Performance of A Sustainable Urban Drainage System in Malaysia- A Case Study of Bio-Ecological Drainage System in USM Engineering Campus

Associate Professor Dr Nor Azazi Zakaria*
Associate Professor Dr Aminuddin Ab. Ghani**
Dr Rozi Abdullah***
Anita Ainan****
Wong Lai Peng*****

* Director of River Engineering and Urban Drainage Research Centre, USM
** Deputy Director River Engineering and Urban Drainage Research Centre, USM
*** Lecturer, School of Civil Engineering USM
**** Engineer, Department of Irrigation and Drainage, Malaysia
***** Research Officer, River Engineering and Urban Drainage Research Centre, USM

Abstract

Growth of urban area in Malaysia brings significant changes in physical properties of land surface by increasing integrated vulnerability of inhabitant and changing of hydrological cycle. Infiltration and groundwater recharge decrease, pattern of surface and river runoff is changed imposing high peak flows, large runoff volume and accelerated transport of pollutants and sediment from urban areas. The traditional conveyance approach in stormwater management is shifted to the storage approach to reduce the impact of urbanization.

In Malaysia, increasing the public awareness to the negative impact of urban runoff to the environment has led the Department of Irrigation and Drainage (DID) introduced the new Urban Storm Management Manual for Malaysia. The Bio-Ecological Drainage System (BIOECODS) is a pilot project that meets the requirements of Storm Water Management Manual for Malaysia and has been constructed at the Engineering Campus of the University Sains Malaysia. BIOECODS forms an alternative method to manage storm water quantity and quality controls for urban areas. BIOECODS represents an alternative to the traditional hard engineering-based drainage system with the application of swales, sub-surface drainage modules, dry ponds/wet pond, and constructed wetland.

The paper is to evaluate the performance of BIOECODS after the construction in term of quantity and quality controls of runoff.

1.0 Introduction

Stormwater management has been promoted for number of years in response to a need to manage urban runoff. The traditional approach in the stormwater management shifted during 1970s to a storage approach with a focus on detention, retention and recharge. Later on, during the 1980s and 1990s stormwater came to be considered as a significant source of pollution, and the main goal of stormwater management shifted to protection of the natural water cycle and ecological system by the introduction of local source control, flow attenuation and treatment in natural or mostly constructed biological systems, such as ponds, wetlands and treatment facilities. Since then variety of new stormwater handling and treatment method have been developed. It is generally accepted that stormwater should be attenuated locally. Awareness of the need for more sustainable drainage systems is a rise among the drainage engineers.

The implementation of various Best Management Practice (BMPS) in Malaysia is still at the early stage. Realizing of that University Sains Malaysia in collaboration with Department of Irrigation and Drainage Malaysia, looking step forward to implement Bio-Ecological Drainage System (BIOECODS) as a showpiece of the Sustainable Urban Drainage in Malaysia. It is a hope that the Bio-Ecological Drainage System will be an example of Best Management Practice in Stormwater management mainly in Malaysia and the general South Asia Region. BIOECODS represents an alternative to the traditional hard engineering-based drainage system with the application of swales, sub-surface modules, dry ponds/wet pond, constructed wetland, and wading stream. The construction of BIOECODS covers an area of 300
acres and was completed in December 2002. His Excellency the Governor of Penang has launched the BIOECODS at national level on 4th February 2003. The BIOECODS project is expected to provide an insight of the BMPs implementation that practitioners in Malaysia and neighboring countries can apply in designing the urban drainage system for a new development. (JPS 2000, 2001,2002,2003)

2.0 Storm Water Management

Urban stormwater management, simply stated, is everything done within a catchment to remedy existing stormwater problems and to prevent the occurrence of new problems. This involves the development and implementation of a combination of structural and non-structural measures to reconcile the conveyance and storage function of stormwater systems, with the space and related needs of an expanding urban population. It also involves the development and implementation of a range of measures or Best Management Practices (BMPs) to improve the quality of urban stormwater runoff prior to the discharge into receiving waters.

