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A LOOK TO THE SUSTAINABLE DRAINING SYSTEMS: CRITERIA OF SUSTAINABILITY AND SUCCESSFUL CASES

Sandra SÁNCHEZ-SABAU[1*]; Marian SABĂU[1]; Linda MONTERO[1];
Jorge GONZÁLEZ-CONEO[1]; Ana ABELLÀN[2]; Camilo OSORIO[1]

[1] Universidad de la Costa, Department of Civil and Environmental Engineering, Calle 58 No. 55-66, 080020 Barranquilla, Colombia.
[2] Ingeniería Hidráulica y Medio Ambiente, 08025 Barcelona, Spain.

Abstract

There have been many studies and research that address sustainable drainage urban systems (SUDS), where factors like costs or the zone where a SUDS is to be installed are determinant, so multicriteria studies are important in decision-making. The development of a multidisciplinary approach could in the future serve as a helping tool to support decision, whose purpose would be to guide users in their choice of the most appropriate solution for managing the collection of rainwater. Another key point is to make use of other strategies to accurately define the most appropriate SUDS for a particular location. Modelling for example, considers different factors to simulate real-time rainfall events and evaluate the performance of rainwater collection systems among other low impact development systems. Based on what has been stated above, some successful cases currently performed all over the world were studied, where it is evident that green roofs can retain between 70% and 100% when rainfall is not high and peak reduction on these may reach 83.3%. Concrete and porous asphalt mixtures differ in their behaviour, but even so, they can maintain over time an average permeability between 0.41 cm/s and 0.22 cm/s, and similar values in the reduction of the infiltration capacity of 79.43% and 82.04% respectively.

Keywords: *SUDS; Urban drainage; Low impact development; Rainwater; Green roofs; Permeable pavements.*

Introduction

During 1960s the impact of rainwater runoff on receptors bodies was evident [1], however only until 1990 the flooding of rainwater became a real concern [2]. Since then, have been managed research and standards that directly involve urban rainwater [3, 4], and started different strategies to improve urban conditions when there are high amounts of rainfall.

Sustainable drainage urban systems (SUDS) can be defined as integral elements of the infrastructure (urban-hydraulic-landscaping) whose mission is to capture, filter, retain, transport, store and infiltrate to the ground excess water caused by urban runoff, trying to reproduce as close as possible the natural water cycle. SUDS have been designed to imitate natural conditions, which through capture, infiltration, and treatment of rainfall at source, seek to reduce the streams formed by the impermeability of soils [5]. The sustainability criteria in which SUDS rely make reference to the environmental, social, economic and technical

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[*] Corresponding author: sandrasanchz8@gmail.com

components, criteria that when making an assessment of SUDS sustainability, generate a significant advantage over the traditional drainage systems [6]. Thus, depending on factors such as soil type, available space and the geology of the site, the best SUDS can be selected for its application. These systems are divided into structural and non-structural measures, where the most representative ones are the structural combining a series of engineering and hydrologic specifications, as in the case of green roofs [7,8], permeable paving [9,10], bio-retention systems [11–13] and other SUDS [14–17]. These systems have obtained very favourable results, which let us think that in coming years will be a great intervention of these systems within global society.

This study delves into SUDS, their classification and main evaluation criteria that influence the investment and construction of these systems, the most widely used hydrological models that contemplate these systems, and a list of successful cases of SUDS implementation, which have happened throughout history.

Materials and methods

Search method

The information on SUDS was taken from several sources of documents as academic databases, among them, Science Direct, Springer Journals, REDALYC, E-Libro and different websites. In addition, in order to establish the legal criteria, national and international standards were consulted, as well as books on hydrology, hydraulics, fluids mechanics and specific SUDS manuals. This article arises as a product of the research entitled “Study for the implementation of SUDS from the hydrological modelling of urban superficial rainfall currents in the city of Barranquilla. The study case of the stream from Carrera 65”, project developed at Universidad de la Costa in Colombia.

The selection of information was based on the most relevant topics of SUDS, for example the different classifications that they may have, the different mathematical-hydrological models found in the market and the main sustainability evaluation criteria for the implementation of SUDS. This selection was made in order to integrate all key components when implementing a SUDS, to obtain better performance and efficiency.

