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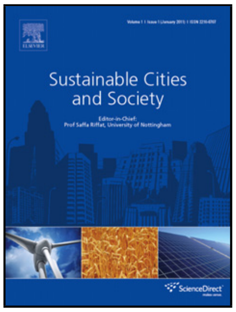

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Economic analysis of wider benefits to facilitate SuDS uptake in London, UK

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Highlights

- The economic feasibility of SuDS in London improves when considering wider benefits
- The investment of stakeholder groups is broken down proportional to their benefits.
- A financial scheme was defined to facilitate SuDS uptake in London based on available incentives and private investment.
- This is a straightforward methodology that uses available tools and data, to improve SuDS feasibility in planning phases.

Abstract

Urban water management via Sustainable Urban Drainage Systems (SuDS) has been successfully applied in cities worldwide. This infrastructure has proven to be a cost efficient solution to manage flood risks whilst also delivering wider benefits. Despite their technical performance, large-scale SuDS uptake in many places has been slow, mostly due to reasons beyond the engineering realm. This is the case of England and Wales, where the implementation of SuDS has not reached its full potential. This paper investigates the strategic role of SuDS retrofit in managing environmental risks to urban infrastructure at a catchment level, through an economic appraisal of all benefits (i.e. flood reduction and wider benefits). The Decoy Brook catchment in London, UK, was used as a case study. Average Annual Benefits were used to monetise the value of SuDS in reducing surface flood risk, whilst a Value Transfer approach was used to appraise wider benefits. It was found that by including the latter, their economic feasibility improves considerably. This paper also shows how to split the investment amongst multiple stakeholders, by highlighting the benefits each one derives. Finally, recommendations regarding incentives and policies to enhance the uptake of SuDS are given. The proposed methodology for SuDS mapping and economic appraisal in the planning phase can be used in cities worldwide, as long as general principles are adapted to local contexts.

List of Acronyms

AAB	Average Annual Benefits
AAD	Average Annual Damages
AST	Adaptation Support Tool
BCR	Benefit Cost Ratio
BeST	Benefit of SuDS Tool
BGS	British Geological Survey
CAPEX	Capital Expenditure
CDA	Critical Drainage Area
CIRIA	UK Construction Industry Research and Information Association

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EA	Environment Agency
FRM	Flood Risk Management
GiA	EA Grants in Aid
LLFA	Lead Local Flood Authorities
MCM	Multi-Coloured Manual
NPV	Net Present Value
ONS	UK Office for National Statistics
OPEX	Operational Expenditure
SuDS	Sustainable Urban Drainage Systems
uFMfSW	EA Updated Flood Maps for Surface Water
WLC	Whole Life Costing

Keywords

SuDS; Urban Infrastructure; Flood Risk; Economic Appraisal; SuDS Wider Benefits; Funding Sustainability.

1. Introduction

The increased frequency of extreme weather events associated with climate change poses a significant threat to the integrity and function of critical urban infrastructure – rail, road, and power and water supply/sewerage networks (Bell et al., 2012; Zevenbergen & Gersonius, 2007). A key threat within the UK is the increased risk of surface water (pluvial) flooding: the conventional approach of channelling runoff to an outfall has proven to be unsustainable during severe storm events. During the winter of 2013/14, twelve major winter storms occurred, resulting in more than 5,000 homes, businesses and infrastructure being flooded in Southern England (Huntingford et al., 2014; Kendon & McCarthy, 2015). To address this issue, Lead Local Flood Authorities (LLFA) in UK are required, under section 21 of the Flood and Water Management Act 2010 (Defra, 2012), to maintain a register of structures and features that are likely to have a significant effect on flood risk in their area.

Green infrastructure, in the form of Sustainable Urban Drainage Systems (SuDS), has been proposed as a mean of minimising the risk of urban flooding (R Ashley et al., 2002; Richard Ashley, Blanksby, Chapman, & Zhou, 2007; Fletcher et al., 2015). SuDS replicate the natural drainage processes of an area - typically through the use of vegetation-based interventions such as swales, water gardens and green roofs, which increase localised infiltration, attenuation and/or detention of stormwater. Hence, SuDS improve flood alleviation capacity. Moreover, SuDS provide ecosystem service benefits (wider benefits), which include mitigation of heat island effect and noise, improvements in water and air quality, plus biodiversity and provision of sites for recreation or urban amenity, amongst others (RM Ashley, Faram, Chatfield, Gersonius, & Andoh, 2010; Fletcher et al., 2015).

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Despite their multi-functionality, SuDS implementation has faced various barriers, with institutional and economic factors typically the biggest obstacles (Richard Ashley, Blanksby, Cashman, et al., 2007). In the UK, the key barriers to SuDS adoption are the performance and economic uncertainties surrounding their use in Flood Risk Management (FRM) schemes (RM Ashley, Newman, Walker, & Nowell, 2010). In particular, SuDS often fail the feasibility criteria of FRM cost-benefit analysis because: a) the multifunctional asset value of SuDS has not been considered; and b) the full scope and extent of the benefits provided have not been quantified. An additional problem is the potential complexity of a SuDS train (i.e. a set/combination of SuDS) for retrofitting in a specific project area (Charlesworth, 2010), given the wide variety of SuDS that are available. There is a clear need to improve current procedures for quantifying the capacity of SuDS to reduce flood risk and evaluate the economics of SuDS retrofitting, taking into consideration all of their multifunctional benefits.

