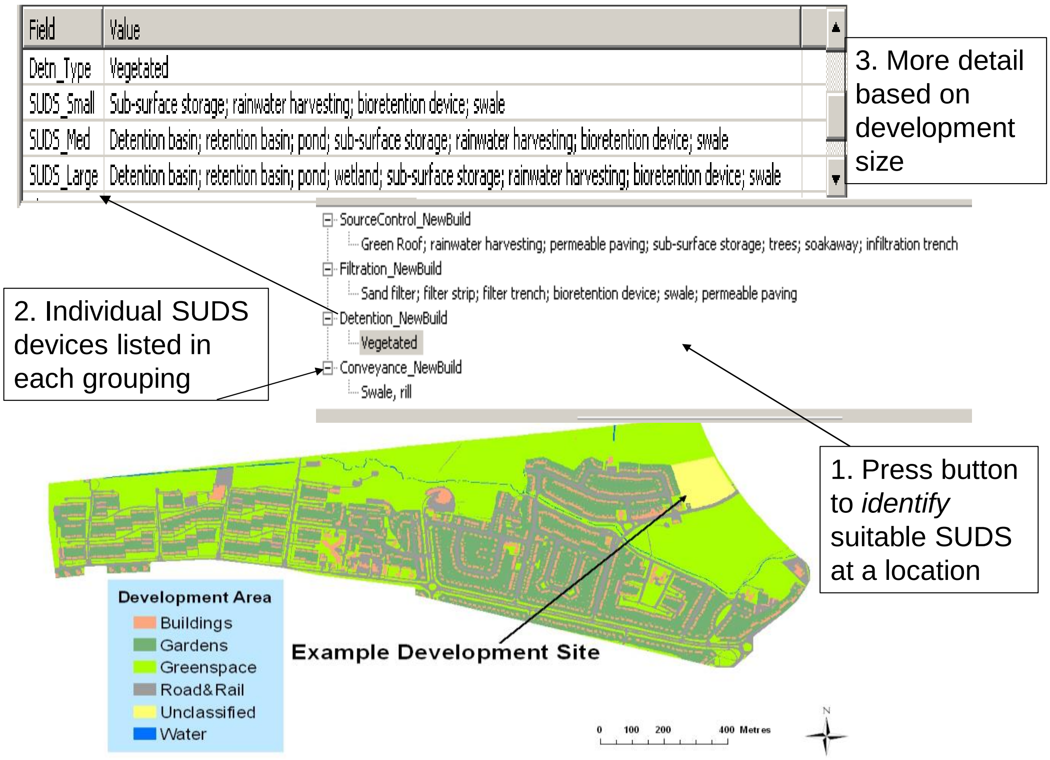
Decision Chart	**Comment**	**Response**
Industrial	1. Underground storage – use a hierarchy of techniques to promote above ground storage	1. The charts were intended to reflect the possible options. The promotion of above-ground storage, and the associated hierarchy, needs to be defined in planning policy.
Roads & car parks	No comments	
Recreational area – small	No comments	
Recreational area - large	No comments	

5.9 EXAMPLE GIS MAP OUTPUTS

This section outlines map usage in a GIS system with an example of the graphical interface to demonstrate standard use of GIS functionality and ease of use.

Having separate layers for each SUDS group allows the user to see results for each set of devices. Turning on all five layers delivered too much information for a visual assessment, but allowed the full set of information to be queried in order to determine all types of SUDS that were feasible at a specific location. Fig. 5.42 illustrates the use of the full set of maps to support assessment of suitable SUDS devices at a potential development site in Coventry. Using standard GIS functionality to ascertain the spatial attributes associated with a location, the feasible SUDS for that location are listed in a query box, categorised under the device groupings. In Fig. 5.42, appropriate devices are presented according to approximate size of the development. Possible SUDS for different land use types, e.g. dense housing development, inner-city commercial areas (see section 4.4), along with the advised number of management train components, could be listed as additional fields in the query box. Changes to the proposed advice to reflect local guidance can be readily made by editing the fields, although the associated locations are statically assigned, so cannot be altered without adjusting the input data. The length of field names is limited by the functionality of the GIS system.

The GIS functionality has been demonstrated successfully in ArcGIS, MapInfo and Quantum GIS. The maps were also output as a layered pdf document, where the full detail of the maps is present, but enquiry and spatial referencing functionality was not available, so users need to know the specific location under investigation. Inclusion of orientation points such as major roads, or ward boundaries, could assist, although inclusion of very detailed information, for instance OSMM data, would lead to unmanageable document sizes and might risk contravening the terms of the Ordnance Survey licence. Examples of the pdf, and shape files for the 10 SUDS location maps, are provided in Appendix A.



Field	Value
Detn_Type	Vegetated
SUDS_Small	Sub-surface storage; rainwater harvesting; bioretention device; swale
SUDS_Med	Detention basin; retention basin; pond; sub-surface storage; rainwater harvesting; bioretention device; swale
SUDS_Large	Detention basin; retention basin; pond; wetland; sub-surface storage; rainwater harvesting; bioretention device; swale

SourceControl_NewBuild
- Green Roof; rainwater harvesting; permeable paving; sub-surface storage; trees; soakaway; infiltration trench

Filtration_NewBuild
- Sand filter; filter strip; filter trench; bioretention device; swale; permeable paving

Detention_NewBuild
- Vegetated

Conveyance_NewBuild
- Swale, rill

3. More detail based on development size

2. Individual SUDS devices listed in each grouping

1. Press button to *identify* suitable SUDS at a location

Fig. 5.42 Operation of the feasibility maps in a GIS system. On choosing an example development site (step 1), the standard GIS *identify* function shows possible SUDS devices for consideration at this site (step 2). For each SUDS grouping, suitable SUDS may vary depending on the size of the development (step 3)

5.10 DEVELOPMENT SCALE USE OF SUDS FEASIBILITY MAPS

This section explains the use of two case study sites for validation of the maps in support of objective 2b, to evaluate the suitability of the SUDS feasibility maps and the applicability of the approach.

5.10.1 New Development – Canley Regeneration Zone

The Canley regeneration zone is situated around 6 km southwest of Coventry city centre, and covered just over 123 ha. Outline planning permission was granted for 700 new dwellings, new community services and open space improvements (CCC 2008d:14). However, in the absence of attracting a developer for the whole project, CCC (2013:2) pursued a piecemeal development for individual land parcels.

Figs. 5.43-5.47 show the SUDS new development feasibility map proposals for the regeneration site. All groups of SUDS devices were feasible except for infiltration (Fig. 5.44). The closest areas for infiltration SUDS lie outside the proposed regeneration zone, the nearest potential site lies approximately 250 m to the south-east, although this was an area of former industrial land so further tests would be required to confirm suitability for infiltration.

A strategic flood risk assessment for Prior Deram Park, one of the development parcels in Canley (Halcrow Group Ltd 2008b), developed as part of the regeneration plans, identified SUDS generically as a requirement to address fluvial flooding issues. The assessment gave no specific recommendations as to suitable SUDS, advising only of the need to "take account of groundwater and geological conditions” (Halcrow Group Ltd 2008b:8). A more detailed desktop assessment for the same development parcel (Lashford *et al.* 2014), utilised detention ponds for storage, swales for conveyance, and permeable paving and green roofs as source controls while modelling combinations of techniques to judge the effectiveness of different SUDS management trains. Infiltration was not regarded as a suitable option at this site due to soil type and prior use of part of the site as a landfill. The recommendations of the feasibility maps are compared with those of Lashford *et al.* (2014) in Table 5.10, which shows broad agreement between the two. The design by these authors aimed to demonstrate the extent to which SUDS could manage flood risk at a redevelopment site, and was oriented towards their inclusion. Nevertheless, they considered a relatively limited range of SUDS, focussing largely on flood risk issues, and not designing for improved water quality except as a by-product, hinted at by the lack of filtration SUDS. The feasibility maps indicated additional options that could have been included, such as rain gardens, rainwater harvesting and bioretention devices.

An evaluation (RPS Planning and Development 2012) for development of a separate 5.4ha parcel of land at Prior Deram Walk, just north of Prior Deram Park (Fig. 5.43), proposed some use of SUDS with emphasis on hard engineered SUDS solutions combined with conventional discharge to surface water sewers (Fig. 5.48). For handling runoff volume and rate, geocellular storage crates were proposed for private curtilages, with disposal to soakaways where possible, also largely in private curtilages. Oversized pipes and a hydrobrake were proposed to limit runoff to greater than a 1-in-30-year event +30% for climate change, and all houses would be provided with a water butt. For improvements in water quality, permeable paving was planned for all shared parking and driveways, albeit the number of these was limited. No vegetated SUDS were included in the design.

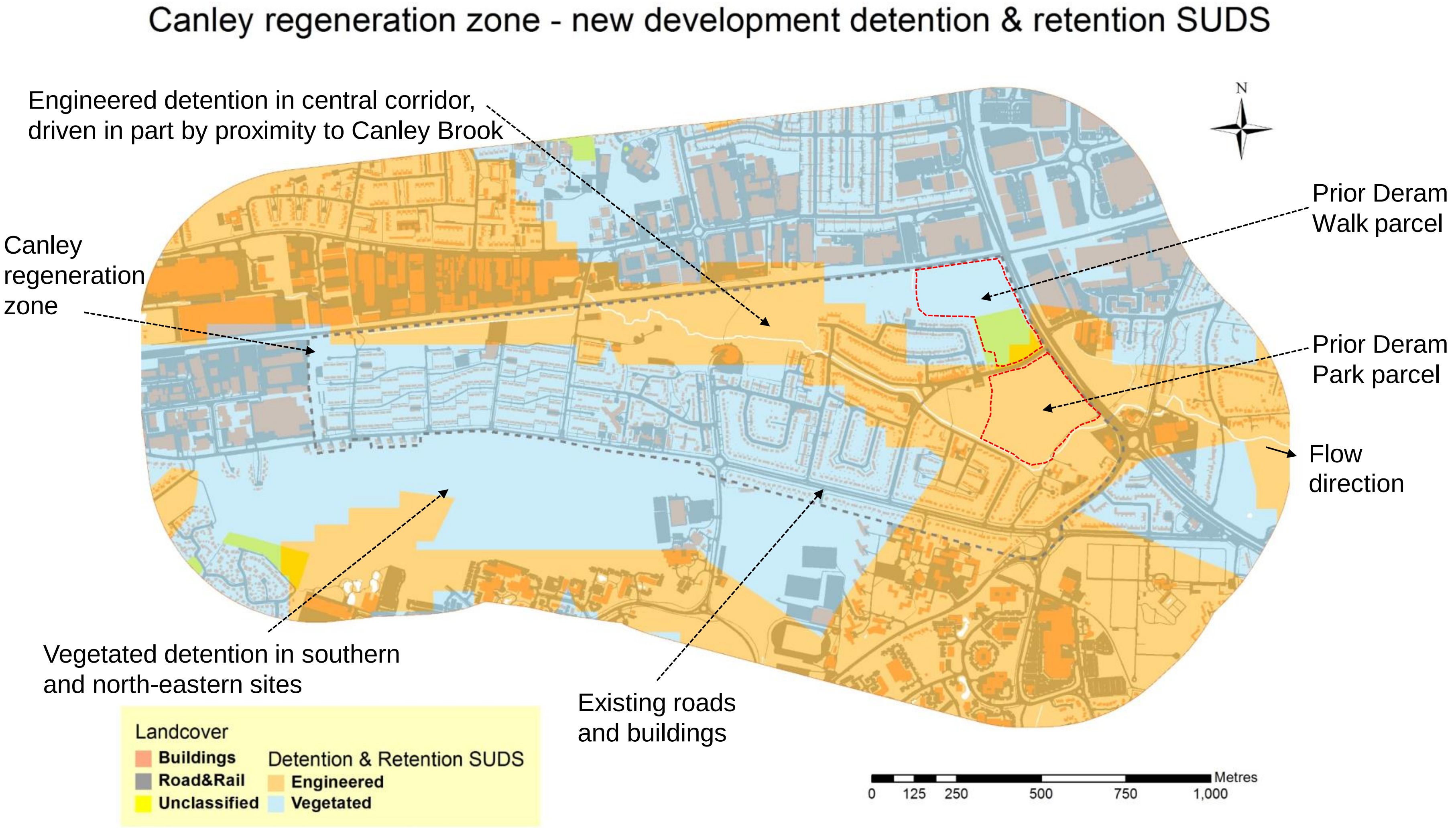
The recommendations of the feasibility maps are compared with those of RPS Planning and Development (2012) in Table 5.10, which shows limited agreement between the two. The solution by RPS placed more weight on conventional drainage than Lashford *et al.*

(2014). In order to reduce land-take, most of the SUDS options were placed underground using geocellular crates and oversized pipes. Limited consideration was given to an effective management train to improve water quality, the three components being specified as water butts on residential properties, permeable paving on shared driveways, and underground storage plus oversized pipes (RPS Planning and Development 2012:15). Vegetated detention was possible across most of the site, and failure to use it is a missed opportunity for broader city wide water management. Even retaining the dense land usage of the site design, feasibility maps offered options which might have been considered. RPS included permeable paving only on shared driveways, but did not explain how runoff from paved front gardens was to be prevented in order to meet the changes to permitted development from 2008. Rain gardens, downpipe disconnection, and bioretention devices would all provide practical small-scale choices.

Feasibility maps considered infiltration unsuitable at this site due to a relatively shallow depth to the water table and soil with impeded drainage characteristics. In the site flood risk assessment (RPS Planning and Development 2012:30), soakaway tests according to BRE365 were performed at five trial pits (Nicholls Colton Geotechnical 2012:13). Two, in the south and west of the site were unsuitable for infiltration, while three in the centre and north-east of the parcel were acceptable, indicating the local variability of conditions which were not identified by the broader scale assessment undertaken for the infiltration feasibility map. However, the detention feasibility map (Fig. 5.43) did indicate that separate conditions influenced the northern compared to the southern part of the parcel. The nearest infiltration zones were situated 1000 m to the west and 800 m to the north according to the feasibility maps. Impeded soil drainage was the main characteristic limiting infiltration.

Nicholls Colton Geotechnical (2012) performed ground investigation for the development in summer 2012. In 26 trial pits dug on 9th and 26th August across the site at depths of 1.45-3 m, only the deepest pit (3m, in the south-east of the site) encountered groundwater. Groundwater monitoring on 4 days from 15 August to 28 September 2012 in 4 pits at depths of 1.2-2.5 m in the south and central areas of the site encountered groundwater in the two pits in the south-west at 1.7 and 2.14 m, although the latter value was in a 2 m deep pit, casting some doubt on the precise measurement. The south-west of the site was the portion closest to the Canley Brook, just over 200 m away. The groundwater depth modelled for the infiltration feasibility map at these two pits was in reasonable agreement, 1-1.9 and 2-2.9 m respectively. The mean water depth from site investigations was 2.1 m (range 1.2-3 m), whereas the modelled depth of groundwater across most of the site was >= 3 m. Given the uncertainties of the groundwater model, the SUDS feasibility maps adopted a more cautious approach to suitability for infiltration than detailed soakaway tests, using 4 m depth to groundwater as the acceptable cut-off point for infiltration SUDS, and advising that the feasibility maps should not replace detailed site investigations.

The presence of a former landfill site to the south, to which a precautionary 250 m buffer was applied, was a further factor preventing suitability for infiltration in the south and centre of the parcel. A geotechnical investigation in the southern section of the site (Nicholls Colton Geotechnical 2012:21) found elevated concentrations of several PAHs, leading to the recommendation that this area was unsuitable for soft landscaping due to the potential risk to human health, which could be addressed with a 600 mm capping layer.



Canley regeneration zone - new development detention & retention SUDS

Engineered detention in central corridor, driven in part by proximity to Canley Brook

Canley regeneration zone

Prior Deram Walk parcel

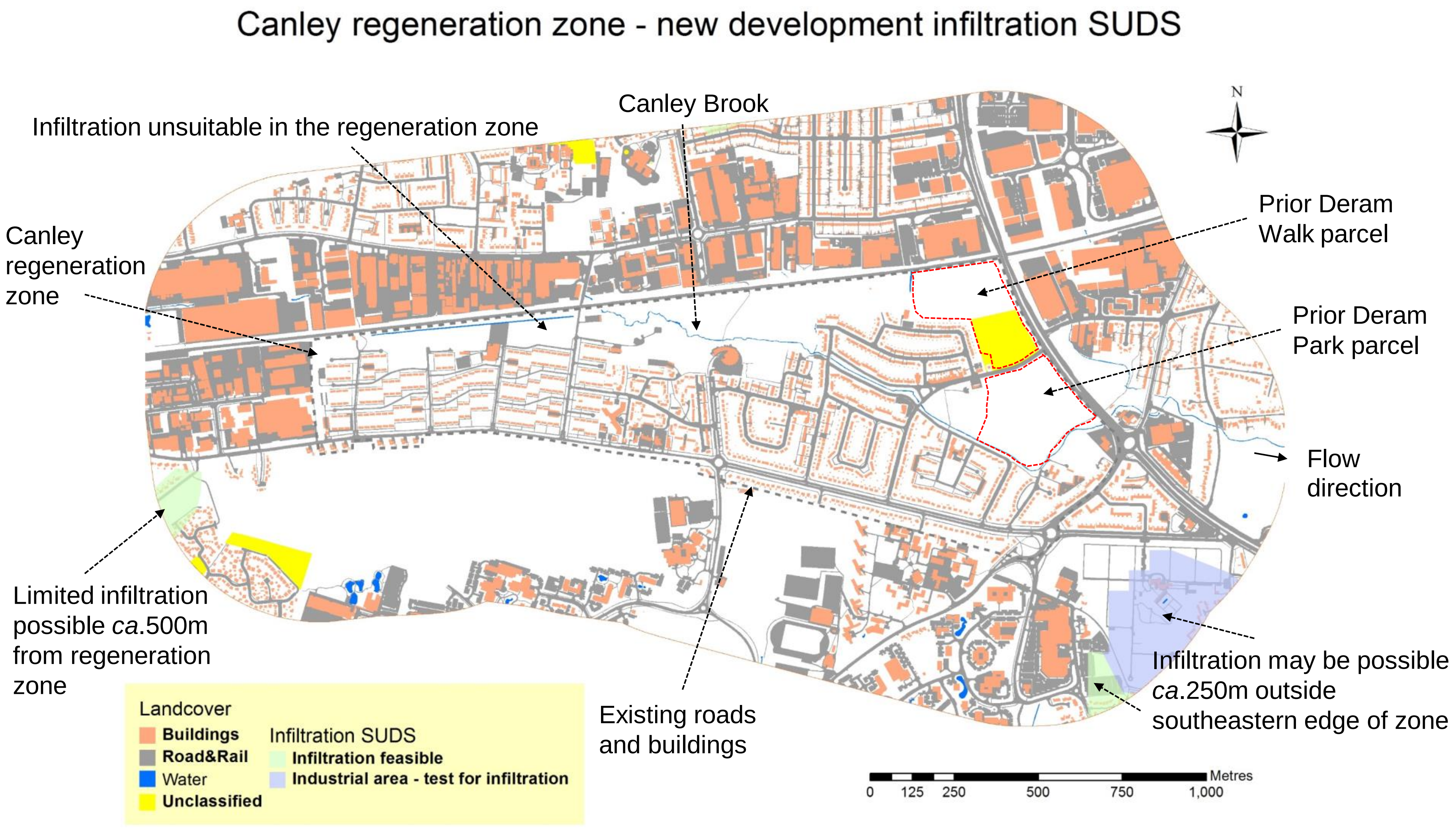
Prior Deram Park parcel

Flow direction

Vegetated detention in southern and north-eastern sites

Existing roads and buildings

Fig. 5.43 Guidance for new development detention and retention SUDS in Canley regeneration zone



Canley regeneration zone - new development infiltration SUDS

Canley Brook

Infiltration unsuitable in the regeneration zone

Canley regeneration zone

Prior Deram Walk parcel

Prior Deram Park parcel

Flow direction

Limited infiltration possible *ca*.500m from regeneration zone

Existing roads and buildings

Infiltration may be possible *ca*.250m outside southeastern edge of zone

Fig. 5.44 Guidance for new development infiltration SUDS in Canley regeneration zone

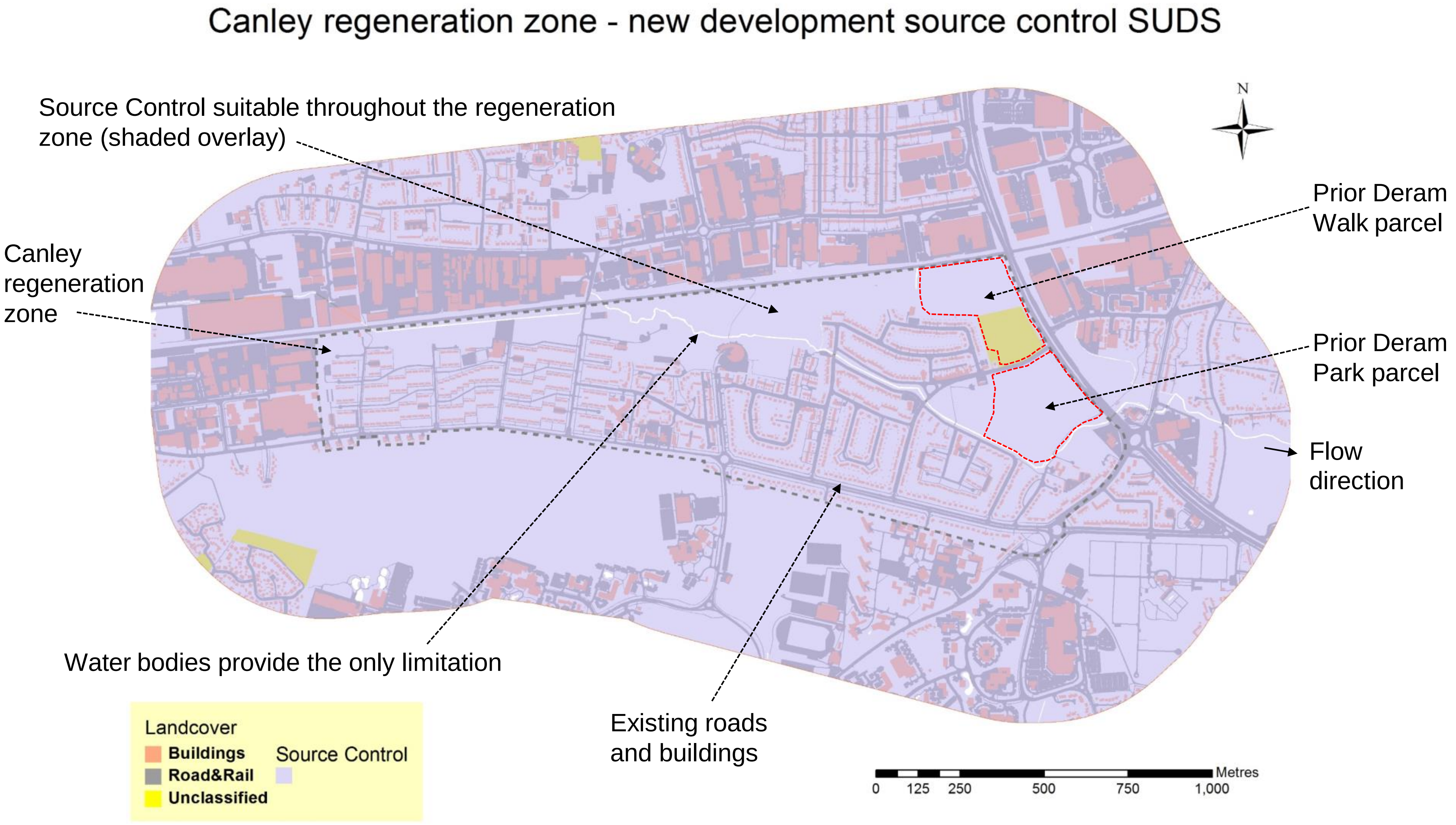


Fig. 5.45 Guidance for new development source control SUDS in Canley regeneration zone

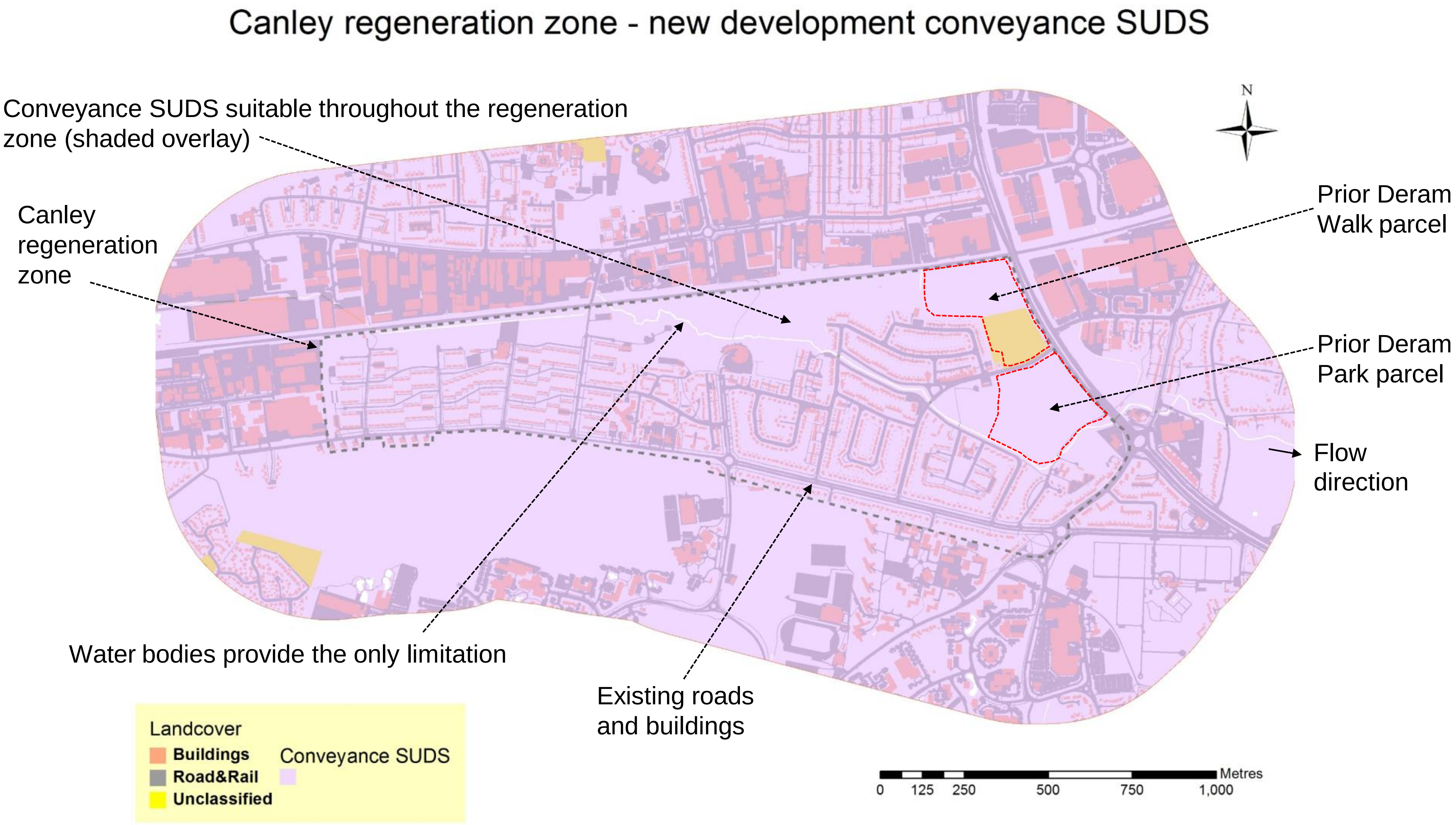


Fig. 5.46 Guidance for new development conveyance SUDS in Canley regeneration zone

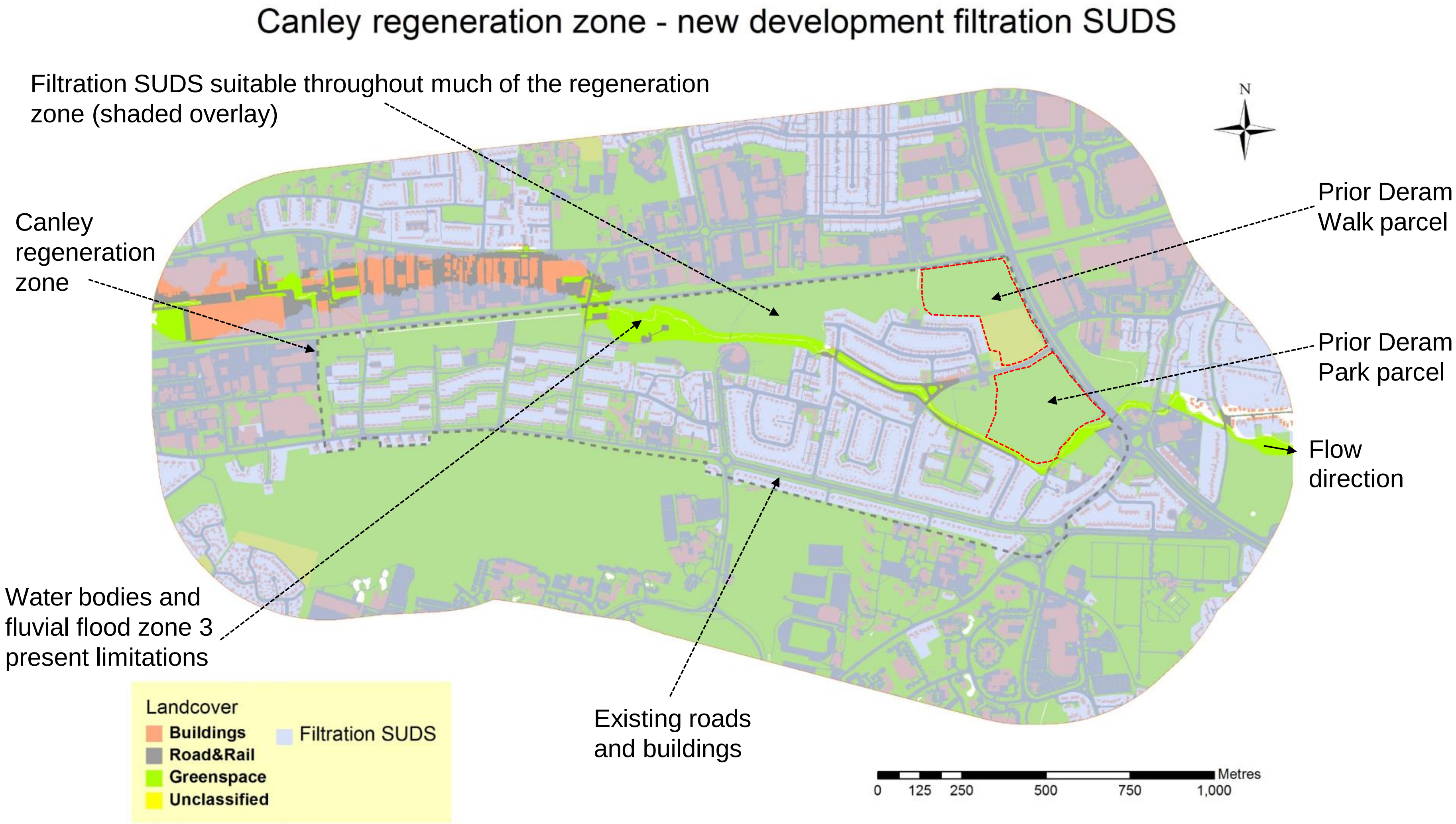


Fig. 5.47 Guidance for new development filtration SUDS in Canley regeneration zone

Table 5.10 Comparison of SUDS feasibility map proposals for Canley regeneration zone with two more detailed studies. Column two lists the SUDS devices suggested by the more detailed study, options in bold agree with proposals from the feasibility maps. Column three shows the feasibility map proposals that could have been considered for this site, options in bold are those defined as having a primary role in Table 4.11.

Device grouping	**Prior Deram Park** (Lashford *et al*. 2014)	**Feasibility map options**
Infiltration	none	none
Detention & retention	**Detention ponds**, Hydrobrake	Engineered: **Detention basin; retention basin; pond**; sub-surface storage; rainwater harvesting; bioretention device; swale
Source Control	**Permeable paving; green roofs**	**Green Roof; rainwater harvesting; permeable paving; sub-surface storage; trees; rain garden; disconnected downpipe**; soakaway; infiltration trench; bioretention device
Conveyance	**Swales**	**Swale, rill**
Filtration	none	**Sand filter; filter strip; filter trench; bioretention device;** detention basin; retention basin; pond; swale; permeable paving

Device grouping	**Prior Deram Walk** (RPS Planning and Development 2012)	**Feasibility map options**
Infiltration	Soakaways	none
Detention & retention	**Sub-surface storage**, oversized pipes, hydrobrake	Vegetated (most of site): **Detention basin; retention basin; pond;** rainwater harvesting; bioretention device; swale; sub-surface storage Engineered (south-east corner): **Detention basin; retention basin; pond;** sub-surface storage; rainwater harvesting; bioretention device; swale
Source Control	**Water butts, permeable paving, soakaways**	**Green Roof; rainwater harvesting; permeable paving; sub-surface storage; trees; rain garden; disconnected downpipe**; soakaway; infiltration trench; bioretention device
Conveyance	Pipes	**Swale, rill**
Filtration	none	**Sand filter; filter strip; filter trench; bioretention device**; detention basin; retention basin; pond; swale; permeable paving

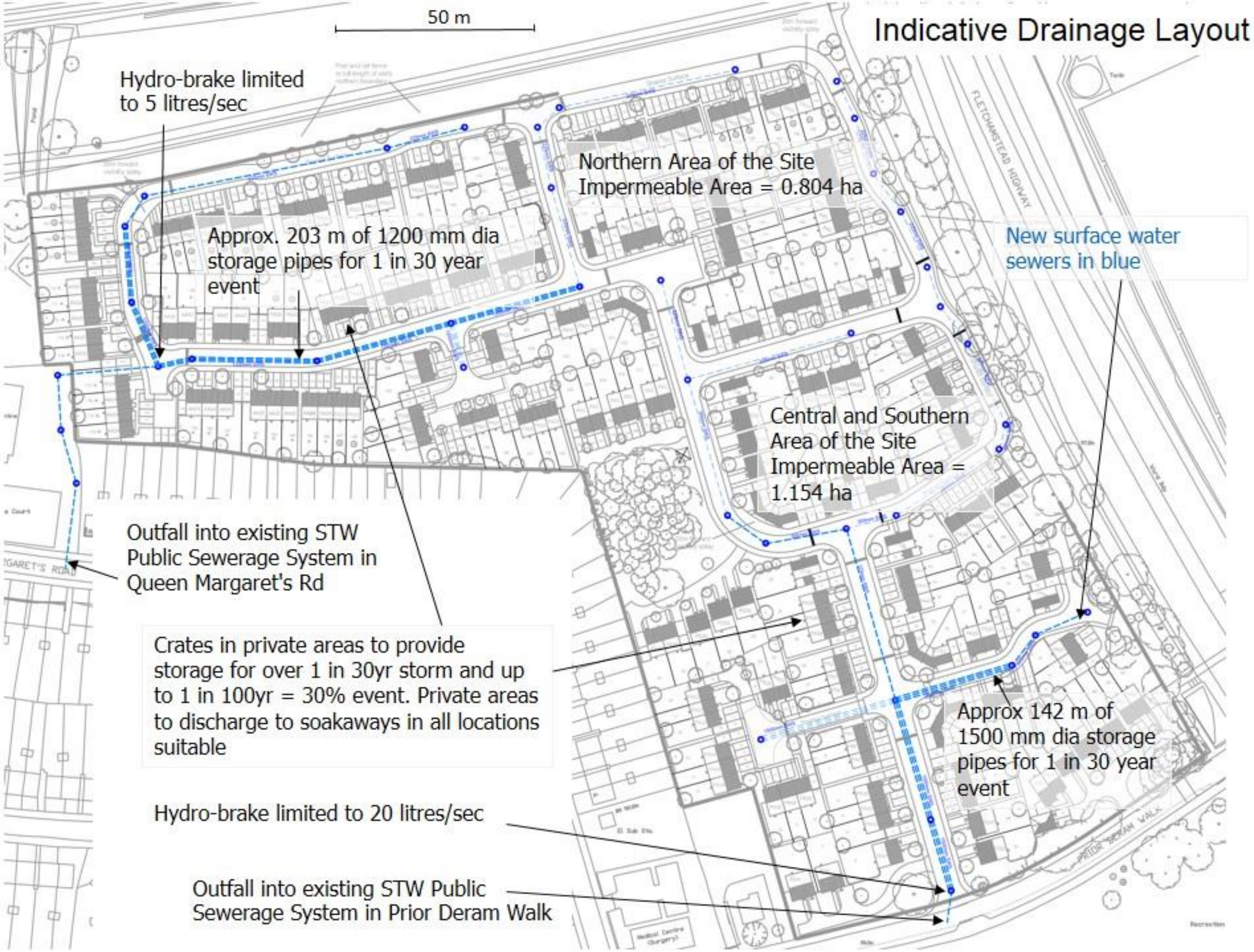


Fig. 5.48 SUDS design for Prior Deram Walk development parcel, Canley, by RPS Planning and Development (2012:30). Text redrawn and scale added

5.10.2 Retrofit - Coventry University

Validation of the retrofit maps was performed by comparison with the Coventry University's 1.62 ha Armstrong Siddeley (AS) sub-catchment analysis from the pilot study (Fig. 4.7). The sub-catchment was 56% impermeable, and for comparison with the pilot results was treated as a medium-sized retrofit site (1-5 ha). The possible options for this type of site are given in the final column of Table 5.11, which also identifies the proposals from the pilot study for comparison. The feasibility maps should have identified relevant SUDS in the different categories, and these devices should have been considered in the more detailed pilot study. In this case, all of the pilot options were present in the feasibility maps, even though some were discounted as impractical by the more detailed evaluation. No infiltration solutions were suggested by either approach. The feasibility maps proposed additional options that were not considered in the pilot study – these are reviewed below.

The site lay at the boundary between vegetated and engineered detention. Most of the existing paved and vegetated areas were suggested as candidates for storage in the feasibility maps. The presence of several culverted channels at the eastern end of the site precluded detention and also suggested a high water table, accounting for the need for engineered storage. A pond or retention basin could be an option at point 1 (Fig. 5.49) to handle runoff from the roof of the southern end of the JA building, although there were no downpipes to connect to a new detention system. The land at point 1 is also relatively steep, falling 3 m over 51 m (6%), so use of natural contours for a pond would not be appropriate. In terms of water quality, a retention basin might contribute to reducing the volume of polluted urban runoff entering the short surface water sewer at the bottom of Gosford St., however a means of diverting runoff away from the road would need to be constructed.

Most locations were suitable for source controls (Fig. 5.50), except for the path of culverted watercourses. Outside the University campus, Gosford St., previously a main artery out of the city, had recently had traffic calming measures applied, and was identified as a minor road in the classification procedure. Porous tarmac or permeable paving might be used as a road surface, although heavy vehicles, including buses, regularly use the road as a thoroughfare. The small traffic islands in Gosford St. could function as small scale bioretention (Fig. 5.50) or filtration (Fig. 5.51) devices to capture and treat road runoff by adding suitable inlets and replacing the central portion with planting above a storage facility. A possible enhancement to the maps would be to select polygons based on size and characteristics to identify similar features for treating road runoff.

Engineered soakaways might be possible in several locations, but bioretention features would more likely to have greater amenity value. Engineered rills could be used instead of swales to convey runoff to storage devices, and these might be preferable in heavily trafficked areas, but the proposed small swales could be implemented more readily on University property (Fig. 5.52). The validation maps show the inappropriateness of some of the guidance, e.g. small traffic islands for conveyance (Fig. 5.52), which were arguably not feasible for this purpose, and a possible refinement would be to remove such small features from the maps based on polygon size. They were retained in this version in case several could be joined. In this case they might be used to transfer runoff to the large roundabout with potential to act as a runoff detention basin.

Although insufficient space was available for filter strips, a filter trench could be constructed at point 2 on Fig. 5.51. The small car park at point 3 is used by delivery vehicles rather than as day parking, and filtration might protect runoff into the nearby surface water sewer which delivers into the R. Sherbourne approximately 20 m downstream. However, attention would need to be paid to the route of the culverted watercourse running between the car park and the vegetated strip.

When reviewed in this way, the retrofit SUDS maps prompted additional options that could have been considered in the original study. They could form the basis for initial discussions as part of wider retrofit schemes. The next sections provide further consideration of using the SUDS location feasibility maps for evaluation of SUDS implementation.

Table 5.11 Comparison of SUDS proposals from pilot study and feasibility maps for Coventry University AS sub-catchment. The pilot details are taken from section 4.2.7.2.1; column two lists the SUDS devices considered feasible for retrofit, while column three identifies options considered but discounted. At the more general scale of the feasibility maps, column four shows the SUDS devices that could have been considered for retrofitting at this site, options in bold are those defined as having a primary role in Table 4.11.

Device grouping	**Pilot - possible**	**Pilot - impractical**	**Feasibility map options**
Infiltration	-	-	none
Detention & retention	Detention basin		Vegetated: **Detention basin; retention basin; pond**; rainwater harvesting; bioretention device; swale; sub-surface storage Engineered: **Detention basin; retention basin; pond**; sub-surface storage; rainwater harvesting; bioretention device; swale
Source Control	Bio-retention features permeable paving green roof	Rainwater harvesting; disconnected downpipe	**Green Roof; rainwater harvesting; permeable paving; sub-surface storage; trees; rain garden; disconnected downpipe;** soakaway; infiltration trench; bioretention device
Conveyance	Swales	-	**Swale, rill**
Filtration	-	Filter strips	**Sand filter; filter strip; filter trench; bioretention device;** detention basin; retention basin; pond; swale; permeable paving

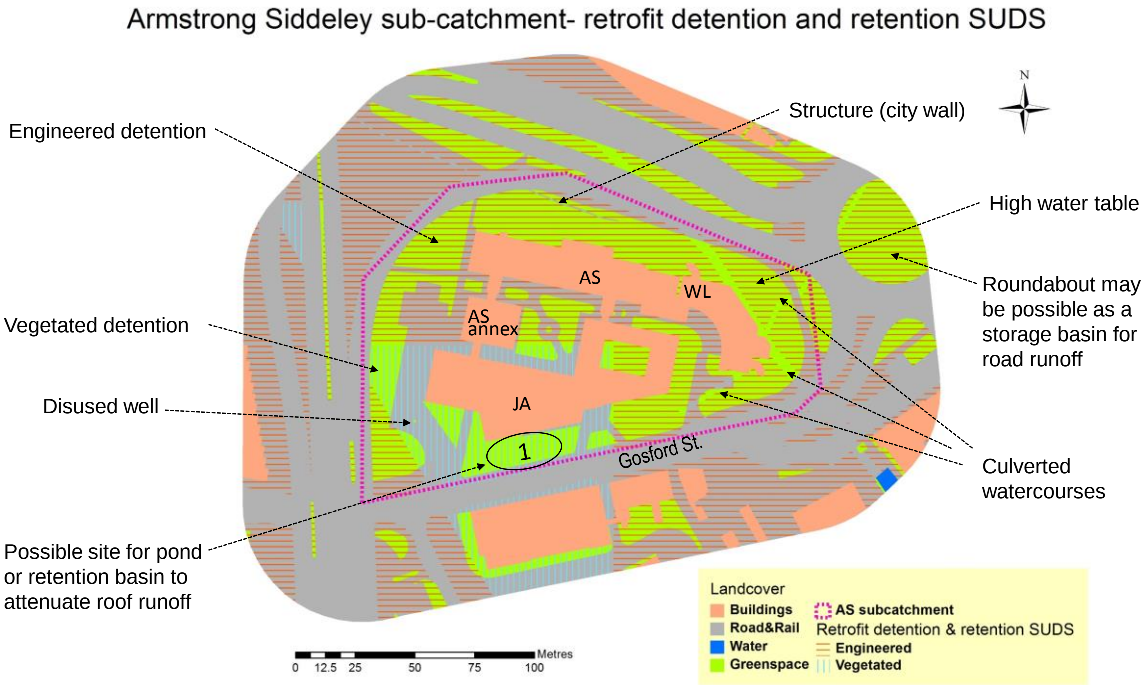


Fig. 5.49 Guidance for retrofit detention and retention SUDS in Coventry University Armstrong Siddeley sub-catchment

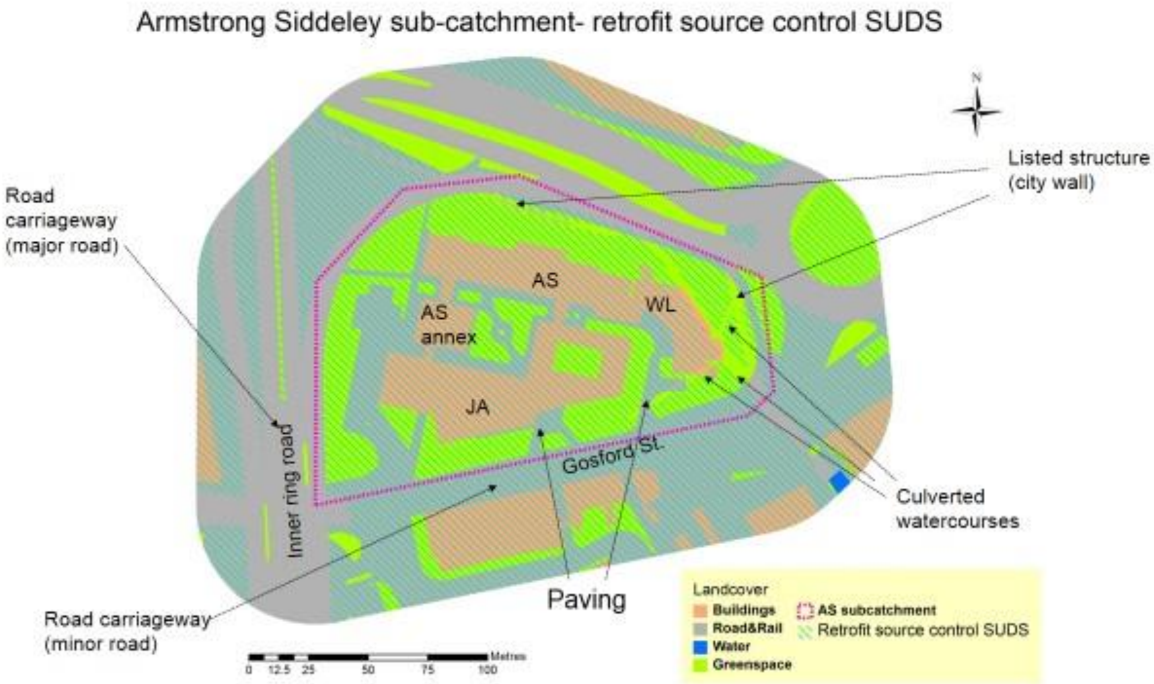


Fig. 5.50 Guidance for retrofit source control SUDS in Coventry University Armstrong Siddeley sub-catchment

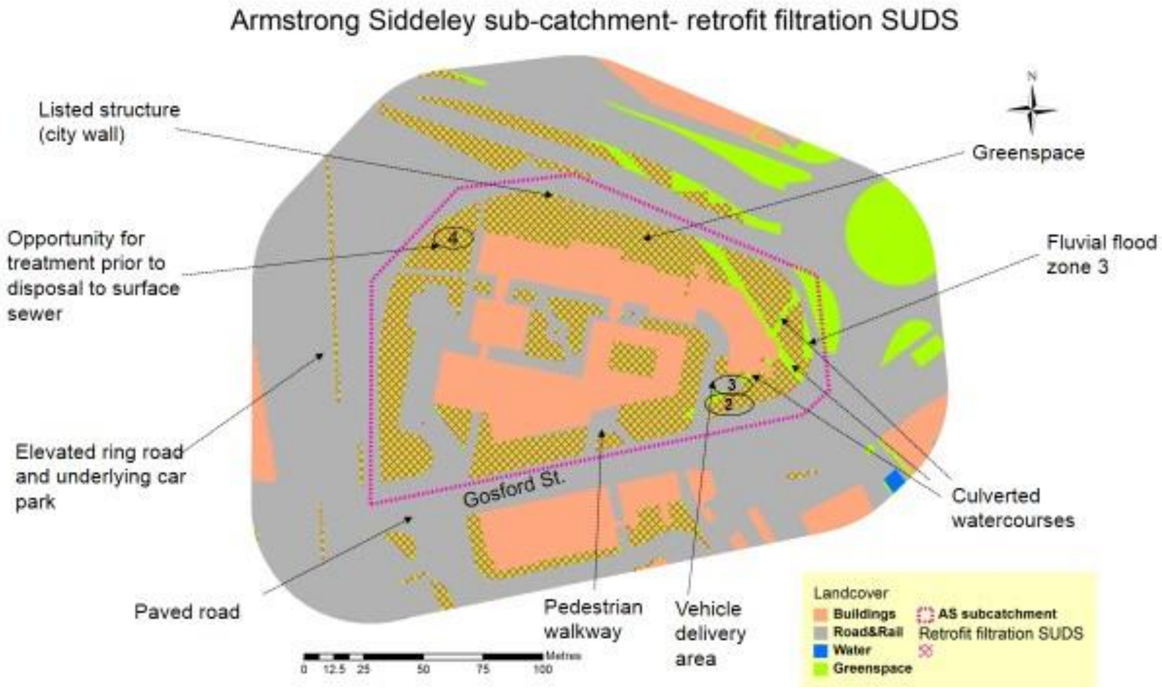


Fig. 5.51 Guidance for retrofit filtration SUDS in Coventry University Armstrong Siddeley sub-catchment. Note the disconnect between fluvial flood zone 3 and its culverted watercourse on the eastern side. The greenspace at the start of the short surface water sewer (point 4) may give an opportunity for treatment to improve water quality. This sewer is likely to convey untreated runoff from highway drains from the elevated ring road and the underlying car park, although confirmatory data were not obtained for this study

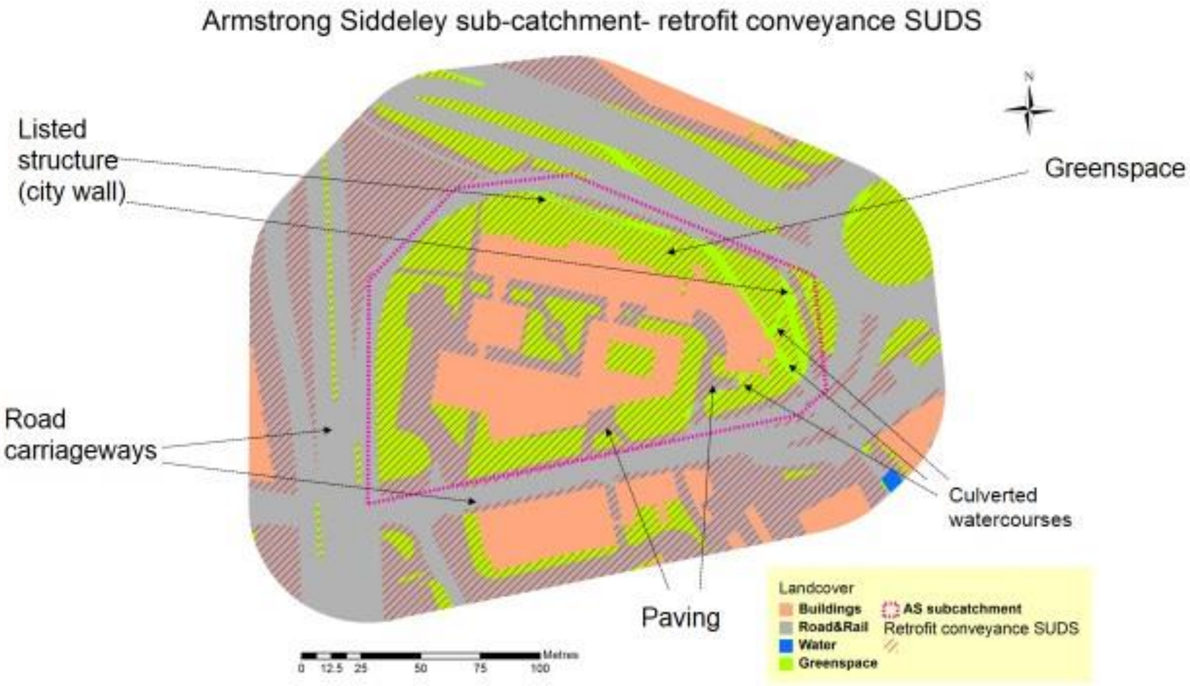


Fig. 5.52 Guidance for retrofit conveyance SUDS in Coventry University Armstrong Siddeley sub-catchment

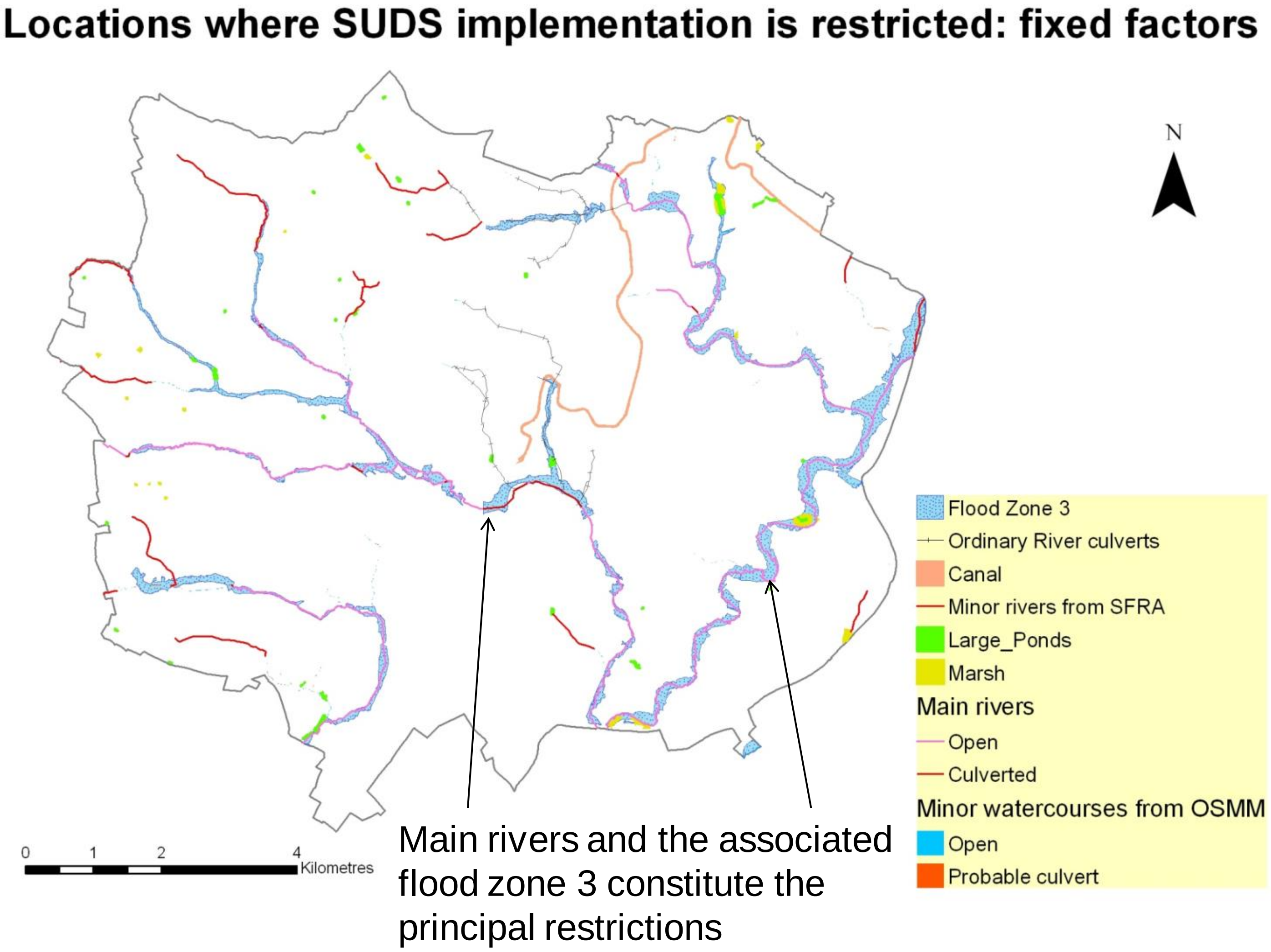
5.11 LOCATIONS WHERE SUDS ARE MORE LIKELY TO BE IMPLEMENTED

This section considers those locations where SUDS had a higher likelihood of implementation across Coventry, based on current conditions and local planning policies.

5.11.1 Factors influencing SUDS locations

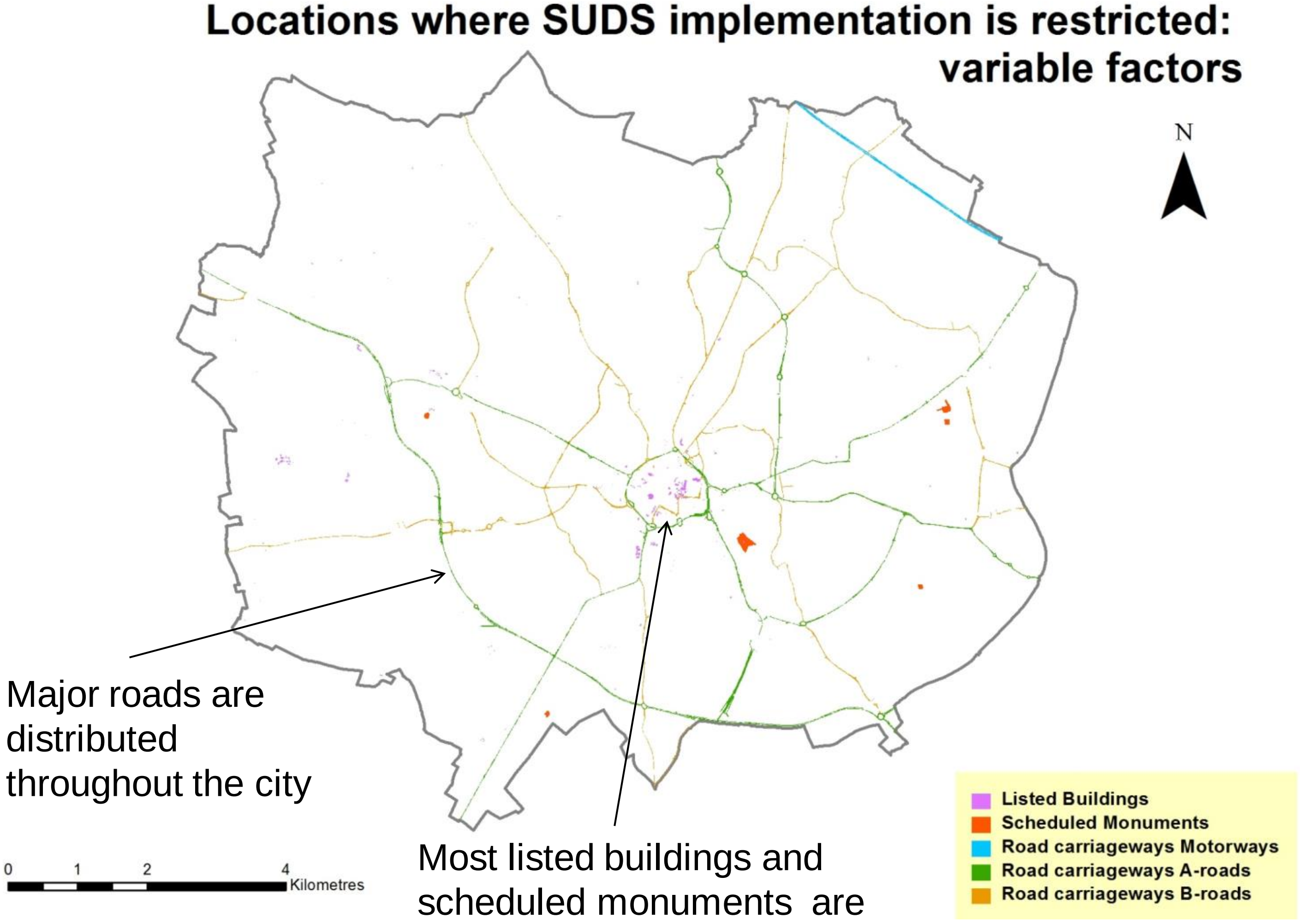
Table 3.26 identified the factors influencing sites with higher likelihood of SUDS implementation. Water bodies and fluvial flood zone 3 provided the few fixed limitations on SUDS implementation (Fig. 5.53). Similarly, few variable restrictions were present (Fig. 5.54), spread throughout the city. Consequently, much of Coventry was theoretically available to implement SUDS.

Fluvial flood zone 2 was the only fixed spatial factor influencing where SUDS implementation in new developments would require additional effort and cost (Fig. 5.55). However, there were many variable factors making implementation more complex. Fig. 5.56 shows significant areas of land cover where SUDS retrofit was achievable but not straightforward. In addition, Fig. 5.57 indicates further planning constraints where SUDS retrofit might be more problematic. These two sets of locations combined (Fig. 5.58) were widely distributed across the city.



Main rivers and the associated flood zone 3 constitute the principal restrictions

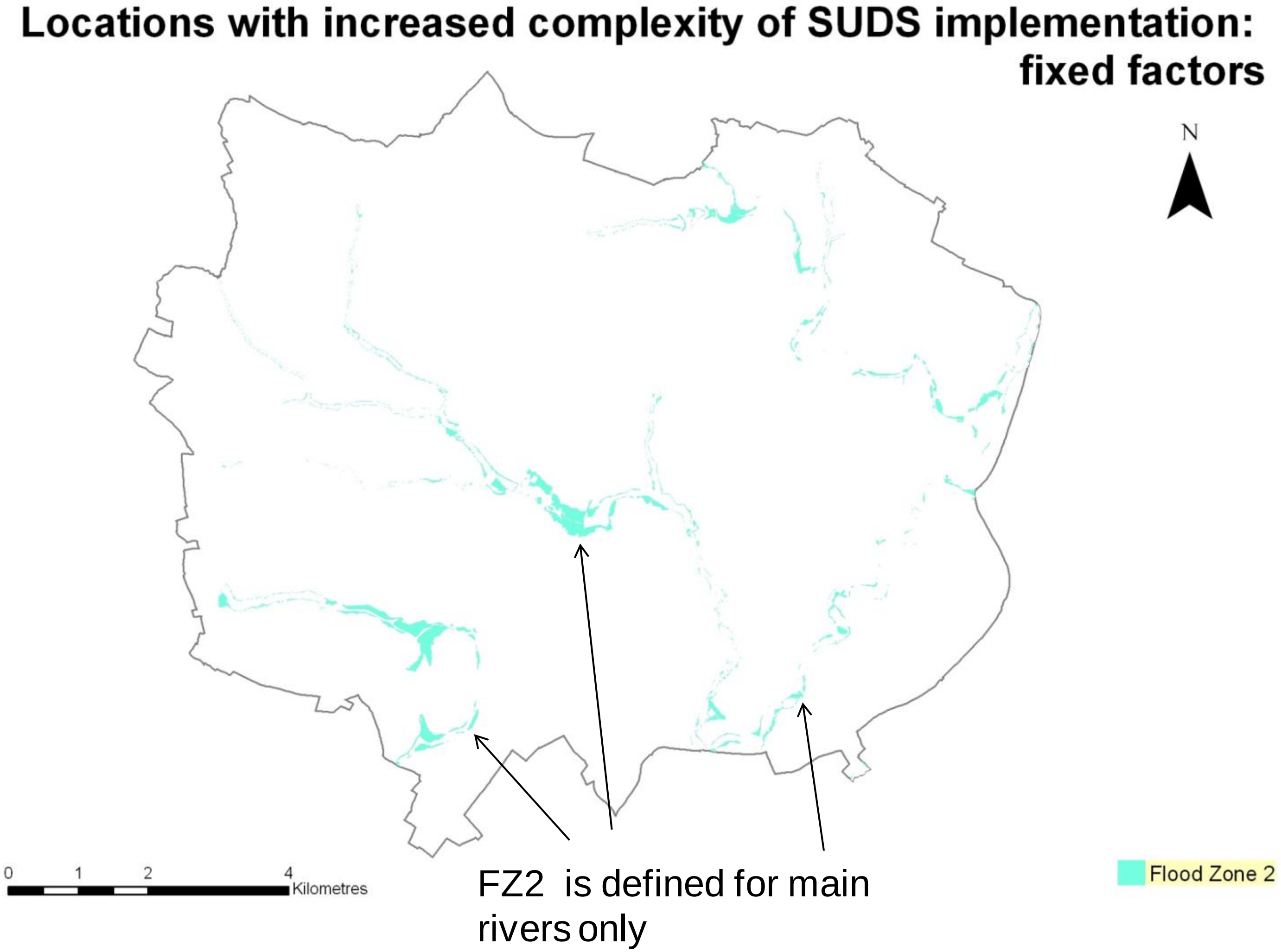
Fig. 5.53 Locations with restrictions on SUDS implementation: fixed factors



Major roads are distributed throughout the city

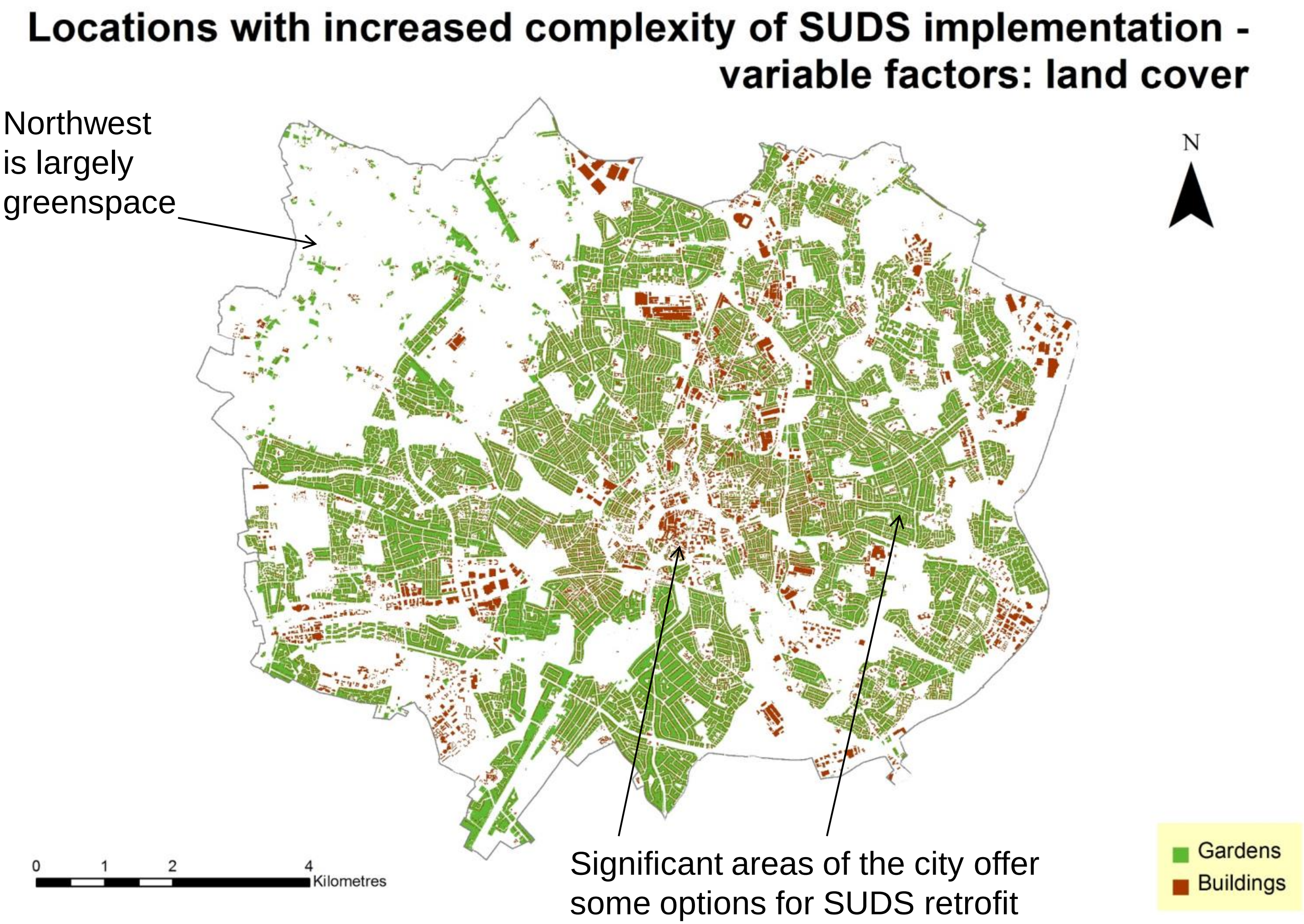
Most listed buildings and scheduled monuments are located in central areas

Fig. 5.54 Locations with restrictions on SUDS implementation: variable factors



FZ2 is defined for main rivers only

Fig. 5.55 Locations with a greater complexity of SUDS implementation. Fixed factors are shown here; variable factors are on Fig. 5.56. Locations with restrictions on SUDS implementation are excluded

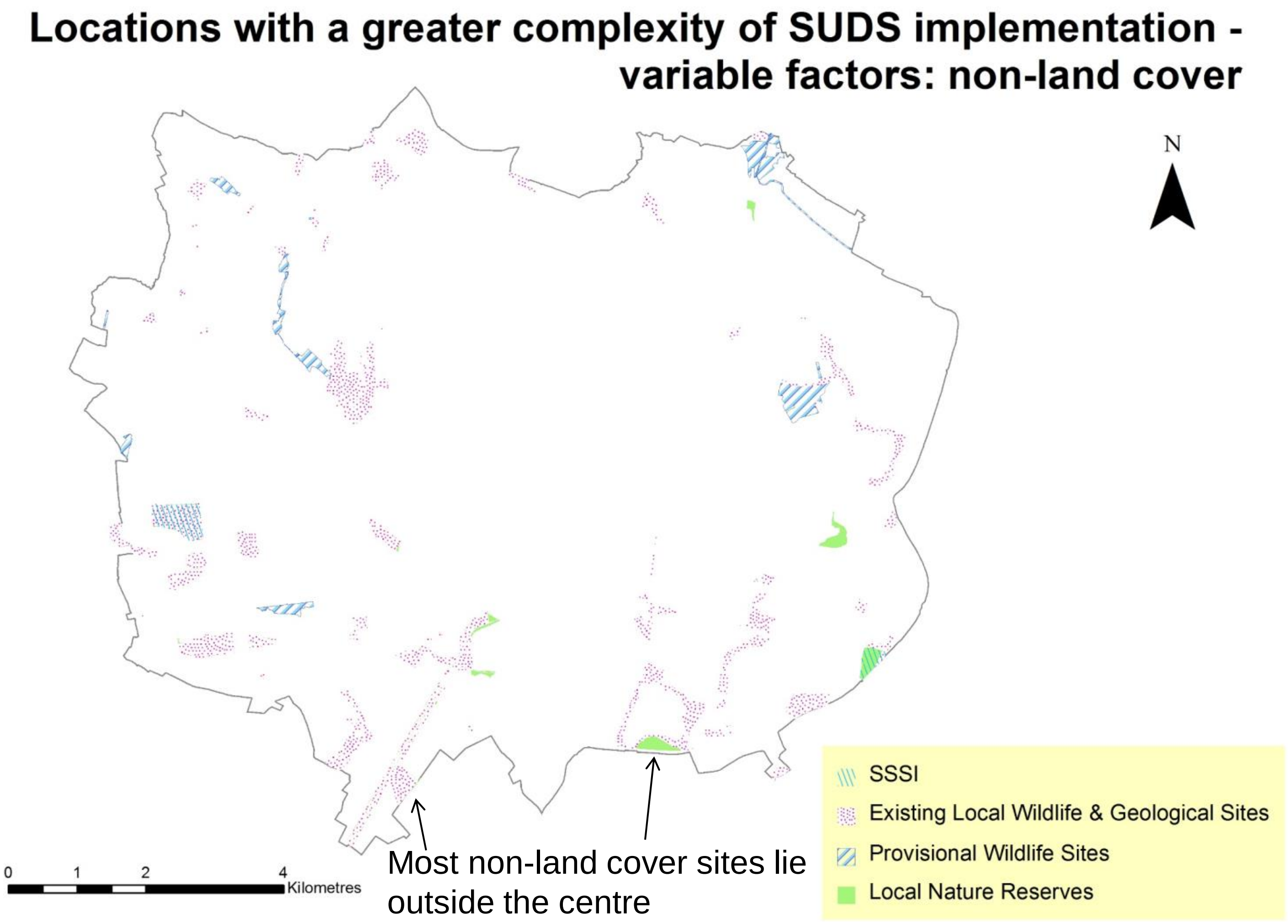


Locations with increased complexity of SUDS implementation - variable factors: land cover

Northwest is largely greenspace

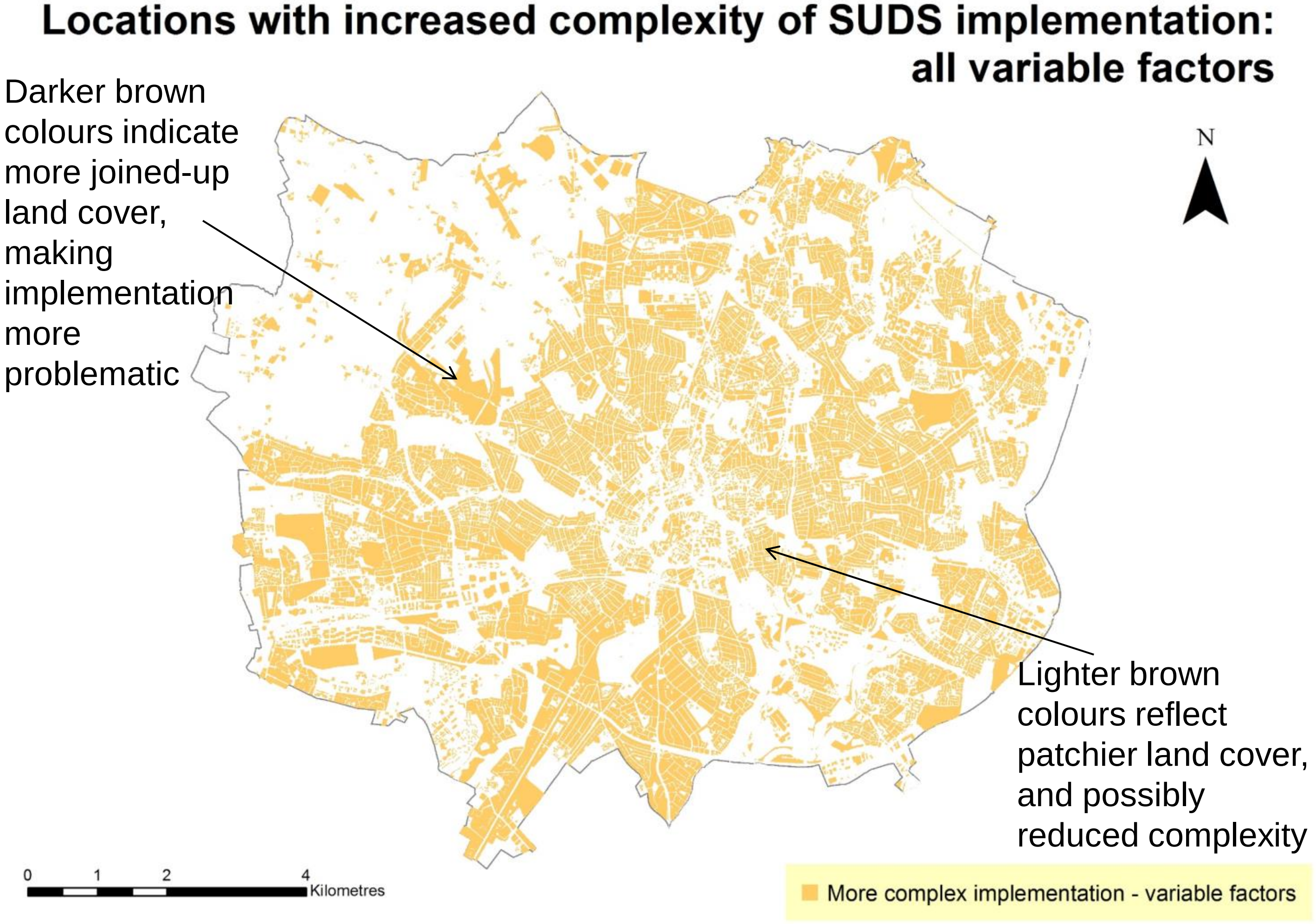
Significant areas of the city offer some options for SUDS retrofit

Fig. 5.56 Locations with increased complexity of SUDS implementation. Only variable land cover factors are shown here; variable non-land cover factors are included on Fig. 5.57, fixed factors on Fig. 5.55. Locations with restrictions on SUDS implementation are excluded



Most non-land cover sites lie outside the centre

Fig. 5.57 Locations with increased complexity of SUDS implementation. Only variable non-land cover factors are shown here; variable land cover factors are included on Fig. 5.56, fixed factors on Fig. 5.55. Locations with restrictions on SUDS implementation are excluded



Locations with increased complexity of SUDS implementation: all variable factors

Darker brown colours indicate more joined-up land cover, making implementation more problematic

Lighter brown colours reflect patchier land cover, and possibly reduced complexity

Fig. 5.58 Locations with increased complexity of SUDS implementation – all variable factors. Land cover (Fig. 5.56) and non-land cover (Fig. 5.57) factors are combined

SUDS had a higher probability of implementation in locations undergoing development, or where there were few existing restrictions. Fig. 5.59 shows planned regeneration and development locations in Coventry over the next 20 years, together with sites where implementation would be relatively easy, such as greenspace and land owned by the local authority and the largest housing association, while factoring out the restricted and more complex sites. While there were several larger blocks of land, such as the regeneration zones, there were also many small blocks of land (Table 5.12), underlining the potentially patchy nature of SUDS implementation even in new developments. 37.3% of polygons for new build and 55.2% for retrofit were under 50 m^2. The size of blocks was larger for new developments than retrofit ($p = 0.000$, ANOVA, 95% confidence level). Blocks over 1 ha in size occupied 50.4% of the city for new developments, and 40.8% for retrofit. For both new development and retrofit, around 95% of polygons were less than the mean area, indicating the availability of a small number of larger land parcels. The median area of retrofit polygons was just over a third the size of that for new developments (35 m^2 compared to 100 m^2). This last result is not necessarily negative, particularly where small-scale source control devices could be emphasised for retrofit. Many of the polygons under 35 m^2 in the retrofit layer were roadside verges and small areas of public paving.

The sites where new development was most likely were those where retrofit also had the highest probability of implementation, as much of the existing building stock may be retained in these areas. Eliminating sites that were more complex to retrofit (Fig. 5.58) left 44.2% of Coventry where retrofit would be more feasible (Fig. 5.60). The resulting areas were distributed in a fragmented pattern, with only the greenspace to the northwest providing substantial space, although this would not be particularly practical due to the lack of existing construction available to retrofit.

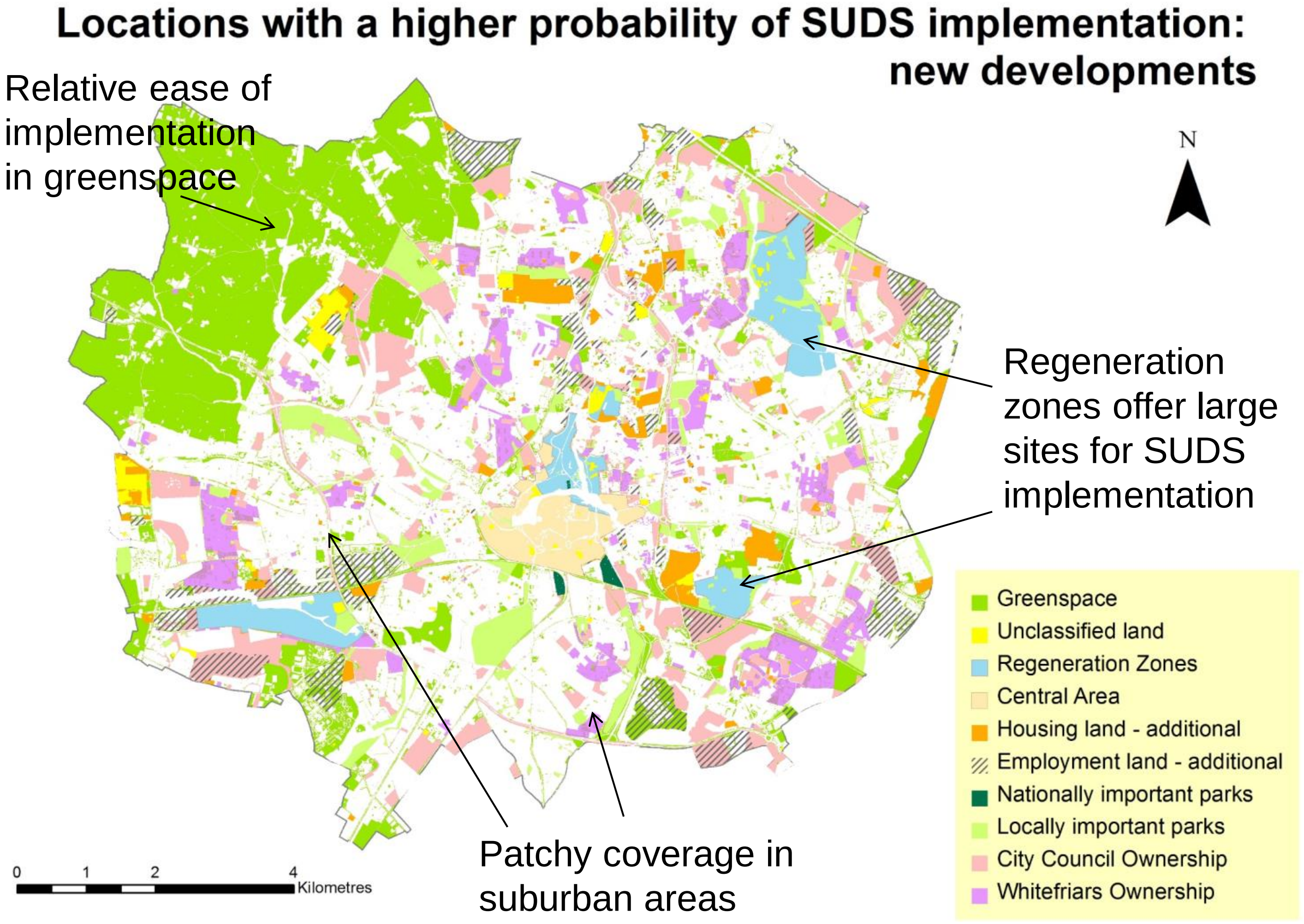
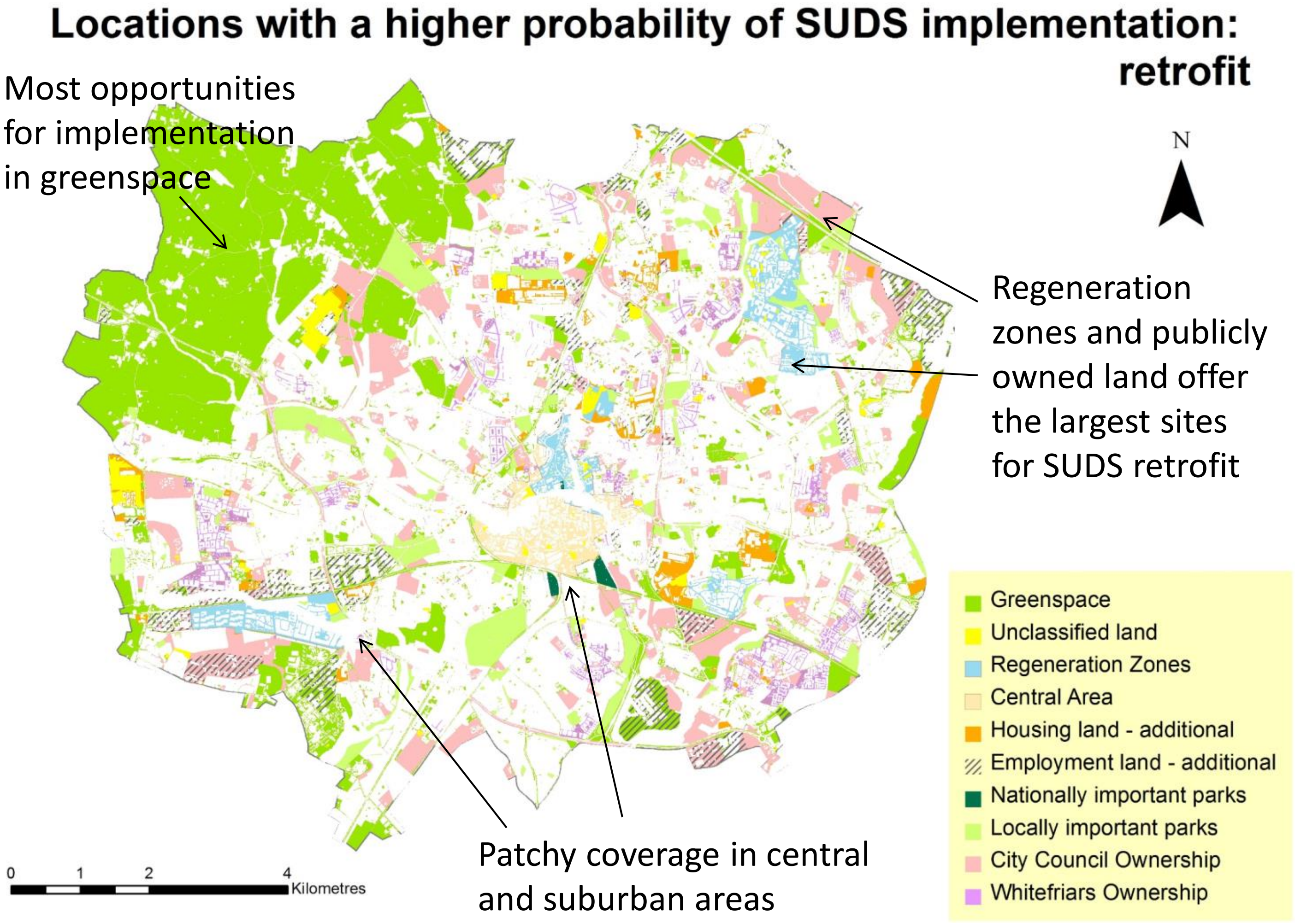


Fig. 5.59 Locations with a higher probability of SUDS implementation: new development sites. Fixed and variable factors influencing locations with restrictions on SUDS implementation, and non-land cover factors of higher complexity, are excluded



Most opportunities for implementation in greenspace

Regeneration zones and publicly owned land offer the largest sites for SUDS retrofit

Patchy coverage in central and suburban areas

Fig. 5.60 Locations with a higher probability of SUDS implementation: retrofit sites. Fixed and variable factors influencing locations with restrictions on SUDS implementation, and of higher complexity, are excluded

Table 5.12 Area sizes with higher probability of new development and retrofit. The ‘polygon area’ rows show the characteristics of polygons in the specified size ranges

	New Developments				**Retrofit**			
	No. of polygons	% of total polygons	Area (m^2)	% of city area	No. of polygons	% of total polygons	Area (m^2)	% of city area
Mean (m^2)			6,350				3,930	
Median (m^2)			100				35	
Standard Deviation			63,995				45,071	
Standard error			699				428	
Sum	8,371		5.32×10^7	53.9%	11,084		4.36×10^7	44.2%
Polygon area								
< 5m^2	843	10.1%	1.12×10^3	0.0%	3,407	30.7%	2.06×10^3	0.0%
< 50m^2	3,120	37.3%	5.57×10^4	0.1%	6,114	55.2%	6.38×10^4	0.1%
< 1ha	8,018	95.8%	3.42×10^6	3.5%	10,755	97.0%	3.26×10^6	3.3%
1-5 ha	187	2.2%	4.50×10^6	4.6%	183	1.7%	4.34×10^6	4.4%
> 5ha	166	2.0%	4.53×10^7	45.9%	146	1.3%	3.60×10^7	36.4%
< mean	7,938	94.8%	2.78×10^6	2.8%	10,585	95.5%	2.22×10^6	2.2%
< median	4,186	50.0%	1.34×10^5	0.1%	5,542	50.0%	3.99×10^4	0.0%

Overall, restrictions prevented implementation of SUDS in 6.0% of Coventry (fixed restrictions 4.5%, variable restrictions an additional 1.5%, Fig. 5.61). Areas where SUDS could be implemented in new developments with relative ease covered 53.2 km^2 (53.9%) of the city, whilst the possible retrofit area was 43.6 km^2 (44.2%). Implementation in new developments would be more complex in an additional 1.5 km^2 (1.5%) of the city. For retrofit, there were a larger number of more complex implementation sites, 38.2 km^2 (38.7%) of the LPA area.

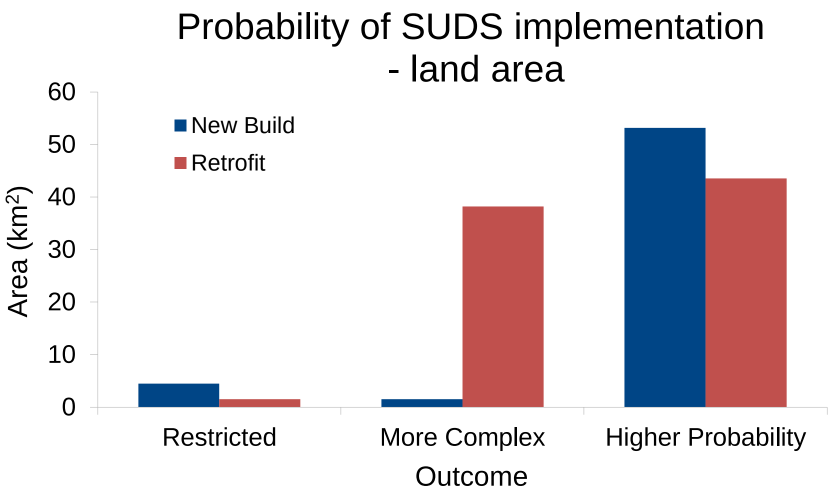


Fig. 5.61 Land area of Coventry in terms of ease of SUDS implementation

5.11.2 Likelihood of implementation for SUDS types

This section assesses the relationship between the SUDS feasibility maps for the city as a whole (sections 5.2 to 5.6), and the maps of locations where SUDS have a higher likelihood of implementation (section 5.11.1). The SUDS feasibility maps take no account of the locations where development may occur in the future as current development policy may change over time. The likelihood maps identify those locations where development was more likely taking into account current planning policy in Coventry, and therefore where SUDS would be constructed in the short to medium term.

For new development and retrofit, the spatial area of higher probability and more complex implementation sites was first determined, and then compared to the spatial area of the same SUDS types from the feasibility maps. It was possible that, although a particular type of SUDS could be widely implemented according to the feasibility maps, more immediate planning concerns would restrict the locations in which this was possible. A strong correlation between the two sets of maps might indicate that this was not the case, while a weaker correlation could suggest that implementation of SUDS was influenced by these shorter-term factors. In the examples in this section, the term ‘probability’ represents the area feasible for implementation.

5.11.2.1 New Development

Detention, filtration, conveyance and source control solutions could be readily implemented (higher probability) in new developments in 53.9% of the city, with more complex sites adding approximately a further 1.5% for these four groups (Fig. 5.62). The focus for detention SUDS was engineered solutions (36.3%). Infiltration solutions had a higher probability of implementation in 8.7% of Coventry (Fig. 5.62). This figure was comparable in relative terms to other SUDS types, representing just over half of the potential implementation area from the feasibility map (Fig. 5.7). Infiltration SUDS were possible in only 117 m^2 (0.0% of the city) in the more complex development sites.

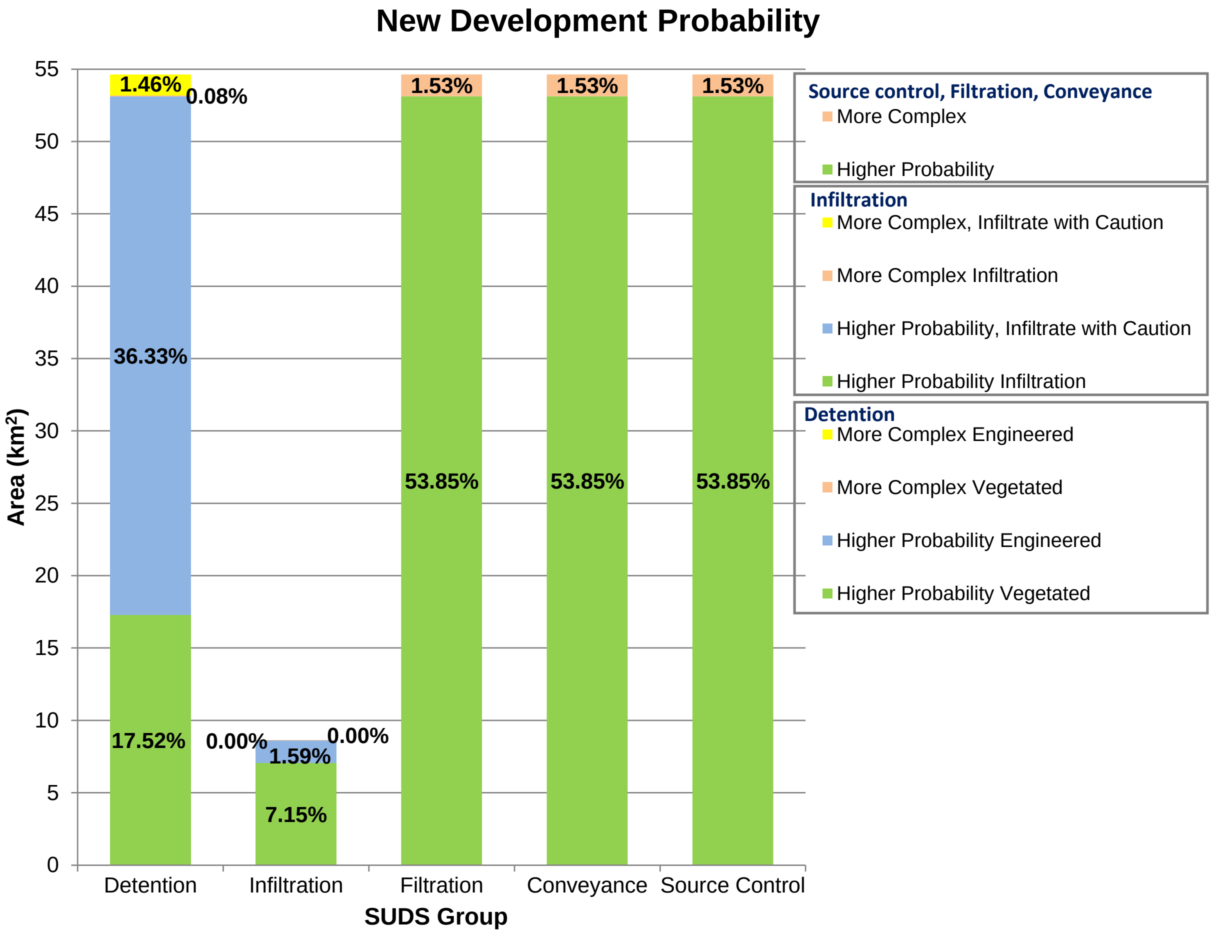


Fig. 5.62 Probability of SUDS implementation in new developments. Each SUDS group is divided into higher probability and more complex spatial areas. Detention is further split into vegetated and engineered. Infiltration areas requiring additional investigation are shown as ‘infiltrate with caution’. Percentages in each bar indicate the percentage area of Coventry for each component in the legend.

There was a strong correlation between the area covered by a SUDS group in Coventry as a whole, and the area of that SUDS group in new developments (Fig. 5.63), i.e. the extent to which SUDS are feasible in the full area was a good predictor of their possible implementation in new developments. The linear trend r^2 value of higher probability sites was 99%, while that of the more complex locations was 93%, this lower percentage due to variation in infiltration and detention. For new developments therefore, there was little influence on the feasible types of SUDS of the locations that were more likely to be developed.

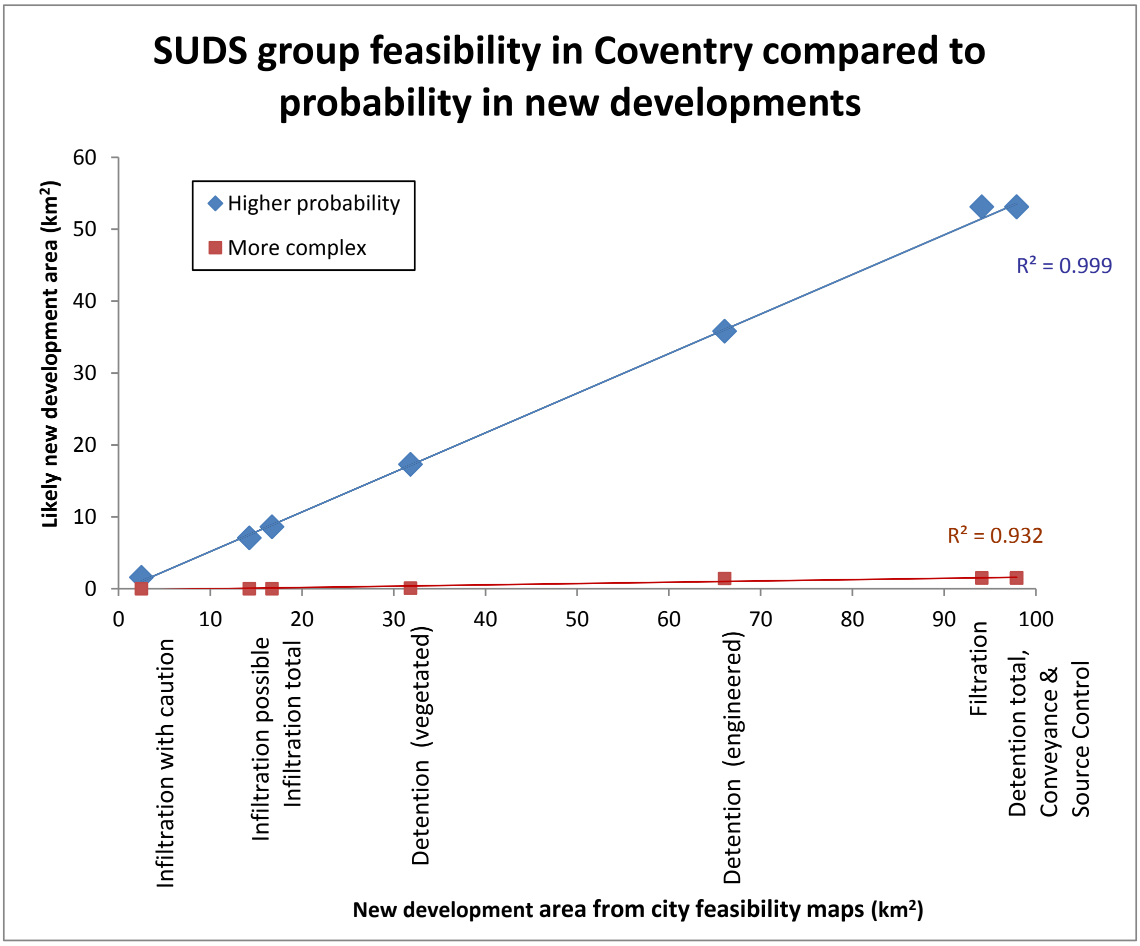


Fig. 5.63 Comparison of SUDS group coverage in full area and in new developments. The SUDS types in the x-axis caption indicate the series of values in the column above

5.11.2.2 Retrofit

The likelihood of retrofit (Fig. 5.64) exhibited more variability than implementation in new developments (Fig. 5.62). No SUDS group exceeded 43% of the entire area for higher probability of retrofit. The limited area for higher probability source control retrofit (22.9%) is noteworthy given the role of source control in addressing water quality issues and low volume rainfall events. The greater complexity of retrofit is also illustrated, with all SUDS groups in Fig. 5.64 having a larger spatial area for more complex sites than was the case for new developments (Fig. 5.62).

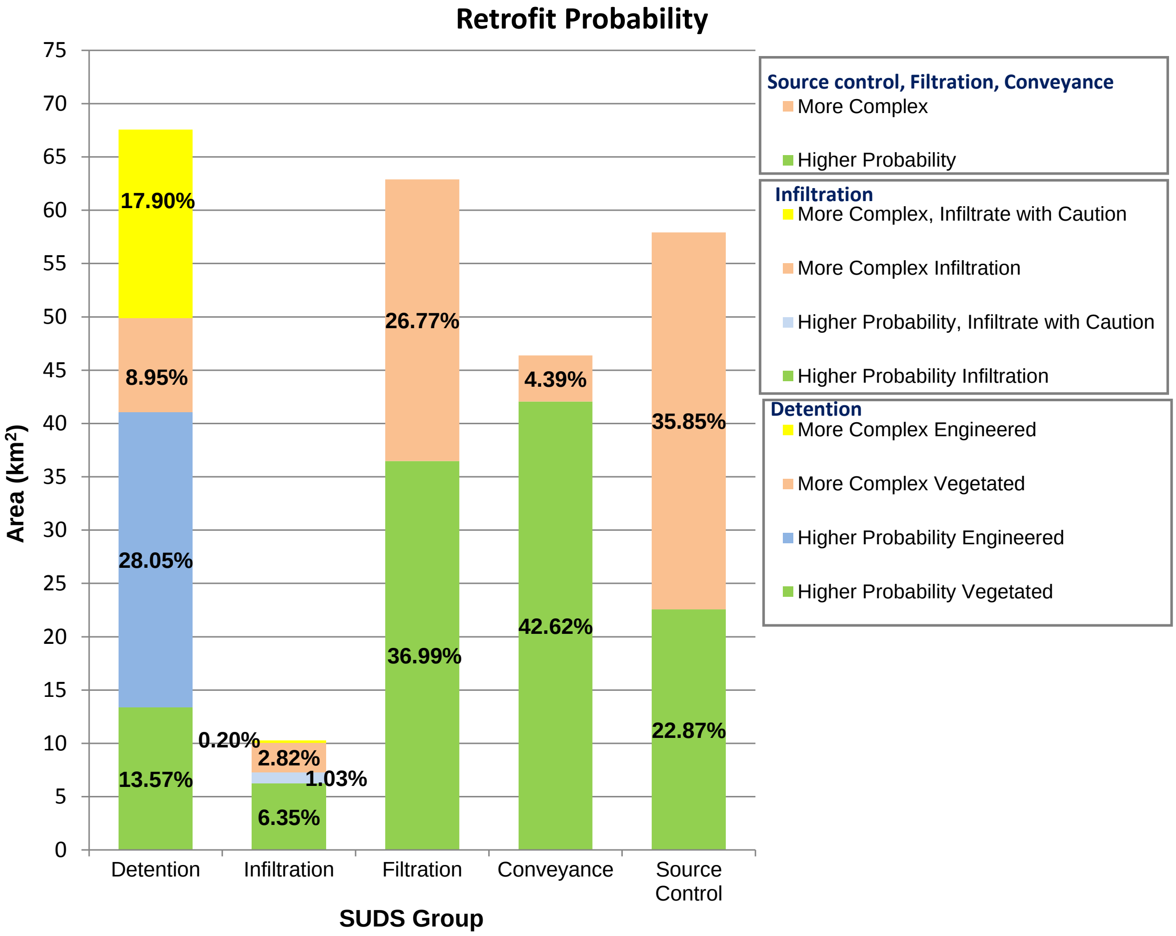


Fig. 5.64 Probability of retrofit SUDS implementation. Each SUDS group is divided into higher probability and more complex spatial areas. Detention is further split into vegetated and engineered. Infiltration areas requiring additional investigation are shown as ‘infiltrate with caution’. Percentages in each bar indicate the percentage area of Coventry for each component in the legend.

There was a moderate correlation between the area covered by a SUDS group in Coventry as a whole, and the area of that SUDS group in sites more likely to be retrofitted (Fig. 5.65). The linear trend r^2 value of higher probability and more complex retrofit sites was lower at 84% and 71% respectively, largely due to the greater variation in source control and conveyance SUDS. There were fewer higher probability locations for retrofit source control compared to the sites for retrofit source control in the feasibility maps. Conversely, a greater proportion of the higher probability locations for retrofit conveyance were available than was the case in their distribution in the feasibility maps. For retrofit, there may be fewer options for source controls, and more options for conveyance, in the locations that were more likely to be developed.

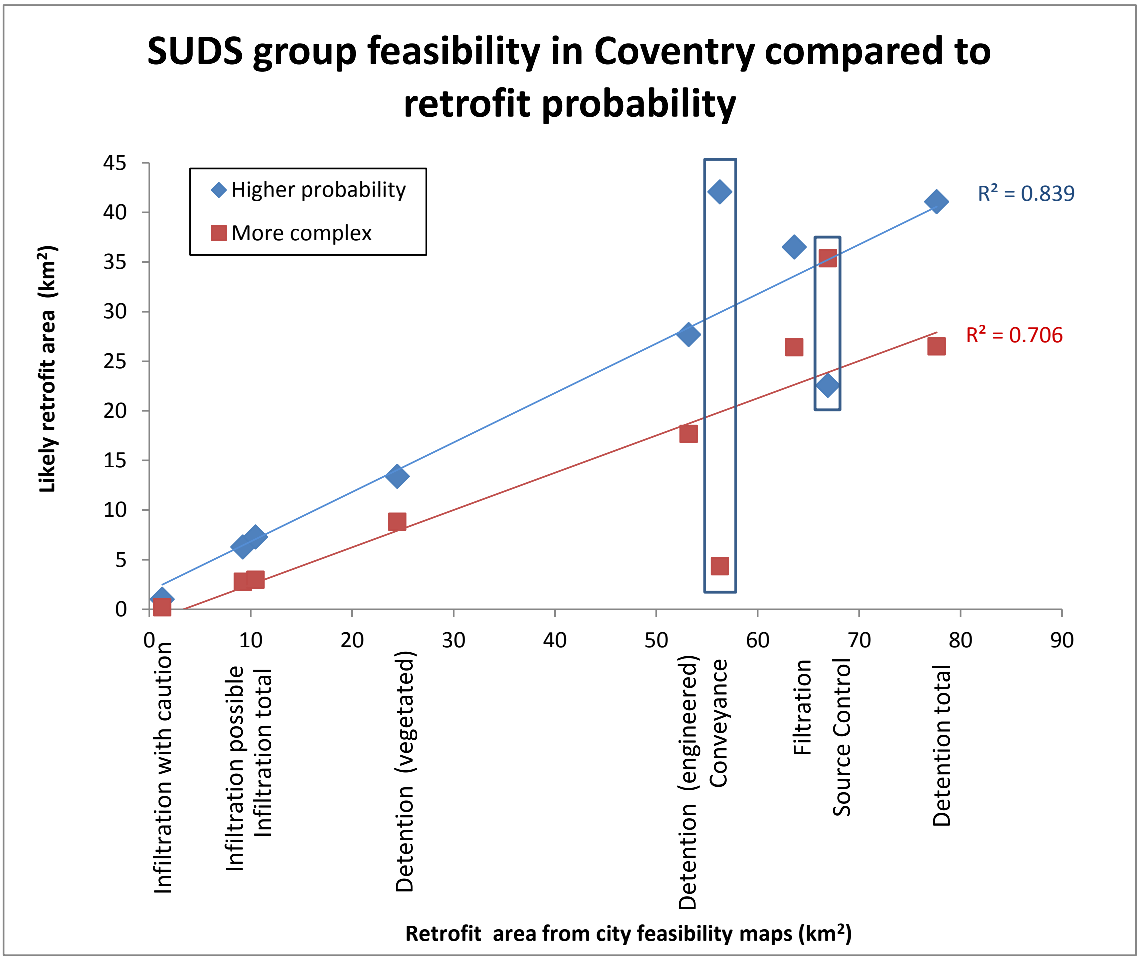


Fig. 5.65 Comparison of SUDS group coverage in full area and in retrofit. The SUDS types in the x-axis caption indicate the series of values in the column above; principal deviations from the trend are highlighted in boxes

5.12 LARGE ROOFS

Large roofs (> 200 m^2 area) are preferred locations for SUDS retrofit because sufficient areas of land should exist nearby that are suitable for infiltration or detention of runoff (Stovin *et al.* 2007:19). In Coventry, sufficient land was available to attenuate runoff from most areas using three modelled storm events, 15 mm treatment volume (Vt), and 30-year and 100-year design storms (Fig. 5.66). In all three scenarios, there was enough greenspace nearby to infiltrate or detain the runoff from the majority of large roofs. The smaller Vt rainfall depth aims to deal with the pollution associated with the first foul flush. As rainfall depth increases with larger storms, available greenspace reduces gradually, but there is sufficient space in conjunction with paved areas to attenuate most of the additional runoff. There were a limited number of roofs with no adjacent land for attenuation, rising from 5% of the total for the Vt scenario to 8% for the 100-year storm.

