DOI: 10.6653/MoCICHE.201812_45(6).0007

通過 可持續城市排水系統 的設計與管理 來保障未來世代水資源：生物生態排水系統 (BIOECODS) — 馬來西亞的經驗

Securing Water for Future Generations through Sustainable Urban Drainage Design and Management: Bio-ecological Drainage System (BIOECODS) - Malaysian Experiences

Chun Kiat Chang／馬來西亞理科大學河流工程及城市水利研究中心 研究員、註冊土木工程師
River Engineering and Urban Drainage Research Centre (REDAC), Engineering Campus, Universiti Sains Malaysia.

Nor Azazi Zakaria／馬來西亞理科大學河流工程及城市水利研究中心 教授

Aminuddin Ab Ghani／馬來西亞理科大學河流工程及城市水利研究中心 教授

Hui Weng Goh／馬來西亞理科大學河流工程及城市水利研究中心 資深講師

近年來，馬來西亞受到嚴重水資源短缺，特別是在超級城市地區。儘管大馬以往的排水系統設計傳統上將其視為廢水處理的一部分，但現今的城市排水系統已逐漸演變成一個不可或缺的重要基礎設施，可為子孫後代在獲取水資源方面發揮關鍵的作用。本文介紹了馬來西亞理科大學工程系分院大約 20 年曆史的生物生態排水系統（BIOECODS），系統為城市排水設計提出了可持續概念。生物生態排水系統於 2002 年完成，是馬來西亞可持續性排水系統的國家試點和展示項目。該系統試圖解決馬來西亞常見的三大問題，即水災，河流污染和水資源短缺。本文介紹了以滲透性、在源頭收集及減緩水流量三大特點的生物生態排水系統的概念，組成部分和功能。本文也簡要地總結了該系統在馬來西亞理科大學工程系分院的性能。生物生態排水系統完全符合馬來西亞城市雨水管理手冊（MSMA）的要求，也就是側重於控制城市城市雨水徑流的流量和質量。生物生態排水系統實施的成功證明，通過創新，馬來西城市雨水管理手冊可以在不影響整體建築成本，美學和功能的情況下成功實施。事實上，該系統為城市雨水管理，公共設施和整體美學增加了更多的增值服務。在過去幾年中，生物生態排水系統也被用於水資源的再利用，展示了城市雨水管理在確保未來水資源方面的巨大潛力。

Abstract

In recent years, water supply shortage has been severely felt in Malaysia, especially in ultra-urban cities. Despite conventionally a system to dispose unwanted excess water, urban drainage has gradually evolved into an infrastructure that would potentially play a pivotal role in securing water for the future generations. This article takes a look into the approximately 20-year old Bio-ecological Drainage System (BIOECODS) in the engineering campus of Universiti Sains Malaysia that has put forward the sustainable concept of urban drainage design. BIOECODS, completed in 2002, has become a national pilot and show piece project in promoting SUDS in Malaysia. BIOECODS attempts to solve

three major problems commonly encountered in Malaysia namely flash floods, river pollution, and water scarcity. The concept, components and functions of BIOECODS which combine infiltration, delayed flow, storage and purification as pre-treatment of stormwater are presented herein. Performance of the system in the USM Engineering Campus is also briefly summarised. The BIOECODS is fully complied with the Urban Stormwater Management Manual for Malaysia (MSMA) requirements which focus on the control of both the quantity and quality of urban runoff. The success of the BIOECODS implementation proved that with innovation, MSMA can be successfully implemented without compromising on the overall project cost, aesthetic, and function. In fact, the system adds in more value-added services for stormwater management, public amenity, and overall aesthetic. In the last few years, BIOECODS has also been used for water reuse, demonstrating the huge potential of stormwater management in securing water resource for the future.

Background

Rapid urban growth in Malaysia over the last 30 years has resulted in increased stormwater flow into receiving waters, increases in flood peaks, and degraded water quality. Traditionally, stormwater management focuses on easing flooding through drainage of stormwater runoff from the urban areas to receiving water bodies. The conventional stormwater drainage has been designed to provide the fastest possible transport (rapid disposal approach) of stormwater runoff out of the catchments into receiving waters. The design philosophy of the conventional drainage system is based on solving localised floods either by transferring excessive flows in drainage system downstream by upgrading the drainage system or relieving localized problems by constructing storm overflows. The consequence of removing the stormwater from the land surface so quickly is to increase volumes and peak rates of flow discharge and finally overloading conventional drainage system. This results in a greater runoff that generally requires expensive enhancement of drainage network to reduce severity and frequency of flooding in urban areas. This also results in a higher pollutant washoff from the urban areas leading to deteriorate water quality in the receiving water bodies (Zakaria *et al*., 2003; Zakaria *et al*., 2004; Ab. Ghani *et al*., 2004).

