BIO-ECOLOGICAL DRAINAGE SYSTEMS (BIOECODS): AN INTEGRATED APPROACH FOR URBAN WATER ENVIRONMENTAL PLANNING

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ABSTRACT

This paper outlines the national approach to stormwater management in Malaysia, and evolving implementation practices by State and Local government authorities. The process of departing from the traditional, monodisciplinary approach is currently going on in Malaysia. Goals of stormwater management have already shifted from the traditional storm drainage and "end of pipe" approaches towards sustainable ecological solutions more in peace with nature. The new approach is based on a deeper understanding of the cyclicity of material and energy flows in nature. The research focused on new concepts for the urban stormwater runoff and the water quality management based on integrated stormwater solutions.

The USM Engineering campus is a pilot project for urban stormwater management strategy as an example of an ecologically sustainable development based approach to urban stormwater management. The concept is based on integrating stormwater best management practices into urban planning and design to achieve multiple objectives, is the most promising approach in newly developing or urbanizing areas. This paper aims to introduce such an alternative - the "Principle of Control-at-Source" namely "Bio-Ecological Drainage Systems (BIOECODS)". The main function is to promote stormwater infiltration from impermeable areas (e.g. roof tops, car parks) by using bio-ecological swales. The second function is to release gradually the stormwater through the use of bio-ecological swales, on-line underground bio-ecological detention storages and bio-ecological dry ponds. Finally, the function of BIOECODS is to enhance treatment of stormwater quality using treatment train concept by utilising bio-ecological swales and bio-ecological ponds (e.g. wet pond, wetland) as the storm water moves downstream. This paper first introduces the basic principles of the concept followed by a description of technical details and preliminary results obtained. Details of the construction activities, costs and market acceptance highlight the potential for the adoption of similar practices elsewhere. Through the research some engineering problems are identified, the importance of which should not be underestimated to achieve the integrated approach for urban water environmental planning.
Keywords: Source Control; Grass Swale; BMPs; detention storage; infiltration systems

1. INTRODUCTION

Rapid urbanization in Malaysia has been accompanied by dramatic hydrologic changes. The detrimental effect of urbanization on hydrological cycle such as infiltration and groundwater recharge decreases, pattern of surface and river runoff is changed imposing high peak flows, large runoff volumes and increased transport of pollutants and sediment from urban areas. Thus, the urban area influences the runoff pattern and the state of the ecological systems not only within the urban area but also in and around a whole river system downstream. The effect of the urbanization on runoff has resulted in producing significantly more runoff volume than predevelopment, and flow peaks are increased by a factor of 2 to more than 10 times (Roesner, et. al, 2001). Study by Drainage and Irrigation Department (DID, 2000) showed that 9% of the country's land mass is prone to floods which affect about 12% of the population. As a result, frequent occurrences of flash flood occur at downstream of new development areas resulting in an average loss of RM 100 million annually.

Traditionally, the objective of stormwater management has been to transport runoff as quickly as possible through the drainage system in order to prevent flooding and protect lives and property. This is referred to as quantity control. Although public health and safety are still the most important goals, other objectives must now be met as well, such as the preservation of water quality and natural habitat. Historical flood and quantity control methods are not always suitable under current conditions, because it can cause problems of flooding, pollution or damage to the environment and are proving not to be sustainable. The current estimated costs to mitigate all existing flood problems by the Federal Drainage and Irrigation Department (DID) Malaysia is reaching RM 10 billion not inclusive projects by DID state and local authorities (News Straits Times, 22 June 2000). Therefore there is a need to seek holistic and sustainable solutions not only to mitigate existing flood problems but also to prevent the occurrences of such problems in new areas to be developed.

Today it is necessary to balance both quantity and quality objectives simultaneously. The concept of "integrated approach" to planning and designing of urban stormwater is moving away from the conventional thinking of designing for flooding to balancing the impact of urban drainage on flood control, quality management and amenity as shown in Figure 1. The integrated approach is in-line with the sustainable development and Local Agenda 21 to manage the balance between social, economic and environmental requirements minimising the conflict that can exist between economic development and the protection of the environment. The built environment is therefore one area where the strategies of sustainable development should be put into practice. BIOECODS is a type of sustainable drainage systems with a new environmentally friendly way of dealing with surface water runoff generated from developed area which avoids the problems associated with conventional drainage practice.
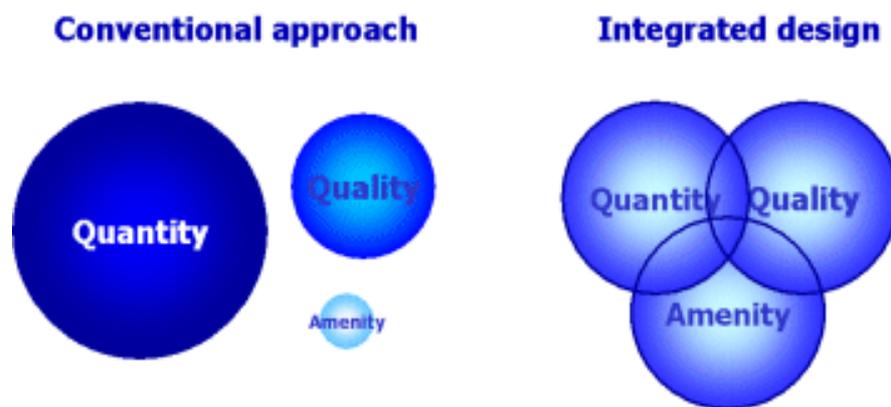
Figure 1: Conventional Approach versus Sustainable Approach (Source: CIRIA, 2001)

The proposed new ecological drainage system contributes to the achievement of sustainable development in urban water resources and brings numerous benefits including prevention of flooding, water pollution problems, loss of habitat, soil erosion and sedimentation, improved aesthetics of urban environments. Consequently, this new approach will added benefits to many issues and related parties as shown in Table 1. The new system will also help restore the natural environment by recharging the stormwater into the ground, maintain river flow, and control ground subsidence.

Table 1 : Benefits of Bio-Ecological Drainage Systems (Mohd Sidek et. al, 2002)

RELATED PARTIES / ISSUES	BENEFITS
Related Government Agencies such as Drainage and Irrigation Department (DID)/Department of Environment (DOE)/ Local Authority	• **Prevents pollution (quality)** by purification of the storm water by ecological/biological processes thus reduce the water contamination; • **Controls flooding (quantity)** by attenuation of flood discharge/zero peak flow contribution. • **Recharges groundwater** by recharging and stabilising the fluctuation of the water. • **Enhances the environment (amenity)**
The Community	• Visual amenity; • Agenda 21 and Biodiversity objectives; • Social opportunity for wetland appreciation; • Understanding of how drainage works.
Planning	• Planning objectives - Sustainablilty targets and demands of statutory consultees are met; • New 'greenfield runoff rate' requirements of the DOE are more easily achieved.
Capital costs	• Construction costs are reduced by 10% - 50% (depends on site condition and soil suitability);
Management	• Maintenance is simple and cheap; • BIOECODS is easily understood and avoids expensive specialist contractors.
Value	• BIOECODS uses natural features in the landscape to create attractive surroundings which add value to development.

