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Capacity down pipe: Comparisons with other sustainable drainage systems

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Abstract: Sustainable drainage systems (SuDS) design is predominantly based on expert opinion supported by descriptive guidance documents. The aim of this paper is to compare the novel Capacity Down Pipe SuDS technique in terms of its design, operation, maintenance, management and cost efficiency with other SuDS techniques. The assessment criteria are based on novel ecosystem service variables including those characterising flood and diffuse pollution control for fitting and retrofitting of key SuDS techniques particularly for the domestic housing market. The paper proposes the application of SuDS techniques that obtain high ecosystem service scores for a specific urban site. This approach contrasts with methods based on traditional civil engineering judgment linked to standard variables based on community and environment studies. For a case study area (Greater Manchester), a comparison with the traditional approach of determining community and environment variables indicates that soakaways and infiltration trenches are generally less preferred than capacity down pipes, ponds and filter strips. However, belowground storage tanks, swales and permeable pavements also received relatively high scores, because of their great potential impact in terms of flood volume control. The application of the proposed methodology will lead to changes of the sustainable drainage infrastructure in the urban landscape by promoting the novel capacity down pipe technology, which has a very low footprint and is inexpensive.

Keywords: Best Management Practice, Cost Comparison, Decision Support Tool, Filter Strip, Footprint, Pond

1. Introduction

1.1. Need to Rethink the Philosophy of Drainage Systems

Traditionally, combined sewer systems are used to deal with wastewater and storm water runoff. These sewerage systems operate on the philosophy of preventing local flooding by conveying surface runoff away as quickly as possible. Combined sewers function by carrying both wastewater and storm water in a single pipeline to a wastewater treatment plant, where it is treated and discharged into a suitable natural watercourse such as a river [1]. During periods of medium or heavy rainfall, when sewers are incapable of carrying an increased flow, a structure called the combined sewer overflow discharges untreated wastewater directly into natural watercourses to relieve combined sewers from high runoff loads [1–3].

Separate sewer systems are nowadays being designed to reduce the pressure caused by medium and heavy rainfall, by carrying surface runoff and wastewater in separate pipes. Surface runoff is conveyed in a dedicated pipe and discharged straight into a watercourse without being treated [2]. This more modern sewerage system is advantageous over the combined sewer system, as it does not discharge wastewater directly into receiving watercourses. However, the untreated surface runoff still contains some unwanted contaminants from urban services [1,3,4].

Traditional drainage often creates flooding and pollution problems in the lower catchment. The implementation of sustainable drainage systems (SuDS) can help to achieve these goals at similar or reduced construction costs [1,3]. The philosophy of SuDS is to mimic the natural drainage into the ground, as closely as possible, prior to its development [4]. Most SuDS techniques are able to do this in number of ways such as attenuation of runoff before entering the watercourse, storage of water in natural contours, infiltration of partially treated runoff into the ground and evapotranspiration of surface water by vegetation [3,5].

The main objective of SuDS is to reduce the negative impact of urbanisation on the quantity and quality of surface runoff, while simultaneously increasing amenity and biodiversity opportunities, where possible. SuDS are capable of managing and controlling surface runoff through techniques such as infiltration, detention/attenuation, conveyance and/or rain harvesting [4,6]. In general, they make use of physical, chemical, and/or biodegradation processes to improve the quality of surface runoff by minimizing the amount of storm water-based pollutants washed into nearby watercourses [3,7]. However, potential improvement opportunities in terms of ecosystem services including amenity and biodiversity by introducing SuDS are often neglected by engineers and planners in practice [3].

1.2. Traditional Sustainable Drainage System Techniques

This section provides a brief and generic overview of the key traditional SuDS techniques assessed and tested in this study. For further information on these techniques and related ones, the reader may wish to refer to other publications [1–5,8].

Permeable pavements: These systems allow surface runoff to infiltrate through their surface and underlying construction layers, as opposed to flowing over it. They are mainly used for car parks and roads where traffic intensity is relatively low. The infiltrated rainwater is usually treated and subsequently stored before it infiltrates into the ground, reused or released to a drainage system or surface watercourse [8,9].

Filter strips: These techniques are a form of passive treatment, which are designed to treat runoff from adjacent impermeable areas [8]. A typical filter strip is a wide area of grass, or other dense vegetation, that is characterized by its gentle slope. Filter strips are usually located between surface water bodies, small car parks and at the side of roads. High groundwater levels and steep gradients can generally be overcome by filter strips [10].

Swales: These structures are a form of permeable conveyance system. A typical swale is a broad and shallow channel, which is lined with suitable vegetation such as grass. As in the case of filter strips, the vegetation that covers the swale slows down the rate of surface runoff, thus reducing peak flows, as well as filtering the particulate pollutants contained within it [8].

Green roofs: These roofs are covered with vegetation and are ideal for a range of flat or gently sloping roofs, and are well-suited for urban areas where space is limited. These roofs are capable of removing pollutants from rainwater by filtering, adsorption onto the substrate and retention by plants [8].

Ponds: These water bodies act as a form of passive treatment. They are usually cost effective (due to a high volume to area ratio) SuDS techniques making them popular to control storm water runoff. Ponds are able to provide enhanced wildlife and amenity benefits and should be designed to do so without compromising the primary function of it being part of a storm water management system. The degree of treatment achieved depends greatly on the residence time of the temporary storage, which typically ranges between twenty-four and forty-eight hours [8,11].