The conventional rapid disposal approach has reached a limit and that there is a demand for alternative technologies. Therefore there is a need to seek holistic and sustainable solutions not only to mitigate existing flooding problems and water quality degradation but also prevent the occurrences of such problems in new areas to be developed. With the increasing understanding of non-point source pollution, which has traditionally included stormwater sources, a holistic design of urban stormwater management systems needs to incorporate the multiple purposes of controlling major and minor floods, as well as stormwater pollution. Government allocations to resolve the current structural work under flood mitigation works such as construction of dam and reservoir, deepening and widening of rivers, increase from time to time. In the Ninth Malaysian Plan (2005-2010) alone, over 70% of the RM 5.3 billion budget granted for Department of Irrigation and Drainage (DID) Malaysia was allocated exclusively for flood mitigation works (DID, 2009a). DID estimates that RM 10 billion is required to upgrade the conventional drainage system made up of concrete channels and channelized rivers to overcome the flash flood enigma. On the other hand, RM 828 million is being spent on flood mitigation projects to conduct clearing clogged drains by local councils. Conventional drainage also contributed to river pollution. During rain event, domestic waste such as solid waste and garbage will easily be carried by water into open drain and subsequently into rivers. Frequent occurrences of flash flood in urban areas result in an average annual loss of RM 100 million in Malaysia.

Water Conservation through Sustainable Urban Drainage System (SUDS)

In general, sustainable urban drainage system (SUDS) is an approach to manage stormwater in developments that replicate the natural drainage regime and characteristics. Runoff is collected and stored to allow natural treatments to occur at source prior to infiltration or controlled release into receiving waters. SUDS blends into the landscape surrounding the development and carry out water treatment with the aim to prevent pollution, flood control, groundwater recharge and environmental enhancement. Runoff is treated using enhanced natural mechanism such as filtration, infiltration, biological uptake, and settlement. It is important to understand how these techniques work together to provide the aims of sustainability in the most practical, cost effective and beneficial way (CIRIA, 2007).

SUDS emphasizes on holistic approach to stormwater management, meeting the multi-objectives of runoff quantity, quality, public amenity aspects and biodiversity (Fig. 1), rather than just quantity aspect of conventional approach. SUDS uses the concept of the stormwater management train, illustrated in Fig. 2. The management train starts with prevention or good house-keeping measures for individual premises, and progresses through to local source control, larger downstream site and regional controls. Water could flow straight into a site control but as a general principle it is better to deal with runoff locally, returning the water to natural drainage system as near to the source as possible. Only if the water cannot be managed on site should it be conveyed elsewhere. This concept of treating and storing water locally is very beneficial for water conservation and has a huge potential on water reuse. Just as rainwater harvesting technique, SUDS can be successfully used to provide water source for non-potable use. The increased green area and enhance infiltration facilities are also important to soil moisture replenishment and ground water recharge at local level.

In response to the needs for paradigm shift the way stormwater is managed, the Malaysian government has launched the Urban Stormwater Management Manual for Malaysia or MSMA (DID, 2000) incorporating the latest development in stormwater management that is known as control-at-source approach. From January 2001 onwards, all new development in Malaysia must comply with new guideline that requires the application of treatment devices or facilities (known as Best Management Practices (BMPs)/ Low Impact Developments (LID) in United States of America or Sustainable Urban Drainage System (SUDS) in the United Kingdom) to control stormwater from the aspect of quantity and quality runoff to achieve zero development impact contribution. This concept of treatments will be able to preserve the natural river flow carrying capacity. The new manual draws on various approach of BMPs/LID/ SUDS now being widely applied worldwide to control the quantity and quality of runoff through detention/retention storage, infiltration facilities, engineered waterway which are capable attenuate flow. The goal of this manual is to provide guidance to all regulators, planners and designers who are involved in stormwater management. It identifies a new direction for stormwater management in urban areas in Malaysia.

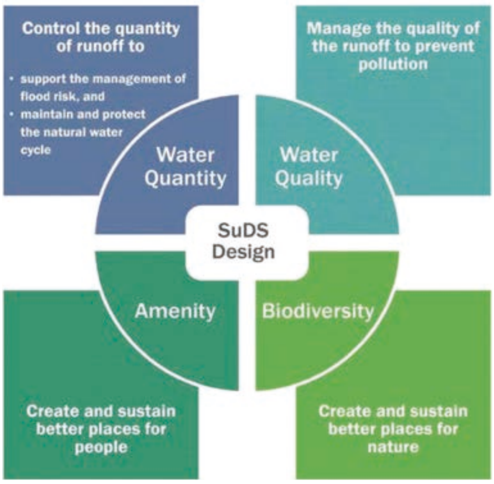

Fig. 1 The four pillars of SuDS design (CIRIA, 2017)

Urban Stormwater Management Manual for Malaysia
馬來西亞城市雨水管理手冊

In Year 2011, a new-look manual, i.e. the 2nd Edition of MSMA has been anticipated and developed through contributions of professionals from the Malaysian Government as well as private professionals and foreign experts. The second edition, which includes revision of design criteria and improved design calculation methods, had contribute greatly to the continual growth of sustainable urban drainage design in Malaysia. The Manual 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 (DID, 2011).

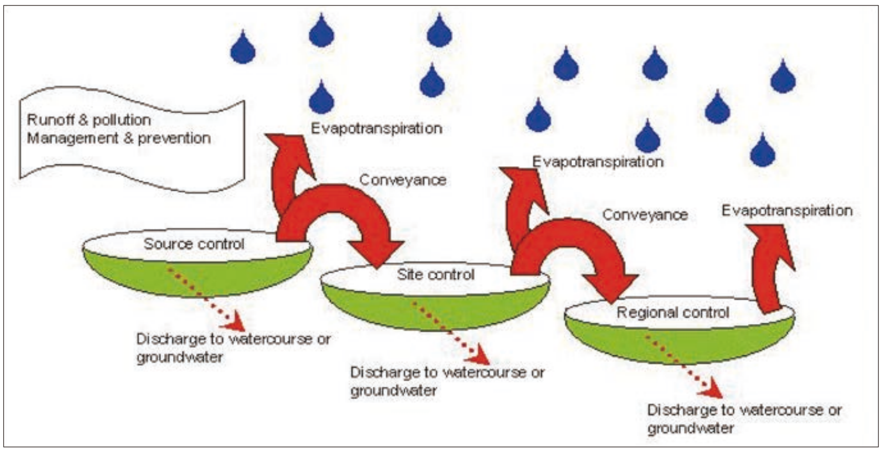

Fig. 2 The Treatment Train Concept for Stormwater Management (CIRIA, 2007)

