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Article

Selecting Sustainable Drainage Structures Based on Ecosystem Service Variables Estimated by Different Stakeholder Groups

Miklas Scholz *, Vincent C. Uzomah, Suhad A.A.A.N. Almuktar and Julie Radet-Taligot

Civil Engineering Research Group, School of Computing, Science and Engineering, The University of Salford, Newton Building, Salford M5 4WT, United Kingdom;
E-Mails: v.c.uzomah@edu.salford.ac.uk (V.C.U.); s.a.a.a.n.almuktar@edu.salford.ac.uk (S.A.A.A.N.A); julie.radet-taligot@ensil.unilim.fr (J.R.-T.)

* Author to whom correspondence should be addressed; E-Mail: m.scholz@salford.ac.uk; Tel.: +44-161-2955921; Fax: +44-161-2955575.

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Abstract: In times of recession, expert systems supporting environmental managers undergo a revival. However, the retrofitting of sustainable water structures is currently undertaken *ad hoc* using engineering experience supported by minimal formal guidance. There is a lack of practical decision tools that can be used by different professions for the rapid assessment of ecosystem services that can be created when retrofitting water structures. Thus the aim was to develop an innovative decision support tool based on the rapid estimation of novel ecosystem service variables at low cost and acceptable uncertainty. The tool proposes the retrofitting of those sustainable drainage systems that obtained the highest ecosystem services score for a specific urban site subject to professional bias. The estimation of variables was undertaken with high confidence and manageable error at low cost. In comparison to common public opinion, statistically significant differences between social scientists and the general public for the estimation of *land costs* using the non-parametric Mann-Whitney U-test were found. It was also surprising to find no significant differences in the estimation of *habitat for species* by civil engineers and ecologists. The new methodology may lead to an improvement of the existing urban landscape by promoting ecosystem services.

Keywords: aesthetics; best management practice; civil engineering; ecology; expert judgment; habitat for species; land size; safety; social science; uncertainty

1. Introduction

Traditional drainage often creates flooding and pollution problems in the lower catchment. The implementation of sustainable drainage systems (SuDS; UK) [1], which has similar characteristics to best management practices (USA) and water-sensitive urban design (Australia) [2], can help to solve these problems. The philosophy of SuDS is to promote infiltration of (partially) treated runoff into the ground [1]. Most SuDS techniques support 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 traditional objective of SuDS is to reduce the negative impact of urbanization 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 [1,6]. Potential improvement opportunities in terms of ecosystem services including aesthetics, amenity and biodiversity by introducing SuDS are often neglected by engineers and planners in practice [5]. Ecosystem services can be integrated within water-sensitive urban design [2] and multi-functional land use planning to maximize wider value opportunities for the benefit of humans and the environment.

The benefits human beings may obtain from the semi-natural (managed) environment can be referred to as ecosystem services [7–9]. Ecosystem services are often defined as the benefits individuals gain from the goods and services produced by nature and its natural systems [10]. The natural resources such as food, timber and water, and functioning natural systems such as healthy fertile soils, clean water [11] and air, and a regulated climate are essential for human wellbeing, security and economic prosperity [7]. A high biodiversity helps to sustain the natural environment and is thus an important factor for ecosystem service provision.

A list of 17 ecosystem service variables and their respective categories is provided in Table 1. The listed ecosystem services have been reinterpreted to make them relevant to SuDS retrofitted in urban areas and are categorized in broad agreement with other guidelines [9,12].

The aim of this article is to outline an innovative decision support tool based on the rapid estimation of novel ecosystem service variables at low cost and acceptable uncertainty. The key objectives to achieve this aim are: (1) to assess the uncertainties of the rapidly estimated SuDS variables based on drainage engineering expert opinion; (2) to evaluate the variability of estimated example variables and the learning process of estimation by different stakeholder groups; and (3) to support the development of a decision support tool for SuDS retrofitting taking into account the perspectives of drainage engineers, developers, ecologists, planners, social scientists and the general public.

The introduction of a transparent weighting system as a function of different professional bias allows for the investigations of "what if" scenarios giving decision-makers more flexibility to test the likely acceptance of various SuDS treatment trains. The tool will improve the urban landscape for the benefit of humans and nature.

Table 1. Ecosystem service variables.

Services	Number	Variable	Abbreviation
Supporting	1	*Habitat for species*	*HS*
	2	*Maintenance of genetic diversity*	*MGD*
Regulating	3	*Local climate and air quality regulation*	*LCAR*
	4	*Carbon sequestration and storage*	*CSS*
	5	*Moderation of extreme events*	*MEE*
	6	*Storm runoff treatment*	*SRT*
	7	*Erosion prevention and soil fertility*	*EPSF*
	8	*Pollination*	*P*
	9	*Biological control*	*BC*
Provisioning	10	*Food*	*F*
	11	*Raw materials*	*RM*
	12	*Fresh water*	*FW*
	13	*Medicinal resources*	*MR*
Cultural	14	*Recreation, and mental and physical health*	*RMPH*
	15	*Tourism and area value*	*TAV*
	16	*Aesthetics, education, culture and art*	*AECA*
	17	*Spiritual experience and sense of place*	*SESP*

2. Methodology

2.1. Site Assessment

A total of 100 sites and corresponding catchment areas that were large enough for the retrofitting of SuDS to have a positive urban drainage impact were identified by studying Ordnance Survey and Google maps of Greater Manchester. Moreover, discussions with local authorities, United Utilities (water authority) and major private land owners regarding suitable SuDS sites were held. The main areas targeted within Greater Manchester were Salford and Manchester.