Constructed wetlands: These structures contain water of varying depth across their area and consist of marsh or wetland vegetation. This is one of the most effective SuDS techniques at providing diverse wildlife habitat and pollutant removal. However, there are also long-held concerns over the dangers of using wetlands designed for pollution accumulation as wildlife habitat [12]. Wetlands are able to eliminate pollutants by both plants and aggregates filtering and screening particles. Inlet and outlet sumps are recommended to deal with excessive sediment, which can quickly overpower the shallow ends of the wetland [13].

Infiltration trenches: These trenches are shallow excavations lined with a geotextile material and backfilled with stones, creating a small below-ground storage reservoir. Storm water runoff that flows into the trench slowly infiltrates into the subsoil. Infiltration trenches are capable of removing pollutants by adsorption, filtration and microbial decomposition in the soil underlying the trench [1].

Soakaways: These SuDS techniques are a form of source control, operating by dispersing surface runoff into the ground. Recent types of soakaways consist of open chambers (in contrast to holes in the ground filled with aggregates) to store large quantities of water [1,4].

Infiltration basins: These basins are open and uncovered areas of ground, and they are relatively shallow features, which can be constructed either by excavating depressions or embankments. If landscaped, they can be aesthetically pleasing and also add amenity value. Infiltration basins store storm water runoff, which gradually percolates through the soil of the basin. The soil’s permeability and the water table depth are mainly responsible for the efficiency of an infiltration basin [1].

Storage tanks: These below-ground (or underground) storage techniques are sub-surface structures that entrap and store surface runoff. The stored water is released at a slow rate to reduce peak flows during medium or heavy rainfalls. If soil conditions are suitable and the water table is located at a significant depth below the chamber, the storage tanks can be designed to allow stored water to infiltrate into the ground thus encouraging groundwater recharge [14].

Water playgrounds: These SuDS have little effect on managing the quantity and quality of surface runoff. Their main purpose is, however, to enhance amenity value through recreational benefits by providing a variety of water features that individuals (particularly children) can interact with [1,6].

1.3. Capacity Down Pipe

The capacity down pipe is a new SuDS invention by the company Watering Pipe. The working of the system is shown in Figure 1. The system can reduce flooding by storing or redirecting roof run-off water. The overall amount can be significant considering that typically about 20% of urban areas comprise roof tops. The stored water can be recycled, reducing the consumption of portable water.

Depending on the actual height of the down pipe, up to approximately 120 litre of water can be stored within the capacity down pipe system. The rainwater is stored within a compact space with a minimum footprint. Considering that a traditional down pipe has the same footprint than the capacity down pipe system, no additional space is lost due to the novel best management technique.

The stored water is being refreshed during a strong rainfall event. When the pipe is full, the overflow system cleans out any sediment or sludge that has built-up at the base of the container preventing water contamination.