The aim of this study is to deliver a step-change in the evaluation of proposed SuDS retrofit during the planning phase, to increase its uptake in cities worldwide. This is done by reviewing scientific and industry literature on this issue, and by analysing a case study through a cost-benefit analysis that includes SuDS flood risk reduction and wider benefits. The methodology is defined such that it uses a set of existing tools to perform a detailed analysis of a SuDS retrofit in an urban area. Special attention is given to the appraisal of wider benefits as these values may be a game changer in the economic analysis of SuDS.

2. Background of SuDS Implementation in London

Despite industry, governments and researchers' efforts, the uptake of SuDS in London has not been as efficient as in similar cities worldwide (Richard Ashley, Blanksby, Chapman, et al., 2007; RM Ashley, Newman, et al., 2010; MWH, 2011). SuDS´ technical performance has been analysed in detail, and proved to be beneficial for mitigating the risk of flash flooding and water course pollution (Fletcher et al., 2015; Nickel et al., 2014; USEPA, 2013). Moreover, guidelines addressing the technical challenges have been widely available for nearly a decade (Dierkes, Lucke, & Helmreich, 2015; Lampe et al., 2004; Woods-Ballard et al., 2007). Multiple institutional frameworks have not, however, been updated to accommodate the implementation/use of SuDS and this hinders their development (RM Ashley, Newman, et al., 2010). Economic, financial and planning regulations need to be enhanced to foster the implementation of SuDS.

2.1 Current challenges

In England and Wales, flood management is currently seen as a separate issue to water supply and water quality management (Richard Ashley, Blanksby, Cashman, et al., 2007; Richard Ashley, Blanksby, Chapman, et al., 2007; Thames Tunnel Commission, 2011). This hinders the possibility of merging efforts and budget across these domains to maximise outputs, through solutions such as SuDS, which simultaneously address several challenges in a cost-efficient way. In addition, because quantification and monetisation of wider benefits is a complex process, SuDS tend to be undervalued by stakeholders (MWH, 2013). Several tools have been developed to

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appraise/quantify these wider benefits (Richard Ashley et al., 2012; MWH, 2015; Natural Economy Northwest et al., 2010; Technology & Rivers, 2010). However, they are yet to be widely accepted and used. It would be desirable that a methodology merging flood risk reduction and wider benefits appraisal was consolidated as general practice within the industry and government.

Furthermore, in the UK water utilities have been privatised. This makes it difficult to differentiate the responsibilities of infrastructure development between companies and government (MWH, 2011), but also may hinder coordination between them (Richard Ashley, Blanksby, Chapman, et al., 2007). In addition, in most cities in the UK, direct and indirect incentives are low, therefore few private investors have supported SuDS development (MWH, 2011). However, these have been key stakeholders in successful examples of green infrastructure developments worldwide.

Water utilities are often criticised for their low involvement in SuDS projects (Environment Agency, 2013a; Thames Tunnel Commission, 2011), however, this may be related to current institutional frameworks. Indeed, strict industry regulations have been identified as another constraint to SuDS implementation in the UK. Due to considerable economic and legal penalties, fewer companies may be eager to invest in SuDS, because, as with any other innovative solution, there is still uncertainty surrounding the viability of proposed solutions (Thames Tunnel Commission, 2011). Developing an *"environment that can accommodate failure"* would reduce negative perceptions among stakeholders, as it would share, among all of them, the potential risks associated with SuDS (MWH, 2011).

The ownership and maintenance of SuDS is another issue, as its performance is dependent upon provision of appropriate maintenance (Dierkes et al., 2015; Lampe et al., 2004). However, as several stakeholders are expected to fund SuDS (e.g. Water Utilities, Local Boroughs, users, etc.), regulations should be updated to clearly define the allocation of ownership of these assets across stakeholders (Environment Agency, 2013a). This would allow; 1) SuDS inclusion in financial statements, which is essential for regulated water utilities; and 2) the identification of stakeholder responsibility for maintenance and management.

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2.2 Benchmarking current situation

When benchmarking UK cities against major cities worldwide, some differences arise. One of them is the lack of generous incentives for promoting the participation of private investors in SuDS schemes. Worldwide, these incentives have included subsidies from cities or regional governments to support the investments, support with maintenance expenses and abatement of surface water charges/fees, among others (Ando & Freitas, 2011; Keeley, 2007; Ngan, 2004; Shuster & Rhea, 2013; Thurston, 2006; USEPA, 2013; Valderrama, Levine, Yeh, & Bloomgarden, 2012). The success of these programmes is facilitated by clear guidance on the technical requirements for obtaining and keeping incentives.

In addition, before granting fees abatement, successful incentive schemes have sometimes involved reforming stormwater drainage charges to be proportional to the size of the impermeable area of a property draining to the network (Keeley, 2011; Ngan, 2004; Nickel et al., 2014; Thurston, 2006; Valderrama et al., 2012). This institutional change is important to achieve an equitable charging system based on the impact to the stormwater network, rather than based on water supply, following the ´polluter pays´ principle.