There is increasing recognition in developed countries overseas that stormwater management needs to be undertaken in a safer and more ecologically sustainable manner. Stormwater should be regarded as an asset and a resource to be valued, rather than the traditional attitude of regarding it as a nuisance to be disposed of as quickly as possible. Many rivers, lakes, and coastal waters are currently degraded by urban stormwater due to excessive flows, poor water quality, removal of riparian vegetation, and the destruction of aquatic habitats. This has resulted fundamentally from a primary focus on a conveyance-oriented approach to stormwater management. Stormwater management practices need to be broadened to consider environmental issues such as water quality, aquatic habitats, riparian vegetation, and social issues such as aesthetics, recreation, and economics.

In UK, stormwater management to manage urban runoff is known as Sustainable Urban Drainage. Sustainable Urban Drainage System (SUDS) have been promoted for number of years in UK to combat pollution arising from diffuse sources in urban areas. The system range from source control, to site and regional control systems have been developed for specific site condition. The initiative to promote Sustainable Drainage System in UK is done by the Construction Industry Research and Information Association (CIRIA). CIRIA have been instrumental in co-coordinating a number of initiatives, which have culminated in the publication of two-design manual for England and Wales and for Scotland and Northern Ireland on Sustainable Drainage System (CIRIA, 2000).

The management train concept advocated by CIRIA can be adopted here to manage urban stormwater runoff. The CIRIA management train concept for example starts with prevention or good housekeeping measures at the household level and progress through local sources control to larger downstream site and regional controls. It promotes the division of the area to be drain into sub-catchment (see Figure 1.0) with different drainage characteristics and land uses, each with its own drainage strategy to suit prevailing condition, land use types, hydrogeology of the site.
CIRIA suggested that this concept does not necessarily pitch alternative systems such as BMPs against conventional piped drainage systems but rather advocates a broad framework of prevention and beneficial reuse (reduce, recycle and reuse). For example, appropriate systems for draining development in a highly urbanized catchment which already has an extensively developed conventional urban drainage infrastructure with poor hydro-geological conditions (e.g. poor sub-soil for infiltration and contaminated land), would be different from that for development on a green field site with good hydro geological condition (e.g. sub-soil with high infiltration rate and no risk of ground water pollution).

3.0 Alternative Stormwater Management For Pilot Study at USM Engineering Campus.

The USM Engineering Campus is located in Mukim 9 of the Seberang Perai Selatan District, Pulau Pinang. It lies between 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 Sri Ampangan, 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 project initially implemented a conventional drainage system. Later the Drainage and Irrigation Department (DID) in cooperation with the River Engineering and Urban Drainage Research Centre (REDAC) has proposed a new ecological drainage concept to be implemented. 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 evaluate an alternative drainage system to the conventional drainage system, appropriate to the climate and local conditions in the area. Due to local boundary conditions, the storm runoff should be infiltrated into ground where possible, or otherwise drained only with emphasis on significant delay. Particular was focused on the opportunity of creating 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 along the riverbank could be preserved.

The USM Engineering Campus project (Figure 2.0) 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 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 Bio-ecological drainage systems (BIOECODS) that contribute to the treatment of the stormwater before it leaves the campus. 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 bio-ecological drainage systems (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.

As a whole, BIOECODS is designed to provide time for the natural processes of sedimentation, filtration and biodegradation to occur, which reduces the pollutant load in the surface water runoff. In addition, BIOECODS can be designed to fit into their environmental setting, adding considerably to the local amenity and/or local biodiversity. 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 storm sewers. The swales provide initial stormwater treatment, primarily infiltration and sedimentation. The landscape dry ponds are the second component. The landscape 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 able to infiltrate a substantial portion of the annual surface runoff volume due to the increased soil permeability that is created by the deep root systems of the landscape vegetation. The detention pond provides the function of a stormwater detention, solids settling, and biological treatment. Finally, wetlands provide both stormwater detention and biological treatment prior to the runoff entering the recreational pond. 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. 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.

Figure 2.0 Layout Plan of USM Engineering Campus

4.0 BIOECODS Concept

The schematic diagram of BIOECODS drainage path is shown on figure 3.0. And flow sequence can be summarized in Figure 4.0.