The standard site assessment template was based on a combination of the frameworks developed by Scholz and his team for retrofitting of SuDS techniques in Glasgow, Edinburgh and elsewhere [4,6], and the Construction Industry Research and Information Association guidelines [1,13]. Each potential SuDS site was assessed during a site visit by a group of experts (2 to 5 team members) to reduce subjectivity [14]. A desk study subsequently supplemented the site visit. The following key information was collected:

1. General site information such as site number and name, postcode, grid reference numbers, location name, names of the inspection team members, site acceptability for SuDS and presence of existing SuDS. Photos of the key site features were taken for each potential SuDS site and its catchment;
2. Land ownership information such as number of owners, ownership type (private or public) and estimated site value (£);
3. Proportions (%) of site classification categories including development, regeneration, retrofitting and recreation;

4. Surrounding area characteristics such as descriptions of the neighborhood to the North, South, East and West, current and future site use, total area of the catchment (m^2), and catchment shape;
5. Location description and distance (m) to the nearest sewer, storm pipe, stream, river, canal, pond, lake and sea, if located within a reasonable distance within or at the border of the catchment;
6. Estimated current and future surface permeability (%) for the land categories grass, trees, shrubs and impermeability of the proposed SuDS site and its catchment;
7. Estimated proportions (%) of current and future roof runoff for the categories institutional, commercial, industrial, high density housing, medium density housing, low density housing and other;
8. Estimated proportions (%) of current and future road runoff for the categories car park, motorway, primary road (or dual carriageway), A road, B road, tertiary road and other.
9. For each sub-catchment, area (m^2) and gradient in the two main directions having an angle of 90° to each other in the horizontal plain;
10. 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);
11. Additional remarks regarding current drainage techniques and potential problems regarding the implementation of future SuDS techniques.

The information collected with the standard site assessment template supports the assessment team in determining the variables required for the ecosystem services approach.

2.2. Ecosystem Service Variable Assessments

Table 2 shows an overview of the new ecosystem services assessment approach. The potentials of new quantitative and qualitative approaches to assessing ecosystem services have been explored by others [8]. Table 1 shows an overview of the proposed 17 new ecosystem service variables that were also determined for the 100 potential SuDS sites. These variables belong to the established four ecosystem service categories of supporting, regulating, provisioning and cultural (Table 1).

2.3. Uncertainties of the Rapidly Estimated Variables

A relative measure of certainty expressed in percentage points 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. Inconsistencies were removed after discussion within the assessment team.

2.4. Variability of Estimated Variables and Learning Process

The approach for evaluating the variability of the randomly selected estimated example variables *aesthetics*, *land cost*, *land size*, *habitat for species* (Figure 1) and *safety* is outlined in this section. Furthermore, the learning process of estimation undertaken by a relevant civil engineering student cohort example is explained with the help of a three-stage questionnaire survey based on a PowerPoint presentation.

Table 2. Overview of the new ecosystem services assessment approach.

Step	Step Description	Comment
1	Select potential sustainable drainage system (SuDS) sites in a case study area	Essential
2	Undertake site visits and note general variables	Essential
3	Desk study for each potential SuDS site	Essential
4	Determine all ecosystem service variables (Table 1) and associated confidence values	Essential
5	Decide on application of a weighting system (if appropriate) for a specific profession (Table 3)	Recommended
6	Decide on dropping variables where the confidence values are too low or undertake further field and/or desk studies	Optional
7	Assess the feasibility of at least the top three proposed SuDS techniques	Recommended

For each variable tested, six corresponding relevant pictures representing virtually the whole numerical spectrum (*i.e.*, very low to very high values; e.g., Figure 1) of possible answers were selected for the questionnaire. The pictures were taken from actual case study sites in Greater Manchester, and did not contain any misleading or irrelevant information such as distracting objects of random occurrence (e.g., an ice cream van or a pedestrian) in the foreground.

A mixture of 51 full-time BSc, BEng and MEng civil engineering students, who were broadly familiar with the overall case study area and studying water resources technology in their third year at The University of Salford, were asked on 19 March 2013 to assign values to each picture associated with a particular variable.

The questionnaire was split into three different stages to test progressive learning. For each stage, the same pictures had to be assessed. However, the order was changed at random. Approximately 15 seconds were allocated for each picture. At Stage 1, students had to assign values that they had to benchmark against their personal perception. They had to make reasonable assumptions about what is a low or high value for a particular variable. In comparison, at Stage 2, students were aware of the range of possible scenarios for each variable, and had the opportunity to refine their first choices purely based on their memory. In the third and final stage, all pictures associated with a particular variable were shown at the same time. Direct picture comparisons and value readjustments were possible.

Each mean score per picture provided by the student cohort was compared to a target score, which was determined by the research team based on professional drainage engineering perception (e.g., Figure 1). The target score is also subjective (expert opinion) and should therefore only be seen as a guideline to the reader.

2.5. Comparison of Variability with Other Cohorts

The variables *aesthetics*, *land cost*, *habitat for species* and *safety*, which were estimated in Section 2.4 by civil engineers, were also approximated by ecologists and social scientists for comparison. On 3 May 2013, 42 undergraduate students studying ecology at The University of Salford were tested. Furthermore, 31 undergraduate social science students were questioned at the same university on 1 May 2013. The same methodology as presented in Section 2.4 was applied. However, Stage 2 of the learning process was omitted.

Figure 1. Relative ranking values for the variable *habitat for species* (%). Ascending order (*i.e.*, from highly inadequate to highly adequate habitat) based on the authors' expertise: (**a**) 9%; (**b**) 23%; (**c**) 45%; (**d**) 62%; (**e**) 70%; and (**f**) 82%. All photographs were taken by the authors and Nathan Somerset in 2012 and 2013 (The University of Salford).