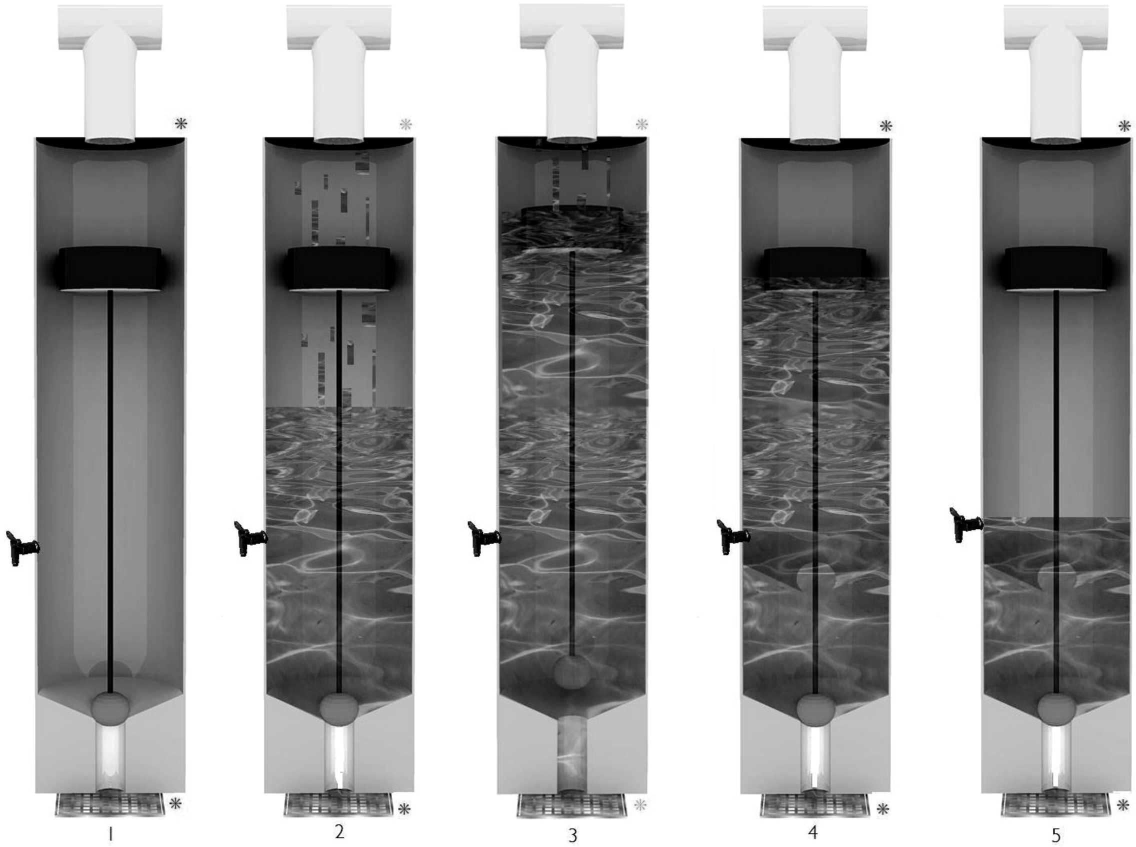

Figure 1. *Working of the capacity down pipe (1, empty; 2, filling-up; 3, over-flowing; 4; full; 5, drained).*

1.4. Ecosystem Services

Ecosystem services are often defined as the benefits human beings can obtain from the semi-natural (managed) environment (e.g., wildlife, green space, open countryside, forest, farmland, river, stream, lake and sea) [15–17]. Furthermore, Defra [18] characterizes ecosystem services as the benefits human gain from the products and services generated by the natural environment. The natural resources and functioning natural systems [19], and a regulated climate are essential for humans [15]. A high biodiversity helps to sustain the natural environment and is thus an important factor for ecosystem service provision.

The Natural Environment White Paper [18], the UK National Ecosystem Assessment [20] and the Economics of Ecosystems and Biodiversity Manual for Cities [21] have identified the following four ecosystem services categories: supporting, regulating, provisioning and cultural services. All existing ecosystem services are strongly linked to one another and to other types of ecosystem services. Supporting services are strongly interrelated to one another by an extensive range of chemical, physical and biological interactions [20].

The goods obtained can be distinguished depending on the degree of human interference. Goods that have been yielded from nature with minimal interference from humans can be referred to as ‘natural production’, while goods that have had a higher level of human interference, such as the use of fertilizers and pesticides, can be referred to as ‘joint production’ [22]. The provisioning service of fresh water is particularly complex in the context of the urban water cycle and the interactions between potential water uses including drinking water supply, irrigation and maintenance of the water supply to urban watercourses [19].

A list of ecosystem service variables relevant for SuDS and their respective categories [17–21] used in this paper is provided in Table 1, which is based on the Economics of Ecosystems and Biodiversity Manual for Cities [21] proposing a comprehensive list of ecosystem service variables of generic nature and Moore and Hunt [17] who chose variables of relevance to wetlands. The variables in Table 1 also recognize the definitions of the ‘Making Space for Nature’ initiative [23] and the Water Framework Directive [24].

Table 1. *Universal ecosystem service categories and variables for sustainable drainage systems (SuDS).*

Service Category	Variable
Supporting	1. Habitats for species (HS) including water, food and shelter
	2. Maintenance of genetic diversity (MGD), which is the diversity of genes within and between populations of species
Regulating	3. Local climate and air quality regulation (LCAR), particularly by green spaces planted with trees
	4. Carbon sequestration and storage (CSS) by ecosystems such as wetlands and urban forests
	5. Moderation of extreme events (MEE) such as storms, floods and landslides
	6. Storm runoff treatment (SRT) particularly by sustainable drainage techniques
	7. Erosion prevention and maintenance of soil fertility (EPMSF)
	8. Pollination (P)
	9. Biological control (BC)
Provisioning	10. Food (F), particularly from agro-ecosystems and freshwater resources
	11. Raw materials (RM) such as wood, biofuel and oil from plants
	12. Fresh water (FW) such as drinking water
	13. Medicinal resources (MR) provided by plants used for traditional medicine
Cultural	14. Recreation, and mental and physical health (RMPH) associated with activities close to the drainage system
	15. Tourism and area value (TAV) associated with an attractive ecosystem featuring a high biodiversity
	16. Aesthetic and educational appreciation and inspiration for culture, art and design (AEAICAD), which can be of high importance to individuals and groups
	17. Spiritual experience and sense of place (SESP) associated with specific parks, watercourses and woods

1.5. Greater Manchester Case Study

Manchester and Salford form the core of the Greater Manchester urban example case study region providing homes to approximately two million people in the North-west of England and comprising 100 tested sites for SuDS retrofitting. However, a few potential SuDS sites are also located in neighbouring municipalities (Bury, Oldham, Tameside and Trafford), which are less urbanized [25]. Figure 2 shows an overview of the assessed sites where SuDS could potentially be retrofitted.

Due to the interconnectivity between local authorities, flooding in one area of the conurbation will usually have a knock-on effect in the remaining local authorities [26]. It is through recognizing this that the ten local authorities joined together in 2011 to form the Greater Manchester Combined Authorities (GMCA) to tackle common problems such as flooding.

Storm water runoff from impermeable surfaces has been identified by strategic flood risk assessments undertaken by local authorities (unpublished internal working documents) as one of the main flood sources in the conurbation. Concerns with this traditional method of dealing with storm water runoff only arose after a serious flood incident in 1998. With the turn of the century, new national policies such as the Planning Policy Guidance Note 25 on the Development and Flood Risk Management [27] were released to address flooding issues. This guidance note (not in force anymore) formally introduced the use of sustainable (urban) drainage systems to deal with storm water management [25,27].

