PEAK FLOW ATTENUATION USING DRY POND

By

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ABSTRACT

The conventional drainage system increases the storm water runoff and produced larger flow discharge at downstream and causing flash flood. This study shows the function and the effectiveness of the BIOECODS that use infiltration engineering, retaining, treatment, and reducing the flow in order to attenuate the peak flow as suggested in Manual Saliran Mesra Alam (MSMA). In other words, this new method is a new development that is very effective in storm water management using 'control at source' method. This study "Peak Attenuation Using Dry Pond" has been carried out to determine the effectiveness of dry pond, one of BIOECODS's components. Dry pond is calculated in terms of its capability to retain and drain the storm water. From this study it shows that the dry pond perform very well in retaining storm water runoff before draining into the storm water systems, therefore avoiding the occurrence of inundation at the downstream end. The emptying time for Dry Pond C and Dry Pond G is less than 24 hours. The infiltration and sieve analysis also performed to show the effectiveness of dry pond to infiltrate slowly to attenuate the peak flow at downstream. Lastly, hopefully this study may achieve its objectives.

ABSTRAK

Penambahan air aliran yang berpunca dari Sistem Saluran Konvensional boleh menyebabkan peningkatan aliran ke hilir dan seterusnya meningkatkan risiko berlaku banjir kilat. Kajian ini memaparkan penggunaan dan keberkesanan Sistem Saliran Bio-ekologikal (BIOECODS) yang bertujuan untuk menggunakan kombinasi pemyusupan, storan penahan, saluran serta perawatan dan melambatkan aliran seperti yang terkandung di dalam Manual Saliran Mesra Alam (MSMA). Dengan kata yang lain, kaedah baru ini merupakan satu kaedah alternative terbaru yang berkesan dalam pengurusan air larian ribut menggunakan konsep kawalan di punca. Kajian ini " Pengecilan Aliran Puncak menggunakan Kolam Takungan Kering" telah dilaksanakan bagi menentukan keberkesanan salah satu komponen BIOECODS iaitu Kolam Takungan kering dalam mengecilkan aliran puncak. Dalam kajian ini, Keputusan daripada ujian yang telah dijalankan menunjukkan bahawa penggunaan kolam takungan kering mampu untuk mengecilkan aliran puncak dan seterusnya mengelakkan risiko banjir kilat. Tempoh pengosongan untuk kedua-dua kolam takungan kering yang dikaji adalah kurang daripada 24 jam. Ujian Penyusupan dan Analisis Ayak juga dijalankan untuk membuktikan keberkesanan kolam takungan kering menyusup secara perlahan dan seterusnya mengecilkan aliran puncak Akhir sekali, diharap kajian ini dapat memenuhi objektifnya.

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INTRODUCTION

1.1 General

The effects of urbanization and the disadvantages of conventional drainage system have been well documented in the literature. Consequently, important result save highlighted here in as a background for subsequent discussion.

Rapid development has resulted in the increase in storm water runoff due to the corresponding increase in impermeable areas (Figure 1.1). Due to lack of permeable areas, most of the rainfall is transformed into surface runoff and increase the peak hydrograph after development and causing flash flood in urban areas.

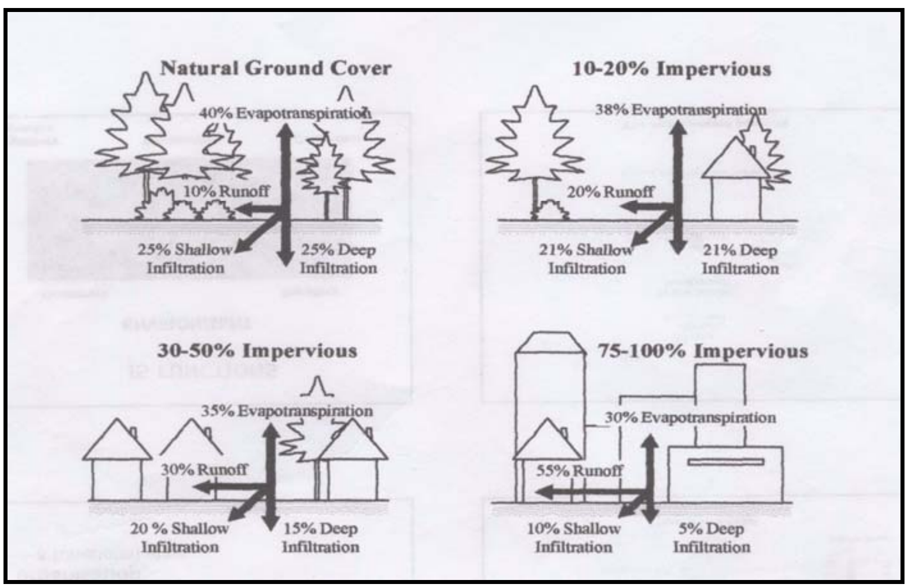


Figure 1.1: Effects of Impervious on Run off and Infiltration (Roesner et al, 2001)

Naturally, most of the rainfall soaks into the top soil and evapotranspirates or migrates slowly through the soil mantle as interflow to the stream, lake or estuary. But urbanization has affected the watershed. With urbanization, rainfall is rapidly collected from the roofs by gutters, and channeled to drains, which quickly and efficiently carries the water to the nearest river. Unfortunately, existing river section is insufficient to cope with this spillage of surface run off and consequently flooding and erosion occurs.

The traditional approach widely practiced in Malaysia to solving all these problems are by improving rivers and drainage system through widening, and channeling rivers and drains. In all but the most unavoidable cases, this curative approach has been found to generate other problems, besides being detrimental to the overall well being of the river. Therefore widely applicable alternatives are needed. Storm water management in urban areas needs to change from Rapid Disposal to Control at Source method. These methods 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.
- Are sympathetic to the environmental setting and the needs of the local community.
- Provide a habitat for wildlife in urban watercourses.
- Encourage natural groundwater recharge.