Surface water drainage methods that take account of quantity, quality and amenity issues are collectively referred to as Bio-Ecological Drainage Systems BIOECODS. The BIOECODS is the example of sustainable drainage systems which has been developed in line with the ideals of sustainable development, by balancing the different issues that should be influencing the design. These systems are more sustainable than conventional drainage methods because they manage runoff flow rates, reducing the impact of urbanization on flooding, protect or enhance water quality, sympathetic to the environmental setting and the needs of the local community, provide a habitat for wildlife in urban watercourses and encourage natural groundwater recharge. The mechanism to achieve the above target is to deal with runoff close to where the rain falls (control-at-source), managing potential pollution at its source now and in the future and finally protecting water resources from point pollution and diffuse sources. The BIOECODS will use 'control at source' approach therefore simulate the natural hydrological cycle in urban area by combining infiltration, on-line and off-line detention storage, delayed flow as well as runoff treatment techniques.

This balance can also be achieved by pursuing regional solutions, such as effective land use planning, which minimizes impervious areas and preserves natural vegetation, especially riparian areas along streams and lakes. Local ordinances and codes can also help to reduce impervious areas and increase vegetation by limiting the extent to which a site can be developed. Quantity and quality goals can also be met at the local level through proper site planning and appropriate design that carefully considers the various impacts of development and application of Best Management Practices (BMPs) to minimize problems.

The stormwater management practices in Malaysia has been transformed drastically after the implementation of New Stormwater Management Manual for Malaysia (MASMA) with effect January 2001. The implementation of integrated measures of storm water Best Management Practices (BMP's) in Malaysia is still at early stages. There is a lack of the research and field data that would provide a basis for sound design practices under Malaysian hydrological condition as Malaysia has tropical climate with a very high intensity rainfall. It is hope this study will provide database to support the New Storm Water Management Manual and to evaluate the effectiveness of the comprehensive Bio-Ecological Drainage Systems (BIOECODS) and BIO-Ecological ponds to control stormwater runoff quantitatively and qualitatively. This paper presents information about a recent bio-ecological drainage systems concept including BMPs for a USM Engineering campus in Southern Penang State.

2.   THE NEW ECOLOGICAL APPROACH OF DRAINAGE SYSTEMS

Stormwater management has evolved from simple removal of runoff to comprehensive management approaches employing control measures. Such controls can be classified into several categories depending on the location where the controls are implemented (DID, 2001). The stormwater controls can be categorized under three categories namely "source control", "collection system controls" and "storage and treatment" (Marsalek, 1990).

Grasses swales are increasingly being employed in developed countries under temperate climate as a stormwater best management practice (BMP) for runoff quantity and quality control. Research has shown that grassed swales can improved the quality of stormwater especially removing the Total Suspended Solids (TSS) and nutrients such as Total Phosphorus (TP). Besides that the grassed swale can also attenuate the peak flow if designed properly. The primary mechanisms for pollutant removal in swales are filtration by

vegetation, settling of particulates, and infiltration into the subsurface zone. As runoff travels through a swale, the vegetation reduces peak velocity while infiltration reduces flow volume. Attenuation of runoff flow promotes pollutant removal (Yu et al. 2001). The term "swale" (e.g. grassed channel, dry swale, wet swale, biofilter) refers to a series of vegetated, open channel practices that are designed specifically to treat and attenuate stormwater runoff for a specified water quality volume. As stormwater runoff flows through the channels, it is treated through filtering by the vegetation in the channel, filtering through a subsoil matrix, and/or infiltration into the underlying soils. There are many design variations of the grassed swale, including the grassed channel, dry swale and wet swale. The specific design features and treatment methods differ in each design, but all are improvements on the traditional drainage ditch. Each incorporate modified geometry and other design features to use the swale to treat and convey stormwater runoff.

Pollutant removal efficiencies of swales reported in the literature covers a wide range (Yousef et al. 1985; Barrett et al. 1998, Yu et al. 2001). In general, grass swales show good performance for removal of large particles, such as suspended solids (TSS) as shown in Table 1. Schueler et al. (1992) reported the U.S. experience with swales which offered mixed performance in removal of suspended solids and attached pollutants, and low removal of solubles. However, he showed that the swale biofilter improved the pollutant removal performance. While it is difficult to distinguish performance removal between different designs based on the small amount of available data, grassed channels generally have poorer removal rates than wet and dry swales, although wet swales appear to export soluble phosphorous (Koon, 1995). Therefore more data is needed to conclude the performance of swale under both temperate and tropical climate.

In a recent design in Germany, the stormwater swale is underlain by a gravel infiltration trench with a throttle drain pipe (the so called MR system). The stormwater infiltrating through an active soil layer is 'pretreated' before entering a gravel trench, and drains via a drain pipe discharging into a manhole with a flow throttle. The system shows a good performance in removing stormwater pollutants (Sieker, 1998).

Sabourin et al. (1997) showed that the pollutant removal rates is increasing when the grass swale is underlain with perforated pipes implemented at City of Napean, Canada tabulated in Table 1. The grass swale - perforated pipe system is a storm drainage design system consisting of a shallow grass swale underlain by a continuous section of perforated pipes which are enclosed in an exfiltration trench. Later, a group of researcher from Cooperative Research Centre for Catchment Hydrology (CRCCH) developed a similar drainage systems called Bio-filtration constructed in the residential area located at the Lynbrook Estate Melbourne, Australia (Lloyd et al., 2001). The system forms part of an innovative stormwater drainage scheme of a 300 allotment residential precinct, consisting of bio-filtration systems, a constructed wetlands and an ornamental pond. The preliminary results showed that the bio-filtration systems can be an effective stormwater treatment measure. However, further investigations and refinements are needed to maximize their potential and efficiency. Amongst the recommendation for future research include assessment of treatment efficiencies of bio-filtration systems with modified parameters (i.e. other forms of swale vegetation, variation in infiltration medium and extended surface ponding) and confirm the significance of insitu graded sand in the adsorption of pollutants.

However, no findings were reported on the performance of grassed swales under the influence of high intensity of rainfall for tropical climate. Table 2 shows the pollutant

removal rates (%) for different type of Best Management Practices (BMPs) for temperate climates. Therefore, it is very necessary to carry out the study on the effectiveness and performance of grassed swale under the tropical climates. This research will focus on a shallow grass swale underlain by a continuous section of drainage modular which is more permeable with higher porosity and flexible to suit local soil and condition.