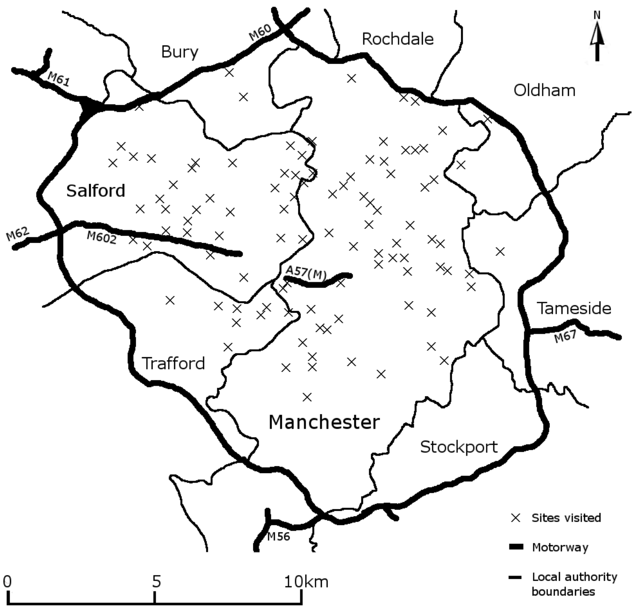

Figure 2. *Overview of the assessed sites where sustainable drainage systems could be retrofitted.*

1.6. Aim and Objectives

The aim is to compare the novel Capacity Down Pipe SuDS technique in terms of its design, operation, maintenance, management and cost efficiency with other SuDS techniques using traditional and novel assessment criteria. The main objectives to achieve this aim are:

(1) to assess the suitability of potential SuDS sites for a wide range of SuDS techniques within an example case study region based on traditional 'community and environment' variables;
(2) to assess the suitability of these SuDS sites for a wide range of SuDS techniques based on ecosystem service variables;
(3) to assess a combination of both approaches for example sites; and
(4) to compare the above assessment outcomes with each other.

2. Methodology

2.1. Overview of Methodology

This sub-section outlines the sequence of steps of the methodological approach. The second sub-section 2.2. explains the standard site assessment variables for 100 potential SuDS sites in Greater Manchester. The third sub-section 2.3. outlines a set of additional ecosystem service variables. The final sub-section explains the determination of SuDS techniques with traditional community and environment variables (objective 1), the selection of these techniques with ecosystem service variables (objective 2) and the combined traditional and new approach (objective 3). Finally, a comparison between all assessment methods (objective 4) is outlined in the last sub-section 2.4. Figure 3 outlines the key seven steps of the proposed methodology of retrofitting SuDS based on estimated ecosystem services variables.

2.2. Case Study Evaluations

A total of 100 potential SuDS sites were identified using Ordnance Survey and Google maps of Greater Manchester. The purpose on focusing the study on this example region was to demonstrate that the implementation of SuDS even within densely built-up cities is possible.

The site assessment template was based on a combination of previously published frameworks [1,4,6,8]. Each potential SuDS site was assessed by two to five research team members (author and students of his research group) to reduce subjectivity [28]. A subsequent desk study supplemented the site evaluation. The reliability of the assessment was judged by the provision of a mark out of 100. Unreliable appraisals were double-checked. The following information was collected to support the assessment team in determining the variables required for the traditional and ecosystem services approaches:

(1) General site information and site acceptability for SuDS and presence of existing SuDS.
(2) Photos of the key site features were taken for each potential SuDS site and its catchment.
(3) Land ownership information and estimated site value (£).
(4) Proportions (%) of site development, regeneration, retrofitting and recreation.
(5) Surrounding area characteristics, total area of the catchment (m^2), and catchment shape.
(6) Location description and distance (m) to the nearest receiving watercourse, if located within a reasonable distance within or at the border of the catchment.
(7) Estimated current and future surface permeability (%) of the proposed SuDS site and its catchment.
(8) Estimated proportions (%) of current and future roof runoff.
(9) Estimated proportions (%) of current and future road runoff.
(10) For each sub-catchment, area (m^2) and gradient in the two main directions having an angle of 90º to each other in the horizontal plain.
(11) Hydro-geological information such as contaminated land (present or absent), soil infiltration (low, medium or high) and groundwater level (below or above 2 m depth).
(12) SuDS technology feasibility proportion (%) for the technologies permeable pavement, filter strip, swale, green roof, pond, constructed wetland, infiltration trench, soakaway, infiltration basin, below-ground storage tank and water playground.

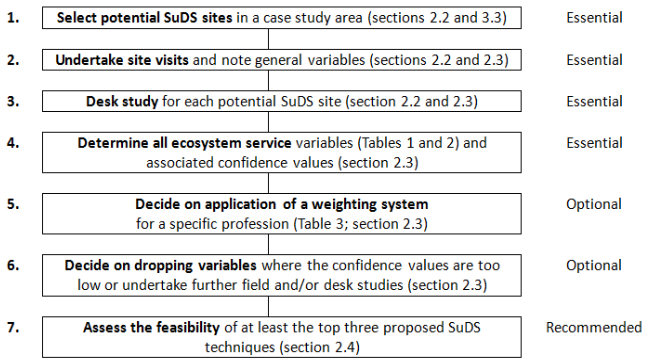

Figure 3. *Outline of the proposed methodology of retrofitting sustainable drainage systems (SuDS) based on estimated ecosystem services variables.*

2.3. Assessment of Ecosystem Services

Table 2 shows the new 17 ecosystem service variables, which belong to the established four ecosystem service categories (Table 1). The quantitative and qualitative approaches to assessing ecosystem services [16] have been applied.