In the UK, the Environment Agency´s Grants in Aid (GiA) are a direct incentive to reduce flood risk (Environment Agency, 2010). However, there are few efficient abatements of fees, or other incentives, to complement this and increase the feasibility of projects. Fees reduction of many utilities is small, and most of them still use traditional charging methodologies where calculations are independent of the property´s impermeable area.

In addition, interventions worldwide tend to tackle several issues at the same time, which means that they promote active engagement from several institutions and citizens. In (Kazmierczak & Carter, 2010) the authors explain how to successfully deliver catchment-wide projects that generate wider benefits, including flood management, water quality improvement, increasing green space in the area, and even developing marginalised areas of cities. The selection of SuDS was achieved by defining the goals of the intervention and involving stakeholders to define the solution. Updated more flexible governmental policies and closer involvement of communities have also been identified as key issues in the development of Water Sensitive Cities in Australia (Bettini & Head, 2014; Brown & Farrelly, 2009; Werbeloff & Brown, 2011). This active cooperation between multiple institutions (private and public), may therefore be a prerequisite to obtain similar results (RM Ashley, Newman, et al., 2010).

3. SuDS Planning Methodology

To address the aforementioned issues, the following methodology was defined to scope and appraise a catchment-wide, SuDS retro-fitting scheme in London: a) SuDS mapping by applying a stakeholder participatory approach; b) economic assessment of both the flood mitigation and wider benefits of selected SuDS schemes; c) developing a potential funding scheme for some of the SuDS.

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3.1 The case study area

The Decoy Brook, located to the North of London in the Borough of Barnet, was chosen as a case study. This urban catchment is part of the Golders Green Critical Drainage Area (CDA) (AECOM & Hyder, 2011) – CDA is a classification given to zones in the UK at high risk of surface water flooding. The Lead Local Flood Authority (LLFA), the London Borough of Barnet in this case, has to identify and promote the reduction of flood risk in their CDAs through *Surface Water Management Plans* (Richard Ashley, Blanksby, Cashman, et al., 2007).

The catchment has an area of 2.5 km^2, with an extended shape approximately 3 km long (see Figure 1). The Brook has both underground and overground sections. The zone is mostly residential, although there are some commercial properties in the main roads (A502 and A598). Relevant infrastructure assets at risk include the Golders Green Police Station, a London Underground Station, three schools and 13 minor electrical substations. Based on the 2011 UK Census (Office for National Statistics - ONS, UK), there are around 16,000 people living in the area.

3.2 SuDS Mapping

The methods used to design and estimate the impacts of SuDS represent a straightforward but efficient approach for a planning stage, as they make the best use of available data. This facilitates a preliminary assessment of SuDS options, however, they do not include detailed hydraulic or flood extension analysis of the dynamics of water in the surface and sub-surface, which are required for a final design.

The Adaptation Support Tool (AST) (Voskamp & Van de Ven, 2015) (an output of the Blue Green Dream project (Rozos, Makropoulos, & Maksimović, 2013)), was used to design the catchment-wide, SuDS based, flood risk mitigation solution. Input data included NASA's SRTM DEM (Gorokhovich & Voustianiouk, 2006; Hirt, Filmer, & Featherstone, 2010; Mouratidis, Briole, & Katsambalos, 2010), the Environment Agency's Updated Flood Maps for Surface Water (uFMfSW) (Environment Agency, 2013b), the British Geological Survey (BGS) Infiltration SuDS Maps (Dearden, 2011) and rainfall and evaporation rates. Local Stakeholders (Environment Agency-EA London, and the London Borough of Barnet infrastructure teams) were consulted during the SuDS' options selection phase through a participatory workshop to design the solution.

In order to simulate the impact of SuDS on the flood extension within the CDA, it was assumed that the volume of water stored in the SuDS would reduce an equivalent water volume on the Updated Flood Maps for Surface Water (uFMfSW) (Figure 2). This calculation was done in two steps: 1) flooded areas that would be influenced by each SuDS were defined based on the expertise of stakeholders and flood historical records; 2) water levels in the uFMfSW were reduced uniformly by equating the volumes of water eliminated with the SuDS storage capacity.

This analysis was done for the three available uFMfSW, which correspond to 1:30, 1:100 and 1:1000 years return period events. Given the properties of the uFMfSW, the drainage patterns in

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the catchment, and the location of SuDS (decentralised in upstream areas of the catchment), this approach is an easy-to-implement approximation useful for planning purposes.

3.3 Economic Analysis

3.3.1 Flood risk mitigation benefits

The economic analysis was based on the Multi-Coloured Manual (MCM) (Penning-Rowsell et al., 2014) and the Flood and Coastal Erosion Risk Management Appraisal Guidance (Environment Agency, 2010). These documents are the standard guidelines to develop the appraisal of benefits of any flood risk reduction project in the UK.

Briefly, the economic assessment of flood risk was done as follows:

1. Identify properties and infrastructure at risk for a determined event (i.e. define water levels in the vicinity of every property or infrastructure asset at risk).
2. Use the information available in the MCM to define the expected losses due to flooding of properties and infrastructure at risk.
3. Using at least three events with different return periods, define the Average Annual Damages (AAD) of floods.
4. Define the effects of the selected SuDS scheme on flood maps (reduction of water levels) and repeat steps 1 to 3 for these, in order to define the AAD with the scheme.
5. Find the difference between AADs determined in steps 3 and 4, in order to define the Average Annual Benefits (AAB) of the intervention.