1.2 Bio-ecological Drainage System (BIOECODS)

The Bio-ecological Drainage Systems (BIOECODS) have been constructed in USM Engineering Campus, Nibong Tebal, Pulau Pinang. This system uses the control at source concept rather than the conventional drainage system. BIOECODS consists of structural BMPs facilities such as swale, dry pond and wet pond which are expected to have a capability to attenuate peak hydrograph and remove pollutant.

Dry pond is a multi-functional facilities blended with the landscape for optimum land use. The operational functions of a dry pond are evaluated in particular to the capability of the dry pond to retain and drain storm water. The capability of the dry pond to retain water can be used to attenuate peak flows. The design criteria of the dry pond are maximum period of surface water inundation is 24 hours and the maximum depth of water inundation around landscape area is 150mm. The dry pond is also potential to provide water quality benefits by removing pollutant. Dry pond is a detention pond, which has been connected to the ecological swale to temporarily store the runoff. The storage tank is placed below the detention pond by which the storm water is drained out by infiltration. The ecological swale is connected to the outflow path of the storage module, in order to drain the dry pond system.

The advantages of BIOECODS are:

- Peak hydrograph attenuation
- Increment of dissolved oxygen level
- Storm water runoff purification
- Alternative of water source for domestic use
- Re-augmentation of ground water
- Increasing aesthetic value to environmental via green landscape

1.3 The Objective of Study

The objectives of this study are to:

- Study the effectiveness and efficiency of dry pond to attenuate peak flow.
- Determine the emptying time for a dry pond on typical events.
- Determine the permeability of soil at selected dry pond.

1.4 Scope of the Study

These are the scopes of this study:

- Data Collection
  - Rainfall Data
  - Water Level Data
- Analysis Data to determine the emptying time for a dry pond
- Infiltration Tests and Sieve Analysis to determine the permeability of soil in studied area.

CHAPTER 2

LITERATURE REVIEW

2.1 Impact of Urbanization on Run off

In the 1990's, the Best Management Practices (BMPs), have been used more and more to control the pollution of urban runoff and protect the receiving waters to which the runoff drain. More recently some investigators [e.g. Maxted and Shaver (1997) and Schueler (1999)] have offered opinions that these BMPs do not protect the downstream aquatic environment. Schueler (1999) now argues that a different approach to management of urban runoff is required to protect urban streams. It is well known that urbanization significantly alters watershed hydrology in urban areas (ASCE, 1998). The effect of these hydrology changes on stream geomorphology and stream ecology can be severe especially in headwater streams. Many investigators have linked their studies of urbanization effects on stream ecology to percent impervious Maxted and Shaver (1997) and Booth and Reinelt (1993).

The urban development can cause the natural hydrology and infiltration characteristics of the previously rural catchments changes. Undeveloped land has very little surface runoff because most of the rainfall soaks into the topsoil and evapotranspirates or migrates slowly as ground water (Roesner et al, 2001). But due to development, most of the rainfall is transformed into surface runoff because most of the land covered over with impervious surfaces. Figure 2.1 shows that hydrograph after development is different from the hydrograph before development.

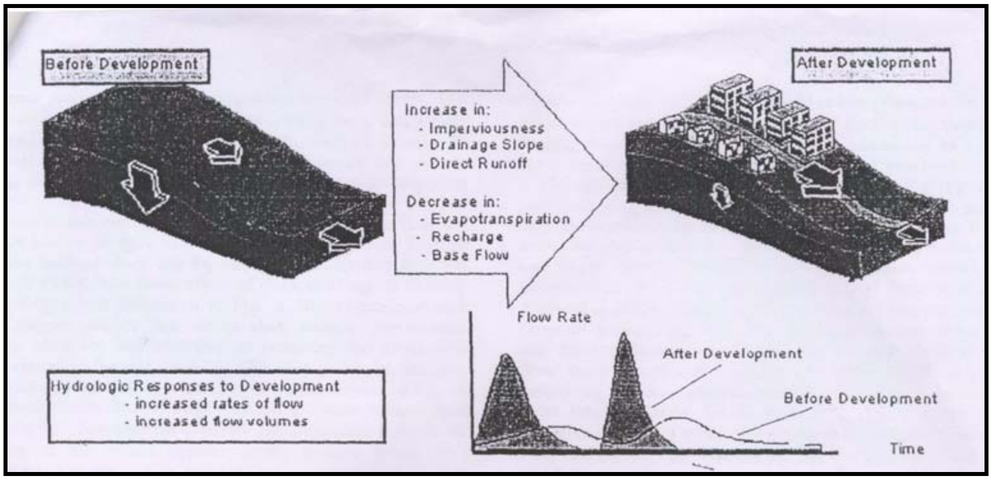


Figure 2.1: Urban Impact on Hydrology (Roesner et al, 2001)

Increased runoff can create flooding problems and increased peak discharge raises the flood plain level, flooding areas which were previously not at risk. The effects of urbanization on stream shape and the flood plain are illustrated in Figure 2.2.