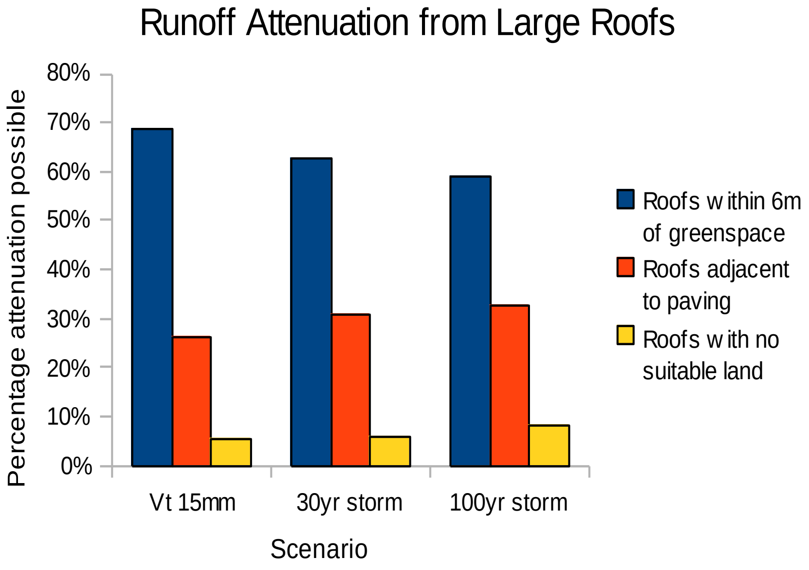


Fig. 5.66 Runoff attenuation from large roofs in three scenarios: a) 15 mm treatment volume; b) 30-year 6-hour storm; c) 100-year 24-hour storm. n = 3863

Storage volume was a function of the amount of rainfall and the depth of storage device (Table 5.13). For example, assuming 0.5 m depth and precipitation from a 30-year 6-hour design storm in Coventry, then a storage area equivalent to 20% of the impermeable area was required. This could be a detention basin, or underground reservoir underneath permeable paving, for example. 68% of large roofs were within 1 m of industrial land, so use of infiltration SUDS would require further investigation to ensure that contamination was not transmitted to groundwater.

Table 5.13 Storage area requirement in Coventry for design storm events of increasing severity. Percentages represent the additional storage area required to retain runoff expressed as a percentage of the impermeable area of the site. A depth of 0.5 m was used in calculating the examples in this section

	Treatment volume	**30-yr 6-hr storm**	**100-yr 24-hr storm**
Rainfall	15 mm	50 mm	90 mm
Storage area required assuming 0.5 m depth	6%	20%	36%
Storage area required assuming 1 m depth	3%	10%	18%

The pattern of land availability did not correspond in a linear manner to roof sizes. Fig. 5.67 shows the land types available to attenuate the 100-year storm. The smaller and larger roofs were less likely to be near greenspace. The likelihood of needing to utilise paving increased with roof size. The smallest and largest classes contained the most roofs with no form of attenuation nearby. The same pattern was observed for the 30-year storm analysis.

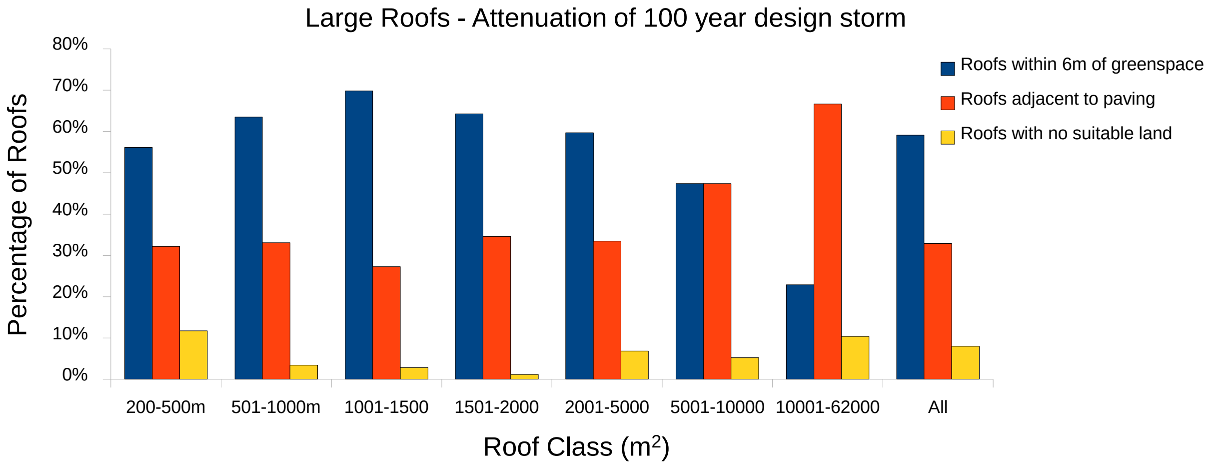
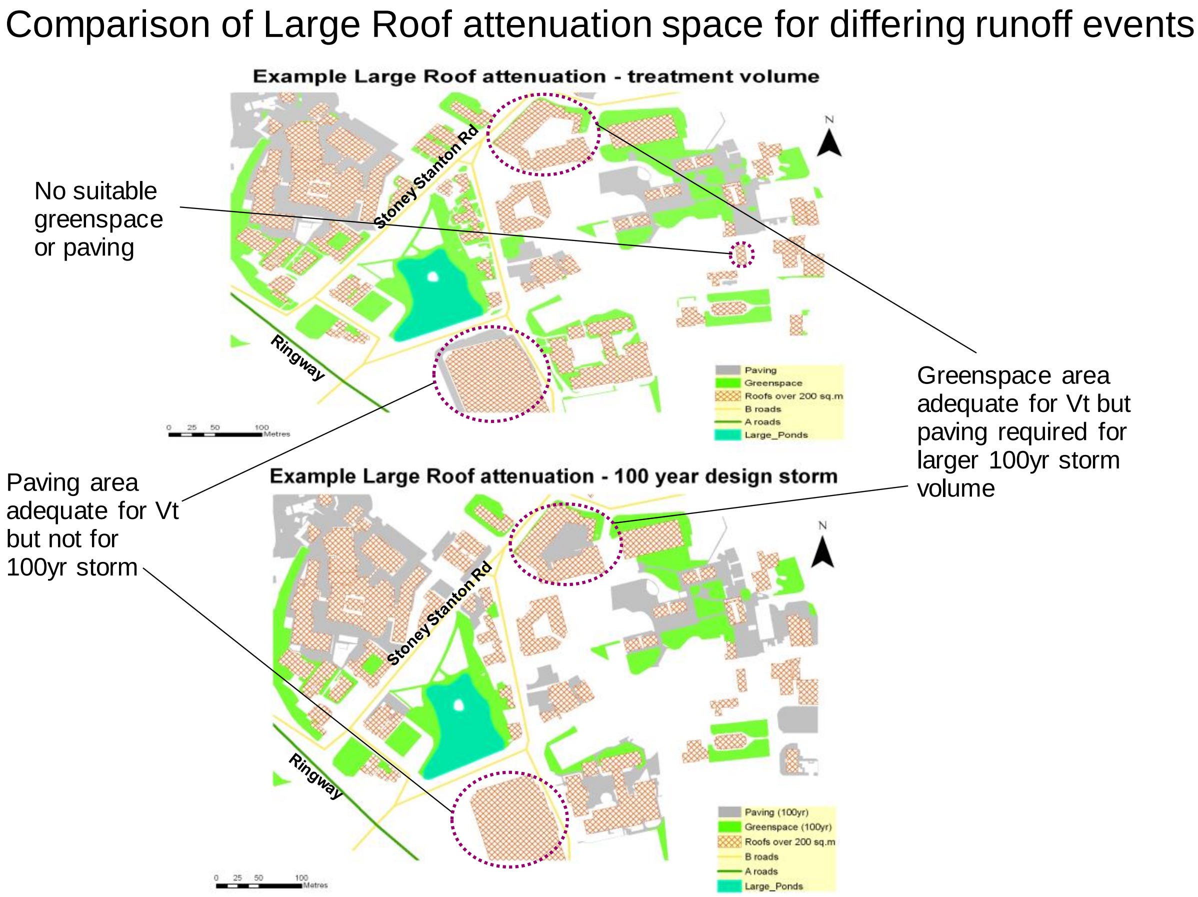


Fig. 5.67 Large Roof attenuation of 100-year design storm

Suitable attenuation space depends on the size of the rainfall event and the roof area. A comparison of results for a sample inner-city area for the Vt and 100-year storm events is shown in Fig. 5.68. As revealed by Fig. 5.66, attenuation capacity was available for most large roofs for most events. In some instances, capacity existed for smaller but not for larger events. In other cases, greenspace might be available to attenuate smaller events, but larger areas of paving were required to manage larger events.



Comparison of Large Roof attenuation space for differing runoff events

Example Large Roof attenuation - treatment volume

Example Large Roof attenuation - 100 year design storm

No suitable greenspace or paving

Greenspace area adequate for Vt but paving required for larger 100yr storm volume

Paving area adequate for Vt but not for 100yr storm

Fig. 5.68 Comparison of large roof attenuation space for differing runoff events in an example inner-city location in the Swanswell regeneration zone

5.13 PAVED AREAS FOR RETROFIT SUDS

Roads and paved areas may be suitable for retrofit source control SUDS. Possible locations were minor road carriageways, paved roadsides, paths. Non-road paving occupied 13.12 km^2, 68.2% of the paved area of Coventry, 13.3% of the total land area (Fig. 5.69). Paved areas unsuitable for retrofit, defined as non-minor road carriageways, rail tracks and built structures, covered 6.12 km^2, 31.8% of the paved area of Coventry, 6.2% of the total land area. The suitability of road, rail and paved areas for retrofit source control SUDS is shown in Fig. 5.70.

Minor road carriageways are less trafficked than the major thoroughfares. Concerns about the durability of permeable paving and porous tarmac under conditions of heavy use (e.g. Knapton *et al*. 2002) indicate that minor roads are more appropriate for retrofitting until paving technology has advanced. However, minor road carriageways in Coventry covered 15.8% of the total carriageway area. Nevertheless, at 1.1 km^2, they still offered scope for conversion to more permeable surfaces. Paved roadsides occupied just over three times the space of minor road carriageways, and may offer an easier or less contentious option for implementing PPS, or could be converted to small swales, filter strips or bioretention devices. Paths accounted for 0.8 km^2, 4.1% of the paved area of Coventry. Paths lay mainly outside of the city centre, and were often less formal areas, serving as pedestrian walkways or access routes to the rear of properties. They could already serve to detain small volumes of rainfall, and did not necessarily deliver runoff to existing drainage systems. If SUDS are to be retrofitted to paths, then gravel or similar materials may be appropriate choices, although paths are likely to constitute a low priority for retrofit.

The largest component of the paved areas in Coventry was non-road paving, covering 7.88 km^2, 39.6% of the paved area of Coventry, 7.7% of the total land area. Car parks could not be easily isolated from other paved areas, and those shown in Fig. 5.70 represent public car parks, while parking on privately owned land forms part of the non-road paving category. In more central areas, non-road paving comprised pedestrianised shopping areas and private car parks, while in the suburbs it was formed from car parks for businesses, and access tracks running at the rear of properties. As with paths, suburban paved areas serving the rear of properties, being less well maintained, could already detain small volumes of runoff. In single-storey car parks, retrofit options include PPS and conversion of some hardstanding to small basins to store and treat runoff.

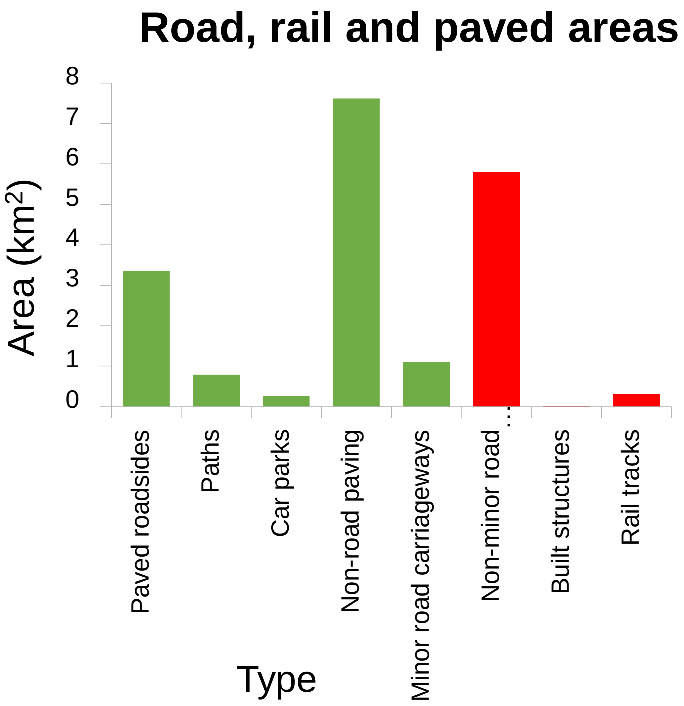
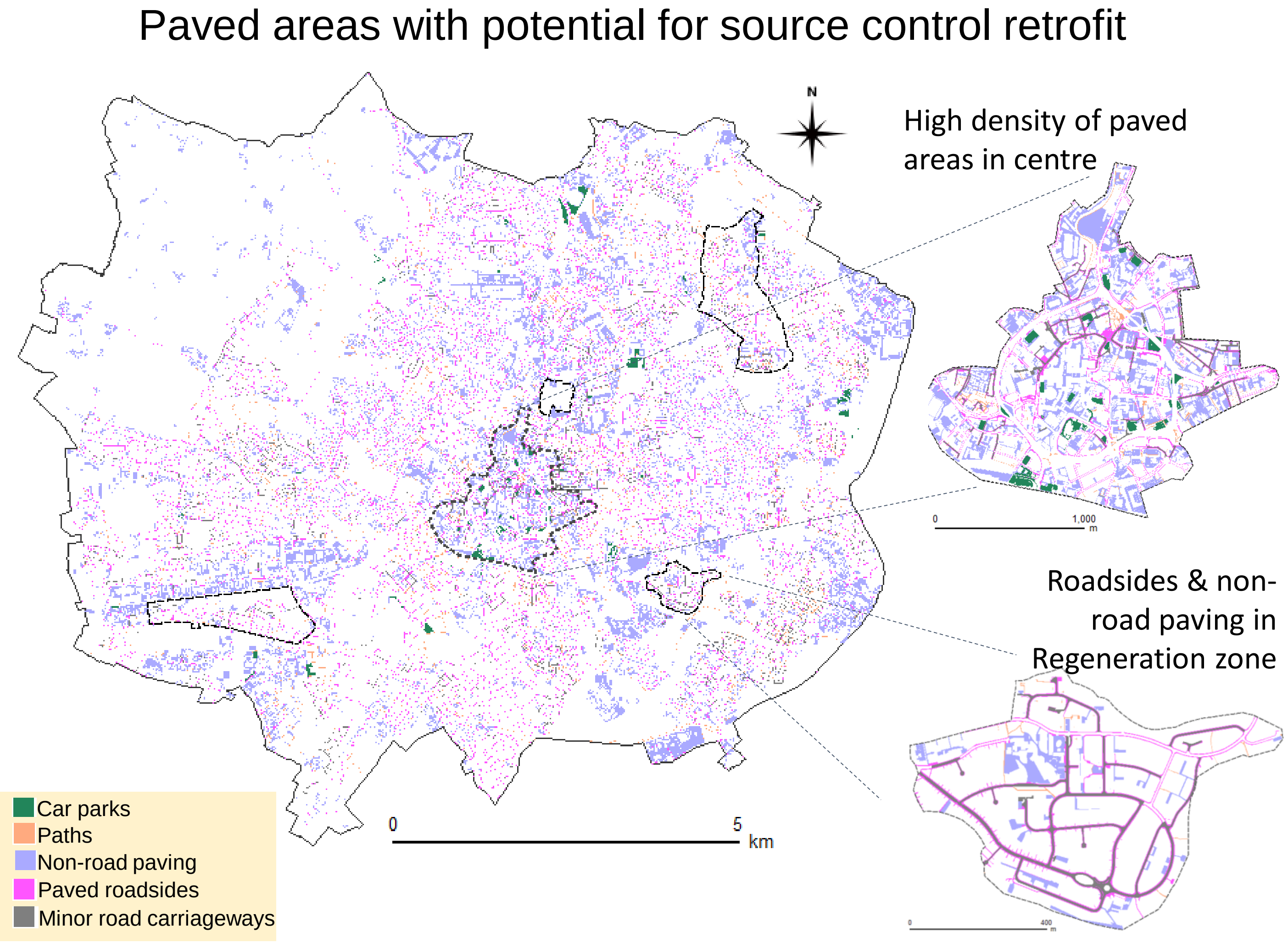


Fig. 5.69 Land area of existing road rail and paved areas, indicating suitability for retrofit source control SUDS. Green bars represent the land cover where retrofit may be feasible, red bars the land cover where retrofit was not considered possible



Paved areas with potential for source control retrofit

High density of paved areas in centre

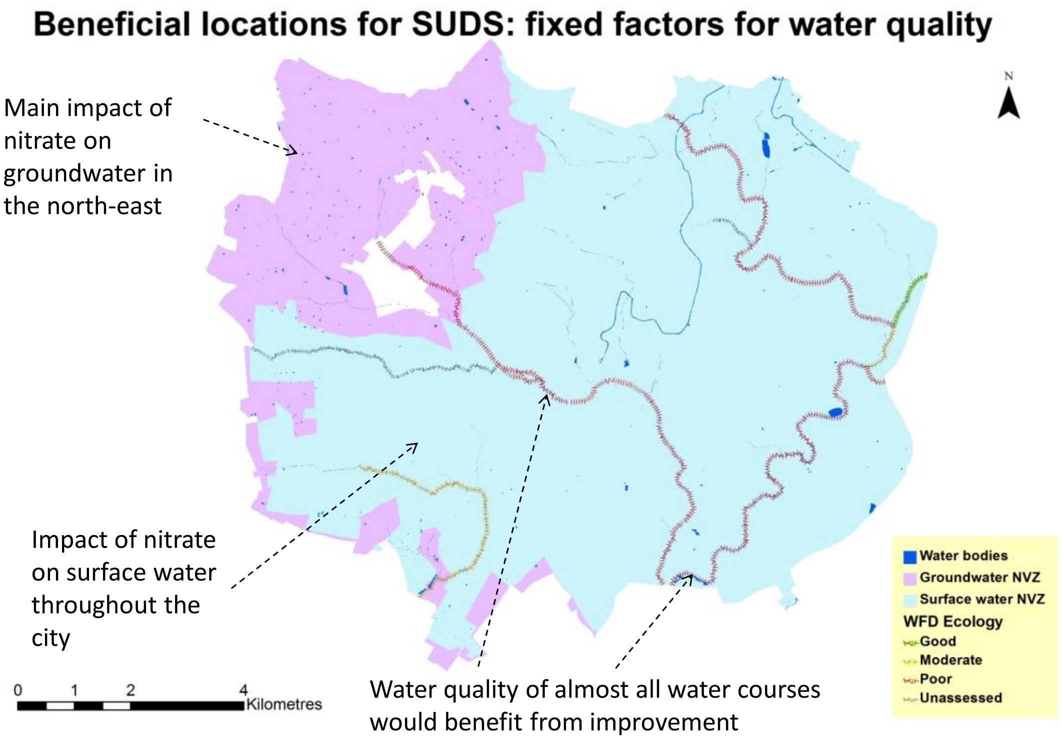
Roadsides & non-road paving in Regeneration zone

Fig. 5.70 Locations of paved areas with potential for source control retrofit. Regeneration zones outlined.

5.14 LOCATIONS THAT MAY BENEFIT FROM SUDS

5.14.1 Problem locations

Table 3.28 identified the factors influencing locations where SUDS implementation might benefit water quality and quantity. Areas where water quality would benefit from improvement covered the majority of Coventry (Fig. 5.71), largely due to the presence of the surface water NVZ. Groundwater dominated areas where water quantity management could be improved (Fig. 5.72). Variable factors influencing possible SUDS implementations are shown in Fig. 5.73. Smaller gardens near roads represented front gardens that may have been paved over, while road carriageways were likely generators of polluted runoff as well as increasing the quantity of runoff.

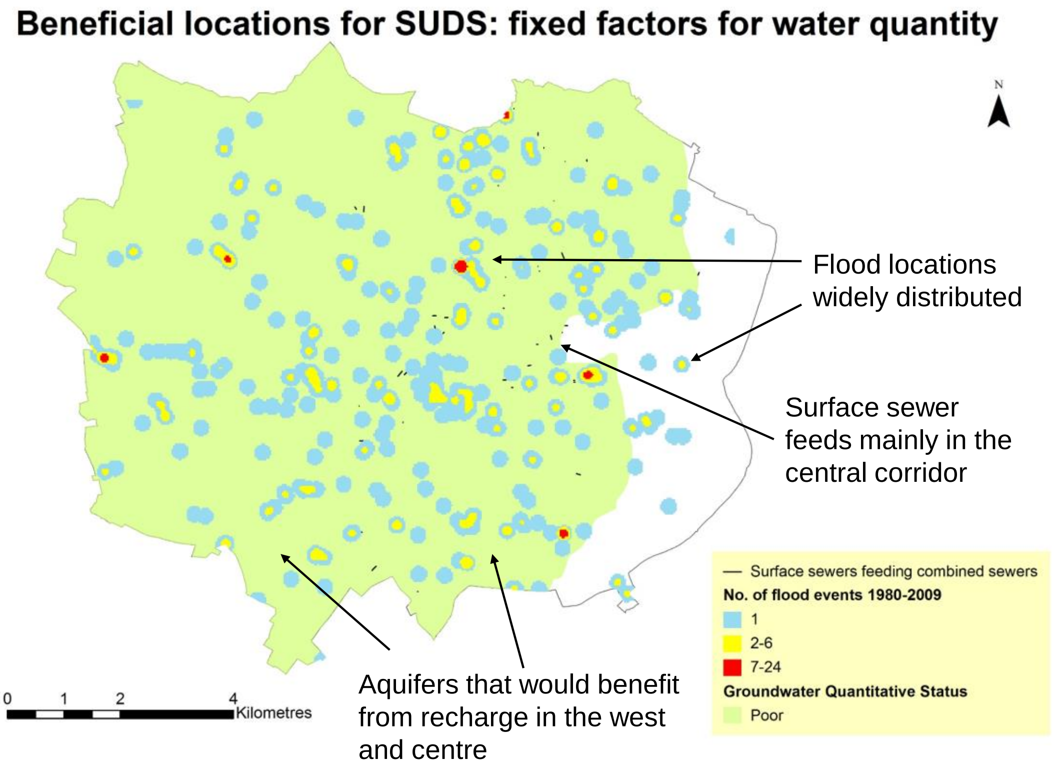

Beneficial locations for SUDS: fixed factors for water quality

Main impact of nitrate on groundwater in the north-east

Impact of nitrate on surface water throughout the city

Water quality of almost all water courses would benefit from improvement

Fig. 5.71 Fixed water quality factors influencing beneficial locations for SUDS

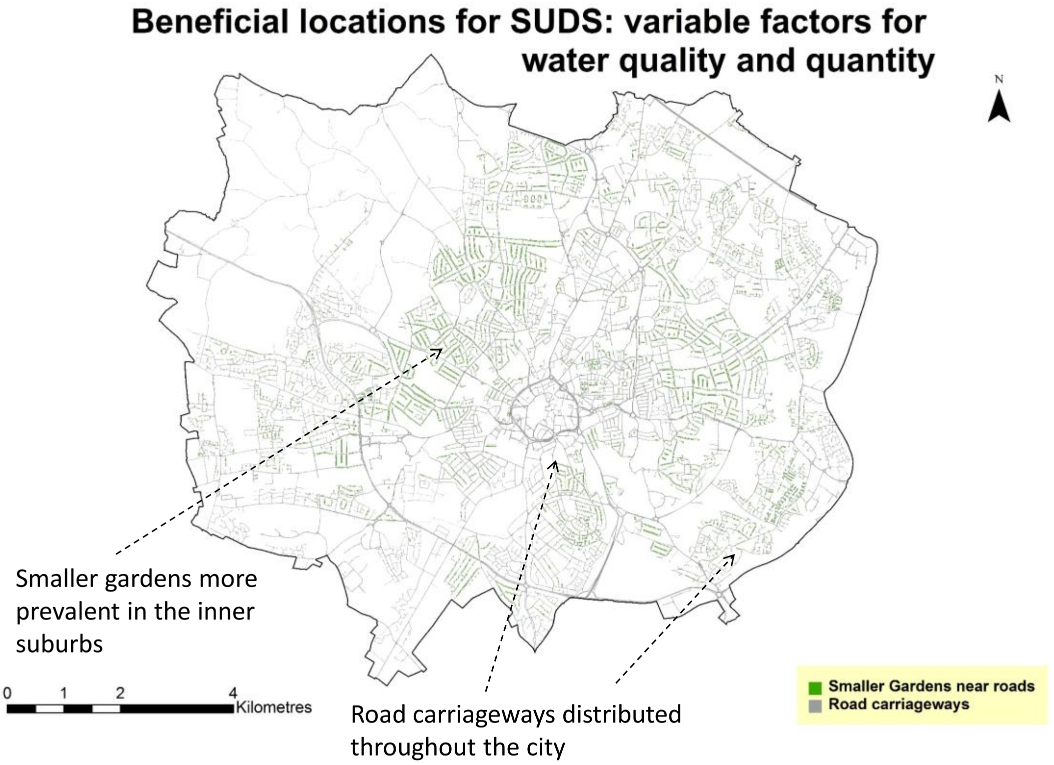


Flood locations widely distributed

Surface sewer feeds mainly in the central corridor

Aquifers that would benefit from recharge in the west and centre

Fig. 5.72 Fixed water quantity factors influencing beneficial locations for SUDS. 436 flood events occurred in the period 1980-2009



Smaller gardens more prevalent in the inner suburbs

Road carriageways distributed throughout the city

Fig. 5.73 Variable water quality and quantity factors influencing beneficial locations for SUDS

Sections below give some examples of how the SUDS feasibility maps could be used in conjunction with known problem locations to investigate potential solutions at the site level, and to improve understanding of the scale of problems.

5.14.2 Groundwater

The WFD groundwater quantity status assessment (EA 2013a) defined that two of the three groundwater units underlying the Coventry LPA area were over-abstracted, so infiltration SUDS might contribute to replenishment of local groundwater stores. Fig. 5.74 shows that almost all locations where retrofit infiltration SUDS are feasible could contribute to groundwater replenishment, although care must be taken a) in the northwest in particular which is a groundwater NVZ, and b) where land contamination might be present.

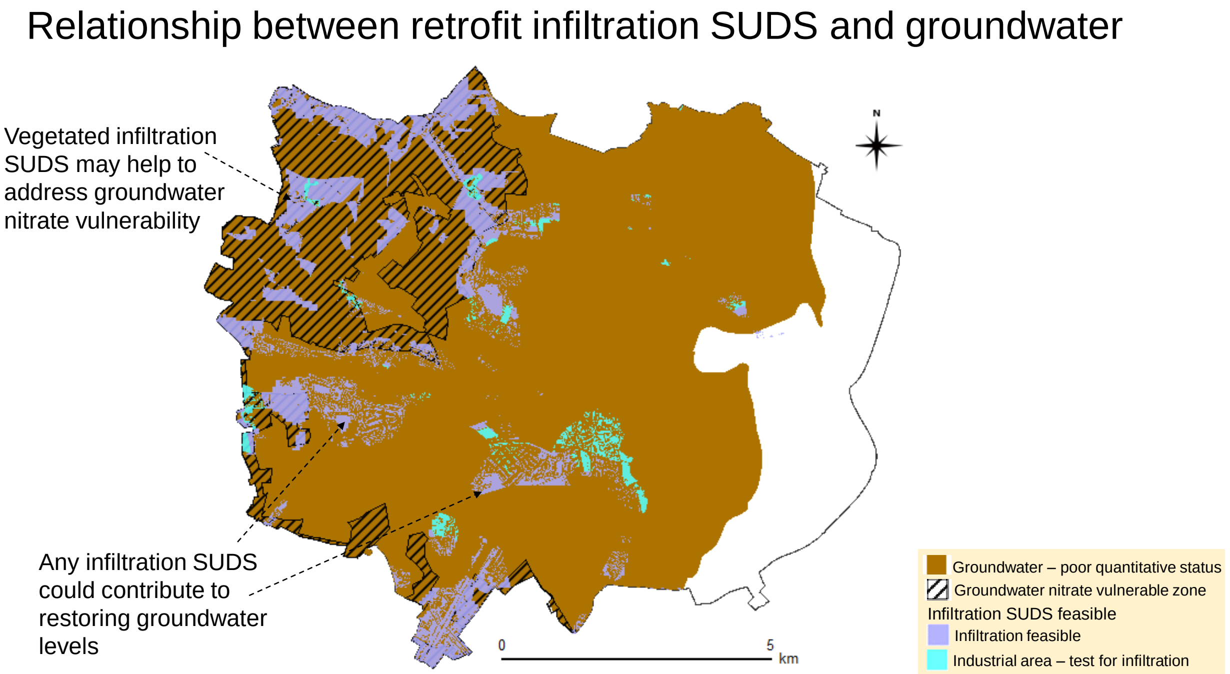
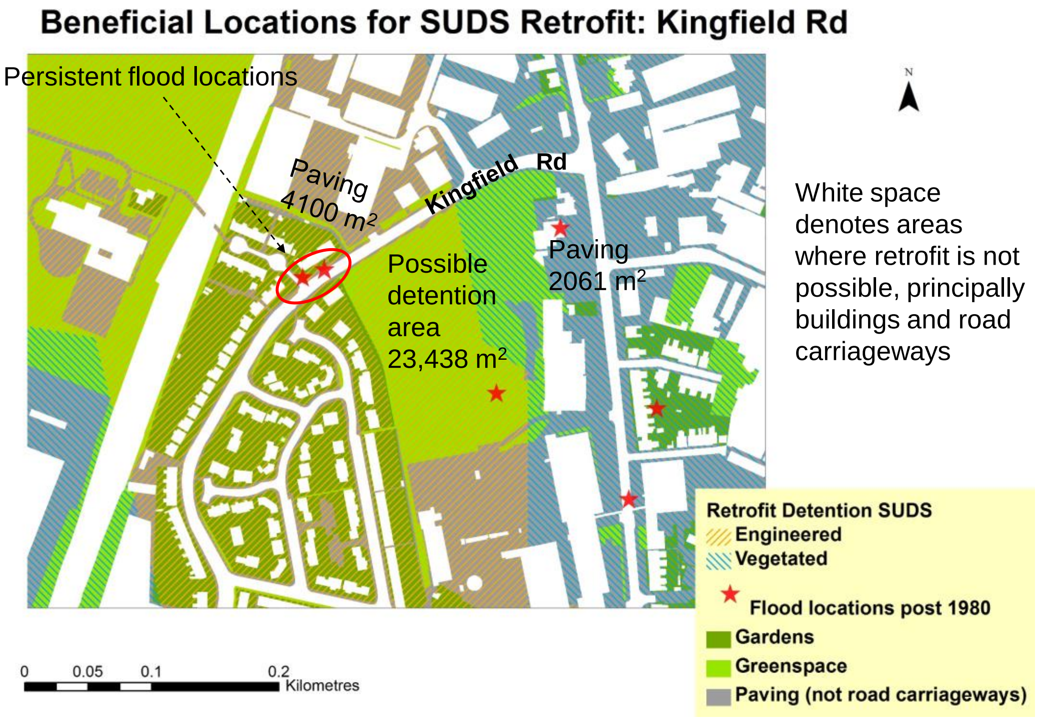


Fig. 5.74 Spatial relationship between retrofit infiltration SUDS feasibility and groundwater issues

5.14.3 Locations of historical flooding

The highest number of historical flood events in Coventry over the past 30 years was at Kingfield Rd. (Fig. 5.75). It was not in an area suitable for infiltration, but there were nearby areas of greenspace and paving that might be considered for flood attenuation, although these were not publicly owned. The nearest location, almost 25,000 m^2, would warrant more detailed investigation, although it had also suffered previous flooding. The greenspace was on the boundary between vegetated and engineered detention, suggesting variable ground conditions in the area. Fig. 5.76 highlights that most of the surrounding area is suitable for retrofit source controls, although most of the land is privately or commercially owned.


Beneficial Locations for SUDS Retrofit: Kingfield Rd

White space denotes areas where retrofit is not possible, principally buildings and road carriageways

Fig. 5.75 Beneficial locations for SUDS retrofit: Kingfield Rd detention

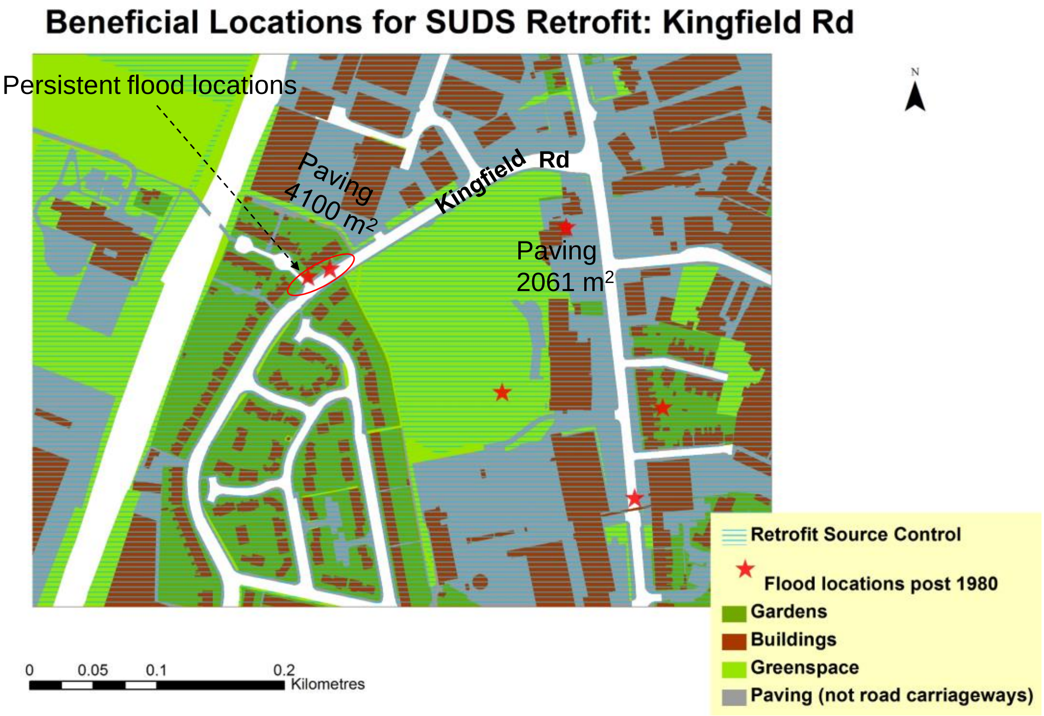


Fig. 5.76 Beneficial locations for SUDS retrofit: Kingfield Rd source control

Fig. 5.77 considers suitable land availability for SUDS to address flooding across Coventry using new development and retrofit detention and source control SUDS. Within 2 m radius of a flood event, a mean 8.6 m^2 of suitable land is available for detention and source control SUDS in new developments, but for retrofit there is less available space (detention 3.1 m^2, source control 5.1 m^2). Hypothesising the need for a 100 m^2 storage area to attenuate a 100-year 24-hour flood, then a minimum buffer distance of 10-25 m is required in which suitable land would be available. The 25 m buffer distance would be sufficient for a storage area up to 400 m^2.

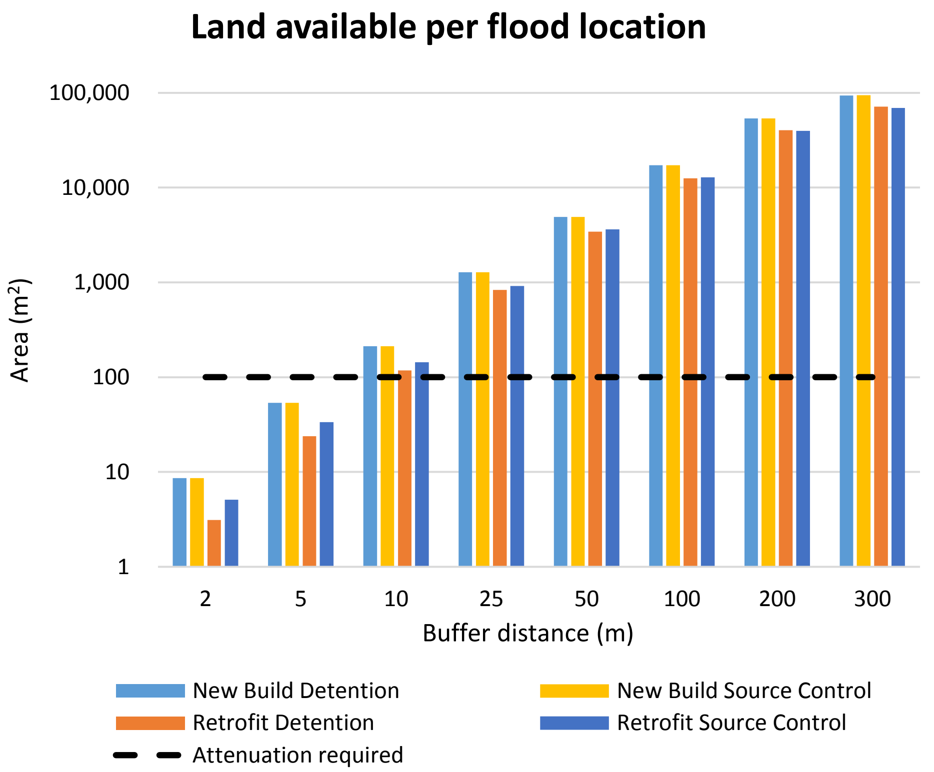


Fig. 5.77 Available space for SUDS to address flooding in Coventry. The x-axis is the space availability at nominated buffer distances from known locations of flooding 1980-2009, normalised per flood location (n = 436). The y-axis shows suitable space for Detention and Source Control SUDS techniques from the feasibility maps ($\log_{10}$ scale for ease of comparison). The target attenuation required is calculated for a 100-year flood affecting an area of 100 m^2, stored in a 1 m deep device

5.14.4 Surface sewers

Fig. 5.78 shows the location where a surface water sewer joined to a combined sewer, placing additional load on the combined sewer in times of heavy rainfall. An area of publicly owned land was located 25-50 m away, and could act as a temporary detention basin to relieve sewer capacity temporarily. The location was suitable for engineered detention, so additional measures may need to be taken to retain water locally. The nearest location suitable for infiltration was over 300 m to the south-west, and would therefore require additional conveyance infrastructure to move the runoff to that point, which would be impractical in the residential setting. There is potential to address capacity issues as all 66 surface water sewers that dispose into combined sewers in Coventry are within 100 m of greenspace (Fig. 5.79), and 95% are within 50 m.

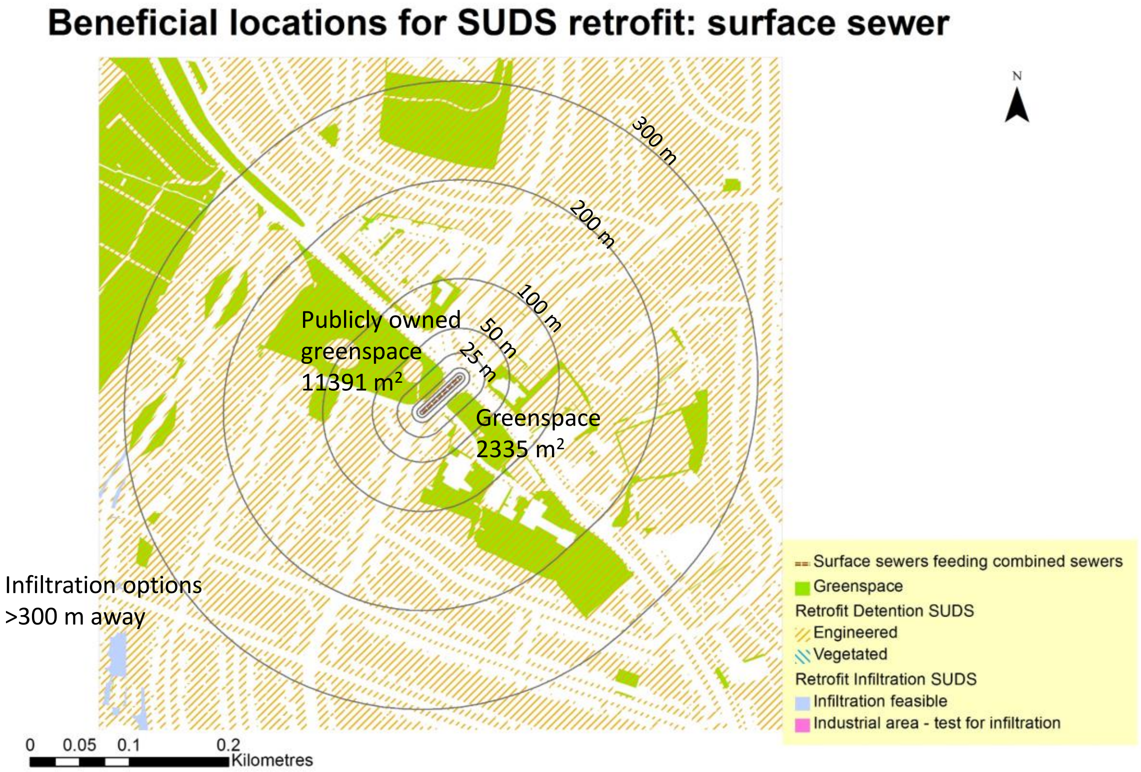


Fig. 5.78 Beneficial locations for SUDS retrofit: surface sewer. Circles show buffer distances from the sewer.

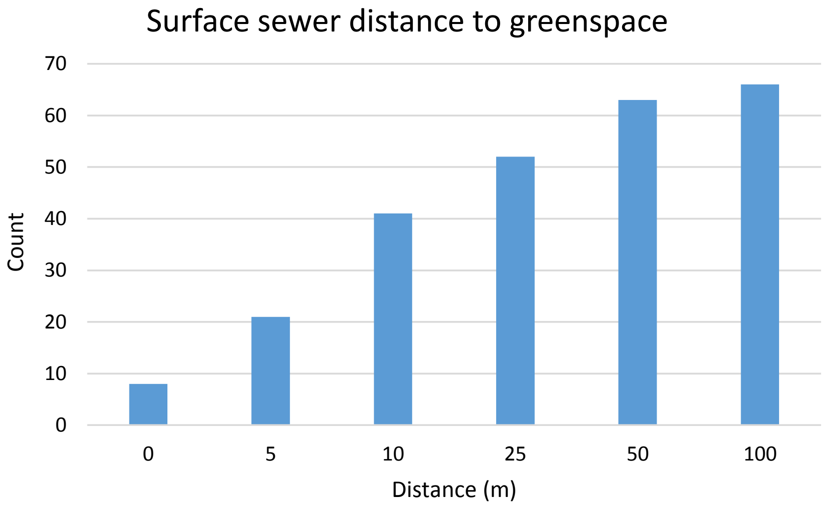
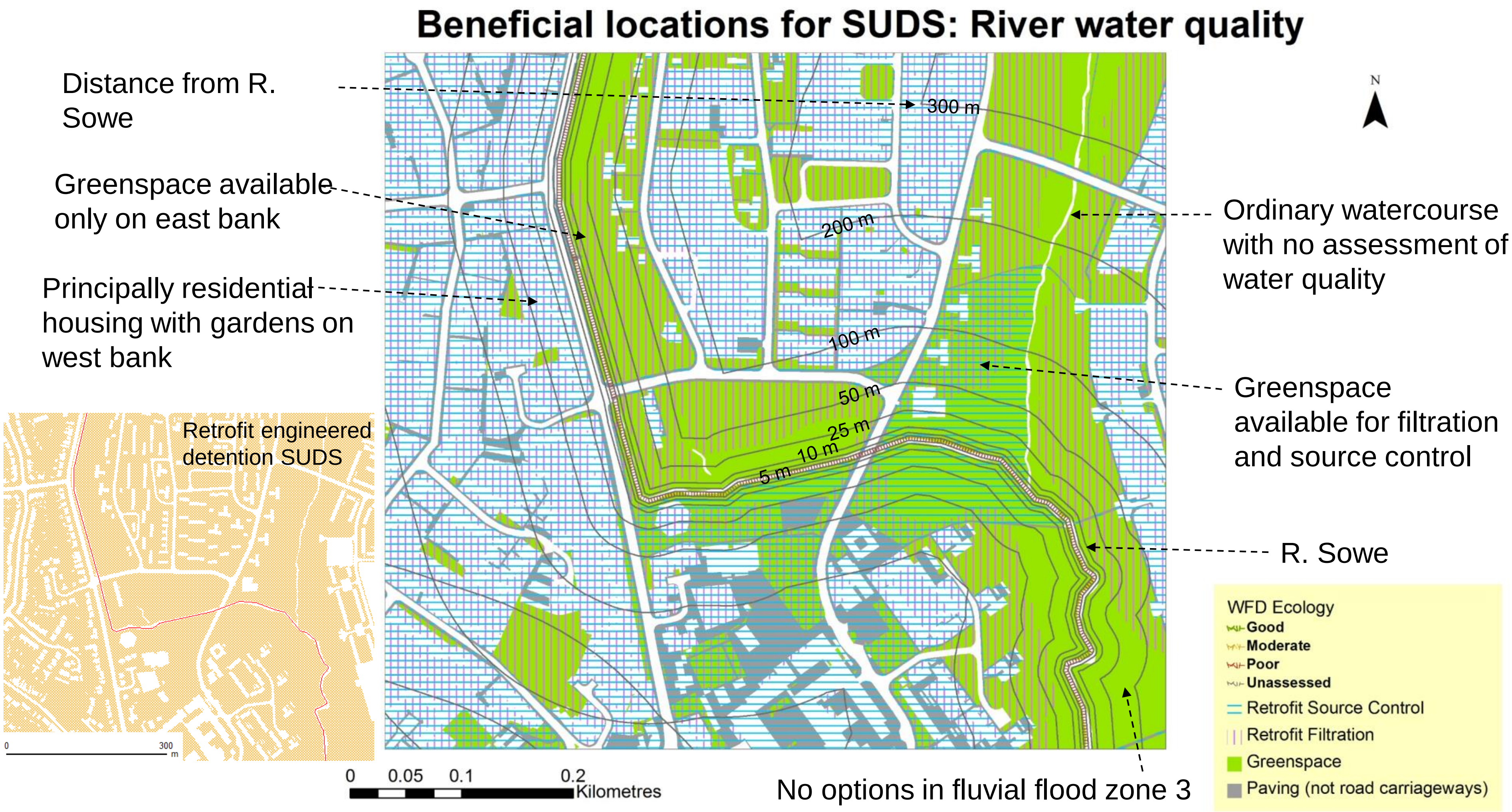


Fig. 5.79 Distance to greenspace of surface sewers joining combined sewers

5.14.5 River Water Quality

Diffuse pollution is seen as a significant contributor to poor water quality in urban watercourses, delivered by direct runoff, eroded banks, surface water sewers and combined sewer overflows. Any area adjoining a watercourse might therefore be suitable for disconnection of surface sewers emptying into the river, for instance, or reduction of overland flow rate and volume. Fig. 5.80 shows options for retrofitting filtration, source control and detention SUDS to address river water quality along a section of the R. Sowe in northeast Coventry.

Practicable measures using greenspace were possible up to about 75 m from the river. Filtration SUDS were excluded from fluvial flood zone 3 (Table 3.23), but there was sufficient space outside this to construct filter strips to slow runoff rate and to capture particulates from roads, with disconnection of highway drains worth further consideration. Retrofit source control devices (Table 4.11) were largely oriented towards managing runoff from urban development, and greenspace was included as suitable land cover if it was near to existing buildings and road carriageways (Table 3.22). SUDS such as green roofs, permeable paving and bioretention were therefore not appropriate for direct management of river quality adjacent to the river, although could contribute to prevention or reduction of the initial polluted runoff before it enters surface water sewers. Detention SUDS (inset of Fig. 5.80) were possible in much of the greenspace adjacent to the river, affording options for offline storage basins and wetlands for treatment.



Distance from R. Sowe

Greenspace available only on east bank

Principally residential housing with gardens on west bank

Retrofit engineered detention SUDS

Ordinary watercourse with no assessment of water quality

Greenspace available for filtration and source control

R. Sowe

No options in fluvial flood zone 3

Land cover © Crown Copyright/database right 2009. An Ordnance Survey/EDINA supplied service

Fig. 5.80 Beneficial locations for SUDS retrofit: river water quality, highlighting options for retrofit filtration and source control SUDS. Inset shows engineered detention SUDS for the same area

The example given here considered a main river for which a WFD water quality assessment had been performed. Unassessed ordinary watercourses are equally likely to be affected by pollution, so a full review of water quality should be based on all watercourses, not solely main rivers.

Fig. 5.81 considers suitable land availability for SUDS to address river water quality in Coventry using new development and retrofit detention, infiltration and source control SUDS. There is almost no suitable land within 2 m of rivers, so installation of end-of-pipe SUDS to disconnect surface water sewers would be problematic in Coventry. However, detention and source control solutions become more viable at 5-10 m distance from rivers. Infiltration SUDS are only possible at a mean distance of at least 200 m from rivers.

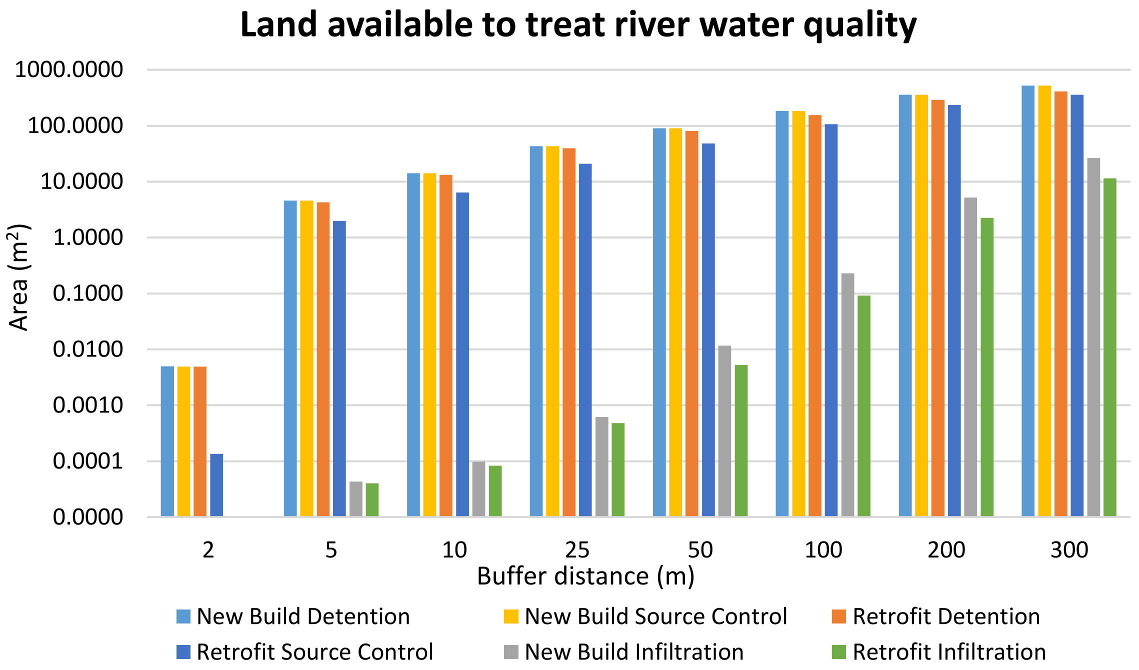


Fig. 5.81 Available space for SUDS to address river water quality issues in Coventry. The x-axis is the space availability at nominated buffer distances from river stretches with WFD water quality assessments, normalised per river length (total 43,863 m). The y-axis shows suitable space for Detention, Infiltration and Source Control SUDS techniques from the feasibility maps ($\log_{10}$ scale for ease of comparison)

6 DISCUSSION

This chapter discusses the work undertaken according to the objectives defined in chapter 1. Objectives 1a and 1c, to identify suitable evaluation techniques to determine SUDS feasibility in an urban environment, and to determine suitable SUDS devices for an urban local authority area were considered in chapter 4. The remaining objectives are discussed in this chapter.

6.1 OBJECTIVE 1B - THE USE OF A FRAMEWORK

Objective 1b was to construct a framework in order to evaluate suitable SUDS devices at the local authority strategic scale. The theoretical framework defined a clear organisation of factors that influence SUDS implementation, and provided a method of ensuring that all identified factors were addressed. Development planners, the target audience, are concerned with the type and size of developments in the early stages of discussions with developers, rather than the characteristics of individual SUDS devices. Consequently, groupings of SUDS devices, similar to the approach of Shoemaker *et al*. (2009) allowed planners to relate to general attributes rather than needing to understand how each device functions, and reduced the number of SUDS features to evaluate. The division into physical and anthropogenic factors was less meaningful to operational users of the maps, but did allow the underlying GIS database to be more unambiguously structured. The separation of fixed and variable factors enabled a transparent relationship to new development and retrofit scenarios, although there was sometimes a lack of certainty about the category to which planning constraints such as listed buildings and SSSIs should be assigned.

During the creation of the feasibility maps, Coventry's draft core strategy underwent three iterations of attempting to define sites for future major development zones. The categorisation of planning considerations as a variable factor ensured that the feasibility maps were not affected by these policy changes. The extent and location of greenfield development was a frequent and at times contentious, point of debate in the city. The 2009 draft of the local development framework core strategy planned to release greenfield sites to construct at least 5,000 dwellings in the LPA area (CCC 2009:44-45), whereas the third draft of the core strategy (CCC 21012b:55) prohibited development on greenfield sites unless exceptional need could be demonstrated. The SUDS guidance maps were not affected by these shifts, and the feasibility recommendations will apply whatever the final decision. The framework therefore provided a degree of flexibility in the light of possible future change.

The implementation of the framework in the GIS system reduced the number of output maps compared to the theoretical design, and took advantage of standard GIS functionality in the same way as Becker *et al*. (2006). The five output map layers equated to the five SUDS groupings from the theoretical framework, and the resulting feasibility maps for new developments were relevant to development planning. Defining the associated information, e.g. the specific SUDS devices for different sizes of development, and the number of components in the management train, as fields in the GIS layer, allowed this data to be easily updated in case of future changes, enabling a flexible response to future variability.

However, the generation of the maps as static representations of a dynamic environment, using rules that had to be agreed in advance, introduced inflexibility to the delineation of location and extent of the individual layers. The division into fixed and variable factors aimed to separate the data that were less likely to change, but would not be responsive to errors in the definitions of that data (see section 6.2). An ideal solution would be the dynamic creation of maps from the latest available data employing a set of rules that could be varied as required, but without software development so that users are not dependent on a specific technology. This is considered further in section 6.3.2.

The framework in its current form considered only factors that could be mapped, and for which data were readily available. Sustainability criteria, such as those defined by Ellis *et al*. (2004a:253) were not included, although these would be a valuable addition at the strategic scale. These social, economic, environmental and performance criteria were included in the Sudsloc tool (Viavattene 2009).

6.2 OBJECTIVE 2A – SUDS FEASIBILITY MAPS FOR A LOCAL AUTHORITY AREA

The data used to determine the SUDS feasibility maps were selected, in part, due to their ease of availability to the LPA. Section 6.2 reviews the accuracy of the datasets, while section 6.3 considers the suitability of the approach.

6.2.1 Data review, limitations and sources of uncertainty

Few studies have mapped the potential for SUDS feasibility across a full LPA area. At this scale, prior studies, e.g. Halcrow Group Limited (2008a) and Ipswich Borough Council (2007), have considered a restricted number of factors in comparison with this research (Table 6.1), although they have recognised the need to base maps on additional data. Data availability has been recognised by other workers as a key consideration (*e.g.* Sleavin *et al*. 2000:4; SNIFFER 2006:17; Digman *et al*. 2012:76). Feasibility assessments covering a narrower area have tended to include more factors. An exception was the BGS national SUDS infiltration map (Dearden & Price 2012), which considered a wide range of geological layers, but limited the focus to infiltration. Despite common use of well regarded datasets such as OSMM, there are limitations and uncertainties with the data contents, and this is reviewed in more detail next.

At the strategic spatial scale addressed by this thesis, some uncertainties were present in relation to the accuracy of information. Digman *et al*. (2012:120) suggested that a means of assessing data and output uncertainty was needed using, for instance, what-if sensitivity analysis to evaluate a range of potential future scenarios, or a scoring mechanism to rank the reliability of data. Such approaches are useful, but the data required to quantify uncertainty, particularly in relation to map depictions, are rarely available (Bales & Wagner 2009:140), and relevant metadata were lacking for many of the data sources used in this research. It would be valuable to classify the spatial variability of each of the data sources, and in some cases even the individual data points, and to represent this on maps, but the effort to achieve this at LPA scale, and the appropriate methods, require further investigation.

One approach to managing uncertainties is to identify sources of error and to clarify them. A second approach is to attempt a level of quantification, for example by comparing information obtained with field surveys against the information held on the GIS database. Undertaking a field survey of the whole study area would be impractical in terms of time and expense, particularly if the method were to be transferable to other local authorities or large landholders. These two approaches are considered in this section. A third means of validating results is to compare with similar information from alternative sources, which is addressed in sections 6.3-6.4. Despite the limitations presented here, the majority of the datasets were taken from national or local sources that have been utilised in other work, and represent the best available knowledge at the time.

Table 6.1 Comparison of factors used to determine maps of SUDS feasibility. The 'used' column (bold font) identifies factors taken into account to create SUDS guidance maps. The 'advised' column (regular font) shows factors that the study did not employ, but considered likely to influence SUDS implementation

Location	**UK (SWMP)**	**UK (C713)**	**Ipswich**	**Telford & Wrekin**		**Lower Irwell, Salford**		**UK (Sudsloc)**	**West London**	**UK (BGS)**	**Coventry**
Reference	Defra (2010b)	Digman *et al.* (2012)	Ipswich Borough Council (2007)	Halcrow Group (2008a)		Doncaster *et al.* (2008)		Viavattene (2009)	Moore *et al.* (2012)	Dearden & Price (2012)	This study
	advised	advised	used	used	advised	used	advised	used	used	used	used
Bedrock geology	y						y			**y**	**y**
Superficial geology	y	y	**y**			**y**				**y**	**y**
Rock and mining instability										**y**	
Depth to permeable geology					y					**y**	**y**
Soil		y	**y**	**y**				**y**			**y**
Attenuation potential of unsaturated zone										**y**	
Topography / slope	y	y			y			**y**		**y**	**y**
Water bodies	y										**y**
Groundwater levels		y	**y**		y	**y**		**y**		**y**	**y**
Areas susceptible to groundwater flooding										**y**	
Borehole records	y										

Location	**UK (SWMP)**	**UK (C713)**	**Ipswich**	**Telford & Wrekin**		**Lower Irwell, Salford**		**UK (Sudsloc)**	**West London**	**UK (BGS)**	**Coventry**
Reference	Defra (2010b)	Digman *et al.* (2012)	Ipswich Borough Council (2007)	Halcrow Group (2008a)		Doncaster *et al*. (2008)		Viavattene (2009)	Moore *et al*. (2012)	Dearden & Price (2012)	This study
	advised	advised	used	used	advised	used	advised	used	used	used	used
Groundwater vulnerability										**y**	
Groundwater source protection zones		y	**y**	**y**			y			**y**	**y**
Drainage area								**y**			
Fluvial flood zone 2 & 3	y	y				**y**					**y**
Surface water quality	y	y								**y**	**y**
Land contamination		y	**y**		y		y	**y**			**y**
Pollutant removal								**y**			
Land cover / land use	y	y			y			**y**	**y**		**y**
Presence of flat roofs								**y**	**y**		**y**
Land ownership		y									**y**
Historical maps		y									**y**
Aerial photography	y	y									
Development density					y						

Location	**UK (SWMP)**	**UK (C713)**	**Ipswich**	**Telford & Wrekin**		**Lower Irwell, Salford**		**UK (Sudsloc)**	**West London**	**UK (BGS)**	**Coventry**
Reference	Defra (2010b)	Digman *et al.* (2012)	Ipswich Borough Council (2007)	Halcrow Group (2008a)		Doncaster *et al*. (2008)		Viavattene (2009)	Moore *et al*. (2012)	Dearden & Price (2012)	This study
	advised	advised	used	used	advised	used	advised	used	used	used	used
Proximity to other urban areas					y						
Planning policies & constraints	y	y									**y**
Willingness to adopt					y						
Sustainability criteria								**y**			
Drainage and utility assets	y	y									
Historical flood records	y										**y**
Critical infrastructure	y										
Maintenance records	y										
Number of factors	14	14	**5**	2	**8**	**3**	3	**9**	**2**	**11**	**17**

6.2.2 Land cover

Gill *et al*. (2008:211) highlighted the weaknesses of regional and national landscape characterisation methodologies such as CORINE (EEA 2009) used by Mitchell (2005:3), which emphasise rural areas and not the complexities of fine-grained land cover in urban environments. An advantage of OSMM was its spatial completeness and logical consistency. Every individual point within the city boundary had an assigned land cover class, and after removal of the few duplicates from the initial dataset, each point belonged to only one class. The 479,571 polygons of the OSMM dataset provided a substantial level of detail relating to land cover in Coventry. One disadvantage of this level of detail was the length of time required to undertake some of the data selection and analysis tasks needed for this study. Despite this level of detail, the representation of Coventry's land cover afforded by OSMM was not necessarily accurate. Inaccuracies could result from omission of features, positional and classification errors, and temporal differences. These are discussed next.

6.2.2.1 Omission of features

The pilot study found that land cover features were omitted from OSMM (section 4.2). The assignment of a single land cover attribute to a polygon could also result in small inaccuracies. For example, underpasses, culverted watercourses, and land cover underneath bridges are unknown and may need to be inferred from nearby features.

6.2.2.2 Positional error

Positional error, where a feature is wrongly located in space, was possible, but this type of error was disregarded in the current work, because the OSMM dataset was logically consistent and spatially complete.

6.2.2.3 Classification error

A confusion matrix (Table 6.2) was created to assess the accuracy of the OSMM classification. The field survey undertaken in the pilot phase was used as the source of accurate information about land cover. The rows in the matrix represent the 576 classified OSMM polygons, while the columns show the count of field observations from the pilot survey. Each polygon from the field survey was associated with a single land cover class in the classified OSMM dataset. For example, reading along the rows, of the 206 polygons classified as greenspace, 125 were confirmed as greenspace in the field survey, but 10 were buildings, 70 were paved areas, and one was water. Reading down the columns, 168 polygons in the field survey represented buildings, but only 153 were classified as Buildings, while four were classed as paved areas, one as a garden, and 10 as greenspace.

A total of 394 polygons were correctly classified (68.4%). Adjusting the percentage of correctly classified polygons by the 167 polygons that could have been correctly classified by chance, the kappa index of correctly classified polygons was lower (58.5%). Paving (56% accuracy) and greenspace (62% accuracy) were the categories most likely to be mis-classified. Although OSMM was the main source of land cover information for this research, the kappa index accuracy value of 58.5% indicated that OSMM cannot be regarded as an authoritative representation of land cover in Coventry. This reflects a finding from the pilot phase that it was not always possible to correctly separate paving and vegetation using the categorisation supplied with OSMM. Paving was most likely to be mis-classified as greenspace, and *vice versa*, so to some extent the errors might balance each other out. However, this error might be important in terms of identifying accurate land cover for retrofit, if extended to the whole city. A weakness of using the pilot field survey as a validation dataset was that it contained no gardens or unclassified land. The accuracy of garden land cover is reviewed next.

6.2.2.4 Gardens

The detail of land cover within gardens was inconsistently included in OSMM (Smith *et al*. 2011:7), perhaps because of the risk of rapid temporal change or the effort needed to construct such information. Categorisation of garden land cover was validated by means of an examination of aerial photographs of Coventry. In the validation sample, 68.6% of garden land cover was vegetated, 6.2% covered by additional buildings, and 25.3% by paving. Coventry’s figure was slightly higher than the 57% vegetated land cover of OSMM garden polygons in London (Smith *et al*. 2011:13). In broad scale hydrological studies, this lack of definition in OSMM may be important. An issue relating to the garden validation was the small sample size (n=59 including one outlier that significantly affected the distribution of data and the statistical results). Relative error of the sample was 31% (excluding the single outlier, 23%). To reduce relative error to 10% required a sample size of 300; however the small sample results are within the range of other studies (see later discussion in section 6.4.1).

Table 6.2 Confusion matrix for the OSMM land cover classification. Rows represent the classified polygons from the OSMM database. Columns reflect field observations from the pilot survey. For further explanation see text. The highlighted cells on the diagonal show the correctly classified polygons.

		Pilot survey observations							
		Buildings	**Road&Rail**	**Unclassified**	**Gardens**	**Greenspace**	**Water**	**Total**	**% correct in database**
OSMM Database	**Buildings**	153	4	0	0	0	0	157	97.5%
	Road&Rail	4	113	0	0	23	0	140	80.7%
	Unclassified	0	0	0	0	0	0	0	100.0%
	Gardens	1	12	0	0	53	0	66	100.0%
	Greenspace	10	70	0	0	125	1	206	60.7%
	Water	0	4	0	0	0	3	7	42.9%
	Total	168	203	0	0	201	4	576	68.4%
	% correct from field survey	91.1%	55.7%	100.0%	100.0%	62.2%	75.0%		

6.2.2.5 House Types

Orford & Radcliffe (2007) found discrepancies between the counts of dwelling types in the 2001 census and the types present in OSMM at the output area level. The total of dwellings in output areas in Coventry was higher by a maximum of 47 (0.04%) than totals from the equivalent lower super output area, middle super output area and ward totals from the 2001 census. Therefore, house type information used was considered sufficiently accurate.

6.2.2.6 Large Roofs

Roofs of houses that had been extended over time sometimes consisted of several smaller polygons in the OSMM database rather than a single polygon covering the total roof area. Whilst this phenomenon was not observed for the larger roof sizes, it remains a possibility that not all large roofs were detected using the selection of individual polygon areas over 200 m^2 if the roof area was constructed from several smaller polygons.

6.2.2.7 Roads

Motorway, A- and B-road datasets were line layers, and did not exactly follow the path of the OSMM roads. CCC’s highways adoptions dataset contained similar polygons to the OSMM roads data, but there were uncertainties relating to type of road (10.5% of database) and road names (7.5% of database), with a combined uncertainty of 16.8%. A few uncertainties could be resolved by using text descriptions.

6.2.3 Geology

The broad areas of bedrock and drift geology may contain unrepresentative variations across the city, for instance in attributes and depth. Bedrock fractures may influence infiltration, but these were not taken into account.

Drift deposits of till, the main occurrence in Coventry, are highly spatially variable (Old *et al*. 1990:15), leading to undocumented flow paths (Lelliott *et al*. 2006:299). Impermeable superficial geology deposits can severely limit infiltration, but in practice the depth to bedrock is also an important factor. A generalisation was applied based on Old *et al*. (1990) that depth of till was thicker in the east of the city, where it would have a greater influence on infiltration. The BGS superficial geology layer did not contain details of made ground, although the long history of development in the city would indicate that it might be widely distributed. The structure and constituents of made ground are very variable and may be contaminated (Royse *et al*. 2008:19), and these attributes might limit the potential for infiltration due to the risk of passing contaminants to groundwater Dearden *et al*. (2013). The alternative dataset of current and former industrial land has been used as a proxy of made ground. In Coventry, both superficial and bedrock geology revealed the same pattern: permeability in the west and centre, and impermeability in the east.

6.2.4 Groundwater

There is no continuous monitoring programme across a sufficient number of borehole sites to permit accurate characterisation of groundwater levels, and such a project would be financially unjustifiable (Lelliott *et al*. 2006:300). Several BGS studies (e.g. Ball *et al*. 2004:19; Lelliott *et al*. 2006:299; Rutter *et al*. 2006:19) have experienced difficulties assessing water table levels in the UK. The assessment of Rutter *et al*. (2006:19) for the Thames Gateway project found insufficient samples from boreholes to generate an accurate map of groundwater levels, a conclusion repeated in this work. The method employed in the current study of extrapolation from river surfaces has been used in other studies (e.g. Ball *et al*. 2004:19), although geological influences on flow were not taken into account as a result.

As a result, a cautious approach was taken to water table depth. Woods Ballard *et al*. (2007:5.6) defined a cut-off of 1m minimum depth to groundwater before infiltration is possible. The view from one consultee was that 2m depth to groundwater should be sufficient for infiltration SUDS (Appendix G), but 4m was used based on the BRE 365 (Soakaway Design) suggestion that a 3m soakaway depth is acceptable, and Environment Agency guidance of a minimum 1m depth between the base of infiltration devices and the water table.

Depth to groundwater was the main dataset where a modelled layer was created instead of obtaining information from a recognised source. Other LPAs would need to acquire this data for their area in order to follow the procedures used in this study.

A sensitivity analysis was undertaken to estimate the areal impact of a less cautious approach to water table depth (Fig. 6.1). 17.0% of Coventry was suitable for infiltration for new developments (Fig. 5.9) based on a depth to water table of 4 m. Reducing the acceptable depth to groundwater would increase the area suitable for infiltration. A modelled water table depth of 2 m would result in infiltration SUDS being feasible in 21.2% of Coventry, and 1 m depth to groundwater in 23.8% of the city. The relative percentage of potentially contaminated land also expanded with each increase in feasible area: 14.8% of total infiltration area for 4 m depth, 19.0% for 1 m depth. The spatial distribution of the additional areas assuming a 1 m depth to groundwater is presented in Fig. 6.2. The majority of the additional feasible area consists of extensions to the existing locations in the west and centre of the city, with the principal additional block of land suitable for infiltration in the north of the city. Although a reduced depth to water table increased the space where infiltration SUDS were feasible, this still accounted for under a quarter of the LPA area (23.8%), and suggest that depth to water table was not the primary factor influencing infiltration SUDS in Coventry.

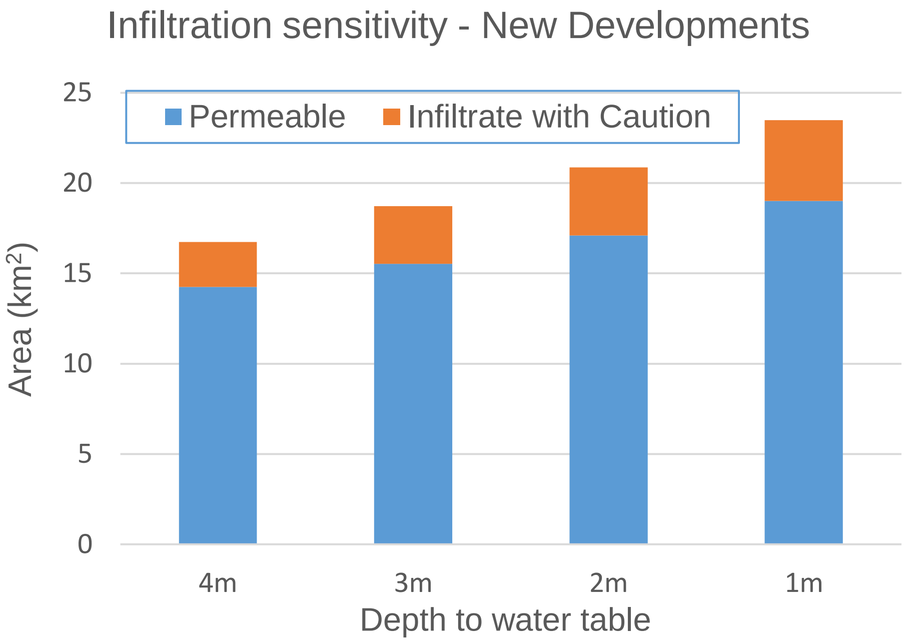


Fig. 6.1 Infiltration sensitivity analysis, showing the increased area suitable for infiltration SUDS in new developments modelling differing water table depths.

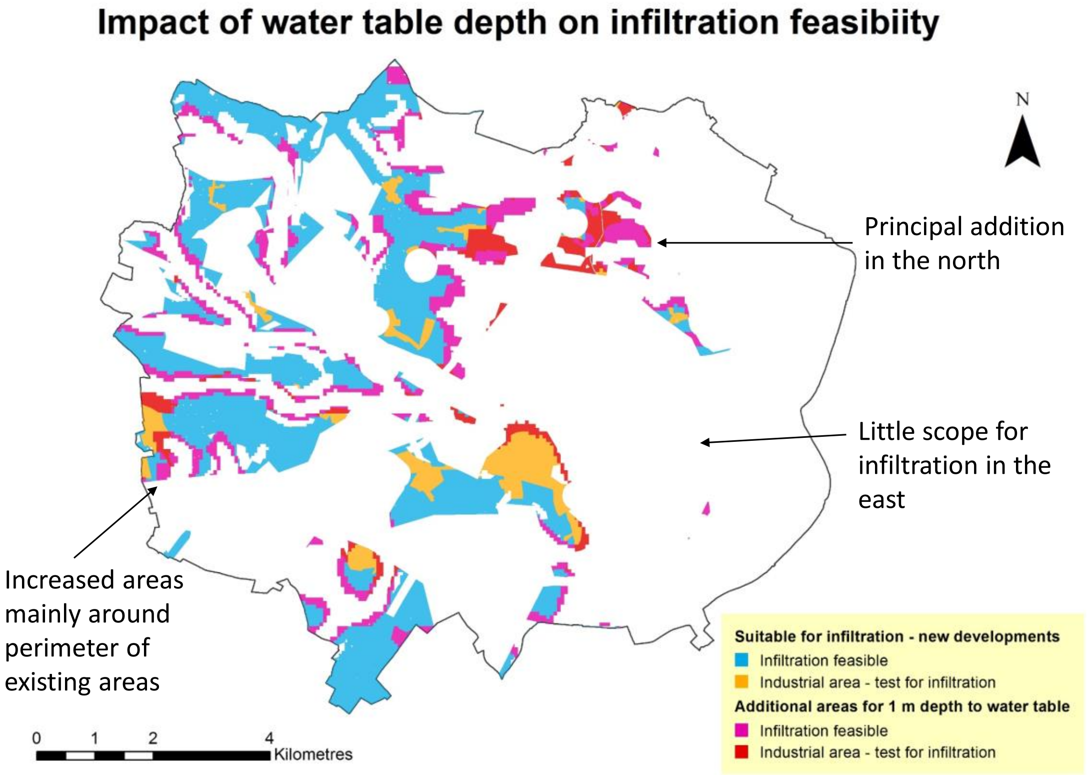


Fig. 6.2 Spatial impact of infiltration sensitivity analysis

6.2.5 Soil

Soil impermeability characteristics were more varied than the uniform SPR values of 0.47 assigned to the whole of Coventry based on an assumption of clay soils (Defra & Environment Agency 2007), or 0.36, relatively low permeability, for the whole catchment in which Coventry is located (EA 2010c). However, since the soil data were manually transcribed into ArcGIS from the two principal sources, errors may have occurred in positioning them. High groundwater levels were shown in some, but not all, river valleys, possibly resulting from an incomplete or outdated representation of rivers in the Soilscapes viewer (NSRI 2010). For example, the high groundwater classification for the R. Sherbourne was roughly equivalent to the location formerly defined as a main river, before extension of the designation. Impeded drainage will have some infiltration capacity, but due to the propensity for waterlogging in winter (NSRI 2010) the rate of infiltration was treated as insufficient for operational SUDS. Anecdotal evidence from one of the city's few infiltration SUDS in north-west Coventry was that a soakaway sized to meet, but not exceed, BRE365 guidelines, overflowed during even moderate rainfall (> 15mm) (pers.comm. CCC and EA).

6.2.6 Watercourses

There was no single repository of information covering all watercourses in Coventry, and information was collated from a number of sources. In particular, the route of culverted watercourses in Coventry was not precisely known, could not be verified from OSMM or field survey, and had to be estimated in places. However, they approximated to the historical locations of the Hall Brook, Radford Brook, Springfield Brook, Spital Brook, and in some locations could be correlated with open water present on OSMM.

6.2.7 Flood zones

Fluvial flood zone boundaries in Coventry were updated during the course of the research, indicating that flood models undergo periodic refinement. Several sources of uncertainty are present in flood inundation maps (Bales & Wagner 2009), but these were not quantified in the available datasets. The absence of flood zone boundaries for ordinary watercourses did not mean that no flooding would occur there, rather that no attempt had been made to model flooding in those catchments.

6.2.8 Historical Floods

Reasons for uncertainties associated with historical flood data are summarised in Table 6.3. More detail is given in Appendix E.

6.2.9 Water quality

Water quality measurements are taken at a few specific pre-defined points, once per month or less frequently. Such point measurements may not provide an accurate assessment of water quality (Defew *et al*. 2013:373-374; EA 2003:3; Hyde 2006). Pollution incidents occurring at other times, or affecting only small stretches, might not be incorporated in published figures. Biological responses to pollution can indicate past pollution events, but are subject to monitoring of appropriate species and taxa, and on their speed of response to and recovery from the pollution incident (Johnson & Hering 2004).

Table 6.3 Reasons for uncertainty in historical flood records for Coventry

Contributor to uncertainty	Mitigation approach adopted	Implications
No single source of flood events	Data compiled from several sources	Reliance on sources to record all events, but many events present in only one or two sources
Flood events not recorded in consulted sources	None	Incomplete dataset
Manual search of local press microfiche archives	Additional research time	Some records not collected
Bias towards collecting events from 1980 onwards	None	Some records not collected. Insufficient weighting of older events
Location of some events imprecisely recorded	Geographic location assumed on the basis of topography for events associated with only a street name. Events with vague descriptions excluded	Inaccurate and missing flood locations
Location of flooding wrongly placed or omitted when added to the GIS database	Checks for illogical locations and validation against data collection records	Inaccurate and missing flood locations
Impact of events often unclear, e.g. number and type of properties affected	None	Scale of impacts unknown
Cause of events undefined, particularly for non-fluvial occurrences	None	Unknown causes for some events
No access to Severn Trent Water's DG5 register of properties at risk of sewer flooding, as the register was considered commercially confidential	Some locations identified from CCC (2008b) and Jacobs Gibb Ltd (2008)	Incomplete dataset
Precise date of events not always recorded	None	Incomplete dataset

6.2.10 Sites of current and former industrial usage

The usage of City Council data to determine sites of potentially contaminated land was conditional upon creating a generalised representation of the base data. The generalisation process involved joining separate areas of industrial land, thus including intervening non-industrial sites. Small areas of industrial land, isolated from other sites, were omitted from the final generalised dataset.

6.2.11 Boundaries

Boundaries are often imposed by external political and social definition, such as the LPA area. Interactions may take place in the physical world across boundaries, influencing for instance runoff and fluvial flood zones. Some historical flood events occurred just outside the south-west boundary of the city and were excluded in this study, but may have influenced the results of the flood frequency analysis. For the most part, runoff was directed to watercourses inside the city boundary.

6.2.12 Temporal differences

Frequency of updating the OSMM database could account for some differences between actual land cover and its representation in OSMM. Despite annual updates being applied to OSMM, outdated land cover remained, e.g. one University building was still omitted from the 2009 update used for this study. OSMM land cover changes after 2009 were not included. Other datasets were created at different times, and changing conditions may have led to data updates not being included in this work, particularly in the variable datasets.

6.3 OBJECTIVE 2B. SUITABILITY OF THE MAPS AND APPLICABILITY OF THE APPROACH

This section reviews the approach taken to creating the SUDS feasibility maps, considers wider implications, and makes some policy recommendations about use of the maps in relation to SUDS implementation.

6.3.1 Suitability of the information for the target community

Despite the alternative judgements that could have been made concerning inclusion and exclusion of particular factors, and specific attribute values employed, discussions with stakeholders with knowledge of the city considered the choice defined for this study was appropriate (section 5.8). Previous studies have relied on a level of understanding of SUDS and hydrology that is unlikely to be found in local authority staff involved in planning processes. The focus on infiltration versus non-infiltration SUDS in previous studies is unhelpful for non-specialists, for whom SUDS are just one of a myriad of planning considerations (Gilmour and Blackwood 2006). The wording used by previous SUDS feasibility mapping studies, e.g. Doncaster *et al*. (2008) and Halcrow Group (2008a), has emphasised infiltration SUDS, yet these were just one of the possible types of sustainable drainage options. Their focus on infiltration did not clarify which other SUDS would be suitable in the remaining areas, 84% of the area in Telford and around 50% in the Ipswich and Irwell Valley studies, reinforcing a common perception that all SUDS require infiltration capability, and that if infiltration is not possible, then no form of SUDS can be implemented (Gill 2008:23). To address this point, the feasibility maps illustrate the full range of SUDS devices, demonstrating that a range of SUDS options exist that can be considered. Inclusion of several SUDS devices in each structured ‘group’ also conveys a message that alternative devices are available if one is considered unsuitable in specific circumstances. Utilising the presentation principles and the generalised rules developed for this research could contribute to an improved understanding amongst planners of the range of available SUDS techniques. The research would thus play a role in addressing the shortage of guidance for planning authorities on the types of SUDS appropriate for specific situations (EA 2009d:v; LGA 2012) identified in chapter one. The maps, and the analysis of the supporting spatial data, could also be used to inform local planning guidance such as a SUDS supplementary planning document (SPD). SPDs can define local policies on SUDS implementation supported by local evidence (LGA 2006:iii), and can influence development designs in order to reduce the environmental impact of buildings.

Draft maps generated by this research have been consulted by CCC during production of their Surface Water Management Plan, SUDS supplementary planning document, and procedures to prepare for the introduction of SABs. The historical flood information collected for this research was one of the calibration datasets used to validate the EA’s revised fluvial flood model for Coventry, and was used by Coventry City Council in writing the PFRA (CCC 2011b). Aspects of the evolving research have been presented at a number of academic conferences, and published in a peer-reviewed article (Warwick and Charlesworth 2013, attached in Appendix L). Presentations have also been made to Coventry’s flood risk management group, and to town planning and sustainability professionals. A summary is given in Appendix K. Although further refinement is needed, the approach to information collection and presentation developed in this research, and interest from the planning and regulatory community, demonstrate that the research methods and outputs are suitable for the target community.

6.3.2 Use of Maps

A review of sustainability assessment tools in the water industry (Hurley *et al*. 2008) concluded that complex multi-criteria evaluation tools, although popular with researchers, have found little acceptance with, and had no practical value for, practitioners. The multi-criteria decision approach may be appropriate to reach decisions concerning a particular location, but its application is less clear when evaluating a wider area to decide feasible SUDS devices, when stakeholders are not yet known. A simple, transparent portrayal of options may be more effective in communicating with decision makers (Blackwood *et al*. 2000:179). Maps provide an accessible overview of the spatial relationships between subjects of interest, and can be used to communicate information rapidly, but are inevitably a simplification of the real world (Longley *et al.* 2005:128). Geographical information systems (GIS) are useful for visualising relationships between multiple factors, particularly in a spatial planning context, as seen in the system created by Jin *et al*. (2006), for which the target audience was a group of planning decision-makers, similar to those in this research. Coventry's planners were already conversant with interpreting GIS-based information, so feasibility maps were appropriate to communicate which SUDS might be suitable in specific locations. The use of GIS ensured that the maps were scaleable, and could be viewed at differing resolutions from the full LPA area down to individual development and regeneration sites. However, uncertainties are associated with all maps (Bales & Wagner 2009:140), especially when they appear to represent absolute boundaries in natural systems. Similarly, all information collected as GIS layers may also suffer from issues of poor and incomplete data collection, inaccurate positioning, and over-simplification (see section 6.2).

Halcrow Group (2008a) simply reproduced individual layers of information to users and relied on them to interpret information appropriately (Fig. 2.11), whereas Ipswich Borough Council (2007, Fig. 2.10) and Doncaster *et al*. (2008, Fig. 2.14) presented indicative locations for SUDS. This latter approach was considered more effective where a large number of factors were compared, as in Coventry, but was at greater risk of mis-interpretation of the base data during creation of the maps, and lack of transparency. The latter issue could be overcome by making available the original input data in case of queries.

Maps are less effective at conveying information that requires prior discussion, consensus or project-specific knowledge. Factors identified by Ellis *et al*. (2004a:256) such as the level of management, or the ability to handle high sediment input, influence the suitability of individual SUDS devices, but are not of themselves straightforward to map. They could be mapped through their association with the SUDS features, e.g. as an additional piece of information in the underlying database of the GIS system. The risk of including too much additional, albeit relevant, information in the database is that it can detract attention from the main message to be conveyed. One possible option is to build links to documents that can be requested by the planner by clicking on an ‘additional information’ button. In the same way, example images of SUDS devices could be integrated into the GIS database in association with particular groups of SUDS, e.g. Ellis *et al*. (2011). This has not been implemented in the current study.

Throughout the research into the full LPA area, the GIS systems used, ArcGIS versions 9.1, 9.2, 9.3 and 10.0 (ESRI 2005-2010), MapInfo v7.3 (Pitney Bowes 2003), and Quantum GIS v1.8 (Quantum GIS 2012), did not process the large volume of data rapidly. Analysis run times regularly exceeded 12 hours, and some processes failed to complete, requiring workrounds and alternative approaches. The retrofit guidance maps posed the main problems in this respect. Run times were only partially related to computer processing power, and were in practice dependent on limitations imposed by the software packages. Dynamic analysis of data and creation of maps would be preferable to cope with continually changing spatial representations of data, but seemed beyond the limits of current technology for the large amount of data needed for a full LPA with this level of detail.

The data collection and analysis period lasted approximately four years, due to the part-time nature of the research. Inevitably, conditions changed over this length of time. However, the SUDS feasibility maps were created as a static, not a dynamically updated, dataset, using data obtained at fixed points in time, in the same manner as the broad scale BGS maps (Dearden and Price 2012). In terms of classification of data, fixed factors were, by their nature, less likely to change. Variable factors such as land cover and planning constraints, can vary on a sub-annual cycle, and these characteristics contained the high data volumes.

The next step in generation of a set of maps that would be more reactive to change, could be development of a front-end system to identify fixed factors and associated rules, and a back-end to automate the analysis. A component approach was employed by Viavattene *et al*. (2010) using software development, and Moore *et al*. (2012:277) used standard ArcGIS Model Builder functionality to automate SUDS map creation. The underlying principle of the current research was to provide a means of using data that was readily accessible to LPAs, analysing it in a relatively straightforward way using commercially available software with standard functionality. Therefore, use of ArcGIS Model Builder could be explored in a future project to automate production of SUDS feasibility maps for new developments, although similar functionality in other GIS packages might not be available. The extent to which the size of the datasets might present an operational limitation requires investigation.

6.3.3 Map validation

6.3.3.1 Canley new development maps

A comparison with two more detailed studies, RPS Planning and Development (2012) and Lashford *et al*. (2014) (section 5.10), was undertaken to validate the results of the feasibility maps. The feasibility maps suggested options that were not put forward by either of these two studies. The more conventional design by RPS appeared to comply with the letter rather than the spirit of sustainable drainage implementation, using underground storage, over-sized pipes and hard engineered features, with disposal to surface water sewers when runoff could not be retained on site. Only one of the three suggested components of the management train, permeable paving on a limited number of shared driveways, offered any potential for water quality improvement. RPS' focus on water quantity management arises from a historical planning emphasis on flooding rather than improved water quality, still reflected in the NPPF. The feasibility maps could have prompted discussion with the developers about these options. Soakaway tests indicated that 55% of the planned properties were suitable for infiltration (RPS, p15, optimistically estimated 70%), but the feasibility maps did not suggest infiltration as an option for this site. In this case, the field geotechnical investigation undertaken for the site FRA should override the proposals of the SUDS feasibility map.

The purpose of the comparison was not to achieve an exact match between the broad scale feasibility maps and more detailed design considerations. Neither was the intention of the feasibility maps to replace the more detailed studies that accompany detailed planning proposal submissions. Rather, they were intended to inform the earlier stage of the outline planning proposals and initial flood risk assessments. These often contain generic statements about SUDS implementation, such as those seen in Halcrow Group Ltd (2008b:8), whereas the feasibility maps would assist earlier consideration of the specific SUDS options available at a development site, supporting the intent of the FWMA that drainage should be considered at the earliest stages of design. The feasibility maps could also inform a strategic drainage plan for wider catchment areas in order to avoid the risk of piecemeal development across individual sites, as envisaged by Surface Water Management Plan guidance (Defra 2010a:39).

6.3.3.2 Coventry University retrofit maps

As with the new development maps, the retrofit guidance maps put forward additional options not originally considered by the pilot study, although, because of the greater restrictions on retrofit, fewer of the options were feasible in practice. The retrofit maps were also useful to assess options near to, but outside of, the study area, and to contribute to more joined-up surface water management. An offsite possibility for storage of runoff was visible, as was an onsite option to treat runoff from a nearby public car park. Further refinement of the retrofit conveyance map may be required to remove small isolated features that may be difficult to join together to create a conveyance system in the current land cover configuration. There is an argument, however, that they could be retained as prompts for possible alternative solutions. Retrofit maps were less likely to be used be development planners, but could be valuable input to reviews of specific retrofit projects.

6.3.4 Scale

If SUDS feasibility assessments are undertaken at varying scales, then different methods and different datasets are currently required at the broader scale, largely due to computing limitations (*cf*. Shoemaker *et al*. 2009; Moore *et al*. 2012:280). At finer levels of detail, data characteristics drive the methods employed, whereas at the broader scale, methods control the data, requiring summary attributes that give a general character to that broader area.

This work has tried to demonstrate that there is a role for map-based SUDS guidance to assist development planners at the local authority strategic working level (Defra 2010b:42). The SUDS maps for new development did not require use of large datasets, and, given agreement on the rules to be applied, the techniques demonstrated here could fairly readily be employed to generate SUDS maps for other local authority areas. The rules and methods in chapter three can be employed as a starting point to implement the guidance given in, for instance, Defra (2010a) and Digman *et al*. (2012).

On the other hand, generation of the retrofit feasibility maps, because of their use of current land cover, required significant amounts of time and computing resource. In the current context where the value of and need for retrofit is not part of the planning system, these maps provide a means of assessing where retrofit might be possible, and would highlight possibilities in locations where SUDS might be beneficial to address existing problems.

6.3.5 Implications of SUDS Feasibility Maps

6.3.5.1 New development maps

New developments are the principal means of SUDS implementation in the current approach to urban stormwater management (Mitchell 2005:1; Stovin *et al*. 2007:1). The planning system in England imposes time limits on reaching formal planning decisions, with a target of eight weeks to determine minor applications, and 13 weeks for major applications. Consequently, rapid assessment tools such as the SUDS feasibility maps can assist discussions during pre-submission enquiries and give high-level guidance about appropriate SUDS options. SAB approval processes will also be subject to defined timescales that must integrate with planning applications, increasing pressure to meet deadlines.

Two of the five SUDS groupings, infiltration and detention devices, offer the capacity for large-scale storage or disposal of runoff. Only 17% of the city's land area was suitable for infiltration (Fig. 5.9). A review of SUDS in Europe (Middlesex University 2003:25) similarly considered infiltration devices the most environmentally sensitive and thus exposed to a greater number of limiting factors. Rock and soil permeability, and groundwater levels, were the principal physical drivers of infiltration feasibility, with slope a small influence in western areas of the city (Fig. 5.1), and these factors generally drive infiltration rates (NERC 1975:303). Many of the suitable sites (48% of the relevant area) coincided with greenspace (Fig. 5.11), which could provide scope for effective infiltration into groundwater reservoirs. However, current development planning designates 40% of the potential area as greenbelt land where development is constrained by both government and local policies (CCC 2012b:17; DCLG 2012:19). Therefore in practical terms the scope for SUDS infiltration solutions in new developments in Coventry was restricted.

The result that 17% of Coventry’s area was suitable for infiltration was at variance with BGS’s national SUDS infiltration map (Dearden *et al*. 2013), which considered 46.8% of Coventry suitable for infiltration, based on geological criteria (13.4% highly compatible, 33.4% probably compatible with infiltration SUDS). Limiting the current study to similar criteria used by BGS (bedrock and superficial geology, depth to groundwater and source protection zones), would result in 42.8% of the LPA area being indicated as suitable for infiltration (-4.0%). The overall difference of 25.8% occurred because although Dearden *et al*. (2013) included a similar number of factors to the current study, and used a more explicit scoring mechanism to grade the characteristics, they focussed only on geological criteria for infiltration (see Table 6.1). The BGS (2013b) product is priced at commercial rates requiring a substantial financial investment by LPAs, while the goal of this study was to base the Coventry SUDS feasibility maps on information that was readily available at zero or low cost. Therefore at the broad scale the SUDS feasibility maps were seen as a reasonable representation of possible sites.

There was greater potential for detention and retention SUDS in Coventry. Soil permeability and water table depth were the main spatial limitations (Figs. 5.13 and 5.15). However, the resulting area suitable for vegetated detention and retention, where above ground SUDS could be implemented with relative ease, covered only 32% of the city (Fig. 5.21). Engineered detention and retention SUDS were possible in a further 67% of the LPA area (Fig. 5.19), although they would necessitate greater attention to design criteria. Engineered detention and retention schemes comprise, for example, underground storage tanks, but could also include above-ground landscape re-profiling to increase water storage volumes. Areas suitable for infiltration overlapped directly with 25% of engineered detention land (Fig. 5.23), so infiltration SUDS would be preferred to engineered detention in these locations.

With the FWMA allocating responsibility for ongoing maintenance of SUDS serving more than one curtilage to local authorities, engineered SUDS present a challenge that will require proactive guidance to be issued by planning departments. Developers may seek to maximise land use and profit by incorporating as many properties as possible in a development, thereby reducing available space for above-ground SUDS (e.g. RPS Planning and Development 2012). Consequently, underground storage may be preferred by developers for flood risk attenuation in new construction sites. In terms of the wider agenda of improved water quality and biodiversity, this may not be an ideal solution. Furthermore, underground storage tanks are more akin to conventional drainage, and may retain some of the existing issues surrounding stormwater management in cities, and therefore risk increasing the effort and expense of ongoing maintenance by the SAB. Above-ground engineered solutions such as landscaping, will be easier to manage and maintain in the longer term, and will have a more positive impact on water quality, measures of biodiversity, and amenity. Therefore, future planning guidance in relation to SUDS would benefit from promoting above-ground, ideally vegetated SUDS, a position confirmed by the consultees of the draft versions of the maps. However, because areas needing engineered detention and retention SUDS will require more investment of time and money, and due to lack of experience in implementing such solutions, increased guidance is likely to be required to encourage take-up of these options by developers.

Source control SUDS are important components of the management train, preventing onward transportation of pollutants, and able to retain the first 5mm of rainfall proposed in the draft SUDS national standards (Defra 2011a:8 point B2). 99% of the city's land area was suitable for source control SUDS (Fig. 5.27), and the feasibility map could be used by planners to encourage wider implementation of source controls in new developments. The FWMA defines local authorities as responsible for maintaining SUDS covering more than one curtilage. SABs could limit the number of SUDS requiring adoption by placing greater emphasis on source control SUDS which, by the nature of their proximity to buildings, will apply to a single curtilage and therefore should be maintained by property owners rather than the SAB. Increased implementation of source control SUDS would also have water quality and amenity benefits, and contribute to the ethos of the SUDS management train. Emphasis on source controls could be achieved by providing local planning guidance, e.g. a SUDS supplementary planning document (SPD), and placing more weight on the number of components in the treatment train. Woods Ballard *et al*. (2007:3.12) suggest a minimum number of train components, but this can be cited in developers' planning applications as the absolute number required. Increasing the required number of train components would reduce the possibilities for reliance on one or two SUDS types, e.g. a few swales and an end of pipe detention basin, and drive more creative solutions involving source controls.

6.3.5.2 SUDS Retrofit maps

Based on the 2012 version of the LDF core strategy (CCC 2012b), just over 8% of the city would be redeveloped in the period 2011-2028 (Appendix D, Table D.20). At this rate of development, it would take over 200 years for the entire city to be redeveloped, and if SUDS implementation is largely driven by new development, may reduce the potential for SUDS to make large scale improvements to water quantity and quality in the short to medium term. The draft strategy has not yet been agreed by the Planning Inspectorate (2013), but even doubling planned development in the city, and assuming SUDS are effectively implemented in all, the horizon for full SUDS implementation exceeds 100 years.

The majority of urban areas comprise existing sites rather than new developments, and two-thirds of the buildings that will be standing in 2050 have already been constructed (BERR 2008:31). Consequently, improvements to increase the sustainability of urban areas may advance more rapidly by retrofitting SUDS into existing locations. Retrofit SUDS designs experience a higher level of practical constraints than new developments (Schueler *et al*. 2007:2), and perhaps for this reason there are relatively few examples of SUDS retrofit in urban areas in the UK (Evans *et al*. 2008:113). Retrofit is considered difficult and expensive (Balmforth *et al*. 2006b:66), particularly in densely developed locations, commonly requiring identification of drivers of change. For instance, the Gloucester SWMP pilot (Dunn 2010:41) dismissed retrofit SUDS as not feasible, although no supporting evidence was provided. Leeds City Council (2009:32-33) costed various options to address existing flooding issues in a regeneration area, concluding that, even though retrofitting SUDS to 30% of the catchment was the second best of 11 options evaluated, the 0.29 ratio of net present value benefits to costs was not economically viable. Nevertheless, studies have demonstrated that it is possible to design retrofit schemes that are technically feasible (Stovin *et al*. 2007:7). Worldwide, cities such as Malmö (Sweden), Portland (Oregon), Seattle (Washington) and Tokyo (Japan) have demonstrated the viability and effectiveness of retrofitting SUDS (DTI 2006; SNIFFER 2006:5-7; Stahre 2008).

Despite limitations, it was still possible to retrofit detention and retention SUDS in 80% of Coventry (Fig. 5.20), with no major location uncovered. Greenspace and gardens were the obvious possible locations for retrofit solutions (Fig. 5.18); paved areas were also included because there was potential for their conversion to vegetation, or for use of permeable paving in conjunction with underground storage. Public ownership of greenspace (27.2%), gardens (10.3%) and paved areas (7.4%) constituted 44.9% of Coventry’s land cover in areas suitable for retrofit detention and retention (section 5.3.5), exhibiting clear potential for Coventry City Council and Whitefriars Housing to implement demonstration projects.

Gardens contributed a significant proportion of the suitable area for retrofit detention and retention (Fig. 5.17, Table 5.3), 23% of the city's land area. Of about 108,000 gardens, 74% were in private ownership, posing a significant challenge to convince individual owners of the value of using their property in assisting surface water management. Comparison could be made with the role played by urban gardens in biodiversity conservation (e.g. Gaston *et al.* 2005), and this may provide a model for a similar study of the possible contribution of smaller scale garden-based SUDS to urban stormwater management.

Gardens, buildings and road carriageways were all unsuited to retrofit conveyance SUDS (Fig. 5.36), so only 45% of Coventry was available (Fig. 5.39). Although roads are sometimes treated as valid installations for conveyance of runoff (Kellagher 2004b:29), this approach was not taken for two reasons:

- concerns relating to water quality
- issues of floodwater being pushed into properties alongside flooded roads when cars

drive along them, which has caused problems in some parts of Coventry (pers.comm. CCC).

Non-road paved areas might seem possible locations for conveyance, but in Coventry these sites were largely pedestrian pavements or parking areas, so were not suitable. The prevailing opinion of consulted stakeholders (Appendix G) was that issues such as land ownership excluded private gardens as potential locations for retrofit conveyance SUDS. As a result, there was limited space in central and inner areas for these devices (Fig. 5.38), and this may limit the extent to which joined-up management trains can be retrofitted. Retrofit SUDS are more likely to be individual, even piecemeal, installations in more densely urbanised areas.

Source Control was the second most available option for retrofit, covering 68% of the city area (Fig. 5.40). Many of the restricted locations were greenspace, where no development currently exists to warrant retrofit (Fig. 5.26). Buildings can be retrofitted with green roofs, and non-road paving can be replaced with PPS. Comparison of feasible locations for retrofitting source controls (Fig. 5.28) versus detention devices (Fig. 5.20) indicated that source controls were feasible in the more problematic, more densely developed areas where even engineered detention was not possible. The absence of space to convey stormwater above ground may focus attention on retrofitting source controls to manage it at source. Alternatively, the lack of scope for retrofitting conveyance SUDS may result in conventional piped conveyance being retained to a greater degree. Even if greater emphasis were to be placed on retrofit, it is likely that a mixture of conventional and SUDS solutions would be necessary in more densely urbanised locations.

In terms of retrofit, buildings were the principal additional factor limiting filtration SUDS (Fig. 5.31), and as a result retrofit was less feasible in more built-up locations such as the city centre (Fig. 5.33), leaving 64% of Coventry available (Fig. 5.34). These infeasible areas are more likely to require filtration SUDS to assist in pollution reduction, so the lack of filtration capacity in the required locations may pose a problem. Permeable paving might be considered suitable for replacing existing paved areas due to its role in hydrocarbon degradation (e.g. Newman *et al*. 2004). In built-up areas source control SUDS may offer alternative pollution remediation possibilities. The lack of filtration options immediately adjacent to watercourses may support the need for alternative solutions to address diffuse pollution.

Overall it is not clear what level of SUDS implementation is sufficient to significantly reduce flood risk and improve water quality in Coventry, and this topic requires further research. Therefore, if water quality and quantity are to be improved in the short to medium term, more attention must be paid to SUDS retrofit solutions, and the SUDS retrofit maps were developed to inform this agenda. However, the value of SUDS retrofit at the broader scale, for other than defined problem sites, has yet to be proven. The technical restrictions on SUDS retrofit may limit whether sufficient suitable land is available, and this is considered in more detail in section 6.4.2.

6.3.5.3 Policy recommendations

6.3.5.3.1 New developments

A hierarchy of recommended SUDS approaches for new developments in Coventry is shown in Fig. 6.3. These recommendations aim to minimise the number of SUDS for which the SAB will have continuing maintenance responsibilities by placing initial emphasis on source controls, which are located within one curtilage, and so do not fall into the SAB's remit under the FWMA. Placing source controls as the initial stage of SUDS also accords with SUDS management train principles that rain should be dealt with as close as possible to the point where it falls. Source controls can be designed to handle runoff from the first 15 mm of rainfall, and will principally address water quality issues, and are feasible in over 99% of Coventry. However, source controls will not manage the large volumes of runoff that increase flood risk, for which one of the remaining approaches in the hierarchy should be selected, and a spatial representation of these is depicted in Fig. 6.4. After implementation of the FWMA, the majority of these SUDS are likely to be the responsibility of the SAB.

Infiltration SUDS, which reduce both the rate and volume of runoff, should be implemented as the second priority, in those locations where potential land contamination is not a risk (14.5% of Coventry). Infiltration effectively removes runoff from a drainage system, rather than retaining it within the system (Swan 2002:165). Where infiltration is feasible, but land contamination is a concern, field investigations should be performed to ascertain suitability before proceeding (2.5% of Coventry). In areas where infiltration is not feasible, above ground vegetated detention and retention SUDS should be prioritised (32% of Coventry). As well as providing options for multi-functional space usage, above ground SUDS will enable easier long-term maintenance than underground storage. Maintenance of SUDS features is perceived as vital for public acceptance, with poorly maintained features generating negative attitudes (Apostolaki & Jefferies 2005:37; Bastien *et al*. 2012:25; Quek *et al*. 2011:14; SNIFFER 2004:19). More SUDS are perceived at this stage as greater workload for parks and facilities maintenance departments. The reduced maintenance costs evidenced at, for instance, Hopwood motorway service area, where savings of 30-50% have been identified (Ciria

2002:4; Heal *et al*. 2009:2493), have yet to be taken on board. In the remaining areas (50% of Coventry), engineered detention and retention SUDS will be needed. Here also, above ground SUDS should be prioritised, although these will require greater design, and possibly construction, effort than in other sites.

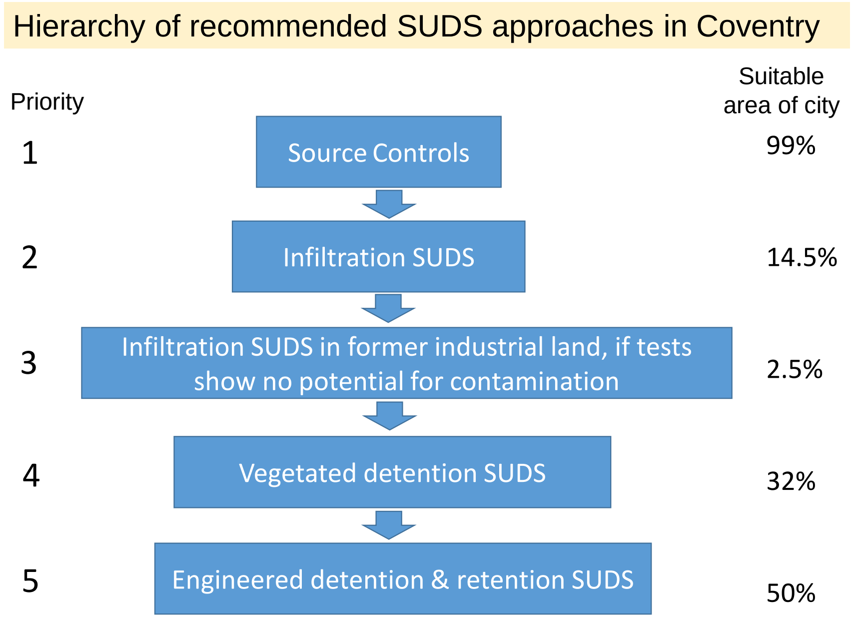


Fig. 6.3 Hierarchy of recommended SUDS approaches for new developments in Coventry

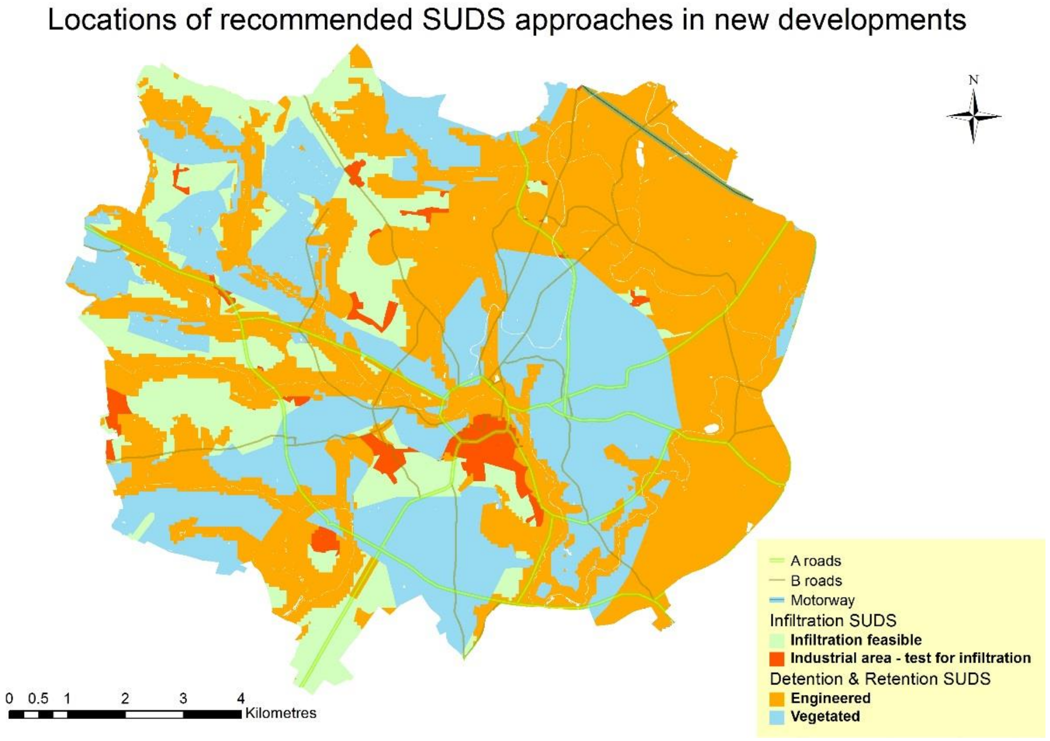


Fig. 6.4 Locations of recommended SUDS approaches for new developments in Coventry. Roads shown for orientation

The different performance characteristics of individual SUDS techniques must be taken into account when considering their suitability for addressing particular requirements at the detailed design stage. It is important to note that Fig. 6.3 offers outline policy guidelines, whereas evidence-based investigations at each site, undertaken for detailed planning and SAB applications, may generate alternative SUDS solutions which should take precedence over these recommendations.

