Design and construction of SUDS towards Integrated Urban Stormwater Management

Chun Kiat Chang
River Engineering and Urban Drainage Research Centre (REDAC),
Universiti Sains Malaysia
Nibong Tebal, Penang, Malaysia
redac10@usm.my

Nor Azazi Zakaria
River Engineering and Urban Drainage Research Centre (REDAC),
Universiti Sains Malaysia
Nibong Tebal, Penang, Malaysia
redac01@usm.my

***Abstract*— Sustainable Urban Drainage Systems (SUDS) have been used widely in Europe, United States and Australia. Sustainable urban drainage system is a concept that includes long term environmental and social factors in decisions about drainage. It takes account of the quantity and quality of runoff, and the amenity value of surface water in the urban environment. From the aspect of quantity control, integrated designs in the field of stormwater management has become as flood protector and runoff controller. Currently, SUDS is the recommended techniques towards solving three major problems in Malaysia, which are flash flood, water scarcity and water pollution. In the past, most of the stormwater runoff especially in urban areas is designed with conventional drainage systems that carry stormwater runoff to the downstream by rapid disposal approach. In order to manage these three major problems, SUDS provide long term solutions to urban stormwater management. With the right combination of SUDS planning and design, SUDS having a prime role in emphasizing the importance of a holistic approach to environmental engineering, landscape architecture, development of Blue-Green solutions and innovative urban green infrastructure. In addition, with the significant advances of integrated urban stormwater management techniques into urban planning and development, a number of completed SUDS projects in Malaysia have proven other benefits can also be achieved.**

***Keywords*—** *SUDS, stormwater management, green infrastructure, control at source, treatment train.*

I. Introduction

Urbanization of a catchment always will increase in impervious surfaces. Typically it is associated with urban development that consistently been shown to result in increased stormwater runoff prior to its discharge to downstream receiving waters, increases in flood peaks and water quality degradation. As a result, the increased stormwater runoff volumes not only impact stream ecosystems through amplified flow rates, but also increase bed and bank erosion, pollutant loadings and an increase in nuisance flooding in urban watersheds.

In order to overcome the above problems, the Department of Irrigation and Drainage (DID), Malaysia has produced an urban drainage manual, known as Stormwater Management Manual or MSMA in year 2000 [1]. The MSMA second edition, which includes revision of design criteria and improved design calculation methods, had published in year 2011 contribute greatly to the continual growth of sustainable urban drainage design in Malaysia. MSMA 2[nd] Edition has been updated to serve as a source of information and to provide guidance and reference pertaining to the latest best practices for engineers and personnel [2]. This manual emphasized on the use of Best Management Practices (BMPs) for the stormwater quantity and quality control, such as the "control at source" and "treatment train" approaches to achieve Zero Development Impact Contribution. In general, MSMA 2[nd] Edition identifies a new direction for stormwater management for urban areas in Malaysia to:

- Control nuisance flooding;
- Provide the safe passage of less frequent or larger flood events;
- Stabilize the landform and erosion control;
- Minimize the impact of runoff to the environment;
- Enhance the urban landscape and ecology; and
- Ensure the safety of the public.

II. Sustainable Urban Drainage Systems (SUDS)

In Malaysia, stormwater management has traditionally been focused on managing flood impacts based on a conveyance-oriented approach. Stormwater systems are designed to collect runoff at some point, and immediately and rapidly convey it to a discharge point, to minimize damage or disruption that could result problems to its downstream areas. In relation to sustainable urban stormwater management, SUDS emphasizes on holistic approach in stormwater management, meeting the multi-objectives of runoff quantity, quality, public amenity aspects and biodiversity (Figure 1), rather than just quantity aspect of conventional approach. SUDS also emphasizes the concept of the stormwater management train, illustrated in Figure 2. Given these conditions, SUDS become the solution towards solving three major problems in Malaysia which are flash flood, water scarcity and water pollution, which dealing with water at the source.

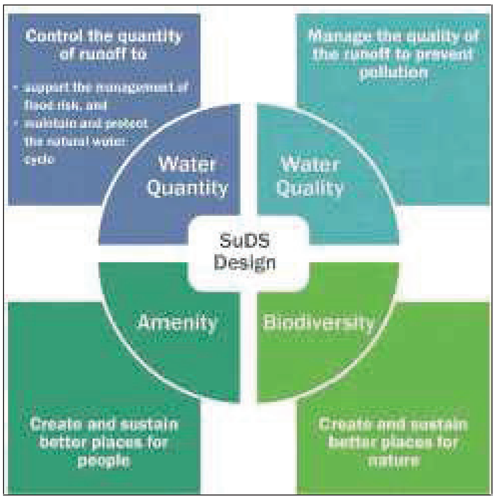


Fig. 1. The Four Pillars of SUDS Design [3]