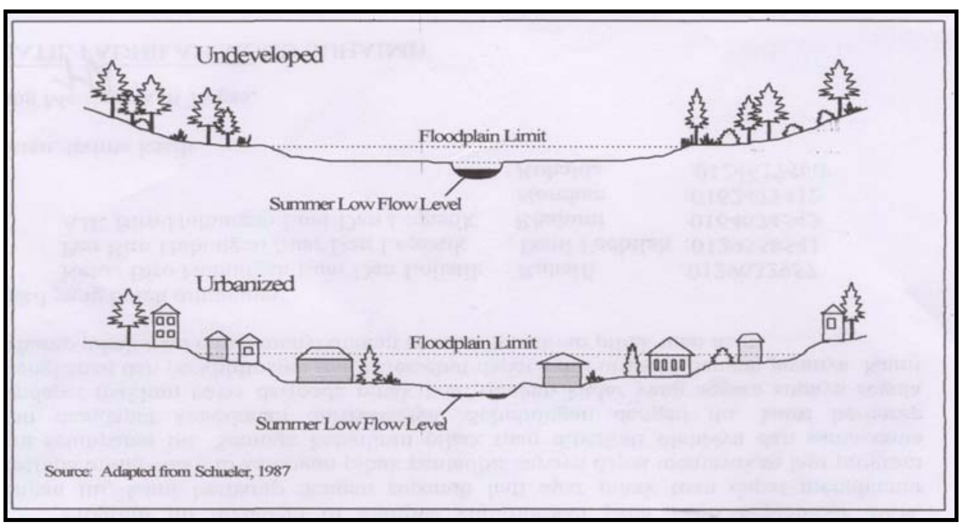


Figure 2.2: Effect of Urbanization on Stream Slope and Flooding (Schueler, 1987)

Urbanization can greatly accelerate the natural process of stream bank erosion. As the amount of impervious area increase, a greater volume of storm water with high velocity is discharged directly to receiving water. The increased volume and velocity of run off can overcome the natural carrying capacity of the stream network and thus create greater potential for stream bank erosion.

Urbanization has a major impact on ground water recharge. As shown earlier in Figure 1.1, due to development and urbanization, both swallow and deep infiltration decrease and increased ground water. This change in watershed hydrology alters the base flow contribution to stream flow, and it is most marked during dry periods. Beside that, the storm water pollution from non-point source due to urbanization and rapid development also decrease the quality of water.

2.2 Storm water Management Solution

The urbanization has produced various problems regarding the storm water runoff, such as increase in storm water flow discharges into receiving waters, increase in flood peaks and degradation of the runoff water quality. As the urban area continue to develop, these problems become more severe and cost- options for treating problems (Barber et al, 2003).

In Malaysia, Department of Irrigation and Drainage (DID) is taking a proactive step by launching of Urban Storm Water Management Manual for Malaysia (Manual Saliran Mesra Alam or MSMA) to solve those entire problems. MSMA emphasizes the implementation of the concept of BMPs, example, wet pond, wetlands, sand filter, dry ponds and grass swales (DID, 2000). Effectiveness of a BMPs component is highly dependent on its design characteristics which influence the detention time and hence treatment efficiency (Yu et al, 2001).

For example, in Roanoke County, Virginia, WA was shaped by the need to improve water quality and reduce flood damage using Storm water Management Facility. An extended detention basin, enhanced by a fore bay and downstream riparian buffer, best serves the existing and anticipated 2020 development scenarios for mitigating flooding and controlling the pollutant loads in Mud Lick Creek. This facility will not only reduce the increase in post-developed storm flows in Mud Lick Creek by as much as 101% (in two-year events), but its pollutant-reduction features will also benefit the health of the Roanoke River, a 303(d)-listed river.

2.3 Storm water Quantity Control

Storm water best management practices (BMPs) have a major impact on stormwater runoff quantity. The increased magnitude and frequency of flow peak can cause severe stream channel erosion and increased flooding at downstream. The most common effects are the physical damage of natural stream channels. The higher frequency of peak flows can cause the stream to cut a deeper and wider channel (Roesner et al, 2001) and destroying the aquatic habitat. Conventional drainage system unfortunately has to lead to increase the occurrence of flash flood at the downstream of the catchments.

Additionally, open drainage invites more polluted to the river and worsened the quality of life in urban area. Therefore conventional drainage is no longer an effective measure in solving flood. Therefore, Department of Irrigation and Drainage (DID) Malaysia is taking a proactive step by introducing the MSMA. The new guideline that required the application of BMPs will help to control storm water and runoff to achieve zero development impact contribution. These concepts of BMP will be able to preserve the natural river flow carrying capacity.

BMPs provide ground water recharge, control peak storm water flows and protect against erosion. The advantages of storm water best management practices (BMPs) compared to conventional method is that in areas with a high percentage of impervious surfaces, infiltration is one of the few means to provide significant groundwater recharge. A source control approach for storm water management was implemented to reduce runoff rate, runoff volume and which include component namely dry pond.

2.3.1 Dry pond

A dry pond is an impoundment formed by constructing a dam or embankment or by a combination of excavation and an embankment with an outlet structure to detain surface runoff for periods of generally around 24 to 30 hours. The primary objective of an extended dry pond is to attenuate peak flows, which is accomplished by regulating the outflow peak discharge and storing flood volumes within the dry pond. An emergency spillway is designed to pass extreme events to protect the embankment and dam from damage. Dry pond can also be designed to provide water quality benefits by removing pollutants attached to settle able particulates.

Generally, an extended detention pond is dry between storms. However, many storm water ponds provide peak flow attenuation only, and generally are not designed to provide water quality control. The storm water in the dry pond recedes by infiltrating through the layer of topsoil and river sand to the storage module underneath and then flow downstream along the sub-surface module of the swale. The cross section of a dry pond is illustrated in Figure 2.3. The flow from the dry pond drains into the adjacent ecological swales when the water in the surface swale is completely drained into the ecological pond.