The value defined in the fifth step represents the monetisation of the benefits that would be accrued, on average, every year due to the reduction of flood risk in the CDA with a determined intervention (in this case a SuDS scheme).

3.3.2 SuDS wider benefits appraisal

The Benefit of SuDS Tool (BeST) (MWH, 2015), developed by the UK Construction Industry Research and Information Association (CIRIA) was used to appraise wider benefits. This is a value transfer approach (Varian & Repcheck, 2010; Young & Loomis, 2014), based on information from other projects from the UK or similar countries. The original studies used techniques such as Willingness to Pay, Willingness to Accept, Hedonic Pricing, among others, to approximate the value of SuDS´ wider benefits such as: amenity, air quality enhancements, biodiversity and ecology, and health improvements, amongst others (Baptiste, Foley, & Smardon, 2015). The value transfer was done after carefully checking the compatibility of the case study with the original references.

3.3.3 SuDS cost appraisal

A value transfer approach based on UK projects was also employed to cost most SuDS (Gordon-Walker, Harle, & Naismith, 2007; Lampe et al., 2004; Speirs et al., 2006; Stovin & Swan, 2007; Wallingford, 2004), while for water tanks a market survey was developed. References analysed highlighted that Operational Expenditure (OPEX) tends to be underestimated, and that the value of

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land, when required to implement SuDS, has considerable impact on final prices. Due to this, short and long term Capital Expenditure (CAPEX) and OPEX were included in detail to develop a whole life costing methodology.

3.4 Economic Appraisal

A period of 50 years was defined to compare benefits and costs of proposed SuDS schemes. This allows the inclusion of long term OPEX, which is fundamental for whole life costing. A discount rate of 3.5% was used as suggested by the UK HM Treasury (HM Treasury, 2003). Net Present Value (NPV) and Benefit Cost Ratio (BCR) were used to compare different potential interventions.

It was assumed that investments would be done in year 0, construction would last one year and benefits could be accrued from year two onwards. SuDS with vegetation components may require different time periods to grow to the point where they deliver full benefits, and sometimes they are built in stages. However, it was found that final results were not sensible to changes (- 1 or + 2 years), in the period required to achieve their full size. In addition, it has been shown that by manipulating nutrients and growth media, and using different technologies, their performance can be further controlled (Li & Babcock Jr, 2014; Nnadi, Newman, & Coupe, 2014).

The lifespan of most SuDS was assumed to be the same as the timeframe of the project (i.e. 50 years), and this is valid as long as proper maintenance is done (Gordon-Walker et al., 2007). Thus, a conservative approach was taken to calculate OPEX from the ranges of prices mentioned in the previous section. There was an exception for rainwater tanks, as the lifespan suggested by manufacturers is shorter (around 17 years). Therefore, two replacements but no maintenance costs were included in calculations, and benefits could be accrued from year 1 after installing them in year 0.

In order to split the investment among all stakeholders, each benefit was linked to its direct benefactor. For instance, flood risk reduction to infrastructure should involve funding from the asset managers/owners (e.g. Transport for London, London Metropolitan Police, Highway Agency, etc.). On the other hand, in residential areas, flood defence, rainwater harvesting, and amenity are benefits to residents, which means that they could involve funding from Environment Agency GiA, local councils and residents.

3.5 Financial Scheme for Roof Disconnection using water tanks

Economic feasibility is a prerequisite for flood management projects, but securing the funds to implement SuDS infrastructure is just as important. As previously highlighted, this is one of the main barriers to UK cities achieving a level of SuDS uptake that is comparable to that attained by similar cities abroad. Government budget is limited, and therefore, further sources of funding must be found. This has been addressed worldwide by merging funds from different institutions, and incentivising the participation of private capitals (Ando & Freitas, 2011; Nickel et al., 2014; Novotny, Ahern, & Brown, 2010).

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To apply concepts from international examples (Dunphy et al., 2007; Keeley, 2007; MWH, 2011, 2013; Nickel et al., 2014; Valderrama et al., 2012) and academic approaches (Moore, Stovin, Wall, & Ashley, 2012), the financial scheme was developed for a specific area only (Police Station sub-catchment), through roof disconnection of properties. This allowed involving multiple stakeholders (e.g. residents, the Borough and the environment agency), benefiting from surface water charges reductions and other wider benefits. In addition, the intervention in this area did not involve London Underground or the Highway Agency, which are institutions with more investment regulations, which would have made the funding strategy more cumbersome.

4. Results

The SuDS scheme scoping and mapping phase of the study considered not only vegetation SuDS (e.g. swales, wetlands and infiltration strips), but also interventions such as rainwater tanks. In addition, the benefit appraisal included only the most relevant benefits accrued from the intervention. Hence, benefits that delivered insignificant impacts relative to the magnitude of the investment over the 50 years period of financial analysis were not included (e.g. reduction of heat island effect, carbon sequestration, crime reduction and health benefits for citizens).

4.1 Technical design and Economic appraisal

Five catchment-wide SuDS schemes were devised and are described as follows:

1. Infiltration strips along the main roads of the catchment (A502 and A598), an urban wetland to the south west corner and a rainwater tank for Golders green station.
2. A 7,500 m^3 basin at Hampstead Heath Extension (east basin) and a 1,000 m^3 basin at Princess Park (west basin).
3. Infiltration strips and roof disconnection in the Police Station Sub-catchment, and a swale to the north of the catchment.
4. Combination of options 1 and 2.
5. Combination of options 2 and 3.