The MSMA 2nd Edition was prepared covering mainly administration, quantity control design, quality control design and conveyance design. The manual draws on various approaches of stormwater facilities now being widely applied worldwide to control the quantity and quality of runoff through detention storage, which are the core elements of achieving one of the major stormwater quantity control criteria. Stormwater conveyance systems (minor and major) shall be planned, analysed, and designed in order to provide acceptable levels of safety for the general public and protection for private and public property based on design storm average recurrence interval (ARIs). Quality control facilities or Best Management Practices (BMPs) such as bioretention, wetlands, water quality pond, etc. shall be planned, analysed and designed to protect the environmental values of the receiving water that receives discharges from the site. The goal of the manual is to provide guidance to all regulators, planners and designers who are involved in stormwater management.

MSMA 2nd Edition identifies a new direction for stormwater management for urban areas in Malaysia (DID, 2011) to:

- Control nuisance flooding and provide for the safe passage of less frequent or larger flood events;
- Stabilise the landform and control erosion;
- Minimise the environmental impact of runoff;
- Enhance the urban landscape and ecology; and
- Ensure the safety of the public.

The stormwater management concept has been embodied in the concept of ecologically sustainable solution to the flooding and pollution problems using the “control at source” and “treatment train” approach, as well as aimed at ensuring that development can occur without long-term degradation of natural resources and the environment.

Control at Source

Urbanisation of a catchment will always increase the quantity of stormwater runoff. The level of runoff quantity control required is dependent on the type of development proposed, new development or redevelopment. Under the implementation of DID manual (DID, 2009b) and MSMA (DID 2000; 2011), it was expected that there shall be no increase in flood discharge and frequency to the downstream catchments resulting from to the urban development. Flow control requirements are stipulated as the following (DID, 2011): Runoff quantity control requirements for any size of development or re-development project is “Post development peak flow of any ARI at the project outlet must be less than or equal to the pre-development peak flow of the corresponding ARI (Qpost ≤ Qpre)”. Direct discharge without control (rapid disposal) from the sub-development to the drain systems or waterways is not permitted. Such high peak discharge was to be reduced by introducing control-at-source facilities such as detention ponds and on-site detentions at strategic locations before it discharges into the river.

Stormwater Treatment Train

The stormwater treatment train represents an ecological approach to stormwater management and has proven effective and versatile in its various applications. The stormwater treatment train was designed with sequential components that contribute to the treatment of stormwater, by minimise the amount of pollution entering the downstream waterways. The components of the stormwater treatment train system were designed to treat stormwater runoff for water quality benefits and to reduce stormwater runoff peaks and volumes. This alternative approach to stormwater management not only has the potential to reduce infrastructure costs, but it also reduces maintenance costs. In addition, there is also a substantial benefit to downstream catchments. By treating stormwater where it falls on the land, responsible landowners are reducing their contribution to downstream flooding and sedimentation.

Green and Sustainability

Sustainable agenda is structured by Malaysia’s aspiration for reduction of carbon emission and develop low carbon cities. Realizing this, implementation of green infrastructure and also provision of green areas (open space and parks) as part of low carbon city initiative to ensure the development becomes a low carbon emission development and thus meeting the national agenda of reducing 40% of carbon emission per gross domestic product (GDP) by 2020.

Bio-Ecological Drainage System (BIOECODS) 生物生態排水系統

The applicability of the design approaches are being tested initially with the national pilot and show piece project of MSMA at Engineering Campus, Universiti Sains Malaysia (USM) with the construction of Bio-Ecological Drainage System (BIOECODS) completed at the end of the year 2002. BIOECODS (Zakaria *et al.*, 2003; Ab Ghani *et al.*, 2004; Ab Ghani *et al.*, 2008; Zakaria *et al.*, 2011; Zakaria *et al.*, 2017) 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. BIOECODS is made up of several important components that ultimately form an efficient stormwater treatment train that control runoff quantity and preserve runoff quality. The BIOECODS is designed to provide time for natural processes of sedimentation, filtration and biodegradation to occur, which reduces the pollutant loads in stormwater runoff. In addition, BIOECODS blends easily into their surrounding, adding considerably to the local amenity and/or local biodiversity (Ab. Ghani *et al*., 2008).

The USM Engineering Campus is located in Seberang Perai Selatan District, Pulau Pinang. The area of the campus is about 320 acres and made up of mainly oil palm plantation land and is fairly flat. The USM Engineering Campus project has taken a series of measures to reduce runoff rates, runoff volumes and pollutant loads by implementing a source control approach for stormwater management as suggested in the MSMA. This include a series of components namely ecological swale, on-line underground storage, and dry ponds as part of the BIOECODS that contribute to the treatment of the stormwater before it leaves the campus (Fig. 3). This system was designed to combine infiltration, delayed flow, storage and purification as pre-treatment of stormwater before discharging to constructed wetlands. In addition to source controls, these measures include integrating large-scale landscapes into the development as a major element of the stormwater management system. The concept of the BIOECODS is to integrate with the Ecological Ponds for further treatment of the stormwater runoff. In combination, these increase runoffs lag time, increase opportunities for pollutant removal through settling and biofiltration, and reduce the rate and volume of runoff through enhanced infiltration opportunities.