Figure 3.0 BIOECODS drainage layout plan
a) The Perimeter swale (Figure 4.0a & b)) is used to cater for any excess water from individual buildings, whilst the flow from impermeable surface will be directed to the individual swale. The perimeter swale is defined as a grass earth channel combined with a subsurface twin Geo-strip enclosed within a permeable geotextile filter fabric.

b) 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 filter fabric. (Figure 5.0)

c) The excess stormwater is stored as 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 capacities and can be arranged accordingly to suit the site conditions.

d) The excess stormwater is also stored on the dry ponds constructed with a storage function. The Dry pond (Figure 6.0) is a detention pond, which has been integrated with the ecological swale to temporarily store the storm runoff. This detention basin is designed to store up 150mm of excess rainfall and designed to blend with the surrounding landscape. The modular storage tank is placed beneath the dry pond where the stormwater is drained out by infiltration. The outflow path of the storage module should be connected to an ecological swale at the lowest point in order to drain the dry pond system in less than 24 hours.
e) Proportion of the excess water from built-up areas flow through overland flow plane before goes into dry pond.

f) With respect to the need for water quality improvements, the flow from an ecological swale goes into a detention pond and a 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”.

g) A Flap gate is incorporated into the outlet of the recreational pond into Sg. Kerian.

h) For the case of flood event, the excess water from the detention pond will be directed to Sg. Kerian via an emergency spillway.

![Figure 4b. View of Perimeter Swale](image)

![Figure 4a Typical Perimeter Swale](image)

![Figure 5b View of Swale type A](image)

![Figure 5a Swale type A](image)

**5.0 Data Collection for monitoring of quantity and quality run-off**

Data collection system to gauge the system effectiveness of BIOECODS is operating from April 2003. The data collection system is concentrated on the ecological swale, dry pond and ecological pond. The effectiveness of ecological swale is studied from the aspect of quantity control in the effectiveness of flow attenuation. The operational functional Dry pond is studied in particular the capability dry pond to retain and drain storm water. Dry pond is an offline storage function to reduce peak discharge at the downstream. The storm water in the dry pond recedes by infiltrate through the layer of top soil and river sand to the storage module underneath and then flows downstream along the sub- surface module of the swale. The water level data from dry pond can be used to access the performance and effectiveness of the pond outlet, which infiltrate the water through sand layer to the modular sub-surface storage. The ecological pond
which is placed downstream of the catchments pond is a community facilities which include the wet pond and detention pond as a facility to control the storm water quantity, constructed wetland for water treatment device, wading river which connects wetland and recreational pond where the treated water flow into. The Ecological pond system is strategically placed at the downstream end of the BIOECODS to optimize and effectively attenuate and treat storm water runoff generated from the Engineering Campus development area. The behavior of BIOECODS was also simulated using of Storm Water Management Model. The simulation is emphasized on the impact of minor flood events on the drainage system. Hence, the basis of the evaluation is the frequent occurrence storm with a design duration and average recurrence interval of 60 min and 10 years, respectively.

Water quality monitored by two methods namely grabs sampling and automatic sampling method. Firstly, used a grab sampling method where sample of water taken from the upstream to the downstream of the catchment. Six parameters were tested in the laboratory for the samples taken on 26th July and 5th September 2002. Among the parameters tested were Dissolved Oxygen, pH, Suspended Solids, Chemical Oxygen Demand, Biological Oxygen Demand and Nitrates. The samples taken on 17 October were tested for the parameters recommended by Urban Drainage Manual for Malaysia. In-line sensing also is carried out to monitor the quality of water in Ecological pond. 15 minutes interval sampling with an-automatic sampling is carried out with 4 parameter i.e. pH, conductivity, temperature and dissolved oxygen.

Figure 6.0 shows an example a result of hydraulic performance of ecological swale type B for the surface and sub-surface swale for the rainfall event on 26 June 2003.