The ecosystem service variables for SuDS retrofitting assessment are described in Table 2. Characteristics for low and high estimations (out of 100 points) are provided. A measure of certainty (%) was given to each variable to indicate the reliability of the assessment; the higher the value given, the more certain was the group of assessors. Only values greater than 50% were considered to be acceptable to progress to the next estimation without conducting further studies.

Table 2 can be adapted by the reader for his or her case studies of concern. More quantitative guidance can be introduced to cater for any specific situation. However, a detailed discussion on this matter is beyond the scope of this paper.

Weightings recognizing differences in regions and stakeholders could be introduced. For example, variables of relatively low relevance for a drainage engineer such as MR in Greater Manchester could be assigned with a low weight of, for example, 1, while variables with a medium (e.g., RMPH) or high (e.g., MEE) relevance could be assigned with a medium (2) or high (3) weight, respectively. Such a proposed weighting system has not been introduced for the case study to keep the methodology simple transparent.

Table 3 proposes potential weights from the viewpoint of a drainage engineer, ecologist, planner and social scientist to support the reader with additional guidance. The weights can be revised for any other case study area and weights for further more specific viewpoints (e.g., structural engineer, ornithologist and housing developer) may be proposed. The capacity down pipe system should receive relatively high ratings from drainage engineers and planners, and rather low values from ecologists and social scientists if compared to more natural systems such as wetlands.

Table 2. *Estimation (maximum of 100 points) of new ecosystem service variables to be used for the generic assessment of retrofitting sustainable drainage system techniques.*

Ecosystem service variable	Characteristics for rather low estimations	Characteristics for rather high estimations
1. Habitats for species (HS)	Wildlife benefits of the proposed SuDS area are low (e.g., little green spaces) due to a virtually unsuitable surrounding area, but mainly due to the impermeable surface coverage of the site	Wildlife benefits of the proposed SuDS area are high due to a suitable surrounding area (e.g., sufficient mature green space) and due to the very permeable surface coverage of site
2. Maintenance of genetic diversity (MGD)	Site is very isolated from other habitats (at least 5 km away) and does not consist of a variety of ecosystems, thus can only maintain a limited number of species; SuDS techniques having a short life-span (e.g., swale) will have no effect on providing a new habitat and thus creating wider diversity	Site is interconnected to neighboring habitats (less than 1 km away) and consists of a large variety of ecosystems, thus maintaining a high number of species; SuDS techniques having a long life-span (e.g., pond and wetland) will have a high impact on providing new habitats and thus creating even wider diversities
3. Local climate and air quality regulation (LCAR)	Areas of trees and surface water are scarce, if any at all	Site is almost entirely covered by dense trees contributing to a great improvement of the air quality for the benefit of human well-being; a mature surface water body is also present
4. Carbon sequestration and storage (CSS)	Small site comprising areas of a few trees	Large greenspace, which is entirely covered by dense trees; presence of a wetland
5. Moderation of extreme events (MEE)	In the case of events such as flooding and drought, the site is inadequate to moderate for the event (i.e. SuDS site becomes ineffective); direct harm to receiving watercourses	In the case of extreme events such as flooding, droughts and fire, the site will moderate these events well (i.e. SuDS site retains most of its functions and stays fit-for-purpose for the direct benefit of human well-being).
6. Storm runoff treatment (SRT)	Low potential to remove pollutants not even through physical processes such as straining; direct harm to receiving watercourses	High potential to remove pollutants through plenty of physical and chemical processes, and biodegradation
7. Erosion prevention and maintenance of soil fertility (EPMSF)	Low erosion prevention potential harming the urban landscape and receiving watercourses, and low likelihood of maintenance of soil fertility (e.g., unprotected soil;. i.e. not even covered by grass or gravel)	High erosion prevention potential (e.g., reinforced structure) and high likelihood of maintenance of soil fertility (e.g., no wash-out of nutrients); rarely applicable variable for SuDS
8. Pollination (P)	Site has a low, if any, potential for the presence of animals (e.g., dense urban area with no green space)	Site has a high potential for the presence of animals such as insects to pollinate surrounding areas (e.g., rural area)
9. Biological control (BC)	Site has very little potential for the presence of predatorily animals and insects to regulate pests and diseases in the surrounding areas (e.g., virtual absence of any green spaces and mature water bodies)	Site has a high potential for the stable presence of predatorily animals and insects to regulate pests and diseases in the surrounding areas (e.g., rich terrestrial and aquatic habitat diversity); no pest nuisance benefiting human well-being
10. Food (F)	Small and contaminated site having no or little potential to produce food (e.g., small site within a dense urban area)	Large and fertile site having a high potential to produce food for the well-being of humans (e.g., large site fully integrated into an agricultural landscape)
11. Raw materials (RM)	Small site having no or very little potential to produce any raw materials (small site within a dense urban area)	Large site with great potential to increase raw material production (e.g., wood from tree production)
12. Fresh water (FW)	Low amount of surface runoff; high pollution harming receiving watercourses (e.g., heavily-trafficked urban street runoff)	High amount of surface runoff; low pollution (e.g., large roofed areas from retail parks)
13. Medicinal resources (MR)	Little potential for plants to be used for medicinal purposes; rarely applicable variable in developed countries	High potential for plants that can be used as medicinal resources; rarely applicable variable in developed countries
14. Recreation, and mental and physical health (RMPH)	Site can be considered as unsafe and provides virtually no recreational opportunities for anybody; SuDS site requires fencing-in	Site provides safe and recreational opportunities of relatively high quality for everybody, directly benefiting human well-being (e.g., bird watching, walking, fishing and group sports)
15. Tourism and area value (TAV)	Site does provide little value for tourism; property value around the site is likely to decrease; rundown estate (e.g., site is fenced-in and has a drainage function only)	Site would attract much attention and a large number of visitors from far away; high increase of property value likely (e.g., site integrated within a mature park located within the city centre)
16. Aesthetic and educational appreciation and inspiration for culture, art and design (AEAICAD)	A SuDS would not increase the attraction of the area or provide additional inspiration (e.g. fenced-in site with pure drainage function)	A SuDS would create an area of outstanding semi-natural beauty providing much inspiration for people with diverse backgrounds; highly valuable education resource
17. Spiritual experience and sense of place (SESP)	Provides people with virtually no connection to the land (e.g., fenced-in site with predominantly drainage function)	The site makes people feel connected to the area and have a sense of strong belonging (e.g., site as part of a community and/or educational project, directly benefiting human well-being)

