Geographical information as a decision support tool for sustainable drainage at the city scale

L'information géographique comme outil aide à la décision pour un assainissement pluvial durable à échelle de la ville

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RÉSUMÉ
Des informations géographiques ont été analysées pour développer une série de cartes indiquant les emplacements possibles pour le drainage durable (SUDS) dans la zone spatiale entière d'une autorité gouvernementale locale en Angleterre. Les modifications apportées à la législation anglaise ont l'intention d'accorder une plus grande responsabilité pour évaluer et maintenir SUDS. Les cartes visent à fournir une orientation initiale aux planificateurs du développement et aux autres ministères du gouvernement local en ce qui concerne le type d'appareils SUDS convenant à des sites individuels dans une zone de planification. Une méthode de créer des cartes appropriées est expliquée, avec des exemples. La méthode a été testée avec une autorité locale anglaise, et l'application de méthodes et de principes vise à être plus largement applicables afin de réduire les obstacles à la mise en œuvre des techniques de gestion des eaux pluviales alternatives et plus durables.

ABSTRACT
Geographical information was analysed to develop a series of maps indicating feasible locations for sustainable drainage (SUDS) devices in the full spatial area covered by a local government authority in England. Changes to English legislation intend to place greater responsibility for assessing and maintaining SUDS on local government. The maps aim to provide initial guidance to development planners and other local government departments on the type of SUDS devices likely to be suitable at individual sites in a planning area. An appropriate method of creating suitable maps is explained, and examples of the output maps are given. The method has been trialled with an English local government authority, and the application of methods and principles is intended to be more widely applicable in order to reduce barriers to implementation of alternative, more sustainable stormwater management techniques.

KEYWORDS
Decision support, Development planning, Geographical information, Stormwater management, Sustainable drainage
1 INTRODUCTION

Sustainable drainage (SUDS) installations are increasingly recognised as potential contributors to address issues of stormwater flooding and poor water quality, and also have a role in climate change adaptation (Charlesworth 2010). This approach has received acceptance in a number of countries worldwide, for example USA, where it is referred to under the banner of Low Impact Development (LID) or Best Management Practices (BMP) (USEPA 2012a; USEPA 2012b), and in Australia as Water-Sensitive Urban Design (WSUD) (Donofrio et al. 2009).

The implementation of SUDS in England and Wales has not proceeded as rapidly as in some other developed countries. Possible reasons for this include: perceptions of problems relating to health and safety, cost, and difficulty; a lack of understanding of SUDS function and of transparency concerning responsibilities amongst stakeholders; and legislative, adoption and maintenance issues (see for example Coulthard & Frostick (2010); Douglas et al. 2010; Ellis & Revitt 2009; Gill 2008; Pitt 2008; Todorovic et al. 2008; White & Alarcon 2009). These issues reflect a reluctance to adopt more sustainable water management practices, a topic explored in greater detail by other authors, e.g. Farrelly & Brown (2011), Harries & Penning-Rossell (2011).

The Flood and Water Management Act (Great Britain Parliament 2010), has passed into law in England and Wales, and one provision is to increase the use of sustainable drainage methods; however, implementation of the Act in practical terms has been delayed compared with initial expectations. The legislation places responsibility on local government for design and construction approval, and for future maintenance, of sustainable drainage systems serving more than one property. On the whole, however, English local authorities have very limited experience of SUDS, and the small number of sites in England provides limited reference for information and support. A further barrier is the issue of funding for the envisaged additional administrative workload and ongoing maintenance, which has engendered a spirit of uncertainty in some local government bodies (e.g. Local Government Association 2012). Hence, the need for capacity building in local authorities has been recognised, as well as a requirement for high level information to support decision making.