Table 2 : Ranges of BMP pollutant removal rates (%)

Type of BMP	TSS	TP	TN	Zn	Pb	BOD	Bacteria	Oil & Grease
Infiltration	0-99	0-75	0-70	0-99	0-99	0-90	75-98	-
Infiltration Trenches	90-99	60-75	60-70	90-99	90	90	90-98	-
Grass Swales	65-98 81	9-100 34	24-100 31	50-90 42	50-91 42	- -	- -	- -
Grass Swales w/perforated pipes	90	75	-	75	93	-	-	-
Bio-filtration (grass swales w/trench)	73-87	55-65	24-41	47-86	-	-	-	-
Bioretention (grass swale with retention area)	90-99	65-87	52-67	64-95	70-95	-	-	-
BIOECODS (grass swales w/drainage modular)	?	?	?	?	?	?	?	?
Grass swales w/check dams	20-40	20-40	20-40	0	0	-	-	-
Vegetative buffer strips	28-70	70	-	51	25	-	-	-
Sand Filters	60-85	60-80	(-110 - 35)	10-81	60-80	60-90	50-70	-

(Compiled Source: Sabourin J.F., 1997; Yu et al., 2001; Schueler, 1987)

3. THE SITE AND ITS CAPABILITIES

USM Engineering Campus (Figure 2) is located in Mukim 9 of the Seberang Perai Selatan District, Pulau Pinang. It lies at about latitudes 100° 29.5' South and 100° 30.3 North and between longitudes 5° 9.4' East and 5° 8.5' West. The locality is known as Ampang Jajar Nibong Tebal Pulau Pinang which is about 2 km south-east of the town of Nibong Tebal, about 1.5 km north-east of the the town of Parit Buntar (Perak) and about 1.5 km north-west of the town of Bandar Baharu (across Sg. Kerian in Kedah). The area of the campus is about 320 acres and made up of mainly oil palm plantation land and is fairly flat.

The required drainage planning specifies that alternative new ecological drainage systems should be used in line with the university-planning concept. The project objective was to

develop and test an alternative drainage systems to the conventional drainage system appropriate to the climate and ground conditions in the area. Due to the local boundary conditions, the storm runoff should be infiltrated into ground where possible or otherwise drained only with a significant delay. Particular stress was laid on the opportunity to create attractive and integrated drainage planning into the 'green planning' for the whole site. This means that the building of the university campus will take consideration towards eco-development by which, some of the oil palm trees and 'nypah' palm forests within the campus and along the riverbank will be preserved (HLA et. al., 1997).
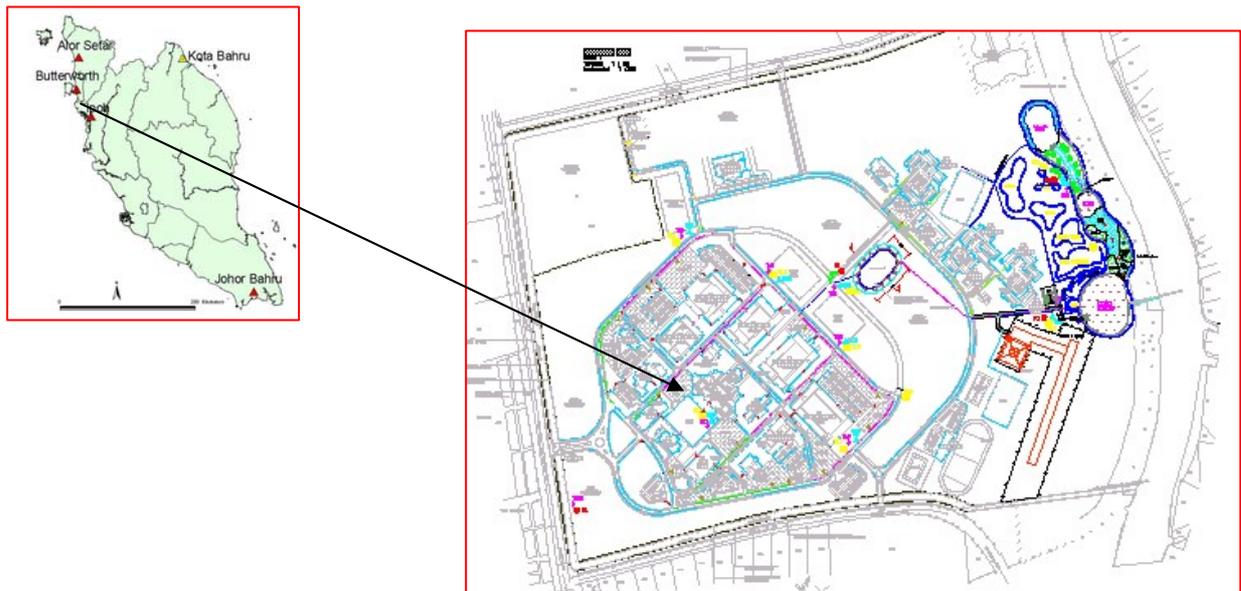

Figure 2: Pilot study area at USM Engineering Campus

Although BIOECODS are drainage devices that rely on natural processes, BIOECODS must be designed, built and maintained in the context of the development control system in Malaysia.

This project was proposed with the following prime objectives:

1. As a pilot project for the use of new ecological drainage systems at private and public buildings.
2. To assess the performance, potential application and continued use of integrated ecological drainage systems consists of different components such as perimeter and ecological swale, dry pond, on-site detention storage (OSD), wetpond, detention pond and wetland under Malaysian condition
3. To monitor and study the effectiveness of individual components of new ecological drainage systems for attenuating the hydrograph and improving the water quality on the aspect of storage efficiency, infiltration, conveyance and purification
4. To develop a modeling procedure for the analysis, design and optimization of the integrated ecological drainage systems.
5. To evaluate the cost effectiveness of the integrated ecological drainage systems
6. To provide guidelines of new ecological drainage systems for local use.

Based on published BMP effectiveness information and hydrologic modeling, the USM Engineering Campus development can be expected to reduce surface runoff volumes by 65% and reduce solids, nutrients, and heavy metals loads by 85% to 100%. Source controls will minimize the impacts of the development even further (Stahre, 1990). The long term result is not only reduces costs to the developer, but also reduces maintenance costs for the community. There is also a substantial benefit to downstream neighbours. By treating stormwater where it falls on the land, the USM campus is reducing its contribution to downstream flooding and sedimentation. Hence, the sustainable development can be achieved

4.   DEVELOPMENT OF BIOECODS

This paper will present the concept of BIOECODS for stormwater management. BIOECODS is a method of stormwater management treatment train implement a combine of "source control", site control and regional approach as illustrated in Figure 3 for stormwater management as suggested in Stormwater Management Manual for Malaysia. 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 stormwater before it leaves the campus. This systems was designed to combine infiltration, delayed flow, storage and purification as pre treatment of stormwater before discharging to the constructed wetlands.