6.3.5.3.2 Retrofit

Retrofit, in the sense used in this thesis, is not the primary concern of development planners. These maps are likely to be of more use to those involved in regeneration projects, for use in specific project discussions. At Coventry City Council this role falls under the remit of the Sustainability and Climate Change team. The FWMA implies that even small land use changes will require SAB approval (schedule 3 paragraph 7.5 refers explicitly to installation of patios), and enforcement of this detailed level may require the involvement of Building Control Officers. LLFAs are tasked with creating surface water management plans (Defra 2010a) to assess strategies for dealing with drainage and flooding at the strategic scale. The WMP guidance envisages an increased role for SUDS, and the retrofit feasibility maps could provide supporting information when reviewing alternative surface water management options.

6.3.6 Applicability to other LPAs

Coventry's land cover was not atypical when compared to other towns and cities. Overall impermeability of Coventry was 32.7% based on OSMM classification. Applying the revised land cover classification derived from analysis of gardens increased impermeable land cover to 39.9%. The limited information found on impermeability levels in other UK LPAs was comparable:

- 21-34% for three UK cities covering smaller areas than Coventry of 13.8-39.3 km^2 (Evans *et al*. 2004:135)
- 37% impermeable area in urbanised Greater Manchester (79 3km^2) (Gill *et al*. 2008:218).

Only factors and attributes applicable to the study area have been considered, and while Table 6.1 shows that this research has evaluated a wide range of factors compared to other studies, some have not been covered. Even if individual factors might vary, the principles and techniques applied in this research are applicable to other strategic planning bodies aiming to undertake an assessment of SUDS feasibility for the full planning area. This study was conducted in a reasonably densely urbanised environment, and additional research could evaluate the extent to which details of the approach vary for a more rural LPA. Identification of suitable proxy datasets that could substitute for missing information, and recommendations for their use, might help to accelerate map production.

If SUDS are to be more widely implemented and become business as usual, there may need to be a shift in attitude away from their being treated as special projects, each requiring detailed discussions between stakeholders, for which multi-criteria decision approaches are suitable. Instead, a greater commoditisation would be appropriate for the larger number of implementations, possibly using an array of standard techniques as is current for conventional drainage implementations.

6.4 OBJECTIVE 2C. POTENTIAL APPLICATIONS OF THE SUDS FEASIBILITY MAPS

This section considers firstly some implications of the potential locations for SUDS implementation in Coventry (6.4.1), and then addresses questions surrounding identification of where SUDS may be of benefit (6.4.2). In addition to the examples presented here, Warwick & Charlesworth (2013) have utilised the maps to estimate the contribution of SUDS to carbon mitigation for a local planning authority.

6.4.1 Locations where SUDS may be implemented

Land cover has a significant influence on urban hydrology, and the level of impermeability is a parameter in equations assessing urban runoff. Consequently, the type and density of development at a site will influence SUDS implementation, yet few published UK studies have differentiated land cover in urban areas (Table 6.4). Of those, gardens have been the main area of interest (e.g. Gaston *et al*. 2005; Loram *et al*. 2007; Smith *et al.* 2005). A greater number of studies have assessed land use rather than land cover (e.g. Gill *et al*. 2007), categorising areas as residential and industrial for example, without identifying the land cover make-up within each category. These assessments of land use were not readily comparable to the current work.

Table 6.4 Comparison of land cover in broad scale UK studies. Impermeable areas of Coventry's gardens have been reallocated to the appropriate alternative land cover

	Coventry	**Merseyside**	**Greater Manchester**	**Urbanised Greater Manchester**	**Greater London**	**Edinburgh**	**Belfast**	**Leicester**	**Oxford**	**Cardiff**	**Urbanised Sheffield**
Area (km^2)	98.65	2.75	1298.5	792.7	1579.2	263.3	114.9	72.6	46.1	141.3	143
Reference	this study	Pauleit *et al*. 2005	Gill (2006:376) [2]	Gill (2006:376)	Smith *et al*. (2011)	-------------- Loram *et al*. (2007) [2] --------------					Gaston *et al*. (2005)
Buildings	13.6%	31.8%	10.0%	15.0%							
Road&Rail	25.3%	28.4%	14.0%	21.0%							
Gardens	15.5%	26.2%	75.0% [1]	62.0% [1]	13.7% [3]	11.3%	15.7%	24.9%	19.6%	16.2%	21-23%
Greenspace	44.0%	12.6%									
Water	0.6%	0.0%	1.0%	2.0%							
Unclassified	1.0%	0.9%									

Notes

[1] Aerial images were employed for land cover classification, so greenspace not differentiated from gardens

[2] Figures represent administrative boundary for comparison with the approach used in this study

[3] OSMM land cover (24%) x 57% covered by vegetation

6.4.1.1 Greenspace

Vegetated SUDS installations are relatively easier to implement where large areas of greenspace are present, although arguably there may be less need for SUDS in such locations. Since the majority of Coventry's greenspace lies in upstream zones of rivers, it may be able to provide increased floodplain storage, following river restoration models used elsewhere, e.g. Bourne Stream Partnership in Hampshire (Shutes 2008:51), R. Skerne in Tyne & Wear (River Restoration Centre 2002), and R. Quaggy in Lewisham (DCLG 2009:31). River restoration and deculverting techniques are also candidates for addressing fluvial issues, but were not considered in detail in this thesis.

6.4.1.2 Gardens

The shortage of greenspace in urbanised areas of Coventry highlighted the importance of gardens as vegetated surfaces (Figs. 5.17 & 5.18). Gardens formed a significant component of house plots in Coventry (Appendix D, Fig. D.23), so one option for SUDS implementation in the city is increased emphasis on gardens. Comparison of the current research with other UK cities determined that garden sizes for different house types, and impermeability rates of gardens, were not substantially different (Appendix H).

Buildings (mean area 54.6 m^2) and gardens (mean area 113.7 m^2) together represented 87% of the polygons in Coventry, and this large quantity of relatively small land cover features suggests that SUDS implementation may ultimately need to focus on a strategy of many small-scale installations rather than a few large-scale schemes in order to alter Coventry's urban hydrology, an approach also identified in the USA (Schueler *et al*. 2007:13). Pahl-Wostl (2005) argued that, to achieve this, there must be a shift from an acceptance of the *status quo* of technological solutions managed by a few large organisations towards a greater participation by local people in the decision processes of urban water management. Individual responsibility for and interest in such issues is more likely to be achieved by placing greater weight on source controls within single curtilages, although this approach will necessitate the involvement of a large number of small private landowners, who will need to be persuaded of their benefits. SUDS for individual domestic properties in Coventry will need to consist largely of source controls given the high proportion of terraced housing in the city and the small garden area associated with each. However, attenuation based on domestic water storage using techniques such as water butts alone may be problematic. In an urban catchment suitable for infiltration, Swan (2002:185-187) considered water butts to be the only usable source control on cost grounds, but calculated that they would not provide sufficient capacity to handle a 10-year storm, even if it were assured that all were empty at the start of the storm to ensure maximum available capacity (SNIFFER 2006:11).

6.4.1.3 Large roofs

The Swan/Stovin hierarchical framework (Stovin *et al*. 2007:19; Swan 2002:89) suggested that large roofs were preferred candidates for disconnection and for installation of green roofs. They were more likely to be under public, commercial or industrial ownership; would be larger compared to roofs on domestic dwellings; and large-scale schemes would be easier to manage and monitor logistically than a greater number of smaller schemes (Swan 2002:163). Consequently, disconnection of larger institutional rather than residential properties would be easier and cheaper to achieve because of the involvement of fewer third parties, although Schueler *et al*. (2007:129) considered that there were easier retrofit options in dense urban areas. On a practical level, large roofs would be more likely to be closer to available land suitable for disposal of water (SNIFFER 2006:30).

There was sufficient greenspace or paved area near 92% of the 3,863 large roofs in Coventry to attenuate runoff from a 100-year storm. Even for the 100-year storm, greenspace could attenuate runoff from 59% of large roofs. A storage depth of 0.5 m was assumed for the results shown in Figs. 5.66 and 5.67. A greater storage depth would be likely to increase the attenuation capability of greenspace, but this was not tested. The addition of green roofs to large buildings would reduce the storage requirement, and was an option suggested by Moore *et al*. (2012:280) after advising roof disconnection to adjacent land as first choice. However, installation of green roofs could be considered more expensive and technically challenging than straightforward disconnection.

The reasons for the pattern of intermediate sized roofs having more available greenspace nearby (Fig. 5.67) were not clearly understood and require further investigation. There was no obvious spatial distribution, although roofs > 10,000 m^2 were more prevalent outside the city centre. The area required to store runoff was calculated as a percentage of the impermeable area, and was heavily influenced by storage depth. Estimates from the simulation ranged from 10% additional land for a 30-year 6-hour storm up to 36% for a 100-year 24-hour storm with a shallow basin. These values were greater than the 5-7% of contributing area suggested by SEPA (2005:2). The basis for SEPA's guidance was unclear, although they may have expected larger retrofits than a single building. Additional research into actual land-take by SUDS would be informative, although would need to identify how to classify multi-functional use of space.

6.4.1.4 Paved areas

Paved areas occupied 25% of Coventry's land cover (section 5.13). The small number of existing SUDS installations in Coventry implied that the majority of road runoff would be disposed of in highway drains, sewers or watercourses. Runoff from paved urban surfaces is linked to poor water quality due to diffuse pollution, but the precise relationship remains unclear (NAO 2010:5).

The substantial paved area of Coventry posed the single largest individual source of risk for runoff generation and delivery of contaminants to watercourses. The contribution of front gardens to increased sewer load has been recognised by a change to Permitted Development Orders which came into force in England on October 2008 (DCLG 2008a), since when, paving of front garden areas over 5 m^2 using impermeable materials requires planning permission. However, over half the city's front garden space (57%) is already paved or covered by additional building. Assuming that half the remainder will ultimately be retained as vegetated space, then 1.68 km^2 (1.7% of the total land area) might be influenced by this revised policy based on the assessment performed for this study.

Non-garden paved areas covered 19.27 km^2 (19.5%) of the city. To reduce runoff and improve water quality, more attention must be paid to these areas, and a range of SUDS devices can assist in addressing these issues. The Highways Agency (2006:11.49) has identified swales, ponds, wetlands, ditches, basins, silt traps, filter drains and soakaways as suitable for managing road runoff. In addition, permeable paving and porous tarmac have been used in some locations instead of conventional paved surfaces. A few SUDS demonstration projects, such as the Dings homezone in Bristol (Digman *et al.* 2012:6) have used PPS on individual roads in housing estates, and 1.1 km^2 of Coventry was occupied by these minor road carriageways (section 6.15). However, paved roadsides covered over three times, and paving not associated with roads seven times, this area, and might result in easier solutions to implement.

Permeable paving and porous tarmac may be suitable for estate roads with low traffic volumes, but their performance on major roads is still to be proven. Where permeable paving has been installed in car parks, it is typically used in parking bays, with the main running course laid using conventional tarmac, *e.g.* Wheatley motorway service area on the M40. Questions remain about the suitability of permeable paving in areas of poor infiltration, such as some parts of Coventry. However, experience at Oxford County Council is that permeable pavement still functions effectively in these circumstances (Hunt & West 2007:8). In cases where permeable paving might not perform adequately, alternative options include provision of separate storage areas, although these will require additional land or underground storage.

Minor road carriageways and non-road paving might offer suitable sites for retrofitting permeable paving in order to manage surface runoff. Existing paving in less trafficked areas could be converted to vegetation or vegetated porous paving. Moore *et al*. (2012, Ttable 2) included road carriageways on minor roads as potential locations for retrofit source controls in London suburbs, but had similar issues identifying such roads, and used manual judgement to do so. The larger extent of the current study did not make consideration of individual roads practical. Moore *et al*. (2012) did not quantify the possible area of minor road carriageways in London. The area of minor road carriageways with the potential for PPS installation in Coventry was 1.1 km^2 (1.1% of the city, Fig. 5.69).

Determination of minor roads as suitable locations for retrofit permeable paving achieved reasonable results (Fig. 3.34). However, some significant thoroughfares were retained, and the algorithm would benefit from additional refinement, and automation of the currently required manual intervention. Similarly, Moore *et al*. (2012:277) included some roads in their methodology for retrofit SUDS based on land cover characteristics, but were reliant on local knowledge and manual selection of data.

6.4.1.5 Land ownership

Land owned by Coventry City Council and Whitefriars Housing Association covered 30.5% of Coventry, and thus offered significant potential for implementation of SUDS in the city. In addition to the specific ownership dataset obtained, the differentiation between greenspace and gardens used in the OSMM land cover analysis may also allow differentiation of private and public land ownership. Moore *et al*. (2012:277) suggested using Ordnance Survey Address data to differentiate private and public ownership of buildings. The dataset is available at additional cost, and does not consider ownership of greenspace, where SUDS are equally likely to be implemented.

6.4.1.6 Development zones

Development zones indicate locations where land use and land cover changes are prioritised. Such locations will provide early opportunities for improving the sustainability of drainage in the city. Development is generally acknowledged to proceed at a rate of 1-2% of a planning authority’s area per year (Dixon 2009:S52; EA 2009a; Gordon-Walker *et al*. 2007:2), and although this assumption seems plausible, no data to support this assertion were found. This rate is higher than that implicit in the latest draft of the LDF core strategy (CCC 2012b) – see section 6.3.5.2. The feasibility of SUDS implementation with relative ease in over 50% of the city (Fig. 5.61), using all but infiltration devices (Fig. 5.62) suggests that SUDS implementation in new developments should be able to utilise SUDS drainage techniques. However, the increased complexities of retrofit were reflected by higher probability areas for all SUDS types (Fig. 5.64) covering a smaller area when compared to new development (Fig. 5.62). A more detailed consideration of the individual SUDS groups highlighted particular issues with retrofitting source controls, with 22.9% of the city having a higher probability of implementation (Fig. 5.64), and fewer sites for source control, in comparison to the feasibility maps, in locations that were more likely to be developed in the short to medium term (Fig. 5.65). However, it would be useful to explore alternative methods for validating the utility of techniques for predicting the likelihood of SUDS implementation over broad scales.

6.4.2 Locations that may benefit from SUDS

Retrofit SUDS are most likely to be employed in current scenarios when existing issues require a solution for which conventional drainage is unsuited or problematic, and successful retrofits have often been driven by a single organisation with the authority to implement solutions (Stovin *et al.* 2007:26). Three drivers are discussed in more detail below: water quality improvements, flood risk alleviation and sewer capacity issues.

6.4.2.1 Historical flood events

Historical flood events in Coventry in the period 1980-2009 saw a reduction in flood events close to watercourses (16%) and an increase in events due to surface water flooding (39%) compared to the previous 70 years, when fluvial flooding was more prevalent (Appendix E). This result corroborated the greater emphasis needed on surface water flooding identified by Pitt (2008). There is clear potential for SUDS to play a role in flood risk reduction in urban environments. Six locations were more frequently affected by flooding over the past 30 years (Fig. 5.72), and these warrant further investigation of SUDS options. Over 25,000 m^2 of potentially useable greenspace and paved attenuation sites were situated within 30 m of the worst affected site (Figs. 5.75 and 5.76), although land ownership might be a significant implementation issue, as these sites were not publicly owned. The feasibility maps were intended to highlight options for SUDS, rather than a detailed examination of precise solutions. For a detailed site-specific evaluation of attenuation potential, the Sudsloc tool (Viavattene 2009) would be more appropriate.

Across the city as a whole, Fig. 5.77 indicated that a mean buffer distance of 10-25 m, equivalent to an area of 315-1965 m^2, would be needed to find enough suitable land to install detention or source control measures to address a 100 m^2 flood site in Coventry. Where flood locations are near to each other, as in Fig. 5.75, then additional storage volume would be necessary.

6.4.2.2 Surface Water Sewers

Current sewer capacity is a further driver of potential SUDS retrofit. Singh *et al.* (2005) suggested that areas where separate sewers drain to combined sewers are important retrofit sites as they indicate where end of pipe solutions may be beneficial. The 66 surface sewers in Coventry that join to combined sewers are all within 100 m of greenspace (Fig. 5.79). Implementation of the FWMA may lead to greater consideration of SUDS to alleviate these issues although, because any installation is likely to cover more than one curtilage, it would need in theory to be adopted by the SAB unless the water company decided to retain responsibility. If adopted by the SAB, the precise interface point would need definition, as would the interaction between the two organisations. Issues such as this have still to be worked through.

6.4.2.3 Water quality assessments

Improvement was required to Coventry's monitored rivers to meet Water Framework Directive (EU 2000) standards, with all but one forecast as failing to meet the initial 2015 target to achieve 'good' water quality. EA (2010b) projects that the further target date of 2027, by which time all rivers must achieve good status to avoid possible financial penalties levied by the EU, will be achieved, although the basis for the forecast, and the programme of measures to achieve it, are still unclear. The timescale requires an improvement of one or two classes over the next 15 years from the current assessment of moderate or poor (Fig. 5.71). Although ordinary watercourses are not monitored, it is reasonable to assume that they would be subject to the same pressures as monitored rivers, and are likely to have the same water quality status. Diffuse pollution is considered one of the main issues influencing poor water quality (D’Arcy & Frost 2001:359-360; Defra 2005b:29-93; Ellis & Mitchell 2006). There is however limited understanding of the precise causes of current failure (NAO 2010:5), and there has been limited progress in recent years, perhaps because EA attention has been focused on flood management driven by the FWMA and the Floods Directive.

The ubiquitous extent of diffuse pollution suggests a need for many relatively small installations to prevent contaminated first flush reaching water courses. Given the complexities of understanding of pollutant pathways in the urban environment (Charlesworth *et al.* 2010:120), these installations may need, at least initially, to be situated close to water bodies and or at the entry points to, or within, storm sewer networks. Insufficient information was available to identify individual locations for potential SUDS that might improve river quality in Coventry, due to the lack of information on sewers that dispose of runoff to watercourses. Therefore all areas were regarded as potential contributors to water pollution in Coventry, and all areas adjacent to water bodies as valuable sites for SUDS.

Assuming the need for a 10 m^2 area adjacent to a main river in order to install treatment devices, Fig. 5.81 suggests that this is possible for retrofit detention SUDS, but that a 25 m distance would be required for source control SUDS, while for retrofit infiltration, an impractical distance of 300 m is necessary. These are rudimentary calculations, as more work is needed to quantify the target parameters, let alone how to utilise SUDS to deal with them.

SUDS close to water bodies would require re-routing of existing storm sewer pipes, and construction of remediation SUDS near to the watercourse. Proximity of pollutants stored close to water raises issues of ongoing management, and of action at times of higher flood risk if the SUDS facility is situated within a flood zone. If improperly designed, flooding may release the stored pollutants from devices in a flood zone into the watercourse. Although flood water volumes will dilute the effect of pollutants, the purpose of the feature, to prevent pollution of the watercourse, needs to be borne in mind.

Given the issues associated with the proximity of pollutant remediation SUDS to watercourses, SUDS at the entry points to, or within, the storm sewer network may present a practical alternative. Such devices have been developed and installed in Berlin, Hannover and Hamburg with greater retention of suspended solids than conventional gulley pots (Sommer *et al*. 2008), although more frequent cleaning may be needed as a result. Initial cost, installation experience and ongoing maintenance are key issues to be addressed, and this approach would require buy-in from water companies, who have in the past not needed to be proactive in addressing water quality concerns. The preferred solution would be to prevent pollution in the first place, but this in itself would require substantial investment in new technology. It is not clear which route would be cheaper, faster, or more effective, and a combination of SUDS and new pollution prevention technology is likely to be required.

Some SUDS techniques are considered more effective at managing pollution. Research in Sydney, Australia (Davis & Birch 2009) determined that runoff from residential properties and roads accounted for 77-80% of the contaminant load of Cu, Pb and Zn in a catchment. Of the SUDS devices reviewed, infiltration techniques, e.g. pervious surfacing materials and infiltration ponds, were the most efficient in terms of pollutant removal performance compared to land-take. On the same basis, wetlands were considered to be one-third as effective as infiltration solutions. The authors discounted source controls as being unsuitable for application with residential property and roads, and only applicable at industrial and commercial sites, although no objective justification for their conclusion was provided. Therefore, despite the effectiveness of source controls, they were judged to make a limited contribution to pollutant management. Gross pollutant traps were considered the least effective of the techniques under investigation, as the coarse screens failed to capture heavy metals that were commonly associated with the smallest sediment particle sizes (<63 μm).

A UK assessment (Revitt *et al.* 2008) evaluated a wider range of heavy metals than in Sydney, plus PAHs and herbicides, concluding that infiltration basins, together with sub-surface flow constructed wetlands, had the highest potential for pollutant removal. Surface flow constructed wetlands and porous paving were the next most effective techniques. Extended detention basins, swales, infiltration trenches and soakaways were less effective. Porous asphalt and sedimentation tanks exhibited the least potential for pollutant removal. Napier *et al.* (2009), as a result of investigating pollutants associated with road runoff, stressed the need to retain sediments locally to reduce downstream contamination. They determined that soil-based SUDS, such as swales and detention basins, were more effective at retaining pollutants, particularly organic matter, than ponds and wetlands. With the limited scope for infiltration devices on a large scale in Coventry due to poor infiltration characteristics, and the limited spatial area for constructed wetlands in urbanised areas, then smaller scale, locally situated, techniques may prove valuable in addressing pollution issues.

6.5 RECOMMENDATIONS FOR FUTURE RESEARCH

Several topics have emerged from this research as requiring further study.

6.5.1 Objective 2a

Improved methods of assessing and depicting uncertainty in output maps resulting from uncertainty in the input data need to be developed. Mechanisms to automate production of the SUDS feasibility maps would enable the maps to use the latest information, and could increase flexibility in how they are generated.

6.5.2 Objective 2b

Applicability of the techniques presented in this research to other, particularly more rural, local authority areas, would serve to validate the suitability of the approach in greater depth.

6.5.3 Objective 2c

It is problematic at present to identify the extent to which SUDS could contribute to improving flood risk and water quality, and to determine the quantity of SUDS installations required to positively impact affected areas, at the strategic scale.

In terms of water quantity, studies such as Gill *et al*. (2007), Diaz-Nieto *et al*. (2008), and Perry & Nawaz (2008), have assessed hydrology at the broader scale using water budget mechanisms. Perry & Nawaz (2008), for instance, determined mean annual runoff for a 1.16 km^2 area using the long-term hydrologic impact assessment (L-THIA) model (Purdue Research Foundation 2004), which simulates variations in hydrology due to land-use / land cover change from input of land surface, rainfall, and soil type. Moore *et al*. (2012) took a different approach by defining generic SUDS as inputs to an InfoWorks model of a catchment. If the potential number and location of different SUDS devices could be estimated, then possible solutions could be evaluated against runoff reduction percentages proposed by Hirschman *et al*. (2008:17). The appropriate method for a strategic scale hydrological impact assessment needs further investigation.

In terms of water quality, better understanding is needed of the extent of disconnection from sewers required to improve river water quality by, for instance, one WFD ecological grade, e.g. from the current 'poor' ecology grade of most stretches of Coventry's main rivers, to 'moderate'.

The lack of formal measures to assess amenity is an obvious gap. Fowler *et al*. (2012) have described an approach for more formal evaluation of amenity as part of ongoing research.

Although increasing emphasis is placed on retrofit SUDS, and individual projects have been successful, the potential for retrofit to contribute to sustainability goals at the broader spatial scale has not been adequately assessed.

7 CONCLUSION

This chapter summarises the main research findings and reviews how the aims and objectives defined in chapter 1 were met (section 7.1). It reviews uncertainty and sources of error in the method employed in section 7.2. Finally, the research's contribution to knowledge is assessed in section 7.3.

7.1 MAIN FINDINGS AND REVIEW OF OBJECTIVES

Aim 1, and its associated objectives, determined an understanding and structure that led on to aim 2. For reference, Table 7.1 matches the aims and objectives defined in chapter 1 to the sections in which the results of the investigation were addressed and discussed.

Table 7.1 Sections where the aims and objectives defined in chapter 1 were met

Aim 1. Investigate the use of GIS to evaluate the feasibility of implementing and retrofitting sustainable drainage systems in an urban local authority area

Objective	**Results section**	**Discussion section**
1a. Identify suitable evaluation techniques to determine SUDS feasibility in an urban environment in order to inform the choice of methods at the local authority strategic scale	4.2-4.3	4.2-4.3
1b. Construct a framework in order to evaluate suitable SUDS devices at the local authority strategic scale	4.4	6.1
1c. Determine suitable SUDS devices for an urban local authority area	4.5	4.5

Aim 2. Evaluate the creation and suitability of map-based recommendations of suitable SUDS devices for an urban local authority area

Objective	**Results section**	**Discussion section**
2a. Develop and apply rules to generate maps showing feasible locations for suitable SUDS devices based on characteristics of the local authority area	5.2-5.7	6.2
2b. Evaluate the suitability of the SUDS feasibility maps and the applicability of the approach	5.8-5.10	6.3
2c. Assess potential additional applications of the SUDS feasibility maps	5.11-5.14	6.4

7.1.1 Objectives for aim 1

For objective 1a, SUDS feasibility techniques were reviewed. Retrofit of SUDS on Coventry University inner-city campus was shown to be technically feasible, and could contribute to reduced flood risk on and off campus, and improve local river water quality. However, no clear message emerged across the range of techniques evaluated as to the appropriate SUDS devices to use in the densely developed setting of the pilot site. None of the evaluation techniques to determine feasible SUDS assessed for the smaller scale of the pilot study were directly useful at the larger strategic scale. The use of GIS to collate, analyse and visualise information was the principal technique taken forward to the strategic scale study.

The constructed theoretical framework (objective 1b) had value as a means of structuring information and considering which factors were important for development planning. Using development type and size, categorising SUDS devices into functional groupings, and identifying the temporal variability of the data items provided a useful structure in which to conceptualise the work. However, the distinction made between physical and anthropogenic factors, although valid, added no real value to the analysis or communication of the results. The mechanism for translating the theoretical framework into a set of GIS maps was effective, allowing a concise but transparent set of data.

Development of the framework proceeded in parallel with identification of SUDS devices for an urban local authority area (objective 1c), with each informing the other. Determination of suitable SUDS devices, and their allocation to types and sizes of development, was built on existing knowledge, and so the identification and classification of SUDS at the generic level was straightforward, although fundamental to the research. The original intent of the objective was to evaluate whether particular SUDS devices were more appropriate in an urban local authority area than others. In practice, device suitability was driven by a range of environmental and institutional factors, each of which had to be evaluated. Issues of scale were addressed by, for example, using functional groupings of SUDS devices.

7.1.2 Objectives for aim 2

Objective 2a was achieved by creating a set of fundamental rules to identify the factors influencing sustainable drainage feasibility at the local authority scale, and demonstrating how they could be applied to generate maps showing the distribution of feasible SUDS devices in an example LPA area, both for new developments, and when including the additional limitations imposed by attempting SUDS retrofit. Maps were created for all five groupings of SUDS devices. The feasibility maps employed information that is consulted by planners when considering planning applications, and the majority of the information used to generate the maps was readily available to local authorities at little or no additional cost.

The suitability of the maps and approach (objective 2b) was addressed by consulting stakeholders, and by comparison with more detailed studies undertaken of particular sites. The new development maps were suitable for use at the outline planning and enquiry stage, where they could prompt an earlier review of possible SUDS solutions than is generally undertaken at present, and the proposals supporting the maps might be used to enhance the range of SUDS options considered by developers. Planners need to take account of national planning policy, including protection of the natural environment and reducing pollution (DCLG 2012:6). The NPPF (DCLG 2012:22) states that LPAs should take proactive steps to address climate change, in particular with respect to water management, using green infrastructure as an adaptation technique. Planners need to consider evidence-based guidance when planning for development and determining planning applications. The SUDS feasibility maps provide summaries of environmental and institutional data in a spatial form. The rule definitions identify the factors that planners need to consider in their decision making, and the feasibility maps summarise this information and can contribute to the formulation of strategic policy in support of national and local plans.

The SUDS location feasibility maps were not suitable to replace the more specific assessment and modelling that should accompany a detailed planning application. Although the recommendations from the feasibility maps did not fully overlap those of the more detailed studies, the feasibility maps were able to highlight additional potential SUDS solutions that might have been considered. The retrofit feasibility maps were more suited to informing consideration of particular problems at defined sites. The greater complexity of SUDS retrofit was mirrored by the greater complexity of generating retrofit feasibility maps. The static nature of the maps leaves them subject to becoming outdated. The factors evaluated for the new development maps were less likely to change over medium term timescales, but the retrofit maps, by inclusion of current land cover, are liable to become out of date more rapidly.

The additional applications (objective 2c) were able to demonstrate how problem sites could be identified, and how the feasibility maps could inform discussions. At the larger scale, the scope for SUDS retrofit in paved areas and around large roofs was highlighted. Paved roadsides and paving not associated with roads offered significantly larger areas, and are likely to offer easier implementations, than estate and minor road carriageways. There was sufficient greenspace or paved area near 3,550 large roofs over 200 m^2 in Coventry to attenuate runoff from a 100-year storm, and a focus on implementing measures at these sites could noticeably reduce total runoff from the city. Land in public ownership covered 30% of

Coventry, and so offered significant potential for SUDS implementation. The limited extent of greenspace in densely urbanised areas highlighted the potential role of existing gardens in attenuation and treatment of runoff, although the large number of individual property owners presents a communication challenge. The difficulties of retrofit were highlighted, and the extent to which a high level of retrofit would be achievable requires further investigation. The new development and retrofit feasibility maps could be used to inform the preparation of local authority surface water management plans which address drainage issues at the strategic scale.

Recommendations for future research based on the above findings were given in section 6.5. Overall, both aims of this work:

1. Investigate the use of GIS to evaluate the feasibility of implementing and retrofitting sustainable drainage systems in an urban local authority area
2. Evaluate the creation and suitability of map-based recommendations of suitable SUDS devices for an urban local authority area

were achieved.

7.2 UNCERTAINTY AND SOURCES OF ERROR

7.2.1 Data

The research was largely desk-based, and the broad spatial scale under investigation rendered detailed field validation of the results difficult to achieve. Although the majority of the data was obtained from well-regarded datasets such as Ordnance Survey Master Map and Environment Agency maps of watercourses, there were limitations and uncertainties with the data contents, examined in more detail in section 6.2. The majority of datasets used were the most recently available, and were employed and accepted as valid by planning departments in England. Maps of environmental data are inevitably simplifications of natural phenomena, and due to the strategic scale of the research the source datasets may have contained undocumented generalisations. The comparison of land cover from a field survey with the characteristics defined by Master Map (kappa index accuracy value 58.5%) was undertaken using one central area, and the review of land cover in gardens used a limited number of sites (relative error of the sample was 23% excluding one outlier), and more work is needed to characterise the level of error in these datasets. In some cases information was unavailable, such as flood zone definitions for ordinary watercourses, and assumptions were needed about their location and attributes.

The feasibility maps did not indicate wide coverage for infiltration SUDS in Coventry. Depth to water table was an important driver of the feasible infiltration solutions, but the lack of an available dataset estimating the height of the water table for the city as a whole resulted in a model of groundwater height being created following procedures used by other researchers. Given the potential importance of depth to groundwater for the infiltration feasibility maps, a sensitivity analysis was undertaken. Reducing the acceptable depth to groundwater from the assumed 4 m to 1 m would increase the area suitable for infiltration in Coventry by 6.8%, but despite this increase infiltration would only be possible in a maximum of 24% of the LPA area. Sensitivity analyses for other factors could have allowed for a range of feasibility maps to be created. However, offering a range of areas for each of the SUDS groups would not provide the clear guidance required by planners.

7.2.2 Methods

Specific values in the source data were the basis for creating the maps, rather than associating levels of uncertainty with ranges of values. This approach result in the maps showing absolute boundaries that might not represent the gradations present in the natural environment. The use of GIS excluded social and institutional factors, such as sustainability criteria, that could not be readily mapped.

The use of GIS was reliant on the absence of software errors that would generate incorrect output, and some problems were encountered that required work-rounds. The majority of the analyses undertaken allowed for a visual comparison of the inputs and outputs, and this assessment was performed at each stage to ensure a thorough review of the validity of the data. Nevertheless, the broad spatial scale could have resulted in small inconsistencies remaining undetected.

The rules and procedures developed in this research have been tested with one local authority, and a wider validation, using both urban and rural local authorities, would be required to determine their applicability at a more general level. The findings of the feasibility maps and the example applications are specific to Coventry. However, the factors used are those suggested by previous published guidance, adopted by other studies, and agreed with local stakeholders. The general approach could be applied by other public and private organisations who wish to ascertain feasible locations for sustainable drainage at a broader spatial scale than individual site developments, and the resulting maps could be used to investigate the larger-scale implications of SUDS implementation.

7.3 CONTRIBUTION TO KNOWLEDGE

This research has contributed to local knowledge of historical flooding, and has informed local planning processes about the suitability of SUDS in the study area of Coventry. High-level recommendations for planning guidance have been created taking into account the likely responsibilities of SUDS Approval Bodies when SUDS provisions from the Flood and Water Management Act are implemented.

The research has added to scientific knowledge through the development of a GIS-based method to determine maps of feasible locations for all types of SUDS at the strategic LPA scale, using factors for both new development and retrofit implementations, which has the potential to be more widely applicable. A draft framework for SUDS planning at the strategic level was constructed, which could be used by planning organisations to structure map-based information relating to SUDS feasibility. The research has built upon previous SUDS feasibility mapping work to demonstrate, through implementation of the framework, that all types of SUDS devices can be represented on guidance maps, and that standard GIS functionality can be used to generate these maps from, for the most part, information that is available to local authorities.

8. REFERENCES

ABI (Association of British Insurers) (2007) *Summer Floods 2007: Learning the Lessons* [online]. Available from <http://www.floodrisk.co.uk/downloads/abi_summer_floods_2007.pdf > [21 March 2014]

--. (2008) *The Summer Floods 2007: one year on and beyond* [online]. Available from <http://www.abi.org.uk/Members/circulars/viewAttachment.asp?EID=19929&DID=16300> [23 June 2008]

Act of Parliament (1991) Great Britain Parliament. *Water Industry Act 1991 Chapter 56*. London: Office of Public Sector Information

--. (2004) Great Britain Parliament. *Planning and Compulsory Purchase Act 2004*. London: Office of Public Sector Information

--. (2009) Great Britain Parliament. *Statutory Instrument 2009 No. 3042: The Flood Risk Regulations 2009*. London: Office of Public Sector Information

--. (2010) Great Britain Parliament. *Flood and Water Management Act 2010*. London: Office of Public Sector Information

--. (2011) Great Britain Parliament. *Localism Act 2011*. London: Office of Public Sector Information

Act of the Scottish Parliament (1968) *Sewerage (Scotland) Act 1968*. London: Office of Public Sector Information

--. (2003) *Water Environment and Water Services (Scotland) Act 2003*. London: Office of Public Sector Information

--. (2011) *Scottish Statutory Instrument 2011 No. 209: The Water Environment (Controlled Activities) (Scotland) Regulations 2011*. London: Office of Public Sector Information

--. (2013) *Scottish Statutory Instrument 2013 No. 176: The Water Environment (Controlled Activities) (Scotland) Amendment Regulations 2013*. London: Office of Public Sector Information

Andoh, R.Y.G. (1994) ‘Urban drainage - the alternative approach’. In: *20th WEDC Conference: Colombo, Sri Lanka* [online]. Available from <http://wedc.lboro.ac.uk/resources/conference/20/Andoh.pdf> [7 March 2014]

Andoh, R.Y.G. and Smisson, R.P.M. (1995) ‘Alternative Urban Drainage Strategy Utilising the Single Pipe System’. In: *Proceedings of the 2nd Novatech Conference on Innovative Technologies in Urban Storm Drainage*. Held 30 May - 1 June 1995 in Lyon, France: 189-196 [online]. Available from <http://www.hrdtec.com/library/stormwater/Andoh-&-Smisson-1995-Novatech.pdf> [7 March 2014]

Apostolaki, S. and Jefferies, C. (2005) *Social impacts of stormwater management techniques including river management and SuDS* [online]. Available from <http://www.sniffer.org.uk/files/3413/4183/8007/SUDS01_1.pdf> [2 September 2013]

Ashley, R.M., Tait, S.J., Styan, E., Cashman, A., Luck, B., Blanksby, J., Saul, A.J., Hurley, L. and Sandlands, L. (2006) *21st Century Sewer Design. UK Water Industry Research project WM/07* [online]. Available from <http://www.wapug.org.uk/> [5 October 2007]

Ashley, R., Blanksby, J., Cashman, A., Jack, L., Wright, G., Packman, J., Fewtrell, L., Poole, A. and Maksimovic, C. (2007a) ‘Adaptable Urban Drainage: Addressing Change in Intensity, Occurrence and Uncertainty of Stormwater (AUDACIOUS)’. *Built Environment* 33 (1), 70-84

Ashley, R., Hurley, L., Mounce, S., Blanksby, J., Smith, H., Cashman, A., Sharp, L., Sefton, C., Codner G., Unwin, D., Ray, E., Kennedy, S., Mounce, R., and Doncaster, S. (2007b) *No Rainwater in Sewers (NORIS). Work Package 3: Sustainability* [online]. Available from <http://www.noris-interreg.eu/daten/documents/Report%20Work%20Package%203.pdf> [6 June 2008]

Atkins Water (2004) *Scottish Water SuDS Retrofit Research Project* [online]. Available from <http://www.scotland.gov.uk/Resource/Doc/921/0004694.pdf> [21 March 2014]

Bablake Weather Station (2013) *Statistics* [online]. Available from <http://bws.users.netlink.co.uk/> [13 March 2013]

Bales, J.D. and Wagner, C.R. (2009) 'Sources of uncertainty in flood inundation maps'. *Journal of Flood Risk Management* 2 (2), 139-147

Ball, D., MacDonald, A., Ó Dochartaigh, B., del Rio, M., Fitzsimons, V., Auton, C. and Lilly, A. (2004) *Development of a groundwater vulnerability screening methodology for the Water Framework Directive* [online]. Available from <http://www.sepa.org.uk/water/monitoring_and_classification/assessment_tools/idoc.ashx?docid=f9a816c3-61dd-4874-8085-696829deec7f&version=-1> [14 July 2010]

Balmforth, D. (2006) 'Conclusions of the Integrated Urban Drainage Pilot Scoping Study'. In: *Chartered Institution of Water and Environmental Management (CIWEM) Conference on Integrated Urban Drainage: Delegate Notes* [online]. Held on 10 May 2006 at the School of Oriental and African Studies London. Available from <http://www.coastms.co.uk/resources/c97a01de-c5d6-406e-a032-747f78394c4d.pdf> [7 March 2014]

Balmforth, D.J. and Dibben, P. (2006) 'A Modelling Tool for Assessing Flood Risk'. *Water Practice and Technology* 1 (1), 8 pages

Balmforth, D., Digman, C., Kellagher, R. and Butler, D. (2006a) *Designing for exceedance in urban drainage – good practice (C635).* London: Construction Industry Research and Information Association

Balmforth, D., Digman, C., Butler, D. and Shaffer, P. (2006b) *Integrated Urban Drainage Pilots: Scoping Study* [online]. Available from <http://archive.defra.gov.uk/environment/flooding/documents/manage/surfacewater/scoperev.pdf> [7 March 2014]

Bamfield, B. (2005) *Whole Life Costs & Living Roofs. The Springboard Centre, Bridgewater* [*sic*] [online]. 2nd edition. Available from <http://www.livingroofs.org/images/stories/pdfs/Living%20roof%20Bridgewater%20003.pdf> [7 March 2014]

Banting, D., Doshi, H., Li, J., Missios, P., Angela Au, A., Currie, B.A. and Verrati, M. (2005) *Report on the Environmental Benefits and Costs of Green Roof Technology for the City of Toronto* [online]. Available from <http://commons.bcit.ca/greenroof/files/2012/01/banting_et_al.pdf> [12 March 2014]

Bastien, N.R.P., Arthur, S. and McLoughlin, M.J. (2012) 'Valuing amenity: public perceptions of sustainable drainage systems ponds'. *Water and Environment Journal* 26 (1), 19-29

Bates, A., Greswell, R., Mackay, R., Donovan, R. and Sadler, J. (2006) *SWITCH Green Roof Project: Rationale and Experimental design* [online]. Available from <http://switchurbanwater.lboro.ac.uk/outputs/pdfs/b08e7f57d69a38c8a4b3509830a807e3.pdf> [18 July 2008]

Becker, M., Geretshauser, G., Spengler, B. and Sieker, H. (2006) 'A stormwater management information system for the catchment area of the River Emscher'. *Water Practice & Technology* 1 (1), 8 pages

Beckers, E. and Degré, A. (2008) 'Is storing roof an alternative for urban rainwater management?'. In: *11th International Conference on Urban Drainage*. Held 31 August - 5 September 2008 in Edinburgh, Scotland

BERR (Department for Business, Enterprise & Regulatory Reform) (2008) *Strategy for Sustainable Construction* [online]. Available from <http://www.berr.gov.uk/files/file46535.pdf> [21 March 2014]

Besien, A. and Pearson, A. (2007) *Groundwater Quality Review: Coventry Carboniferous Sandstones* [online]. Bristol: Environment Agency. Available from <http://publications.environment-agency.gov.uk/pdf/GEHO0309BPST-E-E.pdf> [14 January 2010]

BGS (British Geological Survey) (2003) *UK Superficial Geology 1:625 000 version 1.10* [online]. Available from <http://www.bgs.ac.uk/products/digitalmaps/data_625k.html> [5 July 2010]

--. (2008a) *GeoIndex* [online]. Available from <http://www.bgs.ac.uk/GeoIndex/index.htm> [27 May 2008]

--. (2008b) *UK Bedrock Geology 1:625 000 version 5.17* [online]. Available from <http://www.bgs.ac.uk/products/digitalmaps/data_625k.html> [5 July 2010]

--. (2009) *Britain Beneath Our Feet* [online]. Available from <http://www.bgs.ac.uk/britainbeneath/land_groundwater_level.html> [5 July 2010]

--. (2013a) *Borehole Scans* [online]. Available from <http://mapapps.bgs.ac.uk/geologyofbritain/home.html?mode=boreholes> [4 April 2013]

--. (2013b) *Infiltration SuDS map* [online]. Available from <http://www.bgs.ac.uk/products/hydrogeology/infiltrationSuds.html> [2 September 2013]

Bibby, P. (2009) 'Land use change in Britain'. *Land Use Policy* 26S, S2–S13

Blackwood, D.J., Ashley, R.M., Petrie, M., Oltean-Dumbrava, C. and Jones, C. (2000) 'Making decisions for upgrading wastewater systems'. *Proceedings of the Institution of Civil Engineers: Municipal Engineer* 139, 171-180

Boorman, D.B., Hollis, J.M. and Lilly, A. (1995) *Hydrology of soil types: a hydrologically-based classification of the soils of the United Kingdom. Institute of Hydrology Report No. 126* [online]. Available from <http://www.ceh.ac.uk/products/publications/documents/IH126HYDROLOGYOFSOILTYPES.pdf> [21 March 2014]

Bosher, L., Carrillo, P., Dainty, A., Glass, J. and Price, A. (2007) 'Realising a resilient and sustainable built environment: towards a strategic agenda for the United Kingdom'. *Disasters* 31 (3), 236-255

Bray, R. (2000) 'Design of the Treatment Train at Hopwood Services, South Birmingham on the M42'. In: Pratt, C.J. (ed.) *Proceedings of the Nineteenth Meeting of the Standing Conference on Stormwater Source Control*. Held March 27 2000 at Coventry University. Coventry: Coventry University

Brewington, J. (2012) *Diffuse Pollution – The Water Framework Directive and You* [online]. Available from <http://www.sben.co.uk/uploads/EA%20re%20website%2017.07.pdf> [10 September 2013]

British Academy (2005) *Submission to the Royal Commission on Environmental Pollution for its Study of the Urban Environment* [online]. Available from <http://www.britac.ac.uk/templates/asset-relay.cfm?frmAssetFileID=6437> [26 April 2010]

Broad, W. (2005) 'Examination of site selection methodologies for the retrofit of SUDS'. In: Newman, A.P., Pratt, C.J., Davies, J.W. and Blakeman, J.M. (Eds.) *Proceedings of the Third National Conference on Sustainable Drainage, incorporating the 27th Meeting of the Standing Conference on Stormwater Source Control*. Held 20-21 June 2005 at Coventry University. Coventry: Coventry University: 232-247

Brown, R.R. and Farrelly, M.A. (2009) 'Delivering sustainable urban water management: a review of the hurdles we face'. *Water Science & Technology* 59 (5), 839-846

Burkhard, R., Deletic, A. and Craig, A. (2000) ‘Techniques for water and wastewater management: a review of techniques and their integration in planning’. *Urban Water* 2, 197-221

Butler, D. and Davies, J.W. (2004) *Urban Drainage*. 2nd edition. London: E & FN Spon

Butler, D., Kokkalidou, A. and Makropoulos, C.K. (2006) ‘Supporting the Siting Of New Urban Developments for Integrated Urban Water Resource Management’. In: Hlavinek, P., Kukharchyk, T., Marsalek, J. and Mahrikova, I. (eds) *Proceedings of the NATO Advanced Study Institute on Integrated Urban Water Resources Management*, held in Senec, Slovak Republic, 19-23 October. London: Springer Publishers: 19-34. Available from *WaND Water Cycle Management for new developments* [CD-ROM]

Cabinet Office (2008) *National Risk Register* [online]. Available from <https://www.gov.uk/government/publications/national-risk-register-of-civil-emergencies> [21 March 2014]

Carter, T. and Jackson, C.R. (2007) ‘Vegetated roofs for stormwater management at multiple spatial scales’. *Landscape and Urban Planning* 80, 84–94

Carter, T. and Keeler, A. (2008) ‘Life-cycle cost–benefit analysis of extensive vegetated roof systems’. *Journal of Environmental Management* 87 (3), 350–363

CCC (Coventry City Council) (2001) *The Coventry Development Plan 2001. The City of Coventry Unitary Development Plan 1996-2011* [online]. Available from <http://www.coventry.gov.uk/downloads/download/490/coventry_development_plan_2001> [22 January 2011]

--. (2004) *Contaminated Land Inspection Strategy* [online]. Available from <http://www.coventry.gov.uk/ccm/content/city-services-directorate/public-protection/environmental-health/pollution/contaminated-land-legislation.en> [2 June 2008]

--. (2007) *Land and premises* [online]. Available from <http://www.coventry.gov.uk/info/200059/land_and_premises> [7 March 2014]

--. (2008a) *St Michael's Ward in numbers* [online]. Available from <http://www.coventry.gov.uk/ccm/content/chief-executives-directorate/area-co-ordination/ward-pages/st-michaels-ward/st-michaels-ward-in-numbers.en> [6 May 2008]

--. (2008b) *Strategic Flood Risk Assessment for Local Development Framework: Level 1* [online]. Available from <http://www.coventry.gov.uk/downloads/download/680/evidence_base-strategic_flood_risk_assessment> [21 March 2014]

--. (2008c) *Highways Asset Management Plan* [online]. 3rd edition. Available from <http://www.coventry.gov.uk/downloads/download/785/highway_plans> [21 March 2014]

--. (2008d) *Canley Regeneration Project. Environmental Statement - Non-Technical Summary* [online]. Available from <http://planning.coventry.gov.uk/portal/servlets/AttachmentShowServlet?ImageName=791587> [5 September 2013]

--. (2009) *Local Development Framework Core Strategy: Proposed Submission* [online]. Available from <http://www.coventry.gov.uk/downloads/download/399/evidence_base_submission_documents> [22 January 2011]

--. (2011a) *Strategic Housing Land Availability Assessment (SHLAA) September 2011 Review* [online]. Available from <http://www.coventry.gov.uk/downloads/download/1277/coventrys_proposed_core_strategy_public_consult

ation> [19 October 2011]

--. (2011b) *Preliminary Flood Risk Assessment* [online]. Available from <http://www.coventry.gov.uk/info/10028/flooding/1413/preliminary_flood_risk_assessment> [21 March 2014]

--. (2011c) *Coventry demographics* [online]. Available from <http://www.facts-about-coventry.com/uploaded/documents/Coventry%20population%202010.pdf> [21 March 2014]

--. (2012a) *Strategic Housing Land Availability Assessment (SHLAA) 2012* [online]. Available from <http://www.coventry.gov.uk/download/downloads/id/6019/cs_h1_full_shlaa_report_and_appendix_july_2012> [21 March 2014]

--. (2012b) *Coventry Local Development Plan Core Strategy: Proposed Submission Document with Minor amendments October 2012* [online]. Available from <http://www.coventry.gov.uk/download/downloads/id/6708/core_strategy_proposed_submission_2012_including_minor_changes> [24 April 2013]

--. (2013) *Planning Committee Report Canley Regeneration Site Prior Deram Walk. Application FM/2012/2343* [online]. Available from <http://planning.coventry.gov.uk/portal/servlets/AttachmentShowServlet?ImageName=1053889> [5 September 2013]

CCRS (Canada Centre for Remote Sensing) (2003) *Fundamentals of Remote Sensing* [online]. Available from <http://ccrs.nrcan.gc.ca/resource/tutor/fundam/index_e.php> [10 October 2007]

Charlesworth, S.M. (2010) 'A review of the adaptation and mitigation of global climate change using sustainable drainage in cities'. *Journal of Water and Climate Change* 1 (3), 165-180

Charlesworth, S., de Miguel, E. and Ordóñez, A. (2010) ‘Trace elements in urban environments: a review’. In: *Sedimentology of Aqueous Systems* (eds. Poleto, C. and Charlesworth, S.). Oxford:Wiley-Blackwell: 108-128

Charlesworth, S., Everett, M., McCarthy, R., Ordóñez, A. and de Miguel, E. (2003a) ‘A comparative study of heavy metal concentration and distribution in deposited street dusts in a large and a small urban area: Birmingham and Coventry, West Midlands, UK’. *Environment International* 29, 563-573

Charlesworth, S.M., Harker, E. and Rickard, S. (2003b) 'A Review of Sustainable Drainage Systems (SuDS): A Soft Option for Hard Drainage Questions?'. *Geography* 88 (2), 99-107

Charlesworth, S., Perales-Momparler, S., Lashford, C. and Warwick, F. (2013) ‘The sustainable management of surface water at the building scale: preliminary results of case studies in the UK and Spain’. *Journal of Water Supply: Research and Technology – AQUA* 62 (8), 534-544

Chen, A., Djordjevic, S., Leandro, J. and Savic, D. (2007) ‘The urban inundation model with bi-directional flow interaction between 2D overland surface and 1D sewer networks’. In: *NOVATECH 2007: 6th international conference on sustainable techniques and strategies in urban water management*. Held June 24 - 28, 2007. Lyon, France.

Chen, J., Hill, A.A. and Urbano, L.D. (2009) 'A GIS-based model for urban flood inundation'. *Journal of Hydrology* 373, 184–192

Chocat, B., Ashley, R., Marsalek, J., Matos, M.R., Rauch, W., Schilling, W. and Urbonas, B. (2004) ‘Urban Drainage - Out-of-sight-out-of-mind?’ In: International Association for Hydraulic Research (IAHR) / International Water Association (IWA) Joint Committee On Urban Drainage. *Sustainable Techniques and Strategies in Urban Water Management. 5th International Novatech Conference 2004.* Held June 2004, Lyons, France. Villeurbanne, France: GRAIE (Groupe de Recherche Rhône-Alpes sur les Infrastructures et l'Eau): 1659-1690 [online]. Available from <http://www.petus.eu.com/graphics/FRurbdrainBC.pdf> [7 March 2014]

CIRIA (Construction Industry Research & Information Association) (2002) *SuDS Bulletin Issue 1* [online]. Available from <http://www.ciria.org/suds/pdf/suds_bulletin_%201.pdf> [21 March 2014]

--. (2003) *Case Study: Hopwood Motorway Service Area, M42 Junction 2* [online]. Available from <http://www.ciria.org/suds/cs_hopwood_msa.htm> [29 November 2006]

--. (2007) *Model agreements for sustainable water management systems* [online]. Available from <http://www.ciria.org/suds/model_agreements.htm#ma_suds> [17 January 2008]

Claytor, Jr., R.A. (1998) 'An Eight-Step Approach to Implementing Stormwater Retrofitting'. In: *National Conference on Retrofit Opportunities for Water Resource Protection in Urban Environments: Proceedings. Chicago, Illinois February 9-12:* 212-218 [online]. Available from <http://nepis.epa.gov/Adobe/PDF/30004SI7.pdf> [7 March 2014]

Cobby, D., Morris, S., Parkes, A. and Robinson, V. (2009) 'Groundwater flood risk management: advances towards meeting the requirements of the EU floods directive'. *Journal of Flood Risk Management* 2, 111–119

Comber, A.J., Law, A.N.R. and Lishman, J.R. (2004) 'Application of knowledge for automated land cover change monitoring'. *International Journal of Remote Sensing*, 25 (16), 3177–3192

Coulthard, T.J. and Frostick, L.E. (2010) 'The Hull floods of 2007: implications for the governance and management of urban drainage systems'. *Journal of Flood Risk Management* 3, 223–231

Coulthard, T., Frostick, L., Hardcastle, H., Jones, K., Rogers, D., Scott, M. and Bankoff, G. (2007) *The June 2007 floods in Hull. Final Report by the Independent Review Body* [online]. Available from <http://www.coulthard.org.uk/downloads/floodsinhull3.pdf> [7 March 2014]

Coventry City Council and Coventry Partnership (2012) *Climate Change Strategy for Coventry 2020* [online]. Available from <http://www.coventry.gov.uk/downloads/download/1640/climate_change_strategy_for_coventry> [25 April 2012]

Coventry Evening Telegraph (1954) 25 October, page 9 column 2-3

--. (1960a) *Flooding after thunderstorms*. 10 May, page 6 column 5

--. (1960b) 23 June, page 1

--. (1970) *Editorial* 24 August 1970

Coventry University (2006) *Corporate Plan: Achieving our Objectives* [online]. Available from <http://www.coventry.ac.uk/content/1/c4/25/53/Final28pp_CorporatePlan.pdf> [5 October 2007]

--. (2008) *Coventry University Masterplan* [online]. Available from <http://www.coventry.gov.uk/ccm/cms-service/stream/asset/?asset_id=34629033> [4 August 2010]

Culshaw, M.G., Nathanail, C.P., Leeks, G.J.L., Alker, S., Bridge, D., Duffy, T., Fowler, D., Packman, J.C., Swetnam, R., Wadsworth R. and Wyatt, B. (2006) 'The role of web-based environmental information in urban planning—the environmental information system for planners'. *Science of the Total Environment* 360, 233– 245

Dales, M.Y. and Reed, D.W. (1989) *Regional flood and storm hazard assessment: Report No. 102* [online]. Wallingford: Institute of Hydrology. Available from <http://www.ceh.ac.uk/products/publications/documents/ih102floodandstormassessment.pdf> [21 March 2014]

D'Arcy, B. and Frost, A. (2001) 'The role of best management practices in alleviating water quality problems associated with diffuse pollution'. *The Science of the Total Environment* 265, 359-367

D'Arcy, B. and Wild, T. (2002) *SuDS - Routine Business in Scotland? Diffuse Pollution Initiative Report No.* 4 [online]. Available from <http://www.sepa.org.uk/pdf/dpi/resources/dpi_reports/dpi_004.pdf> [14 January 2008]

D'Arcy, B. and Wild, T. (2003) *SuDS Guidance. Diffuse Pollution Initiative Report No. 10* [online]. Available from <http://www.sepa.org.uk/pdf/dpi/resources/dpi_reports/dpi_010.pdf> [21 January 2008]

da Silva, M.L., Eccleston, P. and Balmforth, D.J. (2008) 'Rapid Assessment of Urban Flood Risk for Strategic Planning'. In: *11th International Conference on Urban Drainage*. Held 31 August - 5 September 2008 in Edinburgh, Scotland

Davis, B.S. and Birch, G.F. (2009) 'Catchment-wide assessment of the cost-effectiveness of stormwater remediation measures in urban areas'. *Environmental Science & Policy* 12, 84–91

DCLG (Department for Communities and Local Government) (2007) *Generalised Land Use Database Statistics for England 2005 (Enhanced Basemap)* [online]. Available from <http://www.communities.gov.uk/documents/planningandbuilding/pdf/154941> [6 May 2008]

--. (2008a) *Impact Assessment – Permeable Surfaces* [online]. Available from <http://www.communities.gov.uk/documents/planningandbuilding/pdf/686153> [13 March 2008]

--. (2008b) *Planning Policy Statement 25: Development and Flood Risk. Practice Guide* [online]. London: DCLG. Available from <http://www.communities.gov.uk/documents/planningandbuilding/pdf/pps25practiceguide.pdf> [12 June 2008]

--. (2009) *Planning Policy Statement 25: Development and Flood Risk. Practice Guide* [online]. London: Department for Communities and Local Government. Available from <https://www.gov.uk/government/publications/development-and-flood-risk-practice-guide-planning-policy-statement-25> [21 March 2014]

--. (2010) *Planning Policy Statement 25: Development and Flood Risk* [online]. London: The Stationery Office. Available from <http://webarchive.nationalarchives.gov.uk/+/http:/www.communities.gov.uk/planningandbuilding/planning/planningpolicyguidance/planningpolicystatements/planningpolicystatements/pps25/> [21 March 2014]

--. (2011) *A plain English guide to the Localism Bill* [online]. Available from <https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/5958/1923416.pdf> [21 March 2014]

--. (2012) *National Planning Policy Framework* [online]. Available from <https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/6077/2116950.pdf> [21 March 2014]

--. (2014) *Planning Flowchart* [online]. Available from <http://www.planningportal.gov.uk/uploads/plan_flow_chart_eng.gif> [21 March 2014]

Dearden, R.A. and Price, S. J. (2012) 'A proposed decision-making framework for a national infiltration SuDS map. *Management of Environmental Quality* 23 (5), 478-485

Dearden, R.A., Marchant, A. and Royse, K. (2013) 'Development of a suitability map for infiltration sustainable drainage systems (SuDS)'. *Environmental Earth Sciences* 70(6), 2587-2602

Defew, L.H., May, L. and Heal, K.V. (2013) 'Uncertainties in estimated phosphorus loads as a function of different sampling frequencies and common calculation methods'. *Marine and*

Freshwater Research 64, 373–386

Defra (Dept. for Environment, Food and Rural Affairs) (2003a) *Review of Existing Private Drains and Sewers in England and Wales: Consultation Paper* [online]. Available from <http://www.defra.gov.uk/corporate/consult/sewers/conpap.pdf> [4 February 2008]

--. (2003b) *Projections of urban growth by county 1991-2016: England* [online]. Available from <http://www.defra.gov.uk/environment/statistics/land/alltables.htm> [3 July 2008]

--. (2004) *Groundwater Protection Code: Solvent Use & Storage* [online]. Available from <http://www.defra.gov.uk/ENVIRONMENT/water/ground/solvents/pdf/solvents.pdf> [27 May 2008]

--. (2005a) *Making space for water. Developing a new Government strategy for flood and coastal erosion risk management in England: Sustainable drainage systems: Summary of issues, consultation responses and proposed next steps* [online]. Available from <http://www.defra.gov.uk/environ/fcd/policy/strategy/suds.pdf> [27 June 2007]

--. (2005b) *Water Quality: A Diffuse Pollution Review* [online]. Available from <http://www.defra.gov.uk/environment/water/quality/diffuse/pdf/diffusepollut-ch3.pdf> [22 December 2006]

--. (2007a) *Impact assessment on the institutional arrangements required to promote integrated urban drainage management – early options for stakeholder comment* [online]. Available from <http://archive.defra.gov.uk/environment/flooding/documents/manage/surfacewater/iapolicyopt.pdf> [7 March 2014]

--. (2007b) *Funding and charging arrangements for sustainable urban drainage systems* [online]. Available from <http://www.defra.gov.uk/environment/quality/water/waterquality/diffuse/non-agri/documents/suds-report.pdf> [26 April 2010]

--. (2007c) *Consultation on Private Sewers Transfer - Implementation Options* [online]. Available from <http://archive.defra.gov.uk/environment/quality/water/industry/sewers/documents/private-sewer-consultation.pdf> [21 March 2014]

--. (2007d) *Review of Existing Private Sewers and Drains in England and Wales: Regulatory Impact Assessment* [online]. Available from <http://archive.defra.gov.uk/environment/quality/water/industry/sewers/documents/regulatory-ia.pdf> [21 March 2014]

--. (2008) *Impact Assessment of transfer of private sewers and lateral drains to statutory water and sewerage companies. Summary: Intervention & Options* [online]. Available from <http://archive.defra.gov.uk/environment/quality/water/industry/sewers/documents/impact-assessment-private-sewers.pdf> [21 March 2014]

--. (2010a) *Surface Water Management Plan Technical Guidance March 2010* [online]. Available from <https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69342/pb13546-swmp-guidance-100319.pdf> [21 March 2014]

--. (2010b) *Annexes to Surface Water Management Plan Technical Guidance March 2010* [online]. Available from <https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69343/pb13546-swmp-guidance-annex-100319.pdf> [21 March 2014]

--. (2011a) *National Standards for sustainable drainage systems. Draft for consultation* [online]. Available from <https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/82421/suds-consult-annexa-national-standards-111221.pdf> [21 March 2014]

--. (2011b) *Consultation on the Implementation of the Sustainable Drainage Systems* *provisions in Schedule 3: Flood and Water Management Act 2010* [online]. Available from <https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/82423/suds-consult-doc-111120.pdf> [21 March 2014]

--. (2011c) *Consultation draft: The Sustainable Drainage (Procedure) (England) Regulations 2012* [online]. Available from <https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/82421/suds-consult-annexd-regs-111220.pdf> [21 March 2014]

–. (2012) *Consultation on implementation of the Sustainable Drainage Systems (SuDS) provisions in Schedule 3 of the Flood and Water Management Act 2010. Summary of Consultation Responses* [online]. Available from <https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/120679/suds-consult-sum-resp.pdf> [21 March 2014]

Defra and Environment Agency (2007) *Preliminary rainfall runoff management for developments. Technical Report W5-074A/TR/1 Revision C* [online]. Available from <http://publications.environment-agency.gov.uk/epages/eapublications.storefront/4db83913000edac4273fc0a802960689/Product/View/SCHO0707BMYS&2DE&2DE> [27 April 2011]

Diaz-Nieto, J., Blanksby, J., Lerner, D.N. and Saul, A.J. (2008) ‘A GIS approach to explore urban flood risk management’. In: *Proceedings of the 11th International Conference on Urban Drainage*. Held 31 August - 5 September 2008 in Edinburgh: 10 pages

Dickie, S., McKay, G., Ions, L. and Shaffer, P. (2010) *Planning for SuDS – making it happen C687*. London: CIRIA

Digman, C.J., Balmforth, D.J., Shaffer, P. and Butler, D. (2006) ‘The challenge of delivering integrated urban drainage’. In: *WaPUG Autumn Conference 2006* [online]. Available from <http://www.wapug.org.uk/> [14 January 2008]

Digman, C.J., Ashley, R.M., Balmforth, D.J., Balmforth, D.W., Stovin, V.R. and Glerum, J.W. (2012) *Retrofitting to manage surface water C713*. London: CIRIA

Dixon, T. (2009) 'Urban land and property ownership patterns in the UK: trends and forces for change'. *Land Use Policy* 26S, S43–S53

Domènech, L. and Saurí, D. (2011) ‘A comparative appraisal of the use of rainwater harvesting in single and multifamily buildings of the Metropolitan Area of Barcelona (Spain): social experience, drinking water savings and economic costs’. *Journal of Cleaner Production* 19, 598-608

Doncaster, S., Stovin, V. and Morrow, B. (2008) *Lower Irwell Valley, Salford, Integrated Urban Drainage Pilot Project. Final Report* [online]. Available from <http://www.defra.gov.uk/environment/flooding/manage/surfacewater/urpilotirwell.htm> [21 June 2010]

Dougherty, M., Dymond, R.L., Goetz, S.J., Jantz, C.A. and Goulet, N. (2004) ‘Evaluation of Impervious Surface Estimates in a Rapidly Urbanizing Watershed’. *Photogrammetric Engineering and Remote Sensing* 70 (11), 1275–1284

Douglas, I., Garvin, S., Lawson, N., Richards, J., Tippett, J. and White, I. (2010) ‘Urban pluvial flooding: a qualitative case study of cause, effect and nonstructural mitigation’. *Journal of Flood Risk Management* 3, 112–125

DTI (Department of Trade and Industry) (2006) *Sustainable drainage systems: a mission to the USA* [online] available from <http://www.catchmentchange.net/wp-content/uploads/2011/07/USA-Sustainable-Drainage-Mission-Report.pdf> [7 March 2014]

Dunn, R. (2010) *Gloucestershire First Edition Surface Water Management Plan. Final Pilot Report* [online]. Available from

<http://www.defra.gov.uk/environment/flooding/documents/manage/surfacewater/swmp1-gloucester.pdf> [25 August 2010]

Duffy, A., Jefferies, C., Waddell, G., Shanks, G., Blackwood, D. and Watkins, A. (2008) 'A cost comparison of traditional drainage and SUDS in Scotland'. *Water Science & Technology* 57 (9), 1451-1459

DWI (Drinking Water Inspectorate) (2009) *Drinking Water Safety: Guidance to health and water professionals* [online]. London: The Drinking Water Inspectorate. Available from <http://www.dwi.gov.uk/stakeholders/information-letters/2009/09_2009Annex.pdf> [14 July 2010]

EA (Environment Agency) (2002) *Sustainable Drainage Systems (SuDS): a guide for developers* [online]. Available from <http://www.environment-agency.gov.uk/commondata/acrobat/a5_suds_v3.pdf> [29 November 2006]

--. (2003) *General Quality Assessment of rivers - biology* [online]. Available from <http://www.environment-agency.gov.uk/commondata/acrobat/bio_method_09_03_559881.pdf> [10 March 2008]

--. (2006a) *A Framework for River Basin Planning in England and Wales – Summary* [online]. Available from <http://publications.environment-agency.gov.uk/pdf/GEHO1205BJWO-e-e.pdf> [3 May 2007]

--. (2006b) *Water abstraction. Getting the balance right: The Warwickshire Avon Catchment Abstraction Management Strategy* [online]. Available from <http://cdn.environment-agency.gov.uk/gemi0706blar-e-e.pdf> [21 March 2014]

--. (2006c) *A Framework for River Basin Planning in England and Wales* [online]. Available from <http://publications.environment-agency.gov.uk/pdf/GEHO0506BKVX-e-e.pdf?lang=_e> [18 May 2009]

--. (2007a) *West Midlands Regional Spatial Strategy (RSS 11). The Impact of Housing Growth on Water Quality and Waste Water infrastructure* [online]. Available from <http://www.wmra.gov.uk/documents/Environment%20and%20Waste/Environment%20Agency%20-%20Water%20Quality.pdf> [21 March 2014]

--. (2007b) *Review of 2007 summer floods* [online]. Available from <http://cdn.environment-agency.gov.uk/geho1107bnmi-e-e.pdf> [7 March 2014]

--. (2007c) *The unseen threat to water quality. Diffuse water pollution in England and Wales report – May 2007* [online]. Available from <http://www.environment-agency.gov.uk/static/documents/Research/geho0207bzlvee_1773088.pdf> [21 March 2014]

--. (2007d) *Consultation on non-agricultural diffuse water pollution in England and Wales* [online]. Available from <http://www.netregs.gov.uk/netregs/legislation/380525/389384/964202/1741292/> [4 February 2008]

--. (2007e) *Underground, under threat: Groundwater protection: policy and practice. Part 1 – overview* [online]. Available from <http://a0768b4a8a31e106d8b0-50dc802554eb38a24458b98ff72d550b.r19.cf3.rackcdn.com/geho1006blmw-e-e.pdf> [21 March 2014]

--. (2007f) *Underground, under threat: Groundwater protection: policy and practice. Part 2 – technical framework* [online]. Available from <http://publications.environment-agency.gov.uk/pdf/GEHO1006BLMT-e-e.pdf> [6 May 2008]

--. (2007g) *River water quality in the West Midlands* [online]. Available from <http://www.environment-agency.gov.uk/regions/midlands/835324/835577/1169194/1268521/?lang=_e> [10 March 2008]

--. (2007h) *Groundwater protection: policy and practice. Part 4 – Legislation and policies. Public consultation 2007* [online]. Available from <http://cdn.environment-agency.gov.uk/geho0708bogu-e-e.pdf> [21 March 2014]

--. (2008a) *Science and research: LIDAR* [online]. Available from <http://www.environment-agency.gov.uk/science/monitoring/131047/> [15 February 2008]

--. (2008b) *Groundwater source protection zones* [online]. Available from <http://www.environment-agency.gov.uk/maps/info/groundwater/> [6 May 2008]

--. (2008c) *Flood maps* [online]. Available from <http://www.environment-agency.gov.uk/subjects/flood/?lang=_e> [29 May 2008]

--. (2008d) *River quality - an overview* [online]. Available from <http://www.environment-agency.gov.uk/yourenv/eff/1190084/water/213902/river_qual/?lang=_e> [10 March 2008]

--. (2008e) *A consultation on the Draft River Basin Management Plan: Severn River Basin District* [online]. Available from <http://wfdconsultation.environment-agency.gov.uk/wfdcms/en/severn/Intro.aspx> [6 February 2009]

--. (2009a) *Flood Risk Standing Advice for England - PPS25 National Version 2.0* [online]. Available from <http://www.environment-agency.gov.uk/research/planning/93498.aspx> [10 March 2009]

--. (2009b) *Flooding in England: A National Assessment of Flood Risk* [online]. Available from <http://cdn.environment-agency.gov.uk/geho0609bqds-e-e.pdf> [21 March 2014]

--. (2009c) *Areas Susceptible to Surface Water Flooding: Guidance for Local Resilience Forums and Regional Resilience Teams for emergency planning and other purposes (not land use planning) – v2 July 2009*. Bristol: Environment Agency

--. (2009d) *Research Framework – The implementation of Integrated Urban Drainage. Science project SC070064/SR* [online]. Available from <http://cdn.environment-agency.gov.uk/scho1009brce-e-e.pdf> [21 March 2014]

--. (2010a) *The costs of the summer 2007 floods in England. Project: SC070039/R1* [online]. Available from <http://nationalfloodforum.org.uk/wp-content/uploads/EA-Costs-of-Flooding.pdf> [21 March 2014]

--. (2010b) *What's in your back yard* [online]. Available from <http://maps.environment-agency.gov.uk/wiyby/wiybyController?x=433500.0&y=278500.0&topic=wfd_rivers&ep=map&scale=9&location=Coventry, Coventry&lang=_e&layerGroups=default&distance=&textonly=off#x=433500&y=278500&lg=1,7,8,9,5,6,&scale=7> [18 March 2014]

--. (2010c) *HiFlows-UK* [online]. Available from <http://www.environment-agency.gov.uk/hiflows/97440.aspx> [5 July 2010]

--. (2012) *Flood Risk Standing Advice for England - Version 3.1* [online]. Available from <http://www.environment-agency.gov.uk/cy/ymchwil/cynllunio/93498.aspx> [22 March 2014]

--. (2013a) *What's in your back yard: Groundwater* [online]. Available from <http://maps.environment-agency.gov.uk/wiyby/wiybyController?x=433500.0&y=278500.0&topic=wfd_groundwaters&ep=map&scale=9&location=Coventry, Coventry&lang=_e&layerGroups=default&distance=&textonly=off#x=433500&y=278500&lg=1,2,7,9,&scale=7> [12 July 2013]

--. (2013b) *What's in your back yard: Nitrate Vulnerable Zones* [online]. Available from <http://maps.environment-agency.gov.uk/wiyby/wiybyController?x=433500.0&y=278500.0&topic=nvz&ep=map&scale=5&location=Coventry, Coventry&lang=_e&layerGroups=default&distance=&textonly=off#x=433500&y=278500&lg=1,&scale=6> [11 July 2013]

--. (2013c) *Water for life and livelihoods* [online]. Available from <http://cdn.environment-agency.gov.uk/LIT_8412_efb268.pdf> [22 March 2014]

--. (2014) *What's in your back yard: River Basin Management Plan – Rivers* [online]. Available from <http://maps.environment-agency.gov.uk/wiyby/wiybyController?x=433500.0&y=278500.0&topic=wfd_rivers&ep=map&scale=9&location=Coventry, Coventry&lang=_e&layerGroups=default&distance=&textonly=off#x=433500&y=278500&lg=1,7,8,9,5,6,&scale=7> [18 March 2014]

Eastman, J.R. (2001) *IDRISI Release 2: Tutorial. Manual Version 32.20* [Computer Program]. Available from Clark Labs, The Idrisi Project, 950 Main Street, Worcester MA 01610-1477, USA

Echols, S. and Pennypacker, E. (2008) 'From Stormwater Management to Artful Rainwater Design'. *Landscape Journal* 27, 268-290

EDINA (2009) *Digimap* [online]. Available from <http://digimap.edina.ac.uk/main/index.jsp> [13 October 2009]

EEA (European Environment Agency) (2009) *Corine land cover 2000 (CLC2000) 100m, version 12/2009* [online]. Available from <http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-clc2000-100-m-version-12-2009> [13 October 2009]

Elgy, J. (2001) 'Airborne remote sensing for urban drainage'. *Urban Water* 3, 287-297

Ellis, J.B. (2000) 'Infiltration Systems: A Sustainable Source-Control Option for Urban Stormwater Quality Management?'. *Journal of CIWEM* 14, 27-34

Ellis, J.B. and Mitchell, G. (2006) 'Urban diffuse pollution: key data information approaches for the Water Framework Directive'. *Water and Environment Journal* 20, 19–26

Ellis, J.B. and Revitt, D.M. (2010) 'The management of urban surface water drainage in England and Wales'. *Water and Environment Journal* 24 (1), 1-8

Ellis, J.B., Deutsch, J.-C., Legret, M., Martin, C., Revitt, D. M., Scholes, L., Seiker, H. [*sic*] and Zimmerman, U. (2006) 'The DayWater decision support approach to the selection of sustainable drainage systems: A multi-criteria methodology for BMP decision makers'. *Water Practice and Technology* 1 (1), 8 pages

Ellis, J.B., Deutsch, J.-C., Mouchel, J.-M., Scholes, L. and Revitt, M.D (2004a) 'Multicriteria decision approaches to support sustainable drainage options for the treatment of highway and urban runoff'. *Science of the Total Environment* 334–335, 251–260

Ellis, J.B., Scholes, L., Revitt, M.D and Oldham, J. (2004b) 'Sustainable urban development and drainage'. *Proceedings of the Institution of Civil Engineers: Municipal Engineer* 157 (ME4), 245–250

Ellis, J.B., Green, C. and Revitt, D.M. (2010) 'Identifying success factors in urban surface water BMP implementation: Mission impossible?'. *Proceedings of the 7th International Conference on Sustainable Techniques and Strategies for Urban Water Management, NOVATECH.* Held 28 June – 1 July 2010, Lyons, France. Villeurbanne**,** France: GRAIE (Groupe de Recherche Rhône-Alpes sur les Infrastructures et l'Eau)

Ellis, J.B., Viavattene, C. and Chlebek, J. (2011) 'A GIS-based Integrated Modelling Approach for the Identification and Mitigation of Pluvial Urban Flooding'. In: *WAPUG Spring Meeting 2011* [online]. Available from <http://www.ciwem.org/media/366727/WAPUG_A%20GIS-Based%20Integrated%20Modelling%20Approach_Presentation%20by%20J%20Bryan%20Ellis,%20Christophe%20Viavattene%20and%20Jennifer%20Chlebek_052011.pdf> [16 August 2013]

Ellis, J.B., Viavattene, C., Chlebek, J. and Hetherington, D. (2012) 'Integrated modelling for urban surface water exceedance flows'. *Proceedings of the Institution of Civil Engineers. Water Management* 165 (WM10), 543-552

English Heritage (2007) *National Monument Record* [online]. Available from <http://services.english-heritage.org.uk/NMRDataDownload/SecurePages/Download.aspx> [12 July 2010]

English Nature (2003) *Green Roofs: their existing status and potential for conserving biodiversity in urban areas. Research Report 498* [online]. Available from < http://publications.naturalengland.org.uk/publication/130019> [7 March 2014]

Entec UK Limited (2003) *The Potential Impacts of Climate Change in the West Midlands. Technical Report* [online]. Available from <http://www.ukcip.org.uk/wordpress/wp-content/PDFs/WM_tech.pdf> [21 March 2014]

ESRC (Economic & Social Research Council) Census Programme (2010) *2001 Census Statistics* [online]. Available from <http://casweb.mimas.ac.uk> [16 June 2010]

--. (2014) *2011 Census Statistics* [online]. Available from <http://www.nomisweb.co.uk/census/2011/ks101ew> [21 March 2014]

ESRI (Environmental Systems Research Institute) (2005) *ArcGIS* (version 9.1) [Computer Program]. Available from ESRI, 380 New York Street, Redlands, CA 92373-8100, USA

--. (2006) *ArcGIS* (version 9.2 Build 1380) [Computer Program]. Available from ESRI, 380 New York Street, Redlands, CA 92373-8100, USA

--. (2009) *ArcGIS* (version 9.3) [Computer Program]. Available from ESRI, 380 New York Street, Redlands, CA 92373-8100, USA

--. (2010) *ArcGIS* (version 10.0 Build 2414) [Computer Program]. Available from ESRI, 380 New York Street, Redlands, CA 92373-8100, USA

EU (European Union) (2000) *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy* [online]. Available from <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32000L0060:EN:HTML> [7 March 2014]

--. (2007) *Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks* [online]. Available from <http://eur-lex.europa.eu/LexUriServ/site/en/oj/2007/l_288/l_28820071106en00270034.pdf> [7 March 2014]

Evans, E., Ashley, R., Hall, J., Penning-Rowsell, E., Saul, A., Sayers, P., Thorne, C. and Watkinson, A. (2004) Fl*ooding Scientific Summary: Volume I - Future risks and their drivers* [online]. London: Office of Science and Technology. Available from <http://www.foresight.gov.uk/OurWork/CompletedProjects/Flood/Docs/Volume1/ContentsVol1.asp> [7 July 2008]

Evans, E.P., Simm, J.D., Thorne, C.R., Arnell, N.W., Ashley, R.M., Hess, T.M., Lane, S.N., Morris, J., Nicholls, R.J., Penning-Rowsell, E.C., Reynard, N.S., Saul, A.J., Tapsell, S.M., Watkinson, A.R. and Wheater, H.S. (2008) *An update of the Foresight Future Flooding 2004 qualitative risk analysis* [online]. London: Cabinet Office. Available from <http://webarchive.nationalarchives.gov.uk/20100807034701/http:/archive.cabinetoffice.gov.uk/pittreview/_/media/assets/www.cabinetoffice.gov.uk/flooding_review/evidence/foresight_report%20pdf.pdf> [21 March 2014]

Farrelly, M. and Brown, R. (2011) ‘Rethinking urban water management: Experimentation as a way forward?’ *Global Environmental Change* 21 (2), 721–732

FLL (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V.) (2002) *Guideline for the Planning, Execution and Upkeep of Green-Roof Sites* [online] available from <http://www.greenroofsouth.co.uk/FLL%20Guidelines.pdf> [7 March 2014]

Förster, M., Thévenot, D., Geldof, G., Svensson, G., Mikkelsen. P.S., Revitt, M., Aftias, E., Krejcik, J., Sieker, H., Legret, M. and Viklander, M. (2004) ‘Urban stormwater source control management in European countries: DayWater project' In: International Association for Hydraulic Research (IAHR) / International Water Association (IWA) Joint Committee On Urban Drainage. *Sustainable Techniques and Strategies in Urban Water Management. 5th International Novatech Conference 2004.* Held June 2004, Lyons, France. Villeurbanne, France: GRAIE (Groupe de Recherche Rhône-Alpes sur les Infrastructures et l'Eau): 341-348

Fowler, S., Warwick, F. and Charlesworth, S. (2012) 'Evaluating the amenity of sustainable urban drainage systems'. In: *SUDSnet International Conference* [online]. Held 4-5 September 2012, at the Coventry TechnoCentre, Coventry. Available from <http://sudsnet.abertay.ac.uk/presentations/National%20Conf%202012/PostGrad_EvaluatingAmenityofSustainableUrbanDrainageSystems_FowlerEtAl.pdf> [15 August 2013]

FRMRC (Flood Risk Management Research Consortium) (2007) *Integrated Surface and Sub-surface Interactive Flooding and Inundation Model. Research Report UR4* [online]. Available from <http://www.floodrisk.org.uk/images/stories/docs/UR4_interactive_flooding_and_inundation_model_WP6_1_v1_0.pdf> [8 January 2008]

FWR (Foundation for Water Research) (2004) *Design Criteria and Performance Standards for Urban Drainage Systems: Is Historic Practice Still Good Enough?* [online]. Available from <http://www.fwr.org/wapug/wapugdes.pdf> [7 March 2014]

Gallay, M. (2008) 'Assessment of DTM quality: a case study using fine spatial resolution data from alternative sources'. In: Lambrick, D. (ed.) *Proceedings of the GIS Research UK 16th Annual Conference.* Held April 2 – 4 2008 at Manchester Metropolitan University. Manchester: Manchester Metropolitan University: 156-162

Gaston, K.J., Warren, P.H., Thompson. K. and Smith, R.M. (2005) 'Urban domestic gardens (IV): the extent of the resource and its associated features'. *Biodiversity and Conservation* 14, 3327–3349

GeoPerspectives (2009) *Aerial photography of Coventry 2007*. [Dataset] Available from Coventry City Council [30 June 2010]

Getter, K.L., Rowe, D.B. and Andresen, J.A. (2007) 'Quantifying the effect of slope on extensive green roof stormwater retention'. *Ecological Engineering* 31, 225–231

Gill, E. (2008) *Making Space for Water: Urban flood risk & integrated drainage (HA2) - Integrated Urban Drainage pilot summary report* [online]. London: Defra. Available from <http://archive.defra.gov.uk/environment/flooding/documents/manage/surfacewater/urbandrainagereport.pdf> [29 November 2012]

Gill, E. and Catovsky, S. (2007) 'Defra integrated urban drainage pilots studies – an update'. In: *WaPUG Spring Meeting 2007* [online]. Available from <http://www.wapug.org.uk/> [14 January 2008]

Gill, S.E., Handley, J.F., Ennos, A.R. and Pauleit, S. (2007) 'Adapting Cities for Climate Change: The Role of the Green Infrastructure'. *Built Environment* 33 (1), 115-133

Gill, S.E., Handley, J.F., Ennos, A.R., Pauleit, S., Theuray, N. and Lindley, S.J. (2008) 'Characterising the urban environment of UK cities and towns: A template for landscape planning'. *Landscape and Urban Planning* 87, 210–222

Gilmour, D. and Blackwood, D. (2006) 'Mapping Stakeholder Interactions and Information Exchanges. Case Study Renfrewshire Council'. In: *WaND Water Cycle Management for new developments* [CD-ROM]

Gloucestershire County Council (2007) *Scrutiny Inquiry into the Summer Emergency 2007* [online]. Available from < http://www.longlevens-flooded.co.uk/documents/inquiry_report.pdf> [7 March 2014]

Google Inc. (2008) *Google Earth* [online]. Available from <http://earth.google.com/> [20 May 2008]

Gordon-Walker, S., Harle, T. and Naismith, I. (2007) *Cost-benefit of SUDS retrofit in urban areas. Science Report SC060024* [online]. Bristol: Environment Agency. Available from <http://a0768b4a8a31e106d8b0-50dc802554eb38a24458b98ff72d550b.r19.cf3.rackcdn.com/scho0408bnxz-e-e.pdf> [21 March 2014]

Government Office for the West Midlands (2008) *Regional Spatial Strategy for the West Midlands* [online] London: The Stationery Office. Available from <http://www.wmra.gov.uk/documents/RSS%20Full%20Doc%20Jan%2008.pdf> [21 March 2014]

Grimm, A. (2007) *The Extent To Which Sustainable Urban Drainage Systems (Suds) Are Considered In Environmental Impact Assessment (EIA)*. M.Sc. thesis submitted to the University of East Anglia [online]. Available from <http://www.uea.ac.uk/env/all/teaching/eiaams/pdf_dissertations/2007/Grimm_Alex.pdf> [21 March 2014]

Halcrow Group Limited (2008a) *Telford and Wrekin Council: Sustainable Drainage Systems for Local Development Framework* [online]. Available from <http://www.telford.gov.uk/site/scripts/downloads.aspx?categoryID=1004> [29 November 2012]

--. (2008b) *Coventry City Council Strategic Flood Risk Assessment. Level 2, Canley Site* [online]. Available from <http://www.coventry.gov.uk/download/downloads/id/1611/appendix_c-level_2_sfra_canley_site> [5 September 2013]

Harries, T. and Penning-Rowsell, E. (2011) 'Victim pressure, institutional inertia and climate change adaptation: The case of flood risk'. *Global Environmental Change* 21, 188–197

Heal, K.V. (2000) ‘SUDS ponds in Scotland - performance outcomes to date’. In: Pratt, C.J. (ed.) *Proceedings of the Twentieth Meeting of the Standing Conference on Stormwater Source Control*. Edinburgh: 1-8

Heal, K. (2010) ‘SUDS: habitat values and water chemistry-ecology interactions’. In: *World Wetlands Day Conference 2010, Wetlands, Biodiversity and Climate Change: Linking Policy, Research and Practice*. Held 2-3 February, Peterborough.

Heal, K.V., Bray, R., Willingale, S.A.J., Briers, M., Napier, F., Jefferies, C. and Fogg, P. (2009) ‘Medium-term performance and maintenance of SUDS: a case study of Hopwood Park Motorway Service Area, UK’. *Water Science and Technology* 59 (12), 2485-2494

Heal, K., McLean, N. and D’Arcy, B. (2004) ‘SUDS and Sustainability’. In: Newman, A.P., Davies, J. and Blakeman, J. (eds) *Proceedings of the Twenty-Sixth Meeting of the Standing Conference on Stormwater Source Control*. Held September 7 2004 at the Business and Learning Conference Centre, Dunfermline. Coventry: Coventry University: 47-56

Hellström, D., Jeppsson, U. and Kärrman, E. (2000) ‘A framework for systems analysis of sustainable urban water management’. *Environmental Impact Assessment Review* 20, 311–321

Hill, J., Rhodes, G., Vollar, S. and Whapples, C. (2005) *Car park designers’ handbook* [online]. London: Thomas Telford Publishing. Available from <http://www.ice.org.uk/bookshop/SampleChapters/Car%20park%20designers%20handbook.pdf> [30 June 2013]

Hirschman, D., Collins, K. and Schueler, T. (2008) *Technical Memorandum: The Runoff Reduction Method* [online]. Available from <http://www.cwp.org/Downloads/ExtremeBMP/RRTechMemo.pdf> [6 May 2008]

Historic Coventry (2008) *Street Maps* [online]. Available from <http://www.historiccoventry.co.uk/covmaps/allmaps.php> [9 June 2008]

House of Lords Science and Technology Committee (2006) *Water Management Volume I: Report. HL Paper 191-I* [online]. Available from <http://www.publications.parliament.uk/pa/ld200506/ldselect/ldsctech/191/191i.pdf> [21 March 2014]

Howe, J. and White, I. (2001) 'Flooding: Are We Ignoring the Real Problem and Solution?'. *Regional Studies* 35 (4), 368-370

HR Wallingford Ltd. (2007) *Dti SAM - System Based Analysis and Management of Urban Flood Risks: Project Overview* [online] Release 1.1. Available from <http://www.dti-sam.co.uk/documents/EX5445%20-%20DTI%20SAM-Project%20Overview-R1.1.pdf> [8 January 2008]

--. (2008) *UK Stormwater Drainage: Guidance and Tools* [online]. Available from <http://gamma.hrwallingford.co.uk/UKStormwaterDrainage/index.htm> [27 April 2011]

Hughes, A. (2008) *Understanding and simulation of groundwater flooding: An urban perspective* [online]. Available from <http://issues.abertay.ac.uk/Seminar3Agenda.htm> [21 March 2014]

Hunt, G. and West, B. (2007) 'Developments in Oxfordshire with SUDS' [online]. In: *CIRIA Landform Conference Delivering sustainable drainage on the ground*. Held at the Royal Academy of Engineering, London, 20 September:8-9. Available from <http://www.ciria.com/landform/event_report_downloads.htm#20September07> [21 March 2014]

Hurley, L., Mounce, S., Ashley, R., Butler, D. and Memon, F.A. (2007) ‘Flexible Process Frameworks for the Evaluation of Relative Sustainability in Water Management Decisions’. *International Journal of Technology, Knowledge and Society* 2 (7), 57-67

Hurley, L., Ashley, R. and Mounce, S. (2008) ‘Addressing practical problems in sustainability assessment frameworks’. *Proceedings of the Institution of Civil Engineers: Engineering Sustainability* 161 (ES1), 23 – 30

Hutchinson, M.F. (1989) 'A new procedure for gridding elevation and stream line data with automatic removal of spurious pits'. *Journal of Hydrology* 106, 211-232

Hyde, M.L. (2006) *Urban Runoff Quality in the River Sowe Catchment*. PhD Thesis submitted to Coventry University

Hyder Consulting (UK) Ltd (2004) *Retrofitting Sustainable Urban Drainage Systems: Case Study - Dunfermline. Report No: NE02351/D1* [online]. Available from <http://www.scotland.gov.uk/Resource/Doc/1057/0004700.pdf> [21 March 2014]

Institution of Civil Engineers (2006) *The State of the Nation 2006: An Assessment of the UK's Infrastructure* [online]. Available from <http://www.ice.org.uk/getattachment/36881afa-2bda-4dba-8d26-ef340058d0c6/State-of-the-Nation-2006.aspx> [7 March 2014]

Ipswich Borough Council (2007) *Draft Strategic Flood Risk Assessment* [online]. Available from <http://www.ipswich.gov.uk/site/scripts/download_info.php?downloadID=450&fileID=892> [29 November 2012]

Ira, S.J.T., Vesely, E-T. and Krausse, M. (2008) ‘Life Cycle Costing of Stormwater Treatment Devices: A Practical Approach for New Zealand’. In: *11th International Conference on Urban Drainage*. Held 31 August - 5 September 2008 in Edinburgh, Scotland: 10 pages

Iwugo, K.O., Andoh, R.Y.G. and Feest, A.F. (2002) ‘Cost-Effective Integrated Drainage and Wastewater Management Systems’. *Journal of CIWEM* 16, 53-57

Jackson, J. (2008) *Communicating ecological values in development and planning: developing trans-disciplinary skills* [online]. Available from <http://issues.abertay.ac.uk/Seminar3Agenda.htm> [21 March 2014]

Jackson, J.I. and Boutle, R. (2008) ‘Ecological functions within a Sustainable Urban Drainage System’. In: *11th International Conference on Urban Drainage*. Held 31 August - 5 September 2008 in Edinburgh, Scotland: 10 pages

Jacobs Gibb Ltd (2008) *Growth Point Studies - Coventry* [online]. Available from <http://www.coventry.gov.uk/ccm/cms-service/stream/asset/?asset_id=17760349> [7 July 2010]

Jefferies, C., Aitken, A., McLean, N., MacDonald, K. and McKissock, G. (1999) ‘Assessing the Performance of Urban BMPs in Scotland’. *Water Science and Technology* 39 (12), 123–131

Jefferies, C., Duffy, A., Berwick, N., McLean, N. and Hemingway, A. (2009) 'Sustainable Urban Drainage Systems (SUDS) treatment train assessment tool'. *Water Science & Technology* 60 (5), 1233-1240

Johnson, R. and Hering, D. (2004) *Standardisation of river classifications (STAR): Framework method for calibrating different biological survey results against ecological quality classifications to be developed for the Water Framework Directive. Strategy paper for the suitability of individual organism groups* [online]. Available from <http://www.eu-star.at/pdf/Deliverable12.pdf> [21 March 2014]

Johnston, J. and Newton, J. (2004) *Building Green: A guide to using plants on roofs, walls and pavements* [online]. London: Greater London Authority. Available from <http://legacy.london.gov.uk/mayor/strategies/biodiversity/docs/Building_Green_main_text.pdf> [7 March 2014]

Jones, P. and Macdonald, N. (2007) ‘Making space for unruly water: Sustainable drainage systems and the disciplining of surface runoff’. *Geoforum* 38, 534–544

Kellagher, R. (2004a) *Preliminary rainfall runoff management for developments. Technical Report W5-074A/TR/1 Revision B* [online]. Available from <http://www.environment-agency.gov.uk/commondata/acrobat/w5_074a_trrevb_918035.pdf> [21 April 2008]

Kellagher, R. (2004b) *Drainage of Development Sites – a Guide (X108)*. London and Wallingford: CIRIA and HR Wallingford

Kirby, A. (2005) ‘SuDS - innovation or a tried and tested practice?’. *Proceedings of the Institution of Civil Engineers: Municipal Engineer* 158 (ME2), 115–122

Knapton, J., Cook, I.D. and Morrell, D. (2002) *A New Design Method for Permeable Pavements Surfaced with Pavers* [online]. Available from <http://www.john-knapton.com/Permeable.html> [21 March 2014]

Lashford, C., Charlesworth, S., Warwick, F. and Blackett, M. (2014) ‘Deconstructing the sustainable drainage management train in terms of water quantity; preliminary results for Coventry, UK’. *CLEAN – Soil, Air, Water* 42 (2), 187-192

Leeds City Council (2009) *Wyke Beck, Leeds, Surface Water Management Plan. Final Report To Defra On the Emerging Plan and Feedback on the SWMP Guidance* [online]. Available from <http://archive.defra.gov.uk/environment/flooding/documents/manage/surfacewater/swmp1-leeds.pdf> [21 March 2014]

Lelliott, M.R., Bridge, D.Mc.C., Kessler, H., Price, S.J. and Seymour, K.J. (2006) 'The application of 3D geological modelling to aquifer recharge assessments in an urban environment'. *Quarterly Journal of Engineering Geology and Hydrogeology* 39 (3), 293-302

LGA (Local Government Association) (2006) *Planning Policies for Sustainable Building: Guidance for Local Development Frameworks* [online]. Available from <http://wwarchive.brix.fatbeehive.com/images/site/Policy/planning%20policies%20complete.pdf> [21 March 2014]

--. (2011) *Framework to assist the development of the Local Strategy for Flood Risk Management* [online]. 2nd edition. Available from <http://www.local.gov.uk/web/guest/local-flood-risk-management/-/journal_content/56/10171/3618366/ARTICLE-TEMPLATE> [1 August 2012]

--. (2012) *Consultation on the Implementation of the Sustainable Drainage Systems provisions in Schedule 3 of Flood and Water Management Act 2010. Draft Response from the Local Government Association (LGA)* [online]. Available from <http://www.local.gov.uk/c/document_library/get_file?uuid=96610780-f8de-4705-81d3-c660650e567b&groupId=10171> [29 November 2012]

Livingroofs.org and Ecology Consultancy Ltd. (2004) *Green Roofs: Benefits and cost implications* [online]. Available from <http://www.sustainable-eastside.net/Green%20Roofs%20Report%202.07.05.pdf> [19 November 2007]

London Assembly Environment Committee (2005) *Crazy Paving: The environmental importance of London's front gardens*. London: Greater London Authority [online]. Available from <http://www.london.gov.uk/assembly/reports/environment/frontgardens.pdf> [6 May 2008]

Longley, P.A., Goodchild, M.F., Maguire, D.J. and Rhind, D.W. (2005) *Geographic Information Systems and Science*. 2nd edition. Chichester: John Wiley & Sons

Loram, A., Tratalos, J., Warren, P.H. and Gaston, K.J. (2007) 'Urban domestic gardens (X): the extent & structure of the resource in five major cities'. *Landscape Ecology* 22, 601–615

Maksimović, C., Prodanović, D., Boonya-Aroonnet, S., Leitão, J.P., Djordjević, S. and Allitt, R. (2009) 'Overland flow and pathway analysis for modelling of urban pluvial flooding'. *Journal of Hydraulic Research* 47 (4), 512–523

Marshall, D.C.W. and Bayliss, A.C. (1994) *Flood estimation for small catchments. Institute of Hydrology Report No. 124* [online]. Available from <http://www.ceh.ac.uk/products/publications/documents/IH124FLOODESTIMATIONSMALLCATCHMENTS.PDF> [6 June 2008]

McKissock, G., Jefferies, C. and D'Arcy, B.J. (1999) 'An Assessment of Drainage Best Management Practices in Scotland'. *Journal of CIWEM* 13, 47-51

McKissock, G., D'Arcy, B.J., Wild, T.C., Usman, F. and Wright, P.W. (2003) 'An Evaluation of SuDS guidance in Scotland'. In: *Diffuse Pollution Conference Dublin 2003* [online]. Available from <http://www.ucd.ie/dipcon/docs/theme04/theme04_03.PDF> [21 March 2014]

Mentens, J., Raes, D. and Hermy, M. (2006) 'Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century?'. *Landscape and Urban Planning* 77, 217–226

Microsoft Corporation (2008) *Live Search Maps* [online]. Available from <http://maps.live.com/> [20 May 2008]

Middlesex University (2003) *Review of the Use of stormwater BMPs in Europe. Report 5.1 of the Adaptive Decision Support System (ADSS) for the Integration of Stormwater Source Control into Sustainable Urban Water Management Strategies (DayWater)* [online]. Available from <http://www.enpc.fr/cereve/HomePages/foerster/DAYWATER-files/Reports/D5-1.pdf> [19 October 2011]

Mitchell, G. (2005) 'Mapping hazard from urban non-point pollution: a screening model to support sustainable urban drainage planning'. *Journal of Environmental Management* 74, 1–9

Mitchell, G., McDonald, A. and Lockyer, J. (2001) *Pollution Hazard from Urban Non-Point Sources: A GIS Model to Support Strategic Environmental Planning in the UK* [online]. Available from <http://www.geog.leeds.ac.uk/projects/nps/> [21 March 2014]

Montalto, F., Behr, C., Alfredo, K., Wolf, M., Arye, M. and Walsh, M. (2007) 'Rapid assessment of the cost-effectiveness of low impact development for CSO control'. *Landscape and Urban Planning* 82, 117–131

Moore, S.L., Stovin, V.R., Wall, M. and Ashley, R.M. (2012) 'A GIS-based methodology for selecting stormwater disconnection opportunities'. *Water Science & Technology* 66 (2), 275-283

Moran, A., Hunt, B. and Jennings, G. (2004) *A North Carolina Field Study to Evaluate Greenroof Runoff Quantity, Runoff Quality, and Plant Growth* [online]. Available from <http://www.bae.ncsu.edu/greenroofs/GRHC2004paper.pdf> [21 March 2014]

Morrow, B. (2008) 'Integrated Urban Drainage – An English perspective'. In: *11th International Conference on Urban Drainage*. Held 31 August - 5 September 2008 in Edinburgh, Scotland

Morrow, B. and Doncaster, S. (2007) 'Integrated Urban Drainage : A year in the life of a Pilot Project'. In: *WaPUG Autumn Conference 2007* [online]. Available from <http://www.wapug.org.uk/> [14 January 2008]

NAO (National Audit Office) (2007) *Environment Agency: Building and maintaining river and coastal flood defences in England* [online]. Available from <http://www.nao.org.uk/wp-content/uploads/2007/06/0607528.pdf> [21 March 2014]

--. (2010) *Environment Agency: Tackling diffuse water pollution in England* [online]. London: The Stationery Office. Available from <http://www.nao.org.uk/wp-content/uploads/2010/07/1011188.pdf> [21 March 2014]

Napier, F., Jefferies, C., Heal, K. V., Fogg, P., D. Arcy, B. J. and Clarke, R. (2009) 'Evidence of traffic-related pollutant control in soil-based Sustainable Urban Drainage Systems (SUDS)' *Water Science & Technology* 60 (1), 221-230

National SuDS Working Group (2004) *Interim Code of Practice for Sustainable Drainage Systems* [online]. Available from <http://www.ciria.org.uk/suds/pdf/nswg_icop_for_suds_0704.pdf> [21 March 2014]

Natural England (2010) *GIS Digital Boundary Datasets* [online]. Available from <http://www.gis.naturalengland.org.uk/default.asp> [12 July 2010]

NCDENR (North Carolina Department of Environment and Natural Resources) (2005) *Updated Draft Manual of Stormwater Best Management Practices* [online]. Available from <http://infohouse.p2ric.org/ref/41/40159.pdf> [7 March 2014]

NERC (Natural Environment Research Council) (1975) *Flood Studies Report*. 5 vols. London: NERC

Newman, A.P., Puehmeier, T., Kwok, V., Lam, M., Coupe, S.J., Shuttleworth, A. and Pratt, C.J. (2004) 'Protecting groundwater with oil-retaining pervious pavements: historical perspectives, limitations and recent developments'. *Quarterly Journal of Engineering Geology and Hydrogeology* 37, 283–291

Newton, J., Gedge, D., Early, P. and Wilson, S. (2007) *BUILDING GREENer: Guidance on the use of green roofs, green walls and complementary features on buildings. Publication C644*. London: CIRIA

Nicholls Colton Geotechnical (2012) *Ground Investigation Report for Proposed Residential Development at Prior Deram Walk, Canley* [online]. Available from <http://planning.coventry.gov.uk/portal/servlets/AttachmentShowServlet?ImageName=1048764> [5 September 2013]

North West Green Infrastructure Unit (2009) *A Green Infrastructure Mapping Method* [online]. Available from <http://www.greeninfrastructurenw.co.uk/resources/A_Green_Infrastructure_Mapping_Method.pdf> [21 June 2010]

NSRI (National Soil Resources Institute) (2010) *Soilscapes* [online]. Available from <http://www.landis.org.uk/soilscapes/> [12 May 2010]

Oberlander, C.H., Whitelaw, E. and Matsuzaki, E. (2002) *Introductory Manual for Greening Roofs for Public Works and Government Services, Canada* [online]. Available from <http://www.sustainweb.org/pdf2/PWGSC_GreeningRoofs_wLinks.pdf> [7 March 2014]

ODPM (Office of the Deputy Prime Minister) (2002) *Building Regulations part H: Drainage and Waste Disposal 2002 Edition* [online]. Available from <http://www.planningportal.gov.uk/buildingregulations/approveddocuments/parth/approved> [7 March 2014]

--. (2006) *National Land Use Database: Land Use and Land Cover Classification. Version 4.4* [online]. Available from <http://www.communities.gov.uk/documents/planningandbuilding/pdf/144275> [6 May 2008]

Ofwat (Water Services Regulation Authority) (2008) *Preparing for the future – Ofwat's climate change policy statement* [online]. Available from <http://www.ofwat.gov.uk/sustainability/climatechange/pap_pos_climatechange.pdf> [21 March 2014]

Old, R.A. (1988) *Geological notes and local details for 1:10 000 sheet SP 37 NW (Coventry Central)*. Keyworth: British Geological Survey

Old, R.A., Bridge, D.Mc.C. and Rees, J.G. (1990) *Geology of the Coventry Area. Technical Report WA/89/29*. Keyworth: British Geological Survey

Orford, S. and Radcliffe, J. (2007) 'Modelling UK residential dwelling types using OS Mastermap data: A comparison to the 2001 census'. *Computers, Environment and Urban Systems* 31, 206–227

OST (Office of Science and Technology) (2004) *Foresight: Future Flooding - Executive Summary* [online]. Available from <http://www.bis.gov.uk/assets/foresight/docs/flood-and-coastal-defence/executive_summary.pdf> [7 March 2014]

Pahl-Wostl, C. (2005) 'Information, public empowerment, and the management of urban watersheds'. *Environmental Modelling and Software* 20, 457-467

Palla, A., Berretta, C., Lanza, L.G. and La Barbera, P. (2008) 'Modelling storm water control operated by green roofs at the urban catchment scale'. In: *11th International Conference on Urban Drainage*. Held 31 August - 5 September 2008 in Edinburgh, Scotland

Palmer, T.C. and Shan, J. (2002) 'A Comparative Study on Urban Visualization Using LIDAR Data in GIS'. *Journal of the Urban and Regional Information Systems Association* 14 (2), 19-26

Parliamentary Office of Science and Technology (2007) *Postnote 289: Urban Flooding* [online]. Available from <http://www.parliament.uk/documents/post/postpn289.pdf> [7 March 2014]

Pauleit, S. and Duhme, F. (2000) 'Assessing the environmental performance of land cover types for urban planning'. *Landscape and Urban Planning* 52, 1-20

Pauleit, S., Ennos, R. and Golding, Y. (2005) 'Modeling the environmental impacts of urban land use and land cover change—a study in Merseyside, UK'. *Landscape and Urban Planning* 71, 295–310

Peck, S. and Kuhn, M. (c.2001) *Design guidelines for green roofs* [online]. Available from <http://www.cmhc-schl.gc.ca/en/inpr/bude/himu/coedar/upload/Design-Guidelines-for-Green-Roofs.pdf> [7 March 2014]

Perry, T. and Nawaz, R. (2008) 'An investigation into the extent and impacts of hard surfacing of domestic gardens in an area of Leeds, United Kingdom' *Landscape and Urban Planning* 86, 1–13

PGCDER (Prince George's County, Maryland, Department of Environmental Resources) (1999) *Low-Impact Development Hydrologic Analysis* [online]. Available from <http://www.lowimpactdevelopment.org/pubs/LID_Hydrology_National_Manual.pdf> [7 March 2014]

Pielke Jr., R. (2007) ‘Mistreatment of the economic impacts of extreme events in the Stern Review Report on the Economics of Climate Change’. *Global Environmental Change* 17, 302–310

Pitney Bowes (2003) *MapInfo Professional* (version 7.5) [Computer Program]. Available from Pitney Bowes Software Inc., One Global View, Troy, NY 12180, USA

Pitt Review (2008) *Learning lessons from the 2007 floods. An independent review by Sir Michael Pitt: Final Report* [online]. Available from <http://webarchive.nationalarchives.gov.uk/+/http://www.cabinetoffice.gov.uk/thepittreview/final_report.aspx> [29 November 2012]

Planning Inspectorate (2013) *Coventry City Council Core Strategy DPD Examination* [online]. Available from <http://www.coventry.gov.uk/info/2000870/core_strategy_examination_in_public_2012/1707/coventry_core_strategy_examination_in_public_2012> [1 March 2013]

Prisloe, S., Giannotti, L., and Sleavin, W. (2000) ‘Determining Impervious Surfaces for Watershed Modeling Applications’. In: *Proceedings of the 8th National Nonpoint Source Monitoring Conference.* Held September 10 -14 2000 in Hartford, Connecticut [online]. Available from <http://nemo.uconn.edu/tools/impervious_surfaces/pdfs/Prisloe_etal_2000.pdf> [23 November 2007]

Prisloe, S., Lei, Y. and Hurd, J. (2001) ‘Interactive GIS-based Impervious surface Model’. In: *ASPRS 2001 Annual Convention, St. Louis, MO, April 23-27* [online]. Available from <http://nemo.uconn.edu/tools/impervious_surfaces/pdfs/Prisloe_etal_2001.pdf> [7 March 2014]

Prisloe, S., Wilson, E.H. and Arnold, C. (2003) *Refinement of Population-Calibrated Land-Cover-Specific Impervious Surface Coefficients for Connecticut* [online]. Available from <http://nemo.uconn.edu/tools/impervious_surfaces/pdfs/Prisloe_etal_2003.pdf> [7 March 2014]

Purdue Research Foundation (2004) *L-THIA (Long-Term Hydrologic Impact Assessment) model* [online]. Available from <https://engineering.purdue.edu/mapserve/LTHIA7/lthianew> [7 March 2014]

Quantum GIS (2012) *Quantum GIS* (version 1.8.0) [Computer Program]. Available from <http://www.qgis.org> [29 June 2013]

Queen Margaret University, Edinburgh (2008) *Sustainability Credentials* [online]. Available from <http://www.qmuc.ac.uk/the_university_college/sustainable_credentials.htm> [28 January 2008]

Quek, B.S., Heal, K., Duffy, A. and Apostolaki, S. (2011) ‘Public perception and amenity value of stormwater retention ponds’. . In: *SUDSnet / CIWEM National and International meeting* [online]. Held 11-12 May at University of Abertay Dundee. Available from <http://sudsnet.abertay.ac.uk/May%202011/Heal_Public%20Perception%20&%20Amenity%20of%20Stormwater%20Retention%20Ponds.pdf> [15 August 2013]

Rawlinson, S. (2006) ‘Drainage systems’. *Building* 31, 68-70

RCEP (Royal Commission on Environmental Pollution) (2007) *The Urban Environment* [online]. Available from <http://www.rcep.org.uk/reports/26-urban/documents/urban-environment.pdf> [26 April 2010]

Reed, D. (2007) ‘Floods: feast and famine’. In: *WaPUG Autumn Conference 2007* [online]. Available from <http://www.wapug.org.uk/> [14 January 2008]

Revitt, D.M., Ellis, J.B. and Scholes, L. (2003) *Criteria Relevant to the Assessment of BMP Performance Report 5.2 of the Adaptive Decision Support System (ADSS) for the Integration of Stormwater Source Control into Sustainable Urban Water Management Strategies (DayWater)* [online]. Available from <http://daywater.enpc.fr/www.daywater.org/> [11 January 2008]

Revitt, M., Ellis, B., Shutes, B. and Scholes, L. (2004) *SuDS Research at Middlesex*

University [online]. Available from <http://sudsnet.abertay.ac.uk/documents/MikeRevittetal_SUDSResearchatMiddlesexUniversity.pdf> [21 March 2014]

Revitt, D.M., Scholes, L. and Ellis, J.B. (2008) 'A pollutant removal prediction tool for stormwater derived diffuse pollution'. *Water Science & Technology* 57 (8), 1257-1264

RHS (Royal Horticultural Society) (c.2005) *Front Gardens: Are we parking on our gardens? Do driveways cause flooding?* [online]. Available from <http://www.rhs.org.uk/Gardening/Sustainable-gardening/pdfs/FrontGardens> [21 March 2014]

Richardson, G.R.A. and Lynes, J.K. (2007) 'Institutional motivations and barriers to the construction of green buildings on campus. A case study of the University of Waterloo, Ontario'. *International Journal of Sustainability in Higher Education* 8 (3), 339-354

River Restoration Centre (2002) *The River Skerne* [online]. Available from <www.therrc.co.uk> [20 December 2006]

Robert Bray Associates and Islington Council (2010) *Promoting Sustainable Drainage Systems. Design Guidance for Islington* [online]. Available from <http://www.islington.gov.uk/services/parks-environment/sustainability/sus_water/Pages/SUDS.aspx> [21 March 2014]

Royse, K.R., Reeves, H.J. and Gibson, A.G. (2008) 'The modelling and visualisation of digital geoscientific data as an aid to land-use planning in the urban environment, an example from the Thames Gateway'. In: Liverman, D.G.E., Pereira, C. and Marker, B. (eds.) *Communicating Environmental Geoscience* [online]. London: Geological Society. Available from <http://nora.nerc.ac.uk/4822/1/D81C305.pdf> [21 March 2014]

RPS Planning and Development (2012) *Flood Risk Assessment: Prior Deram Walk, Canley, Coventry* [online]. Available from <http://planning.coventry.gov.uk/portal/servlets/AttachmentShowServlet?ImageName=1048762> [5 September 2013]

Rutter, H.K., Cunningham, J., Jackson, C.R. and Lewis, M. (2006) *Hydrogeological parameterisation of the Thames Gateway GSI3D model. British Geological Survey Internal Report, IR/06/042* [online]. Keyworth: British Geological Survey. Available from <http://nora.nerc.ac.uk/7190/1/IR06042.pdf> [14 July 2010]

Schmitt, T.G., Thomas, M. and Ettrich, N. (2004) 'Analysis and modeling of flooding in urban drainage systems'. *Journal of Hydrology* 299, 300–311

Scholz, M. (2006) 'Decision-support tools for sustainable drainage'. *Proceedings of the Institution of Civil Engineers: Engineering Sustainability* 159 (ES3), 117–125

Scholz-Barth, K. (2001) *Green Roofs: Stormwater Management From the Top Down* [online]. Available from <http://www.edcmag.com/CDA/Archives/d568f635d8697010VgnVCM100000f932a8c0____> [12 November 2007]

Scottish Water (2007) *Sewers for Scotland* 2nd edition *Down* [online]. Available from <http://www.scottishwater.co.uk/you-and-your-home/connecting-your-home/sewers-for-scotland-and-suds/sewers-for-scotland-2nd-edition> [17 March 2014]

Schueler, T. and Kitchell, A. (2005) *Methods to Develop Restoration Plans for Small Urban Watersheds* [online] Version 2.0. Ellicott City, Maryland: Center for Watershed Protection Available from <http://www.cwp.org/online-watershed-library/cat_view/64-manuals-and-plans/80-urban-subwatershed-restoration-manual-series> [7 March 2014]

Schueler, T., Hirschman, D., Novotney, M. and Zielinski, J. (2007) *Urban Stormwater Retrofit Practices*. Ellicott City, Maryland: Center for Watershed Protection [online]. Available from <http://actrees.org/files/Research/cfwp_manual3.pdf> [7 March 2014]

SEPA (Scottish Environment Protection Agency) (2005) *A DOs and DON'Ts Guide for Planning and Designing Sustainable Urban Drainage Systems (SuDS)* [online]. Available from <http://www.sepa.org.uk/customer_information/idoc.ashx?docid=871d1682-f4de-4b49-acd0-013e8b7ce4ee&version=-1> [26 April 2010]

--. (2014) *The Water Environment (Controlled Activities) (Scotland) Regulations 2011 (as amended): A Practical Guide Version 7.1 March 2014* [online]. Available from <http://www.sepa.org.uk/water/idoc.ashx?docid=f8e4798e-2cab-4ceb-968b-f2a10d7fd8e7&version=-1> [18 March 2014]

Severn Trent Water (c.2005) *Finham Sewage Treatment Works* [online]. Available from <http://www.stwater.co.uk/upload/pdf/Finham.pdf> [21 March 2014]

--. (2006) *Surface Water Drainage: claiming lower sewerage charges* [online]. Available from <http://www.stwater.co.uk/upload/pdf/SURFACE_WATER.pdf> [7 March 2014]

--. (2007) *Central Coventry Sewer Records 1:2500*. Birmingham: Severn Trent Water Limited

--. (2008) *Water Resources Management Plan 2009: Draft version May 2008* [online]. Available from <http://www.stwater.co.uk/server.php?show=nav.6186> [23 June 2008]

--. (2009) *Latest assessment of the supply / demand balance* [online]. Available from <http://www.stwater.co.uk/upload/pdf/2_-_Latest_assessment_of_the_supply_demand_balance.pdf> [6 April 2009]

Sharma, A.K., Gray, S., Diaper, C., Liston, P. and Howe, C. (2008) 'Assessing integrated water management options for urban developments – Canberra case study'. *Urban Water Journal* 5 (2), 147–159

Shaver, E., Horner, R., Skupien, J., May, C. and Ridley, G. (2007) *Fundamentals of Urban Runoff Management: Technical and Institutional Issues* [online]. 2nd edition. Madison, Wisconsin: North American Lake Management Society. Available from <http://www.nalms.org/nalmsnew/Nalms_Publication.aspx?Sid=3> [6 April 2010]

Shoemaker, L., Riverson Jr, J., Alvi, K., Zhen. J.X., Paul, S. and Rafi, T. (2009) *SUSTAIN - A Framework for Placement of Best Management Practices in Urban Watersheds to Protect Water Quality* [online]. Available from <http://www.epa.gov/nrmrl/pubs/600r09095.html> [5 September 2013]

Shoemaker, L., Riverson Jr, J., Alvi, K., Zhen. J.X. and Murphy, R. (2011) *Report on Enhanced Framework (SUSTAIN) and Field Applications for Placement of BMPs in Urban Watersheds* [online]. Available from <http://nepis.epa.gov/EPA/html/DLwait.htm?url=/Exe/ZyPDF.cgi?Dockey=P100DEWI.PDF> [11 July 2013]

Shuster, W.D., Bonta, J., Thurston, H., Warnemuende, E. and Smith, D.R. (2005) 'Impacts of impervious surface on watershed hydrology: A review'. *Urban Water Journal*, 2 (4), 263–275

Shutes, B. (2008) *SWITCH WP2.1 Deliverable 2.1.2. Part B: The potential of BMPs to integrate with existing infrastructure (i.e. retro-fit/hybrid systems) and to contribute to other sectors of the urban water cycle* [online]. Available from <http://www.switchurbanwater.eu/outputs/pdfs/W2-1_GEN_MAN_D2.1.2b_Design_manual_Part_B.pdf> [20April 2011]

Sieker, H., Bandermann, S., Becker, M. and Raasch, U. (2006) *Urban Stormwater Management Demonstration Projects in the Emscher Region* [online]. Available from <http://switchurbanwater.lboro.ac.uk/outputs/pdfs/CEMS_PAP_Urban_stormwater_management_demo_projects_Emscher.pdf> [26 April 2010]

Singh, R., Jefferies, C., Stovin, V., Morrison, G. and Gillon, S. (2005) ‘Developing a planning and design framework for retrofit SUDS’. In: *10th International Conference on Urban Drainage*. Held at Copenhagen, Denmark, 21-26 August

Sleavin, W.J., Civco, D.L., Prisloe, S. and Giannotti. L. (2000) *Measuring Impervious Surfaces for Non-point Source Pollution Modelling* [online]. Available from <http://nemo.uconn.edu/tools/impervious_surfaces/pdfs/Sleavin_etal_2000.pdf> [7 March 2014]

Smith, C., Dawson, D., Archer, J., Davies, M., Frith, M., Hughes, E. and Massini, P. (2011) *From green to grey; observed changes in garden vegetation structure in London, 1998-2008*. London: London Wildlife Trust, Greenspace Information for Greater London, and Greater London Authority.