Table 1 summarises all individual SuDS analysed, their dimensions, and whole life and unitary costs.

Based on the size of selected SuDS, number of houses disconnected and generally accepted design specifications (Stovin & Swan, 2007; Woods-Ballard et al., 2007), it was possible to determine the volumes of water that would be managed by each one of the interventions. Using this information and the three flood maps of the uFMfSW, it was possible to determine the expected stormwater mitigation capacity and ergo, flood risk reduction, for each scheme.

In order to identify flooded properties and infrastructure, water levels from the uFMfSW were compared with GIS data of street and entry levels in the catchment. All flooded properties or assets were logged, with the information required by the MCM (e.g. type of property, level of water, economic activity of commercial properties and the spatial extension).

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Flood reduction economic benefits provided by each scheme were valued in accordance with the MCM. In most cases, the MCM provided step-by-step information of the appraisal process for infrastructure assets such as electricity and gas, roads, schools, public health centres/hospitals, Emergency services, and commercial and residential properties.

However, further data was required to appraise the benefits of avoiding service disruptions to the London Underground system. This was done by analysing information of the value of time of passengers (TFL, 2013), and the quantity that would be affected (TFL, 2014). The latter was estimated as the number of people, entering or leaving, all stations that would be affected by a potential flood in Golders Green Station (all of them downstream of Camden Town Station in the Northern Line Edgware Road branch). This methodology proved to be an accurate calculation when compared to TFL records (through a personal communication).

The benefits of reducing service disruption to roads were not included, but only those related to the reduction of physical damage to them, as most methods in the MCM are mainly applicable to rural roads. Also, the cost of deploying emergency services (e.g. Police and ambulances) was included, while potential costs of disruption of normal services of these institutions were ignored. Bearing in mind the impacts on this infrastructure (e.g. flood extension in roads was not large and water levels were usually no more than a couple centimetres), both assumptions are reasonable for a planning phase in this case study.

Appraisal of wider benefits was conducted using BeST (MWH, 2015), and only the following benefits were analysed: air quality, biodiversity and ecology, groundwater recharge, rainwater harvesting, treating wastewater and surface water charges reduction. This means that in addition to the benefits ignored due to their insignificant effects, others such as recreation and water quality were not analysed to avoid double counting (MWH, 2015). Finally, following BeST guidelines, amenity was included as a wider benefit of basins. This in turn required excluding biodiversity and ecology for these specific SuDS in order to avoid double counting.

It is important to mention that there are two types of double counting; similarities of the categories included in BeST (e.g. amenity and recreation), and double counting due to the source where values are transferred from. The former case was explained in the previous paragraph, the latter should be considered for example when analysing benefits such as amenity and property prices together. Even if these two seem to be unrelated, economic methodologies (e.g. hedonic pricing) applied to property or land prices data are frequently used to understand the value that residents give to the amenity taken from SuDS improvements. This means that property prices analysis is included indirectly, in the form of other benefits. For further details of the BeST methodology the reader is referred to MWH(2015).

Table 2 shows the total costs of each SuDS scheme, the value of the flood benefits, the total value of all benefits (i.e., wider benefits + flood benefits), the Net Present Value (NPV) and the Benefit Cost Ratio (BCR), for both classes of benefits.

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Porous Pavements were excluded from the analysis after the cost-benefit calculations showed that, for this case study, they always underperformed Infiltration Strips. However, this should not be taken as a rule of thumb as this is specific for this context. If a pavement had to be reconstructed in the same roads, and there are no restrictions due to a heavy traffic demand, the added value of using porous pavements would perhaps exceed the marginal cost of building them instead of regular pavements. In such a case they would become a profitable investment, particularly if the ground has a high infiltration capacity.

From Table 2 and Figure 3 it can be seen that the economic feasibility of SuDS considerably increases when wider benefits are taken into account. In some cases, the increments are above 100%. However, not all benefits have a large impact in the total economic value of the intervention. To some extent, this is because some input data of BeST tool give general UK average values, which are small compared to the specific ones for London (*e.g.* Londoners would have higher willingness to pay for air quality improvements due to current worsen conditions). It could be expected that using BeST with local data would increase the accuracy of the benefits appraisal.

In addition, Table 2 and Figure 3 also show that schemes 2, 3 and 5 have positive economic returns when all benefits are analysed. This confirms that basins are some of the most cost-effective SuDS available (Bastien, Arthur, & McLoughlin, 2011). It also shows that roof disconnection and infiltration strips, but especially the former, are the most cost-efficient ways of promoting SuDS and reducing flood risks to properties and infrastructure in hot spots (e.g. the Police Station sub-catchment).

It is worth highlighting that although the surface water charge reduction offered in London for disconnecting a property's roof from the stormwater system is small, this benefit is still valuable in the long term. It would however, have even greater impact if the charge reduction was expressed as a function of the impermeable area disconnected, and if the charge reduction directly promoted disconnection via SuDS use.