Generally, BIOECODS integrate a vegetated swale underlain with drainage module as part of the design. These designs incorporate a fabricated soil bed into the bottom of the channel. Existing soils are replaced with a sand/soil mix that meets minimum permeability requirements. An underdrain modular system is also installed under the soil bed. Typically, the underdrain system is created by a sand layer which encases a modular drainage. Stormwater treated by the soil bed flows into the underdrain, which conveys treated stormwater back to the storm drain system. 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 (ECOPOND) for further treatment of the stormwater runoff. In combination, these increase runoff lag time, increase opportunities for pollutant removal through settling and biofiltration, and reduce the rate and volume of runoff through enhanced infiltration opportunities.
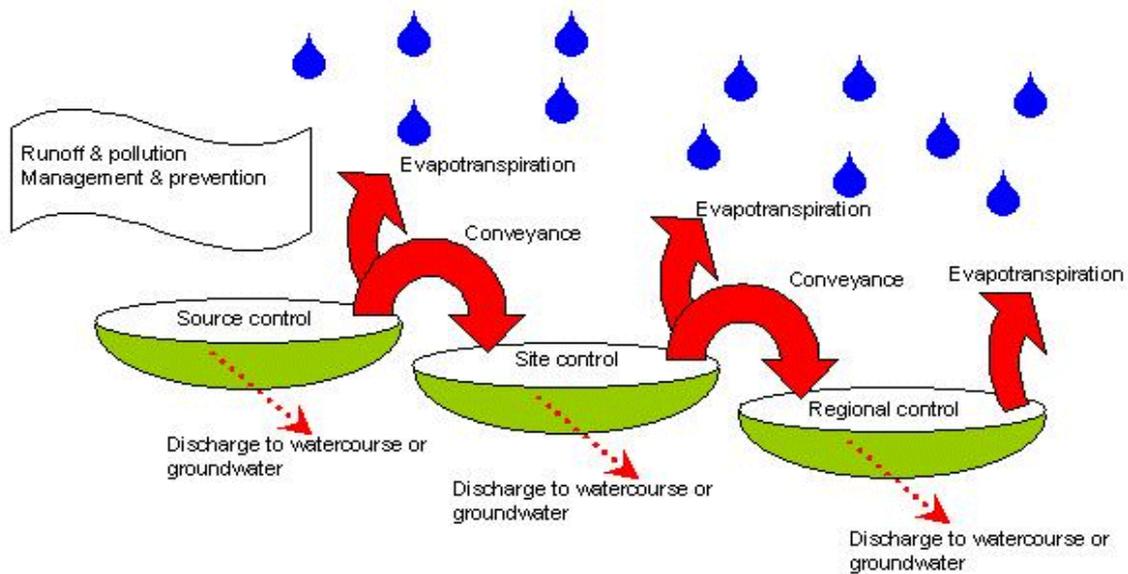
Figure 3: Sustainable Urban Drainage Systems (SUDS) Management Train (CIRIA, 2001)

Stormwater from the built areas is routed overland into open conveyance swales planted with native cow grass and underground conveyance made from special materials, rather than through conventional drainage. The swales provide initial stormwater treatment, primarily infiltration and sedimentation. The landscape lands and dry ponds are the second component. Landscape lands and dry ponds diffuse the flows conveyed by the swales, and the reduced stormwater velocities maximize the campus sedimentation, infiltration and evaporative water treatment. Additionally, the natural adsorption and absorption of the landscape soils enables the soil to hold many contaminants. The aerobic condition of the soil promotes hydrocarbon breakdown. The landscape lands are able to infiltrate a substantial portion of the annual surface runoff volume due to their increased soil permeability which is created by the deep root systems of the landscape vegetation. The detention pond provides stormwater detention, further solids settling, and biological treatment. Finally, wetlands provide both stormwater detention and biological treatment prior to runoff entering the recreational pond and before discharging to Kerian river.

4.1   BIOECODS Design Dimensions

BIOECODS are the most similar to a conventional drainage ditch, with the major differences being flatter side slopes and longitudinal slopes, and a slower design velocity for water quality treatment of small storm events. BIOECODS are the least expensive option, but also provide the least reliable pollutant removal. The best application of a BIOECODS is as pretreatment to other structural stormwater treatment practices. Figure 4 illustrates the design attributes of the BIOECODS system and the completed BIOECODS for swale Type A for USM Engineering Campus.
The following dimensions are recommended for BIOECODS facilities:
- Minimum width should be at least 0.6m and maximum 3 m
- Length of BIOECODS should be at least 60m, or a minimum 30m
- The ponded area should be maximum 150mm and design ponding time 24 hours
- The root zone should have a minimum depth of 100mm
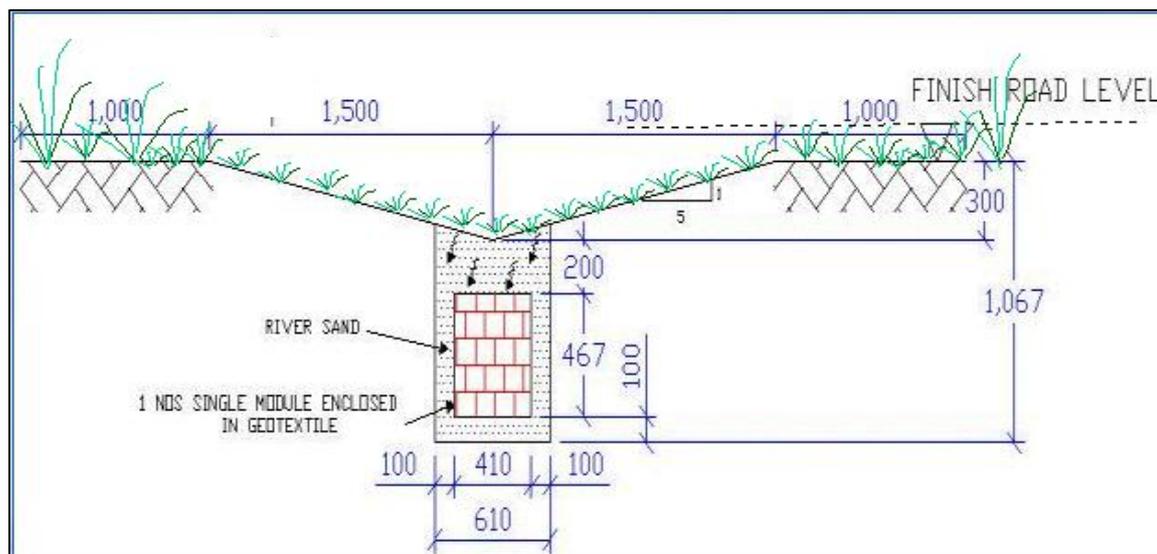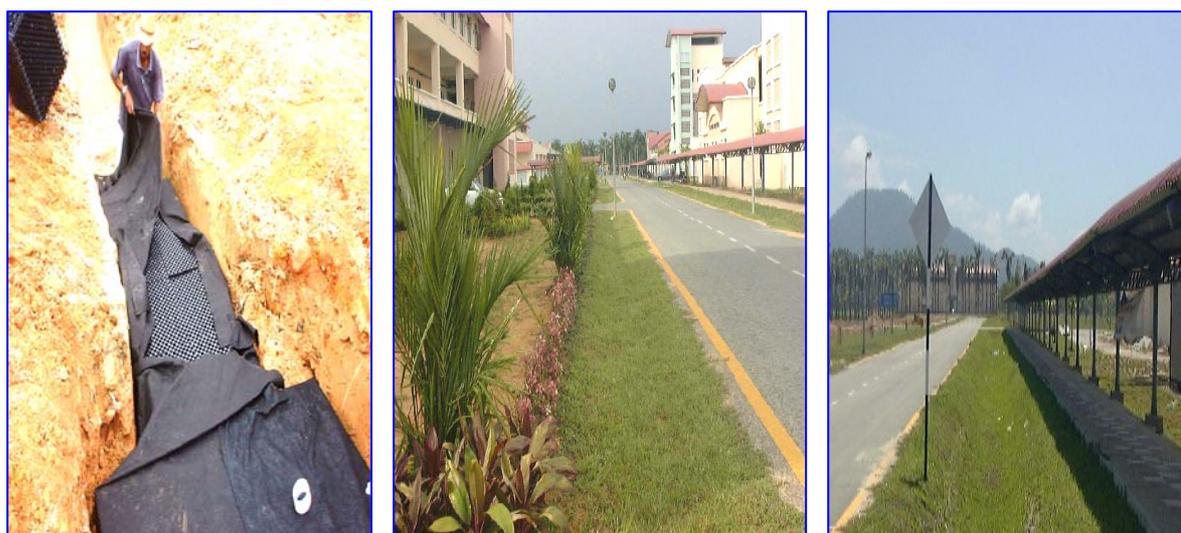- The longitudinal slope should be less than 5%