![Figure 6a Rainfall Depth on 26 June 2003](image)
Figure 6b Hydraulic Performance of Surface Swale

Figure 6c Hydraulic Performance of Sub-Surface Swale ecological swale type B
From the Figure 6.0, it has been observed that is a lag time between rainfall event and resulting flow from the surface and subsurface ecological swale. The catchments response time to rainfall is about 40 min give an indication that ecological swale has a capability to delay the flow to the downstream site. From figure 6b & 6c the hydrograph for the surface swale appears attenuated where the volume of the stormwater is distributed over 3-hour period. The hydrograph for sub-surface swale abruptly to zero.

Figure 7.0 shows water level which was measured using Ultrasonic Water Level at outlet of dry pond.

![Figure 7.0 Performances of Dry Pond](image)

Figure 7.0 shows the retention behavior of stormwater in the dry pond. The stormwater infiltrate and empty the dry pond over the period of seven hours. The emptying time is depends on the capacity of the adjacent ecological swale. The flow from the dry pond drains into the adjacent ecological swale will only take place when the water in the surface swale has completely drained into the ecopond. In this condition, water level in the sub-surface swale slowly recedes and provide the capacity for the flow from dry pond to sub-surface ecological swale.

Figure 8.0 and 9.0 show a result of flow hydrographs from the wet pond and detention pond for rainfall event on 30 April 2003.

![Figure 8.0 Rainfall hyetograph on 30 April 2003 Event](image)
From Figures 8 and 9.0, it was observed there is a lag time between rainfall events and resulting outflows from the wet pond and detention pond. Lag time between 45 min was recorded at this rainfall event. The difference between outflow hydrograph from the detention pond and wet pond showed flow attenuation due to the storage effects of the detention pond. Tables 1.0, 2.0 and 3.0 show the water quality results from the samples taken along BIOECODS site.

<table>
<thead>
<tr>
<th>Station</th>
<th>Parameter</th>
<th>pH</th>
<th>SS (mg/L)</th>
<th>DO (mg/L)</th>
<th>BOD (mg/L)</th>
<th>COD (mg/L)</th>
<th>NH3-N (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road</td>
<td></td>
<td>7.62</td>
<td>28.1</td>
<td>4.58</td>
<td>15</td>
<td>22.4</td>
<td>0.48</td>
</tr>
<tr>
<td>Perimeter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road</td>
<td></td>
<td>6.92</td>
<td>11.5</td>
<td>4.22</td>
<td>10</td>
<td>20</td>
<td>0.95</td>
</tr>
<tr>
<td>Perimeter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type B</td>
<td></td>
<td>6.6</td>
<td>6.9</td>
<td>4.39</td>
<td>8</td>
<td>11.7</td>
<td>0.14</td>
</tr>
<tr>
<td>Type C</td>
<td></td>
<td>6.5</td>
<td>4</td>
<td>5.78</td>
<td>3</td>
<td>13.7</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 9.0 Outflow Hydrographs from Detention and Wet Ponds
### Table 2.0 Water quality result 15 September 2003

<table>
<thead>
<tr>
<th>Station</th>
<th>Parameter</th>
<th>pH</th>
<th>SS (mg/l)</th>
<th>DO (mg/L)</th>
<th>BOD (mg/L)</th>
<th>COD (mg/L)</th>
<th>NH3-N (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perimeter Drain (Library)</td>
<td></td>
<td>6.16</td>
<td>2</td>
<td>6.5</td>
<td>10</td>
<td>15</td>
<td>0.5</td>
</tr>
<tr>
<td>Perimeter Drain (Student Centre)</td>
<td></td>
<td>5.81</td>
<td>2</td>
<td>6.5</td>
<td>7</td>
<td>10</td>
<td>0.32</td>
</tr>
<tr>
<td>Type B (Aero)</td>
<td></td>
<td>5.9</td>
<td>9</td>
<td>6.6</td>
<td>2</td>
<td>4</td>
<td>0.39</td>
</tr>
<tr>
<td>Outlet Type C</td>
<td></td>
<td>6.31</td>
<td>1</td>
<td>6.8</td>
<td>1</td>
<td>3</td>
<td>0.32</td>
</tr>
</tbody>
</table>