Smith, R.M, Gaston, K.J., Warren, P.H. and Thompson. K. (2005) 'Urban domestic gardens (V): relationships between landcover composition, housing and landscape'. *Landscape Ecology* 20, 235–253

Smith, T. (2007) ‘Integrated Urban Drainage: Lessons from the Birmingham Pilot’. In: *WaPUG Autumn Conference 2007* [online]. Available from <http://www.wapug.org.uk/> [14 January 2008]

SNIFFER (Scotland and Northern Ireland Forum for Environmental Research) (2004) *SuDS in Scotland - The Monitoring Programme. Project SR (02)51* [online]. Available from <http://sudsnet.abertay.ac.uk/SNIFFERReport0251.htm> [21 March 2014]

--. (2006) *Retrofitting Sustainable Urban Water Solutions. Project UE3(05)UW5* [online]. Available from <http://www.retrofit-suds.group.shef.ac.uk/downloads/UE3(05)UW5%5B1%5D.pdf> [29 November 2012]

Soil Environment Services Ltd (2008) *Agricultural Land Classification: Allesley / Kerseley* [*sic*], *Coventry* [online]. Available from <http://www.coventry.gov.uk/download/downloads/id/1782/agricultural_land_classification_allesley_and_keresley_report> [21 March 2014]

Sommer, H., Sieker, H. and Post, M. (2008) ‘Experiences with decentralized Inlet-filtration-systems on highly frequented roads’. In: *11th International Conference on Urban Drainage*. Held 31 August - 5 September 2008 in Edinburgh, Scotland

SPSS Inc. (2009) *PASW Statistics Release 17.0.2* [Computer Program]. Available from SPSS Inc., 233 S. Wacker Drive, 11th floor, Chicago, Illinois 60606

SSEW (Soil Survey of England and Wales) (1963) *Soil Associations of the West Midlands* London: HMSO

--. (1983) *Soils of Midland and Western England.* Harpenden: SSEW

Stahre, P. (2008) *Blue-green fingerprints in the city of Malmö: Malmö’s way to a sustainable urban drainage* [online]. Malmö, Sweden: VA SYD. Available from <http://www.vasyd.se/~/media/Documents/Broschyrer/Publikationer/BlueGreenFingerprintsPeterStahrewebb.ashx> [21 March 2014]

Stephens, W.B. (Ed.) (1969) *A History of the County of Warwick Volume 8: The City of Coventry and Borough of Warwick* [online]. Available from <http://www.british-history.ac.uk/source.aspx?pubid=49> [21 March 2014]

Stovin, V. (2010) 'The potential of green roofs to manage Urban Stormwater'. *Water and Environment Journal* 24, 192–199

Stovin, V.R. and Swan, A.D. (2003) ‘Application of a retrofit SUDS decision-support framework to a UK catchment’. In: Pratt, C.J., Davies, J.W., Newman, A.P. and Perry, J.L. (eds.) *Proceedings of the Second National Conference on Sustainable Drainage*. Held June 23 - 24 2003 at Coventry University. Coventry: Coventry University: 171-180

Stovin, V., Swan, A. and Moore, S. (2007) *Retrofit SuDS for Urban Water Quality Enhancement* [online]. Available from <http://retrofit-suds.group.shef.ac.uk/downloads/EA&BOCF%20Retrofit%20SUDS%20Final%20Report.pdf> [22 January 2011]

Sustainability West Midlands (2004) *The Potential Impacts of Climate Change in the West Midlands* [online]. Available from <http://www.gos.gov.uk/497745/docs/177226/394408/Climatechangeinthewm> [28 January 2008]

Swaine, R.M. (2002) *An Investigation of Floods in Coventry: A One Hundred Year Study*. Undergraduate Thesis submitted to Coventry University

Swan, A.D. (2002) *A Decision-support System for the Design of Retrofit Sustainable Urban Drainage Systems (SUDS)*. PhD Thesis submitted to the University of Sheffield

Tait, S.J., Ashley, R.M., Cashman, A., Blanksby, J. and Saul, A.J. (2008) 'Sewer system operation into the 21st century, study of selected responses from a UK perspective'. *Urban Water Journal* 5 (1), 79–88

Teemusk, A. and Mander, Ü. (2007) ‘Rainwater runoff quantity and quality performance from a greenroof: The effects of short-term events’. *Ecological Engineering* 30, 271–277

Telford & Wrekin Council (2008) *Integrated Urban Drainage Management Plan* [online]. Available from <http://www.defra.gov.uk/environment/flooding/manage/surfacewater/urbanrisk.htm> [21 June 2010]

TEP (2007) *Green Infrastructure for the West Midlands Region: Technical Mapping Paper* [online]. Available from <http://www.growingourfuture.org/wmwff/taskgroups/gip/tech_map_paper.pdf> [10 March 2010]

Todorovic, Z., Jones, S.W. and Roberts, C. (2008) 'Role of local stakeholder networks in removing barriers to wider SUDS use'. In: *11th International Conference on Urban Drainage*. Held 31 August - 5 September 2008 in Edinburgh, Scotland

Uhl, M. and Schiedt, L. (2008) ‘Green Roof Storm Water Retention –Monitoring Results’. In: *11th International Conference on Urban Drainage*. Held 31 August - 5 September 2008 in Edinburgh, Scotland

USDA (United States Department of Agriculture) (1986) *Urban Hydrology for Small Watersheds. Technical Release 55* 2nd edition. [online]. Available from <ftp://ftp.wcc.nrcs.usda.gov/wntsc/H&H/other/TR55documentation.pdf> [7 March 2014]

USEPA (Unites States Environmental Protection Agency) (2000) *Low Impact Development (LID): A Literature Review* [online]. Available from <https://engineering.purdue.edu/mapserve/LTHIA7/documentation/downloads/effect.pdf> [6 May 2010]

van der Vleuten-Balkema A.J. (2003) *Sustainable Wastewater Treatment – developing a methodology and selecting promising systems*. PhD Thesis, University of Eindhoven [online]. Available from <http://alexandria.tue.nl/extra2/200312971.pdf> [21 March 2014]

Vander Linden, W.K. (2008) *Wet Weather Performance of an Extensive Vegetated Roof in Waterloo, Ontario*. Masters Thesis, University of Waterloo, Canada [online]. Available from <https://uwspace.uwaterloo.ca/bitstream/handle/10012/4135/VanderLinden_William_Kyle_Thesis.pdf> [21 March 2014]

VanWoert, N.D., Rowe, D.B., Andresen, J.A., Rugh, C.L., Fernandez, R.T. and Xiao, L. (2005) ‘Green Roof Stormwater Retention: Effects of Roof Surface, Slope, and Media Depth’. *Journal of Environmental Quality* 34, 1036–1044

Viavattene, C. (2009) *A GIS Data Integration Tool for Assessing Stormwater Management Options: User Guide* [online]. Available from <http://www.switchurbanwater.eu/outputs/pdfs/W2-

3_GEN_MAN_D2.3.2a_GIS_data_integration_tool_user_guide.pdf> [20 April 2011]

Viavattene, C., Scholes, L., Revitt, D.M. and Ellis, J.B. (2008) 'A GIS based decision support system for the implementation of Stormwater Best Management Practices'. In: *Proceedings of the 11th International Conference on Urban Drainage*. Held 31 August - 5 September 2008 in Edinburgh: 9 pages

Viavattene, C., Ellis, J.B., Revitt, D.M., Seiker, H. [*sic*] and Peters, C. (2010) 'The application of a GIS-based BMP selection tool for the evaluation of hydrologic performance and storm flow reduction' [online]. *Proceedings of the 7th International Conference on Sustainable Techniques and Strategies for Urban Water Management, NOVATECH.* Held 28 June – 1 July 2010, Lyons, France. Villeurbanne**,** France: GRAIE (Groupe de Recherche Rhône-Alpes sur les Infrastructures et l'Eau). Available from <http://www.switchurbanwater.eu/outputs/pdfs/W2-1_CBIR_PEC_Application_of_GIS-based_BMP_selection_tool.pdf> [20 April 2011]

Villarreal, E.L. and Bengtsson, L. (2005) 'Response of a Sedum green-roof to individual rain events'. *Ecological Engineering* 25, 1–7

Voogt, J.A. and Oke, T.R. (2003) 'Thermal remote sensing of urban climates'. *Remote Sensing of Environment* 86, 370–384

Wade, S., Fenn, T. and Barnett, C. (2006) *Defra Research Contract: Climate Change Impacts and Adaptation - Cross-regional Research Programme (Project C - Water). Report SR 682 Release 2.0.* Wallingford: HR Wallingford [online]. Available from <http://www.futuredrought.org.uk/SR682%20Climate%20change%20final%20report_r2.pdf> [24 September 2007]

WaND (2007) *Water Cycle Management for New Developments* [online]. Available from <http://www.wand.uk.net/> [28 January 2008]

Warwick, F. and Charlesworth, S.M. (2013) 'Sustainable Drainage Devices for Carbon Mitigation'. *Management of Environmental Quality* 24 (1), 123-136

Warwick University (2007) *Development Masterplan: Flood Risk Assessment* [online]. Available from <http://www2.warwick.ac.uk/about/campusdevelopment/application/flood_risk_assessment.pdf> [7 March 2014]

Warwickshire Wildlife Trust (2013) *Coventry Brooks Plan*. Unpublished report

Water UK/WRc Plc (2006) *Sewers for Adoption – A Design and Construction Guide for Developers*. 6th edition. Swindon: WRc Plc

--. (2007) *Sewers for Scotland* 2nd Edition [online]. Available from <http://www2.scottishwater.co.uk/portal/page/portal/SWE_PGP_CONNECTIONS/SWE_CORP_CONNECTIONS/SWE_CONN_SUDS/20070402SfS2DRAFT%C2%AD_CONSULTATION_%20APRIL_JUNE_07.pdf> [18 March 2014]

Weng, Q. (2001) 'Modeling Urban Growth Effects on Surface Runoff with the Integration of Remote Sensing and GIS'. *Environmental Management* 28 (6), 737–748

Wentz, E.A., Stefanov, W.L., Gries, C. and Hope, D. (2006) 'Land use and land cover mapping from diverse data sources for an [*sic*] arid urban environments'. *Computers, Environment and Urban Systems* 30 (3), 320–346

West Midlands Regional Assembly (2007) *West Midlands Regional Flood Risk Appraisal* [online]. Available from <http://www.wmra.gov.uk/Planning_and_Regional_Spatial_Strategy/Technical_Work.aspx> [21 March 2014]

Wheater, H.S. (2006) 'Flood hazard and management: a UK perspective'. *Philosophical*

Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 364, 2135-2145

White, I. and Alarcon, A. (2009) 'Planning Policy, Sustainable Drainage and Surface Water Management: A Case Study of Greater Manchester'. *Built Environment* 35 (4), 516-530

White, I. and Howe, J. (2004) ‘The mismanagement of surface water’. *Applied Geography* 24, 261–280

Whitford, V., Ennos, A.R. and Handley, J.F. (2001) ‘“City form and natural process” - indicators for the ecological performance of urban areas and their application to Merseyside, UK’. *Landscape and Urban Planning* 57, 91-103

Wild, T.C., Jefferies, C. and D’Arcy, B.J. (2002) *SuDS in Scotland – the Scottish SuDS database. Project SR(02)09* [online]. Available from <http://www.sniffer.org.uk/files/4013/4183/7992/SR0209.pdf> [21 March 2014]

Wilson, C., Clarke, R., D’Arcy, B.J., Heal, K.V. and Wright, P.W. (2005) ‘Persistent pollutants urban rivers sediment survey: implications for pollution control’. *Water Science & Technology* 51 (3-4), 217–224

Wilson, S., Bray, R. and Cooper, P. (2004) *Sustainable Drainage Systems: Hydraulic, structural and water quality advice. C609*. London: Construction Industry Research and Information Association

Wilson, S., Bray, B., Neesam, S., Bunn, S. and Flanagan, E. (2009) *Sustainable Drainage: Cambridge Design and Adoption Guide* [online]. Available from <https://www.cambridge.gov.uk/sites/www.cambridge.gov.uk/files/docs/SUDS-Design-and-Adoption-Guide.pdf> [21 March 2014]

Woods Ballard, B. and Malcolm, M. (2003) ‘Whole Life Costing for Sustainable Drainage Schemes’. In: Pratt, C.J., Davies, J.W., Newman, A.P. and Perry, J.L. (eds.) *Proceedings of the Second National Conference on Sustainable Drainage*. Held June 23 - 24 2003 at Coventry University. Coventry: Coventry University: 181-192

Woods Ballard, B., Kellagher, R., Martin, P., Jefferies, C., Bray, R. and Shaffer, P. (2007) *The SuDS manual (C697).* London: Construction Industry Research and Information Association

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A GIS-based decision support methodology at local planning authority scale for the implementation of sustainable drainage

By

Frank Warwick

September 2013

Volume II - Appendices

A thesis submitted in partial fulfilment of the University's requirements for the Degree of Doctor of Philosophy

Coventry University

Appendices

Summary of Appendices

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Appendix A: Layers

This appendix gives examples of output maps in two formats: GIS Shape files and a layered pdf. The files are contained on the attached CD.

A1 GIS Shape files

Refer to the enclosed shape files

New Developments	**Retrofit**
Detention_NewBuild	Detention_Retrofit_V2
Infiltration_NewBuild_V3	Infiltration_Retrofit_V3
Filtration_NewBuild	Filtration_Retrofit_V2
Conveyance_NewBuild	Conveyance_Retrofit_V3
SourceControl_NewBuild_V2	SourceControl_Retrofit_V3

A2 Adobe Acrobat pdf file

Refer to the file Coventry New Build SUDS Guidance.pdf.

Use the layer option in Acrobat reader to turn individual layers on and off (see Fig. A1).

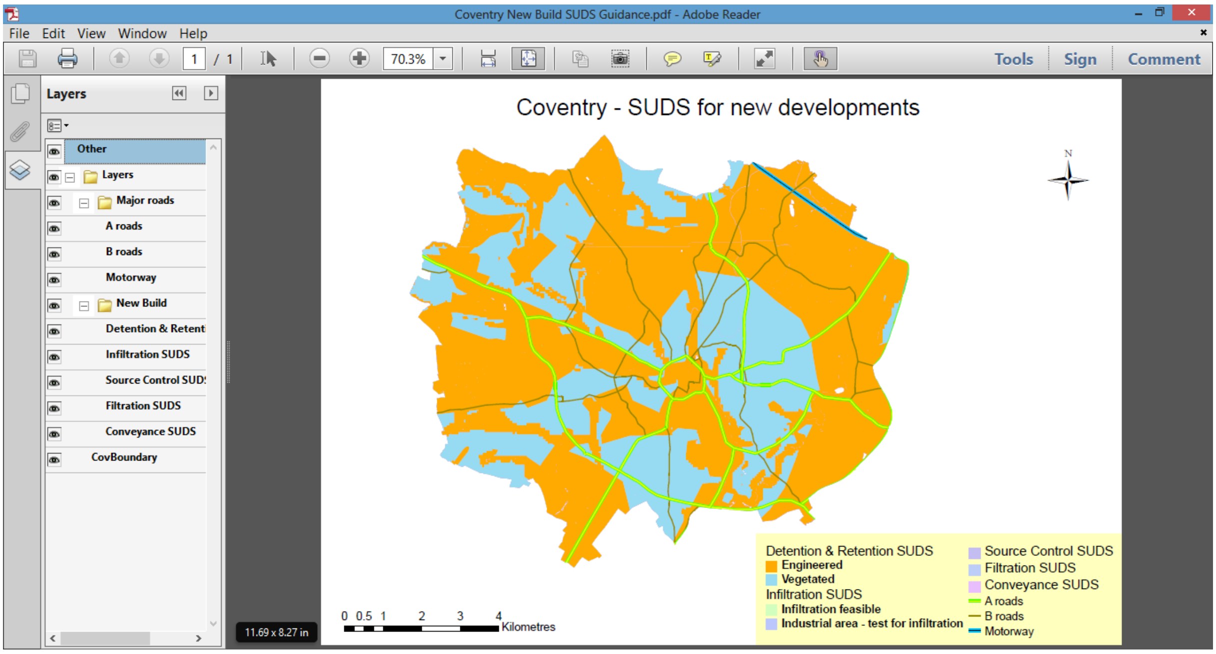

Fig. A1 Example Adobe Acrobat pdf file showing layers for new development SUDS

Appendix B: Ethics Approvals

B1 Ethical Approval

The University's research process requires the submission of proposed work that involves human participants for ethical approval. Ethical approval was requested and obtained for this research (see below). The submitted forms are included as a set of attached files at the end of this Appendix.

B2 Approval of Current and Former Industrial Land Dataset

The Current and Former Industrial Land dataset used in this study was a generalised version of the full dataset held by Coventry City Council. The procedure to create the generalised dataset is explained in Appendix F2.

The email correspondence with the relevant officer, and approval to use the generalised dataset, is reproduced below.

The submission for ethical approval is included on the following pages.

Medium to High Risk Research Ethics Approval

Read this first

Who should use this checklist?

You should only use this checklist if you are carrying out research or consultancy project through Coventry University: This includes:

- Members of academic, research or consultancy staff.
- Honorary and external members of staff.
- Research degree students (MA/MSc by Research, MPhil or PhD).
- Professional degree students (EdD, EngD, DClinPsyc, DBA etc).
- Undergraduate students who have been directed to complete this checklist.
- Taught postgraduate students who have been directed to complete this checklist.

Who should not use this checklist?

You should not use this checklist if you are:

- An undergraduate student (Use the low risk ethics approval checklist first).
- A taught postgraduate student (Use the low risk ethics approval checklist first).
- A member of staff evaluating service level quality (Use the low risk ethic approval checklist first)
- Carrying out medical research or consultancy involving the NHS (Use the NHS online Research Ethics Committee approval form).

Can I begin work before the project is ethically approved?

No. Primary data collection can not begin until you have approval from one of the following:

- The University Applied Research Committee (UARC)
- The Research Degrees Sub-Committee (RDSC)
- An External Research Ethics Committee (NHS Research Ethics Committee, Lead Partner University etc)

Alternatively, if you have established that your project does not require ethical approval using:

- Low Risk Ethical Approval Checklist
- Medium to High Risk Research Ethics Approval Checklist

What will happen if I proceed without approval or falsely self-certify research ethics approval?

Collecting primary data in the absence of ethical approval or falsely self-certifying the level of risk associated with a project will constitute a **disciplinary offence**.

- For **Students –** this means disciplinary action resulting in immediate failure in any module or project associated with the research and potentially dismissal from the University.
- For **Staff –** This means disciplinary action, which may potentially lead to dismissal.

If you do not have ethical approval, the University’s insurers will not cover you for legal action or claims for injury. In addition, you may be debarred from membership of some professional or statutory bodies and excluded from applying for some types of employment or research funding opportunities.

What happens if the project changes after approval?

If after receiving ethical approval your project changes such that the information provided in this checklist is no longer accurate, then the ethical approval is automatically suspended.

You must re-apply for ethical approval immediately and stop research based on the suspended ethical approval.

What about multi-stage projects?

If you are working on a project which involves multi-stage research, such as a focus group that informs the design of a questionnaire, you need to describe the process and focus on what you know and the most risky elements. If the focus group radically changes the method you are using then you need to re-apply for the ethical approval.

Is there any help available to complete this checklist?

Guidance can be found in the ethics section of the Registry Research Unit Intranet. You will find documents dealing with specific issues in research ethics and examples of participant information leaflets and informed consent forms. Further advice is also available from:

- Director of Studies (Students)
- Faculty Research Ethics Leader (Academic Staff)
- Registry Research Unit (Students and Staff)

Which sections of the checklist should I complete?

If your project involves:	**Please complete sections**
Desk-research only, using only secondary or published sources.	**1, 2** and **16**
An application to an External Research Ethics Committee other than the NHS.	**1** to **4** and **16**
Collection and/or analysis of primary, unpublished data from, or about, identifiable, living humans (either in laboratory or in non-laboratory settings).	**1** to **15** and **16**
Collection and/or analysis of data about the behaviour of humans in situations where they might reasonably expect their behaviour not to be observed or recorded.	
Collection and/or analysis of primary, unpublished data from, or about, people who have recently died.	
Collection and/or analysis of primary, unpublished data from, or about, existing agencies or organisations.	
Investigation of wildlife in its natural habitat.	**1** to **5, 15** and **16**
Research with animals other than in their natural settings.	**Do not complete this checklist**. Contact the Registry Research Unit for advice
Research with human tissues or body fluids.	
Research involving access to NHS patients, staff, facilities or research which requires access to participants who are mentally incapacitated.	**Do not complete this checklist.** Make an application using the on-line NHS Research Ethics Committee approval form

How much details [sic] do I need to give in the checklist?

Please keep the details as brief as possible but you need to provide sufficient information for peer reviewers from the Research Ethics Panel to review the ethical aspects of your project.

Who are the Faculty Research Ethics Leaders?

Check the Registry Research Unit Intranet site for the most up to date list of Faculty Research Ethics Leaders.

How long will it take to carry out the review?

If your project requires **ethical peer review** you should submit this to the Registry Research Unit at **least three** months before the proposed start date of your project.

How do I submit this checklist?

The completed checklist and any attachments must be submitted to ethics.uni@coventry.ac.uk

Medium to High Risk Research Ethics Approval Checklist

1 Project Information (Everyone)

Title of Project

The Feasibility of Sustainable Drainage in Coventry

Name of Principal Investigator (PI) or Research or Professional Degree Student

Frank Warwick

Faculty, Department or Institute

Faculty of Business, Environment and Society; Department of Geography, Environment and Disaster Management

Names of Co-investigators (CIs) and their organisational affiliation

None

How many additional research staff will be employed on the project?

None

Names and their organisational affiliation (if known)

not applicable

Proposed project start date (At least three months in the future)

The revised elements of this project requiring approval are scheduled to start in July 2009

Estimated project end date

2010

Who is funding the project?

Coventry University and Coventry City Council

Has funding been confirmed?

Yes

Code of ethical practice and conduct most relevant to your project:

- ~~British Computer Society~~
- ~~British Psychological Society~~
- ~~Engineering Council~~
- ~~Social Research Association~~
- ~~Socio-legal Studies Association~~
- Other (Specify) Natural Environment Research Council (NERC) and the Chartered Institution of Water and Environmental Management (CIWEM)

Students Only

Degree being studied (MSc/MA by Research, MPhil, PhD, EngD, etc)

PhD

Name of your Director of Studies

Dr. Susanne M. Charlesworth

Date of Enrolment

September 2007

2. Does this project need ethical approval?

Questions	Yes	No
Does the project involve collecting primary data from, or about, living human beings?	X	
Does the project involve analysing primary or unpublished data from, or about, living human beings?	X	
Does the project involve collecting or analysing primary or unpublished data about people who have recently died other than data that are already in the public domain?		X
Does the project involve collecting or analysing primary or unpublished data about or from organisations or agencies of any kind other than data that are already in the public domain?	X	
Does the project involve research with non-human vertebrates in their natural settings or behavioural work involving invertebrate species not covered by the Animals Scientific Procedures Act (1986)?[1]		X
Does the project place the participants or the researchers in a dangerous environment, risk of physical harm, psychological or emotional distress?		X
Does the nature of the project place the participant or researchers in a situation where they are at risk of investigation by the police or security services?		X

If you answered **Yes** to **any** of these questions, proceed to **Section 3**.

If you answered **No** to **all** these questions:

- You **do not** need to submit your project for peer ethical review and ethical approval.
- You should sign the Declaration in **Section 16** and keep a copy for your own records.
- Students must ask their Director of Studies to countersign the declaration and they should send a copy for your file to the Registry Research Unit.

---

[1] The Animals Scientific Procedures Act (1986) was amended in 1993. As a result the common octopus (*Octopus vulgaris*), as an invertebrate species, is now covered by the act.

3 Does the project require Criminal Records Bureau checks?

Questions	**Yes**	**No**
Does the project involve direct contact by any member of the research team with children or young people under 18 years of age?		X
Does the project involve direct contact by any member of the research team with adults who have learning difficulties?		X
Does the project involve direct contact by any member of the research team with adults who are infirm or physically disabled?		X
Does the project involve direct contact by any member of the research team with adults who are resident in social care or medical establishments?		X
Does the project involve direct contact by any member of the research team with adults in the custody of the criminal justice system?		X
Has a Criminal Records Bureau (CRB) check been stipulated as a condition of access to any source of data required for the project?		X

If you answered **Yes** to **any** of these questions, please:

- Explain the nature of the contact required and the circumstances in which contact will be made during the project.

4 Is this project liable to scrutiny by external ethical review arrangements?

Questions	**Yes**	**No**
Has a favourable ethical opinion been given for this project by an external research ethics committee (e.g. social care, NHS or another University)?		X
Will this project be submitted for ethical approval to an external research ethics committee (e.g. social care, NHS or another University)?		X

If you answered **No** to **both** of these questions, please proceed to **Section 5**.

If you answered **Yes** to **either** of these questions:

- Sign the Declaration in **Section 16** and send a copy to the Registry Research Unit.
- Students must get their Director of Studies to countersign the checklist before submitting it.

5 More detail about the project

What are the aims and objectives of the project?

The aim of the research is to investigate the feasibility of implementing sustainable drainage systems (SUDS) in an urban local authority area in England, and to identify appropriate methods to assess feasibility.

The objectives are to:

1. Identify suitable techniques to determine SUDS feasibility in an urban environment based on a pilot study
2. To define an appropriate evaluation framework for wider application
3. Apply suitable techniques to assess the feasibility of SUDS implementation in a wider urban area
4. Evaluate the effectiveness of the selected techniques using case studies

The research started as a Masters by Research study covering Coventry University campus, for which ethical approval was obtained. Funding for the Masters was provided by Coventry University. The research study was converted to a PhD with additional funding and the collaboration of Coventry City Council, with the intention of extending the spatial coverage to the city area.

This re-submission for ethical approval is to identify Coventry City Council as a collaborator on the project, and to expand the spatial area and timescale of the study. It includes both stages of the research, covering Coventry University and Coventry City Council.

Briefly describe the principal methods, the sources of data or evidence to be used and the number and type of research participants who will be recruited to the project.

A feasibility study is recommended as the initial step in investigating the potential for SUDS (SNIFFER 2006). This feasibility assessment, to be undertaken in Coventry, will comprise principally a desk study, although some fieldwork may be necessary to gather baseline information. Rapid assessment techniques using readily available data sources are more appropriate to this type of study than in-depth modelling approaches. Initially, relevant data will be collected from published, university and local and national government sources, and from fieldwork (see Table 1). Published information will provide the background of environmental conditions. Field surveys will provide confirmation of land cover, an insight into land use, and a view of localised precipitation and runoff patterns.

Table 1. Information required for the feasibility study, and its planned source

Data Type	**Source**
Land Cover	Ordnance Survey, field survey
Topography	Ordnance Survey, field survey
Rainfall	Met Office, field survey
Sewer locations	Severn Trent, University, City Council, field survey
Drainage (hydraulic) characteristics	University, Severn Trent, City Council
Geology	British Geological Survey
Soil	British Geological Survey, Environment Agency
Groundwater	Environment Agency
Costs of sewerage, maintenance and repair	University Estates Dept., City Council, Severn Trent
Examples of flood damage	University Estates Dept., City Council, local media
Existing SUDS installations	City Council, local media

Previous studies (*e.g.* SNIFFER 2006; Stovin, Swan & Moore 2007) have found that relevant data is sometimes unavailable, so alternative approaches may be required. These may include obtaining information during meetings with representatives of defined organisations. Participants will be determined among professional contacts who are involved with the planning / design of drainage and related environmental issues, and/or have a policy on sustainable drainage (see Table 2).

Table 2. Organisations that may hold relevant information for the feasibility study

Organisation	**Type of information**
Coventry University Estates Dept.	information relating to drainage and flooding
Coventry City Council's Sustainability, Planning, Highways and Parks Departments	information relating to flooding, water quality, drainage and related environmental and urban planning issues, role of SUDS
Environment Agency	information relating to planning, flooding and water quality concerns, role of SUDS
Severn Trent Water	sewerage layout in Coventry, sewer maintenance and condition, sewer flooding, role of SUDS
SUDS suppliers / installers	ascertain technical requirements and costings

Except for the University's Estates Dept. and Coventry City Council, where relevant information is likely to be held by a number of participants, it is expected that a maximum of two people in an organisation will need to be contacted. Participants will be contacted by email or telephone before an interview is arranged.

References

SNIFFER (Scotland and Northern Ireland Forum for Environmental Research) (2006) *Retrofitting Sustainable Urban Water Solutions. Project UE3(05)UW5* [online]. Available from <http://www.sniffer.org.uk/exe/download.asp?sniffer_outputs/UE3(05)UW5.pdf> [26th June 2007]

Stovin, V., Swan, A. and Moore, S. (2007) *Retrofit SUDS for Urban Water Quality Enhancement* [online]. Available from <http://www.retrofit-suds.group.shef.ac.uk/downloads/EA&BOCF%20Retrofit%20SUDS%20Final%20Report.pdf> [26th June 2007]

What research instrument(s), validated scales or methods will be used to collect data?

In the first instance, data will be obtained from publicly available sources, as described in Table 1. Such information is available from a mixture of sources, comprising online internet sites, paper records and maps, and on written request. Field surveys will be used to address uncertainties and gaps in baseline data.

Once initial data collection and basic analysis has been undertaken, interviews may need to be arranged with participants in the organisations listed in Table 2 to ascertain if missing information can be obtained. At the same time, the professional opinion of those contacts will be sought in order to identify specific opportunities for, and barriers to, SUDS implementation in Coventry.

If you are using an externally validated research instrument, technique or research method, please specify.

If you are not using an externally validated scale or research method, please attach a copy of the research instrument you will use to collect data. For example, a measurement scale, questionnaire, interview schedule, observation protocol for ethnographic work or, in the case of unstructured data collection, a topic list.

A list of topics for interviews is attached

6 Confidentiality, security and retention of research data

Questions	**Yes**	**No**
Are there any reasons why you cannot guarantee the full security and confidentiality of any personal or confidential data collected for the project?		X
Is there a significant possibility that any of your participants, or people associated with them, could be directly or indirectly identified in the outputs from this project?		X
Is there a significant possibility that confidential information could be traced back to a specific organisation or agency as a result of the way you write up the results of the project?		X
Will any members of the project team retain any personal or confidential data at the end of the project, other than in fully anonymised form?		X
Will you or any member of the team intend to make use of any confidential information, knowledge, trade secrets obtained for any other purpose than this research project?		X

If you answered **No** to **all** of these questions:

- Explain how you will ensure the confidentiality and security of your research data, both during and after the project.

Information obtained from participants is classified into 2 types, factual and professional opinion – for details see the 'Interview Topics' document.

Factual information provided by participants will be stored on a secure, password-protected server on Coventry University premises. This information will be stored on a secure, password-protected computer on Coventry University premises. The source of that data will not be identified.

Professional opinions offered by participants will be recorded using hand-written notes. During the research period, hand-written notes will be stored in a lockable cabinet on Coventry University premises, accessible only to project researchers. The cabinet is located in a room with controlled access. A summary of the interview may be stored securely on a password-protected Coventry University computer, accessible only by the research team. After the end of the study period, information held on paper that identifies participants by name, or by job title within organisation, will be shredded. Summary information held on computer will be deleted. Signed Consent forms will also be destroyed at the end of the research so that individual participants cannot be identified.

The final research report and any associated publications will be available indefinitely. Professional opinions provided by participants will be treated as representing the type of organisation by which they are employed, and may be included as such in the research report, unless they request otherwise. No interviewee will be identified by name in any report/publication arising from this research, unless they request this or give specific additional written consent to it.

This research project does not collect ‘sensitive personal data’ as defined in the Data Protection Act (1998).

If you answered **Yes** to **any** of these questions:

- Explain the reasons why it is essential to breach normal research protocol regarding confidentiality, security and retention of research data.

7 Informed consent

Questions	**Yes**	**No**
Will all participants be fully informed why the project is being conducted and what their participation will involve and will this information be given before the project begins?	X	
Will every participant be asked to give written consent to participating in the project before it begins?	X	
Will all participants be fully informed about what data will be collected and what will be done with these data during and after the project?	X	
Will explicit consent be sought for audio, video or photographic recording of participants?	X	
Will every participant understand what rights they have not to take part, and/or to withdraw themselves and their data from the project if they do take part?	X	
Will every participant understand that they do not need to give you reasons for deciding not to take part or to withdraw themselves and their data from the project and that there will be no repercussions as a result?	X	
If the project involves deceiving or covert observation of participants, will you debrief them at the earliest possible opportunity?	X	

If you answered **Yes** to **all** these questions:

- Explain briefly how you will implement the informed consent scheme described in your answers.
- Attach copies of your participant information leaflet, informed consent form and participant debriefing leaflet (if required) as evidence of your plans.

Each prospective participant will be provided with a copy of the Participant Information Sheet and the Consent form before an interview takes place. The prospective participant can decline to participate in the study, and can withdraw from the study after the interview.

No interviewee will be identified by name or job role in any report/publication arising from this research, unless they request this or give specific additional written consent to this

If you answered **No** to **any** of these questions:

- Explain why it is essential for the project to be conducted in a way that will not allow all participants the opportunity to exercise fully-informed consent.
- Explain how you propose to address the ethical issues arising from the absence of transparency.
- Attach copies of your participant information sheet and consent form as evidence of your plans.

8 Risk of harm

Questions	Yes	No
Is there any significant risk that your project may lead to physical harm to participants or researchers?		X
Is there any significant risk that your project may lead to psychological or emotional distress to participants or researchers?		X
Is there any significant risk that your project may place the participants or the researchers in potentially dangerous situations or environments?		X
Is there any significant risk that your project may result in harm to the reputation of participants, researchers, their employers, or other persons or organisations?		X

If you answered **Yes** to **any** of these questions:

- Explain the nature of the risks involved and why it is necessary for the participants or researchers to be exposed to such risks.
- Explain how you propose to assess, manage and mitigate any risks to participants or researchers.
- Explain the arrangements by which you will ensure that participants understand and consent to these risks.
- Explain the arrangements you will make to refer participants or researchers to sources of help if they are seriously distressed or harmed as a result of taking part in the project.
- Explain the arrangements for recording and reporting any adverse consequences of the research.

9 Risk of disclosure of harm or potential harm

Questions	Yes	No
Is there a significant risk that the project will lead participants to disclose evidence of previous criminal offences or their intention to commit criminal offences?		X
Is there a significant risk that the project will lead participants to disclose evidence that children or vulnerable adults have or are being harmed or are at risk of harm?		X
Is there a significant risk that the project will lead participants to disclose evidence of serious risk of other types of harm?		X

If you answered **Yes** to **any** of these questions:

- Explain why it is necessary to take the risks of potential or actual disclosure.
- Explain what actions you would take if such disclosures were to occur.
- Explain what advice you will take and from whom before taking these actions.
- Explain what information you will give participants about the possible consequences of disclosing information about criminal or serious risk of harm.

10 Payment of participants

Questions	Yes	No
Do you intend to offer participants cash payments or any other kind of inducements or compensation for taking part in your project?		X
Is there any significant possibility that such inducements will cause participants to consent to risks that they might not otherwise find acceptable?		X
Is there any significant possibility that the prospect of payment or other rewards will systematically skew the data provided by participants in any way?		X
Will you inform participants that accepting compensation or inducements does not negate their right to withdraw from the project?		X

If you answered **Yes** to **any** of these questions:

- Explain the nature of the inducements or the amount of the payments that will be offered.
- Explain the reasons why it is necessary to offer payments.
- Explain why you consider it is ethically and methodologically acceptable to offer payments.

11 Capacity to give informed consent

Questions	Yes	No
Do you propose to recruit any participants who are under 18 years of age?		X
Do you propose to recruit any participants who have learning difficulties?		X
Do you propose to recruit any participants with communication difficulties including difficulties arising from limited facility with the English language?		X
Do you propose to recruit any participants who are very elderly or infirm?		X
Do you propose to recruit any participants with mental health problems or other medical problems that may impair their cognitive abilities?		X
Do you propose to recruit any participants who may not be able to understand fully the nature of the research and the implications for them of participating in it?		X

If you answered **Yes** to **only the last two** questions, proceed to **Section 16** and then apply using the online NHS Research Ethics Committee approval form.

If you answered **Yes** to **any** of the **first four** questions:

- Explain how you will ensure that the interests and wishes of participants are understood and taken in to account.
- Explain how in the case of children the wishes of their parents or guardians are understood and taken into account.

12 Is participation genuinely voluntary?

Questions	**Yes**	**No**
Are you proposing to recruit participants who are employees or students of Coventry University or of organisation(s) that are formal collaborators in the project?	X	
Are you proposing to recruit participants who are employees recruited through other business, voluntary or public sector organisations?	X	
Are you proposing to recruit participants who are pupils or students recruited through educational institutions?		X
Are you proposing to recruit participants who are clients recruited through voluntary or public services?		X
Are you proposing to recruit participants who are living in residential communities or institutions?		X
Are you proposing to recruit participants who are in-patients in a hospital or other medical establishment?		X
Are you proposing to recruit participants who are recruited by virtue of their employment in the police or armed services?		X
Are you proposing to recruit participants who are being detained or sanctioned in the criminal justice system?		X
Are you proposing to recruit participants who may not feel empowered to refuse to participate in the research?		X

If you answered **Yes** to **any** of these questions:

- Explain how your participants will be recruited.
- Explain what steps you will take to ensure that participation in this project is genuinely voluntary.

Most participants will be recruited by initial identification by, and introduction from, the project collaborators.

If the researchers identify additional participants who do not belong to the collaborating organisation, and who may have valuable information, they may be contacted by telephone, in writing or by email to ascertain whether they wish to participate.

The Consent Form process will be used to ensure that all participation in this project is voluntary.

Since this is a feasibility study, an acceptable and valid result is that participants may not want to participate, or to provide certain types of information, *e.g.* where they regard such information as commercially confidential.

13 On-line and Internet Research

Questions	**Yes**	**No**
Will any part of your project involve collecting data by means of electronic media such as the Internet or e-mail?	X	
Is there a significant possibility that the project will encourage children under 18 to access inappropriate websites or correspond with people who pose risk of harm?		X
Is there a significant possibility that the project will cause participants to become distressed or harmed in ways that may not be apparent to the researcher(s)?		X
Will the project incur risks of breaching participant confidentiality and anonymity that arise specifically from the use of electronic media?		X

If you answered **Yes** to **any** of these questions:

- Explain why you propose to use electronic media.
- Explain how you propose to address the risks associated with online/internet research.
- Ensure that your answers to the previous sections address any issues related to online research.

A key deliverable of the research is a map-based analysis of SUDS feasibility created using a Geographical Information System (GIS). Some baseline map data, such as that relating to land cover, topography and environmental characteristics, is only made available through the internet, either on secure servers for Ordnance Survey data through the EDINA service, or is publicly available, such as Environment Agency flood risk and groundwater information.

Since information is either publicly available, or is delivered using an existing and proven secure method which is conventionally used for teaching and research in this discipline, no additional risks of using internet-based electronic media are envisaged.

14 Other ethical risks

Question	**Yes**	**No**
Are there any other ethical issues or risks of harm raised by your project that have not been covered by previous questions?	X	

If you answered **Yes** to **this** question:

- Explain the nature of these ethical issues and risks.
- Explain why you need to incur these ethical issues and risks.
- Explain how you propose to deal with these ethical issues and risks.

Assessment of conflicts of interests

The researcher does not work for or with the University's Estates Dept., and does not form part of any University body that considers or makes decisions concerning the purchase or installation of sustainable drainage facilities. The researcher is not personally acquainted with interviewees from the organisations where data will be sought (see Table 2). If this situation changes, a declaration to this effect will be made in the thesis and any publications resulting from the study.

Conflicts of interest between the thoroughness of the research and the roles of the organisations in Table 2 might arise where information is made available to the study that is not in the public domain. Such information is most likely to be i) financial data, and ii) specific locations liable to flooding which, if identified, may affect property values or influence how organisations might prioritise addressing those locations. Initially, methods of anonymising such data will be sought. If this proves impossible, the data in question will be excluded from the study, and a note explaining the type of data omitted will be included in the thesis. Identification of such barriers to implementation is a relevant finding of the study. The sensitivity of data will be determined by questioning the provider. Decisions concerning data inclusion will be agreed between the researcher and the supervisory team.

Interim and final results of this study, where published or presented in any form, will make clear the sponsors of the study. The sponsors will not participate in the design of the research, in analysis or interpretation of data, or in writing or approval of the thesis – these tasks remain the responsibility of the researcher.

If new conflicts of interest arise during the course of the research, these will be discussed with the supervisory team, who will advise on the necessity for amending the research, disclosing conflicts, and / or seeking further ethical approval using the University's research ethics procedures.

15 Research with non-human vertebrates[2]

Questions	**Yes**	**No**
Will any part of your project involve the study of animals in their natural habitat?		X
Will your project involve the recording of behaviour of animals in a non-natural setting that is outside the control of the researcher?		X
Will your field work involve any direct intervention other than recording the behaviour of the animals available for observation?		X
Is the species you plan to research endangered, locally rare or part of a sensitive ecosystem protected by legislation?		X
Is there any significant possibility that the welfare of the target species or those sharing the local environment/habitat will be detrimentally affected?		X
Is there any significant possibility that the habitat of the animals will be damaged by the project such that their health and survival will be endangered?		X
Will project work involve intervention work in a non-natural setting in relation to invertebrate species other than *Octopus vulgaris*?		X

If you answered **Yes** to **any** of these questions:

- Explain the reasons for conducting the project in the way you propose and the academic benefits that will flow from it.
- Explain the nature of the risks to the animals and their habitat.
- Explain how you propose to assess, manage and mitigate these risks.

---

[2] The Animals Scientific Procedures Act (1986) was amended in 1993. As a result the common octopus (*Octopus vulgaris*), as an invertebrate species, is now covered by the act.

16 Principal Investigator Certification

Please ensure that you:

- Tick all the boxes below that are relevant to your project and sign this checklist.
- Students must get their Director of Studies to countersign this declaration.

I believe that this project **does not require research ethics peer review**. I have completed Sections 1-2 and kept a copy for my own records. I realise I may be asked to provide a copy of this checklist at any time.	
I request that this project is **exempt from internal research ethics peer review** because it will be, or has been, reviewed by an external research ethics committee. I have completed Sections 1-4 and have attached/will attach a copy of the favourable ethical review issued by the external research ethics committee. Please give the name of the external research ethics committee here: Send to ethics.uni@coventry.ac.uk	
I **request an ethics peer review** and confirm that I have answered all relevant questions in this checklist honestly. Send to ethics.uni@coventry.ac.uk	X
I confirm that I will carry out the project in the ways described in this checklist. I will immediately suspend research and request new ethical approval if the project subsequently changes the information I have given in this checklist.	X
I confirm that I, and all members of my research team (if any), have read and agreed to abide by the Code of Research Ethics issued by the relevant national learned society.	X
I confirm that I, and all members of my research team (if any), have read and agreed to abide by the University's Research Ethics, Governance and Integrity Framework.	X

Signatures

If you submit this checklist and any attachments by e-mail, you should type your name in the signature space. An email attachment sent from your University inbox will be assumed to have been signed electronically.

Principal Investigator

Signed Frank Warwick ....(Principal Investigator or Student)

Date 14 May 2009......................................

Students submitting this checklist by email must append to it an email from their Director of Studies confirming that they are prepared to make the declaration above and to countersign this checklist. This email will be taken as an electronic countersignature.

Student's Director of Studies

Countersigned *see attached email* ....(Director of Studies)

Date..

I have read this checklist and confirm that it covers all the ethical issues raised by this project fully and frankly. I also confirm that these issues have been discussed with the student and will continue to be reviewed in the course of supervision.

Note: This checklist is based on an ethics approval form produce [sic] by Research Office of the College of Business, Law and Social Sciences at Nottingham Trent University. Copyright is acknowledged.

For office use only

Initial assessment

Date checklist initially received:	DD/MM/YYYY	
1. Ethical review required	Yes	No
2. CRB check required	Yes	No
Submitted to an external research ethics committee		
3. External research ethics committee (Name)	Yes	No
4. Copy of external ethical clearance received	DD/MM/YYYY	
Ethics Panel Review		
5. Date sent to reviewer 1 (Name)	DD/MM/YYYY	
6. Date sent to reviewer 2 (Name)	DD/MM/YYYY	
Original Decision (Consultation with Chair UARC/Chair RDSC)		
7. Approve	Yes	No
8. Approve with conditions (specify)	Yes	No
9. Resubmission	Yes	No
10. Reject	Yes	No
11. Date of letter to applicant	DD/MM/YYYY	
Resubmission		
12. Date of receipt of resubmission:	DD/MM/YYYY	
13. Date sent to reviewer 1 (Name)	DD/MM/YYYY	
14. Date sent to reviewer 2 (Name)	DD/MM/YYYY	
Final decision recorded (Consultation with Chair UARC/Chair RDSC)		
15. Approve	Yes	No
16. Approve with conditions (specify)	Yes	No
17. Reject	Yes	No
18. Date of letter to applicant	DD/MM/YYYY	

Signature .... (Chair of UARC/Chair RDSC)

Date..

Suds Feasibility in Coventry - List of Topics for Interviews

Factual Information

Historical flooding locations and dates
Costs of repair

Location of existing sustainable drainage implementations

Location of planned sustainable drainage implementations

Known water quality issues

Do you have information related to significant influences on Suds implementation, specifically

- Land Cover
- Topography
- Rainfall
- Sewer locations
- Drainage (hydraulic) characteristics
- Geology
- Soil
- Groundwater
- Costs of sewerage, maintenance and repair

Is that information publicly available? Where and how?

Is that information available to Coventry City Council? Where and how?

Is that information available for academic research purposes? Where and how?

Professional Opinion

Capacity of existing drainage system

Where might sustainable drainage implementations be installed

What benefits might those installations achieve

What factors might prevent or hinder Suds implementation at specific locations

Perceived benefits of Suds in general

Perceived costs of different types of Suds

Drivers for or against Suds implementation in Coventry

Participant Information Sheet

The Feasibility of Sustainable Drainage in Coventry

You are being invited to take part in a research study. Thank you for taking the time to consider doing so. Before you decide it is important for you to understand why the research is being done and what it will involve. Please read the following information carefully. Talk to other people about the study if you wish.

This leaflet has been produced in line with Coventry University's ethics and safety procedures to ensure that research is legal, moral and safe. Please ask if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

What is the purpose of the study?

The purpose of the study is to determine the feasibility of using sustainable drainage techniques in Coventry. Sustainable drainage techniques are means of slowing down the flow of rainwater, and trapping polluting substances that are present in the run-off water in cities, with a view to reducing the effects of flooding and improving water quality. The research will investigate the following topics related to Coventry: flooding, drainage and sewerage, water quality, environmental and recreational amenity issues. The aim of the research is to identify potential sites in Coventry for sustainable drainage installations, and to present those sites in the form of a map.

Why have I been chosen?

You have been selected because you may have specific knowledge or expertise relating to the research topic.

Do I have to take part?

No. It is up to you to decide whether or not to take part. If you do, you will be given this information sheet to keep and be asked to sign a consent form. You are still free to withdraw your consent at any time and without giving a reason.

What will happen to me if I take part?

You will be asked to take part in an interview to provide information on one or more of the following topics related to Coventry: flooding, drainage and sewerage, water quality, environmental and recreational amenity issues, sustainable drainage.
Two types of information are of interest:

1. You may be asked if you can make available, or know of the availability of, factual information that will inform the analysis of SUDS feasibility. Information that is sensitive or commercially confidential will not be used in the study
2. You may be asked to provide a professional opinion about the feasibility of sustainable drainage in Coventry from the point of view of your area of expertise. You may also be asked to comment on specific examples.

An interview is expected to last no more than 60 minutes. Interviews will take place at your normal place of work, or on Coventry University premises, whichever is more convenient to you. Interviews are conducted during normal working hours.

What do I have to do?

Please provide information to the best of your ability. If you are not the most appropriate person to provide information, please indicate a suitable alternative contact.

What are the possible disadvantages and risks of taking part?

None are envisaged.

What are the possible benefits of taking part?

An increased understanding of the techniques and issues associated with the implementation of sustainable drainage in an urban environment. An opportunity to contribute to a greater understanding of the options for sustainable drainage in Coventry.

What if something goes wrong?

If an interview is cancelled at short notice, for instance due to illness, you will be contacted, and another appointment will be arranged.

If you change your mind about taking part in the study, you can withdraw at any point during the interview or up to one month afterwards. You do not have to give a reason for doing so. You should inform the researcher, who will agree with you the extent to which any information you have provided may or may not be used. If you are not happy for information you have provided to be used, then this will be destroyed and will not be used in the study.

Any complaint about the way you have been dealt with during the study will be addressed. If you have a concern about any aspect of this study, you should speak with the researchers who will do their best to answer your questions.
The research team consists of:
Frank Warwick, who is the person undertaking the study (email: warwickf@uni.coventry.ac.uk)
the Director of this research, Dr. Susanne Charlesworth (email: sue.charlesworth@coventry.ac.uk, tel. 024 7688 8370)

If you remain unhappy and wish to complain formally, you can do this through the Coventry University Ethics Committee chair, Professor Ian Marshall, in writing at Room AB122, Coventry University, Priory Street, Coventry CV1 5FB, or by telephone on 024 7688 5293

Will my taking part in the study be kept confidential?

Factual information that you provide will contribute to an analysis of feasible sites for sustainable drainage in Coventry. This information will be stored on a secure, password-protected computer on Coventry University premises. The source of that data will not be identified in any working documents or in final reports.

Professional opinions that you give may be recorded using hand-written notes. Hand-written notes are stored in a lockable cabinet on Coventry University premises, accessible only to the project researchers. The cabinet is located in a room with limited and controlled access. A summary of the interview may be stored securely on a password-protected Coventry University computer, accessible only by the research team. This summary will refer to the organisation for which you work, not to your name or job role.

It is envisaged that different types of organisation will have different views about sustainable drainage. Consequently the professional opinions you provide will be treated as representing the type of organisation by which you are employed, and may be included as such in the research report, unless you request otherwise. You will not be identified by name or job role in any report or publication, unless specific written confirmation is sought separately from you, or unless you request that this happens.

After the end of the research period, hand-written notes held on paper that identify you by name or job title within an organisation will be shredded. Summary information held on computer will be deleted. The final research report and any associated publications will be available indefinitely.

Who will have access to view the information I provide?

The information you provide may be viewed by authorised persons, specifically the researchers and Research and Development audit personnel who monitor the quality of the research. All have a duty of confidentiality to you as a research participant and nothing that could reveal your identity will be disclosed outside the research site, unless you consent to or request this.

What will happen to the results of the research study?

The results of the research will be made available to 2 groups

1. Coventry University's Board of Governors and its Estates Department
2. Coventry City Council to support their decision-making relating to sustainable drainage in the city.

The results of the research can be made available to individual interviewees on request.

A full copy of the final report (the 'thesis') will be held at Coventry University and will be available for academic access. It is also planned to publish the results of the research in scientific journals, and present an overview of the research at scientific conferences. The final research thesis and any associated publications will be available indefinitely.

This research project is scheduled to finish in 2011.

Who is organising and funding the research?

This is a postgraduate student research project, organised by Frank Warwick, a postgraduate student at Coventry University. It is part sponsored by Coventry University and by Coventry City Council.

Who has reviewed the study?

This study has been reviewed by the University's ethics peer review process and has been approved by the Applied Research Committee.

Thank you for taking time to read this sheet and for considering taking part in this research study. If you are not happy to take part in an interview, please advise the researcher who contacted you.

If you are happy to take part in an interview, you will be given a copy of this information sheet and a consent form to keep. You will be asked to sign a copy of the consent form for the researcher to take away.

Contact Details:

If you have any questions or comments about the research, please contact:

Frank Warwick, Coventry University: email: warwickf@uni.coventry.ac.uk

COVENTRY
UNIVERSITY

Research Participation Consent

Title of Project: The Feasibility of Sustainable Drainage in Coventry

Name of Researcher: Frank Warwick

I have read and understood the attached participant information sheet and by signing below I consent to participate in this study.

I understand that I have the right to withdraw from the study without giving a reason at any time before, during, and up to one month after the interview.

Signed:____

Print Name:____

Date:____

Witnessed by:____

Print Name:____

Date:____

Researcher’s Signature:____________________________________

Date:____

When completed, 1 copy to researcher’s site file, 1 copy for participant

REGISTRY RESEARCH UNIT
ETHICS REVIEW FEEDBACK FORM
(Please return to Registry Research Unit within 10 working days)

Name of applicant and Faculty/School: Frank Warwick

Research project title: The Feasibility of Sustainable Drainage in Coventry

Comments by the reviewer

1. Evaluation of the ethics of the proposal: This project has many potential benefits to the community. It looks at sustainable drainage within Coventry using field data and secondary data with some interviews as well. I cannot see ethical issues provided that Mr Warwick is not conflicted in terms of data he collects for this study and his work within the university both in terms of the data and access to individuals he may interview.

2. Evaluation of the participant information sheet and consent form:

Please can you remove this sentence from the PI leaflet “Please note that Coventry University has public liability and professional indemnity insurance to cover negligent harm” The general rule has always been that insurers dislike this information being made public. The other documentation looks fine. Glad to see topic list included – thanks!!

3. Recommendation:

(Please indicate as appropriate and advise on any conditions. If there any conditions, the applicant will be required to resubmit his/her application and this will be sent to the same reviewer).

☐ Approved - no conditions attached

X☐ Conditional upon the following – please use additional sheets if necessary

Removal of clause re PI insurance; Statement addressing any potential conflict of interest and a resolution strategy if appropriate.

☐ Rejected for the following reason(s) – please use other side if necessary

☐ Further advice/notes - please use other side if necessary

Name and signature of reviewer: CF de Nahlik
Date: 1.5. 09

C. APPENDIX C

PILOT STUDY BACKGROUND, METHODS AND RESULTS

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List of Figures

List of Tables

C.1. INTRODUCTION

This pilot study investigated the feasibility of retrofitting sustainable drainage on Coventry University's inner city campus.

C.2. BACKGROUND

C.2.1. The effect of urbanisation on the hydrological cycle

Urban environments impose restrictions on the natural hydrological cycle, resulting in increased water pollution, environmental degradation and flooding (Charlesworth *et al.* 2003b; Shaver *et al.* 2007:16-17; Woods Ballard *et al.* 2007:1.4). Land conversion to impermeable surfaces reduces rainfall attenuation rates (Andoh & Smisson 1995; Chocat *et al.* 2004:4) because rainwater cannot infiltrate into the soil and therefore runs off to accumulate in lower-level sites. Where a large volume of water accumulates at a particular location, flooding can occur. Flooding can originate from more than one source (Balmforth *et al.* 2006b:23), and risks are greater where multiple sources combine. Coventry is potentially affected by all types of flooding except coastal and estuarine flooding.

In the UK, 2.1-2.3 million properties are at risk from river and coastal flooding (Institution of Civil Engineers 2006:17; NAO 2007:9), and 80,000 from intra-urban floods caused by land run-off and lack of sewer and drain capacity (OST 2004:12). However, these figures may be under-estimated, being based on shorter-term records of the incidence of past flooding rather than objective assessment of properties that might flood in the future (Reed 2007:4). For example, public sewers are estimated to comprise only 53% of total drainage assets in England and Wales (Defra 2007d:8), and a further 108,000-282,000 incidents of flooding from private unadopted sewers and drains are thought to occur annually, many of which go unreported (Defra 2003a:4).

Annual insured costs of flooding damage are estimated to be £1.1 billion, excluding transport infrastructure, agricultural land, uninsured losses, or social and environmental costs (NAO 2007:9); this figure preceded the floods of summer 2007. Urban flooding specifically due to sewer overload is estimated to cost £270 million annually in England and Wales (Evans *et al.* 2008:48; Parliamentary Office of Science and Technology 2007:1). Costs attributed to the summer 2007 floods were approximately £4 billion (EA 2010a:5), with insurance costs accounting for approximately £3 billion (ABI 2008:9), the largest insurance payout due to a natural disaster in the UK (ABI 2007:19), and a further £1 billion of other costs identified (EA

2007b:7). The financial effects of flooding include physical damage to buildings and infrastructure, disruption of business and transport, impacts on human health, and in extreme cases loss of life and property (Defra 2007a:6).

Past flood risk assessment has concentrated on river and coastal flooding (Pitt Review 2008:47), but there is now government recognition that the frequency of inland flooding from all sources is increasing (Cabinet Office 2008:11). Flood risks are forecast to increase significantly in the future due to expansion of urban areas and to climate change, but considerable uncertainties exist that require significant additional research (Institution of Civil Engineers 2006:18; OST 2004:16; Evans *et al*. 2008:53).

Additionally, pollution from urban runoff and sewer overflow may result in failure to achieve the target, established by the Water Framework Directive (EU 2000), that all UK water bodies attain 'good status' water quality by 2015 (EA 2006:4). Coventry's rivers fall within the Warwickshire Avon catchment, where 99% of rivers failed to achieve 'good' status for the WFD assessment, the main problems being sewage discharges, urban and agricultural runoff, and individual pollution incidents (EA 2008e:31). The rivers Sowe and Sherbourne and most of their tributaries (EA 2008e:B752-B766, B815-B817) are currently assessed as poor to moderate status and unlikely to achieve good status before 2027, although Finham Brook (EA 2008e:B727-B728) is expected to achieve good status by 2015. The groundwater chemical and quantitative status beneath Coventry is classified as 'poor' (EA 2008e:I14).

The Environment Agency monitors and issues flood warnings for rivers, and erects flood defences to protect from river and coastal flooding. However, because of the short time lag between intense rainfall and the flood peak, it is impossible in practical terms to provide flood warnings to advise of land and sewer flooding (Balmforth *et al.* 2006b:26). No risk maps exist covering land and sewer flooding (Pitt Review 2008:47) and no organisation has the responsibility to provide such information. The interaction between above and below ground flow in urban areas is complex, and the impact of factors such as abrupt, albeit relatively small, changes in surface level can be important (Ellis *et al*. 2012).

The floods that affected Kingston-upon-Hull (Coulthard *et al*. 2007:7) and Gloucester (Gloucestershire County Council 2007:6) in summer 2007 were caused by heavy rainfall overwhelming urban drainage networks, exacerbated by minor streams and rivers bursting their banks, in a setting similar to that of Coventry. Overall, floodwaters originating from surface water drains and sewers affected two-thirds of the homes in the summer 2007 events (EA 2007b:14). Similarly, the 2002 floods in Glasgow derived from three sources: overland flow, sewer overflow and overloading of watercourses (Digman *et al*. 2006:1-2; Jones & Macdonald 2007:539-540). These events have generated recognition that significant improvements are required to reduce flood risk from surface water and poor drainage (ABI 2007:2).

In the Severn water resource zone, where Coventry is located, water demand has exceeded currently available supply since 2006/07 (Severn Trent Water 2008:96). Measures to address the shortfall rely on retrofit water efficiency options, increased household metering and on leakage reduction until additional groundwater sources become available in the period 2015-2020 (Severn Trent Water 2009:17).

Despite the current emphasis on climate change and increased winter precipitation, socio-economic factors (Pielke 2007:305; 2006:63) and land-use change (British Academy 2005:15; OST 2004:23) are expected to have a greater influence on future water issues. Population growth, increased demand for housing, attitudes to water and environmental challenges, water pricing and regulation (Wade *et al*. 2006:62-63) are important drivers. If current sewerage policies and approaches continue, then, over the next 20 years, infrastructure such as pipes will continue to deteriorate but not be replaced, and instances of sewer flooding are forecast to grow (Ashley *et al*. 2006:9-10). Changes in water usage, and additional development may aggravate the risk of urban flooding (Bosher *et al*. 2007:240).

C.2.2. Conventional urban drainage methods

The origin of conventional drainage and sewerage methods lies in solving problems generated by increasing urbanisation in the nineteenth century (White & Howe 2004:263). Both waste water from buildings, and rainwater runoff from urban surfaces, are directed to ‘combined’ sewers, which transport both types of water to a treatment plant for removal of contaminants before its release into a natural watercourse. Systems are sized to handle all foul water, but in periods of intense rainfall, the capacity of the system may be exceeded by the additional volume of rainfall that is directed to combined sewers. Combined sewer overflows (CSOs) are installed to relieve the sewer by diverting excess untreated water, a polluting mixture of storm and waste water, into natural watercourses (Butler & Davies 2004:19-20). These engineered structures increase the speed of water flow by the nature of their smoother surfaces, with the perceived benefit that water is removed rapidly from the urban area they serve.

Traditional rainwater collection and infiltration systems were largely omitted from drainage planning in urbanising communities (Burkhard *et al*. 2000:199). Piped solutions were designed to convey water away from towns as rapidly as possible (White & Howe 2004:263), and to dispose of it in rural areas or out to sea. Concerns about the quality of receiving waters only resurfaced in the latter part of the twentieth century (Butler & Davies 2004:11; Chocat *et al.* 2004:1660). Although many urban sewers are over 150 years old, annual replacement rates between 0.1% and 0.4% by UK water companies imply an expected life of between 250 and 1000 years (Ashley *et al.* 2006:1; Defra 2007a:7), although the lack of data on sewer condition prevents precise definition of asset lifetime (Defra 2007a:7; Evans *et al*. 2008:95).

Until the mid-twentieth century, the large majority of drains fed into combined sewers, which carry both waste and storm water (Butler & Davies 2004:7). Approximately 70% of sewers presently in operation in England are combined (Defra 2005a:22). Over the past six decades, separate sewers for waste and storm water have been implemented (Woods Ballard *et al.* 2007:1.4). In practice, many separate sewer networks feed into combined sewers as they traverse older urban environments on their route to a wastewater treatment plant (Butler & Davies 2004:26; Parliamentary Office of Science and Technology 2007:1).

Both combined and separate sewer systems have been successful at controlling waste- and stormwater flow under average conditions, and have been beneficial in maintaining public health (Butler & Davies 2004:5), but they:

- are designed to meet specific performance criteria which will handle most, but not all, extreme events
- necessitate significant underground installation works
- require periodic maintenance
- utilise centralised processing and treatment facilities that require transmission of inputs and outputs over large distances, typically consume power to move water, and offer limited possibilities for recycling.

Extreme rainfall events can exceed the capacity of sewers, leaving stormwater to find its own path through the urban environment (Jones & Macdonald 2007:537; Ofwat 2008:11), resulting in an increased risk of potentially contaminated overland flow entering buildings. The conventional approach of swift removal of water from urban sites can result in (EA 2002:1; House of Lords Science and Technology Committee 2006:101; White & Howe 2004:262-271):

- increased risks of downstream flooding through more run-off from impermeable surfaces
- higher likelihood of aquatic pollution, e.g. from the ‘first foul flush’ that delivers

accumulated pollutants from urban surfaces into watercourses

- a reduction in biodiversity in polluted waters, and consequent loss of amenity value
- lower groundwater replenishment rates as water is delivered to piped systems
- reduced flows in rivers and streams, leading to changes in aquatic ecosystems and biodiversity decline.

In the past two decades, more sustainable drainage alternatives to surface and combined sewer systems have been sought, aiming to address these problems.

C.2.3. Sustainable Drainage Techniques

Sustainable drainage systems offer a number of benefits for water flow and quality (Heal 2000). Sustainable drainage aims to control rainwater closer to the point where it reaches the land surface (the source) rather than transferring water, and cumulative associated problems, downstream as rapidly as possible (Andoh 1994). Sustainable drainage techniques have been employed since the 1990s in the USA, Australia, Germany and Scandinavia (Butler & Davies 2004:461; House of Lords Science and Technology Committee 2006:98; Jones & Macdonald 2007:537-538; Middlesex University 2003:3; RCEP 2007:75), where they are referred to under the banner of Best Management Practices (BMPs), Low Impact Development (LID), and Water-Sensitive Urban Design (WSUD). Three categories of BMP relate to urban drainage (D'Arcy & Frost 2001):

- housekeeping practices to stop potential pollutants coming into contact with rainfall and runoff, e.g. holding chemicals indoors
- source controls to manage the disposal of rainwater near to or at its point of contact with the ground, including conveyance systems such as swales and filter drains
- treatment controls to detain and dispose of pollutants, including structures such as retention ponds, detention basins, wetlands, and infiltration basins.

The first category of measures is designated 'non-structural', the others 'structural'. This review focuses on structural SUDS techniques, a range of which is available. In larger developments, several SUDS features can be combined into a surface water management train to increase resilience (Fig. C2.1). In principle, water should be treated as close to its source as possible, but in some situations this may be impractical, or backup devices may be required in situations where, for example, additional filtration is necessary.

This

Fig. C2.1 SUDS surface water management train. Adapted from Butler & Davies (2004:471); Kirby (2005:2); National SuDS Working Group (2004:14)

C.2.4. The effectiveness of SUDS in mitigating flooding

The advantages of SUDS compared to conventional drainage methods include (Jones & Macdonald 2007:538; Macmillan & Reich 2007:5-6; Middlesex University 2003:24,26; National SUDS Working Group 2004:14-15):

- decreased overall load on conventional drains
- control of peak flows to prevent capacity overload and downstream flooding
- removal of diffuse pollution
- increased groundwater recharge
- potential for water re-use
- provision of aesthetic, ecological and educational benefits.

SUDS can improve flood control, reduce the costs of upgrading conventional sewerage infrastructure to cope with greater demands, and provide further hydrological benefits by preventing pollution reaching watercourses and retaining water in local groundwater stores, contributing to a reduction in water transportation requirements.

A growing number of SUDS installations in the UK, particularly in Scotland, have been implemented in new developments (Mitchell 2005:1; Stovin *et al.* 2007:1). In Scotland, permeable paving, soakaways and infiltration trenches have been the most commonly implemented SUDS types (Wild *et al.* 2002:15), although performance evaluations (SNIFFER 2004:10) have shown little difference between types in terms of attenuation of water quantity. Most sites made use of only one SUDS type and did not join features into a management train (Wild *et al.* 2002:15), reflecting an understanding that water flow is more directly managed using such source control systems than with site or regional controls (SNIFFER 2004:10). However, individual source control systems have been criticised as significantly less effective at downstream flood control compared to expansion of permeable and green areas (Evans *et al*. 2008:112). This may result from smaller volumes of water being retained by source controls. Most Scottish SUDS sites (71%) were in residential or commercial developments (Wild *et al.* 2002:22). Whereas implementations addressed the water quantity and quality aspects of the SUDS triangle (Fig. 1.1), there was less focus on the amenity value of SUDS (SNIFFER 2004:5; Wild *et al.* 2002:29).

Whilst it is considered more difficult to alter the way that stormwater is dealt with on existing sites (Parliamentary Office of Science and Technology 2007:4), studies have demonstrated that it is not difficult to design retrofit schemes that are technically feasible (Stovin *et al*. 2007:7). Worldwide, cities such as Malmö (Sweden), Portland (Oregon), Seattle (Washington) and Tokyo (Japan) have demonstrated the viability and effectiveness of retrofitting SUDS (DTI 2006; SNIFFER 2006:5-7; Stahre 2008).

Despite these successes, barriers to SUDS implementation in England favour traditional drainage solutions (Stovin *et al*. 2007:7-8) (*cf*. section 2.8). Consequently, there are a limited number of examples where SUDS have been retrofitted to manage runoff from existing urban areas (Hyder Consulting 2004:3; SNIFFER 2006:5; White & Alarcon 2009:524), although, where implemented, successful retrofit installations have solved issues of both water quality, such as at the Houston Industrial Estate in Livingston (RCEP 2007:75), and flooding at two schools in Worcestershire (Atkins Water 2004:Appx. D; SNIFFER 2006:8). Successful retrofits have often been driven by a single organisation with the authority to implement solutions (Stovin *et al*. 2007:26).

Criticisms have been voiced concerning the effectiveness of SUDS installations at dealing with higher water volumes associated with longer return period storms (Charlesworth *et al.* 2003b:105; DTI 2006:39; Evans *et al*. 2008:112). However, the same concern relates equally to conventional piped systems, which are explicitly designed to cope with specific return period storm events. The ‘Sewers for Adoption’ guidelines (Water UK/WRc Plc 2006:29) suggest catering for a 1-in-30 year return period storm event in piped public sewerage systems, but this requirement is not mandatory, and older sewers operate to lower standards (Pitt Review 2008:98).

C.2.5. Water Quality benefits of Sustainable Drainage installations

In urban settings, point source pollution from specific origins such as sewage works or factories can be identified comparatively easily (EA 2007d). On the other hand, diffuse pollution derives from a large quantity of individually minor locations (Charlesworth *et al.* 2003a:563-6; D'Arcy & Frost 2001:359-360; Defra 2005b:29-93; McKissock *et al.* 1999:48) such as:

- sediments collecting on roads, roofs and pavements
- construction sites
- domestic and vehicle cleaning
- use of pesticides
- discarded waste
- atmospheric deposition from industries and transportation
- pet fouling
- misconnected sewers
- contaminated land from past and current industrial operations.

Contaminants deriving from these sources are transported by rainfall runoff into sewers and local watercourses, the 'first flush' effect.

Where stormwater runs off directly into water bodies, pollutants can rapidly compromise water quality (House of Lords Science and Technology Committee 2006:97). SUDS features have proven effective in removing heavy metal and sediment pollutants from run-off, and in attenuating flow (D'Arcy & Wild 2002:5; DTI 2006:40; SNIFFER 2004:4), although increased retention time within an installation is a significant driver of pollutant breakdown (D'Arcy & Wild 2002:9), so larger SUDS devices such as ponds and wetlands are considered more effective at breaking down larger quantities of pollutants than swales and detention basins because of the slower flow-through of polluted water.

Oil and petroleum product leakage from vehicles can be an issue in car parks and roadways (Newman *et al.* 2004:283). Impermeable tarmac and concrete surfaces direct these contaminants into the sewer system or nearby watercourses. Appropriately designed and installed SUDS structures such as permeable paving can effectively collect and degrade slow release oil pollution (Newman *et al*. 2004:283). However, large oil spillages can overwhelm permeable paving installations unless an integrated oil interception device is present (Newman *et al*. 2004:287-290). Uncertainties exist over the extent to which source control techniques contribute to groundwater contamination (Ellis 2000:27). However, several studies have revealed that the risk of groundwater contamination may be exaggerated (Heal *et al.* 2004: 53), with pollutants remaining adsorbed to soil particles below infiltration features. Nevertheless, infiltration techniques are generally inadvisable in areas with vulnerable groundwater stores (Atkins Water 2004:26; D'Arcy & Wild 2003; Woods Ballard *et al*. 2007:1.13).

SUDS devices such as soakaways have proven effective at controlling runoff and reducing pollution (Charlesworth *et al.* 2003b:104). SUDS management trains implemented at Wheatley motorway service station, M40 (Ciria 2003), and Hopwood service station, M42, (Bray 2000; Ciria 2002:4; Heal *et al.* 2009) have successfully attenuated runoff and delivered unpolluted water to local watercourses. Maintenance costs are reported to be less than those of conventional drainage techniques (Heal *et al.* 2009:2493), and savings of 30-50% have been identified (Ciria 2002:4; Heal *et al.* 2009:2493).

The pollutant removal efficiency of SUDS devices is influenced by seasonality, type of pollutant and type of device (Revitt *et al*. 2004). Vegetated SUDS structures ('soft' SUDS), designed to collect particulates and associated contaminants, require maintenance to remove accumulations of silt that reduce water retention capability (Charlesworth *et al.* 2003b:102). Swales used to channel runoff react slowly to large volumes of sediment input such as may be generated during an extreme storm event, merely transmitting the pollutants onwards, and are also less effective at retaining smaller particles (Charlesworth *et al.* 2003b:103). Similarly, pollutants trapped in dry grassed detention basins can be remobilised in the next storm event (Charlesworth *et al.* 2003b:104). Plants in wetlands may accumulate contaminants during the growing season, which can be released during seasonal die-back, or transformed into more bio-available forms (Charlesworth *et al.* 2003b:102).

A wide-ranging European comparison of seven types of SUDS feature (Middlesex University 2003:25-27) determined technical differences between individual SUDS devices likely to influence their implementation:

- Detention basins have the fewest technical and operational restrictions on their use
- Ponds and wetlands offered the greatest potential for direct water re-use
- Infiltration basins and permeable paving were better at retaining water on-site, thus

contributing to volume and flood control

- Infiltration systems, swales and retention basins were more cost-effective, reliable, sustainable and easier to retrofit.

Individual SUDS techniques exhibit different characteristics, and this must be taken into account when considering their suitability for addressing particular requirements.

C.2.6. Barriers to SUDS

Whilst the technical feasibility and value of SUDS installations is gaining acceptance, barriers to SUDS implementation in England favour traditional drainage solutions (Stovin *et al.* 2007:7-8). These barriers have arisen from several factors (Balmforth 2006; Chocat *et al.* 2004:5; D'Arcy & Wild 2002:15; Digman *et al.* 2006:4-6; Ellis & Revitt 2010; Grimm 2007; Hyder Consulting 2004:1; Morrow 2008:3-4; RCEP 2007:75). For the purposes of this review, these barriers have been classified under seven headings:

- Legal and regulatory, e.g. the complexity and uncertainties within legislation
- Institutional, e.g. the number of stakeholders
- Economic, e.g. the costs of implementation, maintenance, and future liabilities
- Urban planning challenges, e.g. lack of guidance for planners
- Informational, e.g. lack of data about sewerage infrastructure
- Social and educational, e.g. levels of public acceptance
- Technical feasibility, e.g. suitable sites for implementation.

These barriers are discussed in more detail below.

C.2.6.1. Legal and regulatory

SUDS implementation in England is hampered by complexities in the legislation and management of storm water (Douglas *et al.* 2010:113; Evans *et al.* 2008:52; House of Lords Science and Technology Committee 2006:99; Morrow 2008:2-3; Stovin *et al.* 2007:i). In contrast, in Scotland, where a different legislative framework applies, the Water Environment and Water Services (Scotland) Act (2003) and the Water Environment (Controlled Activities) Regulations (2005) have facilitated promotion and acceptance of SUDS solutions (RCEP 2007:75; SNIFFER 2006:3).

English legislation has been oriented towards a hard-engineering pipe, drain, and sewer philosophy, rather than the wider range of available SUDS techniques (Defra 2005a:6). A sewer is defined as having a proper outfall to a watercourse, a public sewer, or in some circumstances an adopted highway drain (Defra 2005a:22). A number of SUDS features lack this defined outfall, since their purpose is to infiltrate runoff. This precludes adoption by the relevant Water Authority (Defra 2005a:14; DTI 2006:95).

Section 106 of the Water Industry Act (Act of Parliament 1991) gave an automatic right to connect a building's drain into the public sewer, subject to certain restrictions (Balmforth *et al*. 2006b:18), so there was little incentive to design alternative drainage strategies (Defra 2007a:9). Where no separate surface water sewer exists, this right could contribute to exceedance of available sewer capacity and consequently lead to flooding (Balmforth *et al*. 2006b:18; National SuDS Working Group 2004:15). Even where property owners disconnect existing drains from public sewers in favour of SUDS installations, they had the right of reconnection to a sewer at any time irrespective of capacity changes occurring in the intervening period (DTI 2006:79; House of Lords Science and Technology Committee 2006:99). Consequently, sewerage undertakers could insist on installation of surface water sewers alongside SUDS (RCEP 2007:76), resulting in increased costs. The Flood and Water Management Act (Act of Parliament 2010:57-58) now limits the right to connect to a public sewer to surplus runoff from those developments that have met national sustainable drainage standards. However, the implementation timescale for the new act is not yet defined, and furthermore existing rights to connection will be retained, so reductions in runoff to public sewers will be restricted to new developments, commencing at some point in the future.

Currently, a right to discharge to watercourses is only held by highway authorities, riparian owners and navigation authorities, and sewerage undertakers negotiate agreements with the latter two for disposal of treated and storm water (Defra 2005a:17). This raises questions about overflow from SUDS features under extreme storm conditions, for example, insufficient capacity may be available if they overflow into a sewer, or bank erosion may be caused if the overflow is to a watercourse.

Overall, there is a lack of joined-up government relating to sewerage in England (British Academy 2005:19; Ellis *et al*. 2010:5; Howe & White 2001:369). However, legal and regulatory barriers are not the sole factors hindering more widespread SUDS implementation. An early conclusion of Defra's Integrated Urban Drainage (IUD) pilot studies (Balmforth 2006) was that legislative and regulatory change, although advantageous, was not an essential component in development of more integrated new or retrofit drainage solutions. Key success factors were considered to be:

- alignment of strategic approaches with regional and local planning policies

- engagement with stakeholders and the public
- new tools and models to support development of appropriate solutions.

Legal and regulatory barriers constitute the principal difference between the wider implementation of SUDS in Scotland, and their limited application in England.

C.2.6.2. Institutional

A key issue in inner-urban locations is the number of stakeholders involved in flood and drainage management in England (Ashley *et al*. 2007a:82; Morrow 2008:2-3; Woods Ballard *et al.* 2007), as highlighted in Fig. C2.2. As is clear from Fig. C2.2, responsibility for surface water sewerage does not rest with one single organisation (Balmforth *et al*. 2006b:15; Defra 2005a:7; Defra 2007a:4; Gill 2008:26; Gill & Catovsky 2007:4; Middlesex University 2003:20; Ofwat 2008:11; RCEP 2007:76). Similarly, responsibility for flood management is positioned across a number of bodies, depending on the type of flooding (ABI 2008:14; Defra 2007a:1; Defra 2007b:3-4; Digman *et al*. 2006:4; EA 2007b:14). These uncertainties result in problems assigning responsibility for maintenance and fault rectification, and difficulties aligning objectives between organisations. Ciria (2007) has developed a set of model agreements to assist in clarifying responsibilities, but, with little practical experience of SUDS, most agencies remain cautious and rely on conventional hard-engineering approaches to drainage (Kirby 2005:117-118; Stovin *et al*. 2007:8). The UK Water Industry has been criticised for failing to engage with the public and other stakeholders in constructive discussion of flooding issues (Balmforth *et al*. 2006b:20), resulting, to some extent, from a regulatory emphasis on foul- rather than stormwater drainage (Morrow & Doncaster 2007:6-7).

No comprehensive appraisal of the risks from all sources of flooding is available (ABI 2007:9; Gill & Catovsky 2007:5). The division of responsibilities for urban drainage and flooding issues requires co-operation and co-ordination between a number of authorities. When relevant stakeholders have to co-operate to address drainage issues, progress can be hindered by differing perspectives and priorities, funding cycles, regulatory oversight, spatial scales of interest, local authority boundaries, staffing levels, expertise, and even personality differences between organisations (Morrow & Doncaster 2007:4; Parliamentary Office of Science and Technology 2007:3; Smith 2007:13-14).

Fig. C2.2 The range of stakeholders in drainage and flooding management in England, and associated responsibilities. Adapted from information in Balmforth *et al*. (2006b:11-15) and Pitt Review (2008:84)

C.2.6.3. Economic

Investment funding for new implementations of SUDS features is not generally considered a significant factor, since new developments must include the design and costing of some type of drainage works (Balmforth *et al*. 2006b:18), although where dual SUDS and conventional drainage infrastructure is built, increased costs are likely. Initial capital outlay for SUDS is often lower than for conventional systems (Duffy *et al*. 2008:1454; Heal *et al.* 2004; Hyder Consulting 2004:26), due to reduced costs of labour and materials during installation. For construction of seven regional storage ponds on the Dunfermline Eastern Expansion (DEX) site, Duffy *et al*. (2008:1453) estimate that costs were 70% lower than a conventional drainage solution. However, a sample cost base is lacking for the UK (Ellis *et al*. 2010:6).

A correlation between higher installation costs and distance from the point at which precipitation reaches the land surface has also been suggested (Iwugo *et al*. 2002:56-57). In retrofit situations, funding is more problematic (Balmforth *et al*. 2006b:66), commonly requiring identification of drivers of change. In both new and retrofit developments, organisations responsible for maintenance, especially where different from the developer, may be cautious of incurring commitment to ongoing costs (Balmforth *et al*. 2006b:18; Defra 2007b:iii).

Costs of ongoing maintenance are a concern, with differing views being reported. In the UK (Heal *et al*. 2009:2493), maintenance costs of a vegetated system were reported as 30-50% lower than conventional grounds methods when maintenance was built into regular work cycles. In contrast, in Sweden (Stahre 2008:69), maintenance of above-ground channels to clear litter and algae was reported as up to twice the cost of conventional techniques, though part of this increase may have been due to lack of familiarity with procedures and additional effort while construction was still in progress. At the DEX development, maintenance costs for five of the regional ponds were more expensive than conventional drainage (Duffy *et al*. 2008:1455), although using a whole life costing assessment based on net present value, the authors claim that average yearly maintenance would cost up to 25% less for SUDS (Duffy *et al*. 2008:1457). Whole life costing studies (e.g. Ira *et al*. 2008; Woods Ballard and Malcolm 2003) have aimed to assess the overall lifetime benefits of SUDS, but recognition of their value has stumbled against the practical division of responsibilities between initial capital cost and ongoing maintenance.

In England, sewerage undertakers (largely the water companies) offer limited financial incentives for disconnecting stormwater drains from sewers (Ashley *et al*. 2006:9; Defra 2007b:3; House of Lords Science and Technology Committee 2006:99; Stovin *et al*. 2007:9). These typically require prevention of the full volume of surface water runoff from a property entering a public sewer (Defra 2005a:23; Severn Trent Water 2006). Treatment costs for stormwater that has been filtered by SUDS devices can be reduced by up to 50% (Middlesex University 2003:3), but in England these savings largely accrue to the water utility rather than the owner of the associated SUDS features, and in practice the limited implementation of SUDS in England has meant that the proportion of pre-treated water is likely to be relatively low when mixed with the other contents of combined sewers.

C.2.6.4. Urban planning

Given the range of different stakeholders in England, several factors militate against non-traditional approaches to urban drainage questions (Balmforth *et al*. 2006b:15), including:

- the shortage of guidance for planning authorities on the types of SUDS appropriate for specific situations (D’Arcy & Wild 2003:7; Morrow & Doncaster 2007:6; SNIFFER 2006:12)
- a lack of technical expertise in managing flood risk and drainage planning (Ellis *et al*. 2010:5)
- and the consequent lack of experience in implementing SUDS (Gill 2008:26).

In Scotland, a partnership approach between regulatory and commercial organisations (D'Arcy & Wild 2002:8), in conjunction with legislation, has contributed to the greater level of SUDS implementation than in England. Defra's new approach to surface water management planning (Defra 2010a) aims to improve co-operation between local authorities and other key stakeholders in England and Wales. A duty of cooperation in England arising from the Flood and Water Management Act (FWMA, Act of Parliament 2010) has resulted in greater working together between agencies.

Surveys of Scottish organisations involved with drainage planning and implementation (Apostolaki & Jefferies 2005:37-38; McKissock *et al.* 1999:48-50; McKissock *et al*. 2003:13-14) revealed that maintenance was the primary concern due to future financial commitments. Cost was a further factor for those familiar with implementation of source control systems, while land availability was the concern for organisations without experience of using them.

Planning consideration of new developments on a case-by-case basis can overlook the potential cumulative impacts that individual developments can contribute increased strain on sewerage infrastructure (Defra 2007a:9; Gill & Catovsky 2007:5). The Environment Agency's flood risk standing advice reflects this emphasis on larger developments exceeding 1 hectare (EA 2009a). Since the introduction of PPS25 (DCLG 2010), the Agency must be consulted with respect to flood risk questions, but their principal remit covers river and coastal flooding, not flooding from other causes (Defra 2007a:9). Furthermore their recommendations can be overridden by planning authorities (ABI 2007:12).

An estimated 220,000 km of conventional sewers (Defra 2008:4) were not adopted by sewerage undertakers (Balmforth *et al*. 2006b:21), often due to poor design or construction, *e.g.* failing to meet the 'Sewers for Adoption' guidelines (Water UK/WRc Plc 2006:29) to design for a 1-in-30 year return period storm, and these private drains and sewers were only transferred to the responsibility of statutory water and sewerage companies in 2011. These private sewers may be more prone to generate excess polluted runoff than adopted sewers (Defra 2003a:72,82; Defra 2008:4), since they meet lower standards.

In terms of understanding the flow of water in extreme events in urban settings, each organisation responsible for a particular aspect of flooding considers its own assets and zone of accountability, but largely ignores links to other organisations. In addition, the complexities of integrating river, overland and sewer flooding (Balmforth & Dibben 2006) mean that there have been few integrated attempts to model urban flooding.

C.2.6.5. Informational

The relatively long life-span of drainage and sewerage infrastructure results in a lack of adequate records (Balmforth *et al.* 2006b:19-20), because these records may be held by different organisations, in varying formats, be lost over time, or be poorly documented initially. Public sewerage undertakers must keep maps and records of their assets and make them available for public scrutiny (Act of Parliament 1991:sections 199-200), but commercial and legal considerations can hamper data sharing (Balmforth *et al.* 2006b:19; Digman *et al.* 2006:6; Morrow & Doncaster 2007:4). Data sharing can also be constrained by technical factors such as inconsistent formats across different organisations (Morrow & Doncaster 2007:4). There is no co-ordinated set of records that includes other organisations with underground assets, such as power and communications utilities (Balmforth *et al.* 2006b:20). Furthermore, there is no record-keeping obligation on private landholders, and availability of drainage information is generally considered inadequate (*e.g.* Smith 2007:17).

Minimal information is available from water companies on the specific costs expended on, or income related to, surface water sewerage, relative to their other responsibilities (Defra 2007b:6). The condition of much of the underground sewer network is unknown (Defra 2007a:7; Evans *et al.* 2008:95), and, given its location, difficult to inspect, although new sensor technology may assist in surveying specific problem locations (Evans *et al.* 2008:94). The condition of private drains and sewers, estimated to constitute 47% of sewerage infrastructure in England and Wales (Defra 2007c:49), and local authority highway drains, is perhaps even less well documented.

There is a shortage of acceptable quality, up-to-date data suitable for supporting hydrological and flood modelling in topographically complex urban environments (Balmforth *et al.* 2006b:19-20; Digman *et al.* 2006:5; Gill 2008:25; Smith 2007:17-18). Consequently, forecasts for urban areas hold the greatest level of uncertainty (Balmforth *et al.* 2006b:18-19; OST 2004:17,40; Pitt Review 2008:98; Smith 2007:17). Models inevitably incorporate simplifying assumptions; for instance, sewer flooding models assume that all precipitation immediately enters the drainage system and do not account for overland flow (Smith 2007:20) due in part to a lack of sufficiently accurate data representing surface characteristics (Schmitt *et al.* 2004:311), and a shortage of real-world events for comparison (Chen *et al.* 2009:189). Modelling techniques that integrate flooding from multiple sources, and take factors such as the spatial variability of rainfall into account, are at the leading edge of research (HR Wallingford 2007; Wheater 2006:2138), for example Ellis *et al.* (2012), Maksimović *et al.*

(2009).

It is therefore problematic at present to identify the extent to which SUDS could contribute to reductions in urban flooding, and to state the number of SUDS installations required to positively impact flood-prone areas (Defra 2007b:11-12). Insufficient information is available on longer-term operational and maintenance costs, and on overall lifetime performance, for some SUDS techniques (Kirby 2005:119; Middlesex University 2003:24; Wild *et al.* 2002:30). The impact on groundwater supplies of infiltration devices that have captured pollutants is unclear (Ellis 2000:27). Since the scale of the problem of the water environment in urban settings is not yet known, there is a shortage of quantitative information on the equivalent scale of benefits that SUDS could deliver in terms of water quality, flooding and amenity improvements (Defra 2007b:11).

C.2.6.6. Social and educational

Environmental and socio-cultural factors play an important role in assessing sustainability (Hellström *et al*. 2000:315; Middlesex University 2003:87; van der Vleuten-Balkema 2003:2). Public awareness of drainage issues and techniques is not high (Apostolaki & Jefferies 2005:25; Digman *et al*. 2006:5). A lack of knowledge of and familiarity with SUDS can result in resistance to their selection (Balmforth *et al*. 2006b:19). Critical factors influencing public acceptability of SUDS include availability of information, aesthetics and integration into the local environment (Apostolaki & Jefferies 2005:25). Public engagement and education promotes buy-in to potential alternative drainage solutions (Apostolaki & Jefferies 2005:5; Charlesworth *et al.* 2003b:105; FWR 2004:3). SUDS having the appearance of natural features, typically including vegetation and attracting wildlife, are considered to be aesthetically satisfying (Apostolaki & Jefferies 2005:44), so wetlands and water-filled retention basins achieve higher public acceptance for their amenity and wildlife value, and the resulting educational benefits, than other types of SUDS (Apostolaki & Jefferies 2005:25; Middlesex University 2003:17).

However, standing water features can give rise to health and safety concerns (Rawlinson 2006:70). Apprehension over the safety of open water features is higher in locations without such features (Apostolaki & Jefferies 2005:25), but they are still regarded as less hazardous than living close to a busy road (Apostolaki & Jefferies 2005:34). Overall, shallow water levels and shallow slopes are perceived as contributing a relatively safer environment (Apostolaki & Jefferies 2005:6). Concerns over water safety can be addressed by appropriate design, education and compliance with health and safety guidance and legislation (Apostolaki

& Jefferies 2005:45-47; Defra 2005a:12; Hyder Consulting 2004:22; Stahre 2008:68; Wilson *et al.* 2004:107-108). Maintenance of SUDS features is perceived as vital for public acceptance, with poorly maintained features generating negative attitudes (Apostolaki & Jefferies 2005:37; SNIFFER 2004:19).

C.2.6.7. Technical feasibility

Additional land may be required to retrofit SUDS; SEPA (2005:2) have estimated a requirement of 5-7% of the contributing area, which may not be readily available in inner-urban locations (Charlesworth *et al.* 2003b:105; Hyder Consulting 2004:2; Woods Ballard *et al.* 2007), so the cost of land acquisition can add significantly to the outlay for SUDS implementation (RCEP 2007:75). Further factors requiring consideration include soil type, slope gradient, proximity to groundwater, bedrock and building foundations, land contamination, expected volume of sediment input, and practicalities such as access and traffic usage (Hyder Consulting 2004:21; Middlesex University 2003:25). Retrofit designs experience a higher level of practical constraints than new developments (Schueler *et al.* 2007:2), and have to integrate with existing underground services and overground structures. Issues have also resulted from poor installation practices, often associated with lack of experience and/or training of contractors (Middlesex University 2003:26; SNIFFER 2004:22). Poor design can lead to consequential effects such as an increased risk of groundwater flooding when SUDS infiltration devices were sited inappropriately (Hughes 2008).

The Water Framework Directive 2000/60/EC (EU 2000) aims to protect surface and groundwater from pollution. Accordingly, any discharge from SUDS structures directly into designated water bodies, e.g. the River Sherbourne, must not produce deterioration of aquatic ecosystems. Since SUDS features function as pollutant collectors, questions have arisen as to their suitability to contribute to amenity and biodiversity goals (D’Arcy & Frost 2001:363), and ultimately to their designation as ‘sustainable’. Contaminants from urban run-off accumulate in SUDS infiltration devices (Heal *et al.* 2004:51), and must be disposed of in accordance with waste legislation (Defra 2005a:12; Woods Ballard *et al.* 2007:2.21). However, in conventional sewerage systems, similar issues arise (Heal *et al.* 2004:51), reflecting the presence of contaminants in the urban environment: pollutants and heavy metals accumulate in the sewage sludge generated in waste-water treatment plants; in separately sewered systems, pollutants may be delivered directly into watercourses by storm sewers.

Compared with conventional methods, SUDS techniques base their claim to higher levels of sustainability on greater emphasis afforded to decreased water pollution, on reduced environmental degradation, on improved amenity, on reduction in the use of natural resources such as raw materials, energy and water itself, on reduced risk, and on flexibility with regard to future changes (Butler & Davies 2004:521-523; Woods Ballard *et al*. 2007:1.11). However, being designed to specific performance standards, SUDS features can equally be overwhelmed in extreme storm events, leading to surcharge and overflow in the same way as conventional drainage devices.

Critics highlight maintenance requirements, SUDS failures in the field, impoverished ecology, and accumulation of contaminants (Heal *et al.* 2004:51). In practice, conventional drainage methods also require maintenance, and SUDS failures may be associated with poor design or maintenance (Heal *et al.* 2004:51,54). Pristine ecosystems are unlikely in any highly urbanised environment (Heal *et al.* 2004:54), although research at Upton, Northampton (Jackson 2008; Jackson & Boutle 2008:6-8), has demonstrated that vegetated SUDS have increased species diversity locally. Pollutants collected in SUDS features reflect their presence in the urban environment; approaches to pollutant reduction at source and education measures are more appropriate to solving longer-term contamination (Heal *et al.* 2004:54).

C.2.7. Summary

The current institutional and regulatory structure impacts the capacity and willingness of businesses, landowners and the public to implement and adopt sustainable drainage systems, and thus hinders adaptation to the risk of increasingly intense rainfall events in urban areas (Defra 2007a:4). Financial, technical and social considerations, as well as data availability issues, hinder the acceptance and wider uptake of SUDS.

C.3. METHODOLOGY

This chapter explains the methodology adopted for the Pilot study research.

C.3.1. Pilot Research Site

Coventry (1° 46' W, 50° 04' N) is located on the eastern edge of the West Midlands conurbation in central England (Fig. C3.1). A city of approximately 315,700 inhabitants at the end of 2010 (Coventry City Council 2011c:1), it has been occupied since mediaeval times (Stephens 1969).

The University is the third largest employer in the city centre (Coventry City Council 2008a), with a student population of some 13,200 full-time equivalents as at 2004/05 (Coventry University 2006:4). The study area covered 13.3 ha (33 acres), incorporating buildings used for teaching and administration (Fig. C3.2). The study excluded student accommodation in individual houses throughout the city, and buildings used by the University's commercial arm, Coventry University Enterprises, located on a separate University Technology park. Sports facilities on the edge of the city were also excluded from the study. The 24 major University buildings included in the study are listed in Table C3.1. Small adjoining buildings are not listed, but were included within the study.

Fig. C3.1 Location of Coventry University campus in Coventry city centre. The dotted outline encloses the research site. Source: Edina (2008)

Fig. C3.2 Coventry University inner-city campus. University buildings included in this study are in colour. Red dotted outlines clarify building perimeters. Codes are elaborated in Table C3.1

Table C3.1 Principal University buildings included within the scope of the research, sequenced by sub-catchment. The availability of drainage drawings is indicated

Sub-catchment	**Building**	**Code**	**Drainage drawing availability (Y/N) & date**
1 Singer	Alma	AL	N
1 Singer	Singer Hall	SI	Y 1993
2 John Laing	Ellen Terry	ET	N
2 John Laing	John Laing	JL	Y 1971
2 John Laing	Richard Crossman	RC	N
2 John Laing	Sports Centre Whitefriars	WF	N
3 Library	Frederick Lanchester Library	FL	Y 1998
3 Library	Gulson Extension	GU	Y 2000
3 Library	Student Centre	SC	Y 2005
3 Library	William Morris	WM	Y 1993
4 Armstrong Siddeley	Armstrong Siddeley	AS	Y 1973
4 Armstrong Siddeley	Jaguar Centre	JA	N
4 Armstrong Siddeley	William Lyons	WL	Y 1981
5 George Eliot	Alan Berry	AB	N
5 George Eliot	Charles Ward	CW	N
5 George Eliot	Frank Whittle	FW	N
5 George Eliot	George Eliot	GE	N
5 George Eliot	James Starley	JS	Y 1961
5 George Eliot	Priory Hall	PR	N
5 George Eliot	Student Union Priory Street	SU	N
6 Graham Sutherland	Bugatti	BU	N
6 Graham Sutherland	Graham Sutherland	GS	N
6 Graham Sutherland	Maurice Foss	MF	Y 1980
6 Graham Sutherland	Student Union Cox Street	54	N

C.3.2. Pilot Feasibility Study

Coventry University's Estates Dept. requested an assessment of the feasibility of retrofitting sustainable drainage on the University's inner-city campus, driven initially by the flooding of a number of university buildings during heavy rainfall in summer 2006. Sustainable drainage was suggested as a possible means of mitigating future flooding. The pilot study took place in 2007-08.

It was hypothesised that existing literature, data and methods could provide sufficient information to investigate the feasibility of SUDS for Coventry University's inner-city campus. The aim of this study was to investigate the feasibility of retrofitting sustainable drainage solutions at Coventry University, to be achieved by four objectives:

- Analyse the characteristics of the study site
- Analyse water quantity and quality impacts relating to the study site
- Assess the applicability of SUDS evaluation techniques to the study site
- Determine the feasibility of retrofitting SUDS devices to the study site.

Stages within a feasibility study are outlined, and each stage is then considered in turn.

In the U.K., research into and funding of SUDS feasibility has emphasised new developments (e.g. WaND 2007). Focus on water quality aspects of SUDS in the early 2000s (e.g. Atkins Water 2004; D'Arcy & Frost 2001; D'Arcy & Wild 2002; Hyder Consulting 2004; SNIFFER 2006; Stovin *et al*. 2007) has shifted in England to a greater consideration of water quantity and flooding issues in more recent years, perhaps due to the floods of summer 2007 and the emphasis on flood risk in planning regulations, e.g. PPS25 (DCLG 2010). However, guidance on retrofitting SUDS to existing sites is regarded as incomplete and not generally applicable (Atkins Water 2004:1; SNIFFER 2006:12). Much of the existing resource base addresses questions to be answered once the decision to implement SUDS has been taken (SNIFFER 2006:17).

Prior to designing both new build and retrofit sustainable drainage installations, it is helpful to undertake a feasibility study to ascertain the value of SUDS and the role they can play at a specific site (Claytor 1998:212; SNIFFER 2006:17-28). Available literature in relation to England has focused on techniques to identify SUDS installations suitable for new developments (e.g. Defra & EA 2007; WaND 2007) and specific SUDS devices for particular locations (e.g. Scholz 2006). Previous SUDS retrofit feasibility studies in the UK have addressed water quality issues, *e.g.* bathing water improvement in Ayrshire (Atkins Water 2004; Broad 2005), and water quality concerns associated with combined sewer overflows in Dunfermline (Hyder Consulting 2004) and sewer flooding (Stovin *et al*. 2007:4-5).

Table C3.2 summarises tasks necessary to undertake a SUDS retrofit feasibility assessment, gathered from published methodologies. The SNIFFER methodology (2006) provided UK guidance. It was developed to address water quality issues (2006:17), but is sufficiently generic to have relevance for water quantity. A similar framework methodology to that of SNIFFER (2006) was proposed by Balmforth *et al*. (2006b:64) in the context of the wider-scale Integrated Urban Drainage projects, adding the need to identify sources of funding at an early stage, and emphasising the necessity of distinguishing the causes, scale, frequency, extent, risk and ownership of flooding (Digman *et al* 2006:7) but did not explicitly divide the methodology into feasibility and detailed design stages. SNIFFER (2006) stressed a need to recognise that SUDS might not provide a suitable answer to the defined question.

Table C3.2 Steps to determine feasibility of retrofit from published methodologies. X indicates that the task was specifically included in the methodology

Source	**Claytor (1998:213)**	**Schueler *et al*. (2007:191-232)**	**SNIFFER (2006:Fig. 5)**	**Details**
Goal of method	Implement a stormwater retrofit strategy	Determine feasibility of retrofit	SUDS Retrofit Methodology for feasibility studies	
Task				
Problem definition and scoping		X	X	Build a clear definition of the question to be answered, and therefore overall aim
Identify stakeholders			X	Also identify sources of funding
Identify available data			X	Can sufficient relevant information be collected to support the decision-making process
Identify possible locations	X	X	X	Desktop Analysis
Field Reconnaissance	X	X		Ascertain that sites are feasible and suitable
Compile Retrofit Inventory		X	X	Develop initial concepts for the most suitable retrofit sites by collecting data and building models
Retrofit Evaluation and Ranking	X	X	X	Select the most feasible and cost-effective sites according to multiple criteria to determine the immediate and wider impact of decisions
Public and stakeholder involvement	X		X	Obtain comments
Analysis		X	X	Determine if retrofits can achieve objectives

Combining tasks from Table C3.2, Fig. C3.3 lists the stages, and steps, planned for this research project. Although presented as a sequential process, it was necessary to iterate steps within stages, and even to revise results, methods and conclusions from earlier stages where new information became available, expected information did not materialise, or results demanded a reconsideration of previous work. The methodology used in each of these stages is discussed in more detail below.