Figure 4: Cross Section Design and Completed Images of the BIOECODS blended with
Landscaping at USM Engineering Campus

The minimum depth of 100mm was set to create space for the root system of the grass to
provide for resistance from windthrow, and provide appropriate moisture capacity. The
criterion of designing the length of BIOECODS areas to be at least 30m was established for
the following reasons:

- To allow sheet flow to be dispersed over a greater distance, reducing the
likelihood of concentration flow, and
- To increase the hydraulic residence time (HRT) for the flow to settle the solids
particles
- To allow the flow to infiltrate into the soil particles before entering the drainage
module (sub-surface conveyance)

Table 3 shows some comparison of design criteria being practiced overseas and BIOECODS
systems.

Table 3 : Comparison of Design Criteria for Ecological Swale based on MASMA and others (After Burkhard, 2000)

Min length (m)	Min/Max bottom width (m)	Recommended Slope (%)	Max flow velocity (m/s)	Max depth of flow (mm)	Min/Max Residence Time (min)	Literature Source
60	**0.6/3.0**	**2 % - 4%**	**2.0**	**150**	**0.1**	**Mohd. Sidek et al. (2001)**
30	0.6/2.4	2.0% (0.5 min and 6.0 max)	<0.3	75	N/a	WEF (1998)
N/a	N/a	<4.0% without berms	N/a	N/a	N/a	Bettess (1996)
N/a	1	N/a	N/a	N/a	250 –1000 (total depth)	Leonard and Sheriff (1992)
N/a	N/a	<6.0%	<0.5	N/a	N/a	FRPB (1995)
Min 30, Max 60	0.6	Max 5%	N/a	N/a	N/a	Yu et al. (1994)
Min 30, Max 60	< 8 feet	2% - 4%	< 0.9 fps (6 mth), <1.5 fps (2 year)	N/a	Max 10 (6 month 24 hour storm)	Reeves (2000)

5.   LAYOUT AND MAIN FEATURES OF BIOECODS

Planning was carried out with the help of rainfall-runoff model SWMM, which contains information needed for designing BIOECODS. The design criteria for BIOECODS and comparison with different criteria being practice elsewhere is given in Table 3. The schematic diagram of BIOECODS for USM Engineering Campus is shown in Figure 5 and is divided into seven steps as follows:

Step 1 : Per*imeter swale is to cater any excess water from individual building whilst the flow from impermeable surface will be directed to the individual lot swale*. The perimeter swale is defined as grass earth channel combined with subsurface twin Geo-strip enclosed within a permeable geotextile designed
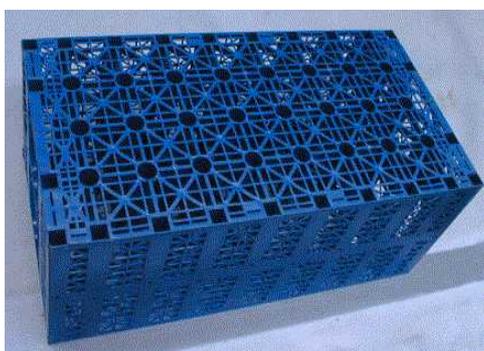

Figure 4a: **A view of the drain building blocks or module.** Drains can now be built using modern materials and be designed to hold water during times of heavy downpour rather than let all the water run-off immediately. During the USM Engineering Campus project one such system was installed at Nibong Tebal, Pulau Pinang, Malaysia

Step 2: *The flow from individual swale (perimeter swale) will be conveyed to inter-lot swale (ecological swale) as main conveyor*. The ecological swale is a grass-earth channel combined with a subsurface module enclosed within a permeable geotextile. The ecological swale is shown in Figure 4a categorised as Type A, Type B and Type C depending on sizes and capacities. Type A consists of one number of single module, Type B consists of two numbers of single module and Type C consists of three numbers of single module. The completed Ecological swale type A is shown in Figure 6. A typical detail for the BIOECODS site water quantity and quality control practices is presented in Figure 5. The components of the BIOECODS areas are:

(a)   Grassy channel (surface conveyance)
The ponding area over the root zone provides for conveyance and surface storage of the storm water runoff, and provides for the evaporation of a portion of the runoff to emulate the hydrological cycle.

(b)   Root Zone
The root zone is the region which provides the source of water and nutrients for the grass to sustain growth. The voids in the soil also provide for stormwater storage.

(c)   Sand Bed
The fabricated soil bed replaces on-site soils, in order to ensure that runoff is filtered as it travels through the soils of the channel The sand bed provides for drainage and aeration of the root zone, and augments the infiltration capacity of the BIOECODS area. The drainage provided by the sand will assist in the flushing of pollutants from the soil material. The hydraulic conductivity of the sand should be at least 10^{-5} m/s as suggested by Sieker (1999).

(d)   Organic layer
The organic layer on the surface of the soil has the following functions:
•   Act as a filter for pollutants in the runoff
•   Protect soil from drying and eroding
•   Provide additional habitat for microorganisms to biodegrade the stormwater pollutants

Step 3 : *The excess stormwater is stored in the sub-surface detention storage*. The storage modules have been designed to be placed at the connecting point, junction and critical point of the system. The storage module is categorized into Type A and Type B with different storage capacity and can be arranged accordingly to suit site condition.

Step 4 : *The excess stormwater is also stored on the dry pond constructed with a storage function*. Dry pond is a detention basin which has been integrated with the ecological swale to temporarily store the storm runoff. This detention basin is designed to store to the surface that of 150mm of excess rainfall and designed to blend with surrounding landscape. The outflow path of the storage module should be connected to ecological swale at the lowest point in order to drain the dry pond system in less than 24 hours.

Step 5 : With respect to the need for water quality improvement, the flow from ecological swale goes into detention pond and wetland for further water treatment. Wetlands are constructed to pass water 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 wetland bed. The end product is expected to improve the aesthetic values for surrounding area with the existence of the "Crystal Clear Blue Water Lake'.