The comparatively large geographic area covered by local government administrative bodies renders problematic the use of available technology to model potential SUDS. Previous research into decision support tools for application of SUDS has largely been carried out at the level of individual projects, e.g. Scholz (2006), SNIFFER (2006), Viavatene et al. (2010). The focus of these tools has often been to address specific concerns in relation to known requirements for or issues related to a housing, commercial or industrial development. However, planning of new urban construction contains an inherent level of uncertainty, because exact details of building and landscape form are unknown at the relatively early stages of planning discussions before designs are finalised. In these situations, a more generic set of information may be helpful.

The aim of the work described here was the development of a decision support tool to provide guidance to local planning authority officers in their initial discussions with developers about options for SUDS. This paper explains the process used to achieve this aim, and provides illustrative examples of the maps produced using geographical information, with reference to Coventry City Council, a local government authority in central England.

2 METHODOLOGY

The overall approach is described, followed by a more detailed explanation of the data and methodology used to create the decision support maps.

2.1 Overall Approach

Factors influencing the implementation of SUDS often have a spatial dimension. Combining these factors by means of a set of rules enables a graphical presentation of feasible locations for SUDS in the form of maps, which are readily understood by local government officers in the UK.

Previous mapping of potential sites for SUDS to guide local government planning in England has emphasised the need for infiltration, and has used a limited set of available data, e.g. Telford (Halcrow Group Limited 2008) and Ipswich (Ipswich Borough Council 2007). Larger scale geological mapping of the UK (Dearden & Price 2012) has also indicated the potential for infiltration SUDS. This focus on infiltration has not taken into account the unsuitability for infiltration in certain areas of England due to
ground conditions such as soil type and possible land contamination.

In order to validate the proposed approach employed in this study, an example set of maps was developed for the city of Coventry, in the English Midlands. The city covers 98.65 km², and has a population of around 315,000 (Coventry City Council 2011). The generated maps address new construction, on both new ‘greenfield’ sites and previously developed land, for 5 categories of SUDS: infiltration, detention, conveyance, filtration and source control.

The intention of this project was that data could be processed and results obtained using standard Geographical Information System (GIS) functionality without the need for additional programming, thus taking advantage of the familiarity of the target audience with known technology. An overview of the process is given in figure 1, and these steps are explained in more detail in this paper. Firstly, functional groupings of SUDS devices were compiled based on the standard SUDS reference work in the UK (table 1).

Figure 1. Overview of the map creation process showing the main steps for creating the SUDS maps. The numbers in each box refer to the sections in this paper where the process is explained in greater detail.

Table 1. Grouping of SUDS devices (after Woods Ballard et al. 2007), with examples for each category. SUDS devices frequently perform more than one function, so only the primary role of each device is shown here.

<table>
<thead>
<tr>
<th>SUDS device groupings</th>
<th>Example SUDS Devices – primary role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detention &amp; retention</td>
<td>Detention basin; retention basin; pond; wetland; engineered detention devices</td>
</tr>
<tr>
<td>Infiltration</td>
<td>Soakaway; infiltration basin; infiltration trench</td>
</tr>
<tr>
<td>Source Control</td>
<td>Green Roof; trees; rainwater harvesting; permeable paving; sub-surface storage; rain garden</td>
</tr>
<tr>
<td>Filtration</td>
<td>Sand filter; filter strip; filter trench; bioretention device</td>
</tr>
<tr>
<td>Conveyance</td>
<td>Swale, rill</td>
</tr>
</tbody>
</table>

2.2 Geographical Data

To determine the types of SUDS suitable in particular locations, the factors driving their feasibility in an urbanised local government area were evaluated. Table 2 shows the role of factors influencing the SUDS groupings defined in table 1. 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. Physical (environmental) factors included geology, soil, topography and the presence of water above and below ground level. Anthropogenic (human-induced) factors were related to definitions of groundwater protection near extraction boreholes, plus known and potential sites of groundwater contamination risk. Existing landcover and planning regulations may impact SUDS implementation over shorter timescales.

The spatial distribution of each factor was then determined. 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.