Finally, the total value of benefits was broken down into the specific stakeholder groups that would receive them. This represents a crucial part of the analysis as it shows how extra funders can be found for a project. Table 3 lists the proportion of the total benefit value that each stakeholder group receives for SuDS schemes 1, 2 and 3. The breakdown for intervention 4 and 5 can be found by doing a weighted average of 1, 2 and 3.

4.2 Financial Scheme for Roof Disconnection

As mentioned in section 2.2, the limitations of the existing funding and regulatory frameworks, have been highlighted as one of the largest obstacles for SuDS development in the UK (Richard Ashley, Blanksby, Cashman, et al., 2007; Richard Ashley, Blanksby, Chapman, et al., 2007; RM Ashley, Newman, et al., 2010; MWH, 2011, 2013; Thames Tunnel Commission, 2011). This section will describe a potential financial scheme for promoting SuDS adoption in London, based on successful examples from cities around the world (USEPA, 2013) and innovative financial schemes

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from other fields such as energy utilities (Galvin, 2010; Gamtessa, 2013; Ma, Cooper, Daly, & Ledo, 2012; Valderrama et al., 2012).

This strategy will be specifically applied to the roof disconnection in scheme 3, as property owners and the Borough (as the LLFA of the CDA) are the main recipients of benefits in this scheme, and their funds are relatively simple to obtain compared to London Underground and the Highway authority.

The main idea behind this proposal is that any investment in flood risk reduction and wider benefits, should involve all stakeholder groups that would benefit from the intervention. This includes, amongst others, Lead Local Flood Authorities (LLFAs), commercial and residential property owners, who are interested in reducing flood risk and obtaining wider benefits, and infrastructure asset managers willing to reduce service disruption due to floods. The methodology used here is similar to the *´polluter pays´* principle, whereby stakeholders invest in proportion to the future benefits accrued. In practice, this is translated to public-private partnerships involving direct and indirect incentives, which encourage private capital to participate.

In this case study, the EA Grants in Aid (GiA) would be a direct incentive provided by the government to the Borough, to assist citizens in their areas of influence. Surface water charges reductions from the water utility company would be indirect incentives given to users, if it is proved that no rainfall from their premises is drained to the network. In London this is a £25 reduction, a small value when compared to other water utilities in the UK and worldwide, and it is independent of the percentage of impermeable area of the premises.

It was assumed that 350 properties would be disconnected from the network, and that on average; each one of them has 80 m^2 of impervious area (roof plus other impervious areas in the property). All of them are located in the Police Station sub-catchment, and it was assumed that they would be resilient to a 1:30 years return period rainfall event, which is the more extreme event that the water utility is obligated to manage. Based on daily historic records of the EA the rainfall rate for this return period is around 50 mm (the yearly average is 640 mm). An average of 2.3 persons per household is assumed (taken from the UK Office for National Statistics data for this CDA).

Based on the previous assumptions, a tank of 4.0 m^3 capacity was chosen for each property. The specific services that households would pay for include: (i) the £25 reduction in surface water charges, and (ii) the reduction in water supply fees, as it is assumed that 30% of the water harvested by the tank would be reused (e.g. for any non-potable use). In addition, the user benefits from the fact that flood risk will be reduced in the area.

The key benefit for the Borough is flood risk reduction in one of its CDA. Nevertheless, in the long term rainwater tanks could be substituted with green roofs or rain gardens (Shuster & Rhea, 2013), and this would improve the aesthetics of the Borough. The water utility company would benefit from the reduction of pollutants entering to the drainage network during flood events, and arriving to the receiving body.

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They would also benefit from reduction of flash floods, as they are entitled of managing events with a return period of 1:30 years or less. Their contribution is limited to the £25 charges abatement explained before. Within current regulatory framework any further contribution from the utility is difficult to obtain and therefore was ignored.

As other flood risk reduction assets in a CDA, the LLFA would lead the installation of the tanks, and would define guidelines for households on how to manage the asset. As with other innovative solutions, the risk of any unforeseen event entailing a failure should be shared between LLFA, citizens and the water utility. The regulatory framework should make room for this, and should avoid excessive penalties or compensations during this pilot project.

The cost of the intervention would be £630 per tank, which includes roof connection although it does not include connection with water devices inside the house; therefore, it is assumed that water from the tank is re-used in outdoor areas. The cost would be divided between the Borough, as a £100 direct incentive (coming from a flood GiA from the Environment Agency), and the household (£530). This distribution was defined based on previous experience in GiA applications from local stakeholders. However, options involving third parties, as employed by electricity utilities (Bardhan, Jaffee, Kroll, & Wallace, 2014; Valderrama et al., 2012), could be used in the future.

Table 4 shows the monetised benefits for the households, assuming an analysis with a lifespan of 17 years, as this is the expected duration of the rainwater tank with no major maintenance. This is a different period than the one used in section 4.1 (50 years), as it is assumed that focusing on returns in the short and medium terms facilitates the uptake of SuDS. However, similar results would be found in a 50-year analysis. The discount rate is again 3.5%, as suggested in the UK Green Book (HM Treasury, 2003).