(**a**)

(**b**)

(**c**)

(**d**)

(**e**)

(**f**)

The variables *aesthetics*, *land cost*, *habitat for species* and *safety* were also estimated by 49 randomly chosen members of the general public between 26 June and 25 July 2013. However, only Stage 3 (see Section 2.4) was applied; *i.e.*, all subjects were only presented with six pictures per variable in random order on a single sheet. The questionnaire survey can be found on the web [15]. The questionnaire will remain live at least until 25 December 2013, and further participation is still welcome.

The general public sample comprised subjects with the following backgrounds or professions: unidentified students (10%), civil engineering students (10%), engineers (33%), ecology students (0%), ecologists (12%), social science students (0%); developers (2%), planners (2%) and others (31%). Engineers and students are overrepresented in this sample. In contrast, members of the public with a below-average education are underrepresented.

2.6. Decision Support Tool for Different Professions

This section outlines the methodology for the development of a decision support tool for SuDS retrofitting taking into account the perspectives of drainage engineers, developers, ecologists, planners, social scientists and the general public as defined elsewhere [16]. A weighting system specific to the needs of a particular stakeholder group was introduced by providing weights for individual variables (Table 3) after consultation with different teams of academics representing different professions within The University of Salford.

Table 3. Weights for ecosystem service variables (Table 1).

Variable	Weights subject to bias					
	Drainage Engineer	**Developer**	**Ecologist**	**Planner**	**Social Scientist**	**General Public**
1	1	1	3	2	2	1
2	1	1	3	1	1	1
3	1	1	3	2	3	2
4	1	1	3	1	1	1
5	3	3	2	3	2	3
6	3	2	2	2	2	2
7	2	2	2	2	2	2
8	1	1	3	1	1	1
9	1	1	3	2	2	2
10	1	1	1	1	2	1
11	1	1	1	1	2	1
12	3	1	2	2	2	2
13	1	1	1	1	2	1
14	2	2	1	2	3	2
15	1	3	1	2	3	3
16	1	2	1	2	3	1
17	1	2	1	2	3	2

Variables of low relevance for a drainage engineer such as *MR* (see Table 1) in Greater Manchester were assigned with a low weight, while variables with a medium (e.g., *RMPH*) or high (e.g., *MEE*) relevance were assigned with a medium or high weight, respectively. Table 3 proposes weights from the viewpoint of different professionals (drainage engineer, developer, ecologist, planner, social scientist and the general public). A simple weighting system with only three categories (1, low; 2, normal; 3, high) has been proposed to keep the case study example simple. A maximum weight of 3 signifies that one variable is three times more important than a variable scoring only 1. However, the reader may wish to replace the proposed system by a more differentiated weighting system based on, for example, ten categories. Depending on the case study location and associated boundary conditions, end-users of the proposed tool may wish to select different weights, which will subsequently impact on the results. It is up the group of experts to decide if a weighting scale should be used and what weights may be appropriate for a particular case study. However, transparency in decision-making is essential.

2.7. Data Analysis

Microsoft Excel [17] was used for data storage and the general data analysis. The non-parametric Mann-Whitney U-test was computed using IBM SPSS Statistics Version 20 [18] and used to compare the medians of two (unmatched) independent samples. This was required because virtually all sample data (even after data transformation) were not normally distributed, so that an analysis of variance could not be applied.

3. Results and Discussion

3.1. Findings of the Assessment Method

Table 2 summarizes the new ecosystem services assessment approach applied to 100 potential example SuDS sites in Greater Manchester. Most ecosystem service variables did relate well to the natural environment such as biologically diverse parks (41% of all sites) and not to the built environment like impermeable car parks (33% of all sites). This relationship reduces the number of sites suitable for retrofitting of most SuDS, as car parks usually only perform well with respect to three ecosystem service variables [*moderation of extreme events* (*MEE*), *storm runoff treatment* (*SRT*) and *fresh water* (*FW*); Table 1]. The presence of public parks did not pull up the overall suitability of retrofitting sites, because they were usually small in size (30% of sites were <25,000 m^2), low in tree coverage (7%) and the presence of surface water [stream (0%), river (11%), canal (21%) and standing water (8%)] of the associated catchment was limited. However, the introduction of a weighting system (Table 3) that puts bias towards what a drainage engineer would perceive as more important variables for SuDS (e.g., flood control as part of *MEE* and water quality control considered by SRT) could increase the suitability of sites for retrofitting.

Table 4 shows the assessment approach in terms of proposed SuDS techniques for Greater Manchester. The relative proportions for each SuDS technique have been expressed in percentage points for all selected professions. Note that there were many occasions where more than one SuDS technique had the same order of preference.

Table 5 shows a comparison of the inter-site variability for a given sustainable drainage technique for Greater Manchester, and helps to interpret the preference distributions in Table 4. The relatively high variability for most variables such as ponds and constructed wetlands cannot be explained by factors relating to specific planning policies for Greater Manchester. Ponds are associated with the greatest inter-site variability because of their potentially relatively small size and great popularity [5,6,19].

Table 4. Drainage system preferences*.