Definition of SUDS

The SUDS, also known as BMP’s (Best Management Practices), seek to recreate the natural hydrological cycle in urban areas [18]. Their aim is to mitigate the problems of both quantity and quality of urban runoff, minimizing the impacts of urban development, and maximizing the landscape integration and social and environmental values relating to the subject [19–21]. In contrast the existing drainage systems aim to evacuate as soon as possible urban runoff generated during rainy season toward the receiving medium [22, 23].

SUDS besides acting on the problem of urban flooding, are also involved in other environmental components such as weather regulation [24], increase of wildlife [25], and restoration of natural flow of the urban water cycle among others, which help the environment and the quality of life of human beings.

Classification of SUDS

SUDS have been classified in dissimilar ways through the years, according to different considerations and criteria. The most consistent classifications that we may find [26] are the ones that propose a division based on where they are to be implemented [27]. That differentiates between the techniques applied in control at source and the ones applied in downstream, and which differ depending on the degree of intervention on the network that can have the techniques of sustainable drainage.

In response to this latter form of classification, SUDS can be classified broadly into two branches: structural and non-structural measures, the latter also known as preventive measures, seeking to prevent on one hand, water pollution by reducing the potential contamination sources, and on the other hand, to partially avoid the transit of runoff downstream and its contact with pollutants [28]. They comprise education strategies and political sciences, giving an added value to the efficient use of water [29]. The structural measures manage the runoff through actions that contain to a lesser or greater degree some constructive element, or involve the adoption of *ad hoc* urban criteria [30]. Inside these, there is a subdivision for the types of constructions; there are infiltration systems, collection and transport systems, and passive treatment systems, which in turn also involve other techniques. In **Error! Reference source not found.** a general classification of SUDS is shown.

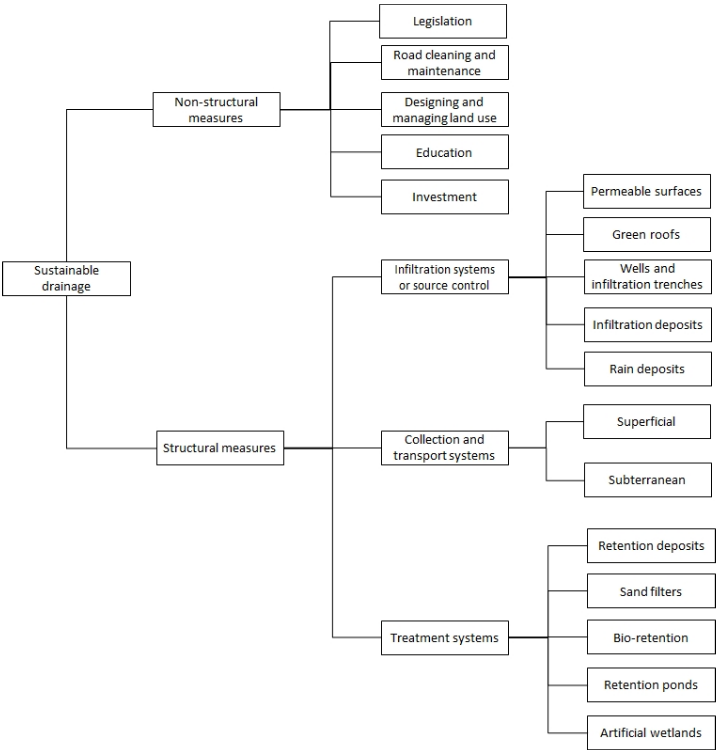

Fig. 1. Classification of sustainable drainage urban systems (SUDS), adaptation based on literature [26, 35, 56, 57]

Criteria to evaluate SUDS sustainability

The issue of sustainable management of rainwater requires different strategies that integrate components such as the political, local and environmental ones, but all these need information and a clear understanding of the possibilities that are at stake, as well as the main consequences of each decision [31]. The information regarding SUDS can be collected from different literature sources, but there are also other alternatives such as modelling, although it requires precise data. A good methodology must consider that decisions made with insufficient information represent costs, loss of time and the possibility of water management problems [32].

At this time a fundamental question in the context of urban design is how to manage rainwater in the city by applying the principles of sustainability, understanding by sustainability a state in which the management of rainfall brings together ecological and technical objectives and it does not limit the city development [33].