The results show that the project is profitable for the households, as it has a positive NPV and a BCR of 2.3. Table 5 shows the expected benefits from the point of view of the Borough. It can be seen that the investment is much more profitable for the Borough, as the BCR including benefits is almost 4. This value is just acceptable for a competitive application for a GiA, which suggests that the contribution from the Borough should effectively be around £100. While a smaller participation would increase the likelihood of getting a GiA, it could also discourage the uptake of the tanks among users. In addition, the whole project would bring total benefits of £421,050, which entails a BCR of more than 12 when it is analysed with the investment of the borough only (£35,000).

This is an example of how an efficient partnership between public and private capital can bring several benefits, following principles highlighted in section 2 such as:

- Targeted direct incentives from public institutions that reduce the private CAPEX, and promote the uptake of SuDS in areas with higher flood risk.
- Indirect incentives from water utilities that make sure that there will be a constant (i.e. reliable/guaranteed) payback.

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- Specific guidelines on how to maintain the surface water charge reduction and other incentives.
- Analysing several benefits to build synergies between them.
- A public institution as a project champion (the Borough in this case) that coordinates stakeholders' participation.

Future improvements of the proposed scheme could involve increasing the participation of the water utility in the asset management, and defining who would pay the investment between tenants and owners, amongst others. In addition, including a parcel-based (e.g. proportional to impermeable areas in the premises) charging model would refine the scheme.

5. Conclusions

This study found that the feasibility of SuDS implementation considerably improves when wider benefits are taken into account, as all Net Present Values were increased when the latter were included. The degree of change and the overall performance depended on the type of SuDS used. Results showed that disconnection of impermeable areas, and in a lesser extent basin implementation, are the most cost-efficient SuDS for the selected case study. The methodology presented used available assessment tools and data, which showed applicability of simplified approaches and limited datasets for appraising economic benefits during planning stages. However, detailed hydraulic/flood extension models are required for final designs.

The MCM Handbook and CIRIA´s BeST proved to be easy to use tools for valuing wider benefits of SuDS. It was also found that in the selected case study, the most relevant benefits provided by SuDS are flood risk reduction, rainwater harvesting, reduction of surface water charges, and amenity. On the other hand, benefits such as air quality, biodiversity & ecology and treating wastewater had a small impact. This study also showed how costs should be divided amongst different stakeholders in proportion to the benefits received, to enable multiple funds resourcing and promote SuDS uptake.

The cost estimation proved to be a complex task when analysing SuDS, as the number of implemented projects in the UK that can provide relevant input data is limited. Bottom-up calculations (e.g. estimating the construction activities required and costing them) may be a good approach; however, this may not be very accurate when determining the activities and inputs required for the maintenance of SuDS. This is quite relevant as literature reports that these costs are usually underestimated. A conservative approach was therefore used in this case study.

It was also found that even in the context established by the local water utility, there are still opportunities to establish public-private partnerships that can help bridge the gap between flood management requirements and the available budget. By implementing policies that have been successful in large-scale SuDS implementation schemes worldwide, it was possible to obtain BCRs that attract both public and private investments.

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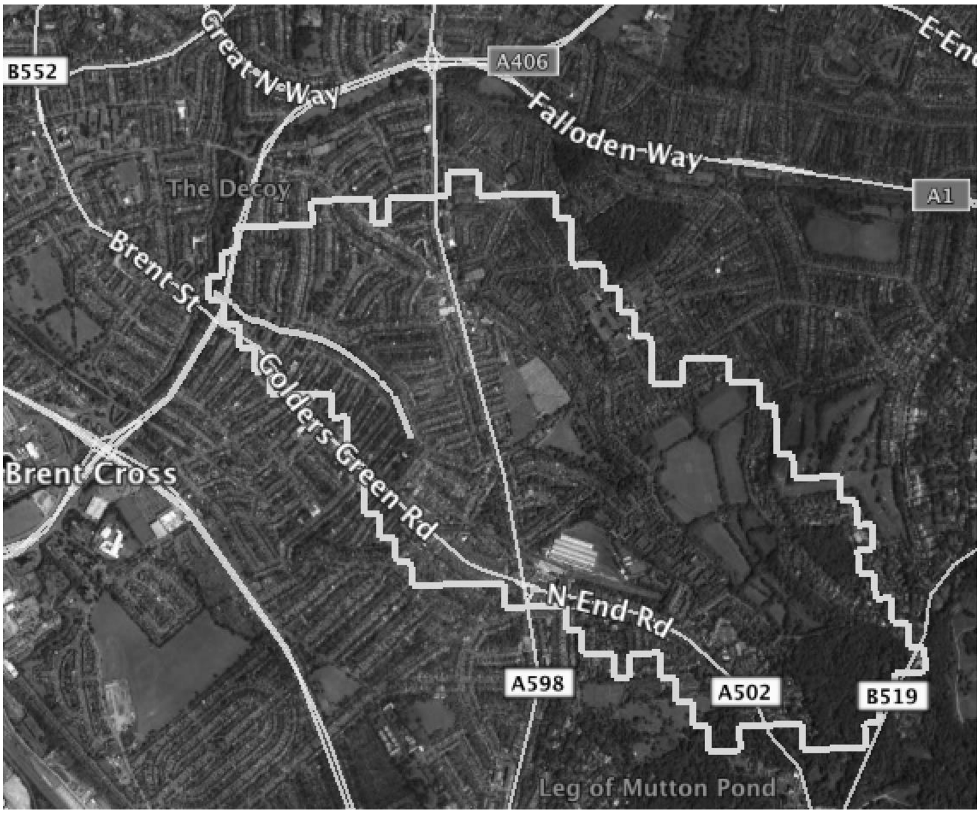

Figure 1. Catchment delineation (based on SRTM-DEM). Base map taken from Google Earth.