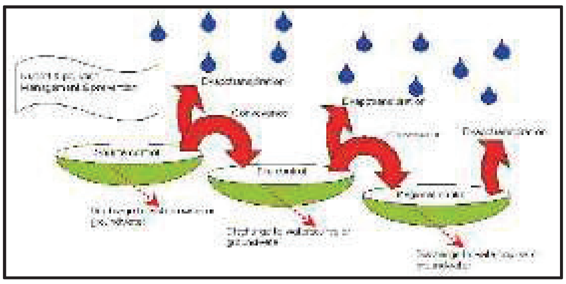


Fig. 2. The Treatment Train Concept for Stormwater Management [4]

Generally in stormwater best management practices, it is recommended that both stormwater quality and quantity management be undertaken in two approaches, namely:

- *Control at Source*
- Stormwater treatment train

A. Control at Source

The emphasis on the control at source approach proposed in MSMA could be divided into three main components, which are water quantity control, erosion and sediment control, and water quality control. Water quantity control is a measure to curb post construction flash flood problems while erosion and sediment control are measures to minimize erosion and sedimentation problems during construction stage. Whilst, the water quality control is intended to reduce post construction non-point source pollution problems [1]. Stormwater quantity control facilities, either detention or retention facilities can reduce the peak and volume of runoff from a given catchment, as well as provision for the temporary storage, which then can reduce the frequency and extent of downstream flooding. Due to stormwater drainage is the highest cost component of hydraulic infrastructure in many urban developments, these storage facilities have been used to reduce the costs of large stormwater drainage systems by directing runoff from impervious surfaces to pervious areas and hence reducing the size required for such systems in downstream areas.

B. Stormwater treatment train

The stormwater treatment train combine multiple stormwater treatment processes and/or practices in stormwater management and has proven effective and versatile in its various applications. A treatment train is a sequence of multiple stormwater treatments which are designed to meet the needs of a particular environment, in order to maximise results for water quality benefits and to reduce stormwater runoff peaks and volumes [4]. This alternative ecological approach to stormwater management not only has the potential to reduce infrastructure costs, but it also reduces maintenance costs. By applying SUDS, native plants are adapted to the environment, and which will not need extensive watering, chemical treatment, mowing, and replanting that non-native species demand. Besides that, SUDS are installed with the expectation of increase pollutant treatment efficiencies reduce pollutants that could affect receiving water and hence provide substantial benefit to downstream neighbours.

III. Bio-Ecological Drainage System (BIOECODS)

Realizing the important of sustainable stormwater management, the design of a drainage system are target to provide time for natural processes of sedimentation, filtration and biodegradation to occur, which reduce the pollutant loads in stormwater runoff as much as possible by applying SUDS. One of the systems would be the Bio-ecological Drainage System (BIOECODS). The BIOECODS [5,6,7] is developed by River Engineering and Urban Drainage Research Centre (REDAC), Universiti Sains Malaysia (USM), which designed with the control at source and treatment train approaches in mind. Since year 2000, BIOECODS at USM Engineering Campus is a national pilot and show piece project of MSMA.

The main function of BIOECODS is to promote stormwater infiltration from impermeable areas (e.g. roofs, car parks, roads and pavements) by using bio-ecological swales. The second function is to release gradually the stormwater through the use of bio-ecological swales (dual layer conveyance system with on-line underground bio-ecological detention storages) and bio-ecological dry ponds or water quality ponds. Finally, the third function of BIOECODS is to enhance treatment of stormwater quality using treatment train concept by utilizing bio-ecological swales and bio-ecological pond (e.g. wet pond, detention pond, constructed wetlands and recreational pond) as the stormwater moves downstream. In addition, BIOECODS blends easily into their surroundings, adding considerably to the local amenity and/or local biodiversity [5]. BIOECODS offers an exemplary model for urban stormwater management under tropical climates by implementing a source control and treatment train approach for stormwater management as suggested in the MSMA. All of these benefits help to ensure that the final discharge from a sustainable urban drainage system will not pollute rivers, nor create flooding downstream.

IV. Integrated Urban Stormwater Management

Urban stormwater systems consist of various integrated components, each of which is intended to perform one or more functions in controlling the quantity and quality of stormwater runoff. From a functional point of view, urban stormwater management consists of planning, design, construction, and operation functions, ideally carried out in the order indicated in Figure 3 [1]. Stormwater management should apply integrated catchment planning principles to ensure that all components of the plan are planned and coordinated so as to achieve the desired result.