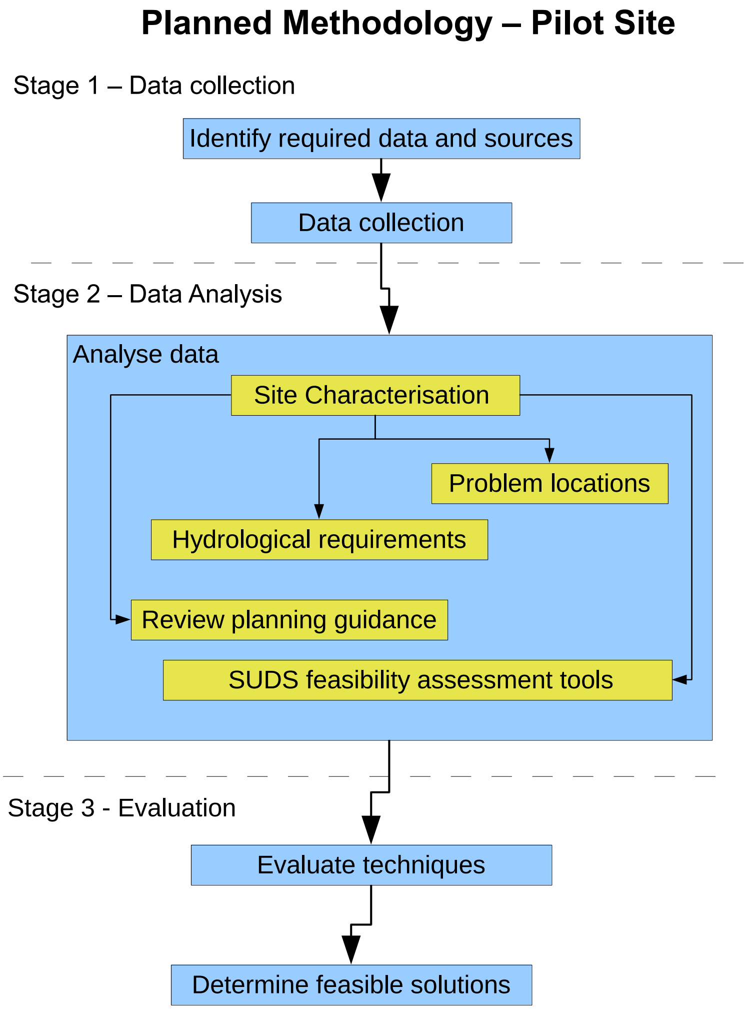


Fig. C3.3 Planned methodology adopted for the pilot study. Main headings are in blue, with sub-divisions in yellow. Arrows indicate the logical sequence of tasks

Higher education institutions such as Warwick University (2007) and Queen Margaret University Edinburgh (2008) have considered, and to some extent implemented, SUDS in new out-of-town developments, but there were no known instances of SUDS retrofit studies in UK inner-urban university locations, and no sector guidance was located pertaining to retrofit of sustainable drainage in city-centre educational establishments. Larger institutions such as Coventry University are considered to offer effective locations for SUDS implementation, due to their ability to reach and implement decisions relating to their own property (Atkins Water 2004:i; SNIFFER 2006:16; Stovin *et al*. 2007). This pilot study highlights key issues at a type of site that is currently considered among the more suitable for retrofit SUDS.

C.3.3. Data Collection

C.3.3.1. Data Requirements and Sources

Government guidelines (DCLG 2009:70-73) recommended that a scoping flood risk appraisal should be based on a qualitative assessment of the site and its risk of flooding, and of causing flooding elsewhere, using published and readily available information. This feasibility assessment comprised principally a desk study, although some fieldwork was found to be necessary to gather baseline information. The intention of the research was to collect relevant data from published and university sources, and from limited fieldwork. Table C3.3 identifies data necessary to determine SUDS feasibility, together with its intended source. Published information was to provide the background of environmental conditions, although, following the experience of previous studies (*e.g.* SNIFFER 2006; Stovin *et al*. 2007) it was expected that not all data would be available in a suitable form, necessitating some alternative approaches. Campus surveys were considered necessary to provide details of land cover, an insight into land use, a view of localised precipitation and runoff patterns, and topography.

In practice, not all required data was available to the research project in the form required, a difficulty also highlighted by other authors (Schueler & Kitchell 2005:A2; SNIFFER 2006:50), so actual data availability is also summarised in Table C3.3.

Table C3.3 Information required for the feasibility study, its planned source, and information obtained

Data type	**Planned Source**	**Available?**	**Actual Source**	**Comment**
Topography	Ordnance Survey, field survey	Partially	Environment Agency (2008a), field survey	OSMM contained a limited number of spot heights for the campus area. The OS Landform Digital Terrain Model data provided 10m resolution, but the Environment Agency Light detection and ranging (Lidar) 1m resolution data (EA 2008a) was the best obtainable, and was used to determine pilot site topography. Image resolution was 1m horizontally, and approximately 15cm vertically (Gallay 2008:158). Some field survey work was undertaken to assess topographical drainage patterns.
Land-use, land-cover	Ordnance Survey, aerial imagery	Partially	Land-cover from Ordnance Survey (Edina 2008), DCLG, field survey	Aerial imagery was insufficiently clear
Precipitation	Met Office, field survey	Yes	Daily records from local Met Office weather station (Bablake Weather Station	

Data type	Planned Source	Available?	Actual Source	Comment
			2013)	
Sewer locations	Severn Trent, Coventry University, City Council, field survey	Partially	Public sewer locations - Severn Trent (2007); University sewer, manhole and drain locations - paper-based 'as designed' drawings were available for 10 of 24 buildings; Field Survey	Public sewers, paper-based records supplied by Severn Trent Water (2007); Private sewer, manhole and drain locations were available for 42% (10 of 24) of university buildings, on paper-based drawings. The remaining drawings had either been lost, mis-filed, or not transferred from Coventry City Council when ownership of buildings changed. Only 'as designed' building drawings were provided, which did not reflect subsequent changes. No information was available for inter-building spaces. Additional survey work and desk research was undertaken to locate manhole and downpipe locations, in order to evaluate the potential private drainage layout of the campus.
Drainage (hydraulic) characteristics	Severn Trent, Coventry University, City	No	No hydraulic drainage network or model relating to the university campus was	Problems with non-availability and inaccuracy of hydraulic models have been encountered by other SUDS feasibility studies, e.g. the Houston Industrial Estate, Livingston

Data type	Planned Source	Available?	Actual Source	Comment
	Council, field survey		available	(SNIFFER 2006:50; Stovin *et al*. 2007:18), and Sheffield University's Bradford/Keighley and Cromer studies (Stovin *et al*. 2007:8,24).
Existing underground services	Coventry University	No	The University held limited drawings of existing underground services	Drawings had not been maintained and were not guaranteed to be current
Geology	British Geological Survey (BGS)	Yes	BGS (2008a), Old (1988:7), Coventry City Council (2008b:11)	
Soil	Soil Survey of England and Wales (SSEW)	Partially	SSEW (1963,1983), NERC 1975), field survey	Soil maps (SSEW 1963; SSEW 1983) and hydrological soil maps (NERC 1975) were consulted
Watercourses and flood zones	Environment Agency		EA 2008c, Coventry City Council (2008b), Edina (2008), Hyde (2006), Historic Coventry (2008)	The course of the river Sherbourne, ascertained from historical records (EDINA 2008; Historic Coventry 2008), and the EA online and SFRA 100-year and 1000-year river flood risk maps, were manually transcribed into GIS.
Groundwater	Environment	Partially	EA (2008b, 2010b), Coventry	Groundwater source protection zones were available from

Data type	**Planned Source**	**Available?**	**Actual Source**	**Comment**
	Agency, BGS		City Council (2008b:54)	EA. No information about current groundwater levels was available from either the EA or BGS
Examples of flood damage	Coventry University	Partially	University, only for one event in 2006. Records unavailable for earlier years	Updated information may have been available in an archive, but the university's filing system was not conducive to its retrieval without significant effort
Water quality	Environment Agency	Yes	EA (2007g)	
Planning constraints and covenants	Coventry University, City Council, national and regional planning guidelines	Yes	CCC (2007), Informal information provided by the University's Estates Dept.	
Land Contamination	City Council	No		
Sub-catchment	Field Survey	Yes	Field Survey	Boundaries representing topographically related areas

Data type	Planned Source	Available?	Actual Source	Comment
boundaries				
University development plans	Coventry University	Yes	Coventry University	

C.3.4. Data Analysis methods

C.3.4.1. Characterisation of Pilot Research Site

This section explains the methods used to analyse data presented in section 4.1.

C.3.4.1.1. Sources of land cover information

The extent and location of impermeable surfaces is a key factor influencing the feasibility of SUDS in urban areas (Dougherty *et al*. 2004:1275; Elgy 2001; PGCDER 1999:16), thus an understanding of land cover was important to a SUDS feasibility assessment. SUDS studies by Atkins Water (2004), SNIFFER (2006) and Stovin *et al*. (2007) recognised the value of geographic information systems (GIS) for rapid assessment and visualisation of potential sites, in particular for assessing the spatial relationship between impermeable and permeable surfaces.

The Dunfermline retrofit desk study (Hyder Consulting 2004:10-11) used Ordnance Survey maps as a background for categorisation of roof, paved and permeable areas contributing to combined and to surface water sewers. SNIFFER (2006:30) recommended the use of Microsoft’s Live Earth aerial photographs (Microsoft Corporation 2008) as a foundation to categorise land cover into industrial roofs, industrial hard standing, highways and green space. Satellite imagery from medium-resolution systems such as Landsat (30m) and SPOT (20m) has been used in broader-scale land-cover assessments (*e.g.* Prisloe *et al*. 2001; Weng 2001), but has been criticised as inadequate for detailed land cover evaluation (Comber *et al*. 2004:3178; Pauleit & Duhme 2000:16; Sleavin *et al.* 2000:3), for example because of inability to distinguish smaller features and to correct for shadows and tree cover (Dougherty *et al*. 2004:1283).

Four sources of land-cover data were assessed to determine the most suitable foundation to create a base-map for subsequent analysis:

- Microsoft’s Live Earth aerial photographs (Microsoft Corporation 2008)
- Google Earth aerial photographs (Google Inc. 2008)
- Ordnance Survey digital MasterMap data obtained through the EDINA Digimap service (EDINA 2008)
- Defra’s Generalised Land Use Database (GLUD), itself adapted from Ordnance Survey digital MasterMap data (DCLG 2007c).

Google Earth images of the study area

Fig. C3.4 Google Earth (Google Inc. 2008) representations of the University campus enclosed by dotted outline. University Square, outlined in red, is shown in enlarged detail in (c) and (d): a) as at September 2007 (note northern section of campus omitted); b) as at February 2008, showing the paved area; c) enlarged section from September 2007, showing University Square, in front of the Alan Berry building, with a grassed area; d) enlarged section as at February 2008, showing a paved area. Note the relatively poor quality of the enlarged images

MS Live Earth image of University Square

Fig. C3.5 MS Live Earth (Microsoft Corporation 2008) outdated representation of University Square (outlined in red) as at February 2008, showing a grassed area that has subsequently been replaced with paving. Note the improved brightness and contrast compared with the more up-to date Google Earth image (Fig. C3.4b & d)

In the preliminary stages of this project, Live Earth and Google Earth images were assessed for their accuracy and clarity. Initial inspection revealed that both sources contained out-dated representations of the university campus, as both depicted images of University Square before redevelopment. The Google Earth and Live Earth images also omitted several recently constructed buildings, e.g. Bugatti, the Sports Centre, and the Student Centre (*cf.* Fig. C3.2 for location). Both sources were re-assessed five months later to check for updates, but this occurred after the initial evaluation phase of this project had been completed. The later Google Earth image had resolved these problems. Both Live Earth and Google Earth images were captured in summer, with trees in full leaf; consequently, the detail of the land surface beneath the trees was obscured. Of the two, Live Earth images offered better contrast, and thus detail was easier to distinguish (compare Figs. C3.4 and C3.5).

Compared to the aerial imagery, MasterMap offered a vector representation of the campus with clearly delineated outlines, and an existing straightforward classification of surface types. It appeared on initial inspection to offer greater accuracy, combined with the least effort required for further classification. Ordnance Survey MasterMap was therefore selected to provide the base data for GIA. However, further inspection of MasterMap data revealed inaccuracies in land-cover of the campus, *e.g.* one missing building (Bugatti), four buildings with incorrect outlines (Jaguar, Richard Crossman, Armstrong Siddeley, Charles Ward - *cf.* Fig. C3.2 for locations), and missing surface differentiation between vegetated and paved areas (see chapter four for details). As a result, an additional dataset was generated, building on MasterMap using input from a field survey, which was intended to provide a more accurate representation of actual land cover.

C.3.4.1.2. Geographic information analysis (GIA)

The data obtained were used to determine the characteristics of the study area. GIA, a computer-assisted spatial analysis technique using a Geographical Information system (GIS), provided an effective means of recording, collating, communicating and analysing spatial data. GIA is based on the concept that the location of objects and events is critical to an understanding of problems (Longley *et al*. 2005:4,316-317). In this study, GIA was used to characterise land-cover, identify areas prone to flooding, and associate these areas with retrofit opportunities. The GIS software used was ArcGIS (ESRI 2006). Conventions used in the GIA process diagrams are shown in Fig. C3.6.

Fig. C3.6 Colour and shape conventions used in the GIA process diagrams. Adapted from Eastman (2001)

Characterisation of the study area was evaluated in three stages:

- Physical and institutional factors informing the research
- Land cover - broad surface types present on the research site

- Impermeability - determination of the extent of impervious surfaces in the study area

C.3.4.1.3. Physical and institutional factors

Data that could be represented digitally from Table C3.3 was input to the GIS database to support understanding of the study site.

C.3.4.1.4. Land cover

A 2D geographic information analysis was performed to categorise land-cover into two classes, each consisting of two sub-classes:

- Impermeable, comprising roofs and paved areas
- Permeable, comprising vegetation and surface water.

The classification was performed for three datasets:

- Ordnance Survey MasterMap (EDINA 2008)
- GLUD employed the same features as MasterMap, but classified land cover in more detail (DCLG 2007c)
- Modified MasterMap, intended to reflect actual land cover more accurately, using the results of a field survey of the campus.

Table C3.4 lists the specific categories from each dataset that were compared.

Table C3.4 Land cover classes utilised in the three classification datasets, and their assignment to the categories used in this study

Dataset **Category**	**MasterMap**	**GLUD**	**Modified MasterMap**
Buildings	Buildings	Domestic buildings Non-domestic buildings	Roof
Paved areas	Roads Tracks And Paths	Roads Paths Other (largely hardstanding)	Paving
Vegetated areas	Land	Greenspace Domestic gardens	Vegetation
Surface water	Water	Water	Water

The proportion of land-cover class and sub-class was determined for each dataset, by sub-catchment and for the full study area. Differences in areas were compared to determine how closely the two readily available datasets reflected actual land cover, in order to assess the effort required to evaluate sources of land cover data. Each process is presented in more detail in Figs. C3.7 and C3.8.

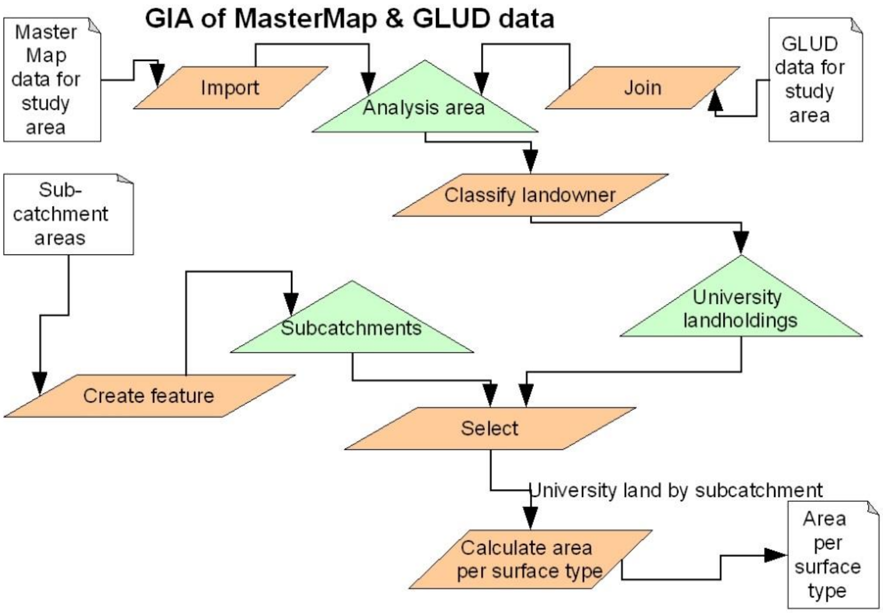


Fig. C3.7 Cartographic map of the process in ArcGIS to determine land cover types using the Ordnance Survey MasterMap and GLUD data. University-owned land was flagged prior to classifying land cover using categories supplied with the MasterMap and the GLUD datasets.

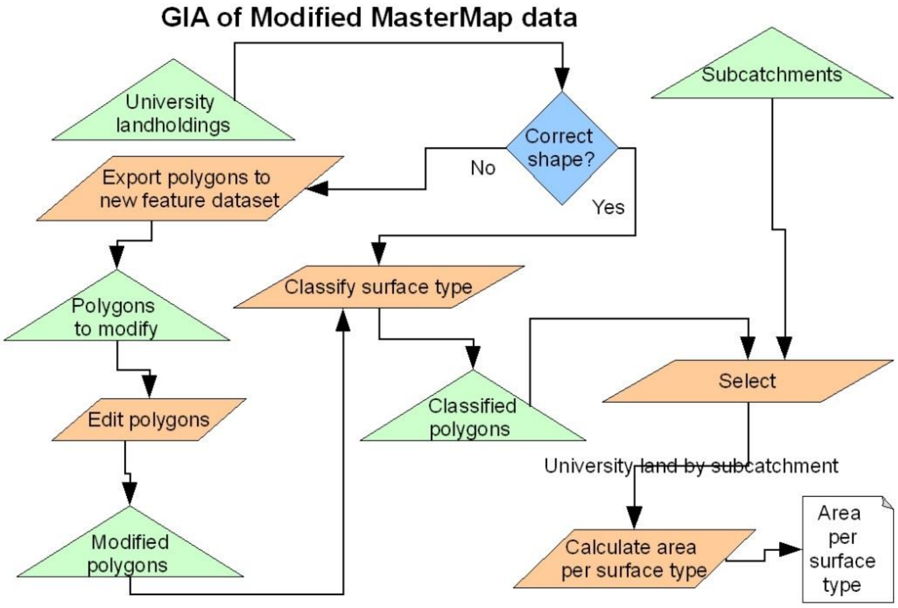


Fig. C3.8 Cartographic map of the process in ArcGIS to modify Ordnance Survey MasterMap data to reflect campus survey, and to determine land cover types. Where significant land cover variation was identified between the MasterMap representation and a campus survey, the relevant polygons were exported to a separate dataset for ease of identification and to reduce the risk of modifying the supplied data incorrectly. Polygons were adjusted to reflect actual land cover. Both modified and unmodified polygons were assigned a land cover category.

Inaccuracies in representing land cover type in raw MasterMap and GLUD were quantified as a percentage of the associated modified MasterMap category using equation C3.1

$$Eld = (Ald - Alm) / Alm * 100 \ (\%) \qquad \text{(Eq.C3.1)}$$

where:

Eld = Classification error in land cover type between specified dataset and modified MasterMap (%)

Ald = Area of land cover type in comparison dataset (raw MasterMap or GLUD) (m^2)

Alm = Area of land cover type in modified MasterMap dataset (m^2).

C.3.4.1.5. Impermeability

Sub-catchment impermeability rates, required for the hydrological calculations, were determined by selecting the land cover classes within each sub-catchment and calculating the relevant surface area. The Modified MasterMap dataset was treated as a sufficiently accurate representation of the study area. The surface area of each surface type in the Ordnance Survey MasterMap and GLUD datasets was compared to the Modified MasterMap dataset in order to determine their accuracy.

C.3.4.1.6. Underpinning Hydrological data

Hydrological analysis of runoff potential requires information concerning surface conditions and precipitation input. Key factors influencing the rate and volume of runoff include rainfall, time, soils, drainage area, land cover and topography (Defra & EA 2007:4; PGCDER 1999:16; Shaver *et al*. 2007:21-35). Geology, groundwater and precipitation data were obtained from the sources in Table C3.3.

C.3.4.1.6.1. Groundwater

Diffuse pollution by nitrate, pesticides, oil and solvents is the principal source of new groundwater contamination (EA 2007h:30) with surface water drainage in urban areas a major source (EA 2007h:34). Sources of potential contamination in the study area were reviewed. There were plans for the EA to produce a map of historical groundwater floods in 2010 (DCLG 2009:41), but this did not become available during the pilot study.

C.3.4.1.6.2. Infiltration tests

Because of the lack of precise information available from the sources consulted, a limited set of infiltration tests was performed in order to obtain an overview of soil permeability, and thus potential rainfall infiltration capacity, across the campus. The soil infiltration characteristics were assessed at four locations (shown on Fig. C4.2) by means of soakaway tests. Two plastic cylinders (104 and 94 mm diameter) were inserted into a permeable ground surface, using a double-ring configuration in an attempt to prevent water leakage. No infiltration tests pits were dug. 500 ml tap water was poured into the inner ring, and the time taken to infiltrate was measured. Tests were performed on dry overcast days during one week in mid-April 2008, without rainfall or bright sun to minimise confounding factors of additional water and evaporation. The month preceding the test week had seen 65 mm of rainfall, 28% above the 30-year norm (Bablake Weather Station 2013).

C.3.4.1.6.3. Precipitation

Several university buildings were flooded on 18th August 2006, but not in 2007. In order to judge the extremity of the precipitation event that caused flooding, daily rainfall totals (Bablake Weather Station 2013) in summer 2006 were compared to those of summer 2007, which suffered the wettest May to July period in 241 years of national records (Pitt Review 2008:3).

C.3.4.2. Pilot Site Analysis

C.3.4.2.1. Flooding

Flood locations were compared to potential influencing factors in the GIS system. GIS hydrological modelling was undertaken to identify runoff flow paths and sites of water accumulation after rainfall in order to identify beneficial sites for retrofitting SUDS. Light detection and ranging (Lidar) data, obtained from the Environment Agency, offered higher-resolution topographical data compared to Ordnance Survey sources. Lidar maps are generated using aircraft-mounted instruments to create higher resolution ground surface maps than is possible from satellite (EA 2008a). The study area was contained within two 2x2 km tiles, SP3278 and SP3478. Image resolution was 1 m horizontally, and approximately 15 cm vertically. Algorithms were applied to the captured Lidar data by the supplier to remove buildings from a digital elevation model in order to create a digital terrain model. The Lidar data collection missions used were flown in March 2005, reducing the effect of tree cover obscuring other surfaces. Lidar instruments record the height of the first surface encountered, so were unable to depict features such as underpasses and bridges which were present on the campus. The study area topography was taken directly from the digital terrain model supplied with the Environment Agency Lidar dataset. No validation was undertaken to assess whether the algorithms used by the EA to remove building cover from the original Lidar data were correct. Other studies (e.g. Balmforth & Dibben 2006; FRMRC 2007; Telford & Wrekin Council 2008) have utilised Lidar data to represent surfaces in flooding models.

Fig. C3.9 outlines the process used to prepare the Lidar data for analysis. Data was provided to generate a full digital elevation model (DEM) including the buildings present within the area, and also a digital terrain model (DTM) with buildings removed to depict the natural land surface.

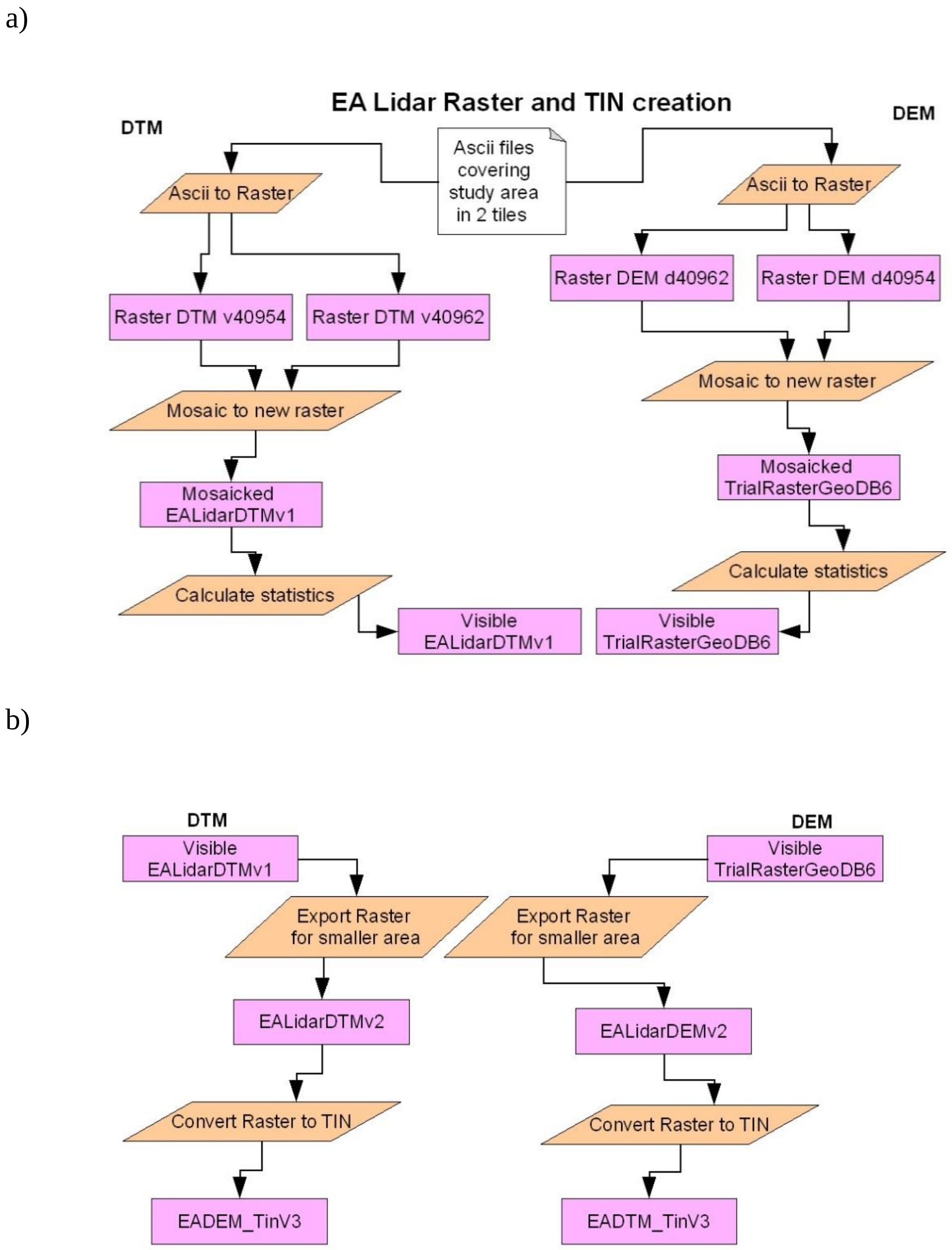


Fig. C3.9 Cartographic map of the process used to prepare the Lidar data for analysis: a) Combination of supplied images into one raster image performed for the full DEM with buildings present, and for the DTM with buildings removed; b) Creation of raster and triangulated irregular network (TIN) datasets for the area with a hydrologic effect on the study locations. This was necessary to reduce computer processing time to analyse the data.

Fig. C3.10 outlines the process used to analyse the Lidar data using standard ArcGIS hydrology functions, with the detail in Fig. C3.11. Flow accumulation images were generated using a DEM, indicating locations that runoff accumulates according to topography depicted by the image. The ArcGIS hydrology tools were unable to generate results for the Lidar data at the resolution and spatial scale supplied, so the 1m horizontal resolution needed to be coarsened to 10 m in order to generate output. Unexpected changes in the measurement in the dataset, called sinks, may represent instrument or recording errors in the dataset supplied, so the extent, and depth of sinks was evaluated (Fig. C3.11b). Flow accumulations both with and without sinks were produced to compare differences. The correlation of flow accumulation to locations flooded in 2006 was examined to judge the utility of the ArcGIS hydrology functions in an urban environment.

Fig. C3.12 reveals a regular pattern of sinks deeper than 34 mm, suggesting that these were artefacts of the data collection, rather than genuine ground depressions.

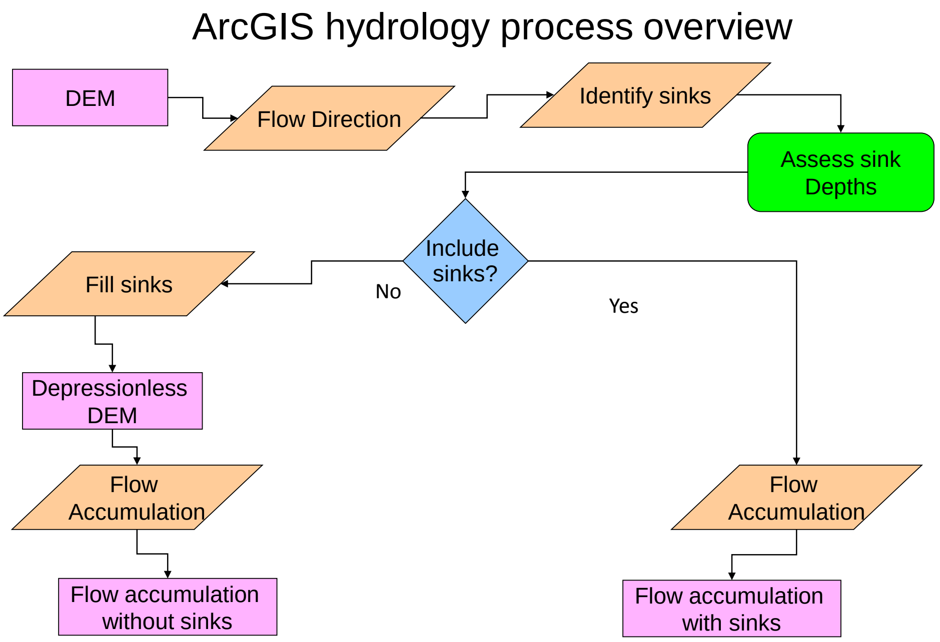
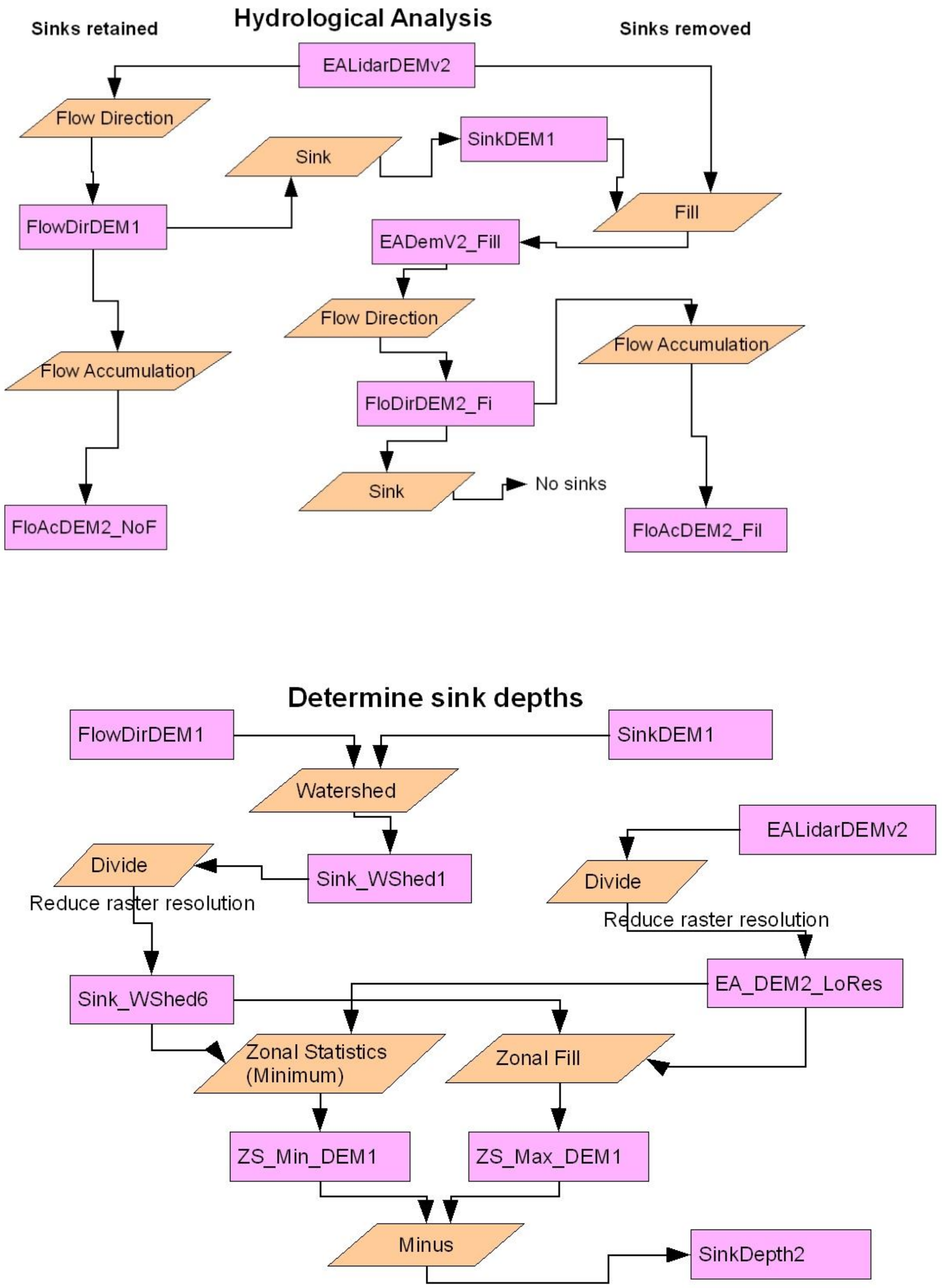


Fig. C3.10 ArcGIS hydrology process overview a)



b)

Fig. C3.11 Cartographic map of the process for spatial analysis of Lidar data: a) Creation of two flow accumulation rasters, one with sinks retained, the second with sinks removed; b) Determination of depths of sinks present in the Lidar data.

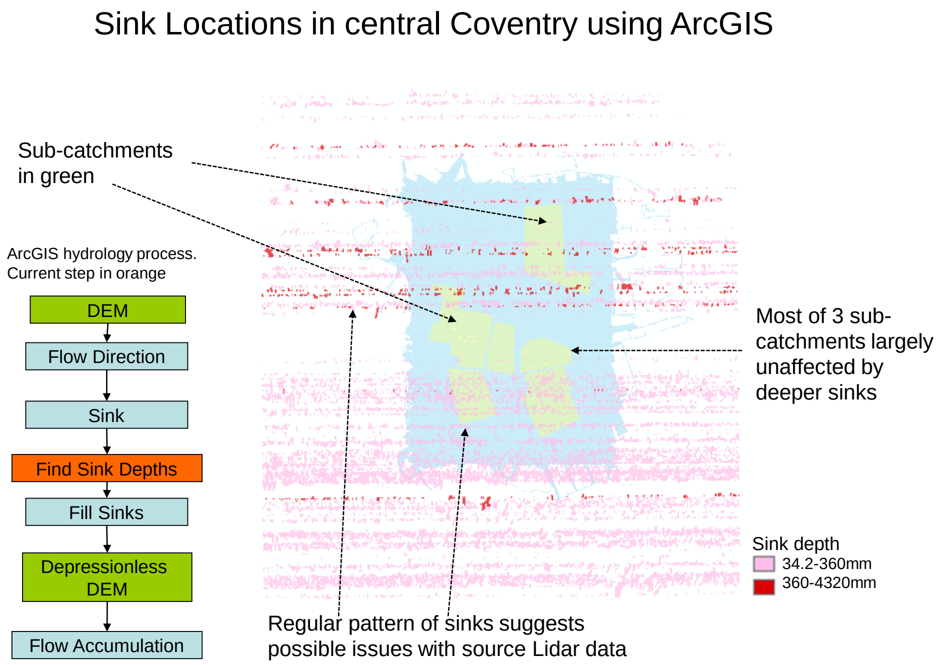


Fig. C3.12 Sink locations in central Coventry in the Lidar dataset

C.3.4.2.2. Water Quality

Water quality of the R. Sherbourne running near the campus was determined as per Table C3.3. The location of surface water sewers on campus disposing to the river was reviewed to ascertain possible sites to improve runoff quality.

C.3.4.2.3. Flood Risk Guidance

Flood Risk Evaluation

100-year and 1000-year river flood risk maps from the EA (2008c) and the SFRA (Coventry City Council 2008b), were compared to University locations to determine areas of fluvial flood risk. The Coventry SFRA (Coventry City Council 2008b) contained a revised river flood risk map based on more detailed hydraulic modelling than was available in the EA published maps**.** The SFRA distinguished no 100-year flood plain in areas likely to affect the campus directly.

PPS25

At the time of the pilot study, PPS25 (DCLG 2010:2) defined national policies to be taken into account when specifying local policies for planning new developments Although new developments were not the subject of the pilot, the Sequential and Exception tests (DCLG

2010:21-29) in PPS25 were applied to understand whether they could add value to an evaluation of retrofit feasibility. In the Sequential test, land is allocated to one of three zones indicating the risk of flooding, with zone 1 having the lowest likelihood (>1 in 1000-year flood) and zone 3 the highest (<1 in 100-year flood). The Exception test is applied to proposed developments in zones 2 and 3, to determine if mitigating circumstances allowed certain land uses in areas of higher flood risk. In addition to the risk of on-site flooding, PPS25 also required consideration of flooding due to other causes, and increased risk of flooding elsewhere due to increased runoff (DCLG 2010:22) - some information was available in the SFRA on these topics.

C.3.4.2.4. Hydrology

Using site characteristics determined in the previous sections, precipitation, runoff and storage requirements were calculated for reach sub-catchment. Hydrological equations were based on published sources of information where these were available. The overall process followed to evaluate the hydrology of the study area is illustrated in Fig. C3.13.

Fig. C3.13. Hydrological factors evaluated. Based on procedures in Balmforth *et al*. (2006a:74); Defra & EA (2007:11); Woods Ballard *et al*. (2007:4.3)

C.3.4.2.4.1. Precipitation

Precipitation influences the volume of runoff from a land surface. Key factors include

(PGCDER 1999:16; Shaver *et al*. 2007:21-30):

- Precipitation type
- Storm intensity
- Storm duration
- Precipitation depth
- Precipitation frequency
- Antecedent rainfall and soil moisture conditions.

These factors are taken into account when using hydrological equations, although a number of simplifying assumptions are made. Ideally, site-specific precipitation data should be used as input to runoff and storage calculations, but these were unavailable, so catchment hydrological characteristics based on UK historical records were substituted. Individual hydrological equations employed either annual rainfall totals or rainfall depths for specific storm return periods. A return period equates to the average time interval between occurrences of a rainfall event of a given magnitude, typically expressed in years (Balmforth *et al.* 2006a:59). Both types were used in the pilot study.

Annual rainfall

No precipitation records were available for the campus or for central Coventry, but daily actual data were acquired from the Bablake Weather Station (2013), the nearest Met Office weather station to the research site, approximately 1.3km northwest of the campus. Values for a range of periods from the full available record, 1870-2012, were compared with each other and with average annual rainfall data estimated by HR Wallingford (2008) to determine a suitable annual precipitation value for runoff and storage equations.

Return periods

Central Coventry is potentially at risk from drainage, overland and river flooding. In order to protect against flood risks, developments must be designed to handle storm events of particular magnitudes. Current recommendations for the use of return periods in evaluation of flood risk in England are (Defra & EA 2007:xiv; Woods Ballard *et al*. 2007:3.2-3.4):

- River flooding: 1 in 100 year flood zone, representing the distinction between medium and high risk of river flooding (DCLG 2010:23)
- Drainage flooding: 1 in 30 year event for the site, reflecting the criteria set by the Sewers for Adoption guidelines (Water UK/WRc Plc 2006:29; Woods Ballard *et al*. 2007:3.17)

- Overland flow: 1 in 100 year 1 hour storm (Woods Ballard *et al*. 2007:3.3).

In addition, a 1 in 1-year storm represents relatively frequent events that may cause morphological changes to a receiving watercourse, such as increased erosion (Woods Ballard *et al*. 2007:3.5). These rainfall return periods were used in this thesis.

Design Storms

Daily rainfall records may be suitable for estimating the total runoff generated by a storm event, but are insufficiently precise for predicting peak runoff volumes (Shaver *et al*. 2007:2.24). However, this more detailed information was unavailable for the study area. Design storm data is in common use for flood studies (Woods Ballard *et al*. 2007:4.10), so assessment methods relied on generic design storm data for the selected return periods. Generic data were determined from statistical evaluations of similar sites in order to determine appropriate rainfall depths, and were obtained for the study area from Dales & Reed (1989), Defra & EA (2007) and NERC (1975).

The Flood Studies Report (FSR, NERC 1975) determined a 2-day rainfall depth of 50 mm for a 5-year return period. Dales & Reed (1989:19) identified regional variations in rainfall patterns, and, using a 67-year period of record (1915-1981), estimated a mean 1-day annual maximum rainfall for the Warwickshire Avon catchment as 32.6 mm. Both methods provided growth curves to extrapolate rainfall depths for additional return periods, and FSR also supplied formulae to extrapolate alternative durations. The NERC rainfall figures were revised to reflect more recent rainfall depths in the Flood Estimation Handbook (FEH) (Defra & EA 2007). For the study area, the NERC 1941-1970 rainfall depths were estimated to be 90% of 1961-1990 rainfall. 24-hour rainfall depths were calculated using the Dales & Reed, NERC and revised NERC methods. In addition, 6-hour rainfall depths were calculated using the NERC and revised NERC methods in order to determine rainfall for the ‘critical flood duration’, which defines the length of time for a storm to generate the greatest flood rate or volume (Woods Ballard *et al*. 2007:4.2). Critical durations for the study area were determined using a table of critical durations and maps of rainfall ratios in Defra & EA (2007:16). For 1-year and 30-year events, the critical durations were 4-6 hours, and 4-9 hours for 100-year events.

A 6-hour, 100-year event was used as the basis for calculating long-term storage requirements, as recommended by Woods Ballard *et al*. (2007:3.7). For Coventry, the 100 year 6 hour rainfall depth was 63 mm (Defra & EA 2007:48).

Climate change may result in changes to the pattern of rainfall in future. Variations predicted as a result of climate change from PPS25 (DCLG 2010:16) are listed in Table C3.5. Given the potential lifetime for SUDS features on campus, the 2025 to 2055 increase of 10% in rainfall intensity was used in this study.

Table C3.5 Recommended national precautionary sensitivity ranges for peak rainfall intensities and peak river flows due to climate change. Source: DCLG 2010:16

Parameter	**1990 to 2025**	**2025 to 2055**	**2055 to 2085**	**2085 to 2115**
Peak rainfall intensity	+5%	+10%	+20%	+30%
Peak river flow	+10%	+20%	+20%	+20%

C.3.4.2.4.2. Runoff

High-level guidance on procedures for determining runoff rates and volumes was obtained from Balmforth *et al*. (2006a:228-240), Defra & EA (2007), SNIFFER (2006:62) and Woods Ballard *et al*. (2007:3.1-4.36). Hydrological calculations are based on parameters driven largely by a site's location in the UK. Hydrological parameters for each sub-catchment were determined according to guidelines in Defra & EA (2007:10-20) and Woods Ballard *et al*. (2007:4.3-4.24), based on the Flood Studies report procedure (Woods Ballard *et al*. 2007:4.10) (Table C3.6). These values were used in calculation of runoff and required storage volumes.

Recommendations for developments are to maintain runoff rates and volumes at greenfield levels. Where a site is already developed, but further changes are proposed, then contemporary guidelines recommended that runoff should be restricted to current rates at least, and preferably reduced (DCLG 2009:130; Defra & EA 2007:xiii). Greenfield and developed runoff rates and volumes were calculated in order to determine the maximum volume that should be discharged from a site (Defra & EA 2007:4; Woods Ballard *et al*. 2007:4.7). Some methods differentiate summer and winter rainfall profiles. Summer profiles have higher intensities and are recommended for sizing conveyance systems, while winter profiles generate more runoff and so are recommended for sizing storage systems (Woods Ballard *et al*. 2007:4.10). Where the methods took these seasonal effects into account parameters, these were evaluated. For the pilot study, greenfield runoff rates were used as the ideal target figures to be achieved.

Table C3.6 Hydrological parameter values used in rainfall, runoff and storage requirement calculations. Parameter abbreviations used in standard equations (*cf.* Appendix J) are listed. Source: Defra & EA (2007)

Runoff Rates

The runoff rates parameters calculated were (Defra & EA 2007):

- Mean annual flood flow rate (Qbar), equivalent to a return period of approximately 2.3 years (Defra & EA 2007:xi)
- Greenfield runoff rate for 1-, 30-, and 100-year events.

Two methods were used to determine greenfield runoff volumes, both derived from Flood Studies Supplementary Report 16 (cited in Woods Ballard *et al*. 2007:4.7-4.9):

- Fixed percentage runoff
- Variable percentage runoff, for summer and winter rainfall profiles.

The methods used to determine developed runoff volumes (Woods Ballard *et al*. 2007) were:

- Fixed Wallingford Procedure, for summer and winter rainfall profiles
- Variable Wallingford Procedure.

The mean difference between greenfield and developed runoff volumes was calculated in order to assess required storage volumes.

Peak developed runoff rates were calculated for each sub-catchment using the Modified Rational Method (Butler & Davies 2004; Woods Ballard *et al*. 2007:4.13-4.14), utilising the 100-year rainfall figure (63 mm).

Discharge limits for each sub-catchment were taken from HR Wallingford (2008), who based calculations on Marshall & Bayliss (1994). Limits were determined where long-term storage was both feasible and impractical. Where provision of long-term storage is feasible, higher discharge rates from developed areas are allowed since the long-term storage facilities attenuate some of the additional runoff. Where long-term storage is not feasible, then lower discharge rates, equal to the Mean Annual Flood (QBar), are required in order to achieve an equivalent runoff rate reduction (HR Wallingford 2008). The reduction in runoff rate necessary to achieve greenfield conditions was calculated as the difference between the winter peak runoff rate and the discharge limit assuming no long-term storage.

Equations used are included in Appendix J.

C.3.4.2.4.3. Storage Requirements

Storage volumes are largely dependent on the volume of runoff generated by a storm event.

High-level guidance on procedures for assessing appropriate attenuation and storage volumes was obtained from Balmforth *et al*. (2006a:228-240), Defra & EA (2007), SNIFFER (2006:62) and Woods Ballard *et al*. (2007:3.1-4.36).

Four types of storage are required to manage different effects of runoff (HR Wallingford 2008; Wood Ballard *et al*. 2007) (Table C3.7). Suggested SUDS devices that may contribute to achieving the defined management objective were identified, although these examples may be more appropriate to new developments. Storage volume formulae were determined using equations in Defra & EA (2007), HR Wallingford (2008), SNIFFER (2006), and Woods Ballard *et al*. (2007). These are discussed in more detail below, and summarised in Table C3.8. Where values were calculated manually, the specific equations are provided in Appendix J. The storage volumes determined using the online SUDS assessment website (HR Wallingford 2008) employed, according to the documentation, the same equations for treatment, attenuation and longterm storage defined in Defra & EA (2007). A value for interception storage was also supplied by HR Wallingford, for which no equation was defined.

Table C3.7. Objectives of the different types of runoff storage. Sources: HR Wallingford 2008; Wood Ballard *et al*. 2007:

Interception volumes were determined using 5mm (HR Wallingford 2008; Woods Ballard *et al*. 2007:3.11) and 7.5 mm as the mean of the minimum 5 mm and maximum 10 mm recommended by Woods Ballard *et al*. (2007:3.11). No interception storage equation was provided by Defra & EA. Treatment volumes (Vt) were calculated using 12 mm (SNIFFER 2006:78) and 15 mm (Woods Ballard *et al*. 2007:4.24) precipitation over the impermeable area. Defra & EA (2007:18) proposed 1Vt as a minimum requirement, and 4Vt was considered to offer an ideal treatment volume by SNIFFER (2006:78). In practice, even impermeable areas will retain and infiltrate some water, e.g. through cracks between paving and depressions on roofs. Guidelines in Defra & EA (2007:xvi) stated that impermeable areas should be treated as 100% impervious to generate a more conservative estimate during initial assessment, and this guideline was followed in all manual calculations for interception and treatment storage. In contrast, HR Wallingford used 80% runoff from impermeable areas in their Vt calculation.

Attenuation storage volumes were determined using the Defra & EA (2007) and HR Wallingford (2008) methodologies. HR Wallingford generated two values for attenuation storage, one assuming that long-term storage was also available, the second that conditions for long-term storage were unsuitable. Both were applicable to a 100 year event. The Defra & EA calculations produced values for 1-, 30- and 100-year return periods. For comparison with the HR Wallingford combined attenuation and longterm storage for 100-year return period, an equivalent volume was determined using Defra & EA data, although this option was not suggested in their documentation. In theory, the equations utilised by the HR Wallingford methodology were the same as those in Defra & EA. A climate change factor of +10% (see Table C3.5) was applied to both methods.

Long-term storage volumes were determined using the Defra & EA (2007), HR Wallingford (2008) and Woods Ballard *et al*. (2007) methodologies. All methods determined the long-term storage volume as a function of the developed runoff volume less the greenfield runoff volume for a 100-year, 6-hour event, equivalent to 63 mm of rainfall. HR Wallingford based their equation on the soil percentage runoff factor, and assumed 100% runoff from impermeable surfaces and 0% from pervious areas. Woods Ballard *et al*. (2007:4.22-4.23) proposed that a factor of 80% could be applied to runoff from impermeable areas to take account of a level of retention and infiltration. The same authors (2007:4.22) suggested, as a simple alternative, that a figure of 60 m^3 ha^{-1} could be used for soil type 4 areas for an initial assessment, based on 80% runoff and 70% impermeability.

Where soil conditions are unsuited to infiltration, long-term storage is unlikely to be feasible (HR Wallingford 2008), so attenuation volumes must be increased accordingly. Combined attenuation and long-term storage volumes were determined using figures from the Defra & EA (2007), and HR Wallingford (2008) methodologies.

The total storage volume required was determined by accumulating the calculated values for the HR Wallingford, Defra & EA and Woods Ballard *et al.* methodologies. Where multiple storage types are implemented, some storage types may duplicate volumes already provided. Rules for removal of duplication were supplied by HR Wallingford and Woods Ballard *et al.*, but not by Defra & EA. The rules are summarised in Table C3.9. These rules were used in the calculation of total storage volumes using the three methods listed. Where no explicit rules for removal of duplicated volumes was given, no values were treated as duplicates of other results. The 1-year and 30-year volumes were only calculated by the Defra & EA procedure. These included attenuation and treatment volumes, as no interception storage equation was provided, and long-term storage was only determined for the 100-year return period.

Table C3.8 Summary of storage volumes calculated in this analysis. A dash indicates that no value or equation was used from the methodology in question. Sources as per table headings

Storage volume type	**Defra & EA (2007)**	**HR Wallingford (2008)**	**SNIFFER (2006)**	**Woods Ballard *et al.* (2007:3.17)**
Interception	-	Value supplied by online tool	-	5mm, 7.5mm
Treatment	Treatment volume	Value supplied by online tool	12mm (1Vt), 48mm (4Vt)	15mm
Attenuation	1-year, 30-year, 100-year	long-term storage available, long-term storage unavailable. (Both for a 100-year event)	-	-
Long-term	100-year event	100-year event, 100% runoff	-	100-year event, 80% runoff, Soil type 4 (60m^3 ha^{-1})
Combined Attenuation & Long-term	Combined Attenuation & Long-term, 100-year event	Combined Attenuation & Long-term, 100-year event	-	-
Total	1-year, 30-year, 100-year	100-year event	-	100-year event

Table C3.9 Rules for removal of duplicated storage volumes when multiple storage types are implemented. Sources as per table headings

Storage Type	**HR Wallingford (2008)**	**Defra & EA (2007)**	**Woods Ballard et al. (2007:3.17)**
Interception	No reduction	No equation provided	No reduction
Treatment	Subtract interception storage	No rule specified	No reduction
Attenuation	No reduction	No rule specified	Subtract interception storage and long-term storage
Long-term	Subtract interception storage	No rule specified	No reduction

C.3.4.2.5. SUDS feasibility assessment tools

Review of the existing literature (chapter 2) revealed a limited number of methodologies addressing SUDS retrofit feasibility, focussed on determining more specifically which SUDS devices were appropriate for individual areas. The following six SUDS decision-making methodologies were evaluated to ascertain their suitability for the pilot study area:

- Swan/Stovin hierarchical framework (SNIFFER 2006)
- Scholz decision tools – two separate techniques (Scholz 2006)
- SEPA Diffuse Pollution Initiative (D'Arcy & Wild 2002, 2003)
- HR Wallingford Stormwater Storage Assessment (HR Wallingford 2008)
- Ellis *et al*. (2004b) assessment of catchment area and soil type.

Although the emphasis of existing methodologies was water quality issues, some of the tools held potential relevance for water quantity problems.

C.3.4.2.5.1. Swan/Stovin hierarchical framework

The Swan/Stovin hierarchical framework (Stovin & Swan 2003; updated in SNIFFER 2006:29) proposed a decision hierarchy (Fig. C3.14) aimed at rapid identification of retrofit opportunities. Surface type, management train and mode of operation criteria were evaluated for each sub-catchment according to the decision framework. Since the pilot study related to the privately-owned University campus, publicly-owned land was not considered further.

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Fig. C3.14 The updated Swan/Stovin hierarchical framework. Redrawn from SNIFFER 2006:Fig. 7

C.3.4.2.5.2. Scholz's decision-support key

The Scholz (2006:120) decision-support key was intended for high-level identification of potential sites (Fig. C3.15). The questions were answered for each sub-catchment.

Fig. C3.15 Hierarchical classification of sites using a Suds decision-support key. Decision boxes are in colour, suggested options in outlined boxes. Adapted from Scholz (2006:Fig. 3)

C.3.4.2.5.3. Scholz's decision-support matrix

The Scholz (2006:120) decision-support matrix evaluated 16 factors for each of 16 SUDS techniques. Each of the 256 'treatments' (16*16) was then weighted as to its relative importance. Resulting values were standardised to indicate whether a technique was highly suitable, good, satisfactory or unsuitable for a particular site. The threshold values and weightings were not changed from their default values. The evaluation was performed for each sub-catchment.

C.3.4.2.5.4. SEPA Diffuse Pollution Initiative

D'Arcy & Wild (2002:12-14; 2003:10-12) suggested decision trees to address pollution risks arising from industrial estates, contaminated land and brownfield sites as part of work for the SEPA Diffuse Pollution Initiative. Of these, the chart for brownfield sites (Fig.

C3.16) was used for the current study and an evaluation was performed for the research site.

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Fig. C3.16 SUDS for Brownfield Sites draining to a Combined Sewer. Adapted from D'Arcy & Wild (2003:11)

C.3.4.2.5.5. HR Wallingford Stormwater Storage Assessment

An online UK SUDS assessment website (HR Wallingford 2008) provided tools for an initial site evaluation of the suitability of nine SUDS techniques. The input parameters for the individual sub-catchments were:

- Development type = commercial
- Drainage ownership = private
- Site size = between 1 and 3 ha, or between 3 and 50 ha, depending on sub-catchment area
- Soil type = '4 or 5', the soil type of the study area defined in the Flood Studies Report (Defra & EA 2007:51)
- Land use = urban infill
- Location = lowlands
- Ground water = less than 2 m below surface for Armstrong Siddeley sub-catchment, more than 2 m below surface for the other five sub-catchments
- Contaminated land = no
- Aquifer with high vulnerability = no
- Water considered to be scarce = no

C.3.4.2.5.6. Ellis et al. assessment of catchment area and soil type

The Ellis *et al*. (2004b) assessment of suitability was based on catchment area and soil type (Fig. C3.17). The median soil infiltration rate from on-site infiltration tests was used as input. This rate was combined with the area of each sub-catchment to ascertain the feasibility of seven SUDS techniques.

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Fig. C3.17 Assessment methodology of SUDS suitability using catchment area and soil type. Source: Ellis *et al*. (2004b:Fig. 3)

C.3.5. Evaluation

C.3.5.1. Evaluation of techniques used

The analyses described above were used to generate an assessment of the SUDS techniques that were potentially feasible in specific locations. Given the characteristics of the pilot site, the suitability of individual SUDS devices (from Woods Ballard *et al*. 2007) across the city centre campus is reviewed. Detailed knowledge acquired during field work was useful for this exercise.

Although the focus of the pilot site was retrofit, a brief comparison was made of the devices proposed by the SUDS feasibility tools against the devices that might be possible in new developments, to determine the efficacy of the tools in putting forward suitable proposals.

The SUDS devices evaluated were those proposed by the six decision methodologies assessed in the pilot study. A three-stage process was followed to determine a score foe each methodology:

1. Suitable devices were identified as those which could be implemented in the inner city pilot site based on characteristics defined in Woods Ballard et al. (2007); unsuitable devices were those whose use was limited by land availability or soil infiltration characteristics
2. The devices proposed by each decision methodology were compared with the device suitability derived in stage one. SUDS devices that were proposed and suitable were allocated a ‘suitable’ score. SUDS devices that were proposed but were not suitable were allocated an ‘unsuitable’ score
3. A total percentage was calculated using Eqn. C3.2. Unsuitable proposals were deducted from the total score since they were likely to be ineffective, but would have cost time, effort, space and money to implement.

$$\frac{\left(\sum(Ss)-\sum(Su)\right)}{\sum(Sp)} \qquad \text{(Eqn. C3.2)}$$

where:

Ss = suitable devices

Su = unsuitable devices

Sp = all possible devices.

The performance of the SUDS feasibility tools was scored in relation to their proposals for retrofit. A simple weighted scoring mechanism was applied of recommendations against possible SUDS options of each device in each sub-catchment (suitable = 1, limited implementation options = 0.25). The same scoring mechanism was used to assess locations that might address water quantity and quality issues. A number of sub-catchment characteristics were assessed against the derived score to judge the most effective at predicting the likely number of retrofit SUDS options. Further techniques originating outside the U.K., with the potential to offer some guidance, were reviewed.

Alternative approaches (*e.g.* Ellis *et al*. 2004:256; Middlesex University 2003:24-27) have involved assessing the utility of specific techniques against influencing factors. Table C3.10 depicts a high-level evaluation matrix to identify factors that may prevent the use of individual SUDS techniques.

Table C3.10 SUDS restrictions evaluation matrix. Y = generally not a restriction; N = may preclude SUDS use; 0 = restriction can be overcome with careful site design. Adapted from Ellis *et al*. (2004:Table 4) and Middlesex University (2003:Fig. 3.1)

C.3.5.2. Multicriteria decision approaches

Comparing drainage options on the basis of installation costs alone ignores longer-term and sustainability criteria. A set of criteria was required that considered economic, technical, social and environmental factors (Ellis *et al.* 2004; Ellis *et al.* 2006; Woods Ballard & Malcolm 2003). These have been published as multi-criteria decision-making and whole-life costing methodologies (*e.g.* Ellis *et al*. 2004; SNIFFER 2006:25-27). Table

C3.11 presents possible evaluation categories and associated headline criteria. Primary criteria were broken down into measurable lower-level indicators. Individual criteria are assigned a weighting factor. Since different factors may be relatively important or relevant in specific situations, weightings must be transparent, and agreed by decision-makers. Total assigned weightings were converted to a percentage for comparison between options.

Table C3.11 Primary criteria for assessing SUDS sustainability. Based on information in: Ashley *et al*. (2007b:28-30); Ellis *et al. (*2004:Table 1); Ellis *et al. (*2006:Table 1); Hellström *et al.* (2000:Table 1); Revitt *et al.* (2003:6-11); Woods Ballard & Malcolm (2003:Fig. 1)

C.3.5.3. Determine feasible solutions

Not all SUDS techniques are suitable for all sites (Woods Ballard *et al*. 2007:5.1), so detailed investigation of the specific environment proposed for retrofit is necessary to determine feasibility. While detailed technical assessments are appropriate when designing sustainable drainage systems, more straightforward, readily understandable techniques are necessary to evaluate the initial feasibility and to support high-level decision-making.

C.3.5.3.1. Examples

The extent to which flooding problems could be addressed by SUDS installations and calculated storage volumes could be achieved in these locations was assessed by investigating two examples in more detail.

Example one involved reviewing the technical potential for retrofitting SUDS in the AS sub-catchment. Each surface type was evaluated in the light of the possible SUDS devices from the pilot site analysis. Storage volumes were calculated for proposed options, and compared to the storage requirement (see section C3.4.2.4.3).

Example two evaluated implementation of a more extensive green roof retrofit. Rainfall storage capability, based on implementation using 50% of the present roof cover, assuming 30% attenuation and a minimal 15 cm substrate depth was calculated using Eqn C3.3.

$$Vol_s = ((Ar / 2) * Ds) * AS \qquad \text{(Eqn.C3.3)}$$

where

Vol_s = Rainwater storage (m^3)

Ar = Roof area (m^2)

Ds = Substrate Depth (m) = 0.15 m

AS = attenuation storage (%) = 30%.

The results were compared with the total storage volume required for the sub-catchment, adjusted by the roof area of the sub-catchment.

C.3.6. Summary

This section has explained the methodology used to assess the feasibility of retrofitting SUDS on Coventry University’s inner city campus.

C.4. CHARACTERISATION OF THE RESEARCH AREA

C.4.1. Characterisation of Pilot Site

This section presents the characterisation of the pilot study area:

- Physical and institutional factors informing the research
- Land cover - broad surface types present on the pilot site
- Impermeability - determination of the extent of impervious surfaces in the pilot area
- Baseline hydrological information.

Only factors that were specific to the pilot study are given here. Attributes that were also applicable at the city scale can be found in sections

C.4.1.1. Physical and institutional factors

This section presents physical and institutional attributes of the pilot research site and adjacent areas. The study area contained six groupings of buildings and land cover features, principally delimited by roadways, frequently a significant influence on catchment hydrology (Shuster *et al*. 2005:267), which were defined as sub-catchments, since each appeared to form a relatively self-contained hydrological area. Fig. C4.1 identifies the topography of the site, the location of the six sub-catchments, their relationship to public sewers and culverted watercourses, and the principal drainage direction for each sub-catchment, overlaid on a background of the supplied MasterMap base data. In general, the site gradient sloped down towards the course of the R. Sherbourne. The highest land surface point within the study site was 86.7 m above Ordnance Datum (AOD) in the Singer sub-catchment, and the lowest point 75.6 m AOD in the Armstrong Siddeley sub-catchment. The elevation change in all sub-catchments was no greater than 10 m.

Fig. C4.2 presents the institutional factors that informed the research: the principal flood locations in 2006, conservation areas and listed buildings on campus, areas scheduled for redevelopment over the next five years, and locations of infiltration tests. Fig. C4.3 shows the individual sub-catchments at a higher resolution. These are included as reference points for later discussion.

Fig. C4.1 Pilot site topography and drainage. The topography reflects zones contained in 5m contour lines. Purple arrows show the principal drainage direction for each sub-catchment. Thicker blue lines represent watercourses, all of which run in culvert until the R. Sherbourne emerges below the AS sub-catchment. Combined sewers are shown in red, surface water sewers in pale blue lines, with arrows identifying the direction of flow; only those sewers receiving water from the campus are shown. The dotted outlines represent approximate areas of the six sub-catchments for orientation purposes: AS = Armstrong Siddeley, FL = Frederick Lanchester Library, GE = George Eliot, GS = Graham Sutherland, JL = John Laing, SI = Singer; note that not all buildings and features in each zone were university-owned property.

Data sources - Base map: Ordnance survey (EDINA 2008); topography: EA Lidar surface extrapolation (2008a); public sewer data, and lines of Springfield Brook and Swan Lane culverts: Severn Trent Water (2007); path of river Sherbourne reconstructed from past maps of Coventry city centre (EDINA 2008; Historic Coventry 2008)

Fig. C4.2 Institutional factors informing the pilot study**.** Dark red hatched areas denote conservation areas and locally listed buildings. Black hatched areas are scheduled for redevelopment in the period 2008-2013 under the University's Estates Master plan. Blue circles indicate building locations flooded on 18th August 2006. Red stars depict the location of soil infiltration tests. The six sub-catchments are outlined - for abbreviations see Fig. C4.1

Data sources - Base map: Ordnance survey (EDINA 2008); conservation areas and listed buildings: CCC (2007); flooded locations: University

a) Singer

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b) John Laing

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c) Lanchester Library

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d) Armstrong Siddeley

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e) George Eliot

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f) Graham Sutherland

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Fig. C4.3 The six sub-catchments within the research site: a) Singer; b) John Laing; c) Lanchester Library; d) Armstrong Siddeley; e) George Eliot; f) Graham Sutherland. Purple arrows show the principal gradient and drainage direction. The names of each of the principal buildings is shown. The features included on the maps are taken from Figs. C4.1 and C4.2

Central Coventry has been home to manufacturing and industrial companies since the 19th century. Past uses for current University sites, determined from earlier Ordnance Survey maps (Edina 2008) included automotive manufacture (1937,1955), engineering (1955), textile mill (1937,1950), aluminium foundry (1937,1950). Such industries pose a risk of legacy land contamination. The City Council’s Contaminated Land Strategy (Coventry City Council 2004:11) indicated that the wide historical variety and distribution of industrial sites within the city rendered a full survey of land contamination impractical. Perhaps as a result, no associated public register of contaminant remediation, which might describe previous contamination on the University campus, was available for consultation in summer 2008.

C.4.1.2. Land cover

Land cover was simplified to four categories.

The OS MasterMap (EDINA 2008) appeared, on initial inspection, to offer the most accurate areal map of the campus (Fig. C4.4). GLUD (DCLG 2007c) used the same features present in MasterMap, but offered a more detailed classification of entities (Fig. C4.5). A number of inaccuracies were identified in the representation of buildings and land cover features in the supplied MasterMap dataset. The main inaccuracies were the absence of one building (Bugatti), the incorrect representation of others (notably Armstrong Siddeley, Jaguar, Richard Crossman) and inadequate differentiation of paved and vegetated areas in some locations. This lack of differentiation appeared unrelated to feature size. A modified MasterMap dataset was created to correct the spatial inaccuracies identified in the supplied MasterMap data. A walked field survey of the campus was performed to identify the main discrepancies. Fig. C4.6 indicates the extent of the differences between the supplied MasterMap dataset and the corrected version.

Fig. C4.4 The supplied MasterMap view of the campus area, classified to represent surface types identified by the Ordnance Survey. The six sub-catchments are outlined. Data source: Edina 2008

Fig. C4.5 Campus using the GLUD classification. The sub-catchments are enclosed by dotted outlines. Data sources: DCLG 2007c; Edina 2008

Fig. C4.7 provides a more detailed comparison of one sub-catchment using the three alternative datasets, to illustrate the type of modifications made when creating the modified MasterMap dataset. The supplied MasterMap (Fig. C4.7a) clearly distinguished buildings and public roads, but did not differentiate paved and vegetated surfaces. GLUD (Fig. C4.7b) also clearly identified buildings, with most correctly classified as non-domestic, although a small section of the Graham Sutherland building was shown as domestic. GLUD was less accurate at identification of paved areas; public roads were correctly isolated, but the logic used to differentiate roads and hard standing on campus was unclear, although this difference was not important for this study because of the amalgamation of GLUD categories into the four classes used in this study. However, the paved walkway to the south-west of the Graham Sutherland building was wrongly shown as greenspace. GLUD incorrectly classified some vegetated areas as domestic gardens. Both raw MasterMap and GLUD, which used the MasterMap polygons, failed to indicate the presence of the Bugatti building. The supplied Ordnance Survey data was corrected after a walked field survey to create a modified MasterMap (Fig. C4.7c), intended as an accurate representation of land cover with classification into the four categories used in this study. Raw MasterMap did not distinguish the majority of paved and vegetated surfaces, so the appropriate classification was applied to the modified MasterMap, for instance the area to the south-west of the Graham Sutherland building. Modified polygons are colour-coded differently on Fig. C4.7c, revealing the reconfiguration of space associated with the construction of Bugatti. In this revised landscape, a new path replaced some of the vegetation.

Fig. C4.6 Differences between the supplied MasterMap dataset and the corrected version for the campus. Features in paler shades represent the supplied MasterMap dataset. Features in bolder shades indicate the areas modified to reflect actual land cover features present on campus. Coloured features indicate University property

a) MasterMap

b) GLUD

c) modified MasterMap

Fig. C4.7 Comparative land cover classification of sub-catchment six, Graham Sutherland, showing differing surface categories for the same location: a) MasterMap b) GLUD c) modified MasterMap. Actual land cover is indicated for example areas on diagrams (a) and (b). a) Raw MasterMap identified buildings but did not distinguish paved and vegetated features; b) GLUD identified buildings, and attempted to separate paved and vegetated features, but not always accurately; c) amendments made to the raw MasterMap data to incorporate accurate land cover classification and feature polygon outlines. Feature outlines on the modified MasterMap diagram (c) reflect the location of the original features from the raw MasterMap dataset. For additional explanation see text

As a result of differing land cover representations and classification across the three datasets, variation in land cover percentages was observed (Fig. C4.8). For the campus as a whole, the raw MasterMap dataset under-estimated paved area, and over-estimated the area covered by vegetation. The features classified as paved areas in raw MasterMap represented only a limited subset of the paved areas present on campus; other non-building areas, whether vegetated or paved, were not differentiated, but classed as ‘land’. Two further sub-classifications were available in the raw MasterMap data, but these also prevented finer differentiation:

- in the first, Description Group, the sub-classification of all ‘land’ areas on campus was 'General surface'
- the second, Make, provided differentiation into 'Manmade', 'Multiple' and 'Natural', but all three included both paved and vegetated surfaces.

In this study, raw MasterMap ‘land’ was treated as vegetation in order to differentiate it from identified roads and paths in raw MasterMap, although it could equally have been deemed ‘paving’, although this would have resulted in an absence of any vegetation on campus.

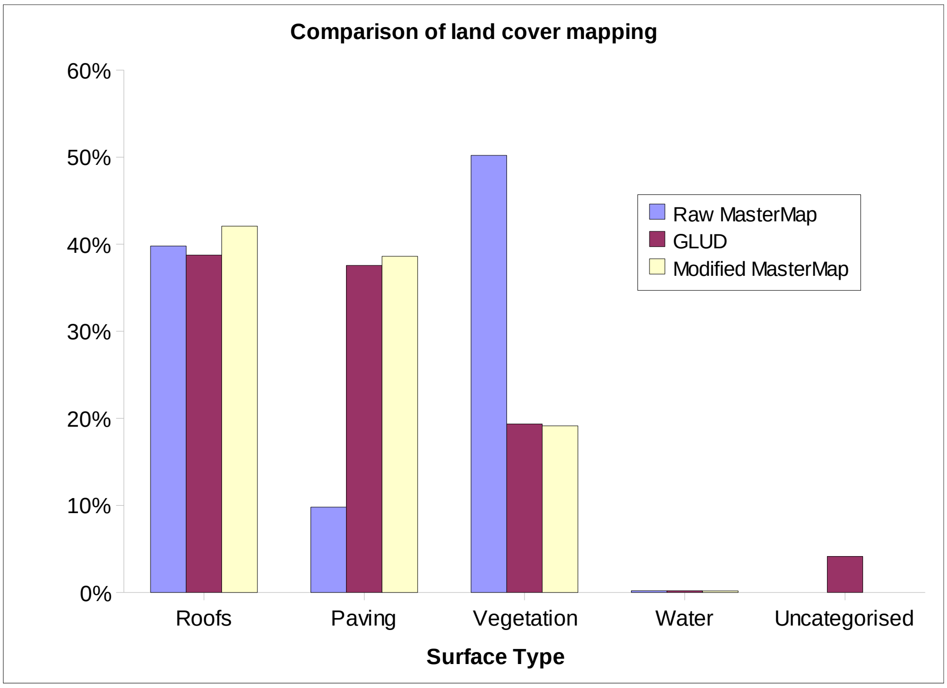


Fig. C4.8 Classified land cover percentages from the raw MasterMap, GLUD and modified MasterMap datasets

GLUD was more accurate at discriminating vegetated and paved areas. The uncategorised element in the GLUD dataset was almost entirely represented by construction of the Student Centre (see Fig. C4.5), which was underway when the dataset was compiled. Assuming the modified MasterMap to be an accurate representation of land cover, the GLUD dataset provided a closer reflection of actual land cover categories than the raw MasterMap, although both used the same base entities. This improvement resulted from enhanced classification in GLUD.

Neither the raw MasterMap nor GLUD dataset identified landowners. This task was undertaken for the modified MasterMap dataset, and then applied to the raw MasterMap and GLUD data. Certain entities in the original dataset covered both university and non-university land-holdings. The additional areas consisted of paving in Cope Street (George Eliot sub-catchment) and Gulson hospital (Frederick Lanchester sub-catchment). The original entities were not divided when applying the land-holder attribute to raw MasterMap and GLUD. Consequently, raw MasterMap and GLUD covered a larger area (13.85 ha) compared to modified MasterMap (13.33 ha), a difference of 0.52 ha (4%). As a validation, the area reclassified as non-campus was determined. The reclassified area should also have been 0.52 ha, but was calculated to be 0.546 ha, a further 267 m^2 (0.2%) discrepancy between the land cover area in raw MasterMap compared to modified MasterMap. This discrepancy was due to manual errors when digitising the modifications.

Inaccuracies in representing land cover type in raw MasterMap and GLUD are shown in Table C4.1. For buildings, the -0.7% variation was accounted for by the missing Bugatti building and incorrect outlines for four other buildings. Since the GLUD dataset was a re-classification of the raw MasterMap but used the same base entities, errors in representing buildings in raw MasterMap were also present in GLUD. The additional variation for buildings with GLUD was due to the Student Centre, which was under construction when the GLUD dataset was compiled, and so was treated as ‘unclassified’.

Given the lack of discrimination between paving and vegetation in raw MasterMap, the quantified differences in Table C4.1 were large but not individually meaningful. For GLUD, an element of the paving and vegetation variation was due to construction of the Student Centre, the remainder to incorrect classification in the GLUD dataset.

Table C4.1 Percentage variations between modified MasterMap, raw MasterMap and GLUD for each land cover class of University-owned property. Column two gives the land cover proportion for each class in modified MasterMap. Columns three and four present the percentage variation within each class for raw MasterMap and GLUD

Land cover type	**Modified MasterMap land cover (%)**	**Raw MasterMap variation (%)**	**GLUD variation (%)**
Buildings	42.1	-0.7	-1.7
Paved areas	38.6	-32.5 (1)	-3.6
Vegetated areas	19.1	+33.1 (1)	+1.0
Surface water	0.2	0	0
Unclassified	0.0	0	+4.3
Total variation		66.3	10.6

The total absolute variation of 66.3% for raw MasterMap compared to modified MasterMap reflected the lack of discrimination between paving and vegetation land cover. For GLUD, the total absolute variation was 10.8%. Removing the known unclassified area, and on the assumption that it would have been correctly classified, the total absolute variation for GLUD was 6.3%. Four weeks effort was expended in surveying the campus and modifying the raw MasterMap dataset to produce an accurate representation of land cover. Given this effort, an overall 10.8% variation between GLUD and modified MasterMap suggests that GLUD may provide an acceptable first-pass land cover classification in similar urban areas and at a similar level of detail, assuming no major developments have taken place since 2005 when GLUD was generated.

The land cover of each sub-catchment is given in Table C4.2. Buildings formed the highest proportion of land cover overall, and in two of the six sub-catchments (JL & GS). In three sub-catchments (SI, FL and GE), paved areas were the highest percentage land cover. In the AS sub-catchment, vegetation formed the principal land cover type.

Table C4.2. Land cover of the pilot study site. Each of the six sub-catchments, and a total for the pilot study area, is shown, utilising the four classes defined for the pilot study. The percentage figure represents the constituent proportion of that land cover class in the sub-catchment.

Subcatchment	**SI**		**JL**		**FL**		**AS**		**GE**		**GS**		**All**	
Land cover	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Buildings	1.06	39.3	0.89	47.2	1.08	37.4	0.57	35.2	1.35	44.3	0.66	55.5	5.61	42.1
Paved areas	1.13	41.9	0.71	37.4	1.26	43.6	0.34	21.2	1.42	46.5	0.29	24.5	5.15	38.6
Vegetated areas	0.51	18.8	0.29	15.4	0.53	18.3	0.71	43.6	0.28	9.3	0.24	19.9	2.55	19.1
Surface water	0.00	0.0	0.00	0.0	0.02	0.8	0.00	0.0	0.00	0.0	0.00	0.0	0.02	0.2
Total	2.70		1.89		2.89		1.62		3.05		1.19		13.33	

C.4.1.3. Impermeability

Determination of land cover type enabled calculation of impermeability percentages for each sub-catchment and for the campus as a whole using the modified MasterMap and GLUD datasets (Fig. C4.9). Because the raw MasterMap data did not allow for clear distinction of permeable and impermeable areas, it was not used in impermeability calculations. Impermeable extent was similar between modified MasterMap and GLUD. Across the total study area, the modified dataset figure was 80.7%, with GLUD showing 76.3% impermeable, plus a further 4.1% unclassified, the majority of which was also developed as impermeable surface (see Fig. C4.3c). In five of the six sub-catchments, impermeable area was higher in modified MasterMap by between 2.8-9.4% per individual sub-catchment. The exception was the JL sub-catchment, where the 6.1% over-estimate of impermeable areas was caused by incorrect classification of a grassed area as hard standing in GLUD. Impermeability ranged between 80-91% for five of the six sub-catchments. Impermeability in the AS sub-catchment was notably lower, at 56.4%.

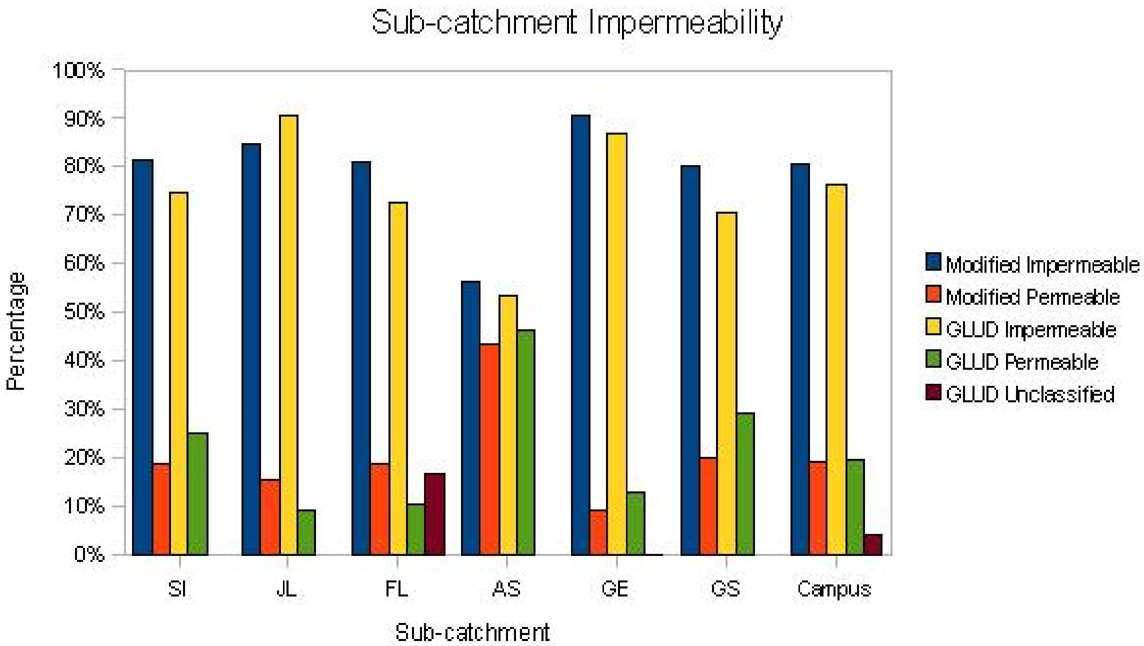


Fig. C4.9 Classified land cover percentages for each sub-catchment, and for the campus as a whole, from the modified MasterMap and GLUD datasets. Each sub-catchment is represented by five bars, the first two showing the classification according to modified MasterMap, the last three the GLUD classification. Key to sub-catchments: SI = Singer, JL = John Laing, FL= Frederick Lanchester Library, AS = Armstrong Siddeley, GE = George Eliot, GS = Graham Sutherland

The impermeability percentages in the modified MasterMap dataset, given in Table C4.3, were used in hydrological evaluations of the campus.

Table C4.3 Levels of impermeability used in hydrological calculations

Sub-catchment	Impermeability percentage
Singer	81.2%
John Laing	84.6%
Frederick Lanchester	81.0%
Armstrong Siddeley	56.4%
George Eliot	90.7%
Graham Sutherland	80.1%
Campus	80.7%

The 13.33 ha city centre campus as a whole, and five of its six sub-catchments, demonstrated impermeability levels around 80-90%. Most UK SUDS retrofit studies have addressed lower levels of impermeability (Table C4.4). Furthermore, impermeability varies by land cover type. In commercial and industrial sites in urban Munich covering 5,000 ha (Pauleit & Duhme 2000:8-9), impermeability of land plots was highest for roads (91%), densely built-up areas (80%), commercial and industrial areas (76%), and large car parks (59%).

Table C4.4 Levels of impermeability addressed in UK SUDS retrofit studies, in descending impermeability ratio sequence

Location	Impermeability %	Area (ha)	Source
Meadowhall Retail Park, Sheffield	87.7	6.0	Stovin *et al*. 2007:13
1 site on Houston Industrial Estate, Livingston	87	0.05	SNIFFER 2006:56
This pilot study	81	13.33	2007-08
Irvine, Ayrshire	70	19.6	Atkins Water 2004:A.9
Girvan, Ayrshire	70	9.8	Atkins Water 2004:A.4
Glasgow	69	283.8	Singh *et al.* 2005:3
Dunfermline	55	642	Hyder Consulting 2004:11
Four sites on Houston Industrial Estate, Livingston	41 to 64	1 to 3	SNIFFER 2006:56

Specific impermeability rates of UK inner-city sites were difficult to obtain (Pauleit *et al*. 2005:306). No country-wide figures were found. Individual UK studies have quoted figures which were interesting but not obviously comparable:

- 21-34% for three cities in Wales, Scotland and northern England covering areas of 1380-3930 ha, with smaller populations than Coventry, thus likely to encompass the entire urban area, not solely the inner city (Evans *et al*. 2004:135)
- 40-100% for industrial areas, and 35-60% for office and retail premises, covering 210-586 ha in cities from 1980-1985 (Mitchell *et al*. 2001:74-75). The authors suggested a value of 55% impermeability to be appropriate for commercial and industrial areas in urban sites, but the results of the pilot study clearly exceeded this figure, albeit in a smaller area

- 61% impermeable area covered by buildings and paving in Merseyside over 25 ha of residential areas (Pauleit *et al*. 2005:301)
- 37% impermeable area in urbanised Greater Manchester (793 km^2), with town centres having the densest cover (Gill *et al*. 2008:218).

Past trends of increasing impermeable area throughout the UK in recent decades are likely to continue into the future (Defra 2003b; Pauleit *et al*. 2005). Predictions for the West Midlands of 66.0% urbanisation in 2016, the second highest level in England after Greater London (Defra 2003b), suggest a high ratio of impervious surfaces. Estimates of the increase in impermeable area in the UK by the 2080s range between 7.5-30%, depending on the economic scenario assumed (Evans *et al*. 2004:142).

A greater number of studies have been carried out in the USA on levels of impermeability in urban areas. A review of nine studies, the majority located in east coast states of the USA (Shuster *et al*. 2005:269), found estimates of impermeable surface for commercial and industrial land uses ranging from 53% to 90%, mean 69.3%; for institutional land use (four studies), the mean was 38.2%, ranging from 33.3% to 50%, all of them smaller percentages than found for the pilot site. The authors (2005:273) also determined no single threshold impermeability value above which runoff rates increased, and concluded that the point at which impermeability percentages affect local hydrology was likely to be site-specific. No information was found that confirmed the applicability of USA figures to the UK. In North Carolina (NCDENR 2005:2.4), institutional plots were determined to have 62% impermeability, with commercial and service land uses typically 82%, and main roads 87%. In Connecticut, Prisloe *et al*. (2003:11) correlated population densities with impermeability coefficients for 29 land cover classes, and calculated a ratio of 55.7% in high density urban areas with commercial or industrial developments and paving. They defined high population density as exceeding 1800 people per square mile (46.6 residents ha^{-1}), which was similar to the population density in St. Michael’s ward, covering central Coventry, of 50.1 people ha^{-1} (Coventry City Council 2008a). However, these authors cautioned that the calculated coefficients were mainly suitable for larger catchments exceeding 1000 ha, as smaller areas were subject to increased classification and calculation errors.

Further factors may influence the land cover and impermeability estimates generated in this exercise. In practice, impermeable areas may not be completely sealed, as rainfall can infiltrate into cracks between paving slabs, for example. Furthermore some permeable areas, e.g. compacted soil or soils with poor infiltration, exhibit some of the characteristics of impermeability, particularly during periods of intense rainfall. Overall, the characteristics of impermeable surfaces, and their relationship to the different components of the hydrologic cycle, are incompletely understood and require further research (Shuster *et al*. 2005:273).

C.4.1.4. Hydrology

This section reports characteristics of the pilot study area used in the hydrological investigation under the following headings:

- Precipitation
- Soil characteristics
- Geology
- Groundwater.

C.4.1.4.1. Geology

Coventry University city centre campus is located on Carboniferous sedimentary bedrock (BGS 2008a), comprising a mix of sandstone and mudstone formations, with mudstone dominating along the River Sherbourne downstream from the city centre (Old 1988:7). The clay-rich Carboniferous rocks under the study area contribute to poor drainage (Coventry City Council 2008:11).

C.4.1.4.2. Groundwater

The pilot study area was not located within a groundwater source protection zone (SPZ) (EA 2008b). The catchment boundary of a groundwater SPZ started approximately 150 m from the western edge of the campus. The risk levels defined in the EA groundwater maps relate only to soil surface activities, and significant building works require a site-specific study (EA 2007f:36). The groundwater level underlying the study area was not explicitly identified. It was assumed to be approximately at the level of the river.

The university has the potential to contribute to diffuse pollution of surface waters and groundwater, for example

- Nitrates through the use of fertiliser
- Pesticides through the use of weed killers to maintain paved areas
- Oil through vehicle leakage in car parks
- Solvents through inappropriate use or disposal of paints, adhesives and cleaning products, and from mobilisation of spills from past industrial and commercial users

Coventry lies within a classified nitrate vulnerable zone (NVZ – Coventry City Council

2008b:54), although agricultural rather than urban sources account for the majority of nitrate input to watercourses. Solvents represent a source of serious groundwater contamination from industrial and commercial environments (Culshaw *et al*. 2006:239; Defra 2004:1), due to their long persistence times, migration pathways, toxicity and complex behaviour. Chlorinated solvents have caused significant pollution to localised hotspots in the shallow top sections of the aquifer underlying central and western areas of Coventry (Besien & Pearson 2007:5). Solvent clean-up costs are typically £0.5-2million per site (EA 2007e:12). Poor maintenance and integrity of private and public drains is a recurrent source of groundwater pollution by solvents, so up-to-date plans of site drainage are considered necessary (Defra 2004:10,13). The university did not possess such plans.

C.4.1.4.3. Precipitation and flooding

Background details of precipitation in Coventry are given in Appendix D. Several university buildings were flooded on 18th August 2006. The daily rainfall total on that day was 14.8 mm, but 23.2 mm the previous day may have led to saturated ground conditions and elevated water levels in drainage and river channels. In comparison with other rainfall events in summer 2006 and 2007 (Fig. C4.10), 14.8 mm was exceeded on three occasions during summer 2006, although the combined 17-18 August 2006 figure of 38.0 mm was the highest that summer. Informal reports from University staff indicated that the James Starley map room flooded on three occasions during summer 2006. 14.8 mm was exceeded on four occasions in summer 2007, and 38.0 mm was exceeded twice, yet no flooding of university premises was recorded from those events.

Fig. C4.10 Daily rainfall totals in summer 2006 and 2007 (June to August). Days with zero rainfall are omitted. The rainfall depth for 1-year, 30-year and 100-year design storms are included for comparison. Data source for daily records: Bablake Weather Station (2013)

C.4.1.4.4. Soil Infiltration Characteristics

University Grounds staff had no specific information relating to site soil characteristics, commenting only on its variability across campus. A limited set of infiltration tests was carried out to clarify uncertainties in the information obtained from published sources. The three grassed areas, in the Frederick Lanchester, John Laing and George Eliot sub-catchments, exhibited infiltration rates from 2.7 to 9.5 mm h^{-1}, with a mean value of 5.38 mm h^{-1} (Fig. C4.11). These sites were likely to be fairly well compacted, as mowing was performed using heavy machinery. The infiltration rate at the uncompacted site, bare soil in a shrub bed in the AS sub-catchment, was 27.6 mm h^{-1}, three times greater than the best of the compacted sites. The overall mean (10.9 mm h^{-1}) was skewed by this higher outlier value. The median value of 6.7 mm h^{-1} may be more representative of the campus as a whole.

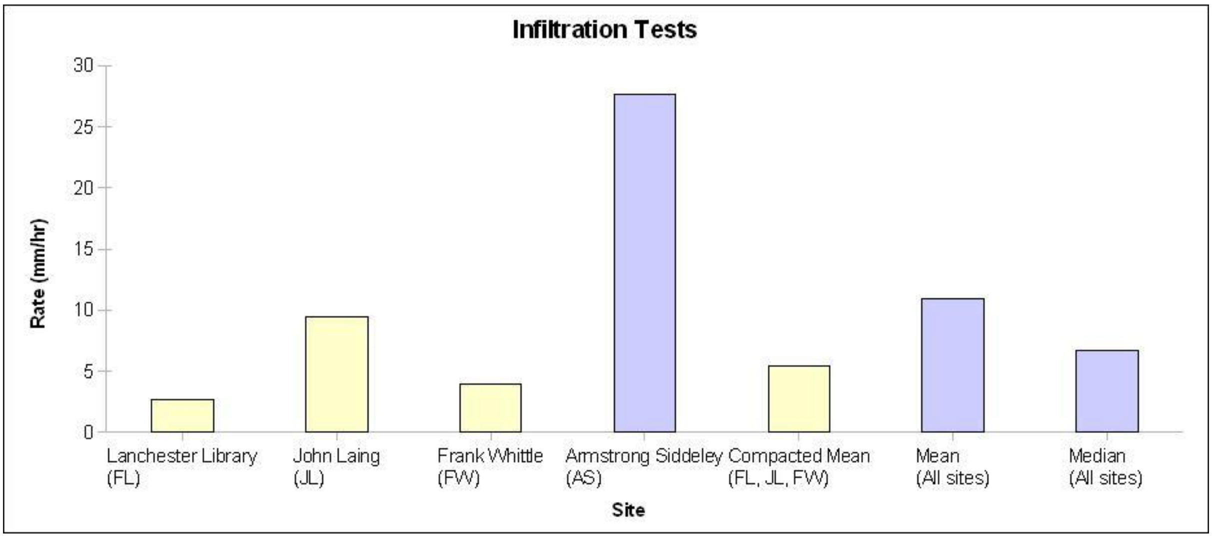


Fig. C4.11 Infiltration tests at four campus locations. Compacted grass areas are shown in yellow, the uncompacted area in blue. Compacted mean is the mean of the three compacted locations. Overall mean and median values include all four locations tested

C.4.1.5. Summary

Ordnance Survey MasterMap (Edina 2008) land cover classification was insufficiently accurate to characterise the variation between permeable and impermeable surfaces on the University campus. GLUD provided a more accurate land cover classification, based on 2005 data, but utilised MasterMap features, so was subject to MasterMap's errors in the representation of physical entities. Overall, the inner-city campus exhibited 80-90% impermeability in five of the six sub-catchments, while one sub-catchment had fewer hard surfaces, with 56% impermeability.

C.5. PILOT SITE RESULTS AND DISCUSSION

C.5.1. Introduction

This chapter, organised into five sections, presents the results of the pilot site investigation of SUDS feasibility techniques in support of aim 1. Sections 5.2-5.5 evaluate the potential for retrofitting SUDS on Coventry University's inner-city campus using a range of techniques:

5.2 Problem locations, considers 'where' SUDS may be of benefit by reviewing a GIS-based hydrological model of flow paths, recent sites of flooding, quality of local watercourses, and locations of surface water sewers disposing runoff into watercourses

5.3 Flood Risk, evaluates the utility of planning guidance

5.4 Hydrological assessment of SUDS devices, considers the question 'how much' by evaluating the requirements for different types of SUDS in a management train in terms of runoff rate and volume

5.5 SUDS decision support tools, applies and evaluates suggested SUDS using feasibility assessment methods employed in previous SUDS studies

Section 5.6 brings together the evaluations to formulate possible SUDS on campus:

5.6 Locations for SUDS on CU campus, evaluates the results from the above approaches and formulates recommendations for possible SUDS on Coventry University campus

C.5.2. Problem locations

A number of techniques were employed to identify locations where retrofit SUDS might provide a benefit in terms of water quantity and quality.

C.5.2.1. Recent sites of flooding

The University suffered flooding in a number of buildings on 18th August 2006, all as a result of surface water rather than fluvial flooding. Of the seven sites impacted, six locations were in the GE sub-catchment, the most impermeable (Fig. C5.1). The buildings affected were Charles Ward (east basement lobby, west ground floor entrance, rooms B40, B45, B51, B52, B53, 145 and the combined heat and power plant (CHP)), and James Starley (room B01). Five of the six in GE were at relatively low elevation points, while JS B01 was at the bottom of a concrete ramp. One location in the JL sub-catchment was impacted on that date in 2006: Ellen

Terry (rear entrance, lift lobby and corridor, and room B10). Flooding occurred on two further occasions in James Starley B01 during that same summer, and again in the summers of 2011 and 2012, despite additional preventive drainage work after the 2006 events to increase the capacity of the storage chamber. These locations might benefit from runoff reduction SUDS.

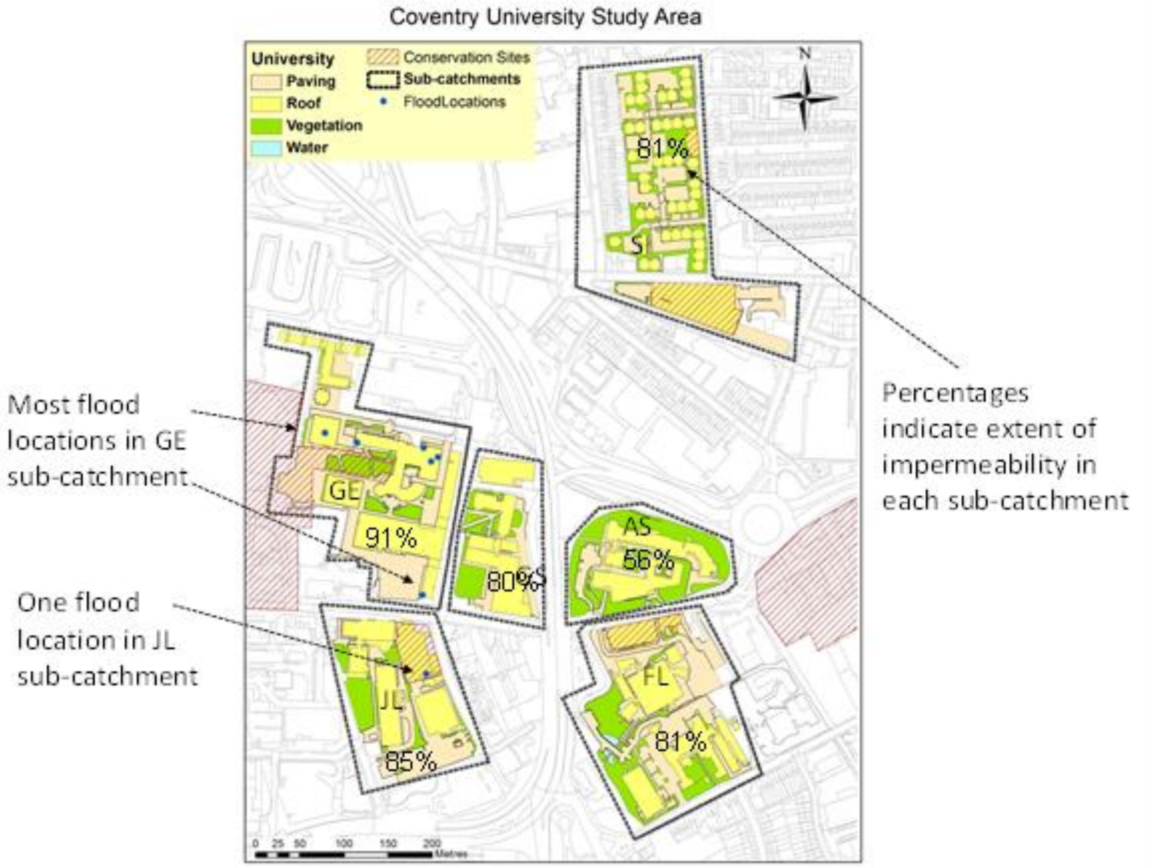


Fig. C5.1 Flood locations on Coventry University campus on 18th August 2006 due to surface water runoff. Flood locations were in the two most impermeable sub-catchments. For sub-catchment abbreviations see Fig. C4.1

C.5.2.2. GIS hydrological modelling

ArcGIS hydrological modelling (ESRI 2006) was undertaken to identify runoff flow paths and sites of water accumulation after rainfall. Fig. C5.2 depicts the resulting runoff flowpaths and areas of flow accumulation for the western section of the pilot area, where runoff accumulation flows were larger. ArcGIS regards sinks in the surface representation as data collection errors, and recommends that they are filled in order to build a valid hydrological surface, and Fig. C5.26 depicts the model results after sinks were filled. Runoff, once it reached road carriageways, ran down the road gullies. Some flow accumulation passed near three of the seven flooded locations, but the paths ignored some of the real-world features, due for example to: the vertical resolution of the Lidar data; the additional coarsening required by the ArcGIS model; and the lack of some modelling functionality. For example, Fig. C5.2 shows the bridge over a road treated as a dam by the model, unrealistically forcing the flow westwards rather than continuing underneath the bridge. This problem is not uncommon when using Lidar data to build a topographical surface in urban areas (Bales & Wagner 2009:141; Diaz-Nieto *et al*. 2008:4).

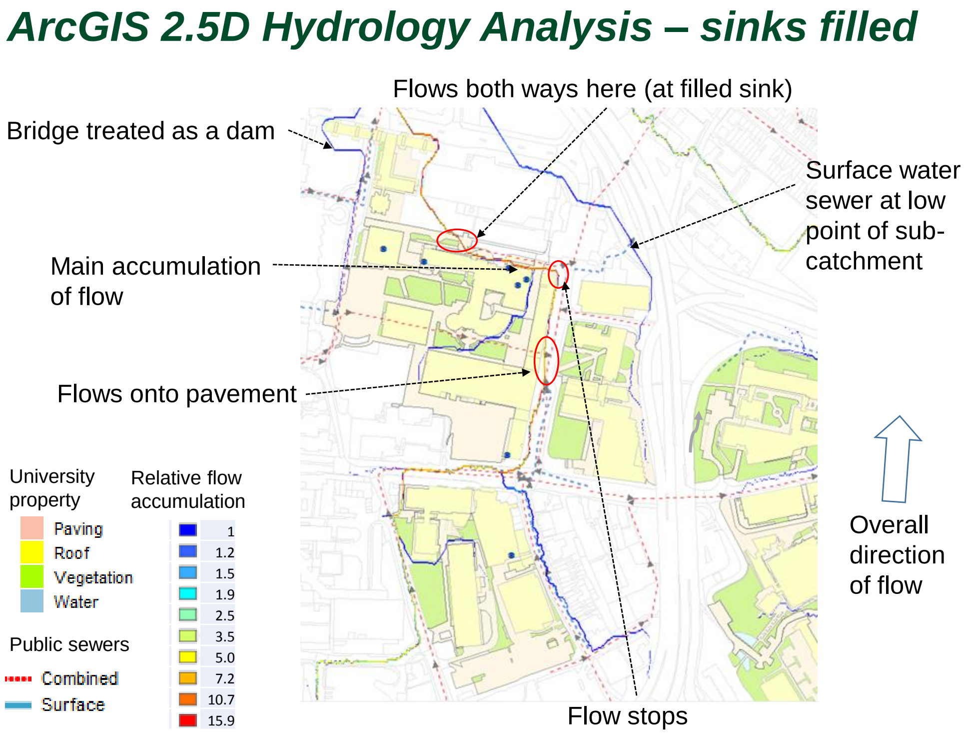
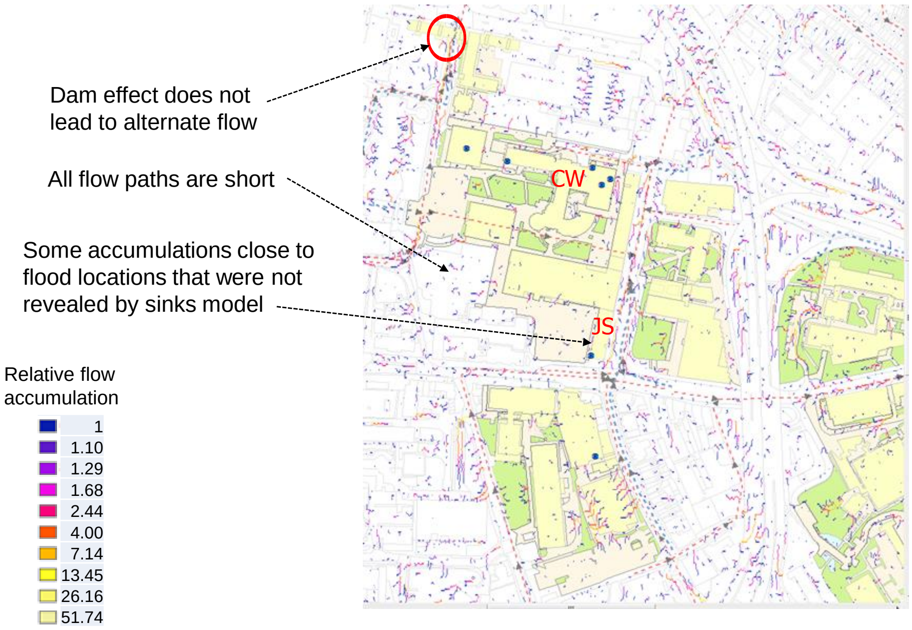


Fig. C5.2 Hydrology analysis with sinks filled. Outline of non-University features in grey.

Since the filled sinks appeared to influence the flow paths, the hydrological model was re-run using unfilled sinks (Fig. C5.3), but overall there was no improvement in the model's performance in predicting known flood sites. On Fig. C5.4, which compares the outputs of the two model runs, most flow paths appeared unrelated to sinks. Fig. C5.5 shows the same flow paths as Fig. C5.4, but with the background and sinks removed to facilitate comparison.

2.5D Hydrology Analysis – sinks unfilled



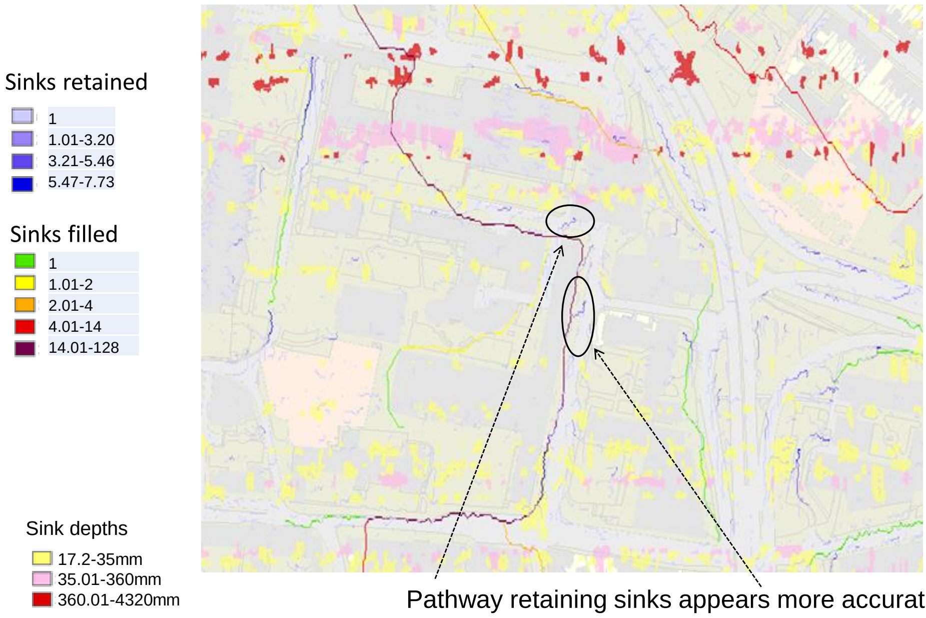
Dam effect does not lead to alternate flow

All flow paths are short

Some accumulations close to flood locations that were not revealed by sinks model

Fig. C5.3 Hydrology analysis with sinks retained

Compare flow paths with and without sinks



Pathway retaining sinks appears more accurate

Fig. C5.4 Flow path comparison with different sink treatments

Flow path comparison without background

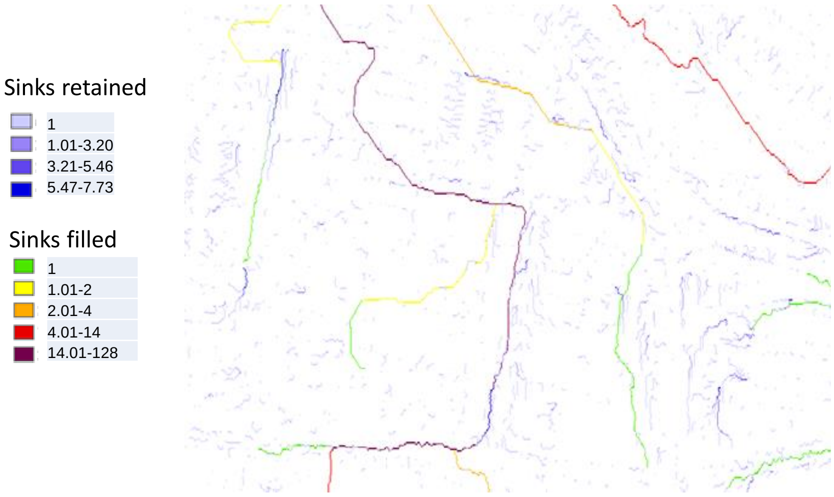


Fig. C5.5 Flow path comparison without background

ArcGIS hydrological modelling did not identify the known flood sites using either model, although the build-up of water at the north-eastern corner of the GE sub-catchment might indicate the potential for problems at this location to those with a detailed knowledge of the site. The model with sinks was better at identifying channels of flow, although it was not certain whether it was more accurate than the model without sinks. There was no apparent relationship to flood locations, or to the river, and no account was taken of drains and sewers, permeable versus impermeable areas, and features that were not identified by the Lidar survey.

The process employed here was an alternative use of the ArcGIS hydrological modelling software to that of Diaz-Nieto *et al*. (2008), who retained sinks to identify possible areas of surface water flooding, but needed to undertake additional work to adjust the input Lidar data and develop the model. ArcGIS hydrology functions were not designed for an urban environment without this additional effort. There was no straightforward method to remove obstructions created as a result of the Lidar representation without altering the underlying data, and existing sewerage infrastructure was not taken into account. Consequently, the absence of actual data, and the non-performance of the hydrological model, indicated the need for using runoff design values to gain a better understanding of runoff behaviour on site.

C.5.2.3. Assessment of river water quality

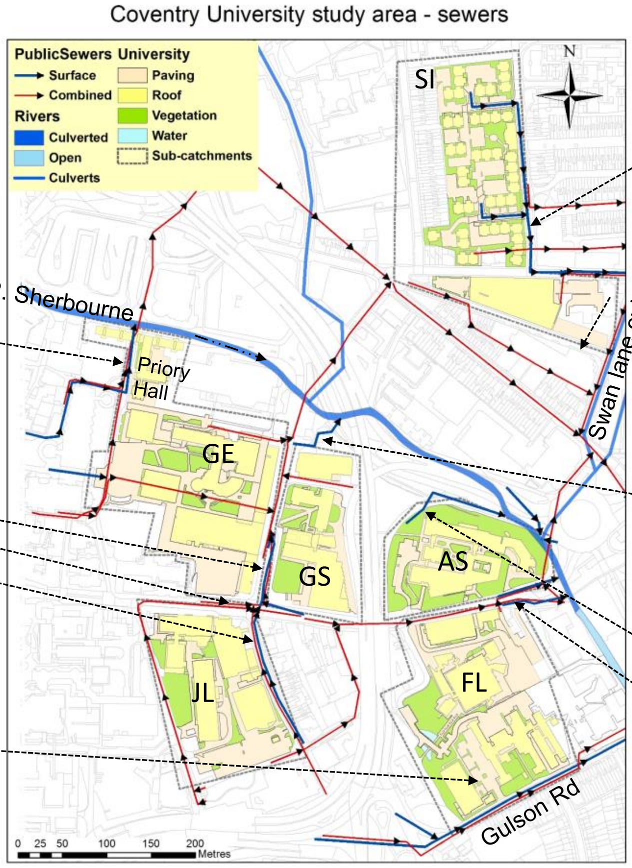
The EA assessed river water quality in the stretch of the R. Sherbourne from Queen Victoria Road, on entry to the city centre upstream of the campus, to the confluence with the R. Sowe at the southern boundary of the city. At the time of the pilot study, fluvial water quality assessments utilised four measures under the General Quality Assessment (GQA) scheme. Results in 2007 are given in Table C5.1. Runoff from the campus would enter this stretch via surface water sewers. Although measures of chemistry (for biochemical oxygen demand, ammonia and dissolved oxygen) were very good, confirming the detailed evaluation based on continuous sampling by Hyde (2006:349), the number of macro-invertebrates present in the river indicated, by contrast, fairly high levels of pollution. Biological quality was 'fair' (grade D) upstream of the city centre, suggesting a deterioration of some elements of water quality as the R. Sherbourne passes through the city centre. Values for these measures were largely unchanged over the previous five years 2002-2006. Improvements in runoff quality from the campus might contribute to improved water quality, and possible locations are assessed in the next section.