Ecological Swale

In order to reduce the drainage footprint of the BIOECODS, as well as to provide additional water treatment, a dual layer conveyance system is introduced. While the surface of the swale is generally not much larger than conventional drain, the total cross section area of the system provides much larger water storage and treatment function than a normal conventional drainage can offer. The surface layer resembles a grassed channel or a swale. Typical swale design, gentle side slope, low gradient and shallow depth applied to this layer. The underground layer, consist of a geosynthetic module enclosed in geotextile. It is connected to the surface layer via a layer of river sand or infiltration media. Figure 4 presents a cross-sectional view of the said ecological swale. Four types of ecological swales were constructed in USM Engineering Campus, namely building perimeter swale, Type A, Type B and Type C depending on the number of modules available underneath the swale.

As runoff builds up on the surface, it is first infiltrated into the sand layers and then the underground modules. This infiltration provides both quantity and quality treatments to the runoff. First, the infiltration delays flow after which the infiltrated water is stored in subsurface modules. Only after the pool of water generates enough energy will it flow downstream within the module. Along the module, water is loss to adjacent ground through exfiltration of water from the side or bottom of the module. This water will percolate through the ground and either retained as soil moisture or recharge ground water. On the surface, ecological swale attenuates flow by providing larger surface friction through the grass way than the smoother concrete channel.

For water quality treatment, three important processes are involved. First, as water flows into the ecological swale from impervious surfaces, grass on swale surface acts as filter media to trap out particulate pollutants. The aerobic condition of the soil promotes hydrocarbon breakdown. The second treatment involved is the infiltration of water through sand layer and into the module. Infiltration filters out particulates

Fig. 3 Aerial View of USM Engineering Campus 馬來西亞理科大學工程系分院

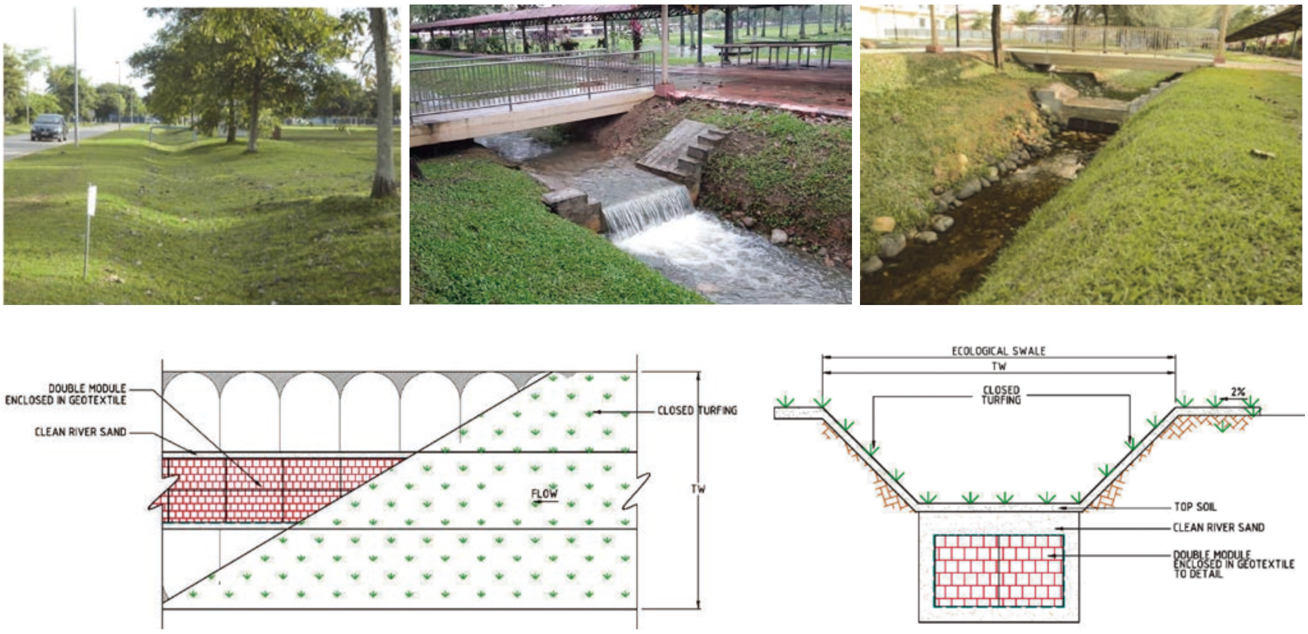

Fig. 4 Ecological swale

and some smaller solid nutrients that attached to them. The geosynthetic module is manufactured such that the internal structure of the module helps to break up water flow, creating turbulence and therefore increase dissolve oxygen. Finally, both the surface and subsurface flows will combine again by both discharging into the ponds and wetlands system.