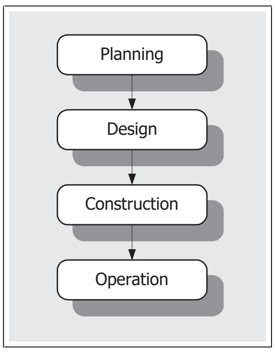


Fig. 3. Stormwater Management Phases [1]

Stormwater quantity design is deals with sizing of infrastructures/stormwater facilities for collecting, conveying, controlling, and disposing of stormwater runoff. Peak discharge and its characteristics are importance as they can be used to derive the maximum cross-sectional area of the necessary structures at a selected event of annual recurrent interval (ARI) for both minor and major systems. In general, runoff quantity control requirements for any size of catchment in the new development is "Post development peak flow of any ARI at the catchment (outlet) must be less than or equal to the pre-development peak flow of the corresponding ARI ($Q_{post} \leq Q_{pre}$) before discharge to the receiving water body [2].

Most stormwater quality management facilities are sized for optimum performance in the "water quality design storm". Stormwater pollutants (non-point source pollutants) are however transported and accumulated in the runoff and pollutant loads are thus estimated and designed for according to the pollutant concentration and total runoff volume in a certain time period. Basic differences between the considerations for stormwater quantity and stormwater quality designs are summarised in Table 1 [1].

However, it is also important for the selection of various stormwater management system facilities across a catchment options. The selection will normally be made based on the master planning process as described in Table 1 below. Generally, the solutions can be diverse in nature and can be designed in many different forms (such as below or above ground, temporary or permanent best management practices), depending on the state and characteristics of the drainage system in place and the components utilized. Such solutions rely on conveyance, infiltration, detention/retention, local treatment, and re-use of water runoff in development areas and thus are in agreement with sustainable principles.

TABLE 1. General Design Considerations [1]

Quantity Control	**Quality Control**
Runoff peak	Runoff volume
Landuse percentage of imperviousness	Landuse activities
Management of infrequent storms	Management of frequent storms
Multi storm ARI design approach (major/minor)	Single storm ARI design approach
Detention/retention may not perform in repeated/multiple storms	Ponds may not be efficient in infrequent storms
Event and continuous (retention only) modelling	Annual average load modelling

A. *Constraints imposed by landuse planning*

The prior existence of landuse will have an impact on the choice of stormwater management options. For that reason, it is highly desirable that landuse planning be carried out in conjunction with stormwater planning.

B. *Economics and community expectations*

The economic value of a drainage and stormwater management system should be assessed as the total lifecycle cost of the system to the community. The designer should aim to minimise the total cost of the system, within practical, social, environmental and legislative constraints. For example, piped drains occupy less land area compared to open channel, but are relatively more expensive to construct than open channel systems. Poorly designed drains may also have a low capital cost but it is offset by high ongoing maintenance costs. Therefore, when evaluating alternatives, the total lifecycle cost must be considered.

Finally, the success of SUDS as an urban planning and design paradigm has rest largely on the ability of the urban design industry to provide engaging and informative landscape design solutions within the public realm. Because of the emphasis on an integrated approach, SUDS is implemented most effectively when it is supported by an interdisciplinary team working together throughout the design process. This is illustrated in Figure 4 [8].

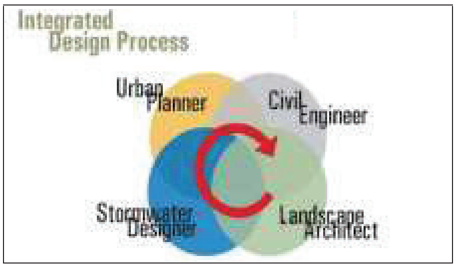


Fig. 4. The Integrated Design Process [8]

The construction of bio-ecological swales is a simple construction method that uses minimum numbers of laborer and machineries (Figure 5). The minimum usage of resources leads to cost effective of construction in this drainage system in the future. Material that are used in this drainage system mostly are environmental-friendly. For the finishes part, the usage of natural resources gives greeneries view for the constructed area. The materials that being used in this bio-ecological swales construction are:

- High density Polyethylene modular tank/drainage cell
- Geotextiles (filter fabric)
- Clean/washed river sand/gravel (filter media) – passed sieving test of BS 1377
- Topsoil/ engineering soil media – thickness (between 50mm to100mm)
- Cow grass (*Axonopus Compressus*)