Table C5.1 GQA assessment of water quality of the R. Sherbourne in 2007

Measure	Chemistry	Biology	Nitrates	Phosphates
Best possible value	A very good	A very good	1 very low	1 very low
Worst possible value	F bad	F bad	6 very high	6 excessively high
Mean value in stretch of R. Sherbourne in 2007 influenced by Coventry University	A very good (natural ecosystem)	E poor (impoverished ecosystem)	4 moderate	4 high

C.5.2.4. Locations of surface water sewers

A number of surface water sewers fed runoff from the campus directly into watercourses (Fig. C5.6). These were located in the Singer, Armstrong Siddeley sub-catchments, the Priory Hall end of the GE sub-catchment, and the southern (Gulson Rd) end of the Library sub-catchment. Measures to reduce or treat runoff from these locations might contribute to water quality improvement in the R. Sherbourne. For water quality purposes, interception and treatment of the initial rainfall depth will reduce river pollution from the first flush effect (SNIFFER 2006:78; Woods Ballard *et al*. 2007:3.11).



Limited runoff from north-west of GE delivered to R. Sherbourne

Surface sewers deliver to combined sewers

Runoff from south of FL delivered to R. Sherbourne

SI surface water delivered to Swan lane culvert

Runoff from north-east corner of GE delivered to R. Sherbourne

Runoff from low points of AS and FL delivered to R. Sherbourne

Fig. C5.6 Public sewers near Coventry University city centre campus. For sub-catchment abbreviations see Fig. C4.1

C.5.3. Flood Risk Guidance

This section evaluates flood risk using published flood risk maps and tests defined in PPS25 (DCLG 2010). Although these techniques were possibly intended for new developments, their value for retrofit was considered for the pilot. PPS25 was in force at the time of the pilot, but was subsequently replaced by the National Planning Policy Framework (DCLG 2012). The tests considered here remained the same.

C.5.3.1. Flood Risk Maps

EA fluvial flood maps (Fig. C5.7, EA 2008c) and the Coventry level 1 SFRA (Fig. C5.8, Coventry City Council 2008b) showed boundaries for 100- and 1000-year river floods, assuming that no flood defences were in place. Neither published map was particularly clearly defined at the detailed resolution required to assess impact on individual buildings. Fig. C5.9 compares the flood plain definitions from these two sources. No buildings appeared to be within the 100-year flood plain, but four lay within the 1000-year risk zone. The SFRA 1000-year boundary covered a larger area than the equivalent EA 1000-year limit. Consequently, more university buildings were categorised at risk using SFRA modelling.

There was some disparity between the precise route of watercourses and the associated flood risk boundaries (Fig. C5.9), which may reflect anthropogenic re-engineering of river channels over time. The flood plain zones most likely to affect the campus were situated between 75 m and 80 m AOD (Fig. C5.10). No clear relationship between flood risk areas and topography was observed at this resolution. The relatively narrow contour bands on the south side of the river and through Singer Hall indicate steeper gradient changes which will serve to protect most of the university buildings from river flooding, except those inside or just outside the 1000-year flood plain. Potentially affected buildings were Priory Hall, the northern end of James Starley and Charles Ward buildings, the Student Union 54 building, and the William Lyons building

Vegetated and paved areas, and access roadways, in the 1000-year zone will be affected. The Alma building in the Singer sub-catchment is subject to most uncertainty because it is located in a broader contour band shared with the both 100-year and 1000-year flood plain. Assuming the location of fluvial flood zones to be correct, minor details such as kerb heights and paving profiles will influence the flood risk for this building.

Fig. C5.7 Flood Risk from the River Sherbourne according to the Environment Agency flood map. Dark blue areas indicate a 1% annual (1-in 100-year) risk of flooding. Pale blue areas indicate a 1 in 1000-year risk. University areas are outlined in red. Note also the generalisation of buildings making individual identification impossible. Data source: EA 2008c

SFRA Fluvial Flood Risk in Central Coventry

Fig. C5.8 Flood Risk in central Coventry according to the SFRA flood map. Darker blue areas indicate a 1% annual (1-in 100-year) risk of flooding. Paler blue areas indicate a 1 in 1000-year risk. Red areas show the functional flood plain of the river, equivalent to a 1 in 20-year risk. University sub-catchments are outlined in yellow. Note the lack of clarity of the image at this detailed resolution, and the outdated representation of university buildings. Data source: Coventry City Council 2008b

Flood Plain Definitions

Fig. C5.9 Comparison of flood risk from the River Sherbourne according to EA and SFRA maps. Only areas impacting the campus are shown. For the SFRA 1000-year zone, only areas additional to the EA 1000-year zone are depicted. Data sources: Coventry City Council 2008b; EA 2008c

Flood Plain Comparison with Topography

Fig. C5.10 Flood risk maps overlaid on a topographical map of the study area. Sub-catchment boundaries are outlined. University buildings within sub-catchments are in yellow. Data sources: Flood plain maps - Coventry City Council 2008b; EA 2008a; topography - EA 2008c

Several sources of uncertainty are present in flood inundation maps, including (Bales & Wagner 2009):

- measurements of streamflow and precipitation are subject to the inaccuracies of gauging equipment
- topographic data is dependent on spatial resolution and accuracy of the source data
- uncertainties in the parameters used to drive hydraulic models
- lack of calibration data to check model results
- model assumptions regarding the speed of inundation of different types of surface
- assumptions of 1D models that the main variation in hydraulic variables (water-surface elevation, water-surface slope, velocity, and cross-sectional area) travels from upstream to downstream, and that these variables do not vary across a land-surface cross section that may intersect a number of streams.

The accuracy of the EA flood risk zones was open to question. The SFRA pointed out that a large number of assumptions had been incorporated during their production (Coventry City Council 2008b:Appx. C). Since watercourses run largely in culvert through Coventry city centre, the culvert provides a form of flood defence, and direct overflow from river banks is not possible in these circumstances. It was unclear from either the EA or SFRA maps and associated description whether the flood plain depicted was a theoretical representation of flood risk if the Sherbourne culvert did not exist, or if the areas shown were those most at risk from sewer surcharge in the event of the culvert filling. If a large volume of water were to fill the river to capacity from higher in the catchment, the start of the culvert would limit the flow, increasing the likelihood of flood upstream of the city centre in the Spon End area. However, elevated water levels passing through the culverted section may cause surcharge of surface water sewers. This risk was associated with a 100-year return period event (Coventry City Council 2008b:22). Recognising the greater accuracy of the SFRA modelling, the EA revised the flood plain maps for Coventry after the period of the pilot study according to the SFRA.

No information was obtained about the likelihood of combined sewer surcharge. Combined sewers throughout the city of Coventry are ultimately directed through a 3.2m trunk sewer to the sewage treatment plant at Finham, south of the city. The storm tanks at Finham hold 28,000 m^3, and are among the largest in Europe (Severn Trent Water c.2005). The capacity of combined sewer infrastructure was likely to have contributed to the fact that no locations in central Coventry (CV1 postcode) were listed on the public sewer flooding register (Coventry City Council 2008b:25).

The EA flood risk maps did not include flooding caused by groundwater, overland runoff, or sewers. Nor did they take potential climate change into account (DCLG 2009:75). The SFRA's conclusions regarding the impact of climate change on the R. Sherbourne, were that the 1 in 200-year flood zone would replace the 1 in 100-year flood plain. However this result was unhelpful, since no 100-year flood zone was shown for the section of the river passing near the campus. The SFRA did not include changes to the 1000-year flood plain due to climate change.

C.5.3.2. Application of PPS25 Tests

Although PPS25 aimed to address all types of flooding, the principal decision-making mechanisms related to river and coastal flooding, based on flood risk maps. This was reflected in the SFRA (Coventry City Council 2008b), which emphasised fluvial flooding, contained a basic consideration of sewer and groundwater flooding, and made very limited mention of overland flooding, relying for quantitative support on water company DG5 records (Coventry City Council 2008b:23-25). This may have been a consequence of the unavailability of flood risk maps for non-fluvial sources of flooding at the time of the pilot.

Applying the Sequential Test, no university property lay within zone 3, the 100-year flood plain. Several buildings fell within the 1000-year flood plain, and were thus categorised in Flood Zone 2, having a medium probability risk of flooding. Using the SFRA flood plain boundaries, the premises at greatest risk of river flooding or surface sewer surcharge were

- Priory Hall
- James Starley
- Students Union Cox St.
- Charles Ward
- William Lyons
- Alma.

The northerly section of Priory Hall fell inside the 1000-year flood plain, categorised as a medium probability of flooding. Student halls of residence were designated among the more vulnerable land uses in PPS25, but were still compatible with the assigned flood zoning (DCLG 2010:26-27), so no exception test was required. No accommodation within this building was situated on the ground floor level, but storage facilities may be affected. The ramp descending from Fairfax St. underneath Priory Hall was also at risk, although only indicated as such on the SFRA 1000-year flood risk map. According to the SFRA, the northern end of the James Starley building, and Students Union Cox St. both fell within the 1000-year flood plain, as did the ramps down to Charles Ward basement rooms on the north-eastern side of the building. The most easterly section of the William Lyons building in the Armstrong Siddeley sub-catchment was also situated within the 1000-year flood plain. All other university buildings fell outside the 1000-year flood plain, and were thus situated within Flood Zone 1, having the lowest probability of fluvial flooding.

Developments exceeding 1ha in zone 1 and all developments in zone 2 needed to consider overland, sewer and groundwater flooding in addition to river and coastal sources, and also the risk of creating additional surface water run-off (DCLG 2010:32). However, techniques to assess these forms of flooding were less well advanced (DCLG 2009:41), so were reliant on historical records and potential sources identified using geological and soil maps. Due to a lack of records (Coventry City Council 2008b:23), the SFRA contained very limited information relating to overland, sewer and groundwater flooding, and no incidents affecting the campus area were identified in that document.

In addition to the risk of on-site flooding, PPS25 also required consideration of increased risk of flooding elsewhere due to increased runoff (DCLG 2010:22). The university properties most likely to be impacted by runoff from other landowners’ properties further upslope were:

- Priory Hall by runoff from overland flow, and surcharge from surface and combined sewers, originating from the Cathedral and from buildings on Bayley Lane
- Alan Berry, Charles Ward and to a lesser extent George Eliot, by runoff from overland flow, and surcharge from surface and combined sewers, originating from the Cathedral, the Herbert Museum, and from buildings on Bayley Lane
- James Starley and the Students’ Union Cox St. by surcharge from surface and combined sewers, originating from Jordan Well, Whitefriars St. and the western end of Gosford St.
- William Lyons by runoff from overland flow, and surcharge from surface and combined sewers, originating from the eastern end of Gosford St.

The main properties belonging to other landowners that might be directly impacted by overland runoff from university premises were:

- The Gulson hospital site east of and down-slope from university buildings
- Premises in Raglan St. down-slope from Singer Hall and near the Alma building, which discharges much of its runoff onto public pavements
- Premises in Alma St. near the Alma building, which discharges much of its runoff onto public carriageways.

Runoff directed to surface and combined sewers contributes to increased flood risk downstream. Surcharge from surface water sewers had the highest probability of impacting the same locations that were affected by direct runoff. Surcharge from combined sewers could potentially impact other landowners' premises in

- Winchester St., Alma St., Raglan St., Hood St. - from the Singer sub-catchment
- the eastern end of Gosford St. - from the Armstrong Siddeley and Lanchester Library sub-catchments
- Gulson Rd. - from the Lanchester Library sub-catchment
- Whitefriars St. - from the John Laing sub-catchment.

The southern side of the public Sports Centre on Fairfax St., although down-slope from much of the George Eliot sub-catchment, would be protected to some extent by the intervening lower-lying vegetated area.

C.5.3.3. Flood Risk Guidance Summary

Overall planning regulation documents were of limited assistance in identifying sources and sites of flooding, due to their focus on fluvial flooding. The processes confirmed some of the potential flood locations at risk.

C.5.4. Hydrological assessment of SUDS

This section reports results of the hydrological investigation for runoff and storage requirements.

C.5.4.1. Runoff

Hydrological calculations were undertaken for each sub-catchment using equations defined in Appendix J.

C.5.4.1.1. Design Values

In order to minimise environmental impact, developments should aim to achieve greenfield runoff rates and volumes. Where a site was already developed, but further changes were proposed, then guidelines recommended that runoff should, as a minimum, be restricted to current rates, and no additional runoff should be generated as a result of the replacement development (DCLG 2009:130; Defra & EA 2007:xiii), while also catering for future climate change.

The calculated runoff rates are listed in Table C5.2. The applied greenfield runoff rates for each sub-catchment are given in Fig. C5.11. Since greenfield surfaces were treated as permeable, sub-catchment runoff rate was a straightforward function of runoff rate per hectare and surface area, thus the larger the sub-catchment, the greater the runoff rate.

Table C5.2 Runoff rates calculated from design storm criteria. Multiplier indicates the relationship of other runoff rates to the 1-year rate

Runoff rate	**Rate (l s^{-1} ha^{-1})**	**Multiplier**
Greenfield mean annual flood flow rate (Qbar)	4.59	1.18
1 in 1 year	3.9	1.00
1 in 30 year	8.58	2.20
1 in 100 year	11.79	3.02

The effective mean soil moisture deficit for the research site was 11.6 mm (NERC 1975:1.Fig. I4.19). The soil moisture deficit represents typical antecedent conditions at a site. Thus, at greenfield sites in Coventry, the first 11.6 mm of rainfall would be expected to infiltrate rather than generate runoff.

Fig. C5.11 Greenfield runoff rates for each sub-catchment. The discharge rates are shown for 1 in 1, 1 in 30, and 1 in 100 year return periods for each sub-catchment. For subcatchment abbreviations see Fig. C4.1. Equations from Defra & EA 2007 (see Appendix J)

Greenfield runoff volumes varied depending on the method used (Fig. C5.12). The fixed runoff volume lay between the variable runoff volumes for summer and winter. Summer volumes were 70% of winter volumes, while fixed runoff volumes were 91% of winter volumes.

Fig. C5.12 Greenfield runoff volumes for each sub-catchment for a 100-year, 6-hour event (63 mm of rainfall). Equations from Woods Ballard *et al*. 2007 (see Appendix J)

Developed runoff volumes also varied according to the method used and are presented in Fig. C5.13. The lowest volume estimate was generated by the Wallingford Variable runoff model for the five most impermeable sub-catchments, and the highest volume by the Wallingford Fixed runoff model using a winter value for the urban catchment wetness index parameter. However, values were similar, with at most 8% difference between the highest and lowest volume.

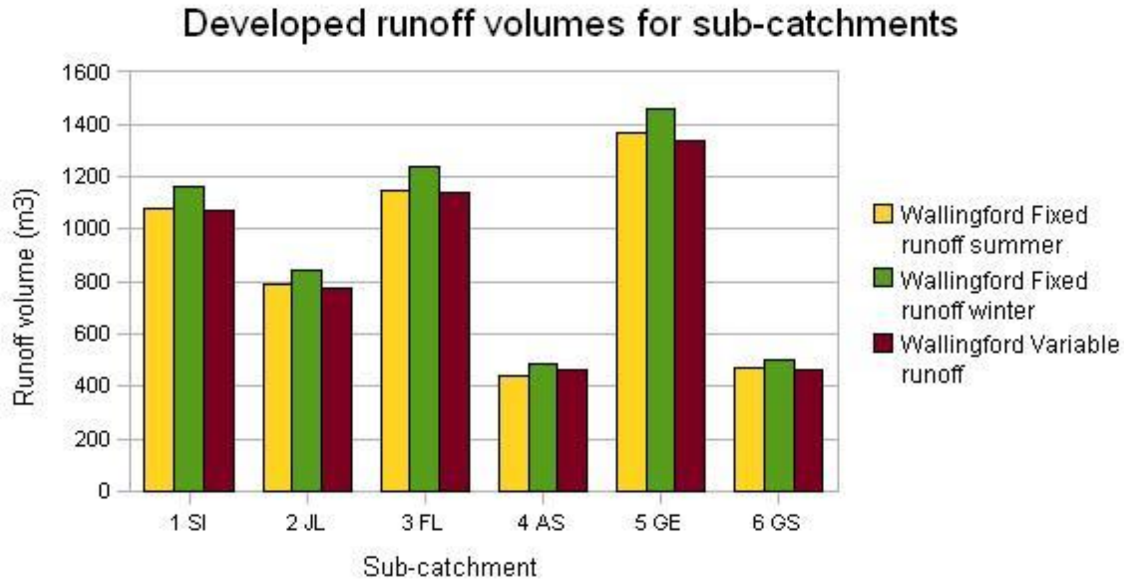


Fig. C5.13 Developed runoff volumes for each sub-catchment for a 100-year, 6-hour event (63 mm of rainfall)

The mean difference between greenfield and developed runoff volumes is shown in Fig. C5.14. This is the volume of additional runoff generated by the current impermeable land cover configuration in each sub-catchment, and is the volume that would be required to return the sub-catchments to greenfield runoff volumes. The most permeable sub-catchment (Armstrong Siddeley) displayed the smallest additional runoff volume, while the largest, most impermeable sub-catchment (George Eliot) had the greatest additional runoff.

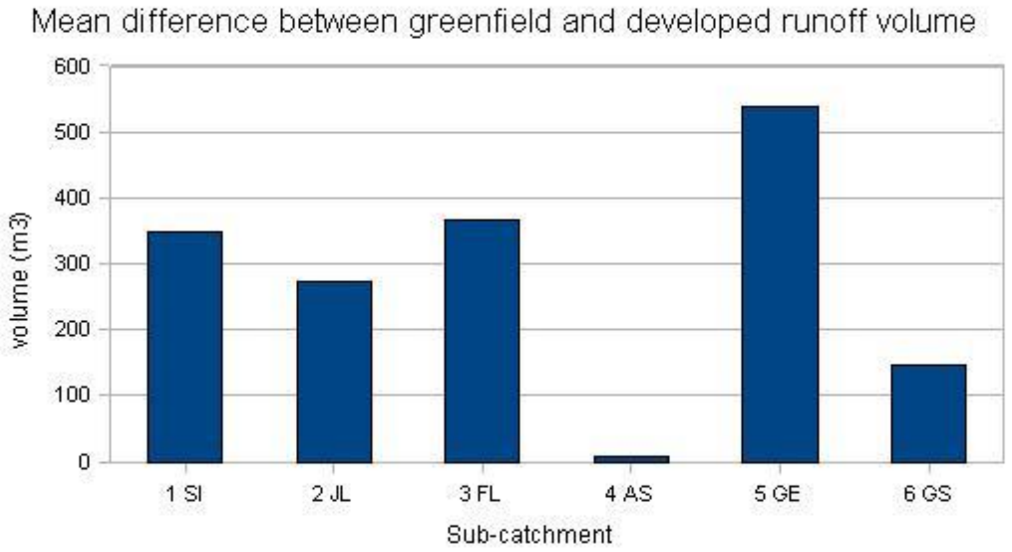


Fig. C5.14 Difference between the mean greenfield and mean developed runoff volumes for each sub-catchment for a 100-year, 6-hour event (63 mm of rainfall)

Developed runoff rates were calculated using the Modified Rational Method, which, although fairly simplistic, is in common use in development planning applications. Peak runoff rate for each sub-catchment is shown in Fig. C5.15. Recommendations to limit runoff to greenfield rates are reflected in the relevant prescribed discharge limits for each sub-catchment (Fig. C5.16). The reduction in runoff rate necessary to achieve greenfield conditions was calculated as the difference between the winter peak runoff rate and the discharge limit assuming no long-term storage (Fig. C5.17). For the five most impermeable sub-catchments, a 34-38 times reduction in runoff rate was required to meet discharge limits; for the Armstrong Siddeley sub-catchment, the required reduction was lower at 25 times.

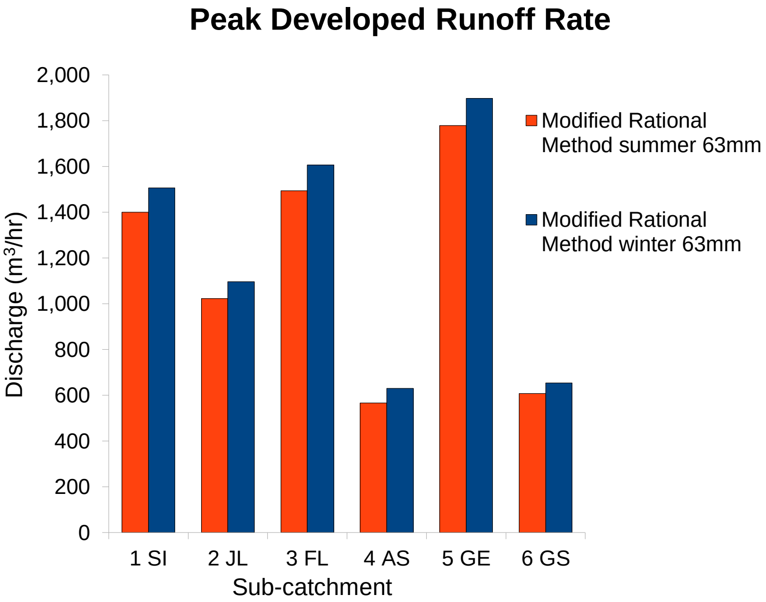


Fig. C5.15 Peak developed runoff rates for each sub-catchment. Discharge (m^3 h^{-1}) in summer was slightly lower than winter rates

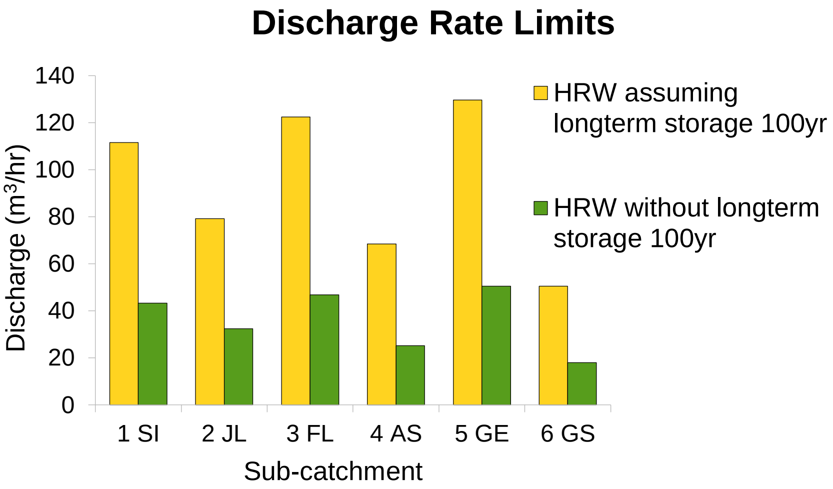


Fig. C5.16 Discharge limits for each sub-catchment to achieve greenfield runoff rates from developed areas. Lower limits are required where long-term storage facilities cannot be provided

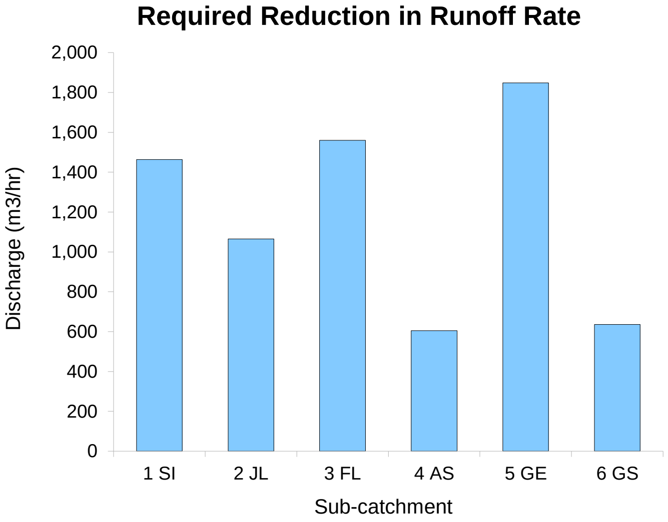


Fig. C5.17 Reduction in runoff rate necessary to achieve greenfield conditions, for each sub-catchment, calculated as the difference between the winter peak runoff rate (see Fig. C5.15) and the discharge limit assuming no long-term storage (see Fig. C5.16)

Although a return to greenfield runoff rates in inner-urban environments is an aspiration, the difficulty of redeveloping previously developed land has resulted in the compromise of meeting current runoff less an allowance of 20% for climate change.

The next section reviews the types of storage required to meet these requirements.

C.5.4.2. Storage Requirements

The results of calculations to determine storage requirements for interception, treatment, attenuation and long-term storage volumes are listed below, together with combined attenuation and long-term storage volumes, and the total storage volume required for each sub-catchment in order to attenuate a 100-year flood. Table 3.10 explained the relationship between these storage types.

C.5.4.2.1. Interception storage

Interception storage volumes for each sub-catchment are presented in Fig. C5.18. For all-sub-catchments, the HR Wallingford values for 5mm were approximately 80% of the 5 mm values that were calculated manually using the recommendation in Woods Ballard *et al*. (2007:3.17). This may have occurred because the HR Wallingford values assumed that only 80% of the impermeable area was actually impervious, allowing for factors such as gaps between paving. However, Defra & EA (2007) guidelines were to use 100% of the impermeable area.

C.5.4.2.2. Treatment storage

Treatment storage volumes for each sub-catchment are presented in Fig. C5.19. For all sub-catchments, the HR Wallingford values were the same as the SNIFFER 1Vt figure. For five of the six sub-catchments, the HR Wallingford values were 63-65% of the manually calculated Defra & EA values; for the more permeable Armstrong Siddeley sub-catchment, the percentage was slightly lower at 57%. The 4Vt volume for the five most impermeable sub-catchments was approximately 2.5-2.6 times the next highest figure, the Defra & EA value; for the least impermeable AS sub-catchment, the figure was lower at 2.25 times.

C.5.4.2.3. Attenuation storage

While the equations utilised by the HR Wallingford methodology were theoretically the same as those in Defra & EA, the results in Fig. C5.20 show that the HR Wallingford volume for attenuation storage, assuming use of longterm storage, was 61-63% of the equivalent Defra & EA volume for three sub-catchments (SI, JL and FL). For the most impermeable George Eliot sub-catchment, the HR Wallingford volume was 56% of the equivalent Defra & EA volume, and for the Graham Sutherland sub-catchment it was 73%. For the most permeable sub-catchment, Armstrong Siddeley, the HR Wallingford volume was 95% of the Defra & EA volume. The range of values varied more widely with increased impermeability.

The HR Wallingford volume was closer to the Defra & EA 30-year volume than the Defra & EA 100-year volume: in the range 99-102% in four sub-catchments (SI, JL, FL and GS), and 89% in the George Eliot sub-catchment. However, in the Armstrong Siddeley sub-catchment, the HR Wallingford volume was 74% higher than the Defra & EA 30-year volume.

C.5.4.2.4. Long-term storage

The long-term storage results in Fig. C5.21 also revealed a difference between the values produced using the HR Wallingford methodology and the manually calculated Defra & EA volume. The HR Wallingford volume was 10-18% higher than the equivalent Defra & EA volume for four sub-catchments (SI, JL, FL and GS). For the George Eliot sub-catchment, the HR Wallingford volume was 5% higher than the equivalent Defra & EA volume, while in the Armstrong Siddeley sub-catchment it was 67% greater than the equivalent Defra & EA volume.

The Woods Ballard *et al*. 80% formula produced figures that were 64-75% of the values derived using the Defra & EA method in all sub-catchments. The Soil type 4 formula produced the lowest results in the five more impermeable sub-catchments, at 35-48% of the next lowest result, the Woods Ballard *et al*. 80% formula. However, in the more permeable Armstrong Siddeley sub-catchment, the Soil type 4 formula generated the highest value, 2.25 times the Woods Ballard *et al*. 80% formula.

C.5.4.2.5. Combined Attenuation and Longterm storage

Where long-term storage solutions are achievable, the sum of attenuation and long-term storage (Fig. C5.22) was 15-31% lower when using the HR Wallingford methodology than the Defra & EA method in the five more impermeable sub-catchments, but 3% higher in the more permeable AS sub-catchment.

Where it is not feasible to provide longterm storage, for example due to poor infiltration conditions, it is necessary to increase the attenuation storage volume. In this case, the increased attenuation volume was 88-89% of the individual attenuation and longterm storage values in five sub-catchments, although in the GS sub-catchment the relationship was 97% (Fig. C5.22). The reason for the difference in GS was not determined.

Where longterm storage was not possible, the HR Wallingford attenuation volume was 78-87% of the equivalent Defra & EA volume for the five more impermeable sub-catchments. In contrast, in the Armstrong Siddeley sub-catchment, the HR Wallingford volume exceeded the Defra & EA volume by 16%.

C.5.4.2.6. Total Storage Volume

The total storage volume for each of three methods for each sub-catchment is shown in Fig.

C5.23. The greatest storage volume was required in the most impermeable GE sub-catchment, and the least in the most permeable AS sub-catchment. There was broad agreement between the values calculated using the HR Wallingford and Woods Ballard *et al*. methodologies for the 100-year return period, with a maximum 10% difference between these two methods across the more impermeable sub-catchments, and 19% in AS. In the five less permeable sub-catchments, the Defra & EA totals exceeded the HR Wallingford values by 21-32%. In the Armstrong Siddeley sub-catchment, there was only 1% difference between the Defra & EA total and the HR Wallingford value.

Only the Defra & EA methodology generated 1-year and 30-year totals. The 30-year total was 61-63% of the 100-year total for four sub-catchments (SI, JL, FL and GE); in the smallest sub-catchment, Graham Sutherland it was 71%, and for the most permeable, Armstrong Siddeley, 55%. The 1-year total was 26-28% of the 100-year total for five sub-catchments, with the Armstrong Siddeley sub-catchment slightly higher at 31%.

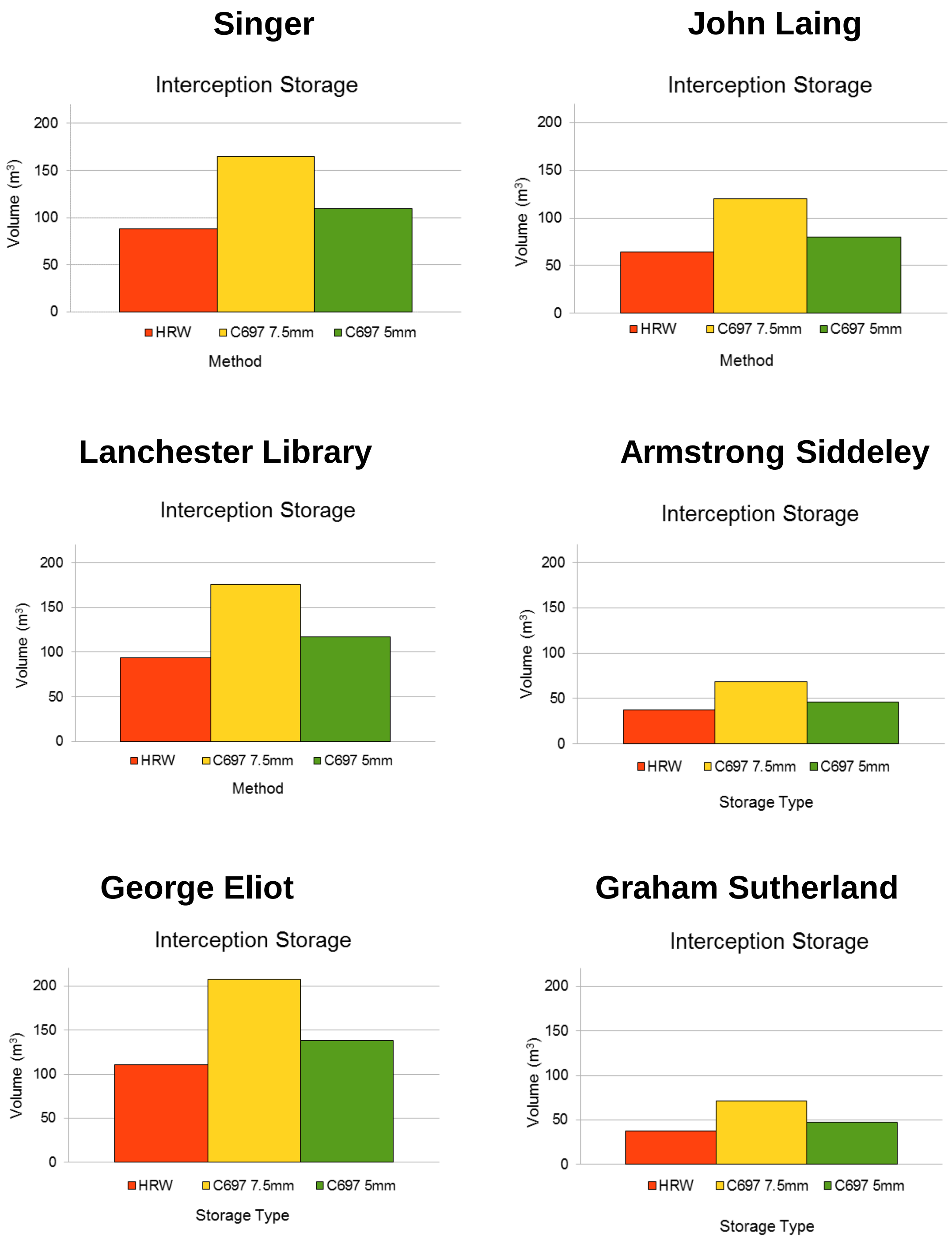


Fig. C5.18 Interception Storage volumes for each sub-catchment. Categories: HRW from HR Wallingford (2008) methodology; C697 7.5 mm is the mean value of the 5-10 mm recommended by Woods Ballard *et al*. (2007); C697 5 mm is the minimum value of the 5-10 mm recommended by Woods Ballard *et al*. (2007). Note same scale on y-axis for each sub-catchment.

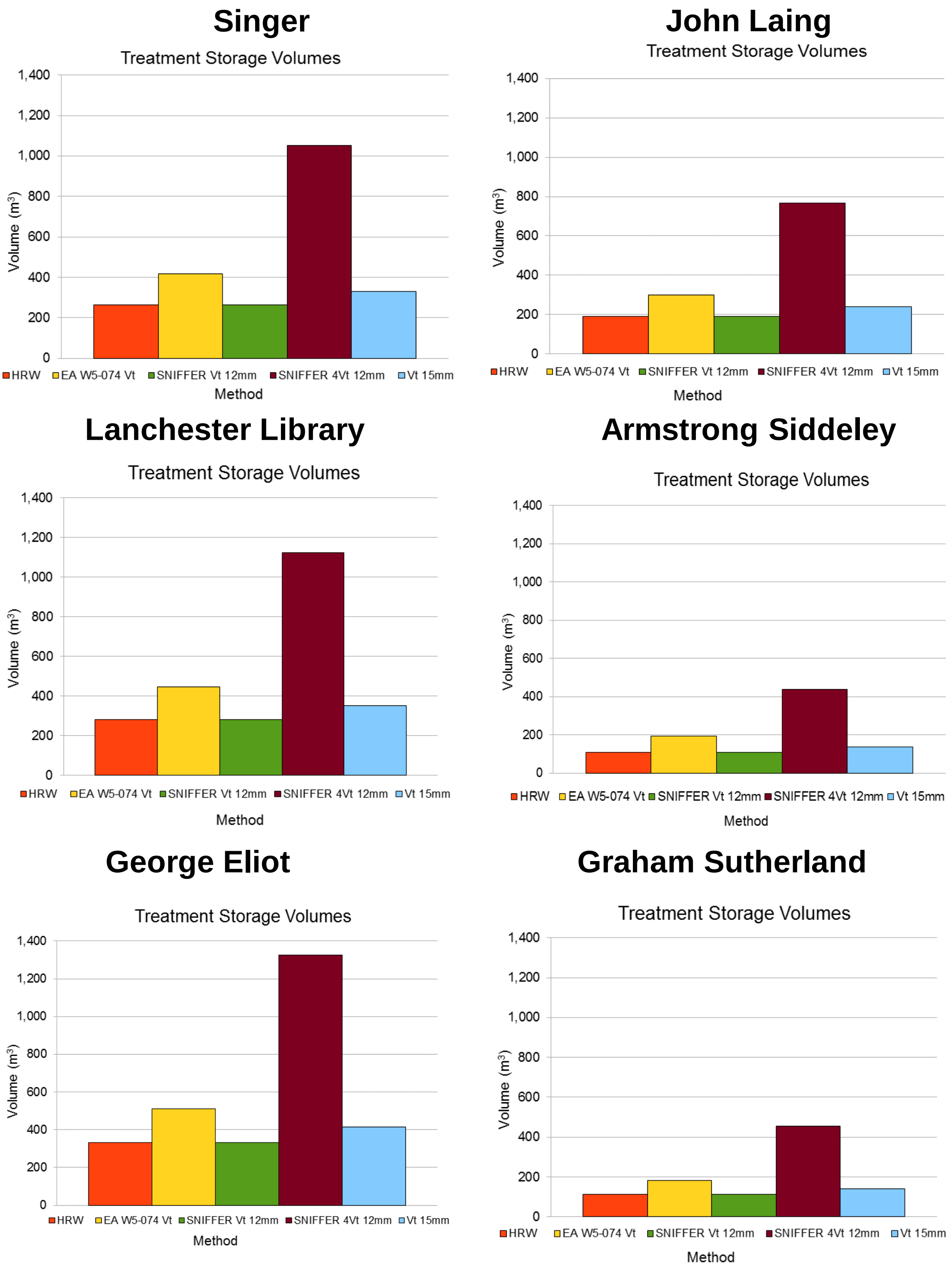
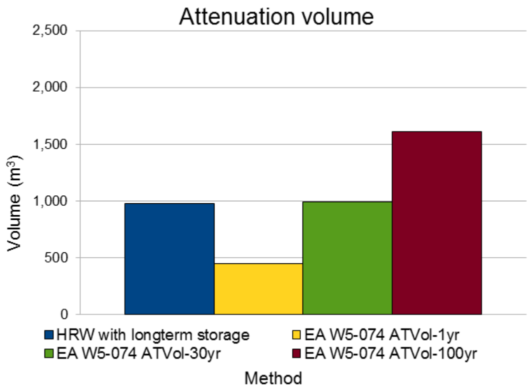
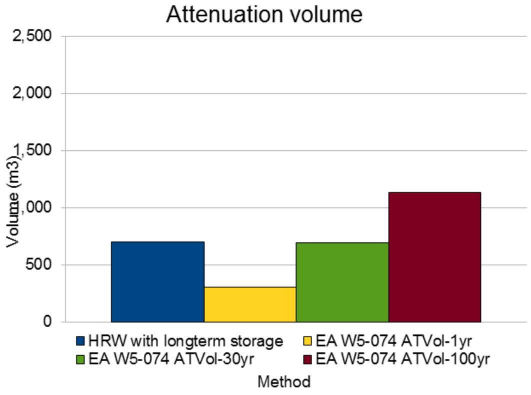


Fig. C5.19 Treatment Storage volumes for each sub-catchment. Categories: HRW from HR Wallingford (2008) methodology; EA W5-074 Treatment Volume from Defra & Environment Agency (2007) methodology; SNIFFER Vt and 4Vt from SNIFFER (2006) methodology; Vt 15mm from maximum recommendation in Woods Ballard *et al*. (2007:4.24). Note same scale on y-axis for each sub-catchment.

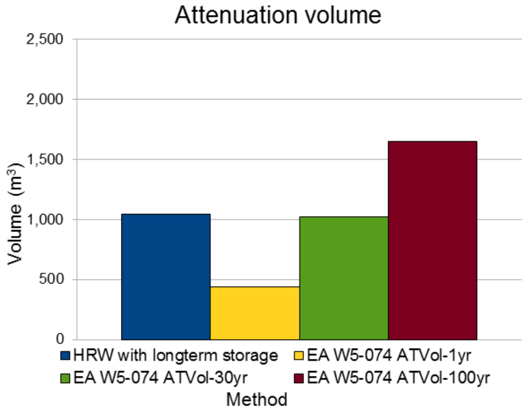
Singer



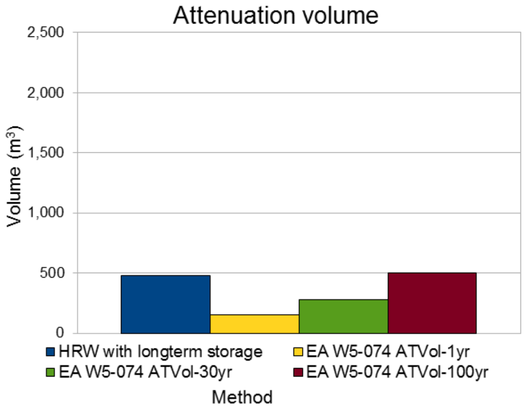
John Laing



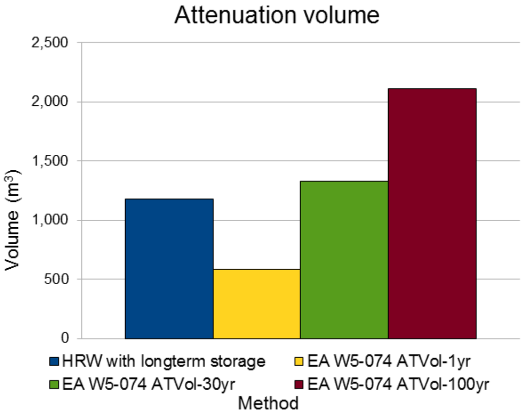
Lanchester Library



Armstrong Siddeley



George Eliot



Graham Sutherland

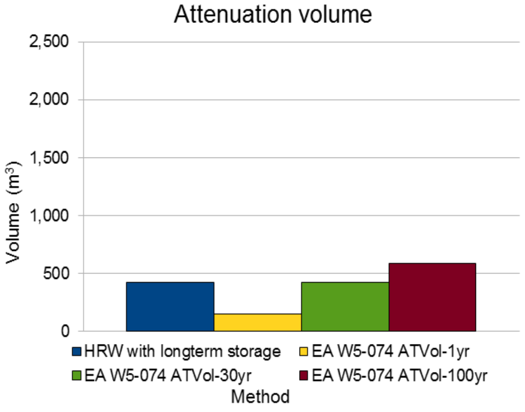


Fig. C5.20 Attenuation Storage volumes for each sub-catchment. Categories: HRW without longterm storage from HR Wallingford (2008) methodology; EA values for 1-, 30- and 100-year return periods from Defra & Environment Agency (2007) methodology. Note same scale on y-axis for each sub-catchment.

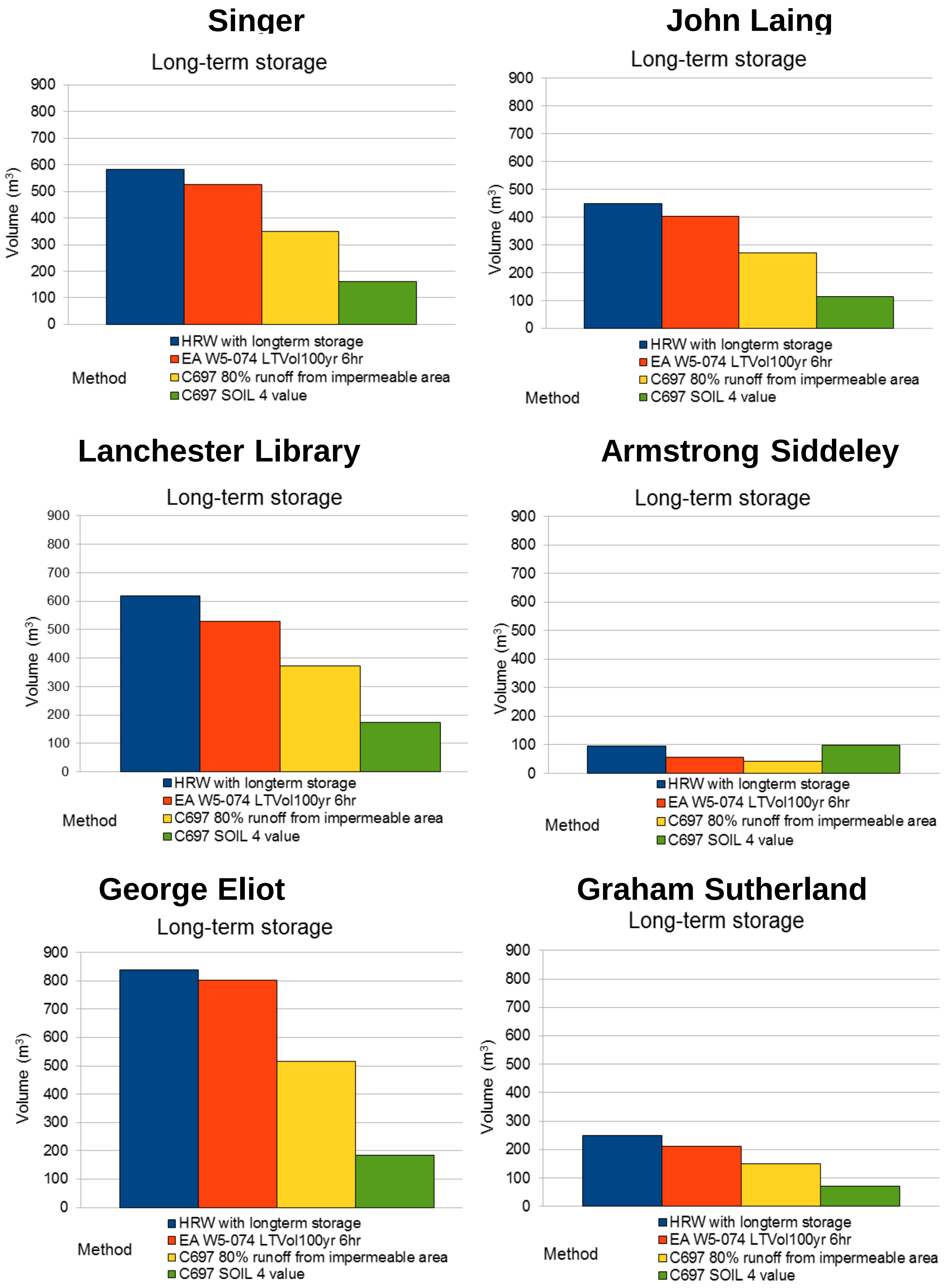


Fig. C5.21 Longterm Storage volumes for each sub-catchment. Categories: HRW without longterm storage from HR Wallingford (2008) methodology; EA W5-074 Longterm Volume from Defra & Environment Agency (2007) methodology; C697 and SOIL 4 recommendation from Woods Ballard *et al*. methodology (2007:4.22-4.23). Note same scale on y-axis for each sub-catchment.

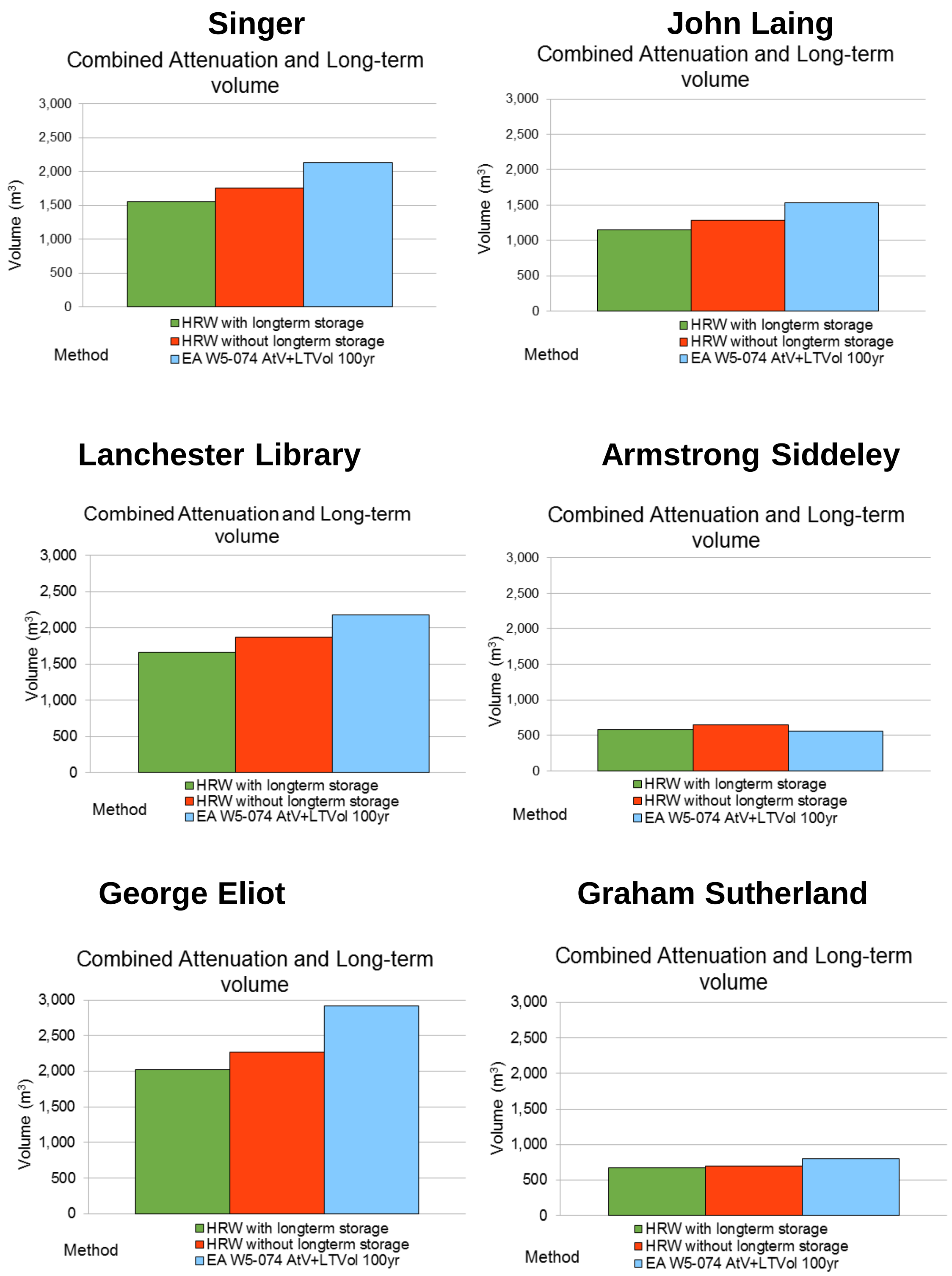


Fig. C5.22 Combined attenuation and long-term storage volumes for each sub-catchment. Categories: HRW with long-term storage from HR Wallingford (2008) methodology; EA values for combined attenuation and longterm storage for a 100-year return period from the Defra & Environment Agency (2007) methodology. Note same scale on y-axis for each sub-catchment.

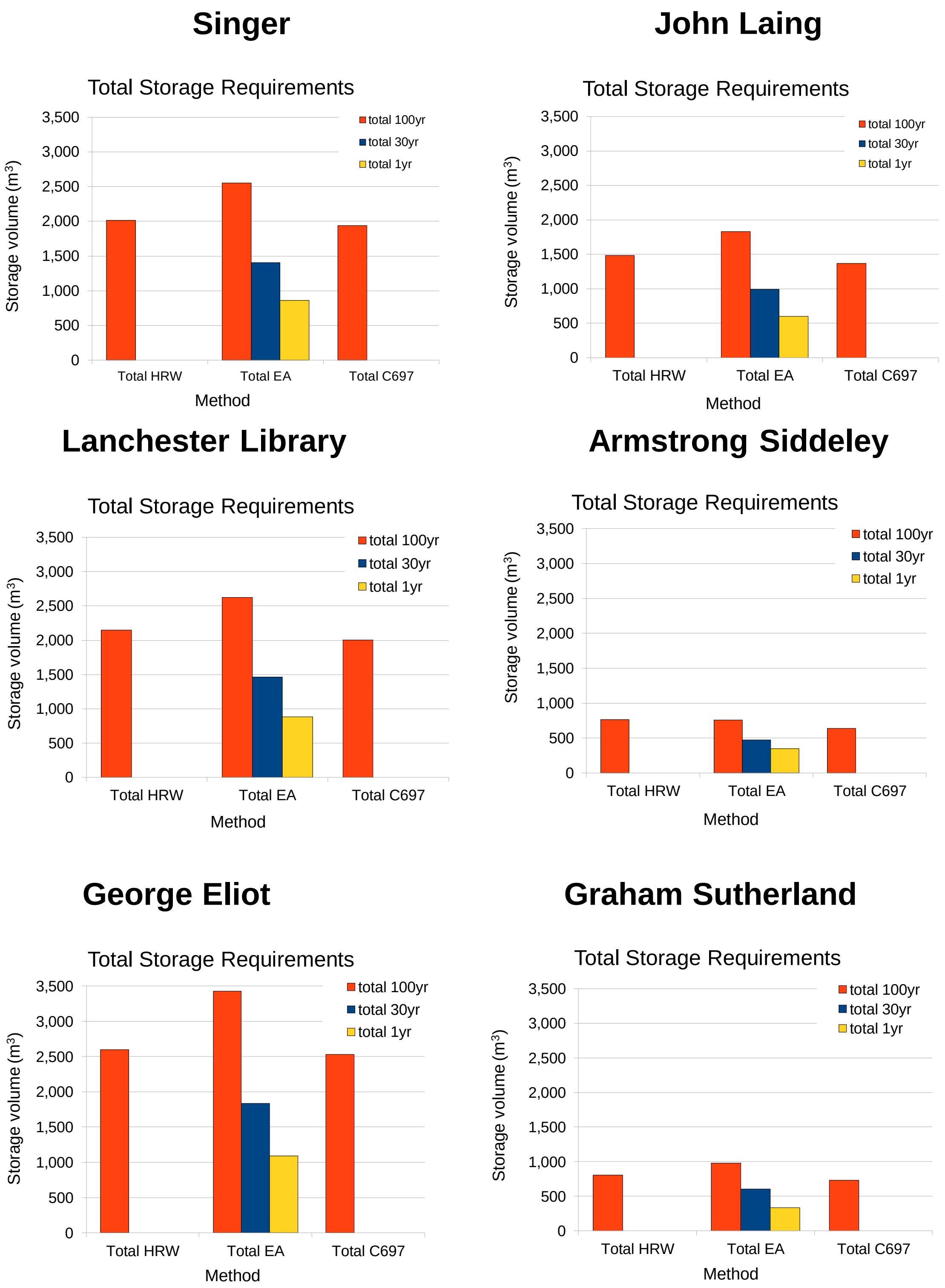


Fig. C5.23 Total storage volumes for each sub-catchment. Categories: HRW values from HR Wallingford (2008) methodology; EA values for 1-, 30- and 100-year return periods from the Defra & Environment Agency (2007) methodology; C697 values from Woods Ballard *et al*. (2007) methodology. Note same scale on y-axis for each sub-catchment.

C.5.4.3. Which are the appropriate results to use?

The most apparent result of the storage requirement investigation was the variability across values obtained using the different methods. Consequently, an appraisal was undertaken to review the most appropriate values to use in further calculations relating to the pilot study area. Each storage type was assessed to determine a relevant value before calculating the total storage volume requirement per sub-catchment. The results of this appraisal are summarised in Table C5.3.

C.5.4.3.1. Interception Storage

Although the different methodologies generated different results for interception and treatment storage, a similar pattern was observed across catchments, allowing a relatively easy selection of an appropriate value for both to use in further evaluation. The manually calculated 5 mm value for each sub-catchment was used as a representative interception storage volume.

C.5.4.3.2. Treatment storage

The SNIFFER 4Vt volume appeared to be an over-conservative solution for this location. The similarity between SNIFFER 1Vt and HR Wallingford values was due to their use of similar rainfall depths: SNIFFER 12mm, HR Wallingford 15 mm * 80% impermeability factor = 12 mm. The 15 mm volume (Woods Ballard *et al*. 2007) seemed to offer an intermediate value between the SNIFFER 1Vt and Defra & EA values for all sub-catchments, and so was used as a representative treatment storage volume for all sub-catchments.

C.5.4.3.3. Attenuation storage

Compared with interception and treatment storage, selection of an appropriate value was less straightforward for attenuation storage. Only the Defra & EA methodology produced volumes for 1-year and 30-year return periods, so these values were taken as representative for all sub-catchments. It was not immediately apparent why the HR Wallingford volumes for 100-year return periods were substantially lower (56-73%) than the equivalent Defra & EA results for five sub-catchments when in theory the same equations were utilised. Even if the HR Wallingford equations applied 80% impermeability levels, this would not account for the total difference. The closer similarity (95%) between results in the more permeable Armstrong Siddeley sub-catchment indicated that impermeability factors contributed to the difference. A further explanation could be a different allocation across attenuation and long-term storage by the two methods. Before deciding on an appropriate value for use in further assessments, attenuation storage values were further evaluated in conjunction with long-term storage volumes (see below, Combined Attenuation and Long-term storage).

C.5.4.3.4. Long-term storage

While the HR Wallingford methodology results for attenuation storage were lower than the Defra & EA values, the opposite occurred for long-term storage. The Woods Ballard *et al*. 80% impermeability formula produced figures that were 64-75% of the Defra & EA values, with variability increasing in relation to sub-catchment impermeability. The Woods Ballard *et al*. 80% impermeability formula was noticeably influenced by the assumption of 20% interception by impermeable areas. By substituting an assumption of 0-10% interception, the values approached or even exceeded the HR Wallingford results in all sub-catchments. The Soil type 4 formula appeared to under-estimate requirements in the five more impermeable sub-catchments, while producing the highest value in the least impermeable sub-catchment. By ignoring impermeability levels, this method appeared too simplistic and was discounted from further consideration. Long-term storage values were further evaluated in conjunction with Attenuation storage volumes to ascertain an appropriate value to use in further assessments (see below, Combined Attenuation and Long-term storage).

C.5.4.3.5. Combined Attenuation and Long-term storage

The combined attenuation and long-term storage results for a 100-year return period appeared to balance out, to some extent, the different allocation observed across attenuation and long-term storage types when these were considered in isolation. Although this combined approach may mask problems, it appeared to achieve a better consensus of values between HR Wallingford and Defra & EA volumes than considering attenuation and long-term storage results separately. Since infiltration rates across campus were likely to be poor, the utilisation of long-term storage was considered to be infeasible (HR Wallingford 2008), leading to use of a combined attenuation and longterm storage volume. The Defra & EA volumes appeared to be calculated independently of each other, not taking into account the relationship between them, unlike the HR Wallingford attenuation storage volume where infiltration storage was not feasible. This last value was used in further assessments.

C.5.4.3.6. Total Storage Volume

The 100-year total storage volume according to the HR Wallingford methods was within 19% of the Woods Ballard *et al.* figure in all sub-catchments. The difference between the total storage volume requirement determined using the HR Wallingford methodology compared to the Defra & EA methods for the five more impermeable sub-catchments ranged from 21-32%, while the difference between the Woods Ballard *et al*. and Defra & EA methods lay between

31-35%. The difference between methods in the more permeable AS sub-catchment was -1% and 18% respectively. The Defra & EA volumes appeared to over-estimate the total storage volume due to the absence of rules concerning the extent to which volumes were duplicated among storage types.

Table C5.3 summarises the volumes used for subsequent evaluation in each sub-catchment. The total requirement rows were determined by subtracting the interception value from the treatment volume to avoid double counting, then adding the relevant attenuation row to the treatment and interception volumes.

Table C5.3 Summary of storage volumes derived using the hydrological assessment methodologies. Total storage = Interception + Treatment + relevant Attenuation value. Treatment volume excludes the interception value. These volumes were used in subsequent evaluation of storage requirements in the pilot study. All volumes are in m^3.

Sub-catchment	**1 SI**	**2 JL**	**3 FL**	**4 AS**	**5 GE**	**6 GS**
Area (ha)	2.70	1.89	2.89	1.62	3.05	1.19
Storage Type						
Interception	110	80	117	46	138	47
Treatment	219	160	234	91	277	95
Attenuation 1-year	446	300	440	154	581	151
Attenuation 30-year	991	693	1,021	276	1,326	420
Attenuation 100-year	1,751	1,289	1,868	653	2,263	693
Total 1-year requirement	775	540	791	291	996	293
Total 30-year requirement	1,320	933	1,372	413	1,741	562
Total 100-year requirement	2,080	1,529	2,219	790	2,678	835

There was a positive correlation between impermeability rate (Fig. C5.24a), sub-catchment total area (Fig. C5.24b), sub-catchment impermeable area (Fig. C5.24c) and the required storage volume based on combined attenuation and long-term storage for the 1-year, 30-year, and 100-year events. An increasing trend of storage volume requirement was apparent with higher levels of impermeability, with r^2 values of 0.99 for the 30-year, and 1.00 for the 1-year and 100-year volume. Based on the r^2 value of a linear trend, sub-catchment impermeable area was the best predictor of storage volume requirements (Table C5.4). There was no relationship between sub-catchment permeable area and storage volume.

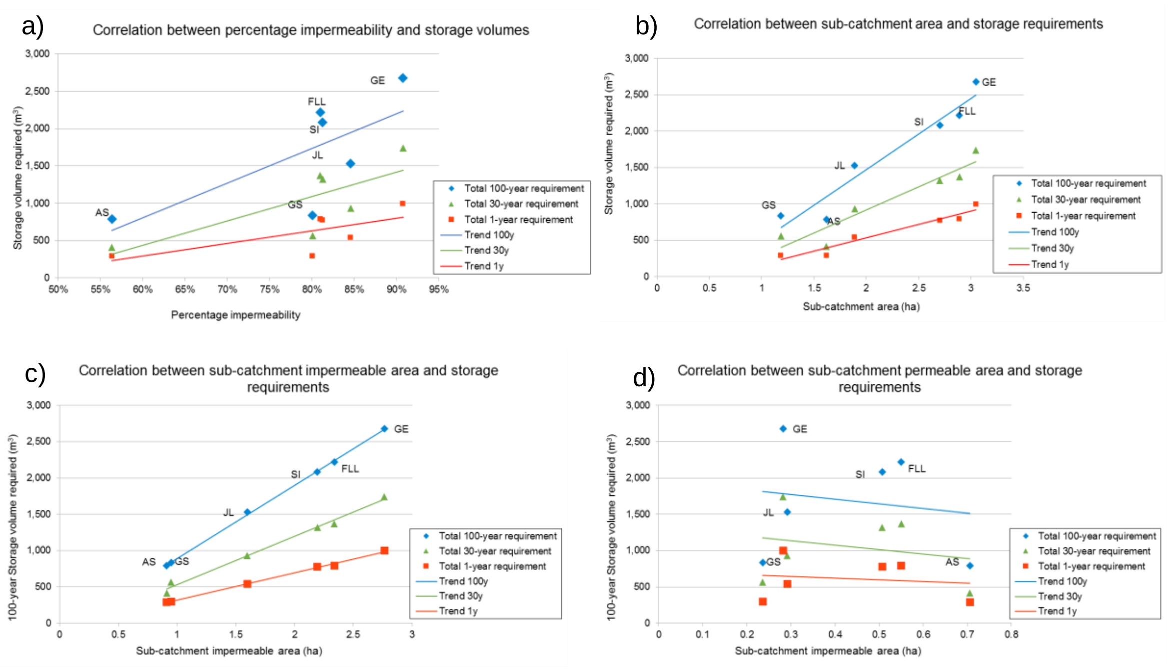


Fig. C5.24 Correlation between catchment characteristics and required storage volume based on combined attenuation and long-term storage for the 1-year, 30-year, and 100-year event. Catchment characteristics: a) percentage impermeability (note truncated x-axis); b) sub-catchment area; c) sub-catchment impermeable area; d) sub-catchment permeable area.

Table C5.4 Relationship between sub-catchment characteristics and volume storage requirements (r^2 - square of Pearson's product moment correlation co-efficient - linear trend)

Characteristic	**1-year**	**30-year**	**100-year**
Percentage impermeability	0.48	0.56	0.50
Sub-catchment area	0.93	0.89	0.93
Sub-catchment impermeable area	1.00	0.99	1.00
Sub-catchment permeable area	0.02	0.05	0.02

C.5.4.4. Discussion

This section considers the results of the pilot study hydrological assessment in further detail.

C.5.4.4.1. Precipitation

Historically, central England experiences annual rainfall maxima in July and August, with the mean date falling in mid-August (Dales & Reed 1989:127; Entec 2003:33). The precipitation associated with flooding of University premises in August 2006 was not the most extreme event on record (Fig. C4.10). Several factors may have resulted in flooding from an apparently smaller storm compared to the events in 2007. Although a lower rainfall total was recorded at the Bablake Weather Station several km away, current methods, including gauges and radar, find difficulty in accurately characterising the spatial and temporal variability of extreme storm events (Balmforth *et al.* 2006a:58).

Precipitation data were only available from one location in Coventry, Bablake Weather Station. Using data from a single point source may mis-represent the spatial variability of precipitation across the study area. Very limited information was available, and only in press reports, to assess rainfall intensity. Other research has also acknowledged problems in collecting information about rainfall intensity, and have experienced the same uncertainty experienced in the pilot phase, resulting from rainfall records that do not appear to relate to flood events (*e.g.* Douglas *et al*. 2010:116).

The spatial variability of rainfall in the city was a factor in the inability to explain historical flood events affecting the University campus. Intense rainfall events can be very localised (Jefferies *et al*. 1999:127), and such an event may have occurred over the city centre, while a lesser depth of precipitation was delivered to the weather station. Without accurate records relating to the campus, it is impossible to define the precise course and cause of events. Alternatively, actions taken to improve conventional drainage after the 2006 flooding may have improved conditions sufficiently to prevent repeat flooding in 2007, although one building was flooded twice in subsequent years despite these changes.

C.5.4.4.2. Soil

The wide range of infiltration rates for typical UK soil types is shown in Table C5.5, and some disagreement between authors was apparent over the relationship between qualitative terminology and quantitative meaning. The median value obtained from the infiltration tests performed on campus (6.7 mm h^{-1}) lay around the boundary between poor and good infiltration capacity. Soils with poor permeability rates are less suitable for infiltration devices, but are preferred for features where water retention is desirable such as ponds, wetlands and detention basins (Ellis *et al*. 2004b:248), so these features would be more feasible if soil conditions alone were considered.

Table C5.5 Typical UK infiltration rates for a range of soil types (in mm h^{-1}).

Infiltration capacity assessment	Soil Type	Minimum infiltration rate (Ellis *et al*. 2004b:249)	Typical infiltration rate (Woods Ballard *et al*. 2007:4.28)	Infiltration rate (Balmforth *et al*. 2006a:210)	Vertical saturated conductivity (Boorman *et al*. 1995:25)
Good	Gravel		10,000-1,000,000		
Good	Sandy Clay Loam	1.5	1-100		>4.2
Relatively good				36	
Good	Silt Loam	7	0.5-50		
Marginal				1.8	0.04-4.2
Poor	Silty Clay Loam	2	0.05-5		
Poor	Clay	0.5	<0.1		<0.04

C.5.4.4.3. *Infiltration*

Infiltration is controlled by multiple factors that govern the amount and rate at which precipitation penetrates the soil profile, such as rainfall intensity and duration, the size, shape and chemistry of soil particles, the size and extent of voids, antecedent water storage, slope and smoothness of the soil surface, and land cover (Shaver *et al*. 2007:17-18). Hydrological equations make assumptions about the rate of infiltration for different surface types, e.g. when calculating long-term storage volumes, roofs and paved surfaces were treated as 100% impermeable by HR Wallingford, but 80% by Woods Ballard *et al*. Conversely, HR Wallingford appeared to use 80% impermeability for interception storage. The reason for this difference was unclear.

The simplifying assumptions of 80-100% runoff from impermeable surfaces, and no runoff from vegetated surfaces, have been challenged by studies examining land cover in greater detail. In Munich (Pauleit & Duhme 2000:15), low-density housing with 60-70% land cover experienced an annual infiltration rate across the study area of only 6%. A review of studies in Germany (Pauleit & Duhme 2000:11) determined infiltration / detention rates for urban surfaces, based on 950 mm y^{-1} precipitation, as

- Buildings 5%
- Asphalt 5%
- Paving 20%
- Bare soil 50%.

Most of the hydrological equations used in this thesis assumed 100% infiltration in permeable vegetated areas, yet agricultural and forested areas in Germany (Pauleit & Duhme 2000:11) exhibited infiltration rates ranging between 25-40%.

Difficulties in predicting the precise operation of soil infiltration systems lead to associated difficulties in forecasting the timing, extent and rate of runoff.

C.5.4.4.4. Runoff

Runoff values based on catchment characteristics, as calculated for this study, are generally less reliable than data directly collected for a specific site (NERC 1975:1.291). However, site-specific values were unavailable. Balmforth *et al.* (2006a:64) found a wide range of results when assessing seven methods of predicting peak runoff, with the highest forecast over five times greater than the lowest. Where a site is already developed, but further changes are proposed, then current guidelines recommend that runoff should, as a minimum, be restricted to current rates, and that no additional runoff should be generated as a result of the new development (DCLG 2009:130; Defra & EA 2007:xiii). The SFRA (Coventry City Council 2008:53) recommended that new greenfield and brownfield developments achieve greenfield runoff rates less 20%, but made no recommendations relating to retrofits. A generalised rule is that pipe networks can absorb precipitation up to approximately 50 mm h-1 before overland flow begins (Defra & EA 2007:19).

C.5.4.4.5. Storage Requirements

Although the methodologies employed to determine storage volumes are promoted as straightforward to use (Defra & EA 2007:1; HR Wallingford 2008), based on their employing simplifying assumptions, in practice the variability between results did not offer a clear picture of the required storage volumes.

The closer agreement of total storage results across methods in the less impermeable AS sub-catchment when compared with the five more impermeable sub-catchments suggested that the methodologies were influenced differently by higher impermeability levels.

There were differences between the results generated by the HR Wallingford software, and the manually calculated results using the Defra & EA formulae, even though theoretically the HR Wallingford software used these same formulae. Part of the difference could have arisen from manual errors in interpolating the diagrams in the Defra & EA procedure. The specific equations used by the HR Wallingford method were unavailable, but these assumed 80% runoff from impermeable areas for treatment volume as opposed to the 100% recommended by Defra & EA, and may have assumed 80% for other values, although this was not stated. A further possible difference was that the FEH rainfall factor used by the HR Wallingford methodology was 0.81 for all return periods, while in the Defra & EA calculations it was 0.9 for 1- and 30-year events, and 0.8 for 100-year events.

C.5.4.5. Summary

Impermeability rate was significant in determining the runoff and storage volume requirements, but the results obtained varied depending on the methods and equations used.

C.5.5. SUDS Decision Support tools

Results from the six decision-support methods evaluated to determine their recommendations for SUDS techniques in the pilot study area are given below.

C.5.5.1. Swan/Stovin hierarchical framework

The decision hierarchy in the Swan/Stovin hierarchical framework (Stovin & Swan 2003; updated in SNIFFER 2006:29; presented in Fig. C3.14) was applied to each sub-catchment to ascertain the potential for SUDS. Since the pilot study related to the privately-owned University campus, publicly-owned land was not considered further. Surface type, management train and mode of operation criteria were evaluated for each sub-catchment according to the decision framework. A summary of the evaluation is provided in Table C5.6, with further explanation below. When reading the explanation, it might be helpful to refer to the layout of each sub-catchment in Fig. C4.3.

Urban Surface Type

In the study area, one separate, relatively short branch containing a surface sewer commenced at Singer Hall, emptying into a culverted stream approximately 120 m away (see Fig. C4.3a). Singer Hall was a development of student houses, administration offices and associated car parking. A combined sewer branch started under Cope St. at the north end of the George Eliot sub-catchment (see Fig. C4.3e). It received input from several buildings before joining the main public sewer network. Both areas might be worth further consideration for disconnection. Of the recommended surface types, large roofs were a feature of all sub-catchments, and significant car parking areas were present in five of the six sub-catchments. Residential roofs existed only in the Singer sub-catchment.

Surface Water Management Train

The decision hierarchy proposed that the provision of site or regional controls to handle runoff was the first option to consider. Such controls require the availability of sufficiently large facilities to store runoff. Only the AS sub-catchment (44% permeable) appeared to offer possibilities for on-campus site controls. A notable feature of the other five sub-catchments was that vegetated areas were sited at the up-slope end of each sub-catchment. Thus, runoff would travel down-slope, away from potential vegetated storage locations. A possible alternative could entail the construction of underground storage at the lower end of the sub-catchment, but this might require significant construction work involving building relocation, and needed a more detailed assessment of volume, area and cost; due to its disruptive effect, such retrofit implementation was considered unlikely. Of the five sub-catchments, FL contained car parks at the down-slope side of the sub-catchment, which were due for redevelopment within five years, although no detailed plans were not available to the pilot study. Consequently, storage would be an appropriate solution as part of a new build, but was not considered further for retrofit. Buildings at the down-slope end of both GS and GE sub-catchments were scheduled for replacement with multi-storey car parks within 10 years, so it may be useful to consider the provision of underground storage at that time, but in terms of retrofit, these locations were not evaluated further.

In the absence of site controls, source controls represented the next option in the hierarchy (Table C5.6). Source controls aim to retain stormwater at source, so green roofs and permeable paving are regarded as valuable options in urban areas where additional land may be unavailable. In low to medium density industrial and commercial areas, 100% disconnection has been demonstrated as technically feasible to achieve source control objectives (SNIFFER 2006:25), but is more problematic in high-density areas such as Coventry University campus. Five sub-catchments offered possibilities for source control. In the sixth sub-catchment, JL, source control options were regarded as limited due to building configuration within the topography, and redevelopment of the Whitefriars Sports Centre car park in a 0-10 year timeframe. Replacement of pedestrian pathways with permeable paving was an option throughout the campus.

Options for conveyance and off-site control were limited. Two areas of publicly owned land near three sub-catchments might usefully be investigated further. The large vegetated central island in the roundabout at the end of A4600 Sky Blue Way, east of the GS sub-catchment, and north-east of the FL sub-catchment, might be a suitable storage area. However, technical difficulties might arise, as the culverted R. Sherbourne runs between the sub-catchments and the roundabout. Furthermore, the roundabout forms a prominent gateway to the city centre, so appropriate design would be required if this location were selected. The second publicly owned space was the vegetated area below the GE sub-catchment, south of the Priory Street Sports Centre. This area contained a significant number of mature trees, and public access was restricted at the time of the pilot. It is close to the culverted R. Sherbourne, and the water table was likely to be high, evidenced by the presence of several willow trees, so potential for storage and infiltration may be limited.

Mode of Operation

Given their potential for attenuation based on the area covered, large roofs and car parks were the first option evaluated. All sub-catchments offered possibilities for increased use of permeable paved areas. In terms of green roofs, the position was less clear. The University's Estates Dept. raised concerns about the poor condition of many building roofs, requiring significant remediation work prior to retrofit of green roof technology. A number of buildings were also scheduled for demolition under the Campus Redevelopment Master Plan (2008). Consequently, the only buildings where consideration of green roofs was progressed were CW (east wing only), BU, and FL.

Infiltration was not considered a viable option for the campus based on soil conditions determined for the site characterisation and on-site tests (chapter 4). This conclusion may also affect the design and installation of permeable paving devices, although Hunt and West (2007) have found that permeable paving can operate effectively in areas unsuited to infiltration.

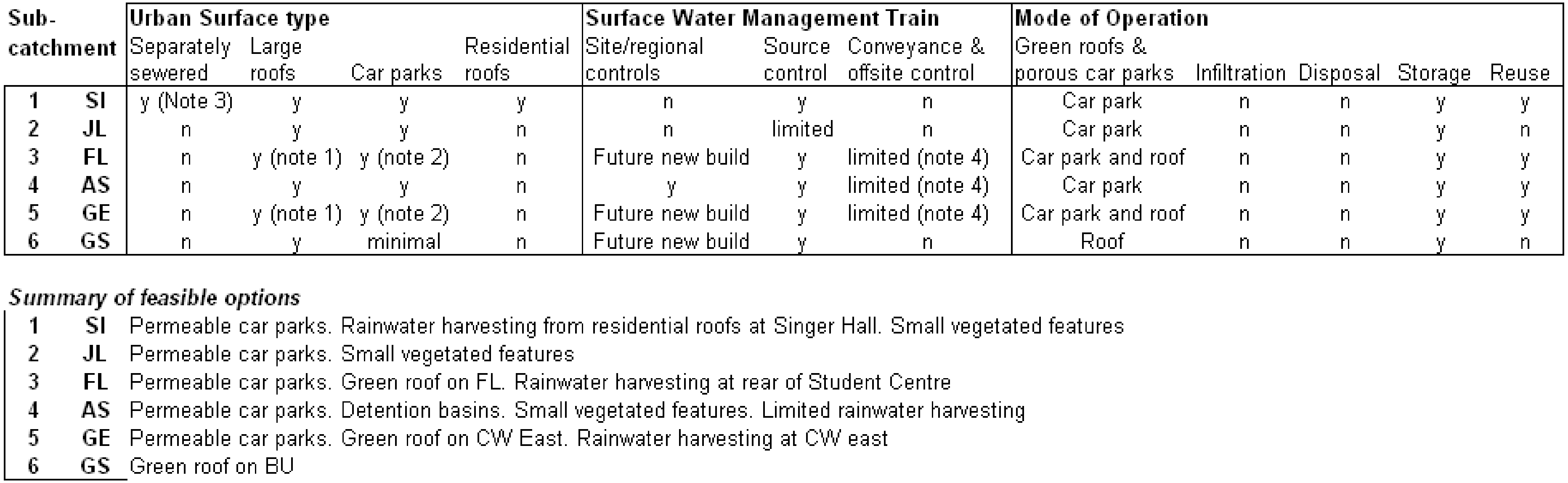
Disposal to a nearby watercourse would add no value to the areas already served by storm water sewers. Given the enclosed nature of the watercourses through the city centre, runoff disposal would be likely to require construction of new surface water sewers. The SI sub-catchment was the area most obviously served by a surface water sewer (Fig. C5.6), with potential to divert paving and road runoff to temporary detention locations. The lack of information about the University's private drainage network did not allow a more detailed assessment of its connection into public surface water sewers – AS and FL sub-catchments had the longest connection routes.

Storage might be a feasible option in conjunction with permeable paving. Limited vegetated areas on campus, and the building configuration, precluded installation of large wetland areas and retention basins. Detention basins may offer some possibilities for temporary storage of runoff, but it was unlikely that sufficiently large features could be created to handle significant rainfall events in five of the six sub-catchments. The exception was the AS sub-catchment, which featured a larger permeable area than other sub-catchments.

Rainwater re-use might be feasible in some sub-catchments. This would be influenced by practical restrictions on placing storage facilities, and access to obtain the water stored within. Potential relatively secure locations were identified on all sub-catchments, but the majority of university buildings do not use external drainpipes to direct rainwater, allowing it to run directly off roofs, using internal pipes to dispose of runoff, or letting it evaporate, so the principal collection options were reduced to individual buildings in four sub-catchments. The University's inner city campus made no use of rainwater harvesting techniques at the time of the pilot, with even flower displays irrigated by mains water. Despite being the least preferred option in the hierarchy, rainwater re-use offered an easily quantifiable financial benefit, because it would produce a direct saving of both supplied water and sewage charges for every cubic metre that was not taken from the public water supply.

Overall, the Swan/Stovin hierarchy provided a useful high-level framework for the proposal of options, with suggestions that appeared logical. Ultimately, several options were unsuitable or impractical due to technical and logistical considerations on campus.

Table C5.6 Assessment of the six sub catchments using the relevant sections of the Swan/Stovin hierarchical framework



Sub-catchment		**Urban Surface type**				**Surface Water Management Train**			**Mode of Operation**				
		Separately sewered	Large roofs	Car parks	Residential roofs	Site/regional controls	Source control	Conveyance & offsite control	Green roofs & porous car parks	Infiltration	Disposal	Storage	Reuse
1	**SI**	y (Note 3)	y	y	y	n	y	n	Car park	n	n	y	y
2	**JL**	n	y	y	n	n	limited	n	Car park	n	n	y	n
3	**FL**	n	y (note 1)	y (note 2)	n	Future new build	y	limited (note 4)	Car park and roof	n	n	y	y
4	**AS**	n	y	y	n	y	y	limited (note 4)	Car park	n	n	y	y
5	**GE**	n	y (note 1)	y (note 2)	n	Future new build	y	limited (note 4)	Car park and roof	n	n	y	y
6	**GS**	n	y	minimal	n	Future new build	y	n	Roof	n	n	y	n

Summary of feasible options

1	**SI**	Permeable car parks. Rainwater harvesting from residential roofs at Singer Hall. Small vegetated features
2	**JL**	Permeable car parks. Small vegetated features
3	**FL**	Permeable car parks. Green roof on FL. Rainwater harvesting at rear of Student Centre
4	**AS**	Permeable car parks. Detention basins. Small vegetated features. Limited rainwater harvesting
5	**GE**	Permeable car parks. Green roof on CW East. Rainwater harvesting at CW east
6	**GS**	Green roof on BU

Notes: 1) Areas within two sub-catchments were scheduled for redevelopment

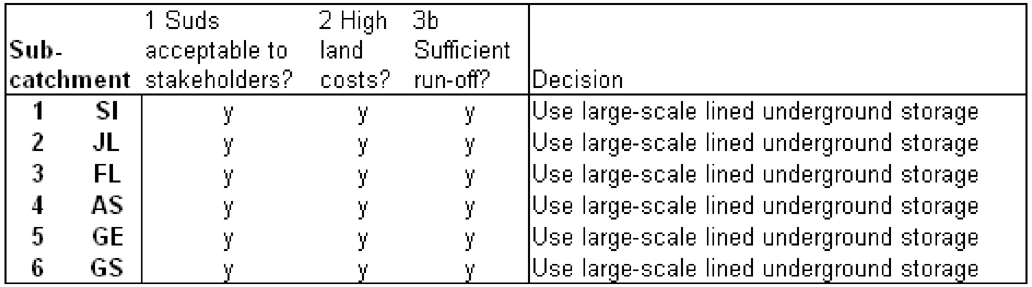
2) The main car park in GE sub-catchment was scheduled for replacement with new buildings within five years as part of the Campus redevelopment. The car parks east of the Library were scheduled for replacement with a multi-storey car park, with development work due to start in 2009

3) Singer was the only sub-catchment that appeared to be served by a separate stormwater sewer. This sewer commenced at Singer Hall, then ran under public roadway, collecting stormwater from the Alma Building on its short passage to the Swan Lane culvert.

4) Two off-site areas were identified with the potential for runoff storage. These were owned by Coventry City Council, and would require further investigation. See text for discussion

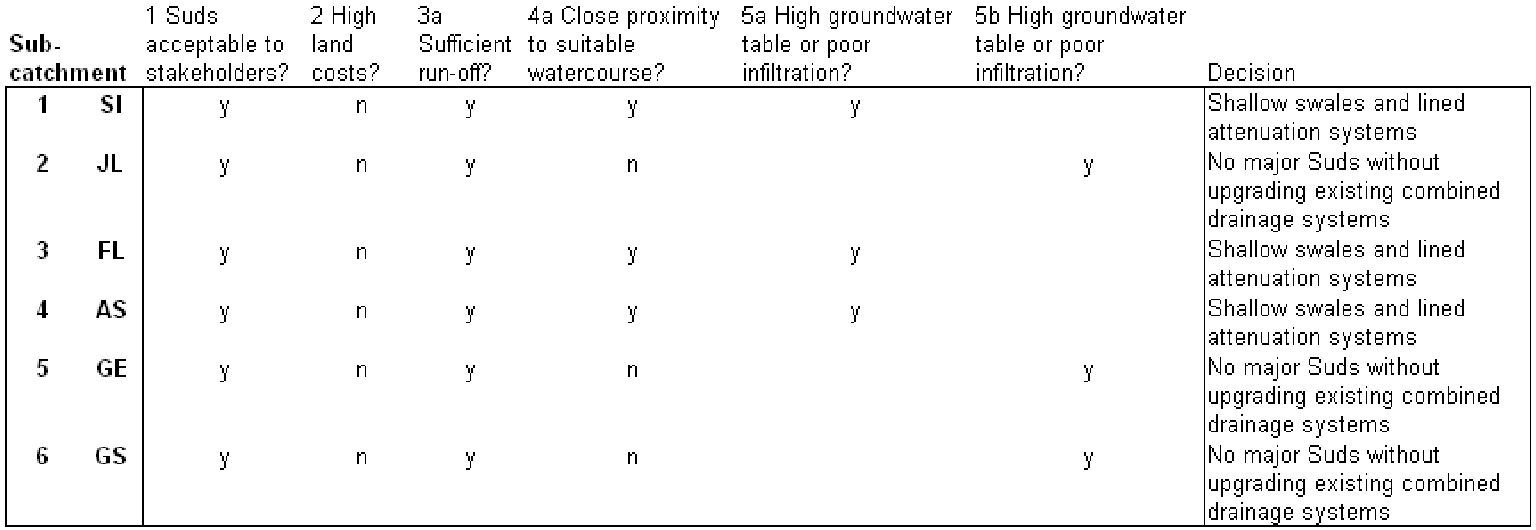
Table C5.7 Results of applying the Scholz decision support key (Fig. C3.15) to the six sub-catchments: a) assuming high land costs b) assuming lower land costs

a)



Sub-catchment		1 Suds acceptable to stakeholders?	2 High land costs?	3b Sufficient run-off?	Decision
1	SI	y	y	y	Use large-scale lined underground storage
2	JL	y	y	y	Use large-scale lined underground storage
3	FL	y	y	y	Use large-scale lined underground storage
4	AS	y	y	y	Use large-scale lined underground storage
5	GE	y	y	y	Use large-scale lined underground storage
6	GS	y	y	y	Use large-scale lined underground storage

b)



Sub-catchment		1 Suds acceptable to stakeholders?	2 High land costs?	3a Sufficient run-off?	4a Close proximity to suitable watercourse?	5a High groundwater table or poor infiltration?	5b High groundwater table or poor infiltration?	Decision
1	SI	y	n	y	y	y		Shallow swales and lined attenuation systems
2	JL	y	n	y	n		y	No major Suds without upgrading existing combined drainage systems
3	FL	y	n	y	y	y		Shallow swales and lined attenuation systems
4	AS	y	n	y	y	y		Shallow swales and lined attenuation systems
5	GE	y	n	y	n		y	No major Suds without upgrading existing combined drainage systems
6	GS	y	n	y	n		y	No major Suds without upgrading existing combined drainage systems

C.5.5.2. Scholz decision-support tools

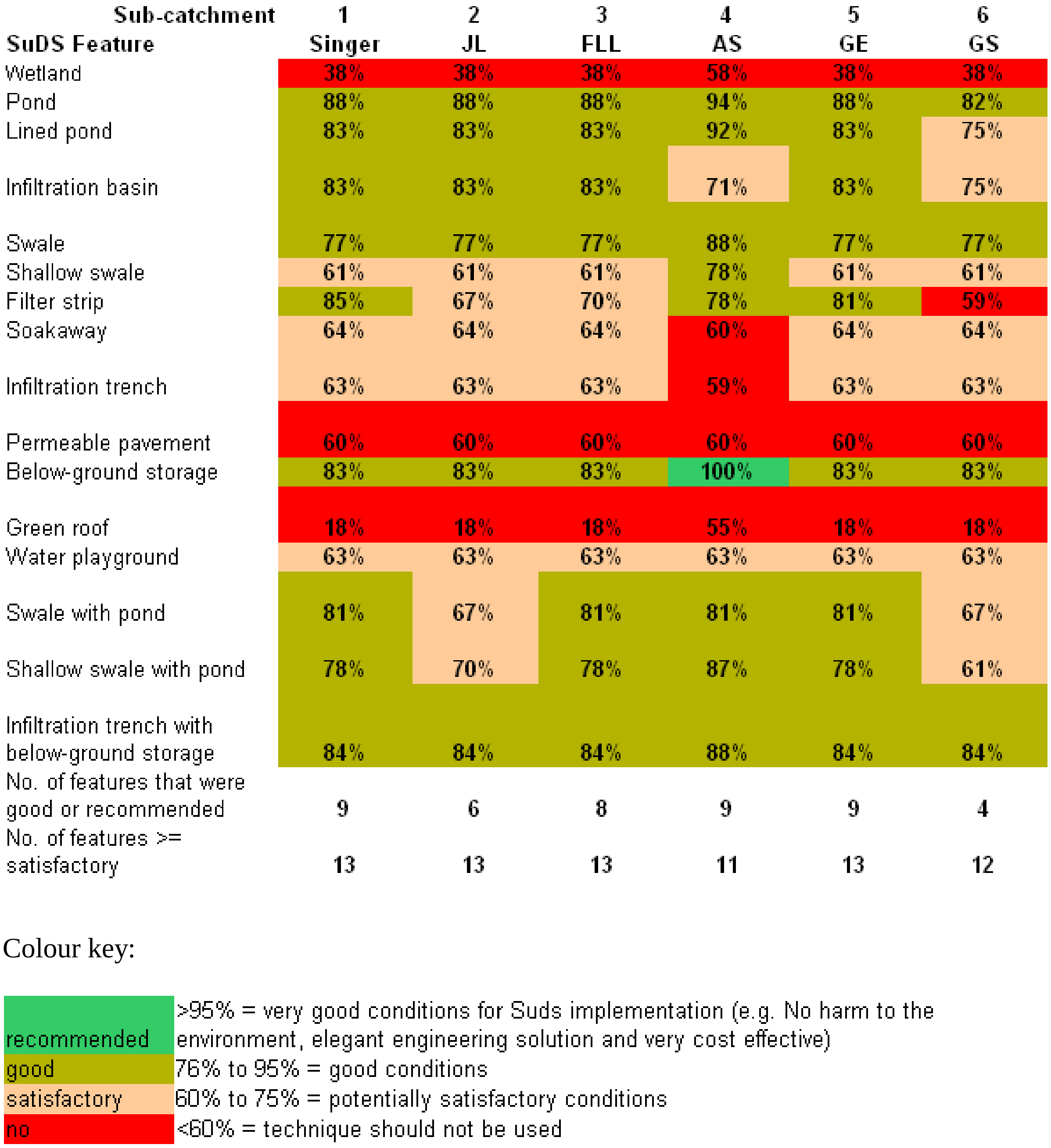
The decision-support key proposed by Scholz (2006) (Fig. C3.15) aimed to identify potential sites. Results of the evaluation are presented in Table C5.7. The first pass (Table C5.7a) identified the use of underground storage solutions for all sub-catchments, but this conclusion appeared driven by high land costs. The reason for proposing lined storage, without determining groundwater levels or potential contamination, was unclear. A second pass was undertaken, assuming that high land costs were not a controlling factor, with the results presented in Table C5.7b. Proximity to a watercourse was the differentiator between sub-catchments in this instance. For the three sub-catchments closer to a watercourse, the suggestion of attenuation systems and swales appeared sensible, although the reason for lined attenuation systems was once again unclear. For the remaining three sub-catchments, the proposal that SUDS were not feasible without upgrading combined sewer systems omitted consideration of green roofs and paving, and assumed that sub-catchments were drained by combined systems.

Scholz (2006) also developed a more detailed evaluation of the suitability of 16 individual SUDS features based on weighted assessment of 16 specific characteristics. Results of applying this matrix to the study site are given in Fig. C5.25, with details of the calculations provided in Table C5.8. Although the methodology was intended as a generic decision-making tool, some factors seemed to rely on knowledge of specific sites, e.g. requirement for specific slope values of a potential site, compared to maximum slope values. Also, while individual weightings within the methodology might be queried, the overall balance appeared reasonable and was not changed when applied to the current research.

The only clear recommendation was for underground storage in the AS sub-catchment, which had the highest permeable area of the six sub-catchments. 50% or more of the listed features were classed as good or recommended for four of the six sub-catchments. Wetlands were classed as impractical in all sub-catchments, driven by insufficient available area. The decision matrix appeared more oriented to vegetated features, as both permeable pavements and green roofs were defined as unsuitable for all sub-catchments, in contrast to the Swan/Stovin recommendations. This may be because only five of the 16 factors were used to evaluate green roofs, and four to evaluate permeable paving. Ponds and swales were regarded as good for all sub-catchments, as were infiltration trenches with below-ground storage. Yet infiltration trenches alone were either unsuitable or just satisfactory. Infiltration basins were deemed less suitable for the two sub-catchments covering the smallest area.

Although the AS sub-catchment had the highest permeability level, fewer SUDS features were considered at least satisfactory for this sub-catchment than for the other five. This was largely because the sub-catchment was classed as having a high groundwater table, being the lowest elevation point on campus and having the culverted river running along a section of its perimeter, so infiltration devices were less suitable.

Overall, the Scholz decision support key (Table C5.7) recommended the use of lined underground storage for all sub-catchments, based on high land costs. The single clear recommendation from the more detailed decision-making matrix (Fig. C5.25) was the use of underground storage in the most permeable Armstrong Siddeley sub-catchment. Combinations of ponds, swales and infiltration devices were proposed as good options for most sub-catchments.



Sub-catchment	1	2	3	4	5	6
SuDS Feature	**Singer**	**JL**	**FLL**	**AS**	**GE**	**GS**
Wetland	38%	38%	38%	58%	38%	38%
Pond	88%	88%	88%	94%	88%	82%
Lined pond	83%	83%	83%	92%	83%	75%
Infiltration basin	83%	83%	83%	71%	83%	75%
Swale	77%	77%	77%	88%	77%	77%
Shallow swale	61%	61%	61%	78%	61%	61%
Filter strip	85%	67%	70%	78%	81%	59%
Soakaway	64%	64%	64%	60%	64%	64%
Infiltration trench	63%	63%	63%	59%	63%	63%
Permeable pavement	60%	60%	60%	60%	60%	60%
Below-ground storage	83%	83%	83%	100%	83%	83%
Green roof	18%	18%	18%	55%	18%	18%
Water playground	63%	63%	63%	63%	63%	63%
Swale with pond	81%	67%	81%	81%	81%	67%
Shallow swale with pond	78%	70%	78%	87%	78%	61%
Infiltration trench with below-ground storage	84%	84%	84%	88%	84%	84%
No. of features that were good or recommended	9	6	8	9	9	4
No. of features >= satisfactory	13	13	13	11	13	12

Colour key:

recommended	>95% = very good conditions for Suds implementation (e.g. No harm to the environment, elegant engineering solution and very cost effective)
good	76% to 95% = good conditions
satisfactory	60% to 75% = potentially satisfactory conditions
no	<60% = technique should not be used

Fig. C5.25 Results of applying the Scholz (2006) decision-making matrix to the study site to evaluate the suitability of individual SUDS features based on sub-catchment characteristics.

Table C5.8 Decision making frame & weightings from Scholz (2006). The matrix evaluates the suitability of 16 individual SUDS features based on weighted assessment of 16 specific characteristics

	Area for Suds feature: m^2	**Serious contamination**	**Land value (£/m^2)**	**Current Run-off quantity (m^2/day)**	**Future Run-off quantity (m^2/day)**	**Run-off quality**	**Drainage to watercourse**	**High groundwater**	**Soil infiltration**	**Impermeable area: %**	**Catchment: ha**	**Sufficient slope**	**Slope: x m in 100 m**	**Maximum slope x m in 100 m**	**Land fragmented**	**High ecological impact**
Wetland	>5000	no	<£100	>100	>100	Average	yes	n/a	n/a	<10	>5	n/a	n/a	<15	no	yes
Pond	>50	no	£100-200	>100	>100	Average	yes	n/a	n/a	<40	>1.5	n/a	n/a	<20	n/a	n/a
Lined pond	>50	n/a	£100-200	>100	>100	n/a	yes	n/a	n/a	<40	>1.5	n/a	n/a	<20	n/a	n/a
Infiltration basin	>50	no	£100-200	>100	>100	Average	n/a	no	High	<40	>1.5	n/a	n/a	<20	n/a	n/a
Swale	>200	no	£100-200	>100	>100	Average	yes	no	n/a	<50	n/a	yes	>1	<10	no	n/a
Shallow swale	>200	no	£100-200	<100	<100	Average	n/a	n/a	n/a	<60	n/a	yes	>1	<15	no	n/a
Filter strip	>500	no	£100-200	>100	>100	Good	n/a	no	High	<30	>1.5	yes	>2	<30	no	n/a
Soakaway	>200	no	£100-200	<100	<100	Average	n/a	no	High	<80	>0.3	yes	>1	<25	n/a	n/a
Infiltration trench	>50	no	£100-200	<100	<100	Average	n/a	no	High	<50	>0.3	yes	>1	<15	no	n/a
Permeable pavement	n/a	n/a	n/a	<100	<100	Average	n/a	n/a	n/a	>10	n/a	n/a	n/a	<40	n/a	n/a
Below-ground storage	>50	n/a	n/a	all	>100	n/a	yes	n/a	n/a	>40	>0.5	n/a	n/a	<15	n/a	n/a
Green roof	n/a	n/a	£100-200	<100	<100	Average	yes	n/a	n/a	n/a	n/a	n/a	n/a	<20	no	n/a
Water playground	>10	no	n/a	<100	<100	Good	n/a	n/a	n/a	n/a	>0.025	n/a	n/a	<50	n/a	n/a

	Area for Suds feature: m^2	**Serious contamination**	**Land value (£/m^2)**	**Current Run-off quantity (m^2/day)**	**Future Run-off quantity (m^2/day)**	**Run-off quality**	**Drainage to watercourse**	**High groundwater**	**Soil infiltration**	**Impermeable area: %**	**Catchment: ha**	**Sufficient slope**	**Slope: x m in 100 m**	**Maximum slope x m in 100 m**	**Land fragmented**	**High ecological impact**
Swale with pond	>300	no	£100-200	>100	>100	Average	yes	no	n/a	<40	>2	yes	>1	<10	no	n/a
Shallow swale with pond	>250	no	£100-200	>100	>100	Average	yes	n/a	n/a	<40	>2	yes	>1	<15	no	n/a
Infiltration trench with below-ground storage	>150	no	£100-200	>100	>100	Average	yes	no	n/a	<60	>0.5	yes	>1	<15	no	n/a
Weightings																
Wetland	2	2	3	1	3	3	2	0	0	1	2	0	0	0	3	2
Pond	2	2	2	2	3	3	1	0	0	1	1	0	0	0	0	0
Lined pond	2	0	2	2	3	0	1	0	0	1	1	0	0	0	0	0
Infiltration basin	2	3	2	2	3	3	0	3	3	1	2	0	0	0	0	0
Swale	1	3	1	2	3	2	2	2	0	1	0	2	2	2	3	0
Shallow swale	1	1	1	2	2	2	0	0	0	1	0	2	2	2	2	0
Filter strip	1	3	1	2	3	2	0	3	2	1	2	2	2	2	1	0
Soakaway	2	2	2	1	3	2	0	3	3	2	2	1	1	1	0	0
Infiltration trench	1	3	1	1	3	2	0	3	3	1	1	2	2	2	2	0

	Area for Suds feature: m^2	**Serious contamination**	**Land value (£/m^2)**	**Current Run-off quantity (m^2/day)**	**Future Run-off quantity (m^2/day)**	**Run-off quality**	**Drainage to watercourse**	**High groundwater**	**Soil infiltration**	**Impermeable area: %**	**Catchment: ha**	**Sufficient slope**	**Slope: x m in 100 m**	**Maximum slope x m in 100 m**	**Land fragmented**	**High ecological impact**
Permeable pavement	0	0	0	1	1	2	0	0	0	1	0	0	0	0	0	0
Below-ground storage	2	0	0	2	3	0	2	0	0	2	1	0	0	0	0	0
Green roof	0	0	0	2	3	2	2	0	0	0	0	0	0	0	2	0
Water playground	1	2	0	1	2	1	0	0	0	0	1	0	0	0	0	0
Swale with pond	2	3	2	3	3	2	2	2	0	1	2	1	1	1	2	0
Shallow swale with pond	2	2	2	2	3	2	2	0	0	1	2	1	1	1	2	0
Infiltration trench with below-ground storage	2	2	2	2	3	3	1	3	0	1	1	1	1	1	2	0

C.5.5.3. D'Arcy & Wild

The decision tree for brownfield sites with combined sewers (D'Arcy & Wild 2003:11 - *cf*. Fig. C3.16) was evaluated, with the results in Fig. C5.26. Although the methodology regarded infiltration options as desirable, they were not considered feasible for the study area because soil infiltration capacity was limited. The university is largely drained by combined sewers, and flow attenuation was one aim contributing to reduced flooding. Consequently, the proposals recommended storage and detention of run-off using either soft engineering structures such as detention basins and swales, or hard structures such as stormwater tanks and permeable paving. Source and site control options were excluded because of poor soil infiltration capacity on site, and feasible options would ultimately discharge to the sewer for the same reason.

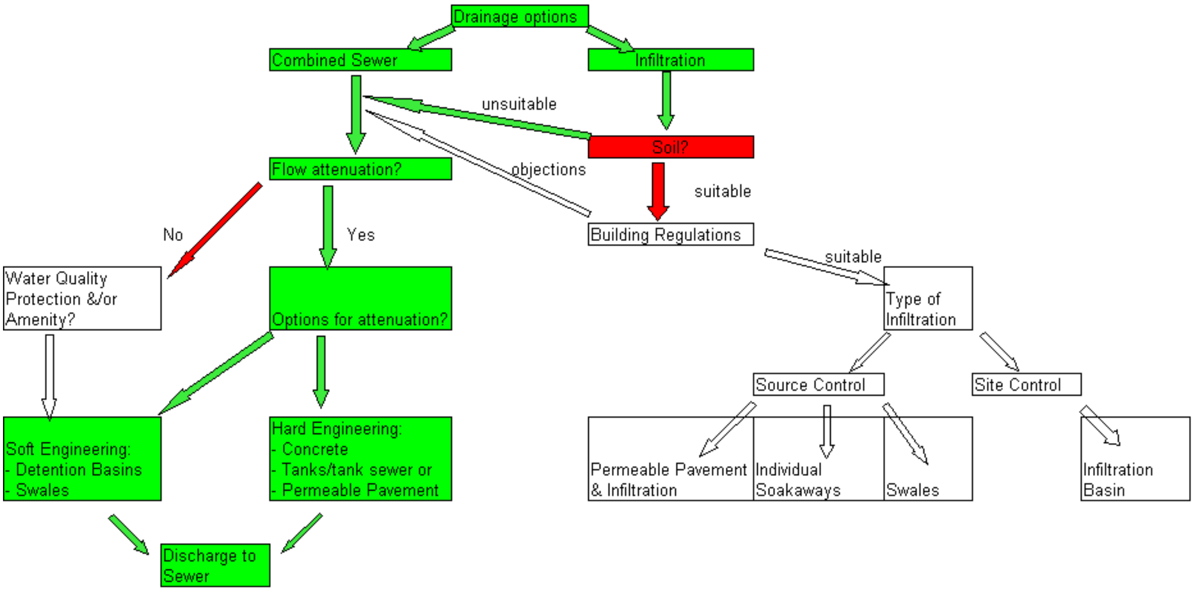


Fig. C5.26 Results of the evaluation of the D'Arcy & Wild decision tree for brownfield sites. Colour scheme: green = positive decision to continue; red = negative decision, do not continue along this path; white = option not evaluated because excluded by previous decision

C.5.5.4. HR Wallingford Stormwater Storage Assessment

The HR Wallingford (2008) Stormwater Storage Assessment generated an evaluation of suitable SUDS devices based on site characteristics, shown in Table C5.9. The same recommendations were produced for all sub-catchments, even though the AS sub-catchment was input to the evaluation having groundwater less than 2 m below the surface, in contrast to the five other sub-catchments. Permeable paving, swales, green roofs, rainwater harvesting and bio-retention facilities were suggested to be suitable for the campus. However, the techniques suggested were subject to some limitations. Swales may occupy significant land area, but are effective in addressing water quality and quantity issues. Green roofs may reduce run-off in ordinary rainfall events, but will have less impact on extreme events. Rainwater harvesting can reduce run-off for all events if sufficiently large tanks are used. Ponds and basins were considered unsuitable due to land take. Infiltration trenches and soakaways were classed unsuitable due to the low infiltration capacity of the soil.

Table C5.9 Site Drainage Evaluation for the use of SUDS in each sub-catchment generated from the HR Wallingford Stormwater Storage Assessment tool (2008)

C.5.5.5. Ellis *et al*. assessment of catchment area and soil type

Ellis *et al*. (2004b) aimed to assess the suitability of various SUDS devices based on catchment area and soil type. The results for each sub-catchment are presented in Table C5.10. Techniques categorised as ‘marginal’ or ’not feasible’ were considered unsuitable for the campus. Detention and retention basins were excluded using this methodology because of the requirement for a larger contributing area than was present in each of the sub-catchments. Permeable paving, and infiltration basins and trenches, were excluded because of insufficient soil infiltration capacity. Swales needed an area over 2 ha, and so were feasible in only three sub-catchments. Inlet devices, such as road and paved area gullies, and roof drains (Balmforth *et al*. 2006a:97-102) are means of applying hydraulic control on input flow rates to both conventional and SUDS drainage devices. They were suitable for all locations, but did not add to the range of SUDS options available, so were not considered further in this study.

Table C5.10 Suitability of SUDS devices applying the methodology of Ellis *et al*. (2004b)

C.5.5.6. Discussion - SUDS Decision Tools

The Swan/Stovin hierarchical framework highlighted the value of using large roofs and car parks as surfaces for SUDS retrofit. Preference for site and regional controls over source controls in the methodology may be an attempt to utilise individual larger spaces in urban sites for attenuation, *e.g.* in industrial and commercial business parks. However, site and regional controls require the conveyance of runoff from source control locations. The sub-catchments in the pilot perhaps needed more than one site control installation. A more practical option would be a management train linking several smaller installations. Priority afforded to separately sewered branches as a result of work in Glasgow (Singh *et al*. 2005) did not add significant value to the current study. Sub-catchment impermeability was a more significant factor driving SUDS feasibility in this research.

The Mode of Operation assessment criteria reflected the importance of hard engineering techniques such as green roofs and permeable paving in urban areas of high impermeability because of the lack of vegetated areas on campus. Both techniques were relevant to this study. Infiltration was appropriate as the next most important method, but it was not feasible in the study area because of unsuitable soil conditions. The prioritisation of disposal as the next choice reflected the Building Regulations drainage hierarchy, and, whilst likely to be easier to implement than storage or infiltration, contributed less to the achievement of SUDS goals. Re-use, although more difficult to achieve, may provide better opportunities for financial justification than straightforward disposal of runoff water to the sewer.

It was difficult to judge whether the proposals generated by the Scholz (2006) qualitative decision-support key were correct, because the reasoning behind the suggestions was not transparent. In contrast, use of the Swan/Stovin hierarchy (SNIFFER 2006) generated recommendations that were understandable and transparent. The Scholz quantitative decision-support key did not appear to take into account characteristics of individual sub-catchments, and so produced similar recommendations for all sub-catchments, perhaps due to the coarseness of the evaluation mechanism. Some of the suggestions from the Scholz feature-level decision-support matrix were not transparent. The method emphasised underground storage, reasonably suitable for an urban site despite future maintenance limitations and lack of amenity value; ponds, assumed to require a smaller area than most other SUDS features; and infiltration devices, without considering infiltration capacity of the local soil. Although the methodology was intended as a generic decision-making tool, some factors seemed to rely on knowledge of specific sites, e.g. requirement for specific slope values of a potential site, compared to maximum slope values. While individual weightings within the methodology might be queried, the overall balance appeared reasonable and was not changed when applied to the pilot evaluation for Coventry University.

The D’Arcy & Wild brownfield evaluation method was oriented towards water quality issues, probably due to its origin in addressing Scottish priorities. It generated the same recommendations for all sub-catchments, proposing attenuation options rather than infiltration devices in recognition of the local soil’s unsuitability for infiltration. The number of available SUDS techniques was limited, possibly reducing the validity of the method for assessing water quantity issues. A study in Glasgow (Singh *et al*. 2005) also determined that different approaches were required when tackling flooding and water quality problems, due to the different volumes of water associated with the two issues.

The HR Wallingford method was relatively new at the time of the pilot, and no literature referring to its proposals was found. Its recommendations were a reasonably accurate reflection of the limitations of the urban study area, and also pointed out the limited potential for significant water attenuation using the proposed options.