### Table 3.0 Water Quality Result 0n 17/10/2003

<table>
<thead>
<tr>
<th>Station</th>
<th>Parameter</th>
<th>pH</th>
<th>TS</th>
<th>Turbidity (NTU)</th>
<th>DO (mg/L)</th>
<th>COD (mg/L)</th>
<th>BOD (mg/L)</th>
<th>TKN (mg/L)</th>
<th>Nitrate (mg/L)</th>
<th>CU (mg/L)</th>
<th>Zn (mg/L)</th>
<th>Total Phospate (mg/L)</th>
<th>Phospate (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student Centre</td>
<td></td>
<td>6.13</td>
<td>84</td>
<td>17.7</td>
<td>7.95</td>
<td>20</td>
<td>13</td>
<td>0.7</td>
<td>0.5</td>
<td>0.229</td>
<td>0.035</td>
<td>0.22</td>
<td>0.01</td>
</tr>
<tr>
<td>Type B (school Mechanical)</td>
<td></td>
<td>6.7</td>
<td>80.5</td>
<td>44.9</td>
<td>7.45</td>
<td>78</td>
<td>16</td>
<td>0.9</td>
<td>0.6</td>
<td>0</td>
<td>0.043</td>
<td>0.16</td>
<td>0.05</td>
</tr>
<tr>
<td>Dry Pond H</td>
<td></td>
<td>7.2</td>
<td>59.5</td>
<td>17.75</td>
<td>7.3</td>
<td>17</td>
<td>13</td>
<td>0.6</td>
<td>0.2</td>
<td>0.013</td>
<td>0.065</td>
<td>0.39</td>
<td>0.05</td>
</tr>
<tr>
<td>Outlet Type B</td>
<td></td>
<td>6.3</td>
<td>64</td>
<td>9.39</td>
<td>7.4</td>
<td>12</td>
<td>15</td>
<td>0.1</td>
<td>0.1</td>
<td>0.001</td>
<td>0.053</td>
<td>0.14</td>
<td>0.0</td>
</tr>
<tr>
<td>Outlet Type C</td>
<td></td>
<td>6.08</td>
<td>61.5</td>
<td>5.9</td>
<td>7.65</td>
<td>30</td>
<td>7</td>
<td>0.2</td>
<td>0</td>
<td>0</td>
<td>0.004</td>
<td>0.03</td>
<td>0.0</td>
</tr>
</tbody>
</table>
From the water quality result, it was observed that water quality from the outlet type C; the most downstream of the catchments has a range of pH between 6.08 to 6.5. SS between 1-61.5 mg/l, DO from 5.78 to 7.65 mg/l, COD between 10.7 to 30 mg/l, BOD between 3-30 mg/l. This range falls under Class 11A standard classified by the DOE. The good water quality observed at the outlet type C give an indication that some purification occurs at the system. This data is further validated through the on-line measurement to monitor the water quality at the wet pond, detention pond and micro pool (Figure 10). Value of pH range from 6.5 to 7.5 also at the range of Class II A and the value of DO range 2-8 mg/l.

![Figure 10.0 Value of pH from On-line Water Quality Monitoring](image)

![Figure 11.0 Value of Dissolved Oxygen from on-line Water Quality Monitoring](image)
6.0 Conclusions

By optimizing the surface runoff at source through the provision of on-site facilities will reduce the peak runoff at the downstream area. Treatment of stormwater at the source will give a better water quality at the downstream area. Water quality of Standard Class II can be achieved if the new developments use the concept of sustainable urban drainage system.

7.0 Acknowledgements

The authors would like to thank the Drainage and Irrigation Department for the support in providing the research contract for this project.

References

CIRIA. (2000). Sustainable Urban Drainage System

HLA Associate & School of Civil Engineering USM. (1997). Laporan Penilaian Alam Sekitar bagi Cadangan Projek Kampus Cawangan (Kejuruteraan) di Transkrian, Nibong Tebal, Seberang Perai Selatan.