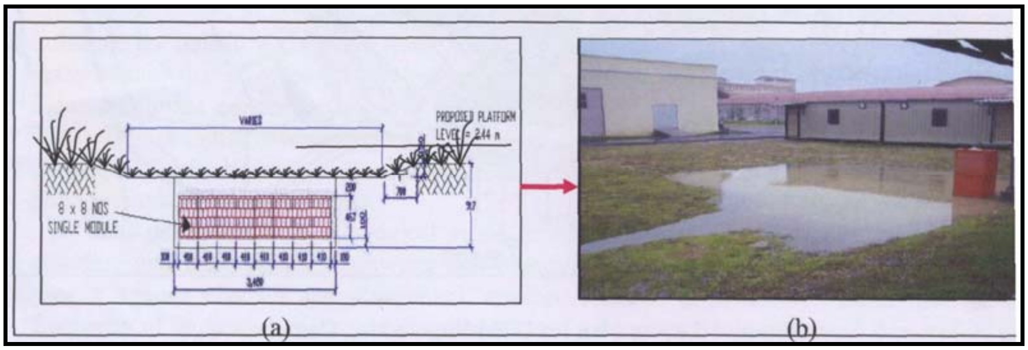


Figure 2.3: Dry Pond (a) Cross section (b) View of dry pond during rainfall event

2.4 Previous Study

Generally, there are many studies that have been completed that have assessed the ability of storm water treatment BMPs to reduce pollutant concentrations and loadings in storm water system discharges (Stercker et al., 2001). But it is also essential to identify the effectiveness of the BMPs from the aspect of quantity. This study is the continuity of the previous study conducted by Zakaria et al.

The previous study is conducted at USM Engineering Campus, Penang, Malaysia. This campus applied The Bio-Ecological Drainage System (BIOECODS) that implemented BMPs concept. The result from the previous study is summarizing in Table 2.1 for the effectiveness of the ecological swale in this campus based on the percentage of reduction in peak flow or volume and it is calculated based on the differences between the inflow and outflow over inflow.

Table 2.1: Flow Attenuation for ecological Swale (June – November 2003) (Zakaria et al., 2004a)

Rain events (2003)	Rainfall Intensity (mm/hr)	ARI	Location Channel	Peak Flow (l/s)		Volume (m^3)		Percentage Reduction (%)	
				inlet	outlet	inlet	outlet	Peak flow	Vol-ume
24/6	11	3 month	Surface	128	91	418.5	246.6	28.9	41.1
			Subsurface	79	32	134.1	16.2	59.5	87.9
26/6	31.6	6 month	Surface	45	22	105.6	31.2	51.1	70.5
			Subsurface	53	53	53.1	31.2	0	41.2
30/8	14.5	3 month	Surface	59	26	388.8	123.6	55.9	66.6
			Subsurface	41	50	119.1	90.9	0	23.7
8/9	13.8	5 year	Surface	59	26	4043.1	3043.2	55.9	24.1
			Subsurface	70	51	160.2	83.1	27.1	48.1
4/10	6.18	2 year	Surface	201	167	2202.9	1560	16.9	29.2
10/10	33.6	2 year	Surface	226	168	1711.8	1380.3	25.7	19.4
3/11	44.2	1 year	Surface	172	120	1134.6	599.4	30.2	47.2
			Subsurface	41	23	108.9	11.7	43.9	89.2
8/11	9.3	6 month	Surface	115	75	607.8	357.9	34.8	41.1

From Table 2.1, the percentage of volume reduction for surface channel is between 19.4% and 69.8%. For the subsurface channel, the percentage of volume reduction is 23.7% and 89.2%. For surface swale the reduction in peak flow is range from 28.9% to 55.9% and about 0% to 59.5% for subsurface channel. This result shows that a BMPs component namely ecological swale can attenuate the peak flow and volume.

And the catchments response time to rainfall is about 40 minutes that is giving an indication that ecological swale has a capability to delay the flow to the downstream site as shown on Figure 2.4.

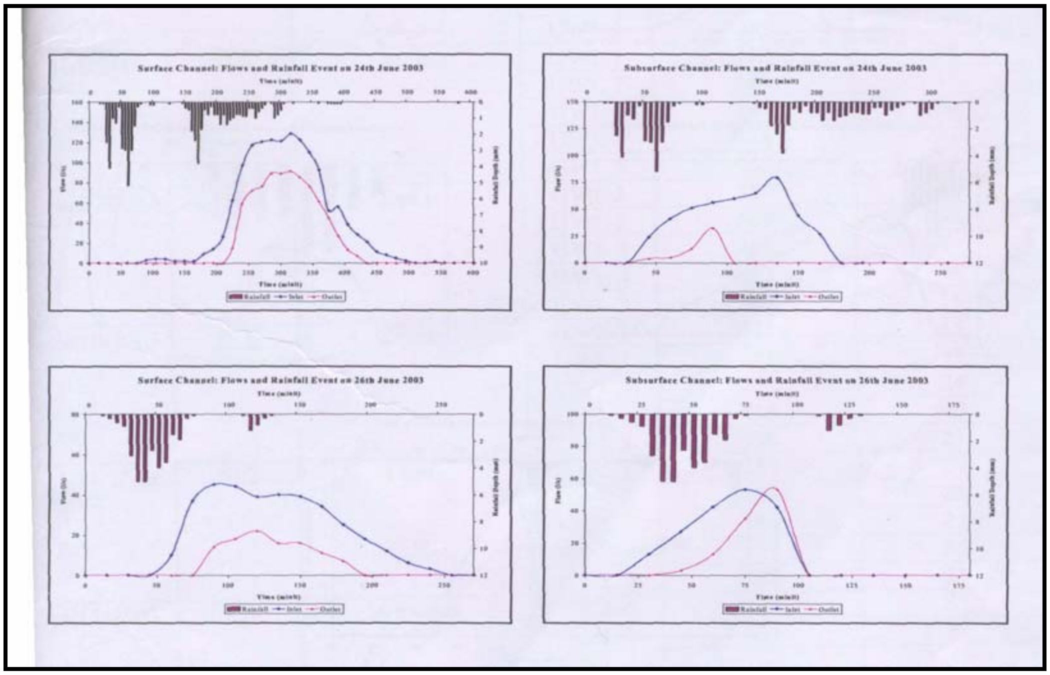


Figure 2.4: Inflow and Outflow Hydrograph for typical rainfall events (Zakaria et al, 2004a)