The Ellis *et al*. (2004b) methodology, similar to the D’Arcy & Wild method, included a limited set of SUDS techniques, and also excluded green roofs. The methodology appeared to treat permeable paving solely as an infiltration technique, ignoring its potential for water storage, and so paving was deemed not feasible for the study area.

C.5.5.7. Summary

Although the methodologies proposed individual SUDS options, a treatment train comprising several components could combine the benefits and capabilities of different SUDS techniques and offer contingency in case of failure. The Scholz detailed decision-support matrix was the only methodology to explicitly propose combinations of SUDS features, although in the case of the pilot site the individual techniques were at times questionable.

The recommendations of the existing tools for the six sub-catchments are summarised in Table C5.11. Despite the same catchment characteristics being used as input to all the evaluations, and the same potential range of SUDS techniques being available, a wide range of alternative solutions was proposed. Permeable paving was the most commonly suggested source control technique, and swales the most frequently proposed site control feature. Devices suggested by two methodologies also had merit. Rainwater harvesting and green roofs were potential source control techniques for several sub-catchments. Bio-retention features and underground storage were possible techniques. Because of the limited vegetated surface area on campus, a detention basin was only valid in the AS sub-catchment.

The weakness of the assessed methods was that some appeared too focused on the individual circumstances of their own study sites and were less generally applicable. All could be improved by indicating how SUDS techniques could be linked in a management train. Overall, the Swan/Stovin framework and HR Wallingford evaluation generated understandable proposals for the Coventry University inner-city pilot site**.**

Table C5.11 Summary of techniques proposed by applying the existing methodologies, based on the particular circumstances of the pilot site. Key to methodologies: D'Arcy = D'Arcy & Wild (2003); Ellis = Ellis *et al*. (2004b); HRW = HR Wallingford (2008); Scholz A = Scholz (2006) decision-support key; Scholz B = Scholz (2006) decision-making matrix; Swan = Swan/Stovin hierarchical framework (SNIFFER 2006)

C.5.6. Locations for SUDS on Coventry University campus

Previous sections in this chapter considered methods to assess the locations at greatest risk from flooding. Assessment of problem locations (Chapter C5.2) showed that the George Eliot sub-catchment had the highest number of historical flood events based on limited available records, and that SI, AS and FL sub-catchments might be able to contribute to river water quality enhancements. Flood maps and PPS25 procedures (Chapter C5.3) highlighted the locations most at risk from fluvial flooding. Hydrological analysis (Chapter C5.4) provided guidance on the volume of rainfall that might affect each sub-catchment, and the volume of storage required to attenuate runoff for precipitation events of different return periods; the most impermeable sub-catchment (GE) had the largest storage volume requirement. Existing methodologies (Chapter C5.5) were applied to understand which SUDS techniques would be most appropriate in individual sub-catchments. Permeable paving and swales gained the highest number of recommendations from the methods evaluated. Fig. C5.27 highlights locations at higher risk of flooding using this information.

This section integrates the findings from previous chapters in order to determine the feasibility of retrofitting SUDS techniques in individual sub-catchments, and the extent to which 100-year storage volumes can be achieved. Firstly, applicability of SUDS techniques recommended in Table C5.11 is considered. This is followed by a review of potential locations for implementing individual SUDS devices.

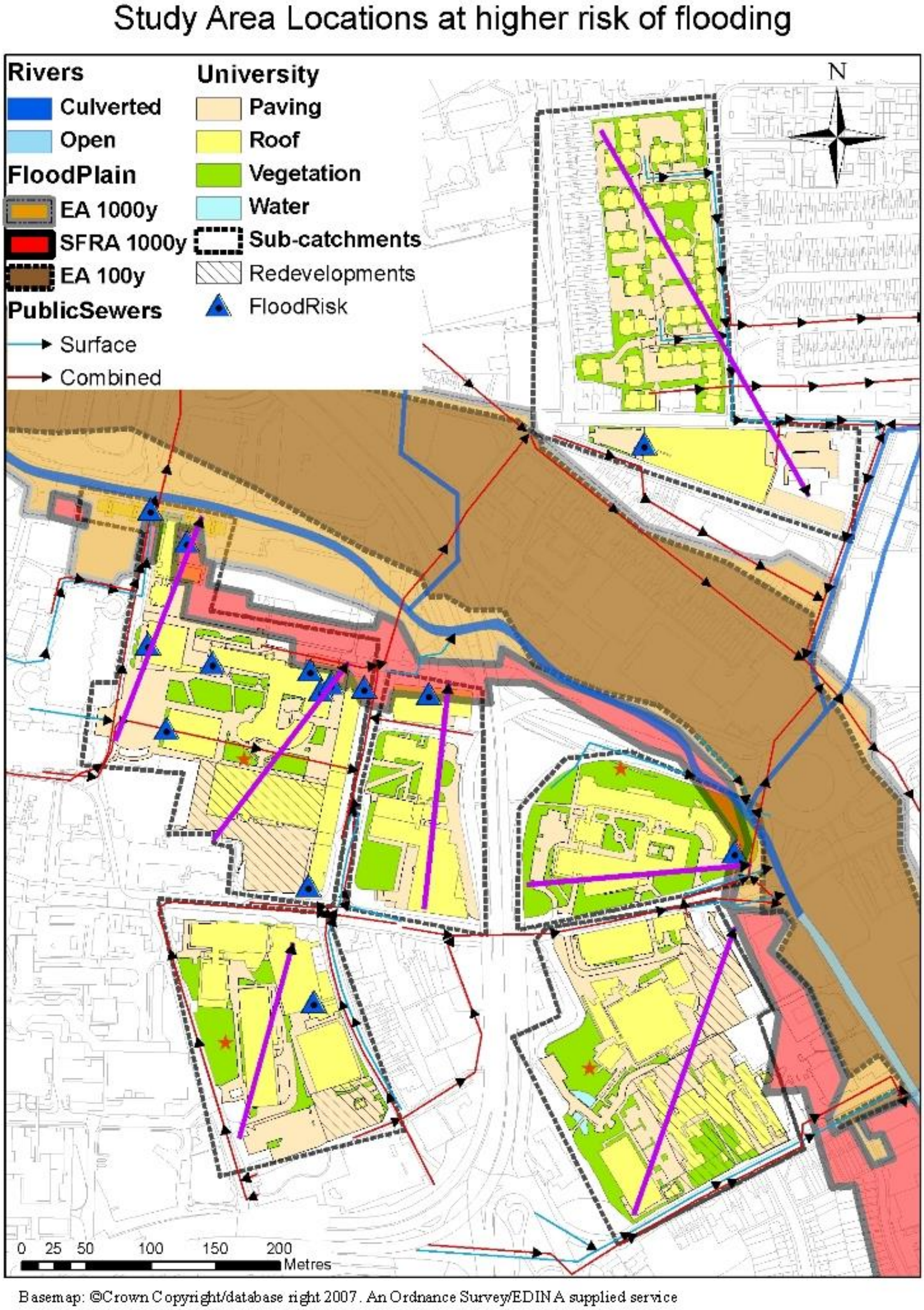


Fig. C5.27 Campus locations at higher risk of flooding from all sources. Purple arrows indicate the principal drainage direction in each sub-catchment. Buildings at higher risk of flooding are indicated. Areas scheduled for redevelopment were not assessed

C.5.6.1. Applicability of SUDS devices to Coventry University campus

The SFRA (Coventry City Council 2008b:40) recommended the use of SUDS in all new developments. Although infiltration techniques were preferred, these were less suitable for the campus due to soil conditions. Above-ground attenuation facilities were suggested in preference to below-ground devices because of their additional water quality and biodiversity benefits. New developments should achieve greenfield discharge rates less 20%, to cater for climate change, but no specification was given for redevelopments or retrofits. On-site attenuation should cater for 100-year return period events, taking climate change into account.

Existing tools proposed a wide range of SUDS devices (Table C5.11). The suitability of each device for the campus is briefly reviewed below, with descriptions of the individual SUDS techniques taken from Woods Ballard *et al*. (2007). Several buildings were due for replacement over the next 10 years under the University's Development Master Plan (Coventry University 2008). Their locations were shown on Fig. C4.2, and they were excluded from the retrofit evaluation below. In practice, these redevelopments might offer larger potential for SUDS implementation. In all cases, detailed design work will be necessary to confirm the proposals made here. The suitability of SUDS techniques at Coventry University is summarised in Table C5.12, and individual methods are reviewed in more detail below.

C.5.6.1.1. **Source controls**

Source controls are the second step in the SUDS management train (Fig. C2.1), dealing with rainfall at the point it reaches the ground surface. In a highly urbanised landscape, they were considered a more preferable option as they removed the need to transport rainwater elsewhere, and could reduce the infrastructure required to achieve that. Source controls included green roofs, rainwater harvesting and permeable paving.

C.5.6.1.1.1. *Green Roofs*

The University's Estates Dept. raised concerns during the pilot about the load bearing requirements of green roofs, particularly for newer buildings. An additional issue was the poor condition of some, in general older, roofs, where a vegetated roof covering might hinder access to carry out frequent maintenance. A number of roofs supported additional equipment e.g. for heating and lifts, which must be taken into account. The pitch of some roofs was unsuitable. Due to the concerns raised, only three existing buildings were evaluated further: Bugatti, the east wing of Charles Ward, and the Lanchester Library.

C.5.6.1.1.2. Rainwater harvesting

There was some potential for rainwater harvesting on campus. However, many university buildings did not have visible downpipes, so additional means of diverting and collecting rainfall would need to be installed, requiring further detailed investigation and almost certainly at additional expense. The areas with external downpipes and so the potential for relatively easy supply of water to rainwater harvesting tanks at specific locations were:

- Most houses in Singer Hall
- Charles Ward
- Student Centre
- Armstrong Siddeley extension
- George Eliot lecture theatre and café annex
- Alma.

C.5.6.1.1.3. Permeable paving

Permeable paving may be used to promote infiltration, or in conjunction with underground storage devices to provide attenuation or rainwater harvesting. Permeable paving may not be suitable for heavy vehicular traffic (e.g. Knapton *et al*. 2002), but this restriction did not apply to any areas on campus, which were used by pedestrian traffic, and for vehicle access and parking. Permeable paving was suitable for the paved areas on campus, although infiltration conditions were not ideal, so a means of using or disposing of captured water would be necessary, for example in conjunction with rainwater harvesting.

C.5.6.1.2. Site Controls

Site controls are the third step in the SUDS management train (*cf*. Fig. C2.1), aiming to manage runoff from several premises, for example by directing water from adjacent roofs and car parks to a large detention or infiltration basin. In larger sub-catchments exceeding 2 ha, it is considered preferable to structure a management train consisting of smaller source control SUDS devices which drain to a final site control (Woods Ballard *et al*. 2007:3.12). Examples of site controls considered included: filter strip, infiltration devices, detention basins, ponds, swales, bio-retention areas and sub-surface storage.

C.5.6.1.2.1. **Filter** *strips*

Filter strips intercept and treat runoff from hard surfaces before it reaches a disposal system, to achieve which a relatively shallow slope over a minimum width of 6 m is suggested (Woods Ballard *et al*. 2007:8.1). There were few areas on campus with sufficient width of vegetated area adjacent to and down-slope from hard surfaces.

C.5.6.1.2.2. Infiltration devices

Infiltration trenches are aggregate-filled excavations that reduce runoff rates and volumes, which may be appropriate in certain locations. Infiltration basins are vegetated depressions designed to store and infiltrate runoff, so were considered less suitable given soil conditions on campus.

C.5.6.1.2.3. Detention basins

Detention basins are dry depressions used for storage and attenuation of peak flows, and can be vegetated or hard engineered. They may perform a dual function, for example also acting as recreational facilities. Several areas on campus may be suitable.

C.5.6.1.2.4. Ponds

Ponds are effective for peak flow reduction, and provide amenity and biodiversity value, but can require significant land-take. Existing ponds in the Lanchester Library sub-catchment were situated at a higher elevation than the rest of the sub-catchment; a small extension to these ponds to provide temporary rainwater storage would not offer significant benefit. Only one other area, in the Singer sub-catchment, might contain sufficient area for a pond.

C.5.6.1.2.5. Swales

Swales are vegetated drainage channels for storage or conveyance of rainwater, which can provide alternatives to conventional gulleys, pipes and channels. Several locations on campus were considered suitable.

C.5.6.1.2.6. Small vegetated bio-retention features

Small vegetated bio-retention features are small landscaped and planted depressions, similar to vegetation beds, which can reduce the rate and volume of runoff. They are an appropriate technique for many of the vegetated areas on campus and can form part of a landscape design.

C.5.6.1.2.7. Underground storage

Underground storage typically comprises structures engineered to retain water for re-use, evaporation, infiltration or slow release. They can be installed beneath permeable paving, so a number of areas were considered suitable, although infiltration options will be limited, and there will be little amenity benefit.

Table C5.12 Suitability of SUDS techniques at Coventry University

Technique	**Description**	**Function**	**Effectiveness for flood control**	**Suitable for University**	**Potential retrofit and refurbishment locations**	**New build potential**	**Additional advantages**
Source Controls							
Permeable paving	Hard landscaping for roads, car parks and pavements	Storage, infiltration and re-use	high	Yes	paths, car parks and roadways throughout campus	paths, car parks and roadways throughout campus	Oil spill treatment
Green roofs	Vegetated drainage layers on roofs	Detention and storage	high	Yes	limited retrofits on CW, Library, SU Cox St.	all new buildings	Biodiversity, increased building insulation, reduced urban heat island effect
Rainwater harvesting	Storage tanks for rainwater	Detention and re-use	low - medium	Yes	Student Centre, Singer Hall, CW	all new buildings	reduced water usage
Site Controls							

Technique	Description	Function	Effectiveness for flood control	Suitable for University	Potential retrofit and refurbishment locations	New build potential	Additional advantages
Bio-retention areas	Planted flower and vegetation beds	Detention and infiltration	low	Yes	existing planted areas throughout campus	new landscaping	
Swales	Broad shallow grass channels	Storage, conveyance and infiltration	medium - high	Yes	AS; limited possibilities in Singer, JL and GE sub-catchments	new landscaping	Biodiversity
Detention basins	Dry basins	Storage of runoff. Water quality treatment	medium - high	Yes	AS; existing grassed areas near GE, CW, JL, FL	new landscaping and hard-scaping	amenity?
Filter strips	wide, gently sloping areas of vegetation	Treatment of runoff from impermeable areas	low	Yes	AS; limited possibilities in Singer, JL and GE sub-catchments	new landscaping and hard-scaping	

Technique	Description	Function	Effectiveness for flood control	Suitable for University	Potential retrofit and refurbishment locations	New build potential	Additional advantages
Filter drains	Trenches filled with permeable material, e.g. gravel, sand	Conveyance	low	Yes		borders to car parking areas	
Infiltration devices	Soakaways filled with permeable material, e.g. gravel, sand	Infiltration of runoff	high	Limited		borders to car parking areas, paths and buildings	
Infiltration Basins	Landscaped depressions in the ground	Storage and infiltration	high	No, due to soil conditions			
Wet ponds	Water-filled basins	Water quality treatment. Temporary runoff storage	low - medium	No, due to insufficient available area			

Technique	Description	Function	Effectiveness for flood control	Suitable for University	Potential retrofit and refurbishment locations	New build potential	Additional advantages
Constructed wetlands	Ponds with shallow margins	Pollutant removal	low - medium	No, due to insufficient available area			

C.5.6.2. Potential locations for retrofit SUDS

C.5.6.2.1. Evaluation

In theory the same SUDS devices would be suitable for retrofit implementation that were proposed for new developments. However, additional restrictions apply when retrofitting SUDS. Considering the different SUDS devices, and the characteristics of the six individual sub-catchments, Table C5.13 shows which techniques may be applied. Three techniques, permeable paving, underground storage, and vegetated bio-retention features, were more generally applicable than other techniques (score = 6). The most permeable sub-catchment, Armstrong Siddeley, offered scope for the greatest number of techniques. GE, although the least permeable, achieved the third highest sub-catchment score due to its larger area and therefore some scope for limited implementation of site controls. In the pilot study, sub-catchment permeable area was the best predictor of the number of SUDS options available (Figs. C5.28 & C5.29).

Table C5.13 Retrofit suitability of individual SUDS devices in sub-catchments of the campus. Annotation: y = several possibilities for implementation in the sub-catchment; limited = few possibilities for implementation; blank = no obvious possibilities for implementation. A weighted summary of possible SUDS options of each device and in each sub-catchment is given (y = 1, limited = 0.25)

Sub-catchment	SI	JL	FL	AS	GE	GS	Score
Source Control							
Green Roof			limited		limited	limited	0.75
Rainwater harvesting	y		y	limited	y		3.25
Permeable paving	y	y	y	y	y	y	6.0
Site controls							
Filter strip	limited	limited		y	limited		1.75
Infiltration devices							0.0
Detention basin			limited	y	limited		1.5
Pond	y						1.0
Swale	limited	limited		y	limited		1.75
Swale with pond							
Vegetated bio-retention features	y	y	y	y	y	y	6.0
Underground storage	y	y	y	y	y	y	6.0
Number of SUDS options	5.5	3.5	4.5	6.25	5.0	3.25	

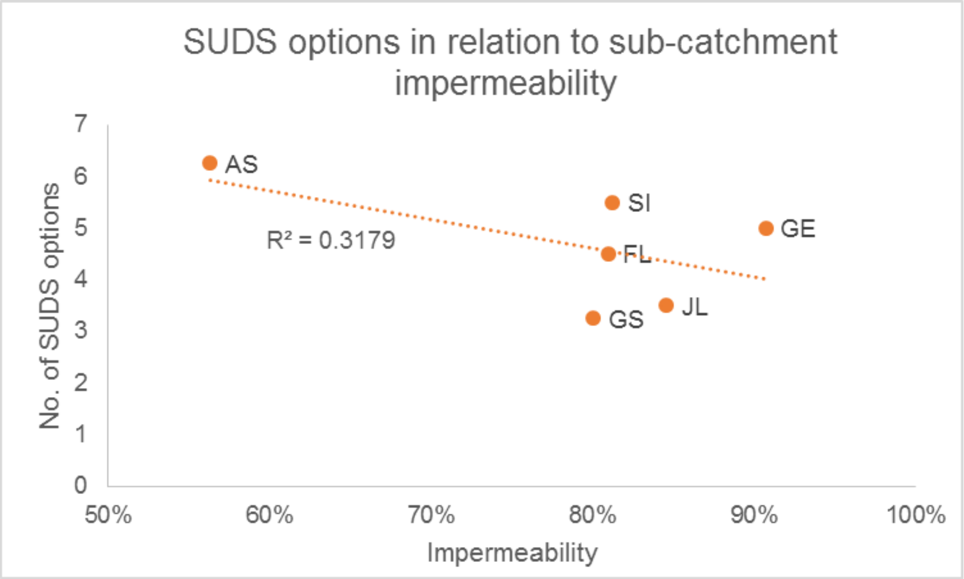


Fig. C5.28 SUDS options in relation to sub-catchment impermeability

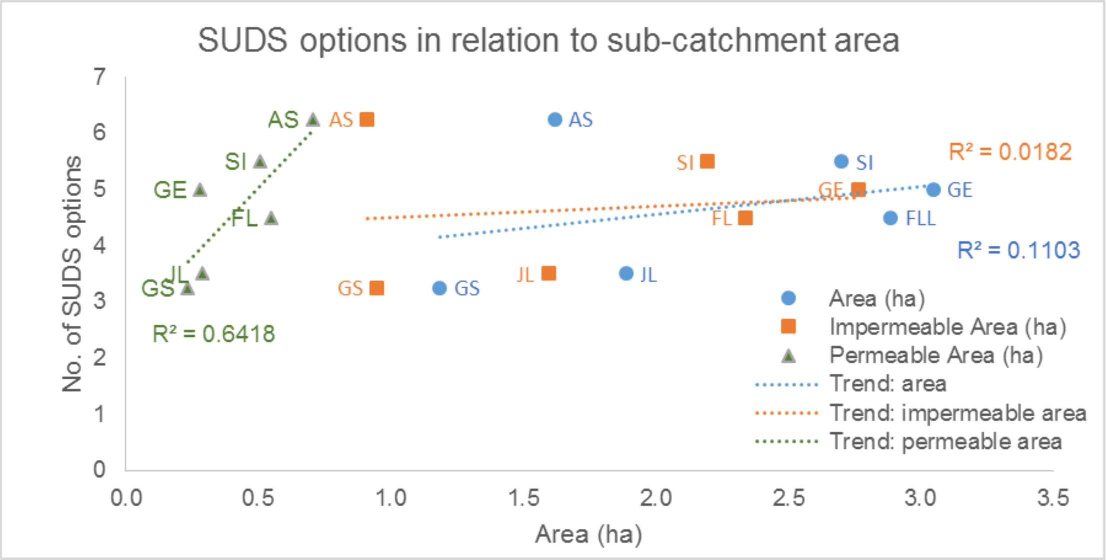


Fig. C5.29 SUDS options in relation to sub-catchment area

When the proximity of potential SUDS locations to areas of higher flood risk was considered, the choice of options was further reduced (Table C5.14). Only hard engineering structures, permeable paving and associated underground storage, offered practical retrofit possibilities to store significant volumes of runoff. Small bio-retention devices were unlikely to provide sufficient storage volume to handle 100-year floods.

Because negative impacts on water quality are often driven by the first foul flush associated with high frequency, low volume rainfall events, there were a greater number of options for contributing to water quality improvements. Four of the six sub-catchments were served by surface water sewers disposing of runoff to nearby watercourses (Table C5.15). There was more scope to retrofit SUDS devices that could contribute to improved water quality than to address flooding issues.

Table C5.14 Suitable SUDS techniques near areas of higher flood risk. Sub-catchments containing buildings at higher risk of flooding are indicated; the FL sub-catchment was not evaluated further. Annotation: y = several possibilities for implementation in the sub-catchment; limited = few possibilities for implementation; blank = no obvious possibilities for implementation. A weighted summary of possible SUDS options within each sub-catchment is given (y = 1, limited = 0.25)

Suitability near flood risk locations	**SI**	**JL**	**FL**	**AS**	**GE**	**GS**	**Score**
Buildings with higher flood risk	y	y	n	y	y	y	
Source Control							
Green Roof					limited		0.25
Rainwater harvesting					y		1
Permeable paving	y	y		y	y	limited	4.25
Site controls							
Filter strip							
Infiltration devices							
Detention basin							
Pond							
Swale				y			1
Swale with pond							
Small vegetated bio-retention features	y	y					2
Underground storage	y	y		y	y	y	5
Number of SUDS options	3.0	3.0	n/a	3.0	3.25	1.25	

Table C5.15 Suitable SUDS techniques near surface water sewers. Sub-catchments with runoff into local watercourses are indicated where water quality improvements were required. Annotation: y = several possibilities for implementation in the sub-catchment; limited = few possibilities for implementation; blank = no obvious possibilities for implementation. A weighted summary of possible SUDS options within each sub-catchment is given (y = 1, limited = 0.25). Suitable devices based on the assessment in Dickie *et al*. 2010:27-29

Suitability near surface water sewers	**SI**	**JL**	**FL**	**AS**	**GE**	**GS**	**Score**
Sub-catchment with runoff to river	y	n	y	y	y	n	
Source Control							
Green Roof			limited		limited		0.5
Rainwater harvesting	y		y	limited	y		3.25
Permeable paving	y		y	y	y		4
Site controls							
Filter strip	limited			y	limited		1.5
Infiltration devices							
Detention basin							
Pond	y						1
Swale	limited			y	limited		1.5
Swale with pond							
Small vegetated bio-retention features	y		y	y	y		4
Underground storage							
Number of SUDS options	4.5	n/a	3.25	4.25	3.75	n/a	

Flooding results when water has been contributed by upslope and upstream areas accumulates in specific locations. Consequently, reduction of runoff from upslope locations can contribute to mitigating flood risk further down the sub-catchment, and also to reducing risks to water quality. It was therefore unrealistic to restrict the search for potential SUDS sites to those locations nearest to areas of highest flood risk. A further evaluation was undertaken to examine the contribution of SUDS techniques throughout an example sub-catchment.

Significant redevelopments planned in the George Eliot and Lanchester Library sub-catchments will alter the landscape, layout and hydrological characteristics of the sub-catchments, but specific details of the planned work were not far enough advanced to be made available in time for the pilot research. Furthermore, sediment loads increase significantly during construction work, so recommendations are to implement or replace SUDS once such work has been completed. Given the lack of certainty regarding future sub-catchment configuration, these two sub-catchments were excluded from further analysis in order to select suitable locations for SUDS retrofit.

Claytor (1998:213) attempted to identify locations with a high likelihood of successful implementation, but these were oriented to less built-up areas than the city centre campus, and none were directly applicable:

- Existing stormwater detention facilities
- Immediately upstream of existing road culverts
- Immediately below or adjacent to existing storm drain outfalls
- Directly within urban drainage and flood control
- Highway rights-of-way
- Within large open spaces, such as golf courses and parks
- Within or adjacent to large car parks.

Recognising this issue, Schueler *et al.* (2007:13-15) contrasted two approaches to retrofit, largely differentiated on the spatial scale of the retrofit and land ownership issues: storage retrofits were considered appropriate to larger areas, but on-site retrofits were more practical in high-density urban areas with limited land availability. Appropriate locations for on-site retrofits included small car parks, individual streets and roofs, filter strips adjacent to impervious areas, and underground sites. These recommendations approached more closely the types of SUDS that would be appropriate on Coventry University campus.

Two examples are given to illustrate the possibilities for SUDS retrofit in Coventry University's inner-city campus. The first example examines the possibilities and impact for a sub-catchment. The second example reviews wider use of green roofs on the campus.

C.5.6.2.1.1. Example One – Sub-catchment

The Armstrong Siddeley sub-catchment (*cf.* Fig. C4.3d) was the least impermeable (56.4%) sub-catchment on campus, and as such was likely to offer the greatest scope for retrofit SUDS implementation. The sub-catchment was characterised by some noticeable gradients (3.6% overall drop) and also by topographical variability. At its widest point, the sub-catchment was approximately 190 x 100 m. Permeable area slightly exceeded 7,000 m2, while paving covered approximately 3,400 m2.

Filter strips would be most beneficial to receive runoff from car parking areas (points 1 - 3 on Fig.C5.30). However, the topographical gradient at points 1 and 2 was away from existing vegetated areas, and installation of new 6m wide filter strips was unlikely as it would remove parking spaces. The grass strip downslope from car park 3 (point 8) was not wide enough to contain a 6m filter strip unless the access pavement were removed (point 9).

A detention basin was only practicable at point 4, to capture roof runoff from the Armstrong Siddeley building. Landscaping work would be required. Electrical cabling ran underground to the William Lyons building through this area, so a more detailed survey would be required to ensure land usage compatibility. A small detention basin was considered at point 5 to capture roof runoff from the Jaguar building. However, part of the current grassed area is subject to water logging (point 6), indicating poor infiltration capability at this location. Additionally, health and safety concerns were raised by the Estates Dept. that standing water could dislodge kerbing stones and cause a trip hazard.

Small swales (point 7) might replace the small concrete open drainage channel to the west of the Armstrong Siddeley, and could convey water to the detention basin. Swales are not recommended for conveyance of water that runs directly off car parking areas due to their potential for transporting pollutants. Assuming effective depths of 40 cm for both detention basin and feeder swales, 119% of the 1-year attenuation storage requirement (346 m^3) could be achieved, equal to 44% of the 100-year requirement.

If a high volume of rainfall were to fill the detention basin, excess water would run off down-slope, as happens without a detention basin. The soil type was not conducive to infiltration, although some water would percolate into the ground surface. Evaporation will account for some dispersal, but relying on infiltration alone, water in the full detention basin and swales would take weeks to drain down, leading to water logging and effectively turning the detention basin into a retention basin. Recommendations are that half the storage should empty within 24 hours to cater for a further rainfall event (Kellagher 2004b:180). Installing an outlet to release water at low flow rates to the drainage system would require additional infrastructure. This would achieve the goal of runoff rate reduction, but would make a minimal contribution to reduction of runoff volume.

Permeable paving had the potential to capture the total 100-year rainfall storage requirement. This could be achieved by converting 50% of the existing paved area to permeable paving, and providing aggregate with sufficient void space, or underground storage devices, to a depth of approximately 0.5 m. Underground storage is less preferred compared to vegetated SUDS as it possesses limited biodiversity/amenity value and provides little treatment (HR Wallingford 2008; Schueler *et al.* 2007:15), although overlying permeable paving has the capability to deal with pollution arising from car parking areas (Newman *et al.* 2004), so would be a feasible option for points 1, 2 and 3 (Fig.C5.30). However, the steeper gradient on the car park at point 1 (around 7%) suggested points 2 and 3 as easier installation sites. As with the detention basin, and with infiltration a poor option, some of the water may need to be transmitted to sustainable or conventional drainage systems. The possibility of linking underground storage with a detention basin would be hampered by the site design, with the AS and WL buildings dividing the 2 locations. A possible alternative might be use of stored water for grounds maintenance – at the time of the pilot the University made no use of rainwater harvesting techniques on the inner-city campus. Installing swales, a detention basin and permeable paving with associated underground storage in half of the existing paved area would enable the 100-year attenuation volume requirement to be met, effectively returning the sub-catchment to greenfield runoff rates.

Existing shrub beds (point 10) could be converted into bio-retention features by replacement of some elements of the lowest brick course with inlet structures. Even this small measure, assuming a 10 cm infiltration depth, would deliver the full interception volume equivalent requirement of 5 mm precipitation from the whole sub-catchment.

Although the University’s Estates Dept. had concerns about the extent of possible remedial preparation work, green roofs could be installed on all buildings in the sub-catchment (point 11) in order to contribute to treatment volume requirements. All had flat roofs, and were of older construction date, thus more likely to have the required structural strength. A later campus building, the Lanchester Library constructed in 2000, had the capability to support a green roof (Charlesworth *et al.* 2013). If 50% of the available roof surface in the AS sub-catchment were occupied by an extensive green roof, with a 15 cm substrate depth and 30% void space, 94% of the combined interception and treatment volume from 15mm of rainfall could be attained (141% of the treatment volume alone). The Swan/Stovin hierarchical framework highlighted the value of using large roofs as surfaces for SUDS retrofit. However, Schueler *et al.* (2007:129) considered that large non-residential roofs were likely to be less cost-effective than bioretention devices, water butts and simple disconnection, although these options would offer fewer attenuation opportunities than green roofs due to the building and landscape configuration in the AS sub-catchment.

There were limited opportunities for rainwater harvesting and downpipe disconnection in the sub-catchment, as there were few external downpipes. One example is shown at point 12. If used as a stormwater attenuation facility, the storage tank would require emptying before a significant rainfall event to ensure full design criteria were achieved. The practicalities of managing this operationally on a large campus reliant on maintenance staff being permanently available made its implementation improbable.

In summary, installation of a detention basin and feeder swales, permeable paving with underground storage for 50% of the existing paved area, green roofs covering 50% of the flat roofs, and bioretention features, if suitably configured, could meet 100% of interception storage requirements, 141% of the treatment volume, and 144% of the 100-year runoff storage requirement for the Armstrong Siddeley sub-catchment. Although a fully vegetated SUDS management train would be an ideal solution to address water quality, quantity and amenity issues, in terms of retrofit in a densely developed urban environment, a mixed solution of sustainable and conventional drainage, incorporating underground storage, would offer a means of addressing the issues currently associated with surface water management in England.

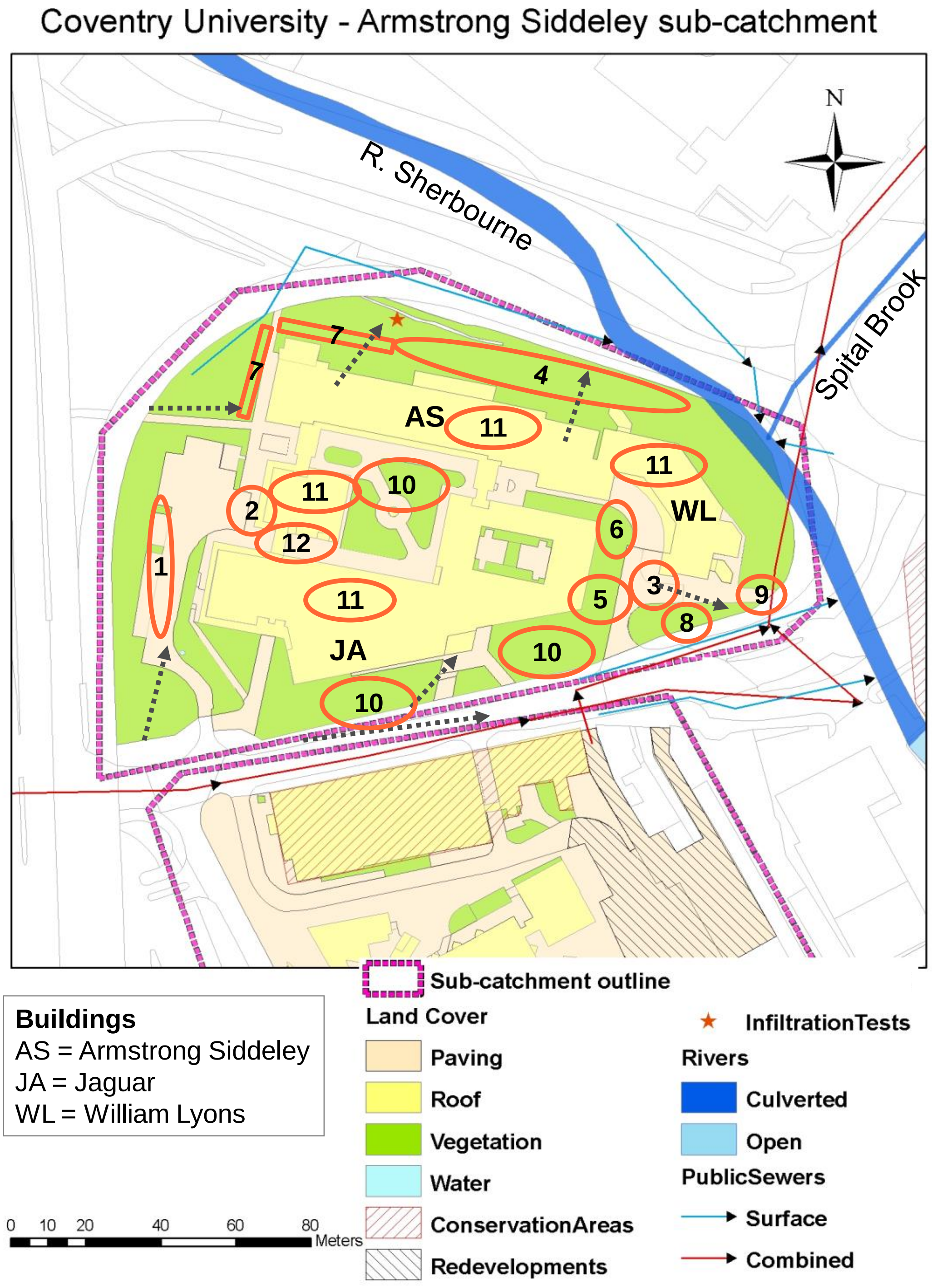


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Fig. C5.30 Armstrong Siddeley sub-catchment showing feasibility of potential SUDS features. Dark dashed arrows indicate the drainage direction at key locations. Point locations: 1) car parking area; 2) car parking area, potential for permeable paving; 3) car parking area, potential for permeable paving; 4) possible detention basin; 5) possible small detention basin; 6) grassed area subject to water logging; 7) small swales; 8) grass strip downslope from car park 3; 9) access pavement; 10) Existing shrub beds with potential for conversion to bio-retention features; 11) possible green roof installations; 12) downpipe. For discussion of marked points, see text.

C.5.6.2.1.2. Example Two - Green Roofs

The implementation of extensive green roofs across the campus could provide a noticeable attenuation of runoff volumes from the roofs (Table C5.16). Green roofs could attenuate the full Vt and interception volumes, preventing runoff from all small rainfall events. Alternatively, they could store between the majority (for AS, all) of the 1-year runoff volume falling on the roofs in each sub-catchment. However, roofs cover only part of the campus surface, and so cannot attenuate precipitation falling on other surfaces.

Table C5.16 Potential impact of large-scale green roof implementation on runoff attenuation. The volume of rainwater stored by green roofs is based on a substrate depth of 15 cm and an assumption of 30% attenuation. Green roofs were assumed to cover 50% of actual roof area. The sub-catchment volume requirements for return periods were taken from Table C5.3

Sub-catchment	**1 SI**	**2 JL**	**3 FL**	**4 AS**	**5 GE**	**6 GS**
Area (ha)	2.7	1.89	2.89	1.62	3.05	1.19
Roof area (ha)	1.06	0.89	1.08	0.57	1.35	0.66
Percentage roof surface in sub-catchment	39.3%	47.2%	37.4%	35.2%	44.3%	55.5%
Green roof rainwater storage (m^3)	478	401	486	256	607	296
Percentage of 5mm Interception	554%	532%	556%	798%	496%	562%
Percentage of 15mm Vt + interception	185%	177%	185%	266%	165%	187%
Percentage of 1-year requirement	78%	79%	82%	125%	69%	91%
Percentage of 30-year requirement	46%	46%	47%	88%	39%	47%
Percentage of 100-year requirement	29%	28%	29%	46%	26%	32%

Other studies based on both physical, e.g. Stovin (2010), and computer models, e.g. Beckers and Degré (2008) and Palla *et al*. (2008), have concluded that peak runoff volumes and rates can be significantly reduced and lag time increased by widespread green roof implementation. Therefore, green roofs can achieve dual objectives relating to water quantity management (Newton *et al*. 2007:54):

- Reduce the total volume of runoff by interception, storage and evaporation of rainfall
- Reduce peak flow rates so that runoff is delivered less rapidly to drainage systems and watercourses.

However, quoted runoff attenuation rates vary quite widely, as shown in Table C5.17. UK figures were at the lower end of estimates, accounting for the relatively cautious approach taken in the pilot study.

Table C5.17 Quoted runoff attenuation rates from published studies of extensive green roofs, in ascending percentage sequence. Rainfall attenuation is the percentage of rainfall retained by the roof. Substrate Depth represents the depth of growing medium and other layers designed to retain rainwater. Rainfall is the volume of precipitation applicable to the study cited. 'UK' indicates whether data originated from research performed in the UK.

Rainfall Attenuation	**Substrate Depth (mm)**	**Rainfall**	**UK**	**Source**
20% (25-35 l m^{-2})	130-165	undefined	Y	English Nature (2003:23)
21-53%	25-100	5-year rainfall in New York City		Montalto *et al*. (2007:122)
38-50% (100-150 mm)	200-400	undefined		Peck & Kuhn (*c*.2001:9)
40% (6 l m^{-2})	50	15 l m^{-2}	Y	Bamfield (2005:6)
40%	20-40	annual rainfall = 650-800 mm		FLL (2002:36-37)
40%	50	50 mm event		Scholz-Barth (2001)
40-45%	undefined	undefined	Y	Newton *et al*. (2007:159) summary of UK research
41.5%	62	June – October = 463 mm		Vander Linden (2008:36-54)
Median 45%	median = 100	annual rainfall = 554–1347 mm		Mentens *et al*. (2006:221) - review of 121 extensive green roofs

Rainfall Attenuation	**Substrate Depth (mm)**	**Rainfall**	**UK**	**Source**
45-60%	Summary of USA studies	Summary of USA studies		Hirschman *et al*. (2008:10)
48-69%	100-350	various		Newton *et al*. (2007:159) summary of non-UK research
50%	60-100	annual rainfall = 650-800mm		FLL (2002:36-37)
58%	75	50mm event		Scholz-Barth (2001)
50-63%	75-100	various		Newton *et al*. (2007:159) summary of non-UK research
60%	55	556mm in 83 rain events		VanWoert *et al*. (2005:1040)
62%	50-100	annual rainfall = 1200mm		Moran *et al*. (2004:6)
54-76%	140	annual rainfall = 443-664mm		Banting *et al*. (2005:21)
61-77%	50-150	annual rainfall = 686-696mm		Uhl & Schiedt (2008:5)

Additional benefits of green roofs may include (Banting *et al*. 2005:7-26; Bates *et al*. 2006:11-12; Carter & Keeler 2008:355; English Nature 2003:19-24; FLL 2002:15-16; Johnston & Newton 2004:11-12,46-49; Livingroofs.org & Ecology Consultancy 2004:11; Newton *et al*. 2007; Oberlander *et al*. 2002:2-4; Peck & Kuhn *c*.2001:8-10,17):

Specific benefits:

- Building thermal insulation *
- Protection of roofing material from weathering *
- External noise attenuation
- Promotion of environmental credentials

General benefits:

- Mitigation of the urban heat island effect *
- Air pollution filtering *
- Increased carbon dioxide uptake
- Rainfall interception and reduced load on the drainage system *
- Habitat creation without additional land-take
- Biodiversity promotion
- Aesthetic benefits

Those marked with an asterisk have been quantified in scientific investigations (see Bates *et al*. 2006:12; Carter & Keeler 2008:355).

Barriers to green roofs have been identified as (Livingroofs.org & Ecology Consultancy 2004:28-30; Oberlander *et al*. 2002:5):

- Load bearing capacity of building to take weight of saturated substrate
- Cost
- Difficulties of roof repair
- Additional maintenance requirements
- Lack of familiarity with and guidance related to green roofs
- Lack of clarity on installation and lifetime warranties
- Safety and access issues
- Aesthetic appeal.

Of these, the building structural capacity is the only technical limitation, while cost requires a corresponding assessment of potential savings. Other barriers can be addressed with planning, education and appropriate design. The saturated weight of an extensive green roof (60-150 kg m-2) was calculated to be equivalent to the weight of a gravel surface (90-150 kg m^{-2}) (Livingroofs.org & Ecology Consultancy 2004:28). The sedum roof for the Recycling Centre in the John Laing sub-catchment was specified at 53.4 kg m^{-2} for a 36mm depth.

Carter & Jackson (2007), VanWoert *et al*. (2005:1040), and Villarreal & Bengtsson (2005:6) determined that green roofs were effective at reducing runoff from small storm events, but less so for larger events, in a similar way to the results shown in Table C5.16. Carter & Jackson's study found that runoff from small precipitation events (12.7 mm) declined by 32-45%, but for larger events (79.2 mm) percentage reductions were 7-11%, and continued to decrease as storm volume increased. They considered the boundary where green roofs became relatively ineffective to be a 2-year, 24 hour event, equivalent to a 35 mm rainfall event in Coventry. The area studied by Carter & Jackson had impermeability ratios of 58-77% where roofs comprised approximately 15-23% of the impervious surfaces, a slightly lower level of impermeability and roof area compared to the current study site.

In a review of 18 publications analysing water retention on green roofs in Germany, substrate depth was the key factor influencing rainfall retention (Mentens *et al*. 2006:221), while roof age, slope angle and length were not significant. In contrast, both Getter *et al*. (2007) and VanWoert *et al*. (2005:1043) found that runoff rates increased with greater roof slope. In the review of German sites, rainfall retention was higher in summer, attributed to increased evapotranspiration rates, a result confirmed by Uhl & Schiedt (2008:4). For substrate depths <50mm, rainfall retention over the 5-month summer period was 62%, compared to 4% for conventional roofs. Villarreal & Bengtsson (2005:5) also determined that antecedent conditions were an important factor.

In addition to rainfall retention, runoff from green roofs is generally delayed in comparison with conventional roofs, as water takes time to infiltrate into a substrate before its release (Newton *et al*. 2007:54; Scholz-Barth 2001; Teemusk & Mander 2007:273). The ecological value of extensive green roofs with a thinner growing medium is more limited than intensive green roofs (Woods Ballard et al. 2007:6.6).

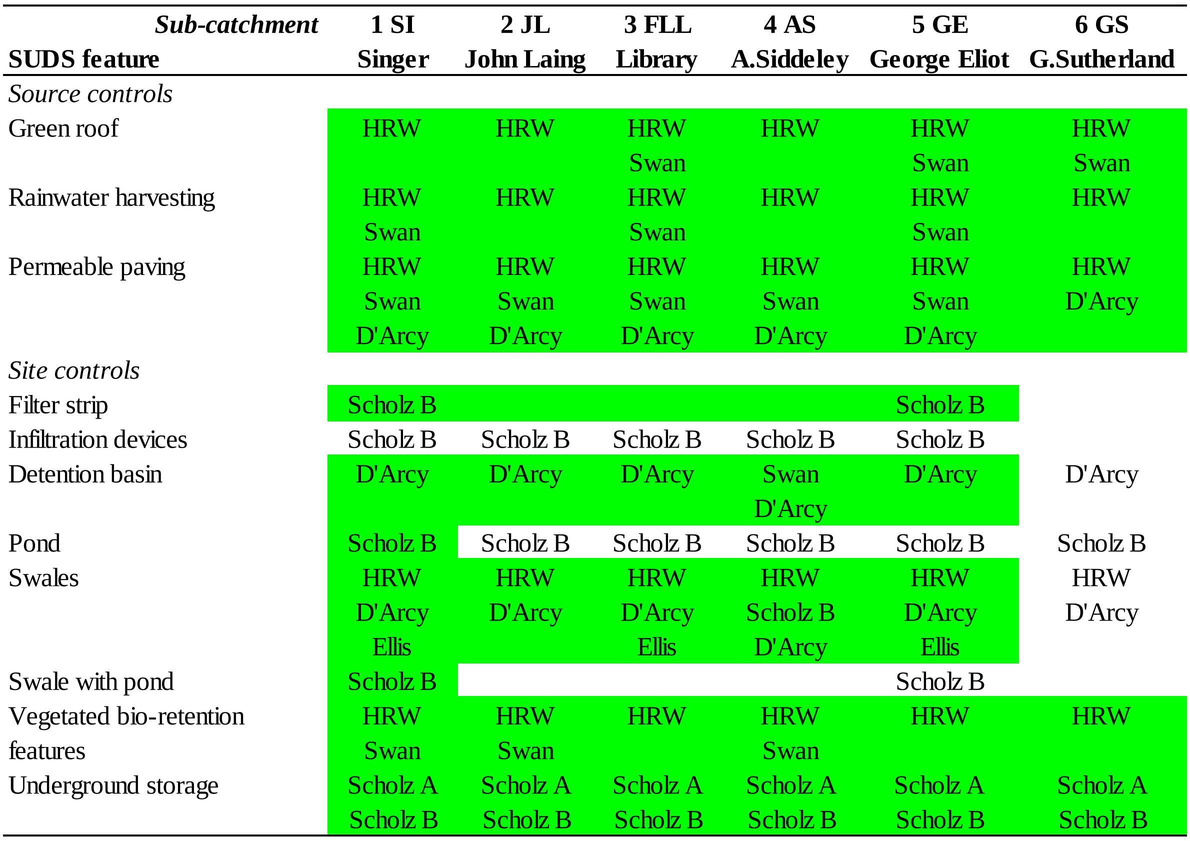
UK runoff attenuation rates (Table C5.17) tended to be at the lower end of estimates. It was unclear whether this was due to natural conservatism on the part of the estimators, whether different substrate types or plants were used, or whether climatic variations accounted for differences. The derivation of the lowest percentage attenuation rates (English Nature

2003) was unclear in their report. Detail was also lacking concerning the Newton *et al.* (2007) research. In order to align with conservative UK estimates, 30% attenuation was applied to the campus sub-catchments.

C.5.6.3. Potential locations for SUDS implementation in new developments

Table C5.18 shows the devices that would be proposed for new developments in each sub-catchment by the SUDS decision support tools. The proposals from Table C5.11 were compared with devices that were judged feasible if a new development were constructed. Most of the listed techniques were appropriate and could have been suggested by the assessment methodologies. Some methodologies suggested techniques that were not appropriate. Table C5.19 summarises the number of times each methodology identified appropriate SUDS, evaluating each sub-catchment separately. The HR Wallingford (2008) method was the only one to achieve a hit rate of practical suggestions exceeding 50%. Methods with a lower hit rate seemed to evaluate a limited range of factors.

Table C5.18 Proposals by existing methodologies for SUDS in new developments, by sub-catchment. Techniques in colour were considered feasible, those in white were not. The methodologies suggesting each SUDS option are given. Key to methodologies: D'Arcy = D'Arcy & Wild (2003); Ellis = Ellis et al. (2004b); HRW = HR Wallingford (2008); Scholz A = Scholz (2006) decision-support key; Scholz B = Scholz (2006) decision-making matrix; Swan = Swan/Stovin hierarchical framework (SNIFFER 2006). The generic recommendations for source and site controls by Swan were excluded from this table



Sub-catchment	**1 SI**	**2 JL**	**3 FLL**	**4 AS**	**5 GE**	**6 GS**
SUDS feature	**Singer**	**John Laing**	**Library**	**A.Siddeley**	**George Eliot**	**G.Sutherland**
Source controls						
Green roof	HRW	HRW	HRW Swan	HRW	HRW Swan	HRW Swan
Rainwater harvesting	HRW Swan	HRW	HRW Swan	HRW	HRW Swan	HRW
Permeable paving	HRW Swan D'Arcy	HRW Swan D'Arcy	HRW Swan D'Arcy	HRW Swan D'Arcy	HRW Swan D'Arcy	HRW D'Arcy
Site controls						
Filter strip	Scholz B				Scholz B	
Infiltration devices	Scholz B	Scholz B	Scholz B	Scholz B	Scholz B	
Detention basin	D'Arcy	D'Arcy	D'Arcy	Swan D'Arcy	D'Arcy	D'Arcy
Pond	Scholz B	Scholz B	Scholz B	Scholz B	Scholz B	Scholz B
Swales	HRW D'Arcy Ellis	HRW D'Arcy	HRW D'Arcy Ellis	HRW Scholz B D'Arcy	HRW D'Arcy Ellis	HRW D'Arcy
Swale with pond	Scholz B				Scholz B	
Vegetated bio-retention features	HRW Swan	HRW Swan	HRW	HRW Swan	HRW	HRW
Underground storage	Scholz A Scholz B	Scholz A Scholz B	Scholz A Scholz B	Scholz A Scholz B	Scholz A Scholz B	Scholz A Scholz B

Table C5.19 Efficacy of existing methodologies for new build SUDS proposals. For key to methodologies, see Table C5.18

Methodology	**Source Control**	**Site Control**	**All SUDS**
D'Arcy	33%	28%	30%
Ellis	0%	10%	6%
HRW	100%	34%	60%
Scholz A	0%	21%	13%
Scholz B	0%	3%	2%
Swan	61%	14%	32%

C.5.6.4. Relevance of Barriers to SUDS Implementation

Table C5.20 summarises the principal barriers to SUDS, and comments on the extent to which each barrier applies to the University, and can be addressed. Features that integrate into the existing landscape, such as bio-retention areas and permeable paving, are more likely to be perceived as acceptable.

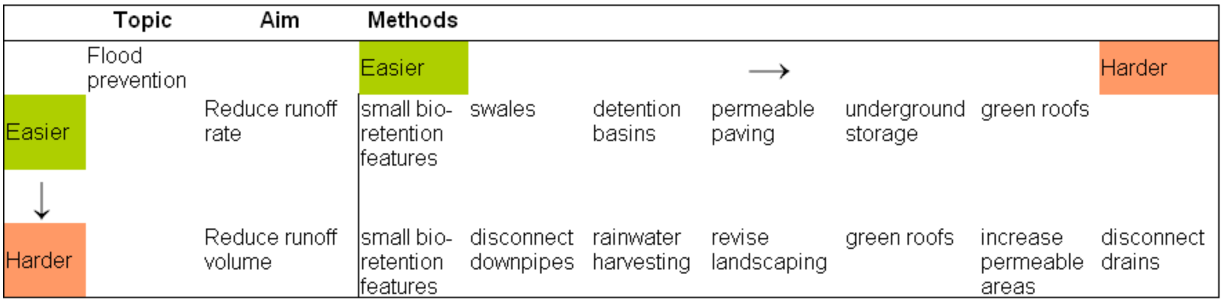
In their study of the implementation of green buildings at a higher education establishment, Richardson and Lynes (2007) found that key drivers for uptake of more sustainable buildings were internal leadership by senior management, financial vision taking whole life costs into account, sustainability targets, and effective communication between stakeholders, rather than a focus solely on technical factors.

Table C5.20 Barriers to retrofit SUDS and their applicability to Coventry University

Barrier	Applicable to University?	Comment
Legal and regulatory	To some extent	Main impact on local authorities and water companies
Institutional	No	University able to make decisions about own landholdings
Economic	Yes	Financial justification for retrofit not straightforward. Justification for new build and refurbishment comparable with conventional options Maintenance and future liabilities comparable with conventional options
Urban planning	To some extent	Lack of awareness and experience of SUDS may necessitate discussion and demonstration to address local planning concerns
Information	Yes	Lack of information concerning the university drainage system, and the scale of events causing overland and sewer flooding, lead to problems in identifying the extent to which SUDS could mitigate future flooding
Social and educational	Yes	Lack of knowledge of and familiarity with SUDS among staff, students and decision makers, with respect to aesthetic and safety concerns, such as open water features on campus
Technical feasibility	Yes	Land take for vegetated SUDS, campus layout, fragmented locations of existing vegetated areas, poor soil infiltration, roof construction and condition

C.5.6.5. Summary of pilot site investigation

Based on the limited set of flood events available, surface water flooding and overland flow generate greater risk than fluvial flooding to Coventry University’s city centre campus. In urban areas of high impermeability such as Coventry University’s inner-city campus, where soil conditions are largely unsuitable for infiltration, a range of techniques exists to reduce runoff and surface water flood risk (Fig. C5.31). Some techniques are easier to implement and more cost-effective than others, and a reduction in runoff rate was easier to achieve than reduction in runoff volume. Temporary detention of rainwater was achievable, but permanent infiltration of rainwater was not. Flood prevention measures might provide financial justification for SUDS retrofit, although economic analysis of the SUDS installation in the pilot study would be the subject of a separate study.



	Topic	Aim	Methods						
	Flood prevention		Easier			→			Harder
Easier		Reduce runoff rate	small bio-retention features	swales	detention basins	permeable paving	underground storage	green roofs	
↓									
Harder		Reduce runoff volume	small bio-retention features	disconnect downpipes	rainwater harvesting	revise landscaping	green roofs	increase permeable areas	disconnect drains

Fig. C5.31 A quick reference chart of flood prevention SUDS techniques relevant to Coventry University’s urban campus with high impermeability and poor infiltration. Based on the current legislative framework and charging mechanisms

Changes to current grounds management approaches could reduce flood risk:

- Bio-retention features: allow water into flowerbeds rather than excluding it
- Change landscaping: avoid the 'grassy knoll' approach, and direct runoff from paving onto grass, not vice versa
- Make greater use of rainwater harvesting: possible locations are Charles Ward and the Student Centre
- Utilise permeable paving and green roofs.

Based on the limited set of flood events available, surface water flooding and overland flow generate greater risk than fluvial flooding to Coventry University’s city centre campus. In urban areas of high impermeability such as Coventry University’s inner-city campus, where soil conditions are largely unsuitable for infiltration, a range of techniques

exists to reduce runoff and surface water flood risk. Some techniques are easier to implement and more cost-effective than others, and a reduction in runoff rate was easier to achieve than reduction in runoff volume. Temporary detention of rainwater was achievable, but permanent infiltration of rainwater was not. Retrofit of SUDS on Coventry University inner-city campus was shown to be technically feasible, and could contribute to reduced flood risk on and off campus, and improve local river water quality. Flood prevention measures might provide financial justification for SUDS retrofit, although economic analysis of the SUDS installation in the pilot study would be the subject of a separate study if retrofit SUDS measures are to be implemented at Coventry University.

D Appendix D – Data Collection Results

This chapter describes the results of the data collection of the features of Coventry's local planning authority area, using the methodology defined in section 3.7.

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Figures

Tables

D.1 Land cover

D.1.1 Ordnance Survey MasterMap

The results of the classification of OSMM polygons to derive a summary land cover class for each polygon are given in Table D.1. A land cover value was allocated to each of the 479,571 polygons. The total area of polygons inside the city boundary was 98,648,653.68 m^2. In comparison, the area of the boundary itself was 98,648,064.15 m^2. The small discrepancy (0.0006%) was considered acceptable. The resulting overall land cover pattern for the city is presented in Fig. D.1. Dense building development is apparent in certain areas from a preponderance of brown shading, for example in the centre of the city. The absence of gardens or greenspace in these locations suggests commercial or industrial development rather than housing. Areas where gardens (dark green) are prominent indicate housing, and these occur in a suburban belt surrounding the central areas, extending in the south and north to the city boundary. Greenspace (light green) covers large areas of the city outskirts, notably to the northwest. Road / rail and paved areas (grey) are visible primarily as the principal road corridors and paved areas associated with industrial sites, but do not appear to constitute a significant proportion of land cover due to the prominence of other features. Few areas of surface water (blue) are visible. A number of larger ponds or small lakes, and the line of the canal can be seen, but the three principal watercourses do not emerge clearly. Unclassified areas (yellow) represent former industrial sites that were awaiting or undergoing redevelopment. The largest sites are visible to the west of the city.

Figs. D.2 to D.7 show the land cover for each of the six classes separately. Buildings (Fig. D.2) were distributed throughout most of the city, with only the north-west quadrant containing fewer buildings, and commercial and industrial areas more apparent from the larger polygons. Gardens (Fig. D.3) occurred mainly in suburban environments; also revealing outlines of the local road network. The main areas of greenspace (Fig. D.4) were located around the outskirts of the city, with only small pockets of greenspace in central and suburban areas.

Although the density of the road network was not clear from Fig. D.1, on Fig. D.5 the distribution of road, rail and paving extended over much of the city, with only the north-west quadrant exhibiting a lower density. Unclassified sites (Fig. D.6) were spread across the city, with the two largest areas, Browns Lane and Banner Lane, to the west. The limited amount of surface water on Fig. D.1 was confirmed by Fig. D.7. The most obvious features were the small lakes and the Coventry canal. The courses of the R. Sowe, R. Sherbourne and Canley Brook did not stand out as well as the canal because the stretches running underground were not included.

Fig. D.8 shows the relative proportions of land cover classes in Coventry as a result of analysing the OSMM polygons. Table D.2 summarises descriptive statistics for the area enclosed by the OSMM land cover polygons. There was notable variation in all six categories. Buildings and gardens contained many more polygons, and the measures of spread were lower for these two classes.

Table D.1 Land cover in Coventry based on characteristics in OSMM, and their combination into classes used in this study

OSMM						**This study**
Theme	**Make**	**Description Group**	**Descriptive Term**	**Count of polygons**	**Area of polygons (m^2)**	**Class**
Buildings				220,159	12,028,024.05	Buildings
Buildings; Roads Tracks And Paths				1	4.92	Buildings
Land	Natural		Marsh Reeds Or Saltmarsh	27	58,391.31	Water
Land	Natural		Marsh Reeds Or Saltmarsh; Scrub	1	883.82	Water
Land	Natural			18,605	40,882,100.91	Greenspace
Land	Manmade	General Surface		13,906	7,882,286.42	Road&Rail
Land	Multiple			196,253	22,309,444.25	Gardens
Land	Unknown			125	78,986.03	Unclassified
Land	Unclassified			89	931,448.92	Unclassified
Land; Rail				1	201.37	Greenspace
Land; Roads Tracks And Paths		General Feature; Road Or Track		8	2,174.86	Road&Rail

OSMM						This study
Theme	**Make**	**Description Group**	**Descriptive Term**	**Count of polygons**	**Area of polygons (m^2)**	**Class**
Land; Roads Tracks And Paths		General Surface; Road Or Track		2	944.89	Road&Rail
Land; Roads Tracks And Paths		Natural Environment; Road Or Track		20	54,919.40	Greenspace
Land; Water				5	3,459.89	Water
Rail	Manmade			77	307,557.42	Road&Rail
Rail	Natural			164	411,995.67	Greenspace
Roads Tracks And Paths	Manmade			23,404	11,057,247.14	Road&Rail
Roads Tracks And Paths	Natural			3,260	1,489,528.15	Greenspace
Roads Tracks And Paths	Unknown			2,229	575,120.70	Greenspace
Roads Tracks And Paths; Structures				6	158.20	Road&Rail
Structures			Upper Level of Communication	3	1,784.58	Road&Rail
Structures			[empty]	329	13,604.04	Road&Rail

OSMM						This study
Theme	**Make**	**Description Group**	**Descriptive Term**	**Count of polygons**	**Area of polygons (m^2)**	**Class**
Structures; Water				1	8.87	Water
Water				896	558,377.77	Water
TOTAL				479,571	98,648,653.68	

Fig. D.1 Land cover distribution in Coventry. Data source: OSMM (Edina 2009)

Fig. D.2 Building distribution in Coventry. Data source: OSMM (Edina 2009)

Fig. D.3 Garden distribution in Coventry. Data source: OSMM (Edina 2009)

Fig. D.4 Greenspace distribution in Coventry. Data source: OSMM (Edina 2009)

Fig. D.5 Road, rail and paving distribution in Coventry. Data source: OSMM (Edina 2009)

Fig. D.6 Unclassified site distribution in Coventry. Data source: OSMM (Edina 2009)

Fig. D.7 Surface water distribution in Coventry. Data source: OSMM (Edina 2009)

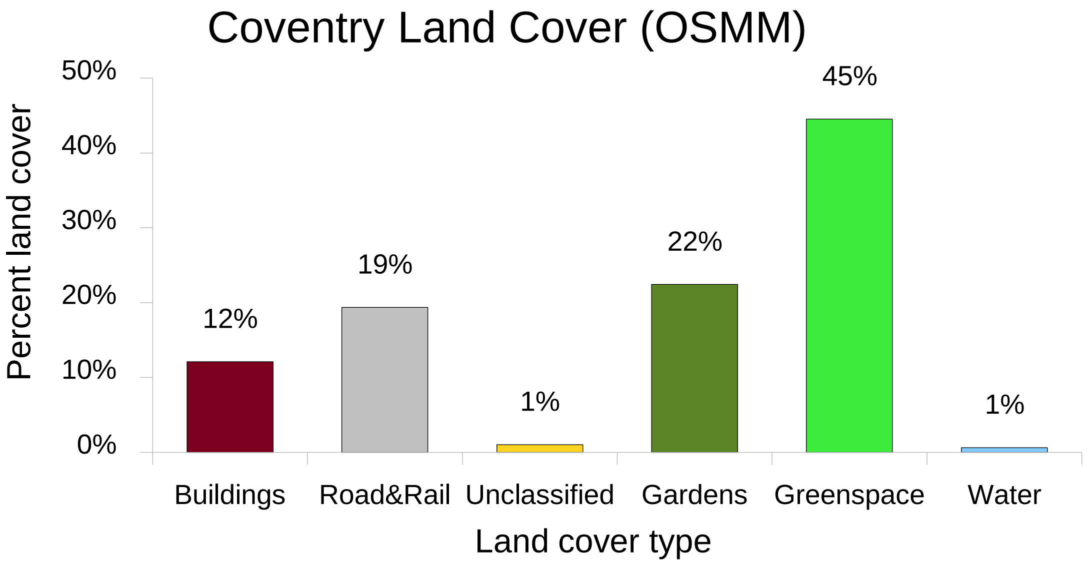

Fig. D.8 Summary of land cover in Coventry based on the OSMM classification

Table D.2 Descriptive statistics for OSMM land cover categories.

Area Statistics	**Buildings**	**Gardens**	**Greenspace**	**Road&Rail**	**Water**	**Unclassified**
Mean (m^2)	54.633	113.677	1,788.124	510.554	667.873	4,721.659
Standard deviation (m^2)	384.060	197.111	8,473.505	1,427.209	1,869.189	22,857.392
Sum (m^2)	12,028,028.975	22,309,444.252	43,413,866.206	19,265,757.543	621,121.758	1,010,434.947
Minimum (m^2)	0.022	0.002	0.002	0.006	0.131	0.562
Maximum (m^2)	61,911.656	13,604.197	306,518.978	79,772.082	31,244.613	252,867.563
n	220,160	196,253	24,279	37,735	930	214
CV	7.03	1.73	4.74	2.80	2.80	4.84
Number of unique values	211,128	195,261	24,264	37,720	929	214
Range (m^2)	61,911.635	13,604.195	306,518.976	79,772.076	31,244.482	252,867.001
Median (m^2)	37.924	66.160	136.131	158.910	202.289	577.811
Mean ÷ Median	1.44	1.72	13.14	3.21	3.30	8.17
Standard error	0.819	0.445	54.381	7.347	61.293	1562.499

D.1.2 Garden land cover

The 'gardens' land cover category contained a mixture of surface cover types that could not be further determined using OSMM classification. Given the sizeable proportion of gardens in the city, a more detailed analysis of gardens was undertaken using aerial photography captured in summer 2007 (GeoPerspectives 2009). Mean and median garden sizes were smallest for terraced houses, and largest for detached houses (Table D.3). However, the standard deviation and inter-quartile range were relatively large, resulting from an overlap between garden sizes of the three house types. The 95% confidence intervals of terraced and semi-detached houses did not overlap, but the 95% confidence interval for detached houses overlapped with both other categories. The garden areas dataset did not meet the assumptions for parametric tests. Garden areas did not exhibit a normal distribution (Kolmogorov-Smirnov test, $p = 0.001$), and population variances among the three house types were unequal (Levene statistic, $p = 0.000$). In practice, the data for terraced houses were normally distributed, but the semi-detached and detached house samples were not, probably a function of the sample size. A median test (Table D.3) showed a significant difference between garden areas across house types ($\chi 2 = 28.741$, $df = 2$, $p = 0.000$), although two cells (33%) had expected frequencies less than five, exceeding the assumption of the test that no more than 20% of cells have expected frequencies under five. Given the significance of the result, however, this is less likely to invalidate the test. The relative error of the garden sample was quite high at 31% (23% excluding one outlier), and the implications of this are considered further in section 6.2.2.4.

Gardens constituted the major component of each plot (Fig. D.9). The three types of housing were associated with different garden sizes, grading from detached as the largest to terraced as the smallest. Error bars show large variability within the detached garden class, but semi-detached and terraced gardens exhibit much lower variability. The final column equates to the mean garden across all house types. Gardens formed roughly the same percentage of detached and semi-detached house plots: detached 83.6%, semi-detached 83.5%, terraced 66.9%, mean 78.7%.

Table D.3 Descriptive Statistics of garden areas for 3 house types, from the garden image dataset (GeoPerspectives 2009)

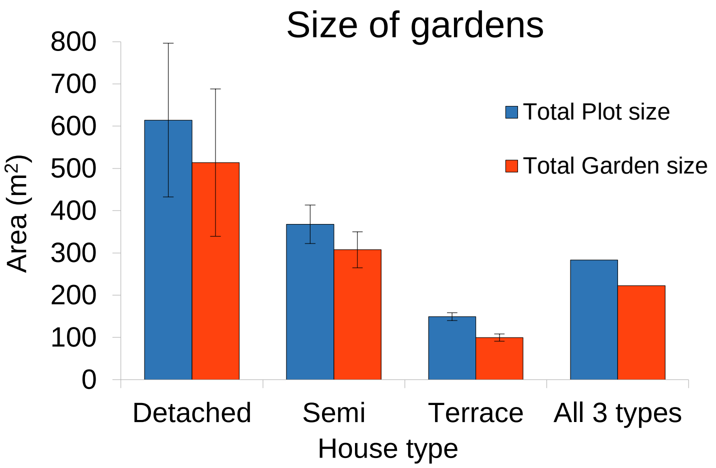

Fig. D.9 Mean size of gardens analysed to determine impermeability (n=59). Areas calculated from OSMM. Gardens constituted the major component of each plot. Error bars show standard error. 'All 3 types' represent the mean garden

Gardens were not completely permeable, but also contained the impermeable land cover types buildings and paving (Fig. D.10). None of the analysed gardens contained water as an identifiable land cover. Following the same pattern observed in garden size (Fig. D.9), detached gardens contained the largest permeable area, followed by semi-detached, with terraced gardens having the smallest permeable area. In percentage terms however, a different pattern emerged. Detached house owners had covered a greater proportion of gardens with impermeable surfaces (36.7%), terraced gardens were less impermeable (31.2%), and semi-detached gardens the least impermeable (26.9%). Error bars show a large variability in permeable area within the semi-detached and detached garden class, but terraced gardens exhibit lower variability. The final column equates to the mean garden across all house types. The mean garden space was 31.4% impermeable.

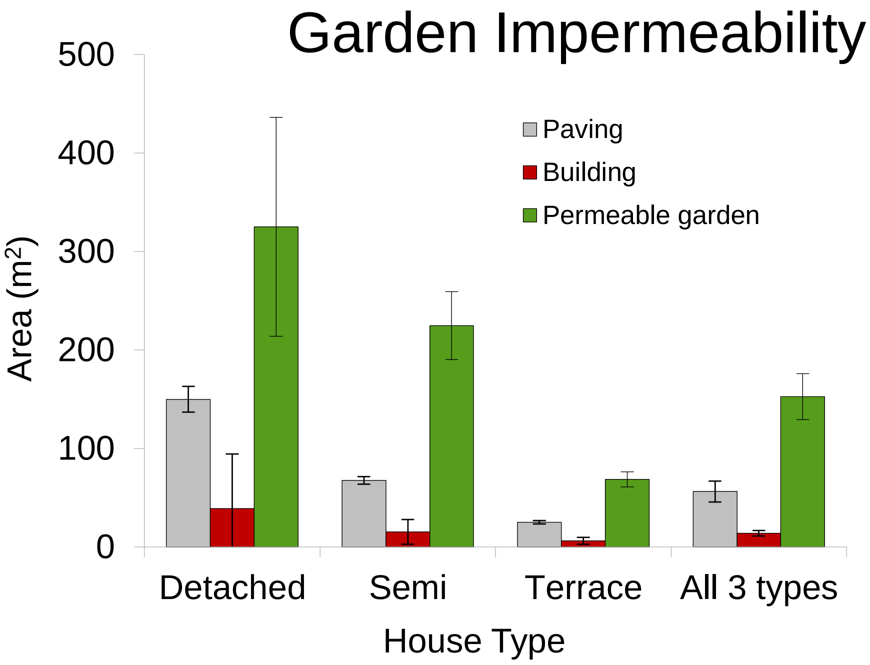

Fig. D.10 Garden impermeability, showing land cover within the different house types (n=59). Error bars indicate standard error. 'All 3 types' represents the mean garden adjusted for relative sizes of garden

Front gardens constituted 26.4% of the garden land cover in Coventry, approximately three times smaller than rear gardens. Front gardens covered 5.9 km^2 (6.0%) of the city. The impermeable area of front gardens for both detached (59.1%) and semi-detached (63.3%) houses was larger than the permeable area (Fig. D.11). In contrast, impermeability of terraced house front gardens was slightly lower at 43.4%. Error bars show a large variability of permeable area within all house types (CV = detached 49%, semi-detached 51%, terrace 63%). The final column equates to the mean garden across all house types. The mean front garden was 56.8% impermeable. On this basis, the impermeable area of front gardens accounted for 3.35 km^2 (3.4%) of the total land area of the city.

The mean terraced front garden was approximately one third the size of semi-detached front gardens, and detached front gardens over three times larger than semi-detached front gardens. The ratio of mean front garden sizes (detached:semi-detached:terraced) was 0.65:0.25:0.9. The scale of differences was similar when considering the permeable area of front gardens, the ratios being 0.65:0.22:0.13.

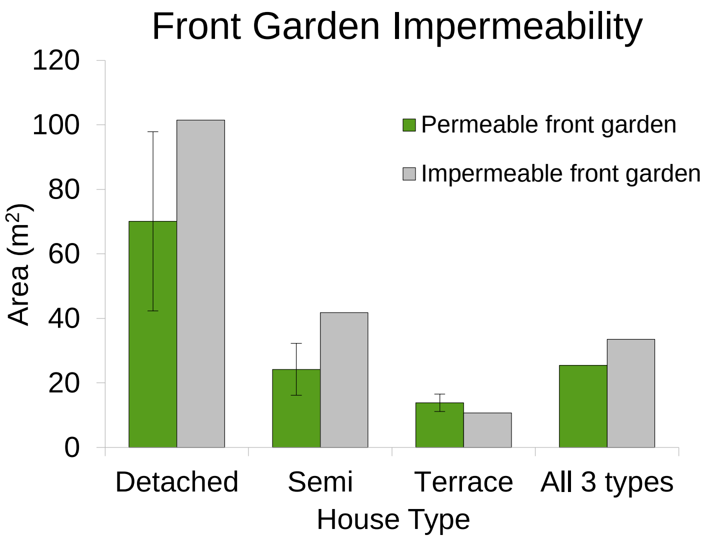

Fig. D.11 Front garden impermeability, showing land cover within the different house types (n=59). Error bars indicate standard error. 'All 3 types' represents the mean garden adjusted for relative sizes of garden

The extent of impermeability was more pronounced in semi-detached front gardens, with 47% over three quarters impermeable (Fig. D.12). In contrast, 33% of detached and 18% of terraced front gardens in the sample were over 75% impermeable. Across all types of front garden sampled, 29% were more than three-quarters impermeable.

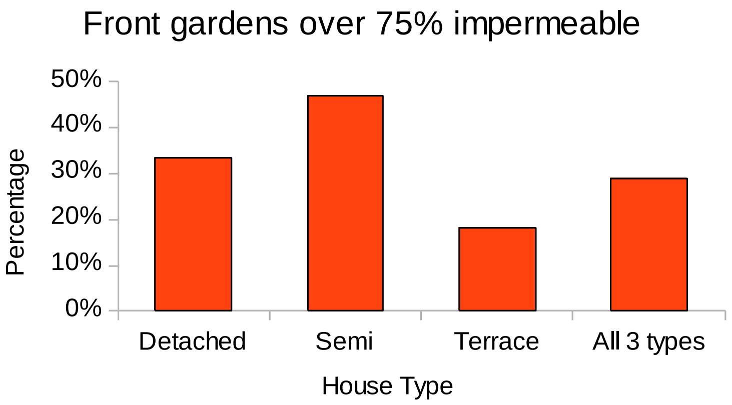

Fig. D.12 Front gardens over 75% impermeable

The mean front garden size in Coventry was 58.9 m^2, compared to 56 m^2 in London (Smith *et al*. 2011:10); a mean of 57 m^2 was used for Fig. D.13, which shows the 44,810 gardens between 12 and 57 m^2, within 5 m of a road carriageway. These were considered more likely to be front gardens which have been paved over and with limited scope to address impermeability issues on site without installing a permeable surface.

Fig. D.13 Locations of small gardens

Rear gardens formed 73.6% of the garden land cover in Coventry, equivalent to 16.41 km^2 (16.6%) of the city. Impermeability was less marked in rear gardens than front gardens (Fig. D.14) with all house types having greater permeable than impermeable land cover. Mean rear garden area of detached houses (342 m^2) was almost 50% greater than that of semi-detached houses (241 m^2). Rear garden area in terraced houses was significantly smaller (75 m^2). Roughly a quarter of rear garden area was impermeable for detached (25.5%) and terraced (27.2%) houses, with semi-detached houses lower at 17.0%. There was less variability in permeability of terraced house rear gardens than for the other house types (CV = detached 75%, semi-detached 60%, terrace 48%). The mean rear garden across all house types was 22.3% impermeable. On this basis, the impermeable area of rear gardens accounted for 3.66 km^2 (3.7%) of the total land area of the city.

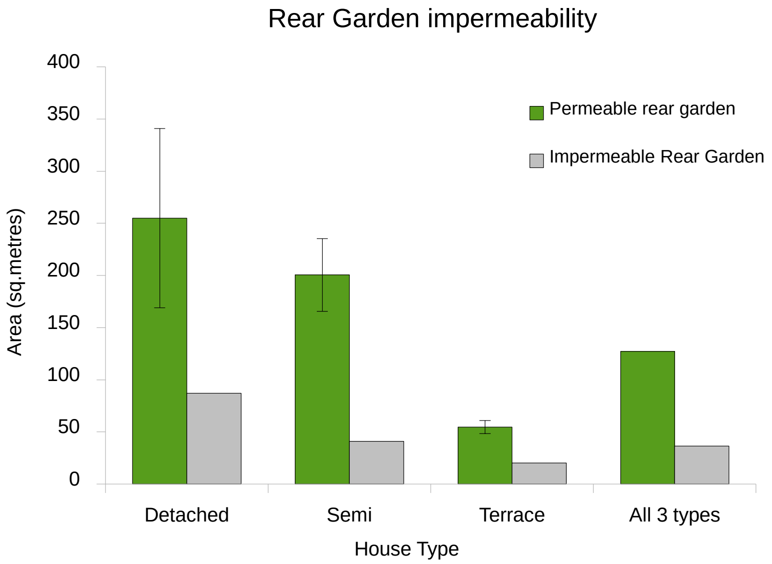

Fig. D.14 Rear garden impermeability, showing land cover within the different house types (n=59). Error bars indicate standard error. 'All 3 types' represents the mean garden adjusted for relative sizes of garden.

D.1.3 House Types

To determine more precisely the relative proportions of each house type in Coventry, household data were retrieved relating to the 2001 census (ESRC Census Programme 2010), the latest data available. Of the 126,820 households in Coventry at that time, terraced houses (47.2%) formed the largest percentage (Fig. D.15). Semi-detached houses accounted for 26.8%, households in blocks of flats 13.5%, detached houses 9.5%, and other types 3.0%. Other types of household (3.0%) included flats within commercial property, converted houses and mobile homes, and because it was not possible to identify these properties individually, and given their relatively small proportion, they were excluded from further analysis. Overall, terraced, semi-detached and detached houses formed 83.7% of the total number of dwellings in the city.

Land classified as 'garden' was associated with houses. Vegetated land surrounding blocks of flats was almost exclusively classified as greenspace rather than gardens, with only three exceptions observed.

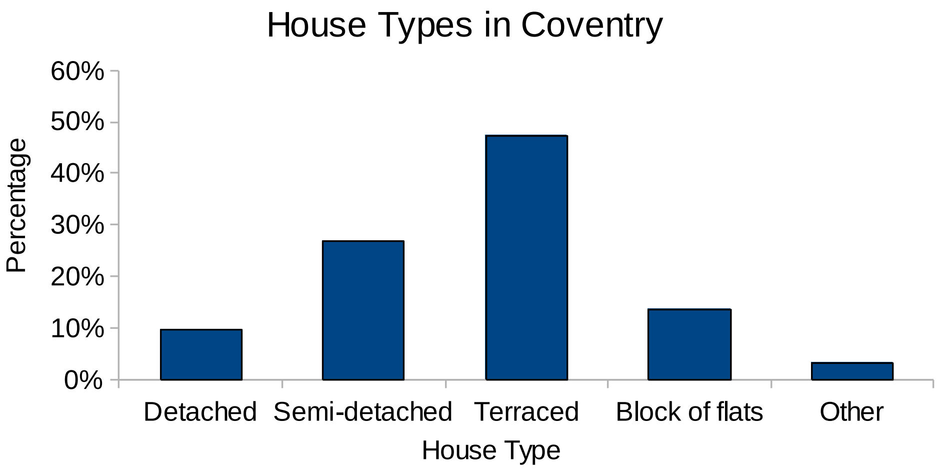

Fig. D.15 House Types in Coventry, as a percentage of all households. Data source: 2001 Census; Key Statistics Table 16 (Census output is Crown copyright and is reproduced with the permission of the Controller of HMSO and the Queen's Printer for Scotland)

Terraced houses formed 56.6% of the total number of houses in Coventry that were associated with gardens (Fig. D.16). Semi-detached houses constituted 32.1% and detached houses 11.3%. Terraced houses were the principal type of housing in 14 of the 18 wards in the city (Fig. D.17). In the remaining four wards, semi-detached housing was the dominant type. In seven of the 18 wards, terraced houses represented over 70% of housing.

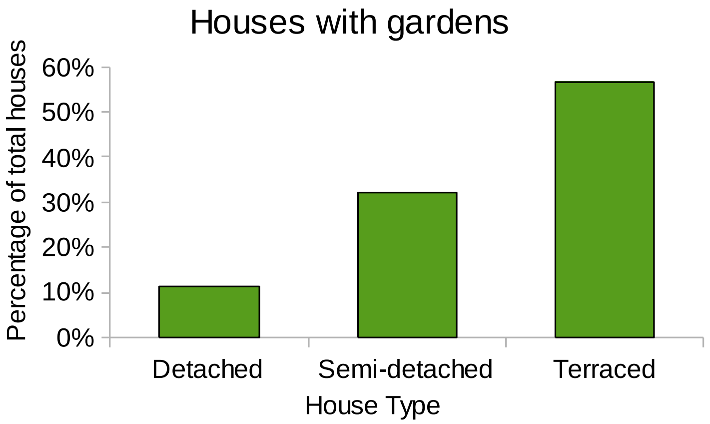

Fig. D.16 Houses with gardens in Coventry, as a percentage of total terraced, semi-detached and detached houses. Data source: 2001 Census; Key Statistics Table 16

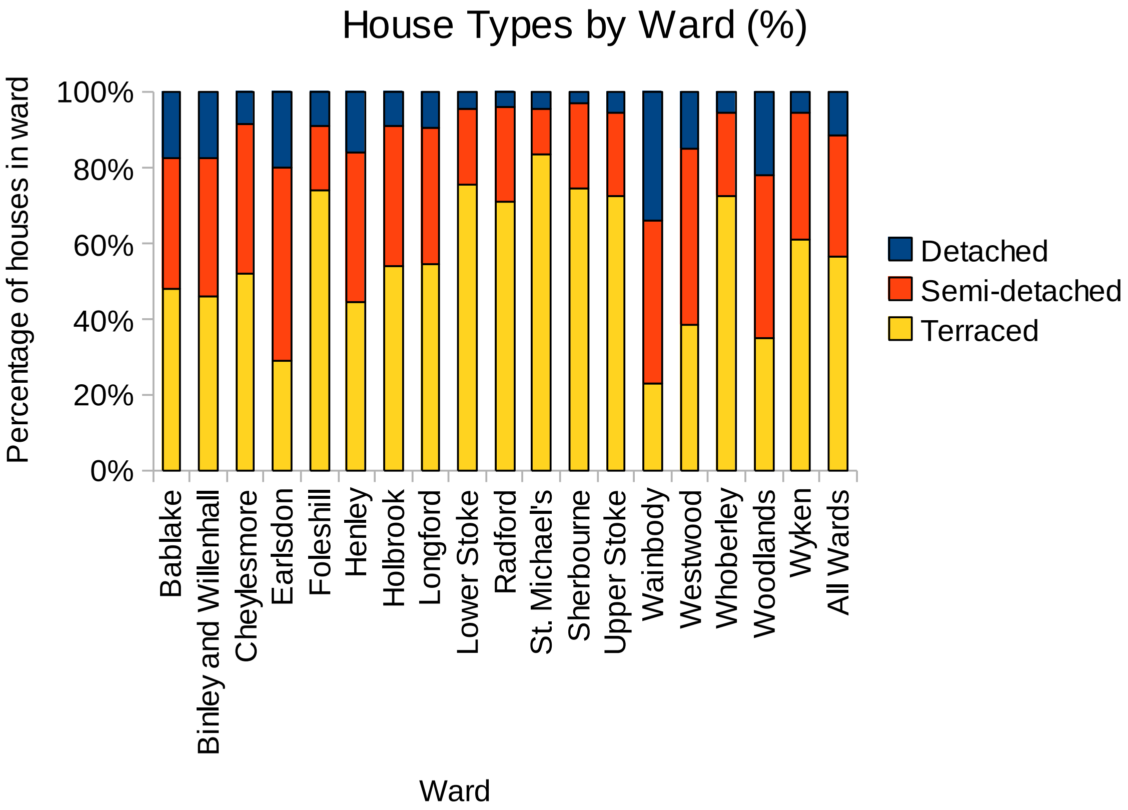

Fig. D.17 House type configuration by ward in Coventry. Percentages represent the proportions of each house type within each ward. Data source: 2001 Census; Standard Table 48

Although there were more terraced houses than other types, terraced houses had the smallest gardens. Applying the number of houses of each type to the mean garden size for each house type indicates the relative proportions of garden in the city (Fig. D.18). Semi-detached houses made the largest contribution to the garden area of Coventry.

The occurrence frequency of the different house types in the sample of gardens was similar to their occurrence in the total house population from the 2001 census (ESRC Census Programme 2010) (Fig. D.19).

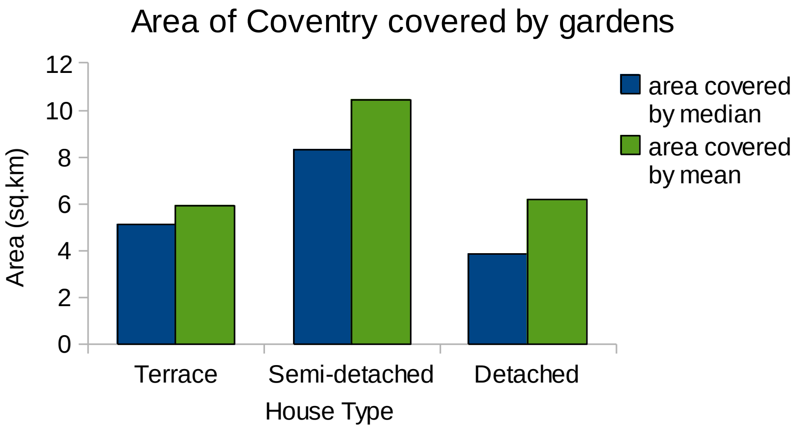

Fig. D.18 Contribution to total garden area of different house types. 'Area covered by median' uses the median garden areas from Table D.3, while 'Area covered by mean' uses the mean garden areas. The median total represented only 78% of the garden area of Coventry. The mean total represented 101%. In both cases semi-detached houses constituted the largest component of garden land cover.

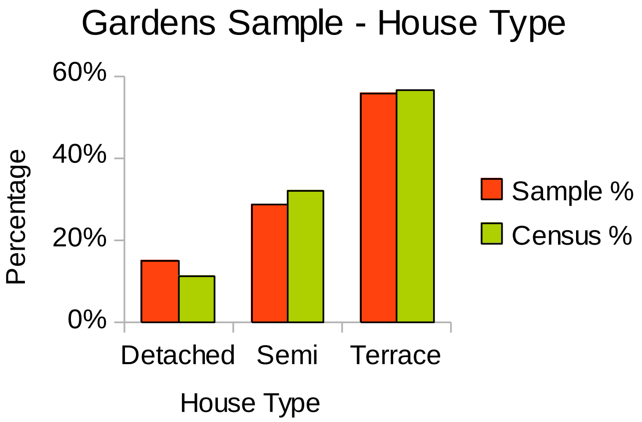

Fig. D.19 Comparison of house types in garden sample with their occurrence in the total population of house types from the 2001 census

D.1.4 Land cover adjusted by garden impermeability

Based on the analysis of gardens, the land cover classed as garden was divided according to the proportions of house type in Coventry (Table D.4). Based on the sample of gardens, 67% of Coventry's garden land cover was permeable, while 33% was impermeable.

Adjusting the land cover percentages from Fig. D.8 according to Table D.4 resulted in a revised land cover assessment, shown in Table D.5. Road and rail increased to cover 25.3% of the city, and buildings increased to 13.6%. Gardens declined to 15.7% of land cover, although this figure now represents solely the vegetated element of gardens. The resultant land cover is shown in graphical form in Fig. D.20 (compare Fig. D.8). Greenspace remains the largest single land cover category, but paved areas (road and rail) have replaced gardens as the second largest land cover in areal terms.

Table D.4 Constituents of garden land cover for each house type. The 'total' row is the proportion of each house type in the city. The 'paving' and 'building' rows indicate the element of the total formed by the different land covers. The 'permeable' row is the vegetated element of gardens. All figures are percentages

House type	**Terrace**	**Semi-detached**	**Detached**	**Total**	
Land cover	**---------------------**	**% in gardens**	**-----------------**		**% in city**
Paving	16.51	7.04	2.84	26.39	5.74
Building	4.27	1.6	0.69	6.56	1.40
Permeable	35.8	23.46	7.79	67.05	15.47
Total	56.58	32.09	11.32	100	22.62

Table D.5 Revised land cover percentages in Coventry after application of garden analysis. OSMM figures carried forward from Fig. D.8

	OSMM		**Changes**	**Using revised garden classification**	
Class	**Area (km^2)**	**%**	**Area (km^2)**	**Area (km^2)**	**%**
Buildings	12.03	12.19%	1.39	13.41	13.60%
Road & rail, including paving	19.27	19.53%	5.67	24.93	25.27%
Green (open) space	43.41	44.01%	0	43.41	44.01%
Gardens (vegetated)	22.31	22.62%	-7.05	15.26	15.47%
Water	0.62	0.63%	0	0.62	0.63%
Unclassified	1.01	1.02%	0	1.01	1.02%
Total	98.65	100%	0	98.65	100%

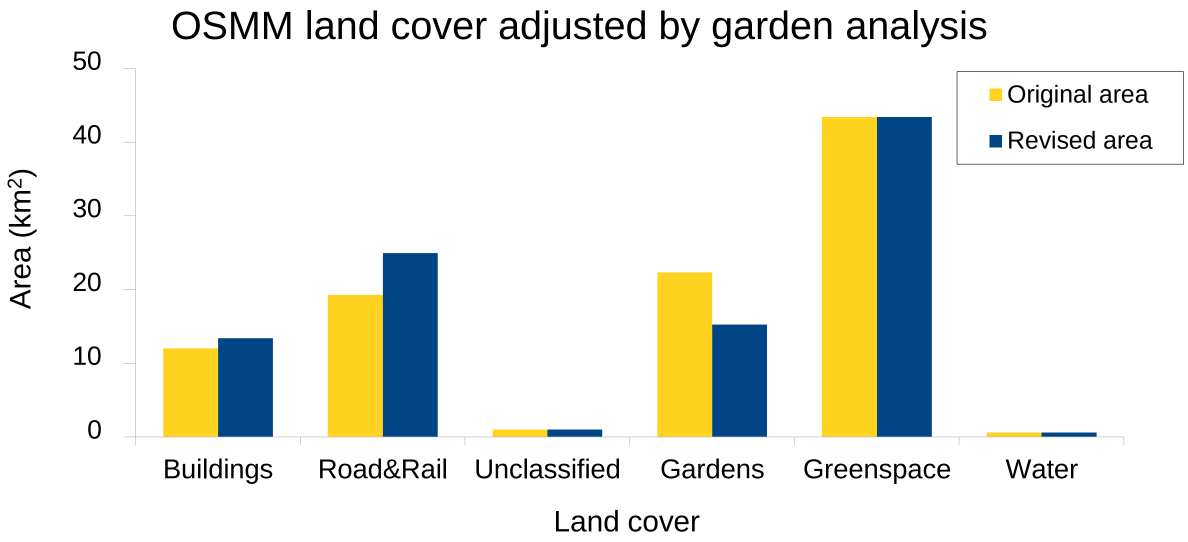

Fig. D.20 Coventry's land cover after application of garden analysis to the classified OSMM dataset.

D.1.5 Large Roofs

Large roofs may indicate sites that are more suitable for SUDS implementation (Stovin *et al*. 2007:19). There were 3,863 roofs over 200 m^2 in Coventry, covering 4.4 km^2 of the land area (4.5%). Large roofs were not restricted to any one particular part of the city, although there were concentrations in the city centre and along industrial corridors to the north and west (Fig. D.21). Large roofs constituted 1.75% of the building polygons in the OSMM dataset, yet covered 36.6% of the land area of buildings in OSMM, and 32.8% of building space after adjustment by the garden analysis.

D.1.6 Roads

Major roads and highways adopted by the Highways Agency and local authority were obtained from Coventry City Council, for use in validating OSMM data, and to separately identify major and minor roads.

Fig. D.21 Location of large roofs over 200 m^2. Data Source: OSMM (Edina 2009)

D.2 Topography

Based on 1m contour lines, the city grades from north-west to south-east, with its lowest point in the Sowe valley (Fig. D.22). Height above OD ranged from 63 m to 165 m. Most of the city lies below 100 m OD. Steepness of slopes is shown in Fig. D.23. The north-east of the city is generally flat, while the north-west and west are more undulating.

Fig. D.22 Topography based on 1 m contour lines

Fig. D.23. Percentage topographical slope change. Watercourses are shown for reference. Known rivers generally remain within zones of little change. One stream documented in the SFRA cuts through the steepest area of the city, which may cast doubt on its precise course

D.3 Geology

Coventry is underlain by sedimentary rocks, with Carboniferous sandstone, siltstone and conglomerate in the west and centre, and Triassic mudstone in the east (Fig. D.24). Superficial deposits comprised relatively porous glacial sand and gravel in the lower Sowe valley, and less permeable glacial till principally in the east and centre of the city, the latter covering just over 26 km^2.

BGS' (2009) qualitative assessment of water flow through bedrock underlying Coventry was of 'medium ease' and 'medium' capability in the majority of the area, although under the eastern edge, indicated as 'mudstone' on Fig. D.24, capacity may decrease to 'medium difficulty', because of the reduced volume of void spaces compared to the other rock types present. Therefore, bedrock types should not be a barrier to infiltration SUDS in central and western areas of Coventry.

Till is characterised as weakly permeable, with deposits over 5 m thick regarded as a barrier to vertical water infiltration, while deposits less than 5 m thick are seen as permeable due to weathering and consequent fracturing (Lelliot *et al*. 2006:296-297). The thickness of Coventry's till deposits is typically 3-5 m, although a maximum of 18 m has been detected in locations in the east of the city (Old *et al*. 1990:15, 28). In the east, till deposits are well-defined and stratified, but in the west they exhibit vertical and lateral variation over short distances (Old *et al*. 1990:15, 28). Based on this information, till deposits roughly coincident with the mudstone and sandstone bedrock in the east and centre of the city were treated as impermeable for the purposes of this study, while those overlying the siltstone and sandstone to the west were assumed to be moderately permeable.

This

Fig. D.24 Coventry's solid and superficial geology. Bedrock is depicted in solid colour. Surface deposits are shown using shading. Data source: BGS 2003 and 2008b

D.4 Groundwater

D.4.1 Groundwater Quantity and Quality

The EA (2010b) assessment of groundwater status for the Water Framework Directive (Table D.6) divided the city into three zones running roughly north to south (shown in Fig. D.25). The 'Warwickshire Avon: Coal Measures Coventry' water body is largely coincident with the 'Coventry' groundwater management unit (GMWU). Groundwater quality was poor under 72% of Coventry, and quantity was poor under 86%. The Sherbourne and Sowe rivers were highly dependent on groundwater to sustain flows (EA 2006b:37), but the Coventry GMWU, when last assessed, was over-abstracted, leading to classification as poor quantitative status (EA 2013a), indicating that existing abstraction was damaging the groundwater-dependent aquatic environment at low flows (EA 2006b:13). Therefore increased detention and infiltration of rainwater might benefit local groundwater supplies.

The British Geological Survey (2009) assessed groundwater vulnerability in the centre of England as very low, and the risk of groundwater flooding as low. The risks due to swelling or shrinking clays were low to nil, although areas to the south and west of Coventry were moderate, and these areas might lie within the city boundary based on inaccuracies due to the scale of mapping.

Fig. D.25 Groundwater WFD Status. Adapted from EA (2013a). The quantity assessment reflects the impact of abstraction, while quality indicates possible groundwater pollution

Table D.6. Assessment of groundwater status in Coventry. Data sources: EA (2010b, 2013a)

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D.4.2 Groundwater source protection zones

Groundwater source protection zones covered 61.1% of the city, and lay principally in the west (Fig. D.26). The inner protection zone (zone 1) defines an area inside which pollution, e.g. toxic chemicals and water-borne diseases, can travel to a borehole within 50 days (0.6% of Coventry's land area). The outer protection zone (zone 2) covers the greater of 25% of the total aquifer catchment or areas where pollution can take up to 400 days to reach the borehole, the minimum time needed to dilute contaminants (14.4% of the city). The total catchment (zone 3) is the area needed to support removal of water from the borehole (46.1% of the city).

Fig. D.26 Groundwater source protection zones. Data source: EA (2010b)

D.4.3 Depth to Water Table

A sample of 125 BGS borehole records (BGS 2013a) were mapped, ranging in date from 1881 to 2005, but no realistic depth to groundwater map could be generated from these records. A time series of data, fortnightly measurements from 1974 to 1984, were available from only a single site, with a range of 2.64 m during this period. Groundwater levels are reported to have risen approximately 3 m since the early 1990s due to reduced abstraction by industry over this period (Besien & Pearson 2007:11), but no detailed information was found relating to risks or locations of groundwater flooding.

The depth to the water table for the region in and surrounding Coventry from the model output is shown in Fig. D.27. Depth to groundwater is fairly shallow, under 4 m, around existing watercourses and in the north-east of the city. Depth to groundwater was greater in the south and west. The shallow water table was largely coincident with known watercourses, one of the validation measures for the model (ESRI 2006), so was taken as acceptable.

Fig. D.27. Depth to water table in the region surrounding Coventry. Watercourses are coincident with zero and negative depths, indicating that the representation is valid. Negative depths below -4 m are artefacts of the input data, resulting from lack of river data in those locations; these occur outside the city boundary, which is included for orientation.

D.5 Precipitation

Standard average annual rainfall (SAAR) in Coventry varied from 440 mm (1898) to 1071 mm (1872) over the full period of record 1870-2012 (Fig. D.28), with a mean of approximately 670 mm, but precise totals varied depending on the periods considered (Table D.7). HR Wallingford (2008) used 660 mm in its calculations. Most rain fell in summer and autumn. In all periods, the highest volume of rainfall was experienced in August (Fig. D.29), except for 1980-2009 (October). February had the least rainfall in all comparison periods. On an annual basis, 1961-1990, the baseline period for climate change forecasts, had the lowest precipitation of all examined periods.

Fig. D.28 Yearly precipitation in Coventry 1870-2012. The dashed black line is a 5-year moving average. Data source: Bablake Weather Station (2013)

Table D.7 Rainfall (mm) in Coventry over a range of periods, Data source: Bablake Weather station (2013)

Given the lack of rain gauge stations in the city, it was difficult to obtain information on the spatial variation of rainfall. Local press reports commented that heavy rain could occur in some parts of the city while other areas remained dry. One local press article (Coventry Evening Telegraph 1960a:6) reported that "rain gauge readings varied widely" across the city.

No detailed records of rainfall intensity were obtained. Press articles from 1954-2009 sometimes reported intensity when a significant number of locations was affected by flooding. Figures above 22 mm in 24 hours appeared to result in several locations experiencing floods, although short duration intense storms over 13 mm in 1 hour seemed to impact a larger number of sites. Because of the lack of spatial and temporal coverage of the reports, no statistical analysis was undertaken.

Fig. D.29 Monthly mean precipitation in Coventry. The full record covers 1870-2012. 1961-1990 is the baseline period against which climate change forecasts are compared, while later climate change assessments use 1971-2000. Data source: Bablake Weather Station (2013)

The design storm data in Table D.8 show that, except for the 1-year return period, the NERC (1975) methodology estimated slightly higher rainfall totals than Dales & Reed (1989) for the 24-hour duration. The NERC rainfall figures were revised to reflect more recent rainfall depths in the Flood Estimation Handbook (FEH) (Defra & EA 2007). For the study area, revised NERC figures produced the highest estimates. Existing methodologies for estimating runoff and storage are based on the updated NERC data, so these figures were employed in subsequent calculations in this thesis. The maximum recorded 24 h precipitation in Coventry was 72.3 mm on 31 December 1900 (Bablake Weather Station 2013).

Table D.8 Rainfall depth for 24 and 6 hours for defined return periods, extrapolated from growth curves in i) Dales and Reed (1989:52) based on mean 1-day annual maximum rainfall; ii) NERC (1975:Vol.II) based on 2-day 5-year return period; iii) NERC revised to reflect more recent rainfall depths determined for the Flood Estimation Handbook (FEH) (Defra & EA 2007). The 24-hour maximum depth was estimated from known maxima at sites in England and Wales

Return Period (y)	**24 hr Rainfall depth (mm)**			**6 hr Rainfall depth (mm)**	
	(Dales & Reed 1989)	(NERC 1975)	NERC 1975 revised for FEH (Defra & EA 2007)	(NERC 1975)	NERC 1975 revised for FEH (Defra & EA 2007)
1	32.6	32.1	35.6	23.0	25.1
30	59.3	63.0	70.0	45.2	49.3
100	78.2	80.6	89.6	57.9	63.1
Max.	n/a	243.5	270.6	n/a	n/a

D.6 Watercourses and associated flood zones

Water bodies in Coventry are shown in Fig. D.32. The EA-defined main rivers are the R. Sowe in the east of the city, R. Sherbourne running northwest to southeast, Canley Brook in the southwest, and Guphill Brook, referred to as Brookstray by the EA, a tributary of the Sherbourne to the west.

There were few lakes or ponds of any significant size in Coventry. As seen in Fig. D.7, there were limited extents of open water in Coventry. Linking isolated stretches of open watercourses where they appeared to be related gave an indication of the location of culverted sections.

The ordinary watercourses, Hall Brook, Springfield Brook, Spital Brook and Radford Brook, were culverted for much of their length. Their status and precise location were less well defined than the main rivers', and there were ongoing discussions between the City Council and the Water Company regarding whether the culverted sections constituted ordinary watercourses or sewers. All watercourses running through the city's central area were culverted, except for a 33 m stretch of the R. Sherbourne in Palmer Lane. Modelled floodplains existed for the main rivers and for sections of the Springfield and Hall Brooks (Fig. D.33). Although open water formed only 0.6% of the city's land cover, fluvial flood zones were substantially larger (Fig. D.30). Flood zone 3, the 100-year flood plain, extended over 7.5% of the city's area, while flood zone 2, the 1000-year flood plain, occupied 18.5%. Flood zone 2 was thus larger than the total area covered by buildings in Coventry.

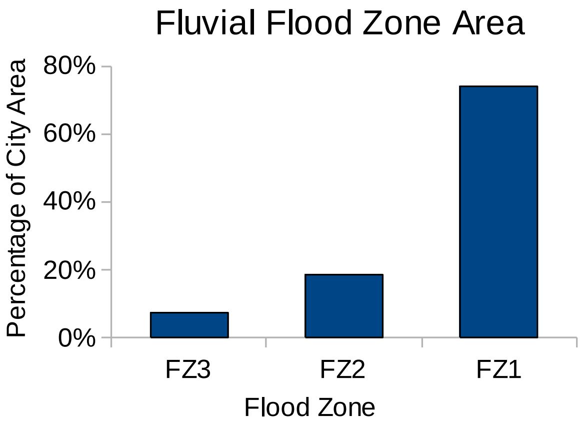

Fig. D.30 Percentage spatial area enclosed by fluvial flood zones in Coventry. Flood zone 3 comprised the 100-year flood plain. Flood zone 2 was the 1000-year flood plain. Flood zone 1 included all other areas. Data source: EA

The percentage areas of surface water flood risk zones (EA 2009c) are shown in Fig. D.31. As with fluvial flood zones, surface water flood zones were nested. The area at greatest risk of surface water floods ('more' susceptible) covered the smallest area (8.0%) of the city. The intermediate zone covered 30.1%, and the less susceptible areas covered over half the city's land area (53.1%), leaving just under half the city (46.9%) outside a surface water flood zone.

The surface water flood risk map (EA 2009c) was an initial attempt by the EA to produce such a map, and thus was subject to a number of limitations. The map had been generated using a simplified methodology that excluded all underground drainage systems and smaller over-ground drainage systems. It was based on a bare earth model and so did not include buildings or vegetation, and was calculated from a single 1 in 200 year rainfall event. Resolution of the topography was 5 m. As a result, substantial uncertainties remained in the dataset at a detailed level, and portrayal of the information was unsuitable at a scale below 1:50,000. However, the information was considered by the EA to be sufficiently accurate to use in an initial assessment of surface water management planning, such as undertaken in this research.

The relationship between flood zones and historical flood events is explored in section D.8.3.

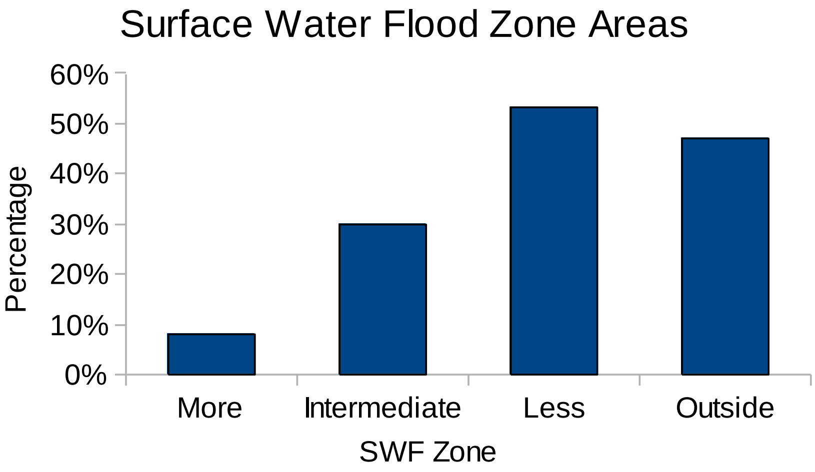

Fig. D.31. Surface Water Flood (SWF) areas. The x-axis categories represent zones of more, intermediate and less susceptibility to surface water flooding, and the area outside all three zones. The bar indicates the proportional area of each zone in relation to the city as a whole

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Fig. D.32 Principal surface water bodies in Coventry. Width of linear features exaggerated (x2) for visibility. For derivation see Table 3.16

Fig. D.33 Fluvial Flood Zones in Coventry. Data source: EA

D.7 Soil

SSEW (1963, 1983) classified Coventry as an unsurveyed urban area, and provided no information on soil types over most of the city. The whole of Coventry was categorised as clay, soil type 4, in the Flood Studies Report hydrological soil classification based on its winter rainfall acceptance potential (Defra and Environment Agency 2007:51; NERC 1975), equivalent to a runoff coefficient of between 45% (Wallingford Procedure) and 47% (Flood Studies report). Type 4 soils have high run-off potential, indicating low permeability levels (Boorman *et al*. 1995:2), so are not generally suitable for infiltration (Defra & EA 2007:35). The impermeability characteristics of local soils are given in Fig. D.34, which reveals a more complex pattern that the summary 'clay soil' definition of NERC (1975). Table D.9 summarises the land area covered by the different types of soil permeability present. Free draining soil, suitable for infiltration, covered just over 30%, occurring principally in a band running through the suburbs. Slowly permeable zones extended over slightly more than a quarter of the city, mainly in the west and north. Impeded drainage areas, less suitable for infiltration, covered over 40% of the city, in the centre and west. High groundwater zones (2.3%) equated to the main river basins. Standard percentage runoff (SPR) values associated with different soil types were assigned to the soil types present in Coventry (Table D.9). A composite SPR value of 0.39 was determined for permeable areas of the city as a whole.

Table D.9 Areas and standard percentage runoff of soil types. Soil types and drainage characteristics from NSRI (2010) and Soil Environment Services (2008). Standard percentage runoff (SPR) values from Defra and Environment Agency 2007:37. SPR component value calculated as Area percentage x SPR value. Saturated hydraulic conductivity values from Boorman *et al*. (1995:25)

Fig. D.34 Soil permeability of Coventry. Data sources: NSRI (2010); Soil Environment Services Ltd (2008)

D.8 Historical flood events

This section identifies those locations in Coventry that have been more susceptible to floods in the past, and which may benefit from the additional protection afforded by SUDS. A survey of historical flood events in Coventry over a 100-year period, 1910-2009, identified a total of 774 flood location events, i.e. flooding affecting a specific location on a particular date.

Historical flood events were examined in terms of spatial and temporal patterns:

- impacts – frequency and location of events
- impacts – number of properties affected by each flood event
- causes of flooding in individual locations
- correlation with fluvial and surface water flood risk maps.

Further analysis of historical flood events is contained in Appendix E.

D.8.1 Summary of Impacts

D.8.1.1 All impact types 1910-2009

774 location events occurred between 1910 and 2009. The most frequently flooded locations in the 100-year period occurred in the centre of the city along the R. Sherbourne, and in Kingfield Rd along the Springfield Brook (Fig. D.35). 308 location events (40%) lay within flood zone 2, the 1000-year fluvial floodplain. Allowing for possible inaccuracies in the flood zone definition, a total of 414 (53%) location events were inside or within 100 m of flood zone 2. A further 77 location events (10%) were within 100 m of culverted ordinary watercourses.

D.8.1.2 All impact types since 1980

The pattern of historical flooding differs to some extent when considering the most recent 30 years. 436 location events (56% of the total) occurred in the 30 years since 1979. The locations most frequently flooded in this 30-year period occurred outside the centre of the city (Fig. D.36). Only one location, Kingfield Rd, remained in the group of highest frequency flood events compared to the 100-year dataset.

A smaller proportion of flood events was associated with watercourses. 88 location events (20%) occurred within flood zone 2, the 1000-year fluvial floodplain. Allowing for possible inaccuracies in the flood zone definition, a total of 165 (38%) location events were inside or within 100 m of flood zone 2. A further 53 location events (12%) were within 100 m of culverted watercourses that were not main rivers.