Dry Pond

The excess stormwater is also stored on the dry ponds constructed with a storage function. The dry pond is essentially an On-Site-Detention (OSD) pond, which has been integrated with the ecological swale to temporarily store the stormwater runoff. The modular storage tank is placed beneath the detention basin where the stormwater is drained out by infiltration (Fig. 5). The outflow path of the storage module is connected to the ecological swale at the lowest point, in order to drain the dry pond system in less than 24 hours. Dry ponds diffuse flow conveyed by swales and the reduced stormwater velocities enable more effective sedimentation, infiltration and evaporative water treatment. The landscape lands are able to infiltrate a substantial portion of the annual surface runoff volume due to the increased soil permeability that is created by the deep and fibrous root systems of the landscape vegetation.

Detention Ponds

Wet pond and detention pond are the community facilities of the BIOECODS (Fig. 6). They are primarily designed for attenuating runoff from developed areas through regulated outlet structures. The facility is typically designed to limit discharge to the pre-development stage, while storing water temporarily.

Fig. 5 Dry pond

Wetlands

With respect to the need for water quality improvements, wetlands (Fig. 7) is designed as a community treatment facility. As much as 90% of the total volume of annual stormwater runoff will flow through an area supporting growing plant material. Contaminants are removed either by direct absorption into plant tissues (soluble nutrients) or by physical entrapment and subsequent settlement on the wetlands bed. Apart from water quality, the wetlands is also designed as a habitat area for biodiversity conservation within a development, supporting species such as small mammals, birds, fish, reptiles and plants.

Wading River

Wading river (Fig. 8) is designed to convey stormwater from the wetlands to recreational pond before discharging to Kerian River. Meanders have been restored in wading river by using graded sediments and gravel. The wading river has two components, i.e. main channel and flood plains. The very large boulders are placed at several locations along the river bank to prevent bank erosion.

Recreational Pond

The end product is expected to improve the aesthetic value for surrounding areas with the existence of the "Crystal Clear Blue Water Lake" (Fig. 9) via physical treatment and biological treatment at the most downstream end of the drainage system. The water level is maintained in the recreational pond by a 600 mm diameter pipe culvert (Fig. 10) discharging into Kerian River. Fig. 11 show the activities at the recreational pond.

Construction of BIOECODS

Materials

Despite its innovative design, the construction materials used to construct a BIOECODS system is rather common and easily available. Common construction materials such as geotextile, river sand, top soil and cow grass are widely used in constructing the system. The only unique material used is the geosynthethic module. Initially designed as underground storage unit in overseas, it has been used innovatively to

Fig. 6 Wetpond (left) and detention pond (right)

Fig. 7 Constructed wetlands

Fig. 8 A meandering wading river upstream of the recreational pond

Fig. 9 Recreational pond

Fig. 10 Check valve used to provide flow in one direction only through a culvert

Fig. 11 Activities in the USM engineering campus

form an underground drainage network in BIOECODS. Despite the module relatively high price in a decade ago, the continuing popularity and more common use in Malaysia has saw this product being manufactured locally, significantly reducing the cost of material.

Construction Methods

The construction of ecological swale is very simple and does not require highly skilled labours. First, a trench will be dug using backhoe to desired depth after setting out. The trench is then backfilled with river sand to create a desired gradient for the subsurface drain. Then a geotextile is layered onto the sand. Geo-synthetic module is arranged side by side on the geotextile to form a continuous conduit, before the modules are wrapped up in the geotextile. The trench containing the enclosed module is then being backfilled with river sand up to desired invert level. It is then topped up with a thin layer of top soil to sustain vegetation growth. Finally, cow grass is turfed on to the depression to create the surface drainage, i.e grass swale (Fig. 12). The entire process involves very minimal machinery. On a daily average, a team of semi-skilled labour of four persons can easily construct 60 - 80 metres of ecological swale. Fig. 9 shows the site condition and working procedure of constructing an ecological swale. The construction of dry ponds are very similar to the ecological swale, which involves dual layer system, i.e. underground detention storage units (also using enclosed geosynthetic module) and surface depression which is turfed. Other BIOECODS components, i.e. detention ponds and wetlands are constructed using typical industry methods.

Performance of BIOECODS

Flow Attenuation and Flood Reduction

Since its establishment, BIOECODS has been closely monitored for its hydrological and hydraulic performances. The first BIOECODS system in USM engineering campus has been monitored with sophisticated water quantity and quality equipments to record its performance during rainfall events continuously for almost a decade now. The most significant benefit of BIOECODS is its ability to reduce flow peak and flow volume. The retardation in ecological

(a) A trench is dug with backhoe and layered with river sand

(b) Module is laid in the trench and wrapped in geotextile

(c) Trench is backfilled with enclosed module buried within

(d) A swale is shaped and topped up with top soil before being turfed

(e) Ecological swale after completion

Fig. 12 Work flow of an ecological swale construction

swale and detention in dry pond, wet pond, detention pond and wetlands have enable BIOECODS to successfully create a stormwater system that mimics natural condition, hence reducing flood risks. Fig. 12 shows flow attenuation with detention pond during an event. These are all genuine records gauged by the site monitoring systems. Tables 1 and 2 provide further examples of flow attenuation in swale and pond respectively.

More detailed observations are recorded in Ainan *et al.* (2004). The performance of ecological swale was also verified using computer model by Abdullah *et al*. (2004) using XP-SWMM. In both cases, the authors found that the system performed admirably to attenuate flow from the catchment. Recently, a water balance analysis by Ayub *et al*. (2010) confirmed that the BIOECODS system actually increases groundwater recharge through infiltration. During drier days, percolated surface water eventually ‘resurface’ to supply much needed base flow to sustain plants and ecology.