Profession	Sustainable Drainage System	First	Second	Third
Drainage engineer	Permeable pavement	43	9	4
	Filter strip	2	7	12
	Swale	0	2	12
	Green roof	0	0	3
	Pond	33	11	4
	Constructed wetland	11	1	2
	Infiltration trench	5	9	44
	Soakaway	0	4	15
	Infiltration basin	1	4	8
	Belowground storage	5	44	13
	Water playground	3	17	9
Developer	Permeable pavement	42	13	12
	Filter strip	11	23	14
	Swale	1	13	11
	Green roof	0	0	1
	Pond	36	9	1
	Constructed wetland	8	6	1
	Infiltration trench	2	32	23
	Soakaway	3	1	34
	Infiltration basin	1	1	8
	Belowground storage	0	11	23
	Water playground	1	2	6
Ecologist	Permeable pavement	39	7	12
	Filter strip	13	22	22
	Swale	2	13	22
	Green roof	0	1	2
	Pond	30	13	5
	Constructed wetland	10	1	3
	Infiltration trench	8	33	26
	Soakaway	1	8	17
	Infiltration basin	2	8	12
	Belowground storage	1	13	32
	Water playground	5	19	8
Planner	Permeable pavement	39	8	6
	Filter strip	8	11	29
	Swale	1	6	17
	Green roof	0	1	1
	Pond	31	12	1
	Constructed wetland	10	1	1
	Infiltration trench	0	6	25
	Soakaway	0	3	16
	Infiltration basin	0	2	9
	Belowground storage	5	42	14
	Water playground	5	19	7

Table 4. *Cont.*

Profession	Sustainable Drainage System	First	Second	Third
Social scientist	Permeable pavement	39	7	6
	Filter strip	12	24	19
	Swale	0	1	11
	Green roof	0	1	0
	Pond	33	10	0
	Constructed wetland	10	0	1
	Infiltration trench	0	9	31
	Soakaway	0	2	20
	Infiltration basin	0	2	3
	Belowground storage	2	33	18
	Water playground	5	20	5

Note: * Proportion (%) of sites at which sustainable drainage system techniques are given first, second or third order of preference based on different professional perspectives (weights in Table 3). Note that numbers not necessarily add-up to 100, because some techniques received the same preferences.

Table 5. Inter-site variability* comparison for a given sustainable drainage technique.

Sustainable Drainage System	Drainage engineer	Developer	Ecologist	Planner	Social Scientist
Permeable pavement	21	17	16	19	16
Filter strip	16	18	19	19	18
Swale	15	17	17	17	13
Green roof	5	0	6	5	5
Pond	31	36	33	32	31
Constructed wetland	21	25	23	21	19
Infiltration trench	13	9	13	12	11
Soakaway	7	5	9	6	5
Infiltration basin	13	16	12	12	11
Belowground storage	17	15	13	15	13
Water playground	18	17	17	19	20

Note: * indicated by the standard deviation based on relative percentage points awarded.

It may come as a surprise that permeable pavements scored relatively highly on ecosystem service variables (Table 4), 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 [5,20]. However, permeable pavements are likely to attract high values for variables such as *SRT* and *MEE*, respectively, if properly designed and managed.

3.2. Expert Judgment

The estimation of certainties associated with expert judgment needs to be undertaken consistently to be informative. Human judgment may vary considerably, and involves an appreciation of reality and what is a realistic solution to a given problem and an understanding of the importance of making the right choice about what action to take [21]. Confidence estimations are affected by ones familiarity of a topic, experience with probabilistic assessments, the level of difficulty of a task, and the environmental context in which the task is performed [22].

Research has proven that a group's level of judgment usually outperforms that of an average individual due to the sharing of responsibility between the group members. This sharing, in turn, leads to an increase in their confidence to communicate judgments [23].

Knowledge used by engineers to make judgments is not entirely of scientific nature, although a substantial part is derived by science, but is based on experimental evidence and on empirical observations of materials and systems. Understanding is built-up over time as a result of continuous unquantifiable but improving judgments and choices [24,25]. The introduction of a weighting system can address differences between assessor groups with different scientific backgrounds.

Previous studies indicate that good expert judgment performance can be observed when both the scientific validity of an estimated observation and the learnability of the estimation by the assessor are high. Poor expert opinion may occur if at least one of these factors is low [26]. Most variables (Table 1) to be estimated in the proposed SuDS retrofitting tool are strongly scientifically valid, and their estimation is uncontroversial and easy to learn (e.g., *SRT* and *FW*). Therefore, this paper focuses on the estimation of some of those more controversial variables that are highly subject to personal opinion and taste (*aesthetics* and *safety*), difficult to learn due to their highly dynamic nature in terms of time and space (*land cost*), and scientific complexity (*habitat for species*).

For example, the indirect assessment of biodiversity predominantly through the supporting ecosystem service variables *habitat for species* and *maintenance of genetic diversity* is difficult due to its scientific complexity in terms of sustainability assessment and ecosystem valuation. Any rapid and cost-effective screening method should preferably be undertaken by experts in order to avoid obtaining poor results based on guesses. In comparison, traditional biodiversity assessments are time-consuming and costly. Therefore, this paper assesses this challenge by researching to what degree users with different experience and scientific background (see Section 3.4) come up with similar findings.

3.3. Variability and Learning Process

An estimation tool has to be relatively simple to learn and apply [26], and should be based more on intuition than on expert understanding to limit the variability associated with estimations for the same variable by different assessors with potentially diverse backgrounds. Table 6 shows the findings of the questionnaire analysis. Figure 1 shows the relative ranking values for the variable *habitat for species* (%) in ascending order (*i.e.*, from highly inadequate to highly adequate habitat).

The example variables *aesthetics* and *land costs* were determined relatively well (Table 6). In comparison, *habitat for species* (Figure 1 and Table 1) and *safety* were associated with higher but still acceptable estimated errors. This can be explained by the high complexity of these variables (see Section 3.2). The cohort had serious difficulties in estimating *land size*. Nevertheless, this is not considered to be a problem, because *land size* can be easily measured in the field or estimated using maps.