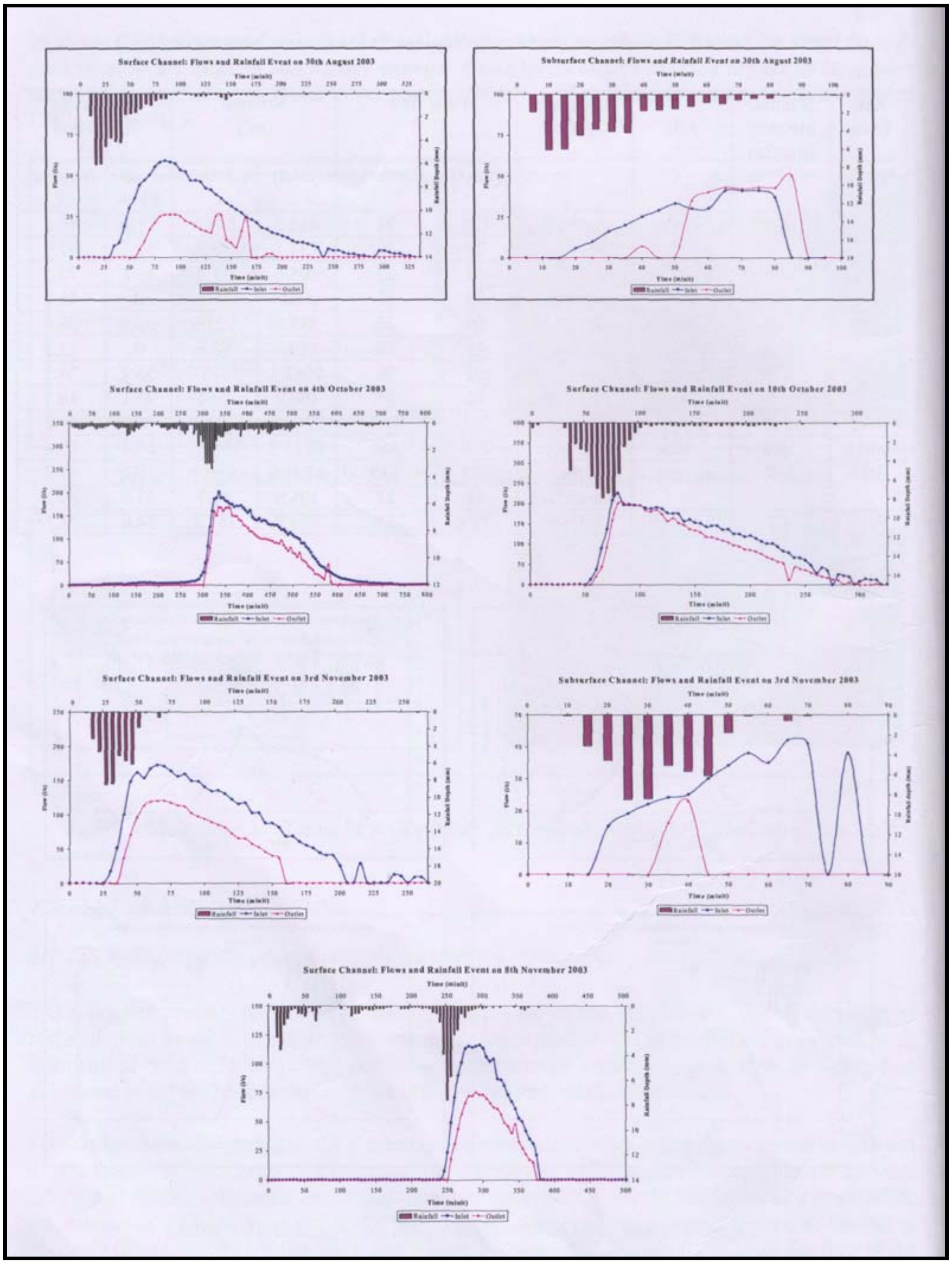


Figure 2.4: Inflow and Outflow Hydrograph for typical rainfall events (Zakaria et al, 2004a) (Continued)

The previous study also studied about the retention behavior of the dry ponds. The water level of 5 selected dry ponds, which are labeled as UWL 1 to UWL 5, on six typical rainfall events, were present in Figure 2.5. The water level at each dry pond outlet was measure using the Ultrasonic Water Level sensor, to represent the retention behavior of dry pond. Table 2.2 showed the water level data.

From Table 2.2, it shows that the empting time of a dry pond depending on the Average Recurrence Interval (ARI).The empting time for dry pond UWL 1 for the rainfall event on 8th of September 2003 with 5 year ARI is 48 hours and 26 hours is needed to empty the dry pond for rainfall event with 3 month ARI on 30th of August 2003. The result showed that the higher ARI of a rainfall event, the longer time is needed to empting the dry pond.

Table 2.2: Performance of dry pond (June-November 2003) (Zakaria et al, 2004a)

Rainfall Event	Rainfall Intensity (mm/hr)	Average Recurrence Interval (ARI)	Location Dry Pond	Maximum Water Level at outlet (mm)	Empting Time (hour)
17/6/2003	35.7	6 month	UWL 1	131	6
			UWL 2	560	16
			UWL 3	73	5
			UWL 4	429	19
			UWL 5	203	7
30/8/2003	14.5	3 month	UWL 1	210	26
			UWL 2	388	17
			UWL 3	144	20
			UWL 4	476	31
			UWL 5	268	15
8/9/2003	13.8	5 month	UWL 1	357	48
			UWL 2	669	36
			UWL 3	266	34
			UWL 4	511	44
			UWL 5	373	28
10/10/2003	33.6	2 month	UWL 1	321	45
			UWL 2	661	31
			UWL 3	242	24
			UWL 4	526	40
			UWL 5	356	21
3/11/2003	44.2	1 month	UWL 1	247	27
			UWL 2	505	25
			UWL 3	164	25
			UWL 4	503	36
			UWL 5	322	21
8/11/2003	8.3	6 month	UWL 1	240	33
			UWL 2	531	37
			UWL 3	169	30
			UWL 4	497	43
			UWL 5	300	22