Table 2. Physical and anthropogenic Influencing factors on the siting of SUDS device groupings. The boxes marked ‘x’ (characteristics) identify the factors applied to each grouping. Factors were defined as ‘fixed’ if they were unlikely to vary significantly over timescales of more than 10 years, while those that may change in the shorter term were classed as ‘variable’.

<table>
<thead>
<tr>
<th>Fixed factors</th>
<th>Infiltration</th>
<th>Detention</th>
<th>Filtration</th>
<th>Conveyance</th>
<th>Source Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geology</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil drainage type</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Topography</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water bodies</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Fluvial flood zones</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Table</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inner Groundwater Source Protection Zones</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Known groundwater contamination sites</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sites of current and former industrial usage</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable factors</th>
<th>Infiltration</th>
<th>Detention</th>
<th>Filtration</th>
<th>Conveyance</th>
<th>Source Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land cover</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Planning constraints</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.3 Map Creation Method

A set of decision criteria (rules) were created for each of the characteristics listed in table 2. For example, different rock types were assessed in relation to their capacity for infiltration or detention of runoff. 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. Each item of geographical data was coded so that the rules could be applied spatially. The spatial relationships between characteristics listed in table 2 were then analysed using a GIS, in order to determine appropriate locations for the different types of SUDS for new developments and regeneration sites.
An example of one sub-process, for geological characteristics in relation to detention SUDS, is illustrated in figure 2. Rules indicating permeability and impermeability of underlying rock and superficial 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 2, namely water bodies, soil drainage type, topography, water table depth, known groundwater contamination sites and land cover. The full set of layers was then combined to determine suitable detention and retention sites based on all factors.

![Example of map creation sub-process for detention SUDS - geology](image)

**Figure 2.** Sample of the map creation sub-process in the GIS system using an example of geological data for the detention SUDS map. More and less suitable areas were determined independently, and their geographical overlaps were then removed.

### 2.4 Map Outputs

The resulting geographical outputs were represented in map form. The use of GIS ensured that the maps were scalable, 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.

### 3 RESULTS AND DISCUSSION

This section explains the application of the methodology to create guidance maps for an English local planning authority, and gives an example of the usage of the map guidance.

#### 3.1 Example application of the methodology

Application of the methodology in Coventry is shown firstly with reference to the maps used to identify suitable areas for detention and retention SUDS. Detention and retention SUDS are more likely to be effective where ground conditions reduce infiltration capacity, but with a sufficiently low water table so that flood risk is not increased by retaining water, and where topography is not steep enough to encourage downslope flow. Figures 3 and 4 show two of the intermediate product maps used to derive feasible locations for detention and retention SUDS. Figure 3 indicates less suitable areas for detention SUDS devices, calculated by applying the spatial rules for each of the relevant factors defined in table 2, while figure 4 identifies those locations where detention SUDS are more likely to be feasible.
Example SUDS Feasibility Maps - interim stage 1

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

Figure 3. Intermediate product map indicating less suitable locations for detention SUDS. Shaded regions show the less suitable areas. The geographical distributions of geology, soil, water table, topography and known areas at risk from pollution, for example, are combined to generate a single area of less suitable locations for detention.

Example SUDS Feasibility Maps - interim stage 2

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

Figure 4. Intermediate product showing more suitable locations for the detention SUDS map. Shaded regions indicate the more suitable areas, determined from soil, geology and topography, while excluding locations identified as less suitable from figure 3.
Interim maps were also calculated using the decision criteria for anthropogenic factors – these maps are not included in this paper. Once all interim maps were created, they were combined to generate a final map indicating suitable locations for detention and retention SUDS for the whole of the geographical area under study (figure 5).