Considering that the concept of "estimation" was new to the students, and they were neither briefed nor trained in advance of the questionnaire, someone might expect considerable progressive learning from stage to stage. However, learning only improved clearly for *land size* estimation between all stages (Table 6). Moreover, the authors expected to identify a clear reduction in variability (indicated by the standard deviation) as learning progressed. Nevertheless, this was not the case (Table 6).

Table 6. Summary of the questionnaire analysis* for the civil engineering student cohort.

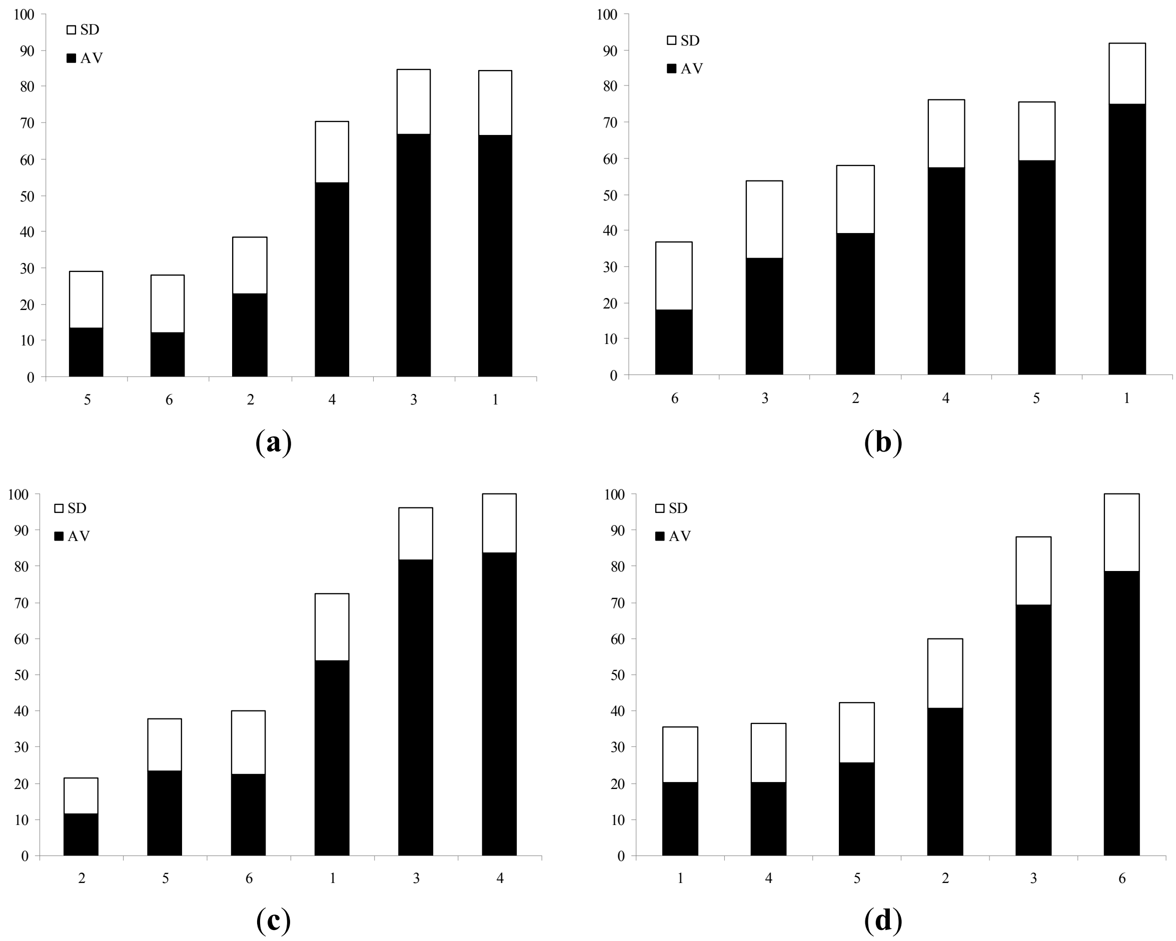
Picture number	Target score	Stage 1		Stage 2		Stage 3	
		Mean	STDEV[a]	Mean	STDEV[a]	Mean	STDEV[a]
Aesthetics (%), which is part of variable 16 (*Aesthetics*, *education*, *culture and art*; Table 1)							
1	30	36	20.9	29	22.0	31	24.4
2	43	35	18.3	36	18.8	40	17.8
3	49	48	22.4	41	27.2	39	24.2
4	62	55	10.6	57	15.5	63	14.8
5	74	58	21.1	65	19.4	69	22.2
6	82	64	23.9	61	22.0	69	20.5
Land size (m^2), which influences all variables (Table 1)							
1	3240	6370	11,613	8510	19,523	8400	14,302
2	4600	8540	11,621	14,630	25,144	10,990	18,423
3	8200	11,560	23,187	10,790	23,532	21,100	59,486
4	9440	57,010	216,610	16,040	35,940	21,690	48,024
5	10,350	49,520	69,104	63,160	149,055	56,650	91,580
6	70,000	123,470	436,125	84,940	159,947	70,790	101,090
Land cost (%), which is part of variable 15 (*Tourism and area value*; Table 1)							
1	27	27	24.9	25	20.0	25	21.9
2	35	42	15.0	45	17.7	44	17.4
3	54	53	22.4	58	21.6	59	22.4
4	60	58	19.3	62	17.1	60	20.3
5	69	65	19.7	63	19.0	64	18.9
6	78	71	17.9	68	18.5	70	20.2
Habitat for species (%), which is variable 1 (Table 1)							
1	9	10	13.2	16	21.5	16	20.6
2	23	30	17.5	29	18.9	28	20.4
3	45	35	22.0	38	20.3	40	19.5
4	62	52	24.4	53	16.7	56	17.5
5	70	67	19.4	62	21.3	64	20.0
6	82	69	23.2	68	23.8	74	23.3
Safety (%); which is part of variable 14 (*Recreation, and mental and physical health*; Table 1)							
1	20	21	20.7	22	20.0	26	32.2
2	29	24	22.6	27	21.6	27	21.2
3	34	33	20.4	32	20.6	31	22.9
4	40	46	24.3	45	22.8	47	32.3
5	62	46	23.9	45	25.2	53	22.5
6	74	59	35.7	61	30.4	64	32.7