Step 6 : Tidal gate will be incorporated at the outlet of the recreational pond into Sg. Kerian.

Step 7 : *In the case of flood event, the excess water from detention pond will be directed to Sg. Kerian via emergency spillway.*
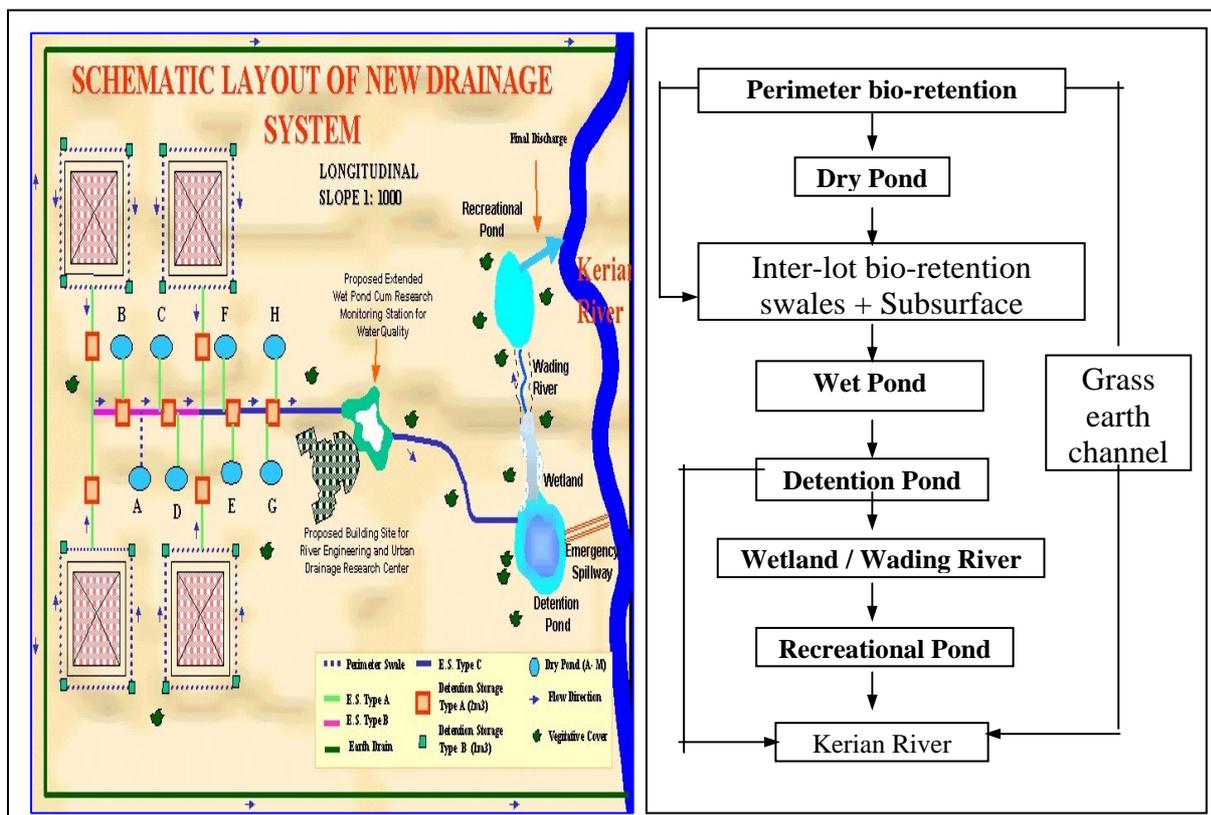

Figure 5: Schematic layout of Bio-Ecological Drainage Systems (BIOECODS)

6.   PRELIMINARY RESULTS

The experimental testing was carried out in the laboratory to investigate the flow pattern and hydraulic capacity in the drainage module. The experimental result showed that the flow velocity is varied along the module. The pattern and internal structure of module has caused the flow to be turbulence flow as expected. In general, all results show that average velocity distribution, maximum velocity, minimum velocity and velocity beside the module is higher than velocity inside the module. Figure 6 shows typical velocity distribution across the triple modules. The finding was interesting as the flow profile in the module was observed to be resemble the flow profile between open channel and pipe flow. Meanwhile, the experimental results also showed that the velocity distribution in the modules resemble closely the pipe flow.

The capability of the drainage module to remove stormwater pollutants was tested in the laboratory experiment. Results from lab-testing of drainage module components as shown in Figure 7a and 7b showed that the drainage module could effectively increase the dissolved oxygen with respect with time, distance and velocity. This may be due to the structure and

pattern of the modular that has created the turbulence flow. The drainage module did not show high metal removal, as low as Zinc (10.9%), Cuprum (38.7%), Nickel (33.3%) and Plumbum (15.9%) probably due to slow chemical decomposition process, no infiltration and very much depends on inflow characteristics.
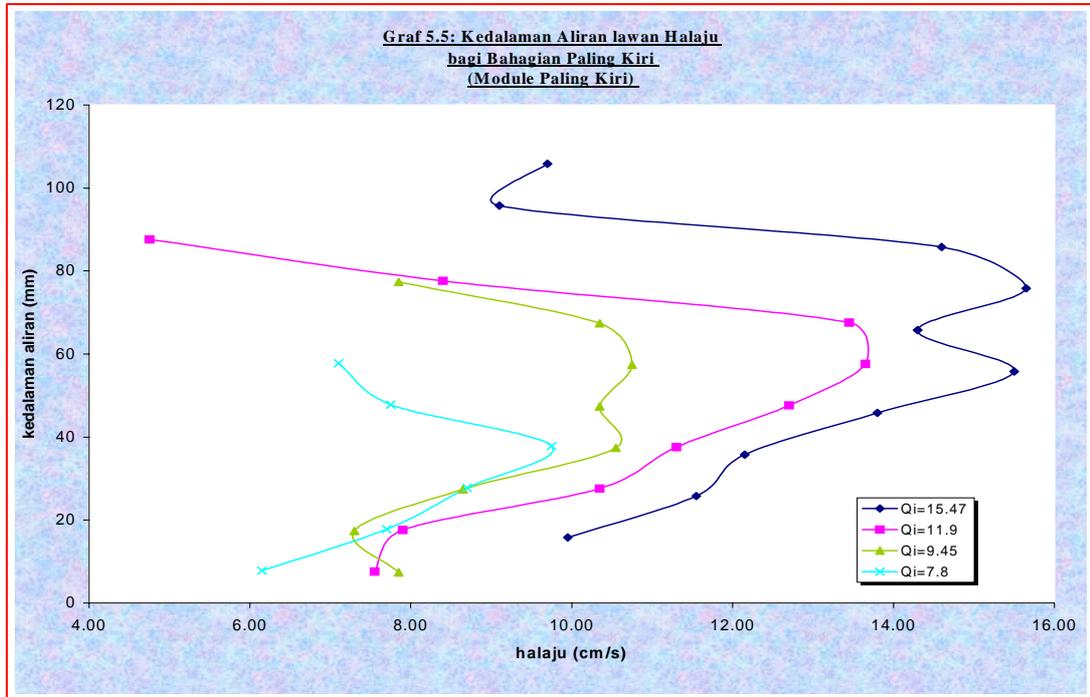