Table 3. *Proposed weights as a function of user preference (not applied for the Greater Manchester case study example to avoid the introduction of bias).*

Category	Variable	Weights			
		Drainage engineer	Ecologist	Planner	Social scientist
Suppor-ting Services	1. Habitats for species (HS)	1	3	2	1
	2. Maintenance of genetic diversity (MGD)	1	3	1	1
	3. Local climate and air quality regulation (LCAR)	1	2	2	2
	4. Carbon sequestration and storage (CSS)	1	2	1	1
Regulating Services	5. Moderation of extreme events (MEE)	5	2	4	2
	6. Storm runoff treatment (SRT)	5	2	2	2
	7. Erosion prevention and maintenance of soil fertility (EPMSF)	2	2	2	2
	8. Pollination (P)	1	3	1	1
	9. Biological control (BC)	1	2	2	2
Provisioning Services	10. Food (F)	1	1	1	1
	11. Raw materials (RM)	1	1	1	1
	12. Fresh water (FW)	4	2	2	1
	13. Medicinal resources (MR)	1	1	1	1
Cultural Services	14. Recreation, and mental and physical health (RMPH)	2	1	2	3
	15. Tourism and area value (TAV)	1	1	2	3
	16. Aesthetic and educational appreciation and inspiration for culture, art and design (AEAICAD)	1	1	2	3
	17. Spiritual experience and sense of place (SESP)	1	1	2	3

2.4. Comparison of Assessment Approaches

The site assessment was based on previous work [1,6,8]. The guideline C609 [8] bases the selection of a SUDS type on assessments regarding hydrology, land use, physical site characteristics, community and environment, economics and maintenance. These criteria have been adapted from a previous report [29]. Scores for each criteria range from one to five, where one refers to a SuDS technique being very unsuitable, and five signifies a SuDS technique being very suitable for that particular criterion. The SuDS type obtaining the highest sum of scores is likely to be most suitable for a particular site. The minimum and maximum overall score for all criteria were 0 and 25, respectively.

The traditional 'community and environment' approach comprises the conventional variables safety, pond premium, aesthetics, wildlife habitat and acceptance [8]. Variables that are not relevant for ecosystem services were ignored for the purpose of this study. Each potential SuDS type was assessed for each site according to safety with respect to people and pets, water premium recognizing property value, aesthetics, wildlife habitat and public acceptance by the local community. In comparison, Tables 1 and 2 were used to estimate numerical values for the proposed ecosystem service variables. A numerical comparison between the traditional method and new approach recognized that the latter method comprises more variables and higher maximum values than the former.

A combination of the traditional and new approach was also tested. In the combined assessment, the traditional criteria aesthetic and wildlife habitat were replaced by the four ecosystem service categories shown in Table 1. Those SuDS techniques that were associated with the highest preferences for a site were recommended to land owners for subsequent implementation.

3. Results and Discussion

3.1. Discussion of the Ecosystem Service Variable Assessment

This research study combining new ecosystem service variable assessments for all key SuDS techniques with a simple assessment system applied for a large database of real case studies is unique. However, Danso-Amoako et al. [30] assessed sustainable flood retention basins with respect to dam failure and a limited set of ecosystem variables [31] in Greater Manchester as well. Moreover, Gill et al. [32] and White and Alarcon [25] were concerned with green infrastructure in the context of climate change, planning and drainage in the same study area. Nevertheless, ecosystem services were not assessed in a similar context. The specific ecosystem service variable assessment is outlined below:

(1) Habitats for species (HS): This assessment was influenced by the permeability of a potential SuDS site and the surrounding urban area. Green areas with highly permeable surfaces and plenty of vegetation provide wildlife benefits were rare in Greater Manchester.
(2) Maintenance of genetic diversity (MGD): The interconnectivity between sites providing habitats for a wide variety of ecosystems is often responsible for a relatively large number of species. The interconnectivity between and the quality of green spaces within Greater Manchester is relatively poor. The implementation of SUDS techniques such as wetlands and ponds, having a long life span, will further enhance the site's ecosystem service potential.
(3) Local climate and air quality regulation (LCAR): Tree coverage rates and surface water numbers were rather low in the study area.
(4) Carbon sequestration and storage (CSS): Woodlands

and wetlands were rare within the study area.