Notes: * indicating the variability for example variables and progressive learning; [a] standard deviation.

Figures 2–4 show the findings for the ecology students, social science students and the general public, respectively. The standard deviations associated with variable estimations were usually lower for the ecology compared to the civil engineering students. In comparison, the same was the case for social science students (except for *aesthetics* and *habitat for species*). The standard deviations for ecology and social science students and the general public were rather similar.

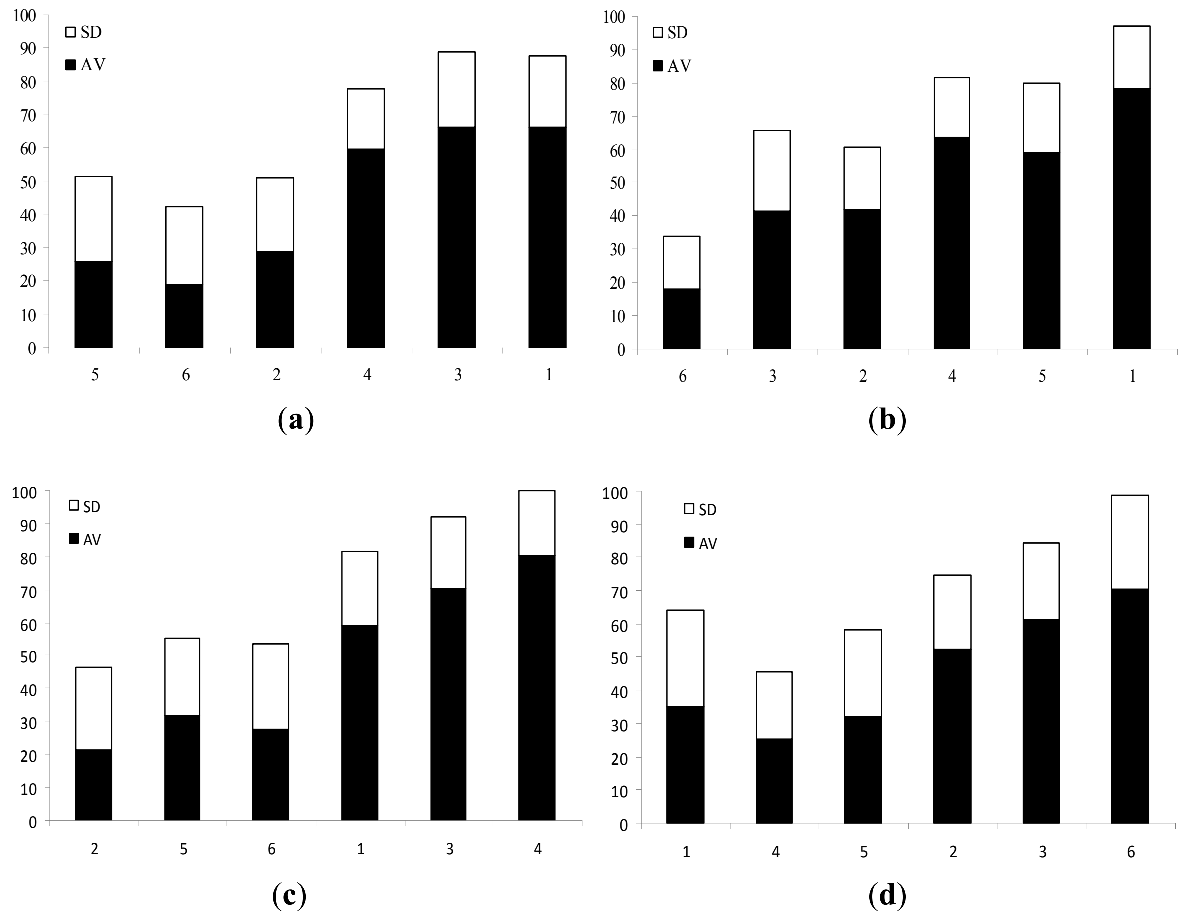
Table 7 shows an assessment of the statistically significant differences between different cohorts of estimators for selected SuDS characterization variables using the non-parametric Mann-Whitney U-test. There were five relationships that could be considered as unexpected with respect to commonly hold public opinions. Civil engineering compared to ecology students had similar views regarding *habitat for species* (P = 0.994; Table 7) and *safety* (P = 0.494; Table 7). However, one might assume that *habitat for species* would be much more important to ecologists than engineers. On the other hand, engineers are usually more aware of health and *safety* matters than ecologists.