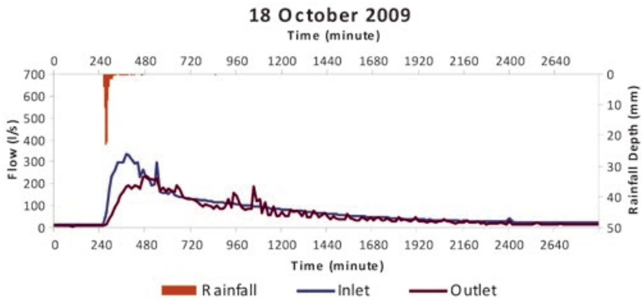

Fig. 12 Example of Flow Attenuation by Detention Pond.

Water Quality Improvements

Apart from water quantity, water quality control of BIOECODS is also being constantly monitored through in-situ test as well as laboratory testing for the common water quality parameters. The final discharge from the system are most of the time conform to Class IIB of National Water Quality Standard published by Department of Environment. It is worth mentioning that the use of this system significantly reduce the pollutant loads especially particulate pollutants, i.e. sediment. For the entire system, TSS was non-detectable, indicating that even if sediments were washed into the system, they are trapped very early on by the ecological swale networks. With the use of detention ponds and wetlands, most biological activities are concentrated in this area, the biological load is rather higher, but still in Class IIB limit. However, the discharge from wetlands is significantly of better quality, indicating the success of biological treatment occurring within the ponds and wetlands. Mohd Sidek *et al*. (2004a) and Ayub *et al*. (2005) provide more detailed presentation of the water quality treatment results of BIOECODS.

Other SUDS Projects

Other SUDS projects that REDAC has been involved with include the BIOECODS facility as follow:

- Tanjung Rambutan Hospital at Ipoh, Perak;
- Health Clinic at Taiping, Perak,
- Campus of Universiti Malaysia Kelantan (UMK) at Bachok, Kelantan;
- Student Village, University of Automotive Malaysia (IUCAM), Pekan, Pahang;
- Astaka Park and field at Petaling Jaya, Selangor;
- Raban Lake Resort at Lenggong, Perak;
- The Residency of the Governor of Penang at George-town, Penang;
- District Police Headquarter at Pasir Mas, Kelantan;
- Kwasa Damansara Township, Selangor (2230 Acres) (Fig. 13).

REDAC has received many visitors from Malaysia and also international visitors such as from the UK, USA, Japan, Australia, Thailand, Indonesia, Vietnam, Hong Kong, India, etc (Fig. 14).

Conclusions

The introduction of Urban Stormwater Management Manual for Malaysia, or MSMA, changed the stormwater management landscape in the country. However, with the increasing need of meeting demands for green technologies and climate change, stormwater engineers are facing a stiffer challenge to produce effective and sustainable drainage system. This requires the need to inject new technologies or innovation into the design of drainage facilities. The Bio-ecological Drainage System or BIOECODS was introduced in 2001. Adopting the concepts of integration, control-at-source and sustainability, BIOECODS paved the way for a promising development in drainage design in Malaysia that fulfils the MSMA criteria. Through innovation in design, the designers introduced the ecological swale,

Table 1 Example of ecological swale performances for frequent rainfall events (Zakaria, 2011)

Precipitation Event	Average Rainfall Intensity (mm/hr)	Estimated (ARI)	Peak Flow (l/s)		Total Runoff Volume (m^3)		Percentage of Reduction (%)	
			Inlet	outlet	Inlet	outlet	Peak Flow	Runoff Volume
24/6/2003	11	3 months	128	91	418.5	246.6	28.9	41.1
30/8/2003	14.5	3 months	59	26	388.8	123.6	55.9	66.6
8/9/2003	13.8	5 years	195	176	4043.1	3043.2	10.0	24.1

Table 2 Example of detention pond performances for frequent rainfall events (Zakaria, 2011)

Rain Event	Total Time (mins)	Rainfall Depth (mm)	Rainfall Intensity (mm/hr)	Peak Flow (m^3/s)		Volume (m^3)		Percent of Reduction (%)	
				Inlet	outlet	Inlet	outlet	Peak Flow	Volume
14/4/2007	40	23.5	35.3	0.041	0.032	2,214	1,777	21.95	19.74
16/4/2007	70	23.2	19.9	0.034	0.026	1,545	1,200	23.53	22.33
18/10/2009	65	84.6	78.1	0.335	0.235	23,919	18,365	29.85	23.22
11/11/2009	155	171.5	66.4	0.689	0.289	38,859	18,870	50.65	51.44