(5) Moderation of extreme events (MEE): The ability of a potential SuDS site to manage extreme events such as flooding and drought were relatively high in Greater Manchester.

(6) Storm runoff treatment (SRT): The likelihood of runoff treatment was high for most sites.

(7) Erosion prevention and maintenance of soil fertility (EPMSF): Only a few sites were covered by dense vegetation. Sites with bare soil and poor grass cover did not provide much erosion protection.

(8) Pollination (P): Green spaces such as parks, woodlands and fields, which act as a habitat for pollinators, were rare in city areas.

(9) Biological control (BC): Predatory animals capable of regulating pests and diseases were rare for most of the smaller case study sites.

(10) Food (F): The assessment was based on the potential of a SuDS site to provide food. The size of a site as well as its soil and associated contamination are important indirect evaluation parameter. A cultural change in the study area and a deepening of the current recession would be required to realize the potential of transforming parts of the potential SuDS sites into allotments and gardens used to grow food and rear small livestock.

(11) Raw materials (RM): This evaluation considered the potential of a site to provide a range of raw materials such as wood, grass and water. The active harvesting of RM is underutilized within most parts of the study area due to a lack of local policies promoting the multi-purpose use of green spaces.

(12) Fresh water (FW): The quantity and quality of surface runoff for most sites was sufficiently high.

(13) Medicinal resources (MR): Some plants covering a potential SuDS site may have medicinal benefits for people and animals. This variable is unlikely to be relevant for the UK in the medium-term future.

(14) Recreation, and mental and physical health (RMPH): There is an underutilized potential for the multi-purpose use of potential SuDS sites predominantly due to cultural and political reasons.

(15) Tourism and area value (TAV): There is a considerably underutilized potential for attracting visitors to score high in Greater Manchester, mainly due to the presence of a few large parks suffering from under-investment.

(16) Aesthetic and educational appreciation and inspiration for culture, art and design (AEAICAD): There is an underutilized potential for aesthetics to score high in Greater Manchester, mainly due to public under-investment in park infrastructure.

(17) Spiritual Experience and sense of place (SESP): A potential SuDS site's ability to encourage people to feel connected to the area and their associated community, giving them a strong sense of belonging, was evaluated. Considering the high multi-cultural diversity in Greater Manchester, there is a potential for SESP to score high in some areas.

3.2. Strengths and Limitations of the New Ecosystem Services Assessment Approach

The strengths of the proposed methodology, particularly in comparison to the community and environment approach adopted by [29] and CIRIA [8], are the generic retrofitting approach based truly on universal ecosystem service variables and not on conventional engineering understanding. The evaluation is also inexpensive and easy-to-understand. On the other side, weaknesses include methodological subjectivity, which was addressed by involving groups and using uncertainty values for all estimations [28,30,31]. Some ecosystem service variables are also rarely applicable in the developed world such as the UK. Finally, the possibility of multicollinearity among variables can be seen as a potential risk [33].

3.3. Comparison of Assessment Approaches

Table 4 indicates a comparison of all assessment approaches, which follow similar methodological principles. However, the main difference lies in the selection of variables as outlined in sections 2.3 and 2.4. The relative proportions for each SuDS technique have been expressed in percentage points for each column to allow for a direct comparison between approaches and preferences for the example case study area. High confidence values were only obtained for the first three preferences.

Table 5 shows a comparison of the inter-site variability expressed with the help of the standard deviation capturing the variance around the mean for a given sustainable drainage technique for Greater Manchester, and helps to interpret the preferences distributions in Table 4. The standard deviation is an appropriate statistic to explain data spread as a result of subjective assessments. The new ecosystem services and the traditional assessment approaches have the lowest and highest inter-site variability, respectively, for virtually all techniques. The relatively high variability for most variables such as ponds and constructed wetlands can not be explained by factors relating to specific planning policies for Greater Manchester [25]. Ponds are associated with the greatest inter-site variability for all three approaches because of their potentially relatively small size and great popularity [3,6,9], particularly with the traditional and combined approaches (Table 4).

Green roof and capacity down pipe techniques received very low standard deviations for both the traditional and new assessment criteria. This can be explained by the low footprint and small size requirements for both techniques. Capacity down pipes can virtually be applied for all sites if roof structures are present.

It would not be right to assume that the Greater Manchester case study findings apply necessarily to other areas as well. The key contribution to knowledge is the proposed generic methodology for SuDS retrofitting and not the example case study findings.

Findings based on Table 4 indicate for first preferences that soakaways and infiltration trenches are generally less preferred than capacity down pipes, ponds and filter strips. This can be explained by the fact that different sets of variables were applied. Table 4 also indicates that the first preferences of the combined approach for the SuDS techniques permeable pavement, pond, infiltration trench, soakaway and below-ground storage are more similar numerically to the novel ecosystem services than the traditional approach. This is the other way round for swales. Moreover, the combined approach is in-between the traditional and new approach for the capacity down pipe technique, which is unique.