Figure 6: Relationship between Flow Depth versus Velocity in the Drainage Module
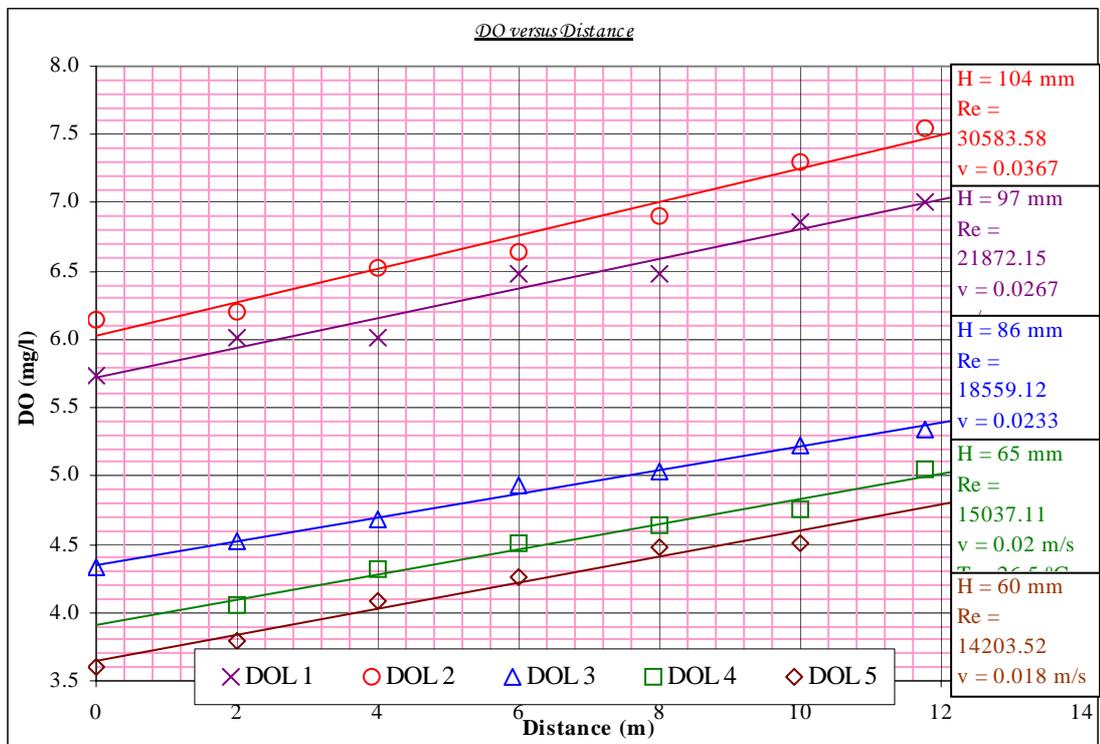

Figure 7a: Relationship between Dissolved Oxygen and Distance in the Drainage Module
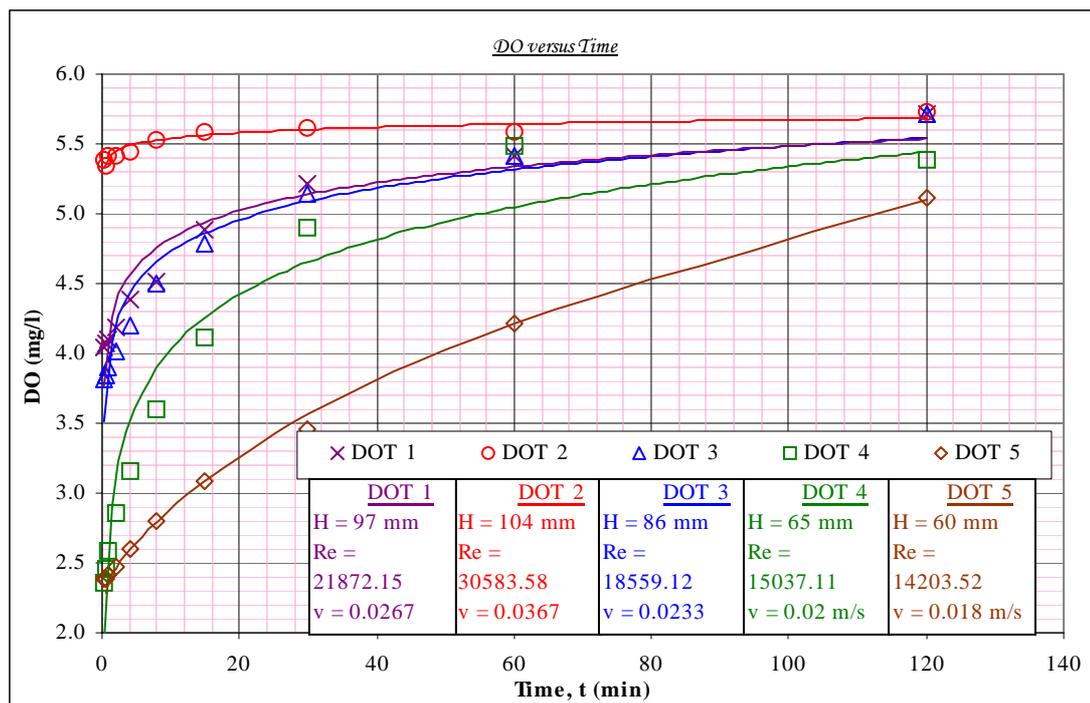
Figure 7b: Relationship between Dissolved Oxygen and Time in the Drainage Module

7. CONSTRUCTION COST AND MAINTENANCE ISSUES

There is little data available to estimate the difference in cost between various swale designs. However, the experience in construction of BIOECODS showed that the system can save up to 5% of the total construction cost. The total cost can be reduced substantially if the drainage module is produced locally in future. The detail of the cost appraisal and life cycle assessment will be reported in the future.

The grass swale has been practiced widely in U.S and some study has reported the construction cost of the grass swale. One study (SWRPC, 1991) estimated the construction cost of grassed channels at approximately 25¢ per square foot. This does not include the design costs, or contingencies. Brown and Schueler (1997) estimate these costs at approximately 32% of construction costs for most stormwater management practices. For swales, however, these costs would probably be significantly higher since the construction costs are so low compared with other practices. A more realistic estimate would be a total cost of approximately 50¢ per square foot, which compares favorably with other stormwater management practices. The rough cost of an infiltration facility being practiced in Japan can be referred to Table 3a.