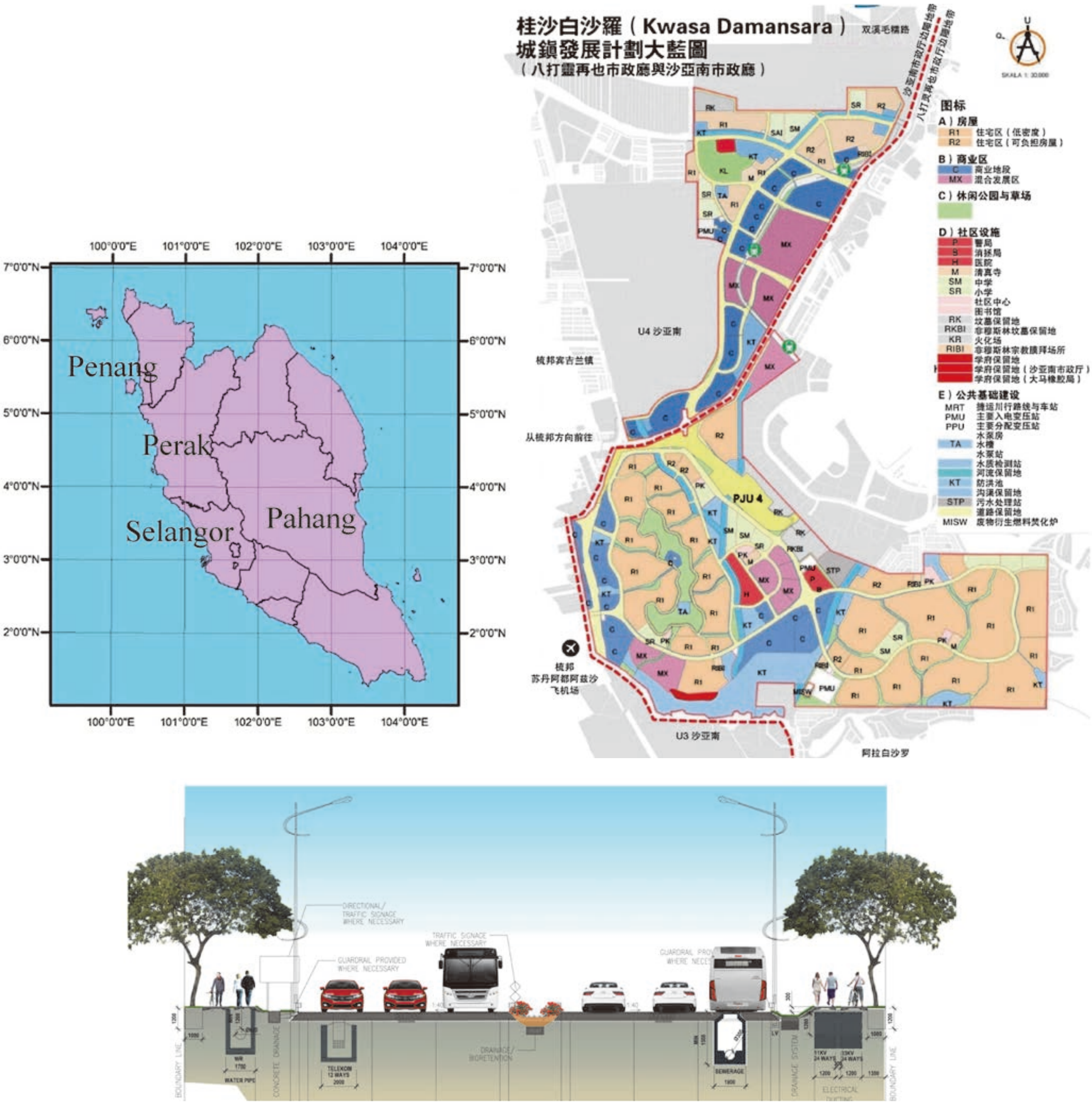

Fig. 13 Kwasa damansara township development master plan (Mohd Noh *et al.,* 2017)

(a) Professor Joseph Lee, University of Hong Kong

(b) Professor Larry Roesner, Colorado State University, USA

(c) Professor Collin Grant, University of Bath, UK

Fig. 14 International visitors to BIOECODS, USM engineering campus a dual layer conveyance system that minimize drainage footprint but provide additional water quantity and quality treatment. Other components such as dry ponds, wet ponds and wetlands are further evidences of the integration of stormwater facilities into surrounding landscape, adding significant values to otherwise worthless open spaces. The project also overturned the stigma of increased cost due to innovative drainage. Final construction costs proved to be slightly cheaper than a conventional drain. A series of continuous research and monitoring also found that stormwater is effectively controlled in quantity and quality. The system is a living proof for feasibility and multi-benefits of MSMA implementation. BIOECODS also testified that the current stormwater management concept is ready to face the challenges of climate change.

馬來西亞城市雨水管理手冊（MSMA）改變了該國的雨水管理格局。然而，隨著滿足綠色技術和氣候變化日益增長的需求，城市水利工程師面臨著設計有效和可持續排水系統的嚴峻挑戰。這需要在排水設施的設計中註入新技術或創新。生物生態排水系統於 2001 年推動。生物生態排水系統採用一體化，源頭控制和可持續發展的概念，符合馬來西亞城市雨水管理手冊標準的排水設計準則。通過創新的設計，水利工程師引入了滲透性窪渠，這是一種雙層排水系統，可以大幅度地減少排水量，同時提供額外的水數量和質量處理。其他組成部分，如乾積水池，蓄水池和濕地，進一步證明了排水設施與周圍景觀的融合，為其他無用的開放空間增添了重要價值。該項目還推翻了由於創新排水而增加成本的問題。事實證明，最終的建築成本比傳統的鋼骨水泥排水系統更便宜一些。一系列持續的研究和監測還發現，雨水的數量和質量得到有效的控制。該系統是馬來西亞城市雨水管理手冊實施的可行性和多重效益的證明。除此之外，生物生態排水系統也證實，目前的雨水管理概念已準備好迎接氣候變化的挑戰。