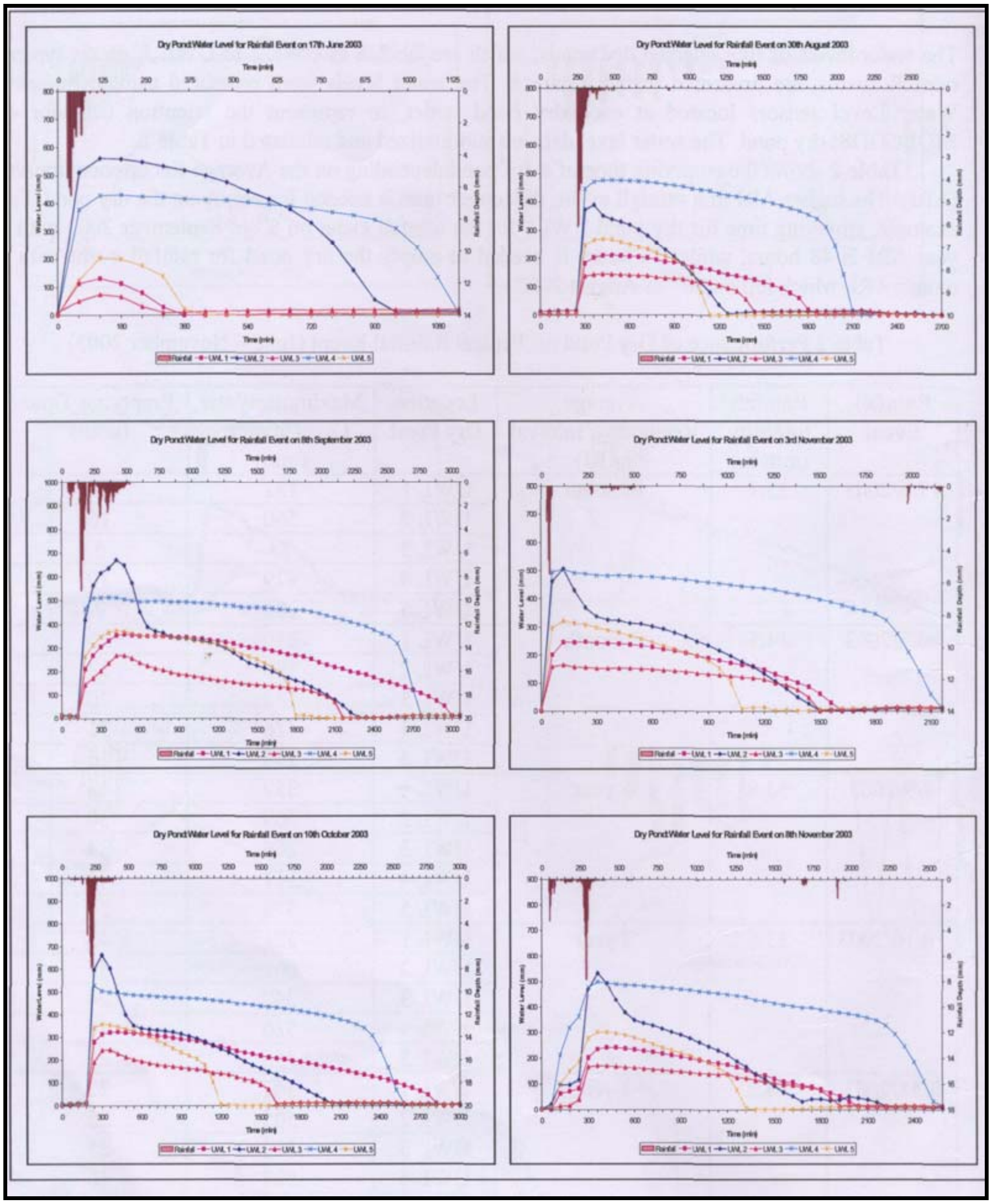


Figure 2.5: Water Level outlets of UWL 1 to UWL 5 on Typical Rainfall Events (Zakaria et al, 2004a)

Other study that shows that extended pond is effective in attenuating peak flow is conducted in Fort Collins, Colorado, USA. The result of Nehrke and Roesner (2002) study is shown in Figure 2.6. As seen from Figure 2.6 the BMP provides excellent control for small storms. In Colorado storms producing run off volume less than that of the BMP are effectively drawn back towards predevelopment levels. The BMP overtops at flows greater than 0.012 m^3/s, and this evidenced by the sharp increase in peak flows associated with storms occurring less than four times per year.