Table 3a: The construction cost of rainwater infiltration facility in Japan (ASRIT, 2000)

No	Infiltration Type	Cost (thousand yen)	Notes
1.	Infiltration connection box (manual earthwork)	92 (112) per unit	*Data inside the ( ) indicates cost with 30% miscellaneous expenses.
2.	Infiltration connection box (machine earthwork)	70 (91) per unit	
3.	Infiltration trench (manual work)	12 – 13 (15 –17) per meter	* Land coverage of trench: 150-450mm
4.	Infiltration trench (machine work)	14-16 (18-21) per meter	*Depending on country cost will be different
5.	Permeable pavement – ASCON (with Asphalt etc)	3 (4) per meter square	
6.	Permeable pavement (with permeable concrete block etc)	8 (10) per meter square	

Maintenance of grassed channels mostly involves maintenance of the grass plant cover. Typical maintenance cost and activities are included in Table 4a. The care of sustainable drainage schemes is simple and easily understood by site managers that can be undertaken by landscape contractors or site personnel. The most important issue is that the maintenance costs are reduced as sustainable drainage schemes can be managed as part of normal landscape care and avoids the need for expensive specialist contractors.

Typical frequently asked questions about sustainable drainage by the developer and local authority is the issue on operation and maintenance cost. To give some ideas the cost involves for sustainable drainage practiced in other countries for example United Kingdom, Table 4a provides a general estimate for such operation and maintenance costs (based on 1993 prices) which suggest an overall ongoing average annual cost of between £430 to £600 depending on size of the ground area and the requirement for general care of the site. However, this figure excludes costs to cover any major repair and replacement. Andoh and Declerck (1999) found that retention and infiltration measures used as a source controls reduced infrastructure maintenance and rehabilitation cost by a factor of five and also significantly reduced pollution of receiving waters.

Table 4a: Average annual operation and maintenance costs for a sustainable drainage
(e.g. grass swale) for United Kingdom (Ellis, 1998)

Component	Estimated Unit Cost	Swale size	Swale size	Comments
	(£)	0.5m deep 0.3m bottom width 3m top width (£)	1m deep 1m bottom width 7m top width (£)	
Mowing	$0.6/100m^2$	98.0	163.0	Mow 2/3 times per year
General Grass Care	$6.0/100m^2$	110.0	185.0	Grass Maintenance area is (top width + 3m) x length
Debris/Litter Removal	$0.35/m^2$	63.0	63.0	
Reseeding/ Fertilisation	$0.24/m^2$	4.0	7.0	Area revegetated is 1% of maintenance area per year
Inspection & General Administration	$0.5/m^2$	156.0	156.0	Inspection once per year
TOTAL		**431.0**	**574.0**	

Another good local example of the cost of maintenance for sustainable drainage is the proposed mixed development project in Tuanku Heights Seremban. The estimated maintenance cost was to be RM 30,000 per month and the detail of each items are shown in Table 4b. The detail cost of operation and maintenance of BIOECODS will be reported in future.

Table 4b : Summary of Estimated Maintenance cost for Mixed Development Project at
Tuanku Heights, Seremban (Source: Azman, 2001)

ITEM	DESCRIPTION	AMOUNT
1.	Swale	RM 13,890.45
2.	Pond/wetland	RM 13,661.50
3.	Gross Pollutant Traps – CDS unit	RM 2,448.10
	Total Maintenance Cost per month	**RM 30,000.05**

Sustainable drainage like any other source control devices need regular and systematic inspection to ensure a continued operational effectiveness. Operational failures are as often due to lack of proper routine maintenance as to poor initia1 design or installation. Such operation and maintenance needs must be considered and costed at the site planning and design phase and not left as an afterthought. To date operation and maintenance of source control facilities has generally been a very low budgetary priority which is often reflected in either structural or aesthetic deficiency or failure. Inspection records should be data processed and computer filed together with any site photographs and correspondence to provide a basis for long term cost information.

8.   PROBLEMS ENCOUNTERED & LESSONS LEARNT

Based on the experience of the construction of BIOECODS at USM's Engineering Campus, several suggestions are proposed for the construction of a similar drainage systems in other locations.

- Coordination among relevant parties need to be understood from the planning and design phase
- Construction of temporary earth channel at the site needs to be made. The construction of swales are made only after the completion of building and landscape phases
- Individual grass channels cannot treat a very large drainage area more than 2 ha
- Grass channels do not appear to be effective at reducing bacteria levels in stormwater runoff. Need further treatment by constructed wetland to enhance the stormwater quality
- Wet swales is not suitable under tropical climate which may become a nuisance due to mosquito breeding. Dry swale is more suitable for local condition.
- If designed improperly (e.g., proper slope is not achieved), grassed channels will have very little pollutant removal.
- A thick vegetative cover is needed for proper function. Normal grass height should be at least two inches above design flow depth
- The developer should be responsible for providing the land, meeting the capital costs and landscaping costs of Best Management Practices (BMPs)
- Legal arguments around who is responsible for the long term maintenance are common. Hence, any conflict on this issue should be resolved as soon as possible.
- A public campaign needs to be conducted nationwide to highlight the new concept of drainage system

The very important aspect to ensure the successful of the stormwater program is to educate the public (public awareness). There is a need of paradigm shift in Malaysian way of thinking and action towards sustainable drainage systems. The program should starts from school to educate the young generations how they can help in the battle against stormwater pollution as part of integrated water environmental planning program. The problem is so large that there will never be enough money to clean all of the runoff once it becomes dirty. Without the help and support from the public to keep pollutants out of water to begin with, the effort will be hopeless. The public can participate by taking simple actions such as not dumping grass clippings, leaves, and trash in the gutters, decreasing mowing intervals, reducing pesticides and fertilizer usage, recycling oils and chemicals, and bagging trash are important activities in which all public can participate.

For any new development, the smart-partnership between the developer and responsible authority should be encouraged through involvement in the demonstration project. The developer of the identified project must agree to incorporate model erosion and sediment control systems, innovative stormwater control systems, and design concepts that minimize land-disturbing activities. The Project assists the developer in these practices through technical assistance, cost share, and marketing arrangements. In return, the developer allows the site to be used as a field demonstration site that serves as an outdoor classroom for others in the area involved in land development. Besides, the long term monitoring can also be carry out in the demonstration project and the data collected can be used for the development of stormwater best management practices database for Malaysia.

9.   CONCLUSIONS

The results of the study indicate that the BIOECODS can be a viable method for the water quantity and quality treatment of site runoff. The system can be applied independently of soil conditions and other local circumstances. It can be applied in different technical ways depending on the local conditions, the objectives, and the imagination of the designer. Therefore, where applicable, BIOECODS promises to be an effective on site source control.

BIOECODS adopted an integrated approach to obtain both practical and cost effective solutions to minimize the impact of urbanization on the environment. As a rule it combines three elementary engineering techniques to manage rainfall-runoff, infiltration, storage and conveyance draining by ecological swales. Widespread of this techniques in new developments would result in a long-term improvement in the quality of urban rivers and a reduction in the risk of flooding. In addition, urban environment would not only be more sustainable, but also more varied and attractive, with water a feature rather than being hidden underground.

As an alternative within the fragmented urban watershed, the sustainable framework strategy illustrates potential planning options beyond traditional means. It offers a view of the relationships between the built and natural landscapes that hopefully, will foster support for new alternative sustainable solutions. To ensure the successfulness of the BIOECODS, the public should be involve very actively. Besides, consideration should also be given to the planning system as a whole if 'holistic water environmental planning' is to be achieved.

10.   ACKNOWLEDGEMENT

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