References

1. Ab. Ghani, A., Zakaria, N.A., Abdullah, R., Yusof, M. F., Mohd Sidek, L., Kassim, A. H. & A. Ainan. (2004). Bio-Ecological Drainage System (BIOECODS): Concept, Design and Construction. 6th International Conference on Hydroscience and Engineering (ICHE-2004), May 30-June 3, Brisbane, Australia.
2. Ab. Ghani, A., Zakaria, N.A., Chang, C.K. & Ainan, A. (2008). Sustainable Urban Drainage System (SUDS) – Malaysian Experiences, 11th International Conference on Urban Drainage, August 31 – September 5, Edinburgh, UK.
3. Abdullah, R., Zakaria, N.A., Ab. Ghani, A., Mohd Sidek, L., Ainan, A. & Wong, L.P. (2004). BIOECODS Modelling Using SWMM. 6th International Conference on Hydroscience and Engineering (ICHE-2004), May 30-June 3, Brisbane, Australia.
4. Ainan, A., Zakaria, N.A., Ab. Ghani, A., Abdullah, R., Mohd Sidek, L., Yusof, M. F. & Wong, L.P. (2004). Peak Flow Attenuation Using Ecological Swale and Dry Pond. 6th International Conference on Hydroscience and Engineering (ICHE-2004), May 30-June 3, Brisbane, Australia.
5. Ayub, K.R., Mohd Sidek, L., Ainan, A., Zakaria, N.A., Ab. Ghani, A. & Abdullah. R. (2005). Storm Water Treatment using Bio-Ecological Drainage System. Special Issue Rivers'04, International Journal of River Basin Management, IAHR & INBO, Vol. 3, No. 3, pp. 215-221.
6. Ayub, K.R., Zakaria, N.A., Abdullah, R. & Ramli, R. (2010). Water Balance: Case Study of A Constructed Wetland As Part of the Bio-Ecological Drainage System (BIOECODS). Water Science & Technology, pp. 1931-1936.
7. Construction Industry Research and Information Association or CIRIA (2007). The SUDS Manual. CIRIA, London, UK.
8. Construction Industry Research and Information Association or CIRIA (2017). The SUDS Manual. CIRIA, London, UK.
9. Department of Irrigation and Drainage or DID, (2000). Urban Stormwater Management Manual for Malaysia (MSMA). DID, Kuala Lumpur.
10. Department of Irrigation and Drainage or DID, (2011). Urban Stormwater Management Manual for Malaysia (MSMA), 2nd Edition. DID, Kuala Lumpur.
11. DID (2009a). Compendium: Data and basic information of DID. DID, Kuala Lumpur.
12. Departments of Irrigation and Drainage or DID. (2009b) DID Manual. Vol.2: River management. Ministry of Natural Resources and Environment Malaysia, Kuala Lumpur.
13. Mohd Noh, M.L., Othman, M.R., Hashim, N., Abu Hashim, H., Zakaria, N.A. & Chang, C.K. (2017). Sustainable Urban Stormwater Management Towards Achieving The New Urban Agenda for Sustainable Development. 37th IAHR World Congress-Managing Water for Sustainable Development - Learning from the Past for the Future, Kuala Lumpur, Malaysia. 13 – 18 August.
14. Mohd Sidek, L., Ainan, A., Zakaria, N.A., Ab. Ghani, A., Abdullah, R. & Ayub, K. R. (2004a). Stormwater Purification Capability of BIOECODS. 6th International Conference on Hydroscience and Engineering (ICHE-2004), May 30-June 3, Brisbane, Australia.
15. Mohd Sidek, L., Takara, K., Ab. Ghani, A., Zakaria, N.A., Abdullah, R. & Desa, M.N. (2004b). A Life Cycle Costs (LCC) Assessment of Sustainable Urban Drainage System Facilities. 1st International Conference on Managing Rivers in the 21st Century: Issues & Challenges, September 21-23, Penang, Malaysia, pp. 329-343.
16. Mohd Sidek, L., Ab. Ghani, A., Zakaria, N.A., Desa, M.N. & Abdullah, R. (2006). An Assessment of Stormwater Management Practices in Malaysia. Bulletin Institution of Engineers Malaysia, pp 8-19, IEM, Kuala Lumpur.
17. Zakaria, N.A., A. Ab. Ghani, Abdullah, R., Mohd. Sidek, L., Kassim, A. H. & A. Ainan. (2004). MSMA- A New Urban Stormwater Management Manual for Malaysia. 6th International Conference on Hydroscience and Engineering (ICHE-2004), May 30-June 3, Brisbane, Australia.
18. Zakaria, N.A., Ab. Ghani, A., Abdullah, R., Mohd Sidek, L. & Ainan, A. (2003). Bio-Ecological Drainage System (BIOECODS) for Water Quantity and Quality Control. International Journal of River Basin Management, IAHR & INBO, Vol. 1, No. 3, pp. 237-251.
19. Zakaria, N.A. (2011). Green Ways of Optimising Natural Resources with Effective Planning for Sustainble Development. 2nd Annual GreenTech Asia Conference: Optimising Green Water & Waste Management for Sustainable Future, September 26-27, Kuala Lumpur.
20. Zakaria, N.A., Ab. Ghani, A. and Chang, C.K. (2017). Bio-Ecological Drainage Systems (BIOECODS) An Alternative Sustainable Approach To Overcome Water Related Issues, Hydrolink No.2/2017, pp. 42-43.