Figure 2. Stage 3 estimations (%) by ecology students for the variables (**a**) *aesthetics*; (**b**) *land cost*; (**c**) *habitat for species*; and (**d**) *safety* based on different pictures represented by numbers on the x-axis. SD, standard deviation; AV, average.



Someone might expect that civil engineering and social science students might have different views regarding *habitat for species*. However, the study showed that the data were rather similar (P = 0.379; Table 7). It could be expected that ecology students would have a different opinion regarding *habitat for species* compared to the general public. However, their assessments were rather similar (P = 0.072; Table 7), which is surprising considering that ecologist should have a better understanding of the associated science and might therefore have different assessment criteria. Finally, social scientists and the general public might be expected to have similar opinions with respect to the estimation of *land* *costs*. However, their estimations were significantly different (P = 0.006; Table 7), which could be explained by the dominance of engineers in the general public sample.

Figure 3. Stage 3 estimations (%) by social science students for the variables (**a**) *aesthetics*; (**b**) *land cost*; (**c**) *habitat for species*; and (**d**) *safety*. based on different pictures represented by numbers on the x-axis. SD, standard deviation; AV, average.

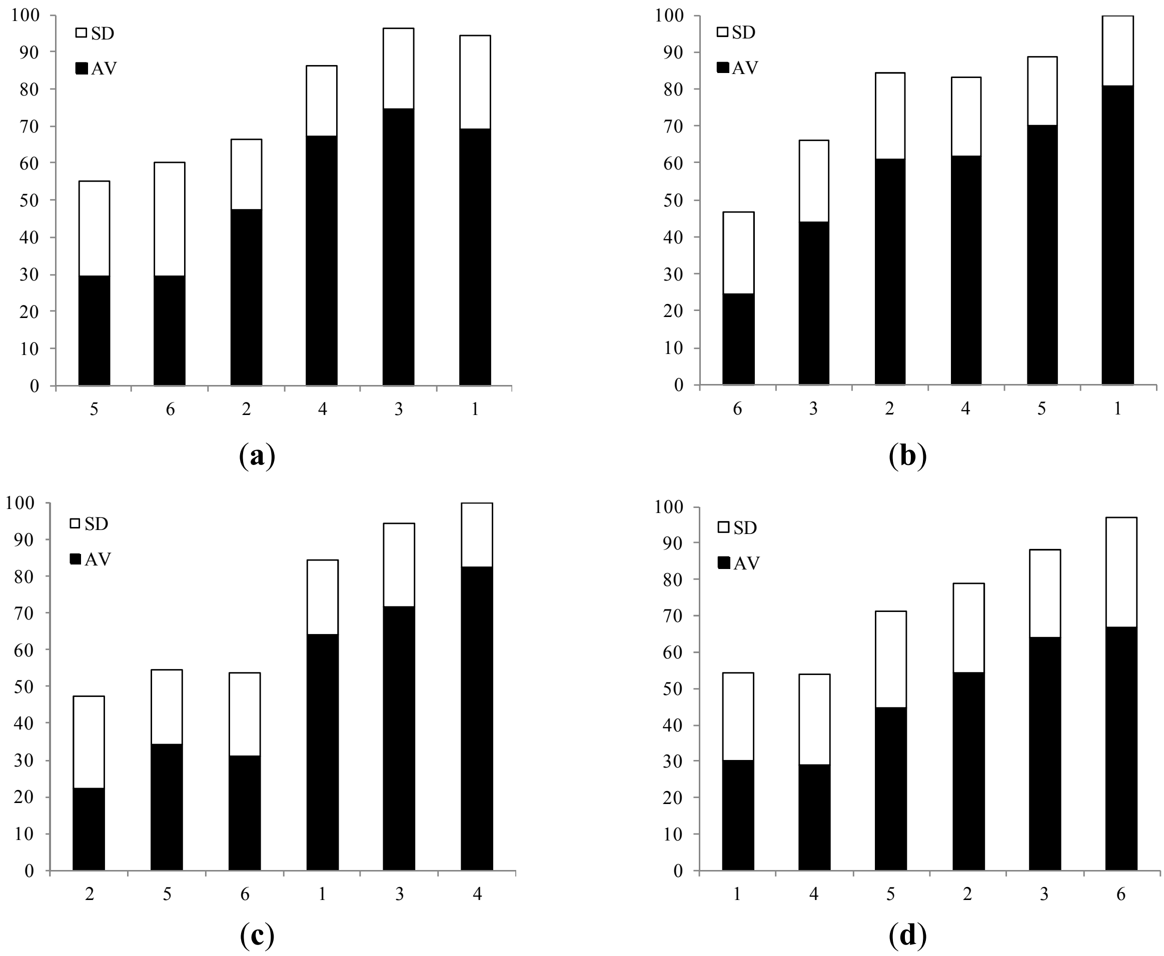


3.4. Different Professional Perspectives

Different professions will want to assign a higher importance to those variables that are of greater relevance to their interests (Table 4). Therefore, the new tool takes into account the diversity of professional opinions by giving any user the opportunity to select a weighting system (Table 3) of greatest relevance to his or her line of thought. However, the introduction of associated bias can be avoided by not selecting any weighting system.

In case a result that is free of any bias and error associated with the estimation by a specific cohort is preferable, the findings in Section 3.3 can be used to adjust the estimation results. For example, if an estimation is made by cohort A for a variable x, and it is known that A consistently overestimates x by 10% compared to all other relevant cohorts, x could be reduced by 10%, which would result in an estimation more acceptable by the majority of stakeholders. With respect to this study, the general public sample is dominated by engineers (at least 43%; Section 2.5). Considering that engineers consistently overestimate *aesthetics* for less beautiful (<50% for aesthetics) SuDS sites in comparison to, for example, ecologists and social scientists (Table 6; Figures 2 and 3), their estimations could be reduced by at least 15% and 5%, respectively, to bring them in line with those made by ecologists and social scientists. Such relationships can be formalized in numerical models based on uncertainty estimations associated with different cohorts and variables [27].