D.8.1.3 All impact types 1910-1979

338 location events (44% of the total) occurred in 1910-1979. The locations most frequently flooded in the 70-year period occur in the centre of the city along the R. Sherbourne (Fig. D.37). Flood events are clustered along watercourses and in the centre of the city. A smaller proportion of flood events are associated with watercourses. 220 location events (65%) were within flood zone 2, the 1000-year fluvial floodplain. Allowing for possible inaccuracies in the flood zone definition, a total of 249 (74%) location events were inside or within 100 m of flood zone 2. A further 24 location events (7%) were within 100 m of culverted watercourses that were not main rivers. In practice, watercourses shown as culverts on Fig. D.37.were still open during the earlier part of this period.

The changing pattern of flood risk in more recent times compared to the 100-year historical period is summarised in Table D.10. In the 70 years from 1910, 81% of flood events occurred within 100 m of a watercourse. In the 30 years since 1980, this percentage has reduced to 50%, indicating a greater influence from other causes of flooding, e.g. sewer flooding and overland flow.

Table D.10 Comparison of flood impacts and proximity to watercourses. 'Flood Zone 2' defines events occurring within the current 1000-year flood plain. 'Flood Zone 2 + 100 m' includes events occurring within 100 m of flood zone 2, allowing for inaccuracies in its definition. 'Culverts +100 m' includes events within 100 m of known culverted ordinary watercourses. 'Watercourse + 100 m' totals adds 'Flood Zone 2 + 100 m' and 'Culverts +100 m' to represent flood events within 100 m of all watercourses.

Period	Impact type	Flood Zone 2	Flood Zone 2 +100 m	Culverts +100 m	Watercourse + 100 m
1910-1979	All events	65%	74%	7%	81%
1980-2009	All events	20%	38%	12%	50%

Fig. D.35 Flood location events in Coventry 1910-2009 – all impacts. The locations most frequently flooded in the 100-year period occur in the centre of the city along the R. Sherbourne, and Kingfield Rd along the Springfield Brook. Flood events are clustered along watercourses and in the centre of the city.

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Fig. D.36 Flood location events in Coventry 1980-2009 – all impacts. The locations most frequently flooded in the 30-year period occur outside the centre of the city

Fig. D.37 Flood location events in Coventry 1910-1979 – all impacts. The locations most frequently flooded in the 70-year period occur in the centre of the city along the R. Sherbourne. Flood events are clustered along watercourses and in the centre of the city. Although shown as culverts, watercourses were still open during the earlier part of this period

Fig. D.38 Causes of flooding by location 1980-2009. All impact types included.

D.8.2 Causes of Flooding

The spatial distribution of the causes of flooding in the period 1980-2009 is shown in Fig. D.38. Each location is depicted only once for each different cause, although multiple location events may have taken place there. No overall cause emerged in any one area of the city. Rather, the complexity of the causes of flooding can be seen. In some locations, multiple causes indicate that multiple solutions may also be required. In several locations, interaction took place between sewers and their disposal into nearby rivers. The presence of fluvial floods away from the watercourses shown may indicate that further small unmapped streams exist within the city boundary, or alternatively that events were mis-classified in the source document. In some, but not all, instances, further small watercourses were present in the current OSMM dataset. In the city centre, the cause of most events was either unknown or defined as overland flow. This may reflect the fact that the R. Sherbourne runs in a substantial culvert through most of the central area, thus reducing cases of river flooding. The prevalence of overland flow may result from dense development in the city centre.

Over the 100-year period 1910-2009, no single cause emerged clearly across the city as a whole (Fig. D.39). Flood causes were frequently unrecorded: the cause of 53% of location events over this period was undefined. Sewer flooding accounted for 25% of events, and river flooding for 13%. Canal flooding occurred once in the 100-year period (15th December 1978), but had a widespread impact across the north of the city.

The level of certainty was higher for the latest 30-year period (Fig. D.40), but the cause of 175 location events (38%) was still undefined. This lack of certainty regarding the precise source of flooding may reflect the complexity of water in an urban environment, where different factors can interact. As in the 100-year dataset, sewer flooding accounted for the majority of events where the cause was known (39%), while river flooding caused 16%. There were few instances of groundwater flooding (1%).

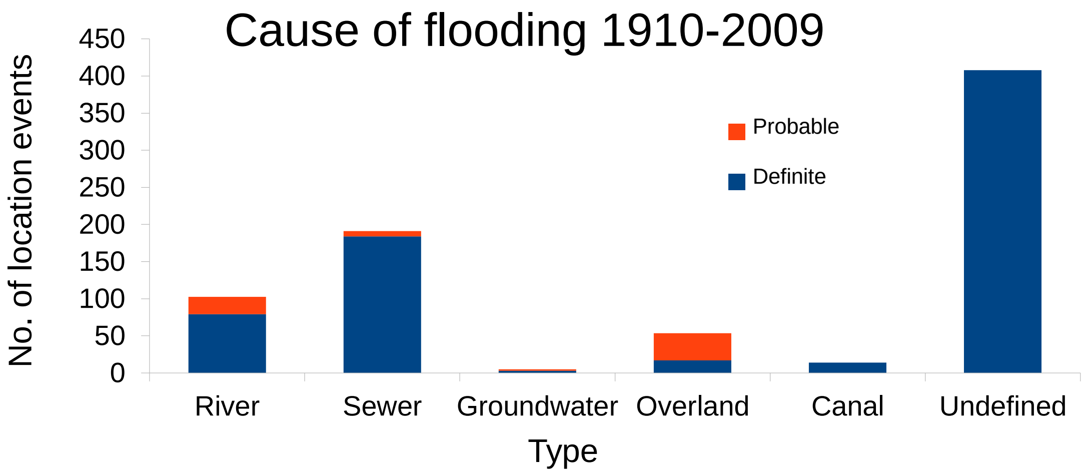

Fig. D.39 Cause of flooding 1910-2009. 774 events were included. Events were allocated to a single cause where known. Events where the cause was unknown, or due to multiple causes, were assigned to undefined. 'Definite' represents a high level of certainty regarding the cause, whereas 'probable' indicates a reasonable degree of certainty

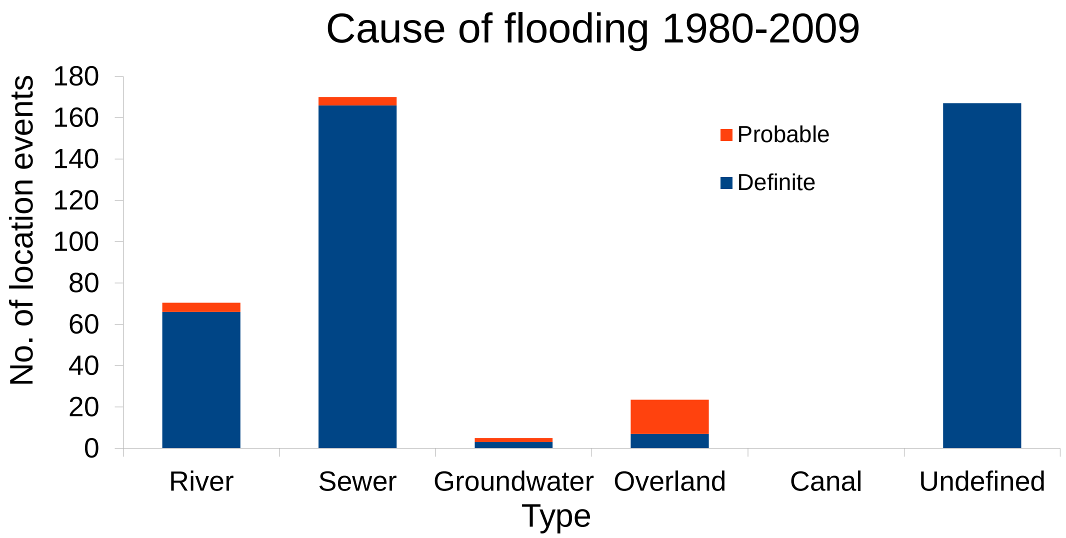

Fig. D.40 Cause of flooding 1980-2009. 436 events were included. Events were allocated to a single cause where known. Events where the cause was unknown, or where multiple causes applied, were assigned to undefined. 'Definite' represents a high level of certainty regarding the cause, whereas 'probable' indicates a reasonable degree of certainty

D.8.3 Relationship to EA Assessment of Susceptibility to Surface Water Flooding

EA maps of susceptibility to surface water flooding (EA 2009c) were intended to indicate the probability of risk to specific areas of the city. The relationship between surface water flood

(SWF) zones and historical flood events is given in Fig. D.41, which compares the proportional area covered by SWF zones and the relative percentage of flood events occurring in that zone. Note that flood zones are nested, so intermediate susceptibility includes the spatial area and flood events of the 'more susceptible' category.

More flood events occurred inside SWF zones than outside. Zones of more and intermediate susceptibility appear from Fig. D.41 to be better predictors of historical flood locations based on the proportion of events in those zones. Despite having only three zones, Spearman's rank order correlation indicates a significant positive association between SWF zones and flood events (r_s = 1.000, p=0.01, 2-tailed test). However, Fig. D.42 shows that, while SWF zones may indicate the risk of flooding (r^2 = 0.95), no single zone was a better predictor in Coventry. The usefulness of the SWF zones may also be questionable, as they cover over 50% of the city's spatial area.

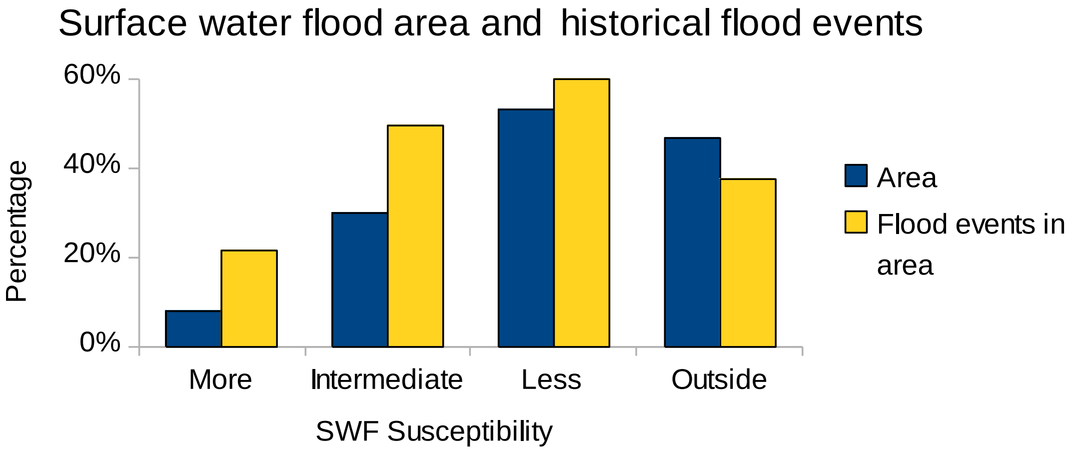

Fig. D.41. Surface Water Flood (SWF) areas and historical flood events. The x-axis categories represent zones of more, intermediate and less susceptibility to surface water flooding, and the area outside all three zones. The left-hand bar indicates the proportional area of each zone in relation to the city as a whole. The right-hand bar shows the percentage of historical flood events

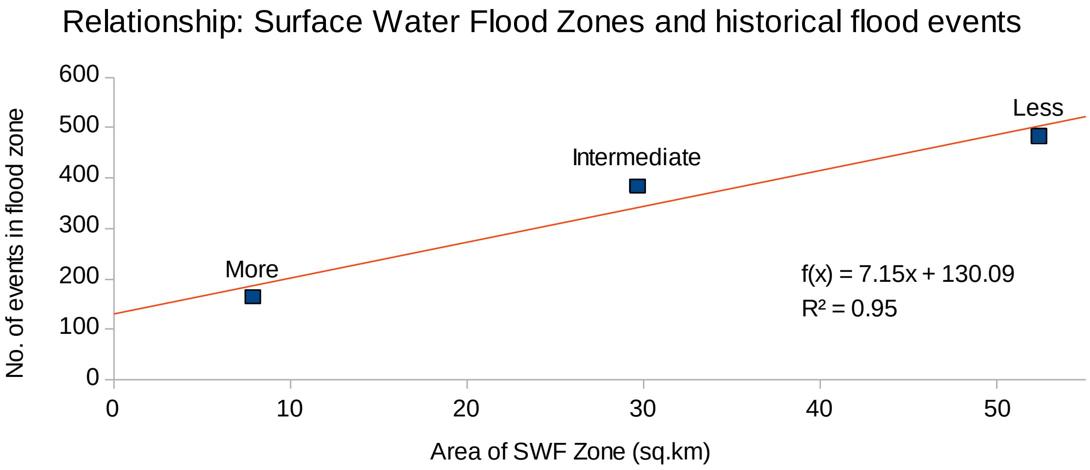

Fig. D.42. Relationship between surface water flood zones and historical flood events 1910-2009.

D.9 Water quality assessments

The water quality of Coventry's main rivers is summarised in Fig. D.43, with details in Table D.11. No water quality assessment was available for ordinary watercourses. Diffuse pollution impacted the rivers Sherbourne and Sowe, both of which were forecast to fail to meet the 'good' standard required by the Water Framework Directive by 2015 (EA 2010b). Elevated nitrate levels are typically due to farmland runoff, while phosphates derive from both urban and agricultural sources (Defra 2005b; EA 2007c; EA 2007a). Treatment of runoff prior to delivery from surface water sewers into the Sowe and Sherbourne would help to improve the quality of both rivers. However, the locations of surface water sewers could not be identified from publicly available data. No significant change in water quality status was predicted by the EA (2010b) before 2015, except to remove the source of tributyl tin pollution in the lower reaches of the R. Sowe. Consequently, the quality of the large majority of Coventry's watercourses will continue to require improvement in future years in order to meet WFD 'good' standard.

Sites where nitrate and trichloroethene concentrations approached or exceeded defined guidelines (Besien & Pearson 2007:5, 33-34) are also shown on Fig. D.43. Higher nitrate concentrations were present near the agricultural areas to the north of the city. Elevated trichloroethene levels were detected at two sites associated with engineering, one on the eastern edge of the city centre, the other in the industrial corridor to the north of the centre. These levels exceed the drinking water standard of 10 μg l^{-1} for trichloroethene and tetrachloroethane combined, although these substances can be removed using specialist treatment (DWI 2009:57). Besien & Pearson (2007:15) caution that developments should take steps to prevent deeper transmission of solvent pollutants into groundwater in order to prevent contamination.

The persistent herbicide atrazine was widespread at low concentrations throughout the city (Besien & Pearson 2007:5), suggesting the need for a cautious approach to infiltration in order to protect groundwater stores. However, atrazine and similar herbicides can be broken down in soil, thus vegetated SUDS could play a role in ameliorating future contamination.

Almost all of Coventry lay within defined nitrate vulnerable zones affecting both surface water (98.1% of Coventry) and groundwater (21.5% of the city) (Fig. D.44).

Fig. D.43 River water quality in Coventry. River Quality Assessment using Water Framework Directive (WFD) criteria: ecology criteria use a five-point scale: 1, very good, to 5, bad; chemical criteria use a pass or fail assessment. Known contamination sites affecting groundwater. Data sources: Besien & Pearson (2007), EA (2010b)

Fig. D.44 Nitrate vulnerable zones in Coventry. Data source EA (2013b)

Table D.11 Coventry's river water quality. Data source: EA (2010b). GQA measurements from 2008, WFD measurements ca.2008.

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D.10 Sites of current and former industrial usage

Sites of current and former industrial usage may influence the ability to use infiltration SUDS. The principal sites of current and former industrial usage covered 28.42 km^2 (29%) of the city's land area (Fig. D.45). A broad swathe of industrial land occupying the central area plus a corridor running north accounted for a substantial proportion of this total. There were also significant areas to the north-east and the west of the city. Depending on the specific industrial processes employed, land at these sites may be at risk from contamination. The main implication for sustainable drainage is in conjunction with groundwater stores, as infiltration solutions risk transporting pollutants into groundwater.

Fig. D.45. Areas of current and former industrial usage. Main roads shown for orientation. Data generalised from information supplied by Coventry City Council.

D.11 Sewer and drain locations and characteristics

No GIS layers for public or private drainage were obtained. Visual assessment of a plan of the city's public sewer system, available in Jacobs Gibb (2008:23) indicated that over 50% of Coventry was served by combined sewers, with storm sewers more prevalent in the eastern and western suburbs.

D.12 Planning constraints and covenants

A range of planning constraints is shown on Fig. D.46. Vegetated features are located towards the outskirts of Coventry, while the majority of buildings are situated around the city centre. Greenbelt land occupied 33.4 km^2 (33.9%) of the city's area. There was considerable overlap between the allocated areas for other designated land use constraints.

In addition, current and historical waste and landfill sites were available from the EA.

Fig. D.46 Location of planning constraints. Data sources: Coventry City Council, English Heritage (2007), Natural England (2010)

D.13 Land ownership

Council-owned land constituted 22.53 km^2 (23.0% of Coventry's land area, Fig. D.47), and land owned by Whitefriars Housing Association covered a further 7.17 km^2 (7.3%, Fig. D.48), in total 29.91 km^2 (30.3%). The different types of land cover owned by these two organisations are presented in Table D.12. Gardens formed most (47.7%) of the land cover owned by Whitefriars, while greenspace (77.1%) was the main component of land cover owned by the City Council. Greenspace owned by the City Council and Whitefriars accounted for 42.3% of the total greenspace in Coventry, and 18.6% of the total land area of the city. 24.1% of the paved areas in Coventry were owned by these two organisations. Large roofs over 200 m^2 covered 4.5% of the city. Private ownership accounted for the majority of large roofs in Coventry (76.2%, Table D.13), although Council-owned large roofs constituted 22.9%.

Fig. D.47 Land ownership - Coventry City Council. Status January 2013

Fig. D.48 Land ownership – Whitefriars Housing. Status June 2010

D.14 Development Zones

Planned development areas in Coventry are shown in Fig. D.49. There were five major regeneration zones, plus significant renewal planned for the city centre to 2028. In addition to these zones, land defined as unclassified in OSMM, and land allocated for planned housing and employment development were included.

If allocated land were developed as planned, then just over 8% of the city would be redeveloped in the period 2011-2028 (Table D.14). Release of greenfield and greenbelt land is to be prioritised after regeneration zones and previously developed land (Coventry City Council 2012b:55-56). This rate of development indicates that full turnover of sites would take over 200 years.

Table D.12 Land cover categories owned by the two main landowners, Coventry City Council and Whitefriars Housing Association. Columns two and three show the area covered by the different land cover types for the two principal landowners. Column four sums columns two and three. Column five, 'Percentage of Whitefriars area', indicates the relative proportions of land cover types owned by Whitefriars. Column six, 'Percentage of Council area', indicates the relative proportions of land cover types owned by the City Council. Column seven, 'Percentage of Public area', indicates the relative proportions of land cover types across the two landowners. Column eight, '% of Land cover class'' shows the proportion of the total area of each land cover class owned by the city council and Whitefriars (column four) in relation to the proportion of that land cover class in the city. Column nine, 'Total Percentage of City', shows the proportions of land cover types owned by the two landowners relative to the total land area of the city.

Land cover	**Whitefriars area (km^2)**	**City Council area (km^2)**	**Total area (km^2)**	**% of Whitefriars area**	**% of Council area**	**% of Public area**	**% of Land cover Class**	**Total % of city**
Buildings	1.21	1.23	2.45	16.9%	5.5%	8.2%	20.3%	2.5%
Gardens	3.42	0.42	3.84	47.7%	1.9%	12.9%	17.2%	3.9%
Greenspace	1.00	17.36	18.36	13.9%	77.1%	61.8%	42.3%	18.6%
Road&Rail	1.48	3.15	4.63	20.7%	14.0%	15.6%	24.1%	4.7%
Unclassified	0.05	0.13	0.18	0.7%	0.6%	0.6%	17.6%	0.2%
Water	0.01	0.24	0.25	0.1%	1.1%	0.8%	39.6%	0.2%
Total	7.17	22.53	29.70	100.0%	100.0%	100.0%	30.1%	30.1%

Table D.13 Large roofs on land owned by the two main landowners. 'Number' is the quantity of roofs over 200 m^2. 'Area' indicates the land covered by large roofs. 'Percentage of large roofs' is the proportion of large roofs on land across owners. 'Percentage of city area' shows the percentage of land in Coventry occupied by large roofs in each category

Ownership	**Number**	**Area (km^2)**	**Percentage of large roofs**	**Percentage of city area**
Whitefriars	76	0.04	0.9%	0.04%
City Council	958	1.01	22.9%	1.02%
Private	2567	3.35	76.2%	3.40%
Total roofs >200 m^2	3863	4.40	100%	4.46%

Table D.14. Development Zones in relation to Coventry's land area. Column two shows the land area covered by each development type. The 'Assumed change' column reflects how much of the area is expected to be developed over an 18 year period – it is unlikely that the full extent of all development types will be redeveloped. The 'Unclassified land' row represents parcels of land that are currently awaiting or undergoing development. The '% of city area' row relates the potential development areas to the total land area of the city. Over the 18-year horizon of the Core Strategy, the 'Annual change' row indicates the annual percentage change in land cover for the city as a whole. The 'Years to 100% development' row shows how long it will take to achieve the defined extent of development in full

Development Type	**Area (km^2)**	**Assumed change**	**Change (km^2)**
Regeneration areas	4.27	50%	2.14
City centre zone (excluding Swanswell Regeneration area)	1.94	30%	0.58
Unclassified land outside development zones	0.81	100%	0.81
Housing outside development zones	2.57	100%	2.57
Employment land outside development zones	6.76	30%	2.03
Total	16.35		8.12
% of city area	16.6%		8.1%
Annual change of city (%)			0.46%
Years to 100% development			219

Fig. D.49 Planned development areas in Coventry 2012. Major regeneration zones are shown, together with unclassified land awaiting development, and housing and employment land outside the major regeneration zones. Data sources: Coventry City Council 2012a; Coventry City Council 2012b

E Appendix E – Additional analysis of historical flood events

This section provides more detailed analysis of the flood events collected for this thesis.

Coventry Evening Telegraph Editorial 24th August 1970

E.1 Detailed Impacts

Some types of flood impact are regarded as more severe. A hierarchy of impacts was defined, with property as the most severe impact, through garden, road and finally greenspace flooding. Significant sewer enhancement and capacity extension works were carried out by the City Council in the 1960s through to the early 1980s to solve existing sewer flooding problems in the city. Therefore, the more detailed assessments described below concentrate on the period from 1980 onwards. Firstly, three frequency assessments review the relative frequency of flooding affecting property; property and gardens; and roads. A second assessment examines the severity of impacts by applying the defined hierarchy. The third assessment depicts the number of properties affected at each location. A fourth assessment reviews the type of features impacted.

E.1.1 Frequency Assessment - Property

144 location events in the period 1980-2009 affected properties and involved water ingress into buildings (33% of all location events since 1980). Sixteen groups of sites experienced more than one property flood in this period. The three areas with the highest proportion of flood events were located in the northern part of the city (Fig. E1): Kingfield Rd near the culverted Springfield Brook; and Wheelwright Lane and St. Luke's Rd on culverted tributaries of the R. Sowe. Other sites experiencing more than one flood event were distributed around the city. Noticeable clusters occurred in the city centre, along the Walsgrave Rd (A4600) corridor, and around Kingfield Rd / Lockhurst Lane. 18 location events (13% of property floods) were within flood zone 2, the 1000-year fluvial floodplain. Allowing for possible inaccuracies in the flood zone definition, a total of 44 (31%) property location events were inside or within 100 m of flood zone 2. A further 23 property location events (16%) were within 100 m of culverted ordinary watercourses. Thus, a total of 47% of property flood events occurred within 100 m of a watercourse, indicating the importance of non-fluvial sources of flooding in the past 30 years.

E.1.2 Frequency Assessment - Property and Garden

Although flooding of gardens was regarded as less severe than property flooding, an increased intensity or severity of events, for instance under future predictions of climate change, could see flood water currently restricted to gardens entering properties. Twenty-four groups of sites experienced more than one flood in this period. Two areas with the highest proportion of flood events were situated in the northern part of the city (Fig. E2): Kingfield Rd near the culverted Springfield Brook, and Rowleys Green Lane, near the R. Sowe. The inclusion of gardens in the analysis revealed that additional sites were affected by garden flooding, as opposed to a more severe effect on the sites already impacted by property flooding. Other sites experiencing more than one flood event were distributed around the city. 223 location events since 1980 affected properties and/or gardens (51% of all location events since 1980). Of those 37 (17% of property and garden floods) were within flood zone 2. Allowing for possible inaccuracies in the flood zone definition, a total of 83 (37%) location events were inside or within 100 m of flood zone 2. A further 32 location events (14%) were within 100 m of culverted ordinary watercourses. In total 49% of property and/or garden flood events occurred outside a 100 m buffer around a watercourse, again indicating the importance of non-fluvial sources of flooding in the past 30 years.

E.1.3 Frequency Assessment - Roads

150 location events since 1980 (11% of all location events since 1980) affected roads without impacting property or gardens. 21 sites experienced more than one flood in this period. These sites were widely distributed throughout the city. The five locations experiencing four or more floods were (Fig. E3): Hen Lane & Bedlam Lane; Foleshill Rd; Walsgrave Rd; Abbey Rd; Broad Lane western end. 30 road flooding events (20% of road floods) lay within flood zone 2. Allowing for possible inaccuracies in the flood zone definition, a total of 49 (33%) location events were inside or within 100 m of flood zone 2. A further 14 location events (9%) were within 100 m of culverted ordinary watercourses. Thus, a total of 41% of road flood events occurred within 100 m of a watercourse, again indicating the importance of non-fluvial sources of flooding in the past 30 years.

Fig. E1 Historical flood location events since 1980 affecting property. Red locations experienced 4 or more floods, yellow 2-3, and blue 1 flood. Annotation in red identifies the sites with 4 or more flood location events; annotation in black shows the sites with 2-3 events.

Fig. E2 Historical flood location events since 1980 affecting property and gardens. Red locations experienced 9 or more floods, yellow 2-5, and blue 1 flood. Annotation in red identifies the sites with 9 or more flood location events; annotation in black shows the sites with more than 1 event.

Fig. E3 Historical flood location events since 1980 affecting roads, but not property or gardens. Red locations experienced 4 or more floods, yellow 2-3, and blue 1 flood. Annotation in red identifies the sites with 4 or more flood location events; annotation in black shows the sites with more than 1 event.

E.1.4 Impacts 1980-2009

This assessment examines the severity of impacts by applying the defined hierarchy. Each location event is depicted once, although multiple impacts may have occurred, for example, a property flood may well include road flooding as the water will often use the highway as a means of reaching the property. This assessment does not show the number of times a location was affected, nor the number of properties affected.

The diffuse distribution of flood events across the city indicates no overall pattern to the type of impact in any one area of the city. (Fig. E7). The principal impact clusters were properties in the city centre and Cheylesmore, and gardens along the course of the Guphill Brook.

E.1.5 Number of properties impacted 1980-2009

This assessment reviews the number of properties affected at each location. Most events affected only a limited number of properties (Fig. E8). The largest event, a sewer flood, occurred in Tile Hill in 1999, flooding 62 houses. Over 10 properties were flooded in four locations: Kingfield Rd; Stoney Stanton Rd; Longfellow Rd; and the Riddings / Canley Rd / Beechwood area. Of the 144 location events impacting properties since 1980, the highest percentage (44%) affected only one property (Fig. E4). No information was found on the number of buildings affected for 46 events (32%).

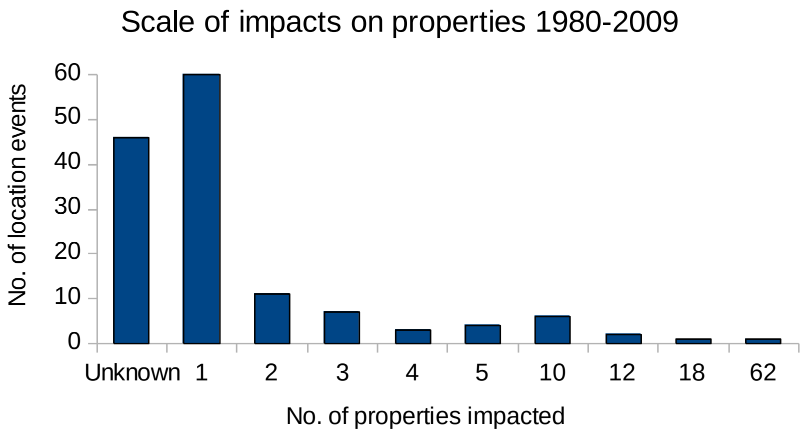


Fig. E4 Scale of flood impacts on properties 1980-2009.

E.1.6 Type of Features Impacted

In terms of the type of features affected over the 100-year period (Fig. E5), the impact of 33% of location events was undefined, constituting the largest individual component in this particular analysis. Road flooding accounted for 29% of events, and property flooding for 26%. Garden flooding constituted 11% of location events over the 100-year period.

Over the most recent 30 years (Fig. E6), the level of certainty rose, but the pattern of the defined categories was similar to that in the 100-year horizon. The impact of 12% of location events was undefined. Road flooding (34%) accounted for a similar proportion of events to property flooding (33%). Garden flooding constituted 18% of location events over the 30-year period.

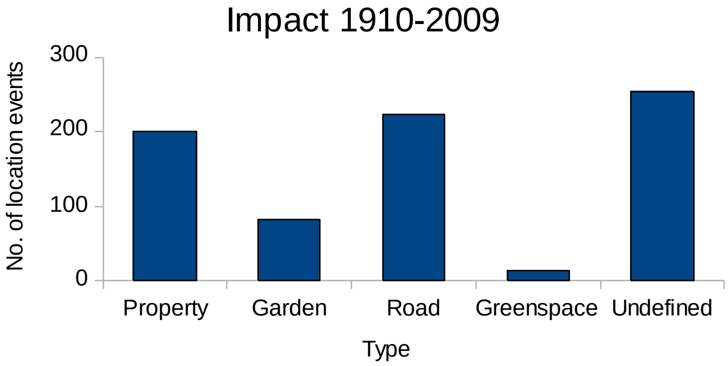


Fig. E5 Impact of flooding 1910-2009. 774 location events were included. Events were allocated to a single impact where known, using the hierarchy property, garden, road and greenspace. Events where the impact was unknown were assigned to undefined.

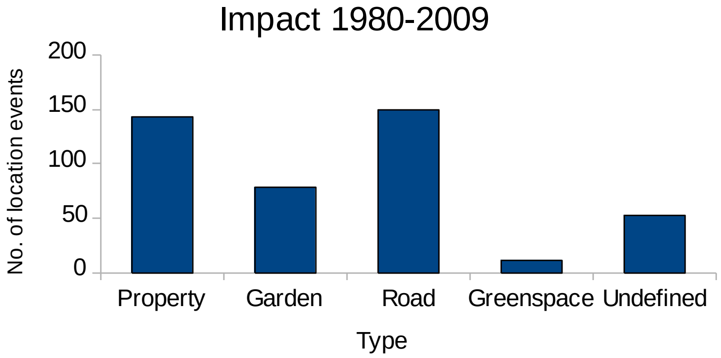


Fig. E6 Impact of flooding 1980-2009. 436 location events were included. Events were allocated to a single impact where known, using the hierarchy property, garden, road and greenspace. Events where the impact was unknown were assigned to undefined.

Property impacts
in Cheylesmore

Fig. E7 Historical flood location impact types since 1980. The impact of each location event is shown once, based on the hierarchy:

property -> gardens -> roads -> greenspace

Fig. E8 Number of properties impacted by location, 1980-2009

E.2 Temporal patterns of flooding

The number of flood location events for each decade are shown in Fig. E9. The fewest events happened in the 1940s, while the most occurred in the decade 2000-2009. Both a linear trend line and a 30-year moving average show an increasing frequency of location events in more recent decades, peaking in the 2000s. However, based on the r^2 value, the linear trend line is only a moderate predictor of future flood events. Additional factors may influence this result, particularly in relation to the inclusion of older historical events – see section E1.3.

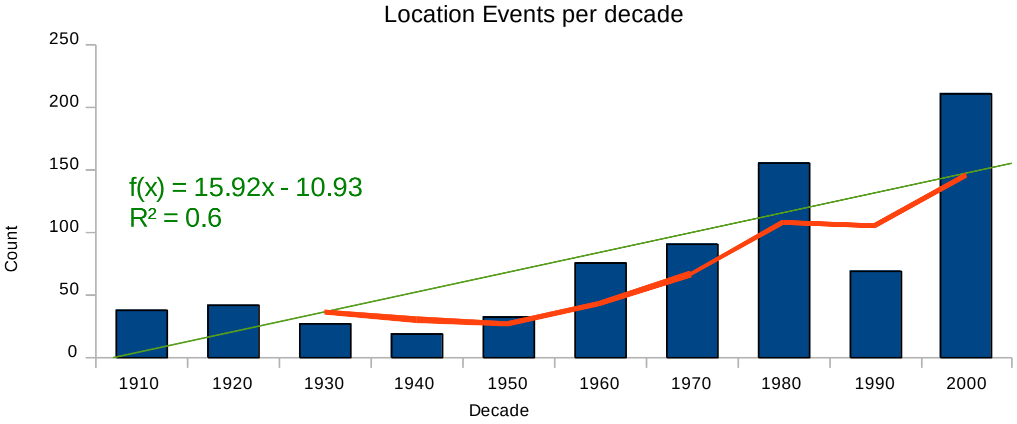


Fig. E9 Flood location events per decade 1910-2009. 766 (99%) events are included; 8 events are excluded where no specific decade was identified. The green line represents a linear trend, and its equation and correlation coefficient (r^2 value) are given. The red line is a 30-year moving average

In comparison with Fig. E9, the number of days when flooding occurred in each decade (Fig. E10) shows a similar pattern, except for the most recent decade. The number of days remained fairly constant from the 1910s through to the 1950s, and then peaked in the 1980s. Both a linear trend line and a 30-year moving average show an increasing frequency of days of flooding in more recent decades. Based on the r^2 value, the linear trend line is a weak predictor of future flood events.

Fewer days of flooding occurred in the 2000s compared to the 1980s in Fig. E10. However, the 2000-2009 decade included several sources where dates of flooding were not specified, and as a result fewer location events (88) were taken in account than were excluded (123) for this decade.

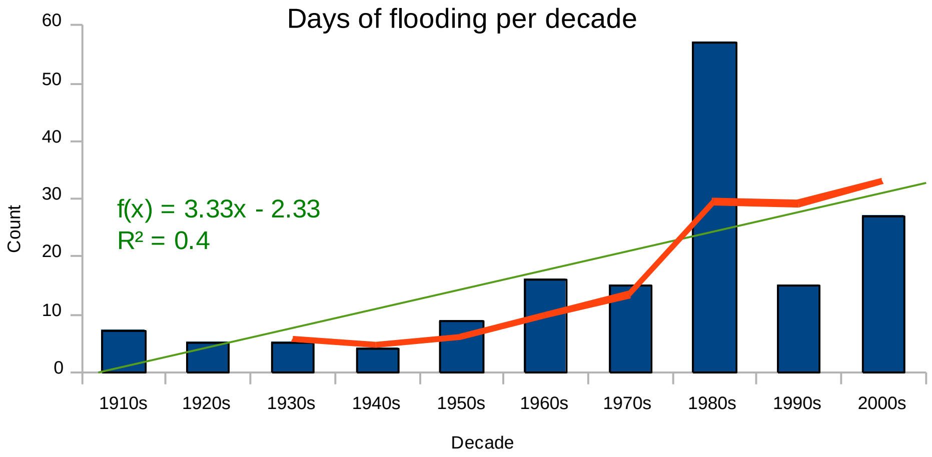


Fig. E10 Days with flooding per decade. 608 (79%) events are included. 160 (21%) events are excluded because no specific date was identified; 123 of those (16%) occurred in the 2000s. The green line represents a linear trend, and its equation and correlation coefficient (r^2 value) are given. The red line is a 30-year moving average

The relationship between the data in figures E9 and E10 is shown in Fig. E11, which depicts the number of locations impacted on those days when flooding occurred. The mean number of locations affected on a day when flooding occurred was 5.44, ranging from 2.74 in the 1980s to 8.8 in the 1920s. Despite having the second highest number of location events, the 1980s experienced the lowest impact per day because events were distributed across a greater number of days. The 30-year moving average shows limited variation from the 1950s onwards. The low r^2 value of 3% shows that the linear trend line cannot be used to predict future flood events. The value for the 2000-2009 decade is open to question. The results were taken by comparing dataset one, the number of locations events (766) with dataset two, the number of location events that could be allocated to a specific date (608). For most decades the number is similar, but in the 2000s, only 42% of the entries included in dataset one were also included in dataset two.

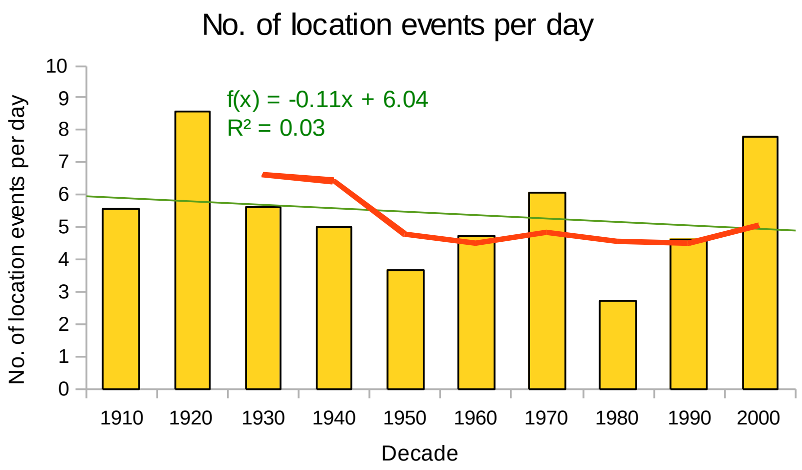


Fig. E11 Number of flooded locations on days when flooding occurred. 766 location events were included in the count of events. 608 events were included in the count of days on which flooding occurred. The green line represents a linear trend, and its equation and correlation coefficient (r^2 value) are given. The red line is a 30-year moving average

The number of days on which flooding occurred in each individual year is shown in Fig. E12. Flooding occurred in every year but one from 1977-1995, with 1982 experiencing the highest number of days with flooding (15). Every year from 2005 to 2009 also saw flooding, with 2006 having the second highest number of days with flooding (11). Based on this 100-year timescale, the city will undergo flooding at a mean rate of 1.7 days a year, although 43 of the 100 years experienced no recorded flooding. The number of locations affected by flooding in each year is shown in Fig. E13. The highest number of location events occurred in 2006 (57), with more than 40 locations also impacted in 1982 (49), 1980 (44), 1999 (43) and 1960 (42).

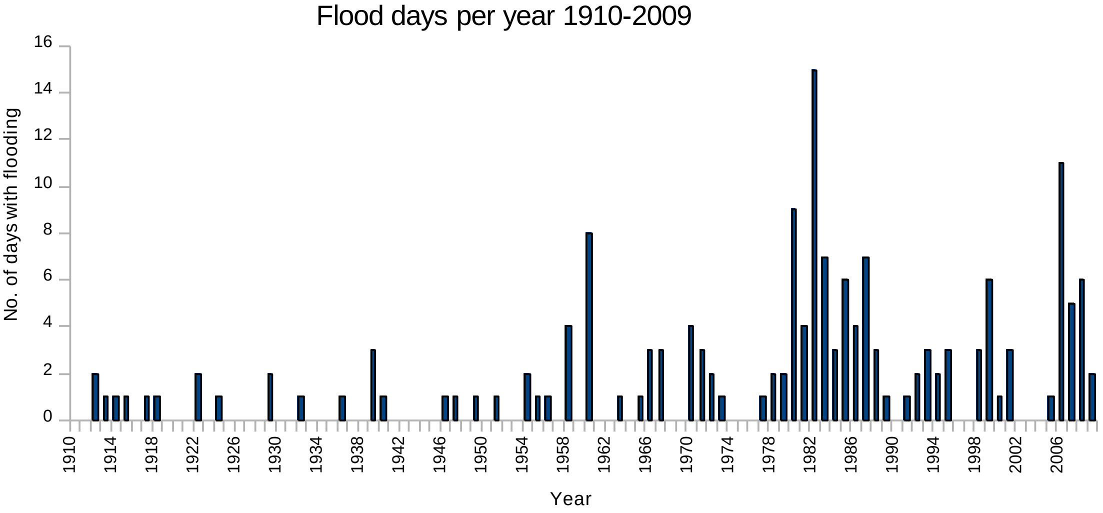


Fig. E12 No. of days on which flooding occurred in each year 1910-2009. 626 location events are included; those without an identifiable date or month (148) are excluded.

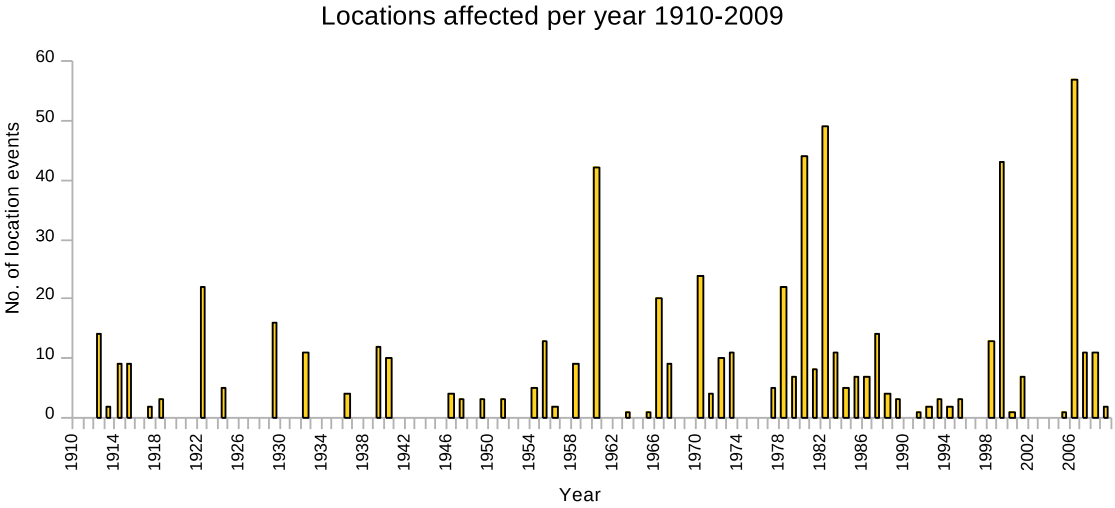


Fig. E13 No. of locations affected by flooding in each year 1910-2009. 626 location events are included; those without an identifiable date or month (148) are excluded.

Flooding was more likely to occur during the summer months (Fig. E14). August saw the highest number of flood events (17%), with July at 15% and June at 11%. Thus 43% of historical flood events occurred in summer. December had the next highest figure (9%). No month was defined for 148 events (19%), so these were excluded from the analysis. Only one occurrence of flooding during the 100-year period was recorded in a February.

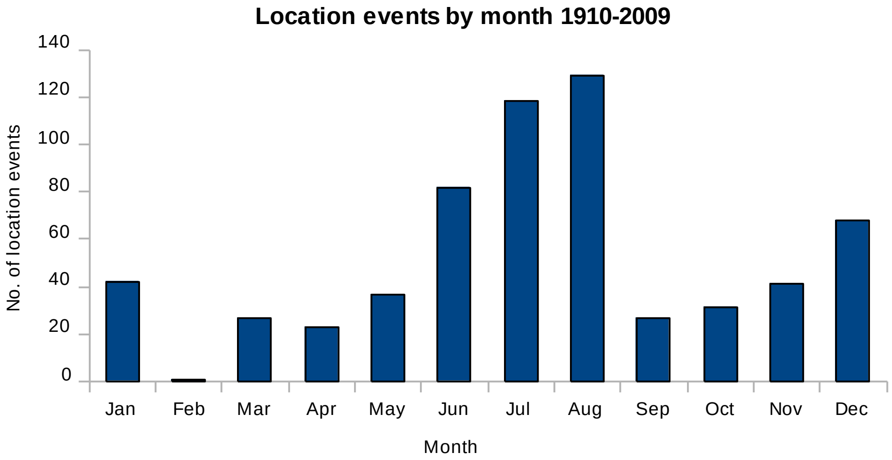


Fig. E14 Month in which flooding occurred. 626 location events were included. 148 events were excluded because no specific month was determined

Although there appeared initially to be some correlation between the number of flood events in a month (Fig. E14) and the rainfall in that month (Fig. E17), this was not found to be a strong relationship. A scatterplot of the count of flood events per month against the mean monthly rainfall resulted in r^2 values under 0.5. The association in the 100-year period 1910-2009 is shown in Fig. E15, while that for the 30-year period 1980-2009 is given in Fig. E16. The two periods show similar trends, and most points lay close to the trend line in both periods. The notable exceptions in both cases were the summer months of June, July and August, which lay above the trend in both periods. It is likely that additional or alternative factors accounted for the increased incidence of flooding in summer months. Further limitations and sources of error relating to historical floods are addressed in section E1.3.

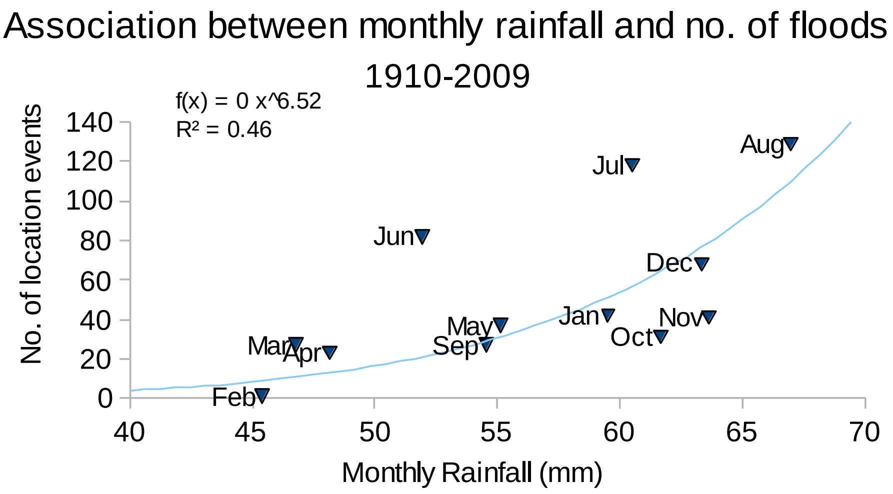


Fig. E15. Correlation between mean monthly rainfall 1910-2009, and count of monthly flood events 1910-2009. A power trend had the largest r^2 value of 0.46.

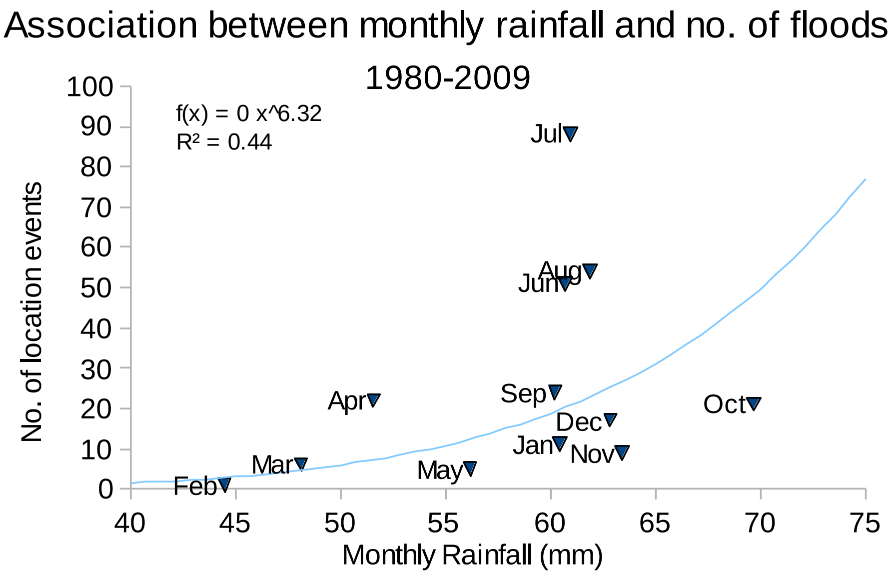


Fig. E16. Correlation between mean monthly rainfall 1980-2009, and count of monthly flood events 1980-2009. A power trend had the largest r^2 value of 0.44.

Fig. E17. Precipitation in Coventry in periods covered by the flood analysis. Data source: Bablake Weather Station (2013)

E.3 Sources of uncertainty

Several factors influenced the uncertainty associated with historical flood data. The first was the lack of a single source of flood events, so data were compiled from a number of sources. A significant implication of this was the reliance on these sources to record all events. In practice, it was clear from cross-validation that this did not happen. Many of the events were present in only one or two sources. Validation of events present in only one source was not possible. It is inevitable that some events have not been recorded at all. One major source was the local press, which required manual searches of microfiche archives. Consequently, some events will have been missed by the labour-intensive nature of these searches. The collected flood records showed a bias towards more recent events, reflected in the large number of records from the most recent decade, 27% of the total. The focus by this author was also on searching for events from 1980 onwards.

The location of some events was imprecisely recorded. This was particularly true of press reports. In some instances, where the event was associated only with a street name, its geographic location was assumed, usually on the basis of topography. In other cases, event descriptions were sufficiently vague as to warrant exclusion. For example “roads in low lying places” (Coventry Evening Telegraph 1954:9) and “hundreds of calls about flooded properties” (Coventry Evening Telegraph 1960b:1) proved too challenging a description for any meaningful map location, despite the likely severity of the events.

A consequential error could arise if the point of flooding was wrongly placed or omitted when being added to the historical floods GIS database. Cross checks for illogical locations and validation against spreadsheet records allowed some instances to be detected and corrected.

Frequently, records did not identify the full impact of an event in terms of the type of feature affected, *e.g.* internal property flooding, garden only. The scale of impact, *e.g.* the number of properties affected, was often unclear from the description.

The least well-defined information was the cause of events. This applied particularly to non-fluvial causes of flooding, where the range of possible causes and potential interactions between them led to difficulties in determining the exact origin(s) of flooding. One reason for this lack of certainty may be the desire to avoid apportioning responsibility for resolving the problem, and the resultant financial liability.

This study was not granted access to Severn Trent Water's DG5 register of properties at risk of sewer flooding based on historical events, as the register was considered commercially confidential. Some of these locations could be identified at a relatively coarse scale from Coventry City Council (2008b) and Jacobs Gibb Ltd (2008). In practice, DG5 registers do not include all affected properties (da Silva *et al*. 2008:7): some events are not reported by occupiers, and not all locations are recorded when a large number of properties are affected. The DG5 register is also not necessarily a guide to future surface water flooding (Douglas *et al*. 2010:211).The precise date of events was not always recorded. This was particularly true of recent City Council records, which were often compiled from officers' memories of events. In contrast, the City Council's flood index, covering events up to the late 1980s, was the most detailed record used, since at the time the Council were responsible for resolving the reported problems. Devolved responsibility for managing flooding in force until recently (see Appendix C, section 2.6.1) appears to have dissipated and reduced efforts to maintain detailed records of flooding locally.

Not all events in the City Council's flood index were transferred to the register of flood events used in the current research. The choice of records transferred was based on their status in an undated review carried out by City Council drainage engineers, at some time during the 1980s, to define those locations where the causes of flooding had been resolved by engineering works. Only those locations where flooding was noted as unresolved were used in this research. Because of the substantial work undertaken to improve and update the city's sewers in the 1960s and 1970s, all events prior to 1980 were also excluded.

Only 13 greenspace floods were recorded over 100 years (1.68% of total), despite the probability of greenspace flooding being higher than other types due to its proximity to rivers. This may reflect a lack of disruption caused by greenspace flooding, or even a perception that greenspace inundation should not be categorised as flooding. There were few instances of groundwater flooding, but nationally groundwater flooding is hampered by a lack of detailed data, which may result in part from the difficulty of identifying groundwater as the specific cause (Cobby *et al*. 2009:115). No flooding was recorded for 43 individual years of the 100 year period (Fig. E12). This fact may indicate gaps in data collection or recording rather than an absence of flood events.

F Appendix F – Data Collection details

This appendix gives details of the process steps undertaken to turn input data to a form that was useable in further analysis.

F.1 Land cover

F.1.1 Clip OSMM polygons to the city boundary

In order to analyse land cover in the city, an initial dataset was created using ArcGIS (ESRI 2006) containing only those features within the city boundary. The downloaded OSMM dataset consisted of different types of features: annotation, lines, points, symbols and polygons. Of these, land cover area and location could be derived from polygon features alone, so all features lying completely outside the city boundary were removed. Those partly inside and partly outside the required area were clipped to the boundary.

In practice the procedure to clip OSMM polygons to the city boundary was not straightforward. The ARCGIS software proved unable to process the large number of polygons in the downloaded OSMM dataset, and failed after several hours run time using straightforward Select and Clip commands. To solve this technical problem, a temporary dataset was created by copying all polygons in the dataset, then manually deleting all polygons inside the city boundary that were not close to the boundary, to leave an annulus of polygons along the city boundary. This left a reduced number of polygons that could be selected with the function 'crossed by the outline of' the city boundary (1111 polygons). These were then processed with the Clip command to cut overlapping polygons at the city boundary. The Clip execution failed because topology was not correctly defined in OSMM, due to, for example, the lines that formed polygons not joining, or because polygon boundaries were not coincident. These problems were partially resolved by running the Integrate command. The resulting data were then validated using the Check Geometry function. All 1111 polygons had 'unclosed rings', which indicated that the last defined point in each polygon did not join to the first point to form a complete shape. These problems were resolved by running the Repair Geometry function. As a result of repairing the geometry, the Integrate function needed to be re-run to ensure that polygon boundaries were coincident. With the updated dataset, this function did not execute successfully using ArcGIS v9.2. Consequently, the data were exported in a format compatible with the next release of ArcGIS, v9.3 (ESRI 2009), where the Integrate function executed without error.

Using ArcGIS v9.3, the clip to cut overlapping polygons at the city boundary was executed successfully, generating the expected 1111 polygons. Each of the reduced area 'clipped' polygons shared a unique identifier, the topographic ID (TOID), with the original unclipped polygons in the full dataset. The two datasets were joined by means of the TOID, using a selection by attributes where the TOID of the clipped polygons matched the TOID of their corresponding polygons in the full dataset. This enabled the changed polygons to be identified in the full dataset. The 1111 selected polygons in the full dataset, whose outlines crossed the city boundary, were deleted. The 1111 clipped polygons were then merged into the full dataset using the Append command, resulting in two sets of polygons, either completely within, or completely outside the city boundary. The remaining polygons that were completely outside the city boundary were deleted manually, leaving the 481,008 polygons that comprised the basis for area calculation and land cover characterisation inside the boundary of the city of Coventry.

F.1.2 Overlapping Polygons

North West Green Infrastructure Unit (2009:4) suggested that overlapping polygons could be identified as having field Descriptive Group containing the word “Landform” or field Physical Level = 51. These attributes enabled identification of three categories of features that overlaid other features, thus incorrectly increasing the notional area of the city. These duplicate features were categorised in the OSMM dataset as

- Description Group = Slope
- Description Group = Cliff
- Theme = Structures and Descriptive Term = Pylon.

F.1.3 Derivation of land cover classes from OSMM

The decision rules in Table F.1 were applied to derive the classes used in this study from the OSMM classification.

Table F.1. Characteristics in OSMM, and their combination into classes used in this study. Blank cells indicate all values were included

OSMM fields				**This study**
Theme	**Make**	**Description Group**	**Descriptive Term**	**Class**
Buildings				Buildings
Buildings; Roads Tracks And Paths				Buildings
Land	Natural		Marsh Reeds Or Saltmarsh	Water
Land	Natural		Marsh Reeds Or Saltmarsh; Scrub	Water
Land	Natural			Greenspace
Land	Manmade	Landform		Greenspace
Land	Manmade	General Surface		Road&Rail
Land	multiple			Gardens
Land	Unknown			Unclassified
Land	Unclassified			Unclassified
Land; Rail				Greenspace
Land; Roads Tracks And Paths		General Feature; Road Or Track		Road&Rail
Land; Roads Tracks And Paths		General Surface; Road Or Track		Road&Rail
Land; Roads Tracks And Paths		Natural Environment; Road Or Track		Greenspace
Land; Water				Water
Rail	Manmade			Road&Rail
Rail	Natural			Greenspace
Roads Tracks And Paths	Manmade			Road&Rail
Roads Tracks And Paths	Natural			Greenspace
Roads Tracks And Paths	Unknown			Greenspace

OSMM fields				This study
Theme	**Make**	**Description Group**	**Descriptive Term**	**Class**
Roads Tracks And Paths; Structures				Road&Rail
Structures			Upper Level of Communication	Road&Rail
Structures			[empty]	Road&Rail
Structures; Water				Water
Water				Water

F.1.4 Garden land cover validation dataset

Land cover in gardens was determined from a visual assessment of photographic images (Geoperspectives 2009) for samples of detached, semi-detached and terraced housing in Coventry To obtain a random sample of houses, all polygons with land cover = building, and area > 25 and < 200 m^2 were selected. A trial selection of buildings determined that houses lay within this range. Each was allocated a sequence number, and a set of random numbers was generated in order to identify a sample of houses. New polygons were digitised to represent the different types of land cover on house plots and their associated gardens. These new polygons were defined using the land cover categories: buildings, paving, water and vegetation. It was not always possible to identify land cover in gardens precisely, particularly in areas of dense shade. Where land cover was not clear, it was assumed to be permeable. Newly created polygons were defined as belonging to front or back gardens, using the rules defined by Perry & Nawaz (2008:5), who differentiated back gardens on the one hand from front and side gardens on the other, as the latter were deemed nearer to roads, and therefore more likely to drain to public sewers. Statistical analysis of the garden data was undertaken using PASW (SPSS Inc. 2009). A median test was used to test the null hypothesis that house types had the same median garden area. The test makes no assumptions other than that the median is a valid measure of central tendency.

Garden land cover was adjusted to its component categories according to the proportions of house types determined from the 2001 census (ESRC Census Programme 2010):

buildings, paving, and water, leaving the land cover category 'garden' to include only the vegetated element.

F.2 Current and former industrial land

In order to create a generalised representation of current and former industrial land, the following procedure was undertaken. The data were supplied as a MapInfo TAB file, containing 2,696 polygons colour-coded as either industrial sites or ponds. The full dataset was imported into ArcGIS, where the colour value was assigned to a new field for each polygon. The ponds were then removed, leaving 1,562 industrial sites. The Integrate command was executed to resolve problems of invalid topology, prior to grouping adjacent polygons using the Dissolve command, which aggregated features based on specific data attributes. The resulting dataset contained a polygon covering much of the city centre and the industrial corridor running to the north. Individual industrial sites not adjoining other sites were retained at this stage. Since the dataset contained no unique attribute, then all features had been merged into one polygon containing multiple elements. This was split, using the Explode tool, into 1,051 individual polygons.

The area of each polygon was calculated, and small polygons under 1,000 m^2 were removed, leaving 501 polygons. The next step was to reduce these 501 to a smaller number of generalised polygons if they were located within a defined distance of each other. This functionality was provided by the Aggregate Polygons command, but this option was not available in ArcGIS, only in ESRI's mainframe ArcInfo product. No similar functionality was available in MapInfo either. The generalisation process was therefore performed manually. Holes within existing polygons, which were identified if a polygon had more than one sketch part, were removed. A 15 m buffer was created around each of the 10 largest polygons, and any enclosed polygons were removed. Groups of polygons within a distance of about 100 m of each other were combined manually. Any remaining polygons under 10,000 m^2 were removed, leaving 62 polygons, of which 21 were still unchanged from the original dataset. In order to generalise these, adjacent polygons were merged again, using an approximate buffer distance of up to 350 m. The result was 20 generalised polygons, of which one resembled the input dataset since it was not situated near any other industrial sites.

F.3 Depth to water table

In order to achieve full coverage of the city study area, rivers outside the city boundary were taken into account. River lines outside the city boundary were obtained from the

SFRA (Coventry City Council 2008b), and merged with lines of watercourses inside the boundary. However, ArcGIS could only determine spot heights for individual points. Therefore the merged river lines were converted to a raster dataset, which was then converted back to a point dataset. Spot heights (elevations) for each point were derived from the DTM, and the points were then interpolated to create a hydrologically correct water table surface (using algorithms based on Hutchinson 1989). The difference between the DTM heights and water table surface at each point gave a depth to the water table at that point.

F.4 Land ownership

Information on land ownership was available from Coventry City Council. Only the two major public landowners were identified: Coventry City Council and Whitefriars Housing Association. Land cover for the major landowners was calculated by selecting polygons in the classified land cover that intersected each of the two landowner datasets. The area of large roofs within land belonging to the two large landowners was determined by selecting building polygons > 200 m^2. An area of 14,715 m^2 (0.01%) of the city's land cover overlapped between these two owners. The seven largest overlapping features made up 95% of the total overlap area, and were principally housing, inside other blocks of Whitefriars owned housing. Therefore the overlapping area was allocated to Whitefriars ownership, and was removed from the City Council ownership area.

G APPENDIX G – STAKEHOLDER REVIEW COMMENTS

This appendix gives details of the comments received from consultees on draft versions of the SUDS feasibility maps and the land use decision support charts. This appendix contains the feedback issued to stakeholders. No further comments were received to this feedback after its issue.

G.1 SUDS feasibility maps

Stakeholder comments on SUDS feasibility maps, with responses, are in Tables G.1 (new developments) and G.2 (retrofit).

G.2 Decision Support charts

Stakeholder comments on SUDS decision charts, with responses, are in Table G.3.

Table G.1 Stakeholder comments and responses – SUDS maps for new developments

New developments	Comment	Response
Detention & retention	1. Division into above and below ground solutions is inflexible. Better to show one colour and indicate a hierarchy of above then below ground solutions	1. The intention underlying the map is that above ground, vegetated solutions, are preferable to below ground solutions, as the latter may require additional maintenance effort which may cause increased disruption in the future. The map currently differentiates a) locations suitable for 'detention solutions' where above ground, vegetated solutions can be implemented fairly readily using landscaping techniques, as compared to b) 'engineered detention solutions', where physical characteristics and/or historical land use make above ground vegetated solutions less suitable. The map provides more information by retaining that distinction as it indicates 'engineered detention' areas where more thought may need to be given to appropriate SUDS solutions. To encourage overground storage, the definitions of the two categories will be reworded to emphasise the 'engineered' rather than the 'underground' aspects of the engineered storage locations, and to indicate that landscaping may form part of overground storage (see also point 2 below). For example, an above-ground engineered solution may simply involve including a barrier such as an impermeable sheet to prevent infiltration, and then constructing an above-ground detention basin. In summary, the final version will include alternative wording for explaining the difference

New developments	Comment	Response
		between the two categories rather than altering their separation on the map. The hierarchy approach may be usefully included in planning guidance.
	2. Why not use overground storage, especially in the floodplain? Could reprofile land to increase storage in case of large / frequent events	2. Agreed that this is a reasonable approach, and is in line with 'water-compatible development' defined in the Technical Guidance to the National Planning Policy Framework (DCLG 2012 Table 2). Reprofiling would, in theory at least, not occupy additional land for stormwater management facilities since that land is flood zone 3. In such cases, it would be valuable to retain amenity value at such locations, so large, steep-sided basins would not be appropriate. Because the floodplain is likely to have a relatively high water table, detention / retention facilities could risk increasing the height of the water table leading to groundwater flooding. In these circumstances infiltration may be undesirable, and an engineered solution may be preferable to dispose of water to the watercourse.
	3. Risks with engineered solutions in floodplain – performance and inspection	3. Agreed, but this should not exclude their potential for consideration
	4. Engineered detention not appropriate in private	4. This may be true for large devices under 'public' management, but a means of encouraging

New developments	Comment	Response
	gardens	householder responsibility for stormwater management at the small scale is needed, so it may be possible for small devices to be installed in new developments, for instance in conjunction with rainwater harvesting techniques. Communicating information on the impact of development on flood risk and water quality may also be useful as a means of educating householders in management of stormwater on their properties. This should be a policy or a detailed planning decision, rather than a map recommendation of what might be possible.
Infiltration	1. Exclude Flood Zone 2 to take into account climate change allowance	1. Agreed – the maps will be updated
	2. Why is the water table 4 m? 2 m should be adequate	2. Measurements of the water table in Coventry were not available, so a simulation was created using a British Geological Survey procedure. Because of the lack of accurate data about existing groundwater levels, the BRE 365 (Soakaway Design) suggestion that a 3 m soakaway depth is acceptable, and Environment Agency guidance of a minimum 1 m depth between the base of infiltration devices and the water table, the 4 m depth was used for safety.
	3. Groundwater Source protection Zones (SPZ):	3. Groundwater source protection zones for Coventry can be seen on the Environment Agency's 'What's in your backyard?' website, and an explanation is available at

New developments	Comment	Response
	how complicated are they, what are the limits on infiltration; are contaminants present; is a separate SPZ map required?	http://www.environment-agency.gov.uk/homeandleisure/37833.aspx. A GIS copy of the SPZ map was used to create the infiltration SUDS map. The map selection criteria excluded areas of groundwater vulnerability and potential contamination. It is possible to overlay SUDS and SPZ layers in GIS to see the relationship between the two. In Coventry, no SUDS infiltration areas fall into SPZ 1, the inner protection zone; most of the areas suitable for infiltration fall into outer protection zones SPZ 2 and 3, at locations where groundwater vulnerability and potential contamination do not prevent infiltration.
Filtration	1. Private gardens unsuitable due to maintenance, policing and enforcement considerations	1. Location of private gardens on new developments is not known in advance. Agreed that large-scale filtration is unsuitable in private gardens, but householders could take individual responsibility for the run-off from their premises. In the spirit of the National Planning Policy Framework (DCLG 2012), point 17, bullet 7 ("contribute to conserving and enhancing the natural environment and reducing pollution"), this needs to be handled as a policy issue. Better water management by householders could be encouraged by alternative charging mechanisms for stormwater management in conjunction with implementation of SUDS measures by the Flood and Water Management Act (Act of Parliament 2010)
Conveyance	No comments	
Source Control	No comments	

New developments	**Comment**	**Response**
General	1. Colours not always suitable	1. Representation in GIS is flexible, so desired colours can be selected as required

Table G.2 Stakeholder comments and responses – SUDS maps for retrofit

SUDS type	**Comment**	**Response**
Detention & retention	1. Not suitable in private gardens, unless exceptional cases	1. This may be true for large SUDS devices under 'public' management, but a means of encouraging householder responsibility for stormwater management at small scale is needed
Infiltration	No comments	
Filtration	1. Not suitable in private gardens	1. This may be true for large SUDS devices under 'public' management, but a means of encouraging householder responsibility for stormwater management at small scale is needed
Conveyance	1. Suitable for public open spaces only 2. Not suitable in private gardens	1. Agreed, due to practical considerations of maintenance and definitions of responsibility. I will update the maps accordingly. However, it would be valuable to find a means of encouraging individual householder responsibility for stormwater management at the small scale. 2. Agreed – the maps will be updated
Source Control	1. Sub-surface storage not appropriate in private gardens	1. This may be the case for large SUDS devices under 'public' management, but a means of encouraging householder responsibility for stormwater management at small scale is needed. If there is sufficient space in a garden, it should be possible to include storage facilities that will not affect building foundations

Table G.3 Stakeholder comments and responses – SUDS decision charts

Decision Chart	Comment	Response
Housing - terraced	1. No need to differentiate house types; scale of development is the important factor 2. swales, filter strips, detention basins and underground storage not appropriate for private gardens	1. Scale of development will influence the likelihood of implementing SUDS schemes, with larger schemes having more scope to design in appropriate solutions. However, even small-scale developments should implement some form of stormwater management. The space available for SUDS will be influenced by the density of development and therefore there is a need to differentiate housing densities. Consequently, the three 'house type' charts will be renamed to high, medium, and low density rather than terraced, semi-detached and detached, using the densities employed in Coventry City Council's Strategic Housing Land Availability Assessment (SHLAA) September 2011 Review (CCC 2011a, section 4.23). This terminology should be meaningful as the primary use is for planning purposes. The scale of development is already reflected in the x-axis options. 2. Swales – agreed. Filter strips, detention basins and underground storage – these should be an option, in order to encourage householder engagement with and individual responsibility for stormwater management

Decision Chart	**Comment**	**Response**
Housing – semi-detached	1. swales, detention basins and underground storage are not appropriate for private gardens 2. ponds are acceptable in public open space	1. Swales – agreed. Detention basins and underground storage – these should be an option, in order to encourage householder engagement with and individual responsibility for stormwater management 2. Agreed. This is already reflected in the charts
Housing – detached	1. underground storage should not be used 2. swales, bioretention, filter strips, ponds, detention basins and wetlands are all OK in public open space	1. Agreed that using above ground storage is preferable, but circumstances may dictate that there are no suitable alternative options. Underground storage could be integrated into a rainwater harvesting facility. 2. Agreed. These are already reflected in the charts
Commercial inner-city	1. Special case in city centre as all water is discharged	1. Not all runoff in the city centre is currently discharged into the R. Sherbourne. However, it is desirable to discharge treated runoff into the river, and consequently a means of

Decision Chart	**Comment**	**Response**
	into R. Sherbourne, so not clear that conveyance is required 2. needs more soft landscaping and open space	conveyance is necessary. Rather than vegetated swales, engineered rills may be preferable in this setting, and a number of the decision charts will be updated to include this option. 2. Agreed. The only additional vegetated SUDS devices that may be suitable are detention (but not retention) basins and filter strips. Filter strips, shallow sloping strips of vegetation aimed at improving water quality, are unlikely to be practical in an inner-city setting with high pedestrian traffic. Grassed areas could be landscaped to form detention basins, but will temporarily hold standing water that will drain down over a period of, say, 24 hours – this may not be desirable in an inner-city environment. Therefore, in SUDS terms, the options presented are the feasible ones. It is valuable to encourage soft landscaping and open space in the inner city, but this is a policy rather than a SUDS mapping issue.
Commercial outer-city with parking	No comments	
Industrial	1. underground storage – use hierarchy of techniques to	1. The charts are intended to reflect the possible options. The promotion of above-ground storage, and the associated hierarchy, needs to be defined in planning policy.

Decision Chart	**Comment**	**Response**
	promote above ground storage	
Roads & car parks	No comments	
Recreational area – small	No comments	
Recreational area - large	No comments	

H. Appendix H – Review of Gardens

This appendix compares the characteristics of gardens in Coventry to gardens in other cities to determine similarities and differences.

H.1 Comparison of Coventry Gardens with other UK cities

Coventry's garden land cover was at the lower end of the range of UK studies (Fig. H.1), although not disproportionately different. In general, garden land cover decreased as the spatial scale of the research increased. Mean and median garden sizes in Coventry were comparable with other UK cities (Table H.1), as were the sizes of gardens associated with different house types. Detached houses had the largest gardens, and terraced the smallest, in all cities studied. The proportion of garden area per house type was similar to the five UK cities studied by Loram *et al*. (2007), although in comparison to London, Coventry had more terraced and fewer semi-detached houses. In all five cities investigated by Loram *et al*. (2007:609), as in Coventry, terraced houses formed the largest share of the housing stock. But, given their larger size, gardens of semi-detached houses in Cardiff, Leicester and Oxford, as in Coventry, comprised the largest element of garden land cover in these cities.

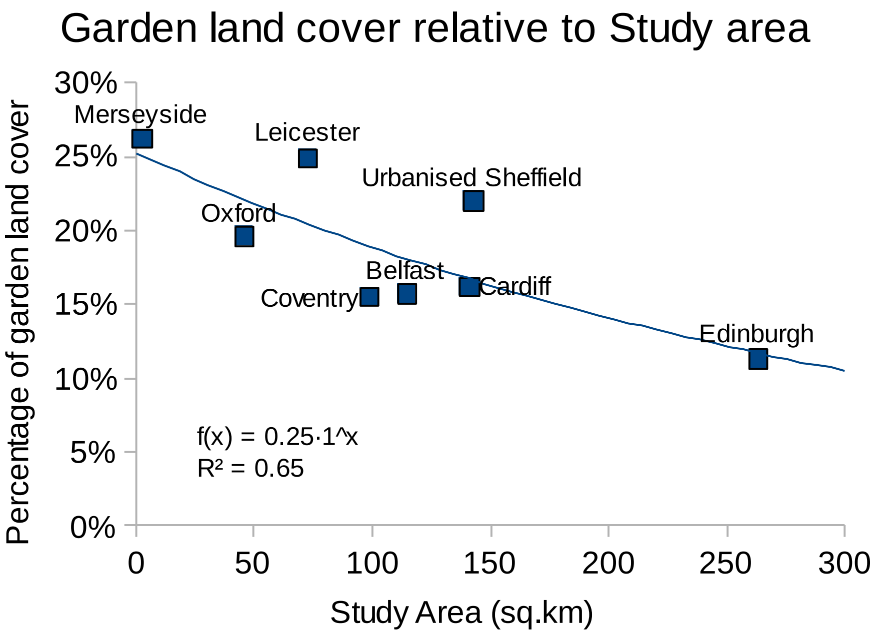


Fig. H.1 Garden land cover relative to study area. An exponential trend showed the best fit to the plotted points. Data sources - see Table H.1

Detached and semi-detached front gardens had a larger impermeable than permeable area. In practical terms this may be understandable. Terraced front gardens in Coventry were quite small (mean 24.5 m^2, median 21.0 m^2), possibly insufficient to offer alternative uses such as off-road car parking. In contrast, the front gardens of semi-detached and detached houses were large enough to provide off-road parking, and had often been adapted for this purpose in the Coventry sample. In Leeds, Perry & Nawaz (2008) drew similar conclusions about the use of front garden space in their study of mainly semi-detached housing. Increased car ownership and the difficulties of on-street parking are important drivers of the trend for paving front gardens (London Assembly Environment Committee 2005:10).

Front and rear gardens in Coventry made an approximately equal contribution to the extent of impermeability in the city. Rear gardens were omitted from the 2008 change to permitted development, yet in Coventry, impermeable areas in rear gardens covered 3.7 km^2, slightly more than the existing area of front gardens. A crucial question, which required information unavailable to this study, was quantification of the volume of runoff retained in gardens versus the volume delivered to sewers. The Flood and Water Management Act (Act of Parliament 2010:54) has taken a stance that paving in rear gardens can generate runoff to sewers, as it specifically cites construction of patios as requiring planning approval in future, although the way in which this will be achieved is yet to be precisely defined.

The impermeable area of front gardens covered 3.35 km^2 (3.4%) of the city's land cover, and so would contribute a substantial element of runoff. In Leeds (Perry & Nawaz 2008), the impermeable area of front gardens covered 6.5% of the 1.16 km^2 study area. Perry & Nawaz (2008:10) considered the extent of paving of front gardens in their Leeds study to be “exceptional”, and a contributory factor to the increased recent incidence of local flooding. It was certainly almost double the 3.4% of the Coventry sample and 3-4% in London (Table H.2). The lower impermeable front garden cover in Coventry may be due to the wider mix of housing types included than in Leeds, where the sample was principally (88%) semi-detached bungalows in an area with relatively high socio-economic status. In Coventry the figure was offset to some extent by impermeable rear gardens (3.7% of the study area compared to 3% in Leeds). Another contributory factor may be the smaller spatial area of the Leeds study. Coventry's front garden impermeability was similar to London's (Table H.2), although given Coventry’s smaller study area, impermeable surfaces in front gardens were a more significant land cover. The noticeable feature of Table H.2 is the lack of comparable UK information on garden permeability, and further research on this topic would bring greater clarity.

The RHS analysis of front garden impermeability throughout Great Britain (*ca*.2005:3) identified that 21% of front gardens in the West Midlands were more than three-quarters paved, but did not explain the methodology used to determine this figure. In the current study of Coventry, 29% of front gardens were over three-quarters paved, larger than the RHS estimate, but still within the wide 14-47% range for regions of Great Britain as a whole. This difference could be accounted for by differences in methodology, study area and sample size, but also because of increased paving of front gardens since the RHS survey.

Table H.1 Comparison of garden sizes in UK cities.

Location	**Sheffield**	**Edinburgh**	**Belfast**	**Leicester**	**Oxford**	**Cardiff**	**Leeds**	**London**		**Coventry**
Attribute	Gaston *et al*. (2005)	------------------- Loram *et al*. (2007) --------------					Perry & Nawaz (2008)	London Assembly Environment Committee (2005)	Smith *et al*. (2011)	This study
Sample size	218	517	513	519	507	547	100	14 samples of 500m^2	646	59
Mean garden size (m^2)	151	155 to 253							200	223
Median garden size (m^2)	140	213	96	145	162	159				146
Mean front garden size (m^2)		41.8							56	58.9
Mean rear garden size (m^2)		79.5							150	163.7
Terraced gardens (m^2)		84 ^{1}					40-100			86.1 ^{1} (0-225)
Semi-detached gardens (m^2)		213.5 ^{1}					140-1500			244.5 ^{1} (141-717)
Detached gardens (m^2)		364.8 ^{1}								325.4 ^{1} (117-1797)

Location	**Sheffield**	**Edinburgh**	**Belfast**	**Leicester**	**Oxford**	**Cardiff**	**Leeds**	**London**		**Coventry**
Attribute	Gaston *et al*. (2005)	------------------- Loram *et al*. (2007) --------------					Perry & Nawaz (2008)	London Assembly Environment Committee (2005)	Smith *et al*. (2011)	This study
Ratio front:back garden area		1:2						1:4-5	1:2.5	1:3
Front gardens as % of total garden area		26-38%						17-20%	24.8%	26%
Proportion of total garden area contributed by										
Detached		0.13						0.15		0.11
Semi-detached		0.32						0.58		0.32
Terraced		0.55						0.29		0.57

Notes

[1] median value

Table H.2 Permeability of house plots and gardens

Attribute	**London**	**London**	**Leeds**	**West Midlands**	**Munich**	**Coventry**
	Smith *et al*. (2011)	London Assembly Environment Committee (2005)	Perry & Nawaz (2008)	RHS (ca.2005:3)	Pauleit & Duhme (2000)	This study
Impermeable % of front gardens	63%	67%				57%
Impermeable area of front gardens as % of study area	3%	4%	6.5%			3.4%
Impermeable area of rear gardens as % of study area			3.0%			3.7%
Garden impermeable area (m^2)			53.4			70.0
Front gardens over 75% paved		14% [1]		21%		29%
Terraced plot % impermeability					46%	46%
Semi-detached plot % impermeability						61%

Attribute	London	London	Leeds	West Midlands	Munich	Coventry
Detached plot % impermeability					31%	53%

Notes [1] data source: RHS (ca.2005:3)

I. Appendix I – Decision Support Graphics

This appendix gives details of the methodology used to create the decision support graphics, and the resulting outputs.

I.1. Methods

The decision support charts were intended as a rapid reference point for development planners. The guidance in Woods Ballard *et al*. (2007), Dickie *et al*. (2010:56) and Digman *et al*. (2012) indicating suitable SUDS for different types of land use was synthesised into a single page summary for eight urban land use types (Table I.1), simplified from the urban morphology types defined by Gill *et al*. (2007:117). Suitable devices for different sizes of development were portrayed, and a classification into hard and soft landscaping was made. The size and type of land use will impact the advised number of management train components, and this information was taken from Woods Ballard *et al*. (2007:3.12).

Table I.1. Urban land use types for which SUDS guidance charts were created

Urban land use type
Housing – high-density
Housing – medium-density
Housing- low-density
Commercial – inner city
Commercial – outer city
Industrial sites
Roads and car parks
Recreational areas

An overview of the process to create the SUDS guidance charts for Coventry is presented in Fig. I.1.

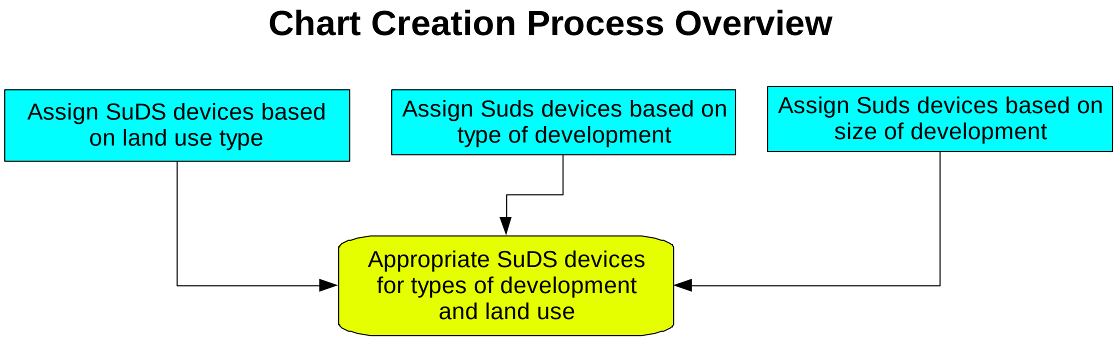


Chart Creation Process Overview

Fig. I.1 Process to create SUDS guidance charts

Stakeholders from a range of organisations were consulted for comments on draft versions of the SUDS decision charts – see section I2.1.

I.2.Results

Groups of SUDS techniques suitable for eight land use types were created, intended as a rapid overview of suitability for different types of development:

- Housing – high-, medium- and low-density (Fig. I.2)
- Commercial – inner-city, outer-city with parking (Fig. I.3)
- Industrial; roads and car parks (Fig. I.4)
- Recreational areas (Fig. I.4).

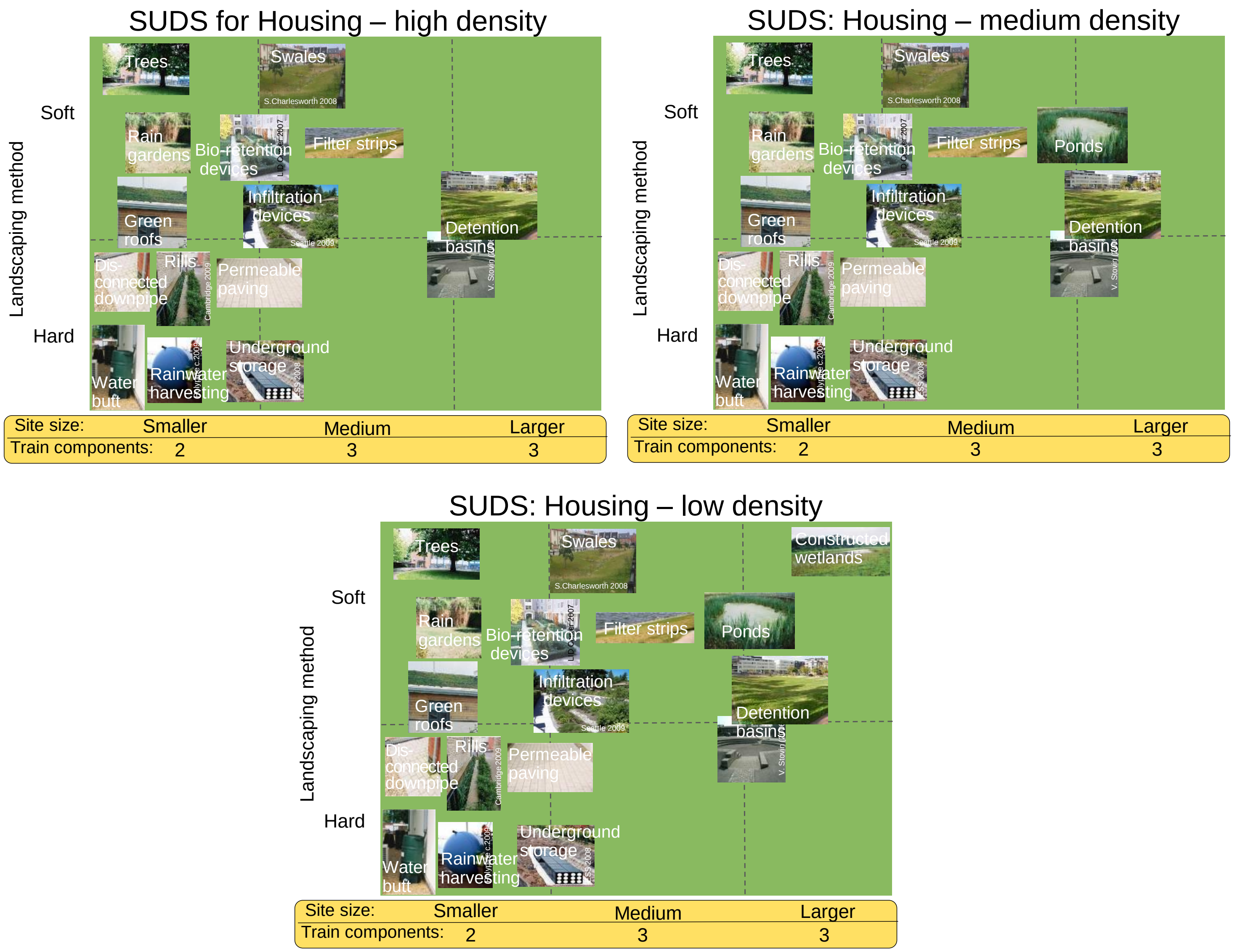
The graphical presentation shows options suitable for hard and soft landscaping, across different sizes of development, and also indicating the likely number of components of the management train. The diagrams expand the recommendations given by Dickie *et al.* (2010:56), but are at a reduced level of detail compared to those in Digman *et al.* (2012).

The single page reference guides were intended to show that SUDS were possible in all types of development. The options for small sites are also available for medium and large developments. Lack of space on the charts leaves apparent gaps for medium and large developments, and it might be interpreted that no SUDS devices are suitable, whereas the intention was that all SUDS appropriate at the smaller scale are also applicable at larger scales.

I.2.1. Stakeholder Validation of SUDS decision support charts

Comments from Coventry City Council, the Environment Agency, Severn Trent Water and Coventry University were received on draft versions of the SUDS decision charts. These comments are collated and summarised in Appendix G, together with the responses given to consultees. Most comments (89%) applied to housing and commercial development. This is likely to reflect current planning focus in the city. As a result of the comments, a number of adjustments were made to the charts, and these changes are incorporated in the versions presented in this document.

The main change effected as a result of comments was to redefine the categorisation of housing. Initially portrayed as different types of housing, terraced, semi-detached and detached, the consensus from respondents was that housing, in planning terms, should be considered in terms of dwelling densities.



SUDS for Housing – high density

SUDS: Housing – medium density

SUDS: Housing – low density

Fig. I.2 SUDS decision support charts – housing. Options for high, medium and low density housing are shown separately.

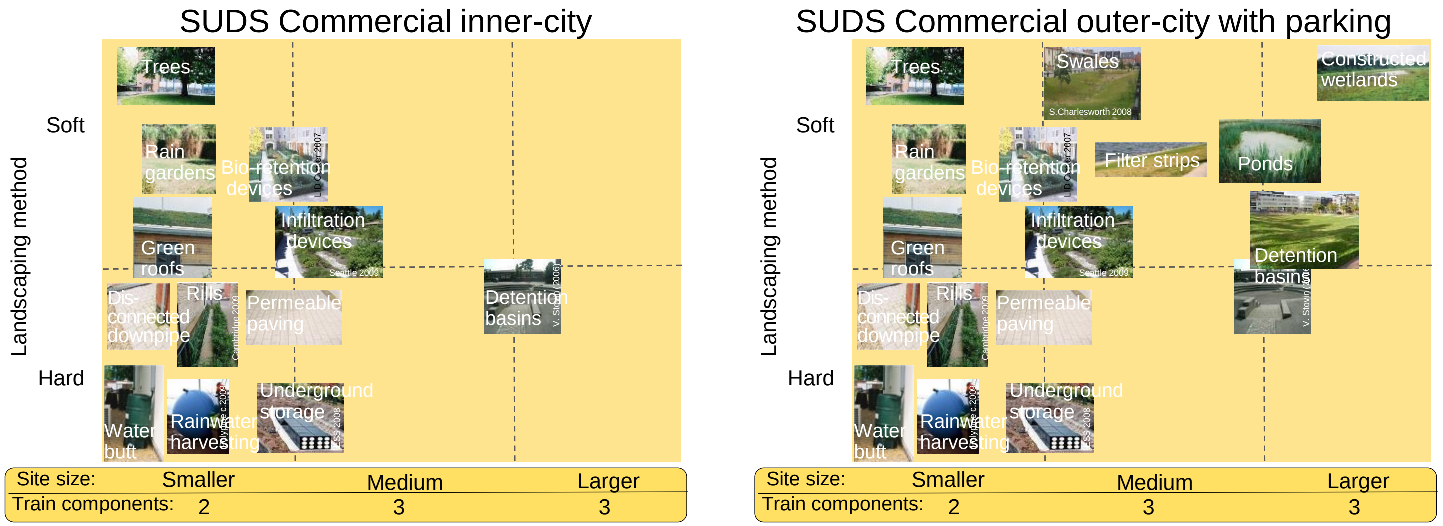
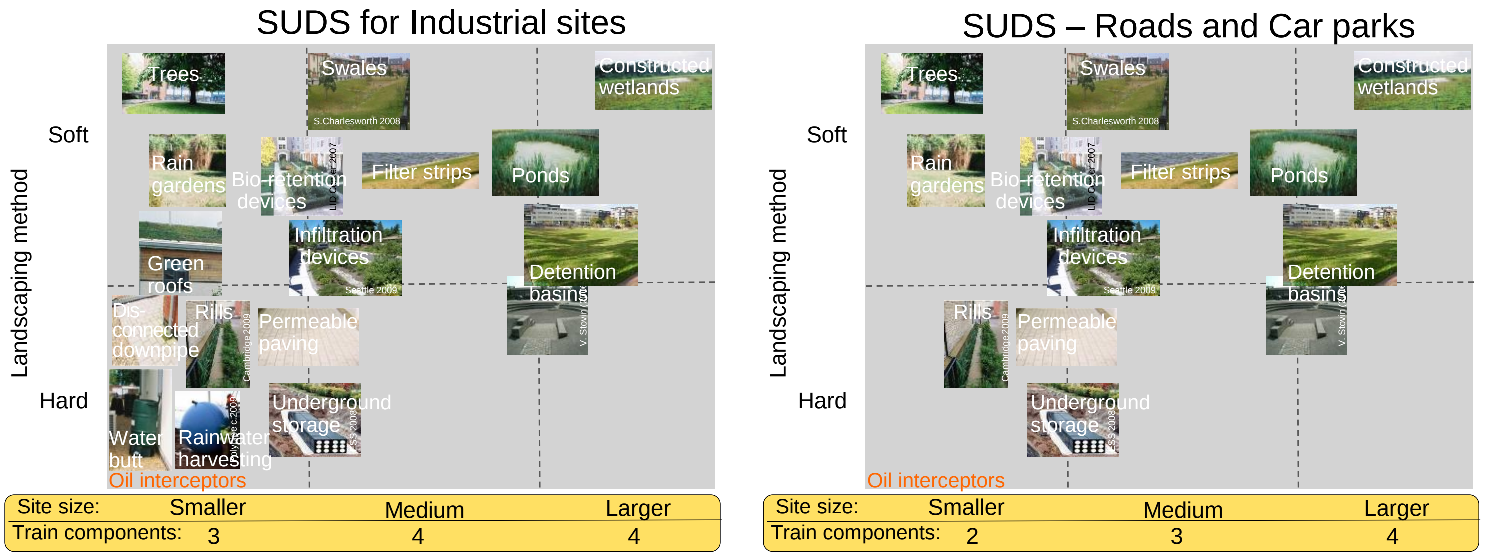


Fig. I.3 SUDS decision support charts - commercial sites



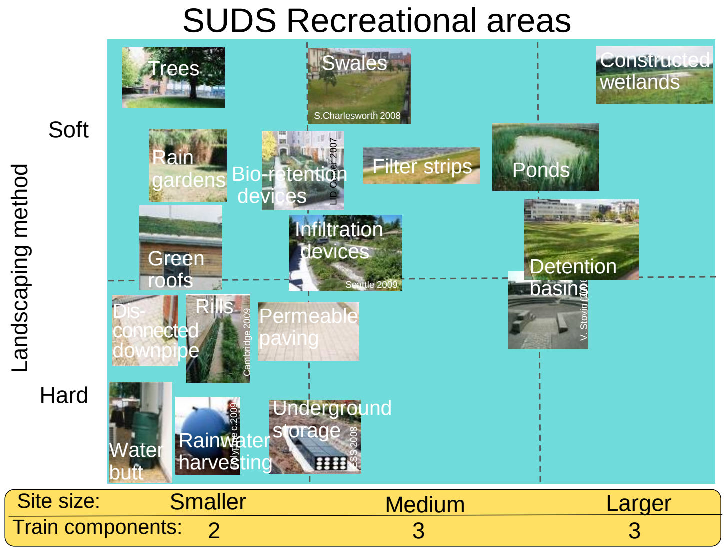


Fig. I.4 SUDS decision support charts - industrial, traffic and recreation sites

J. Appendix J: Hydrological Equations

J.1. Runoff

J.1.1. Greenfield runoff rate

$$QBAR_{rural} = (1.08*50^{0.89} \text{ x } SAAR^{1.17} \text{ x } SPR^{2.17}) *(AREA/50) \qquad \text{(Eq.J1)}$$

where

$QBAR_{rural}$ = mean annual peak flow (approx. 43% annual probability or 2.3 year return period (l s^{-1})

AREA = study area (ha)

SAAR = standard average annual rainfall 1961-1990 (mm)

SPR = Standard Percentage Runoff coefficient as a weighted sum of soil class fractions.

Since the formula should not be applied to areas under 50 ha, Qbar is calculated for 50 ha and the result for the smaller area is extrapolated linearly.

Sources: HRW (2008); Marshall & Bayliss (1994:37); Woods Ballard *et al*. (2007:4.5)
Note that the version of the equation in Defra & Environment Agency (2007:13) is incorrect. The multiplication by 1000 has already been factored in by revising the original value ‘0.00108’ specified in Marshall & Bayliss (1994:Eq7.1) to ‘1.08’.

J.1.2. Greenfield runoff rate per unit area

QBAR per unit area (l s^{-1} ha^{-1}) = QBAR / AREA (Eq.J2)

where the terms are defined for Eq.J1.

J.1.3. Peak discharge rate of runoff per unit area

The Peak discharge rate of runoff per unit area was calculated for 1yr, 30yr and 100yr return periods.

$$Q1yr\ (l\ s^{-1}\ ha^{-1}) = QBAR/AREA * 0.85 \qquad \text{(Eq.J3)}$$

where

Q1yr = Peak discharge rate of runoff per unit area for 1yr return period ($l\ s^{-1}\ ha^{-1}$)

QBAR/AREA is the greenfield runoff rate per unit area from Eq J2.

$$Q30yr\ (l\ s^{-1}\ ha^{-1}) = QBAR/AREA * GC30 \qquad \text{(Eq.J4)}$$

where

Q30yr = Peak discharge rate of runoff per unit area for 30year return period ($l\ s^{-1}\ ha^{-1}$)

QBAR/AREA is the greenfield runoff rate per unit area from Eq J2

GC30 is the growth curve ratio for the 30 year event for hydrological region 4 = 1.87

$$Q100yr\ (l\ s^{-1}\ ha^{-1}) = QBAR/AREA * GC100 \qquad \text{(Eq.J5)}$$

where

Q100yr = Peak discharge rate of runoff per unit area for 100year return period ($l\ s^{-1}\ ha^{-1}$)

QBAR/AREA is the greenfield runoff rate per unit area from Eq J2

GC100 is the growth curve ratio for the 100 year event for hydrological region 4 = 2.57

Source : Defra & Environment Agency (2007:13). Growth curves were obtained from Defra & Environment Agency (2007:46)

J.1.4. Runoff Volume

$$\text{Runoff Volume} = PR * AREA * P \qquad \text{(Eq.J6)}$$

where

PR = Percentage runoff (see sections J1.5, J1.6 and J1.8)

AREA = catchment area

P = rainfall depth (mm)

J.1.5. Fixed Percentage greenfield runoff

$$PRrural = SPR + DPRcwi + DPRrain \qquad \text{(Eq.J7)}$$

where

PRrural = Total percentage runoff for the greenfield site for a particular event

SPR = Standard Percentage Runoff coefficient as a weighted sum of soil class fractions = 47

DPRcwi = dynamic component of percentage runoff = 0.25 (CWI - 125)

CWI = catchment wetness index, a function of SAAR = 106

DPRrain = dynamic component that increases runoff for large events = $0.45*(P-40)^{0.7}$ for P > 40mm

P = rainfall depth (mm)

Source: Woods Ballard *et al*. (2007:4.8)

J.1.6. Variable Percentage greenfield runoff

$$PRrural = SPR + DPRcwi + DPRrain \qquad (Eq.J8)$$

where

PRrural = Total percentage runoff for the greenfield site for a particular event

SPR = Standard Percentage Runoff coefficient as a weighted sum of soil class fractions = 47

DPRcwi = dynamic component of percentage runoff = 0.25 (CWI - 125)

CWI = catchment wetness index, a function of antecedent rainfall and soil moisture deficit = 64 in summer, 125 in winter

DPRrain = dynamic component that increases runoff for large events = $0.45*(P-40)^{0.7}$ for P > 40mm

P = rainfall depth (mm)

Source: Woods Ballard *et al*. (2007:4.9&4.18)

J.1.7. Modified Rational method

$$Q= 2.78\ CiA \qquad (Eq.J9)$$

where

Q = Design peak runoff (l/s)

C = Non-dimensional runoff coefficient = CvCr

Cv = Volumetric runoff coefficient PR/PIMP

PR = Percentage runoff calculated as per Appendix J1.8

PIMP = Percentage impermeability (0 – 100) determined for each sub-catchment

Cr = Dimensionless routing coefficient (1 to 2), fixed value recommended for design = 1.3

i = rainfall intensity for the design return period (mm hr^{-1}) and for a duration equal to 'time of concentration' of the catchment. For design purposes, a conservative value of 50 mm was assumed

A = Catchment area (ha)

Sources: Butler & Davies (2004); Woods Ballard *et al*. (2007:4.13-4.14)

J.1.8. Wallingford Fixed procedure percentage runoff

$$PR = 0.829PIMP + 25SPR + 0.078UCWI - 20.7 \qquad \text{(Eq.J10)}$$

where

PR = Percentage runoff

PIMP = Percentage impermeability (0 – 100) determined for each sub-catchment

SPR = Standard Percentage Runoff coefficient as a weighted sum of soil class fractions = 47

UCWI = Urban catchment wetness index, a function of antecedent rainfall and soil moisture deficit = 64 in summer, 125 in winter

Sources: Butler & Davies (2004); Woods Ballard *et al*. (2007:4.13-4.14)

J.2. Storage Volumes

J.2.1. Defra & Environment Agency Treatment Volume

$$Vt = 9A * M_5 60 * (SPR/2 + (1 – SPR/2) * \beta\ PIMP/100) \qquad \text{(Eq.J10)}$$

where

Vt = Treatment Volume (m^3)

A = Sub-catchment area (ha)

$M_5 60$ = 5 year / 60 minute rainfall depth = 20 mm

SPR = Standard Percentage Runoff coefficient as a weighted sum of soil class fractions = 0.47

β = Proportion of impervious area requiring Treatment storage = 1.00

PIMP = Percentage impermeability (0 – 100) determined for each sub-catchment

Source: Defra & Environment Agency (2007:18)

J.2.2. HR Wallingford Attenuation Storage Volume

Attenuation Storage Volume sheet ASV2, equation 8 to determine Development mean annual peak flow (QBAR). The equation included a multiplication of the result by 1000, which was added as a modification of the previous version of the document (Kellagher 2004a), but this addition was not employed in the example in Appendix 2, nor in other flood risk assessments (e.g. DBA 2006, Taylor Wimpey 2008). It was considered incorrect and ignored

J.2.3. HR Wallingford Long-term Storage Volume

$$V_{XS} = RD \cdot * A \cdot * 10 \cdot * (PIMP/100 – SPR) \qquad \text{(Eq.J11)}$$

where

V_{XS} = Volume of additional runoff of development compared to greenfield rates (m^3)

RD = 1 in 100 year 6 hour rainfall depth

A = Sub-catchment area (ha)

PIMP = Percentage impermeability (0 – 100) determined for each sub-catchment

SPR = Standard Percentage Runoff coefficient as a weighted sum of soil class fractions = 0.47

Source: HR Wallingford (2008)

J.2.4. Woods Ballard *et al*. Long-term Storage Volume

$$V_{XS} = RD * A *10 * [(PIMP/100) * (alpha0.8)+(1-(PIMP/100) (beta*SPR) - SPR] \qquad \text{(Eq.J12)}$$

where

V_{XS} = Volume of additional runoff of development compared to greenfield rates (m^3)

RD = 1 in 100 year 6 hour rainfall depth = 63 mm

A = Sub-catchment area (ha)

PIMP = Percentage impermeability (0 – 100) determined for each sub-catchment

alpha = proportion of paved area draining to network/river with 80% runoff (values 0 to

1) = 1.0

beta = proportion of pervious area draining to network/river (values 0 to 1) = 0.3

SPR = Standard Percentage Runoff coefficient as a weighted sum of soil class fractions = 0.47

Source: Woods Ballard *et al*. (2007:4.23)

K Appendix K - Summary of presentations and publications

K.1. Presentations

K.1.1. Oral presentations

4.3.08 Faculty Research Student Symposium – Feasibility of Sustainable Drainage at Coventry University
Internal research student seminar. First prize

20.5.08 University Research Student Symposium – Feasibility of Sustainable Drainage at Coventry University
Internal research student seminar. First prize

22.7.08 SUDS Applied Research Group - Sustainable Drainage Feasibility on Coventry University Campus
Internal applied research group seminar.

28.8.08 Royal Geographical Society & Institute of British Geographers Annual Conference - Sustainable Drainage Feasibility on Coventry University Campus.

30.9.08 Hanson Formpave, Coleford
Sustainable Drainage Feasibility on Coventry University Campus.

17.11.08 Coventry City Council
SUDS Retrofit in Coventry city centre
Presentation to local authority planning department.

21.9.09 Royal Institute of Chartered Surveyors, Stafford
An introduction to sustainable drainage.

12.11.09 SudsNet national Conference
Planning for the bigger picture: the feasibility of sustainable drainage in Coventry, UK

20.11.09 SUDS Applied Research Group - Planning for the bigger picture: the feasibility of sustainable drainage in Coventry, UK
Internal applied research group seminar

15.4.10 Coventry multi-agency surface water management group (City Council, Environment Agency, Severn Trent. Whitefriars housing association)
Historical floods in Coventry, 30 minutes

24.11.10 Department of Land and Natural Resources, People’s Republic of China. Presentation on sustainable drainage to officials of the Department during their visit to the UK.

15.1.11 Coventry multi-agency surface water management group (City Council, Environment Agency, Severn Trent, Arup, Middlesex University)
Locations for Sustainable Drainage in Coventry

30.1.11 Locations for Sustainable Drainage in Coventry, 15 minutes. Presentation to Environment Agency Midlands Area Local Authority Forum

23.2.11 Retrofitting SuDS Workshop in WAPUG Training Day, Birmingham.
'Managing flood risk in a changing environment'.

11.5.11 Warwick, F. and Charlesworth, S.M. (2011) 'Think global climate change, act locally: the capture and storage of carbon in Sustainable Drainage (SUDS) devices using Coventry, West Midlands, UK as a case study'. SUDSnet conference presentation

13.7.11 Think global climate change, act locally: the capture and storage of carbon in Sustainable Drainage (SUDS) devices using Coventry, West Midlands, UK as a case study. Coventry University faculty of Business, Environment and Society internal conference.

29.7.11 Feasibility of sustainable drainage in Coventry: a status summary. Internal applied research group seminar

29.6.12 Decision support for SUDS Approval Bodies when assessing SUDS feasibility. Coventry University Faculty of Business, Environment and Society internal conference.

5.9.12 Decision support for SUDS Approval Bodies when assessing SUDS feasibility. SUDSnet international conference

22.11.12 Locations for SUDS in Coventry. Presentation to Coventry City Council officers.

K.1.2. Poster presentations

March 2009 Coventry University Faculty Research Student Symposium – SUDS in the city: is sustainable drainage feasible at an urban site? Second prize

June 2009 Coventry University Research Student Symposium
SUDS in the city: is sustainable drainage feasible at an urban site? Third prize

July 2009 Vitae Midlands Hub Poster Competition

SUDS in the city: is sustainable drainage feasible at an urban site?

February 2010 SUDS in the city: is sustainable drainage feasible at an urban site? Million+ Group of Universities. New Universities' Research launch at the House of Commons

June 2013 Warwick, F., Charlesworth, S. and Blackett, M. (2013) ‘Geographical information as a decision support tool for sustainable drainage at the city scale’. *Novatech conference*, Lyon, France

June 2013 Warwick, F., Charlesworth, S. and Blackett, M. (2013) ‘Geographical information as a decision support tool for sustainable drainage at the city scale’. Coventry University faculty of Business, Environment and Society internal conference. 2nd prize

K.2. Reports

21.7.10 Coventry City Council – “Historical Floods in Coventry. A report to Coventry's Multi-Agency Surface Water Management Group”

Short report summarising results of research into the locations of 100 years of floods in Coventry

26.7.10 Coventry City Council - “Historical rainfall patterns and climate change forecasts for Coventry”. Short report for Coventry City Council Sustainability Team

K.3. Publications in approximate date sequence

Charlesworth, S.M. and **Warwick**, F. (2011) 'Adapting and Mitigating Floods Using Sustainable Urban Drainage Systems (SUDS)'. Chapter 15 in Lamond, J., Booth, C., Hammond, F. and Proverbs, D. (Eds.) *Flood Hazards: Impacts and Responses for the Built Environment*. Boca Raton, Florida: CRC Press

Charlesworth, S.M. & **Warwick**, F. (2011) 'Addressing global climate change locally: capturing and storing carbon in Sustainable Drainage (SUDS) devices using Coventry, West Midlands, UK as a case study'. *IEMA Environmental Knowledge Exchange Conference* held 19th January 2011 at King’s House Conference Centre, Manchester. Available from http://www.iema.net/conferences/knowledge_exchange/2011/papers?aid=19855. Accessed July 2011

Warwick, F. and Charlesworth, S.M. (2011) 'Think global climate change, act locally: the capture and storage of carbon in Sustainable Drainage (SUDS) devices using Coventry, West Midlands, UK as a case study'. SUDSnet conference paper May 2011

Charlesworth, S.M., Nnadi, E., **Warwick**, F., Jackson, R., Oyelola, O. and Lawson D. (2011) 'Assessment of the use of green and food based compost for a use in a Sustainable Drainage (SUDS) device such as a swale'. SUDSnet conference paper May 2011

Charlesworth; S., Nnadi; E., Oyelola; O., Bennett; J., **Warwick**; F., Jackson; R. and Lawson, D. (2012) 'Laboratory-based experiments to assess the use of green and food based compost waste to improve water quality in a Sustainable Drainage (SUDS) device such as a swale'. *Science of the Total Environment* 424, 337-343

Charlesworth, S.M., **Warwick**, F. and Booth, C. (2011) 'Green Roofs and walls and climate change'. *Sustain Magazine*.

Lashford, C., Charlesworth, S.M., Blackett, M. and **Warwick**, F. (2012) Investigation of the use of a SUDS Management Train to reduce flooding in an urban environment. *GISRUK Conference*, Lancaster University 11th - 13th April 2012

Charlesworth, S.M., Booth, C., **Warwick**, F. and Lashford, C. (2012) 'Rainwater harvesting'. Chapter 14 in *Water Resources in the Built Environment – Management Issues and Solutions*. (Eds. Booth, C. and Charlesworth, S.). Oxford: Blackwell Publishing

Warwick, F. and Charlesworth, S.M. (2013) 'Sustainable Drainage Devices for Carbon Mitigation'. *Management of Environmental Quality* 24 (1), 123-136

Charlesworth, S.M., Perales-Momparler, S., Lashford, C. and **Warwick**, F. (2013) 'The Sustainable Management Of Surface Water At The Building Scale: UK And Spanish Case Studies'. *The Water Efficiency in Buildings Network Conference*. Held 25-27 March 2013, in Oxford, UK. Available from http://www.waterefficientbuildings.co.uk/55-240 [17 May 2013]

Charlesworth, S., Perales-Momparler, S., Lashford, C. and **Warwick**, F. (2013) 'The sustainable management of surface water at the building scale: preliminary results of case studies in the UK and Spain'. *Journal of Water Supply: Research and Technology – AQUA* 62 (8), 534-544

Lashford, C., Charlesworth, S., **Warwick**, F. and Blackett, M. (2014) 'Deconstructing the sustainable drainage management train in terms of water quantity; preliminary results for Coventry, UK'. *CLEAN – Soil, Air, Water* 42 (2), 187-192

Appendix L: Peer reviewed publication

This appendix includes the peer-reviewed journal article derived from this research and published before submission.

Warwick, F. and Charlesworth, S.M. (2013) 'Sustainable Drainage Devices for Carbon Mitigation'. *Management of Environmental Quality* 24 (1), 123-136.