Table 1 shows the main criteria for evaluating the sustainability of SUDS.

Table 1. Main criteria for the evaluation of SUDS sustainability [6, 34]

Sustainability Criteria	
Category	**Primary Criteria**
Physical characteristics of space	Occupied area Characteristics of soil and subsoil
Technical and scientific performance	System performance (quantity and quality) System reliability System durability System flexibility and adapting capacity Impact over drainage system
Environmental impacts	Impact of water volume Impact on water quality Ecologic impact Use of resources
Social benefits and urban community	Services, aesthetics, access, and benefits for the community Public information, education, and sensitization Acceptability of interested parties, perception and attitude towards the risks and benefits Health and security risks Contribution to a sustainable development
Effectiveness and maintenance	Maintenance, provision, and responsibilities of the system Performance of system integrity, health, and safety Management risks Design life
Calculation of economic costs	Financial risks Affordability Life cycle costs Soil costs

There are other criteria and indicators for the evaluation and management of SUDS, which will not be covered in this article, but these are necessary when making decisions to implement SUDS, such as for example the ones proposed by CIRIA in its recent publication [35].

However, in this article are highlighted the most common impediments when implementing SUDS strategies, and possible solutions.

Table 2. Main obstacles and solutions for sustainable management of rainwater [36]

Impediment	Solution
Uncertainties about performance and costs	Conduct research about on the costs and performance of large-scale basins
Insufficiency of engineering standards and guidelines	Create a model of ordinance and promote guidance documents
Fragmentation of responsibilities	Integrate management across levels of government and the water cycle
Lack of institutional capacity	Develop workshops directed to educate the professionals
Lack of laws	Use popular actions to obtain support for the ordinances and regulations
Lack of funding and effective market incentives	Solve obstacles and address market approaches to provide financing mechanisms
Resistance to change	Educate and engage the community through training

Models to evaluate SUDS

Rainfall models are important tools in the design and management of urban drainage systems. The results that these models may yield are reliable, assuming that the input data is real [37].

Comprehensive modelling of urban drainage systems in principle is summarized in three key points:

- modelling of a multitude of components (biophysical, economic and others) and the interactions between them;
- consideration of acute, chronic, and delayed effects of quality and quality processes of water of a simulation over a long period of time;
- ability to see both local and global processes to improve decision-making, political or scientific knowledge.

These aspects according to [38] apply throughout the urban waters system and are not limited to a specific area.

In recent years have been studies about the different models which have made great advances in the field, involving new components to ensure a better understanding of SUDS practices [39,40], as well as an analysis to determine different scenarios for modelling water resources [41] and the simulations of SUDS [42–44].

Also there have been developed tools for decision-making [39] which, used in conjunction with the models help to optimize the previous evaluation in the classification and selection of alternative drainage by incorporating sustainability criteria. These types of tools are of the integral kind, meaning they encompass an analysis that integrates various aspects, hydrological, environmental, economic, social and risk factors [45], and among them stand out the one created by the United States Environmental Protection Agency that incorporates the SWMM model [46], or the one done in Europe, Daywater project [47].

Results and discussions

Study cases

Green roofs

Event 1

Installation of 4 platforms (3 green roofs and 1 traditional roof) located on the roof of the Scientific Educational Center of the University of Environmental and Life Sciences, Wroclaw - Poland, during the period from June to November in 2009 and 2010 [8]. The mean registered retention values were: green roof 3 - 77.7%, green roof 2 – 74.2%, and 72.9% for green roof 4, in comparison to roof 1 (traditional) that was 29.9%. The rainwater retention inside the structure of the green roofs contributed significantly to a reduction of peak runoff.

Event 2

On the campus of the Faculty of Agronomy at the University of Buenos Aires, through the construction of plots of land that simulate vegetated roofs with different layers of vegetation and different thicknesses, it was determined the reduction potential of surface runoff. They studied 32 plots, with a layer thickness of 30 cm (high plots) and others with a thickness of 6 cm (low plots) [48]. After the analysis, the results of retention percentage in general were high, and they vary from 70% to 100% when rainfall is not heavy (around 20mm), except in those cases when the humidity of the substrate was high (due to the occurrence of rain the past two days to measurement). In these cases, the low plots presented lower retention, close to 30% and around 60% in the high ones. When rainfall reached 35 to 40mm, the maximum retention percentages were located around 65%. When rainfall reached 90mm to 100mm, the retention percentages were reduced significantly, with values between 25% and 35%. It was noted that in rainfalls with wind the effect of the distribution of the plots was affected.