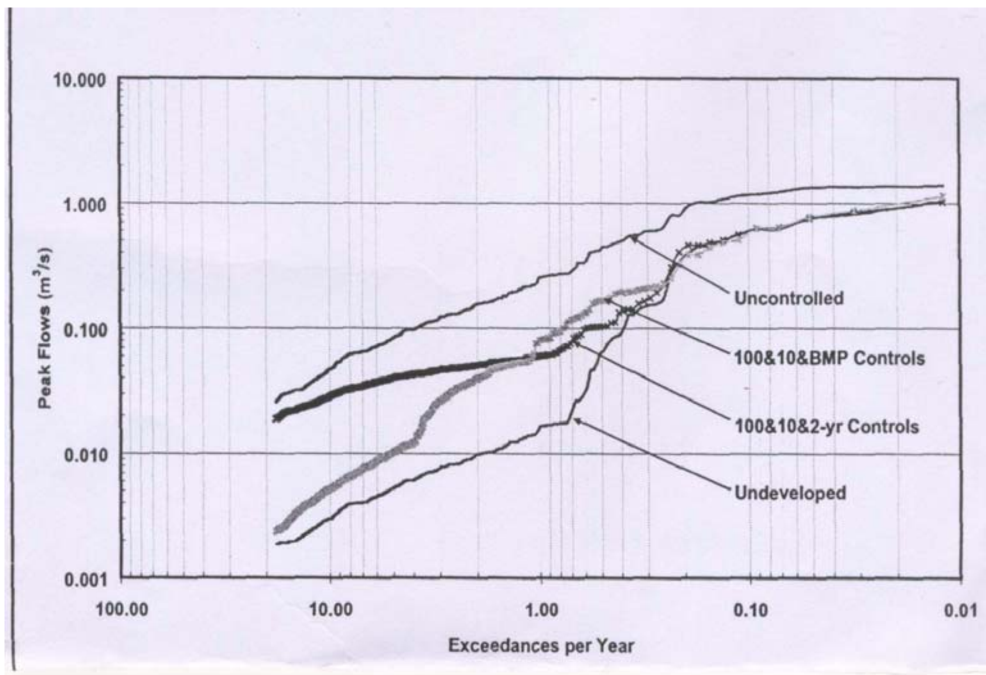


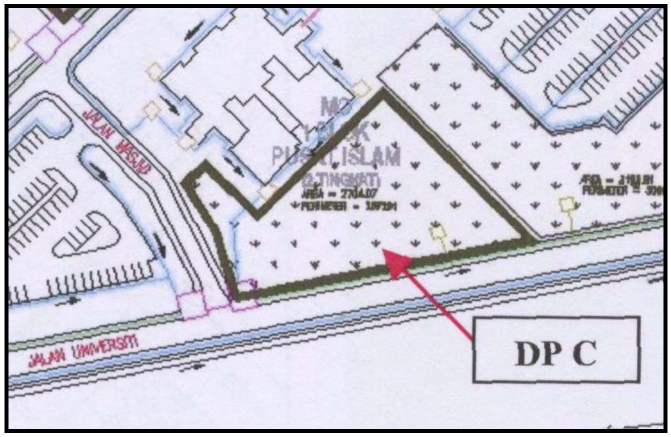
Figure 2.6: Effect of detention and extended detention basins in Fort Collins, Colorado (Nehrke and Roesner, 2002)

CHAPTER 3

METHODOLOGY

3.1 Location of study

This study was performed at USM Engineering Campus, Nibong Tebal, Pulau Pinang as depicted in Figure 3.1 and Figure 3.2. This 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 selected dry ponds for this study were labeled as Dry Pond C and Dry Pond G. Water level at five points was measured manually over the landscape area of the dry ponds. Automatic measurement was made using Ultrasonic Water Level sensors located at each dry pond outlet, to represent the retention behavior of BIOECODS's dry pond.



(a)

(b)

(c)

Figure 3.1: Selected Dry Pond C, DP C: (a) Site Plan; (b) View of Dry Pond C during rainfall event and (c) during dry period.