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Figure 2. Flooded areas with (right) and without (left) the influence of SuDS. Base map taken from Google Earth.

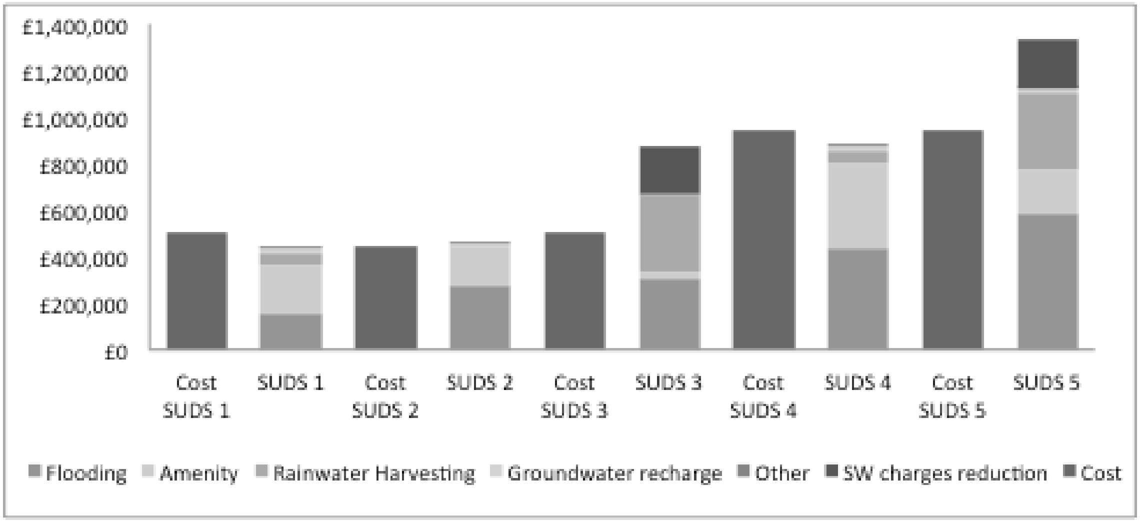

Figure 3. Relevance of individual benefits relative to the total value

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Table 1. Whole Life Costs (WLC - 50 yr.) and Unitary Costs of selected SuDS

SUDS	Dimension	WLC Cost (CAPEX + OPEX)	Unitary Cost
West Basin	1,000 m^3 – 2,000 m^2	£54,131	£54.13 / m^3
East Basin	7,500 m^3 – 7,500 m^2	£405,980	£54.13 / m^3
Roof disconnection	30,000 m^2 - 350 Properties	£364,818	£1,042.34 per property
Infiltration Strips (Police St. sub Catchment)	1,532 m2	£139,083	£90.76 / m^2
Urban Wetland	1,050 m^3 – 2,100 m^2	£62,150	£59.19 / m^3
Infiltration Strips (Whole Catchment)	4,350 m^2	£394,787	£90.76 / m^2
Bio Swale	609 m^2	£15,416	£25.31 / m^2
Galvanised Steel tank for Golders Green Station	1,000 m^3	£64,899	£64.90 / m^3

Table 2. Net Present Value (NPV) and Benefit Cost Ratio (BCR) of the SuDS schemes.

	Cost	Flood Benefits	NPV	BCR	All Benefits	NPV	BCR
SuDS 1	£521,837	£158,758	-£363,079	0.32	£459,100	-£62,737	0.91
SuDS 2	£460,110	£290,241	-£169,869.04	0.66	£470,495	£10,385	1.06
SuDS 3	£519,318	£319,589	-£199,729	0.64	£910,278	£390,960	1.82
SuDS 4	£981,947	£448,999	-£532,948	0.47	£919,206	-£62,741	0.97
SUDS 5	£979,428	£609,830	-£369,598	0.65	£1,380,773	£401,345	1.46

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Table 3. Benefits breakdown per stakeholder group.

	SuDS 1	SuDS 2	SuDS 3
Residential properties	51.8%	93.8%	83.1%
Non-residential properties	16.4%	2.6%	2.7%
Electrical Infrastructure	0.0%	2.2%	9.6%
School Infrastructure	0.0%	0.0%	0.2%
Road Infrastructure	22.4%	0.0%	0.0%
London Underground	6.3%	0.0%	0.0%
Emergency Infrastructure	1.4%	1.1%	4.0%
Society	1.1%	0.0%	0.1%
Water Utility Company	0.5%	0.2%	0.2%

Table 4. NPV and BCR of the investment of rainwater tanks from the point of view of households.

	Household point of view	Whole project
Investment	£ 530	£ 630
Surface Water Charges Reduction	£316	£316
Water Supply Fees Reduction	£508	£508
Flood Risk Reduction in the Area	£379	£379
NPV	£673	£573
BCR	2.3	1.91

Table 5. NPV and BCR of the investment of rainwater tanks from the point of view of the borough (including flood benefits only).

Investment	**£ 35,000**
Flood Risk Reduction in the Area	£132,800
NPV	£97,800
BCR	3.8