Fig. 5. Bio-ecological swales

V. SUDS EXAMPLES

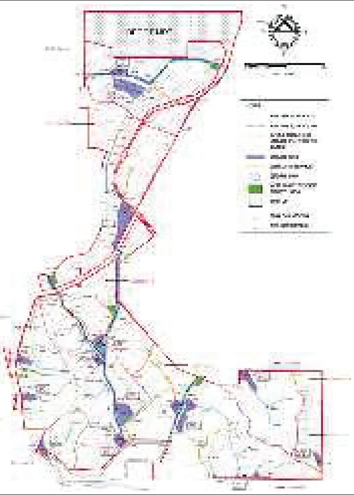
This section introduces three examples of projects that successfully applied the principles of sustainable urban stormwater management in Malaysia. The selected projects reflect various scales to which SUDS can be applied to 3 different scales:

- on-site level "small scale"
- community level "medium scale", and
- regional level "large scale"

Table 2 shows the selected projects titles, scales, locations, area of development and main SUDS components applied in the project.

Table 2. Selected SUDS Projects in Malaysia

1	Project title	Health Clinic
	Location	Taiping, Perak
	Scale	On-site
	Area	6.20 acres
	SUDS Components	Bio-ecological swales, dry-ponds, gross pollutant trap(GPT), on-site detention (OSD)
		
2	Project title	USM Engineering Campus
	Location	Nibong Tebal, Penang
	Scale	Community
	Area	320 acres
	SUDS Components	Bio-ecological swales, dry ponds, wet pond, detention pond, constructed wetlands, wading river, recreational pond
		

3	Project title	Kwasa Damansara Township
	Location	Sungai Buloh, Selangor
	Scale	Regional
	Area	2,330 acres
	SUDS Components	Bio-ecological swales, bio-retention, bio-engineered channel, gross pollutant trap (GPT), on-site detention (OSD), sediment forebay, detention pond, constructed wetlands
		

VI. CONCLUSION

In the past decade, water related crisis such as flash flood, water scarcity and water pollution has caused socio-economic losses to the people in Malaysia. The concept of sustainable urban stormwater management is based on formulating development plans that incorporate an integrated approach to the management of the urban water cycle. The primary goal is to minimise the impact of urbanisation of the stormwater environment and to strike a balance between social, economic and environmental concerns to achieve sustainable development. This paper reveals the contribution SUDS can participate with in the rehabilitation of various scale of development projects. In relation to stormwater management, SUDS involves a pro-active process which recognises the opportunities for urban design, landscape architecture and stormwater management infrastructure to be intrinsically linked. SUDS can be applied at large scales to serve a region or a catchment area. The challenge ahead is to continue the SUDS holistic planning and design approach to urban stormwater management and to provide technically robust solutions that excite and engage communities to deliver improved environmental outcomes for today and future generations.

ACKNOWLEDGMENT

The authors would like to acknowledge the financial assistance from Ministry of Education Malaysia under HICoE's niche area of Sustainable Urban Stormwater Management (Grant No. 311.PREDAC.4403901).

REFERENCES

1. DID, *Urban Stormwater Management Manual for Malaysia (MSMA)*. 2000, Department of Irrigation and Drainage, Malaysia: Kuala Lumpur.
2. DID, *Second Edition of Urban Stormwater Management Manual for Malaysia (MSMA 2nd Edition)*. 2011, Department of Irrigation and Drainage, Malaysia: Kuala Lumpur.
3. CIRIA, *The SUDS Manual*. 2017, Construction Industry Research and Information Association, UK: London.
4. CIRIA, *The SUDS Manual*. 2007, Construction Industry Research and Information Association, UK: London.
5. Zakaria, N.A., Ab. Ghani, A., Abdullah, R., Mohd Sidek, L. & Ainan, A., Bio-Ecological Drainage System (BIOECODS) For Water Quantity And Quality Control, *International Journal River Basin Management*, 2003, 1(3): p. 237-251.
6. Ab. Ghani, A., Zakaria, N.A., Abdullah, R., Yusof, M. F., Mohd Sidek, L., Kassim A.H. & Ainan, A., "Bio-Ecological Drainage System (BIOECODS): Concept, Design and Construction". in *Proc. of The 6th International Conference on Hydroscience and Engineering (ICHE-2004)*, Brisbane, Australia. 2004.
7. Chang, C.K., Zakaria, N.A., Ab. Ghani, A. & Goh, H.W. Securing Water for Future Generations through Sustainable Urban Drainage Design and Management: Bio-ecological Drainage System (BIOECODS) - Malaysian Experiences. The Magazine of The Chinese Institute of Civil & Hydraulic Engineering. 2018, 45(6): 41-52.
8. McAuley, A. & McManus, R. Water Sensitive Urban Design Planning Guide - Prepared for: Northern Territory Department of Planning and Infrastructure. 2009.