Figure 4. Stage 3 estimations (%) by the general public for the variables (**a**) *aesthetics*; (**b**) *land cost*; (**c**) *habitat for species*; and (**d**) *safety.* based on different pictures represented by numbers on the x-axis. SD, standard deviation; AV, average.



3.5. Strengths and Limitations

The strengths of the new ecosystem services approach to SuDS retrofitting, particularly in comparison to the community and environment methodology adopted by others [13,28], are as follows:

- Generic retrofitting approach based on universal ecosystem service variables;
- Recognition that various professions have different priority variables;
- Expert judgment may be more accurate than prediction models if the science base is strong, the learnability high and sufficient information is available [21,26];
- Inexpensive, user-friendly and easy-to-understand evaluation; and
- Overall ecosystem service potential of a site expressed through an individual value.

The potential weaknesses of the ecosystem services assessment approach are:

- Subjectivity and aggregation are generic limitations of an expert-based system, which can be addressed by involving expert groups and determination of uncertainty values for all estimations [14,29,30];
- Some ecosystem service variables are not always applicable;
- Strong perceived (often falsely; see below) bias towards natural sites and "soft" SuDS (e.g., ponds and wetlands) in contrast to urban sites and "hard" SuDS (e.g., permeable pavements and belowground storage systems); and
- Possibility of multicollinearity among variables due to potential dependencies between some of them [31].

Table 7. Assessment of the statistically significant differences between different cohorts of estimators (civil engineering, ecology *and* social science students, and the general public) for selected SuDS characterization variables (*aesthetics*, *land cost*, *habitat for species* and *safety*) using the non-parametric Mann-Whitney U-test (see also Section 2.7).

Cohort comparisons	Statistic	*Aesthetics*	*Land cost*	*Habitat for species*	*Safety*
Civil engineers and ecologists	*P*	0.000	0.004	0.994	0.494
	H	1	1	0	0
Civil engineers and social scientists	*P*	0.004	0.157	0.379	0.027
	H	1	0	0	1
Civil engineers and the general public	*P*	0.396	0.094	0.050	0.002
	H	0	0	0	1
Ecologists and social scientists	*P*	0.070	0.183	0.500	0.175
	H	0	0	0	0
Ecologists and the general public	*P*	0.000	0.000	0.072	0.018
	H	1	1	0	1
Social scientists and the general public	*P*	0.002	0.006	0.311	0.453
	H	1	1	0	0

Notes: *P* value, probability of obtaining a test statistic at least as extreme as the one that was actually observed, assuming that the null hypothesis is true; H, response indicator; if H = 1, filters are statistically significantly different ($P < 0.05$) for the corresponding water quality parameter; if H = 0, the difference is not significant.

Some of the above limitations such as subjectivity are also inherent in traditional assessment approaches [1,13]. However, multicollinearity might be a more relevant problem with the proposed ecosystem services approach due to the use of a high number of variables. In order to avoid artificial dependencies between some variables that could be considered as similar by the inexperienced assessor, all assessors need to be clear about their differences, which require training by more experiences evaluators. Considering that any tests for multicollinearity is case study-dependant, the inevitable bias associated with a case study does not allow for objective testing unless the number of case studies is very high and there is an adequate geographical spread to reduce bias. Nevertheless, a principal component analysis was carried out to identify redundant variables in order to reduce the risk of multicollinearity [31]. Findings indicate that all ecosystem services variables (Table 1) were considered to be necessary for the proposed expert system.

4. Conclusions and Recommendation for Further Research

A rapid estimation-based assessment methodology for retrofitting of SuDS was successfully introduced. This tool can be used together with water-sensitive urban design, multi-functional land use planning and regeneration strategies to prioritize sites for SuDS retrofitting, which is particularly important during difficult financial times.

The variable estimations and the assignment of associated confidence figures were based on expert judgment. However, findings show that estimation errors and variability are relatively low even for virtually untrained example cohorts. The introduction of a transparent and justified weighting system as a function of different professional bias leads to the preferred selection of some SuDS techniques by several professions. This methodology allows for the investigations of various "what if" scenarios giving decision-makers more flexibility to test the likely acceptance of various SuDS treatment trains.

Statistically significant differences between different cohorts of estimators for selected SuDS characterization variables using the non-parametric Mann-Whitney U-test were not found for about half of the possible combinations of cohorts. However, there were four of these relationships that could be considered as unexpected with respect to commonly hold public opinions. Civil engineering compared to ecology students had similar views regarding *habitat for species* and *safety.* Someone might also expect that civil engineering and social science students might have different views regarding *habitat for species*. However, the study showed that the data were rather similar. It could also be expected that ecology students would have a different opinion regarding *habitat for species* compared to the general public. However, their assessments were rather similar.

In comparison, statistically significant differences between cohorts for SuDS characterization variables using the non-parametric test that were surprising, were only found for social scientists compared to the general public, where someone might expect similar opinions concerning the estimation of *land costs*. However, corresponding estimations were significantly different.

More research on estimation adjustments to eliminate cohort bias, variability and errors would be welcome. Moreover, larger data sets would be beneficial in making judgments with higher confidence. It is therefore recommended to test the tool in different towns and cities to prove its validity for other case study scenarios.

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Conflicts of Interest

The authors declare no conflict of interest.

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