It may come as a surprise that capacity down pipes and permeable pavements scored relatively highly on ecosystem service variables, which contradicts the common belief among some engineers that there has to be a strong bias towards natural and soft techniques when using ecosystem service assessment techniques [2,3]. However, capacity down pipes and permeable pavements [35,36] are likely to attract high values for variables such as SRT and MEE, if properly designed and managed, and present in large numbers across a site. Nevertheless, these specific findings relate to the Greater Manchester case study area and might therefore not apply to other areas.

Table 4. *Comparison of assessment approaches in terms of proposed sustainable drainage system (SuDS) techniques for all selected sites in Greater Manchester.*

SuDS Technique	Proportion (%) of sites at which SuDS techniques are given first, second or third order of preference for the ecosystem service approach			Proportion (%) of sites at which SuDS techniques are given first, second or third order of preference for the community and environment approach			Proportion (%) of sites at which SuDS techniques are given first, second or third order of preference for the combined approach		
	First	Second	Third	First	Second	Third	First	Second	Third
Capacity down pipe	16	14	6	0	16	15	7	19	7
Permeable pavement	15	9	3	12	11	5	19	9	4
Filter strip	15	20	9	8	14	11	15	19	7
Swales	5	5	12	0	0	9	0	2	11
Green roof	0	2	8	0	0	5	0	1	6
Pond	28	6	7	17	7	7	29	5	6
Constructed wetland	5	2	8	4	0	9	5	1	7
Infiltration trench	0	9	12	13	13	13	3	11	17
Soakaway	0	14	10	29	19	3	2	22	13
Infiltration basin	0	5	10	0	2	6	0	3	7
Below-ground storage	16	11	6	17	8	8	20	6	4
Water playground	0	3	9	0	10	9	0	2	11

Table 5. *Comparison of the inter-site variability for a given sustainable drainage technique for Greater Manchester.*

SuDS Technique	Standard deviations (based on relative percentage points awarded)		
	Ecosystem services approach	Community and environment approach	Combined approach
Capacity down pipe	8.45	8.44	12.05
Permeable pavement	12.55	32.04	21.97
Filter strip	14.36	29.87	21.91
Swale	12.42	24.04	18.03
Green roof	3.76	6.19	5.01
Pond	35.10	39.63	35.75
Constructed wetland	20.35	25.04	22.23
Infiltration trench	8.45	26.77	17.46
Soakaway	5.67	19.06	12.00
Infiltration basin	9.70	19.65	14.73
Below-ground storage	11.83	30.46	20.67
Water playground	9.52	28.99	18.26

Scholz and Uzomah also developed a rapid decision support tool based on more specific ecosystem service variables particularly for retrofitting of permeable pavement systems in the presence of mature trees [37]. Findings indicate that permeable pavements score even higher on ecosystem services if mature trees are present. This is the case because of the important role of trees in terms of water and air quality improvement and flood alleviation. Moreover, the run-off stored within capacity down pipes could be diverted to irrigate urban trees without the use of pumps.

4. Conclusions and Recommendations for Further Work

A rapid assessment methodology for retrofitting of SuDS was successfully introduced to reduce the currently high level of subjectivity in practice. Retrofitting of SuDS is possible for a high number of sites within a densely build-up area such as Greater Manchester. Generic ecosystem service variables suitable for SuDS were determined and their assessment indicated that most sites had a relatively low ecosystem service potential.

The suitability of sites for SuDS retrofitting was assessed based on traditional 'community and environment' variables and the ecosystem service variables. A comparison shows a slight bias of the old tool towards semi-natural SuDS techniques such as soakaways and infiltration trenches. In contrast, the new approach favoured capacity down pipes, ponds and filter strips.

A combination of the traditional and new approach shifts first preferences towards the ecosystem services approach for permeable pavements, ponds, infiltration trenches, soakaways and below-ground storage tanks. However, differences for some SuDS technique are insignificant. The capacity down pipe popularity for the combined approach was in-between that of the new and old approach.

All sites were suitable for the retrofitting of SuDS when the traditional assessment based on 'community and environment' variables was carried out. In comparison, the ecosystem services approach shows that nearly half of the sites visited are valued as having a relatively low ecosystem services potential, making them of limited use for retrofitting of most SuDS techniques. This finding can be used to prioritize sites for SuDS retrofitting, which is particularly important during difficult financial times. The application of the new tool is therefore likely to change the drainage infrastructure promoting ecosystem services and reducing urban pollution. The new capacity down pipe technique is likely to benefit from a greater acceptance of the ecosystem services approach in the future.

More research is recommended to develop the ecosystem service assessment approach further, particular for small sites dominated by domestic housing, where the capacity down pipe approach could make a significant difference. Additional urban but also rural case studies with a larger number of sites could be assessed to test the robustness of the new approach and to subsequently refine it.

Specific weighting systems for the ecosystem service variables as a function of individual SuDS techniques, the preference of the user, and different climatic regions and cultures could be introduced to reduce the impact of what may be perceived as less relevant ecosystem service variables. However, this would introduce extra bias considering that, for example, an engineer would have a different weighting system than an ecologist. The capacity down pipe technique would benefit from a weighting system used by engineers and planners who are likely to appreciate the water attenuation function of down pipes.

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