### 3.2 Final map products

Of the 5 different SUDS groupings, only two, infiltration and detention devices, offer the capacity for large-scale storage or disposal of runoff. Coventry has limited potential for infiltration SUDS (figure 6), so further exploration of detention and retention was undertaken. The more suitable sites shown in figure 4 present the optimum conditions for above-ground vegetated installations. The less suitable locations (figure 3) require additional effort and/or expense to implement suitable SUDS. For instance, re-landscaping options could retain increased volumes of stormwater runoff, and underground storage tanks, while not ideal, could operate as rainwater harvesting systems to feed alternative water supplies, or could at least reduce flood risk as required by current planning guidance (Department for Communities and Local Government 2012). The balance between these 'engineered' solutions and vegetated SUDS is shown in figure 5. In Coventry, approximately one-third of the city's area is suitable for vegetated SUDS, while some form of engineered solution is likely to be necessary in two-thirds of the local authority area.
Potential implementation area for SUDS types

Majority of Coventry suitable for most SUDS types in new developments …

Local Planning Authority Area covered by SUDS Types

… very limited scope for infiltration SUDS

Figure 6. Areal extent of Coventry that is suitable for different types of SUDS in new developments. Most SUDS types can be utilised, except for infiltration SUDS where there is limited scope.

<table>
<thead>
<tr>
<th>Field</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deton Type</td>
<td>Vegetated</td>
</tr>
<tr>
<td>SUDS Small</td>
<td>Sub-surface storage; rainwater harvesting; bioretention device; swale</td>
</tr>
<tr>
<td>SUDS Med</td>
<td>Detention basin; retention basin; pond; sub-surface storage; rainwater harvesting; bioretention device; swale</td>
</tr>
<tr>
<td>SUDS Large</td>
<td>Detention basin; retention basin; pond; wetland; sub-surface storage; rainwater harvesting; bioretention device; swale</td>
</tr>
</tbody>
</table>

2. Individual SUDS devices listed in each grouping

3. More detail based on development size

Example Development Site

Figure 7. An example development site (indicated). On choosing the relevant 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)
Figure 7 illustrates the use of the full set of maps to support assessment of suitable SUDS devices at a specific site awaiting development in Coventry. Using standard GIS functionality to ascertain the spatial attributes associated with a location, in this case the potential development site, figure 7 lists the feasible SUDS for that location, categorised under the device groupings. Some SUDS features only operate effectively across wider spatial scales (Ellis et al. 2004), so appropriate devices are presented according to approximate size of the development.

The scope for implementation of the different types of SUDS in Coventry is shown in figure 6. While there is limited potential for infiltration SUDS in the city due to adverse ground conditions, this does not exclude the potential for many other SUDS devices.

4 CONCLUSION

Increasing use of SUDS in England will require local government to improve their understanding of stormwater management techniques. This paper explains a method to identify feasible locations for SUDS installations across a wider scale than is considered by most development and regeneration projects. The resultant maps are intended to support local government officers with their new responsibilities in assessing the use of SUDS in new construction and regeneration projects during the early stages of discussions with developers. It is recognised that, while the maps are suitable for the early stages of discussion, more technical tests and modelling results will be required once a detailed planning application can be submitted, and other design approaches will be more appropriate for these later stages. However, the utility of the approach explained in this paper is that it provides a readily understandable source of information to support initial discussions between planning officers and developers, and achieves this in a form with which local government is already familiar. Consequently, it may contribute to the reduction of potential barriers limiting the uptake of more sustainable forms of stormwater management.

The work outlined in this paper has described creation of maps showing the feasibility of SUDS in new development sites, since legislation is enforced through the planning system in relation to such sites. Arguably, however, current rates of urban development will not proceed sufficiently rapidly to offer adequate adaptation possibilities against the increased risks associated with climate change (Charlesworth 2010). Consequently, there may be a need to retrofit SUDS into towns and cities to combat existing drainage problems, and a complementary set of maps is under development taking into account the additional restrictions posed by retaining much of the existing urban infrastructure while still seeking feasible retrofit locations for sustainable drainage.

ACKNOWLEDGEMENTS

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LIST OF REFERENCES