Event 3

Genoa University developed an experimental roof to investigate the hydrological response of a green roof in the Mediterranean climate in a controlled environment. They evaluated different slope conditions (2%, 5% and 10%), depths, soil types, rain intensities (108mm/h, 134mm/h, 158mm/h, 181mm/h, and 194mm/h) for a duration of 15 minutes and return periods of 5, 10, 20 and 30 years. They also conducted a large-scale experiment on the roof of the Environmental Engineering Laboratory of the university [49]. The runoff coefficient calculated according to the results for a time interval equal to the duration of the rain fluctuates between 33% and 48%. They found that the highest runoff coefficient was 48%, obtained for rainfall intensity of 134 mm/h, duration of 20 minutes and 46 seconds, and a slope of 10%. They found that the runoff coefficient increases with the slope, rain intensity and duration. On the other hand, the results obtained in the large-scale experiment on the green roof, shown that the green roof was as an efficient device, with average values for retained volumes of 51.5% and a peak reduction of 83.3%.

A comparison between all the three events is presented in Fig. 2 considering the volume retention capability of the green roofs. It can be seen that the values range from 50% to 80% of the total rainfall volume, which means that the green roof system is an effective tool to significantly reduce rainwater runoff generation.

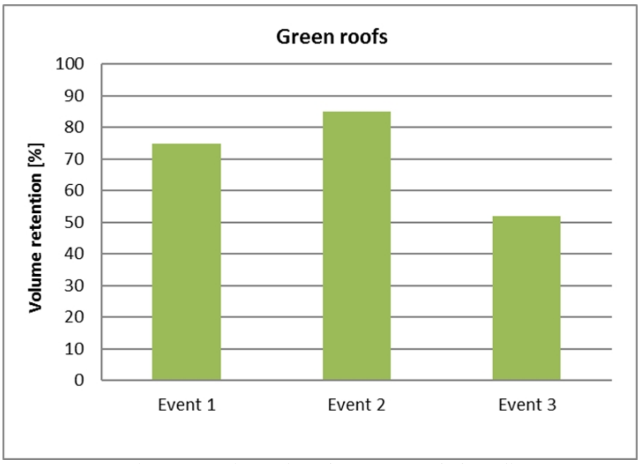

Fig. 2. Average volume retention values for green roofs from literature [8,48,49]

Permeable pavements

Event 1

The study evaluated the infiltration rate of 8 permeable pavements to consider their compliance under two criteria. First with the infiltration guidelines from Netherlands which stipulate an average value greater than or equal to 194mm/h, and other guidelines in the Netherlands which recommend maintenance when the infiltration is below 20.8mm/h [50]. The infiltration rates of the 8 sidewalks differ between 29 and 342mm/h, determined as follows: Zwolle3 - 342mm/h, Zwolle1 - 284mm/h, Dussen2 - 132mm/h, Delft1 - 124mm/h, Effen1 - 109mm/h, Utrecht2 - 71mm/h, Dussen1 - 69mm/h, Utrecht1 - 29mm/h. According to the criteria with which the performance of permeable pavements is evaluated, none of these required immediate maintenance.

Event 2

The University of Cartagena - Colombia, in order to evaluate the advantages of permeable pavements conducted a pilot project to design 3 permeable pavements located in the parking lot of Piedra de Bolívar Campus of the university. Among these are cobblestones, permeable concrete and porous asphalt pavements, each with an area of 15m^2 (5.00 x 3.00). In the structural design they used the ICPI methods [51] for the cobblestones, PCA [52] for the concrete and AASHTO Mechanist [53] for the asphalt. The field test was designed for a one-hour rain with a return period of 10 years [54].

The values obtained from the design are the following: for porous asphalt a slab thickness of 10cm, a sub-base of 40cm and a base of 25cm, for porous concrete a slab thickness of 17cm and a base of 20cm, and for the cobblestones a thickness of 8cm and a base of 20cm. Eighty percent of rainfall occurred in its entirety after 12 minutes of a one-hour storm. The water drainage level is determined by the rain intensity, due to the permeability of permeable pavement and its base, which is capable of infiltrating a greater amount of water than the one falling. The field test revealed a 93% performance, meaning that it allows a 93% infiltration for 10% exceeding rainfall in Cartagena. They also conducted an analysis by finite elements of the behaviour of the water-field test system, this decreased the peak flow at the beginning of the rain, resulting useful to decrease the runoff flow.

Event 3

The research aimed to quantify the reduction of the infiltration capacity of porous concrete (PMPC) and porous asphalt (PA) under the criteria of the permeameter (LCS). The research was carried out in a parking area at the University of Cantabria after several years of use [55]. In the evaluation of surfaces with patterns that define the permeability of porous mixtures, the following values were recorded for the infiltration capacity: for concrete an average permeability of 0.41cm/s with a high score and a reduction of infiltration capacity of 79.43%, for porous asphalt an average value of 0.22cm/s with a mean score and a reduction of infiltration capacity of 82.04%. The difference in behaviour of these mixtures was observed in the value of permeability, but even so, they have similar values in the reduction of infiltration capacity after 5 years of use.

A comparison between all the three events is presented in Figure 3 considering the infiltration capacity of the permeable pavements. It can be seen that the lowest values were for concrete interlocking pavers, while the highest values were for concrete pavement, with the asphalt pavement presenting intermediate values.

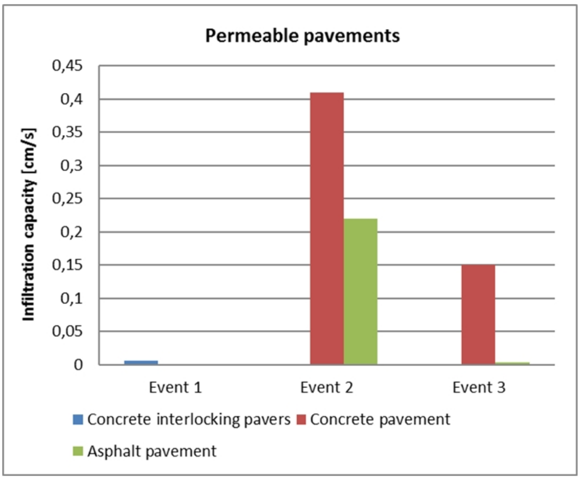

Fig. 3. Average infiltration capacity values for permeable pavements from literature [50, 54, 55]

Swales

The study was done in order to compare SUDS with traditional drainage systems, within a specific location in the United States [16]. The runoff coefficient of suburban residential areas was typically between 0.25 and 0.40. The traditional drainage systems used in the study area had a runoff coefficient of 0.19 and 0.24 and the implementation of SUDS techniques had a runoff coefficient of 0.07.

Mixed - green roofs, porous pavements, and wetlands

The study presented a simple model to evaluate the cost-effectiveness of SUDS to reduce combined sewage flooding on urban basins [18]. Green roofs could reduce flooding in combined sewers by 26%. Porous pavements could generate reductions of approximately 11%, and the wetland area could reduce the flooding by 10%.

Conclusions

SUDS are one of the most viable alternatives to control urban runoff caused by rainfall. These types of systems began to be implemented in the 80s in countries like the United States or the United Kingdom, and their development has grown to the point that recently, the use of some of these sustainable techniques is established by law to the detriment of the so called conventional techniques. That happens not only in pioneer countries in the use of these techniques, but in others countries in northern Europe as well. But obviously, it does not happen everywhere in the world, in Colombia there is little implementation of these systems, this subject is not widely known because is not common, however there has been progress regarding SUDS integration in the land management plans.

The reduction of runoff volumes and peak flows can solve the hydraulic lack of capacity of the conventional rainfall collection systems, with respect to the not expected population growth. With this it can be avoid the need to increase the traditional systems or the fact of having to assume more frequent flooding.

According to the literature, it can be said that SUDS have the capacity to control and significantly influence the generation of surface rainwater runoff and thus provide economic, environmental and social benefits that promote sustainable urban development.

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