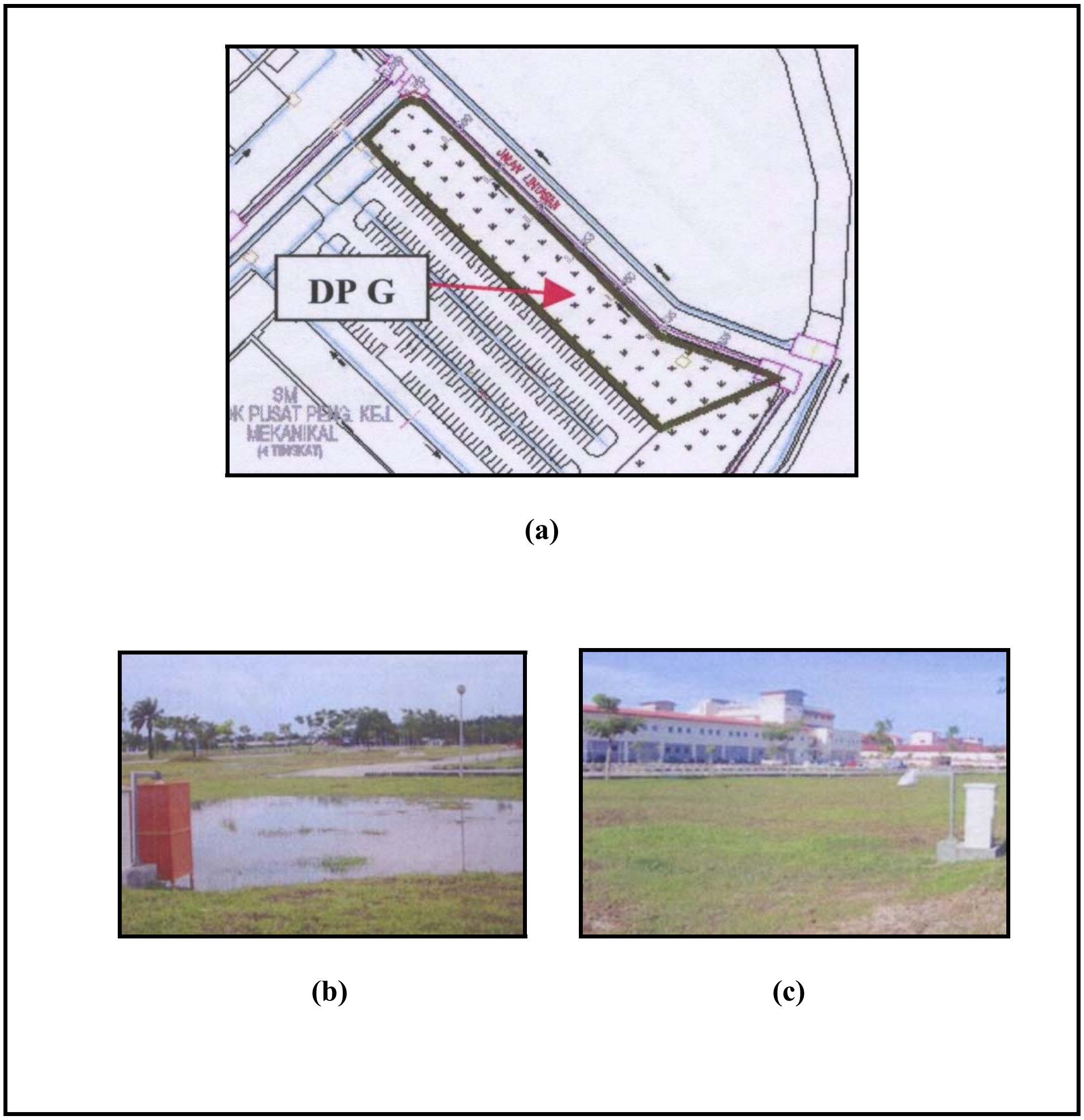
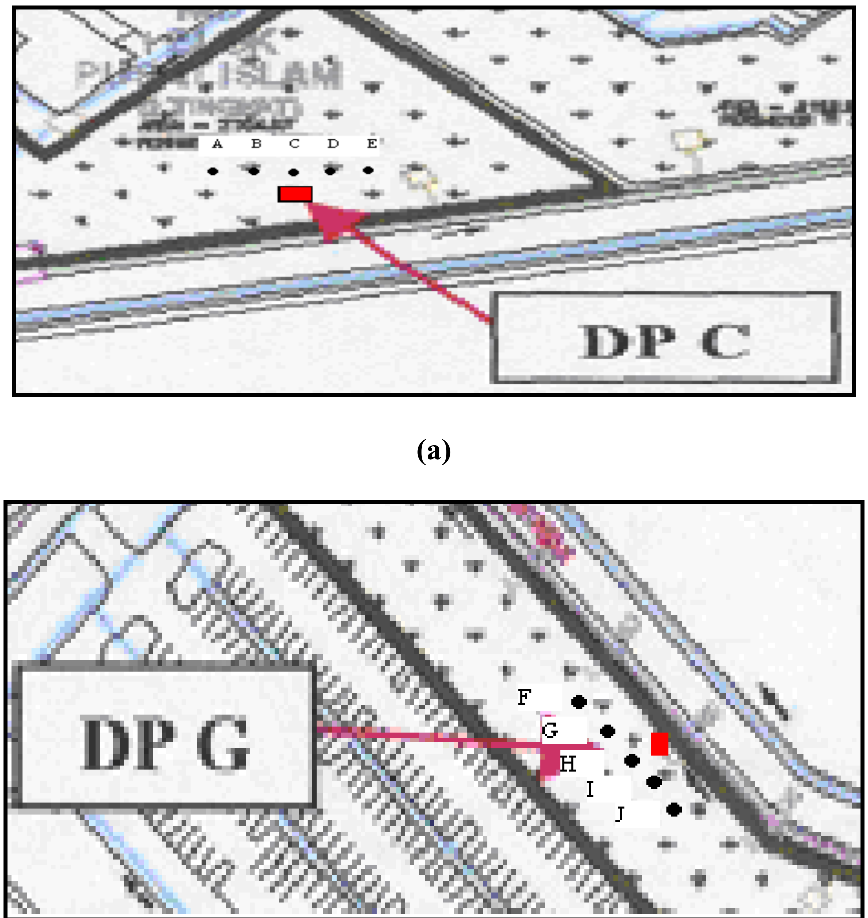


Figure 3.2: Selected Dry Pond G, DP G: (a) Site Plan; (b) View of Dry Pond G during rainfall event and (c) during dry period.

3.2 Data Collection

Five points (Figure 3.3) were identified at the landscape area of each dry pond. Water level was measured manually using measuring tape at each point. The distance between each point was 1 meters. The Water Level was measured with interval time 30 minutes. The Water Level at Dry Pond C and Dry Pond G was also measured using ISCO 4110 Ultrasonic Water Level Logger (Figure3.4).



(b)

Figure 3.3: Sampling Points (a) Dry Pond C; (b) Dry Pond G

Figure 3.4: ISCO 4110 Ultrasonic Water Level Logger

3.3 Soil Permeability Tests

Two tests have done in order to determine the permeability of soils at the selected dry pond. The two tests are to:

i. Infiltration Test

ii. Sieve Analysis Test

3.3.1 Field Infiltration Test

Infiltration test was done using double-ring infiltrometer (Figure 3.5) to get the Infiltration Rate and the Infiltration Curve. The Infiltration Rate is the velocity or speed at which water enters into the soil. The Infiltration rate depends on soil textures (the size of the soil particles) and soil structure.

Figure 3.5: Double-ring infiltrometer

<u>Field Infiltration Test Method:</u>

a) Before start doing test, prepare all the required equipment such as double-ring infiltrometer set, rubber hammer and clock time to make sure the test will be properly done without interfere.

b) Hammer the inner ring (30 cm diameter ring) 55 mm into the soil and hammer the outside ring (60 cm ring) 50 mm into the soil to prevent a lateral spread of water from the infiltrometer.

c) Start the test by pouring water into the inner and outside ring until it is full.

d) After record the initial reading, then start clock time and next reading will continuously recorded the reading with time interval 1-2 minutes depend on the soil type.

e) The reading is recorded based on the water level on the measuring rod in the inner ring.

f) For soils with low permeability rate, take time interval about 30 minutes for each reading because it takes time to infiltrate.

g) Continue recording the reading until the water levels that have poured reach the water level at the outside ring.

h) For soils with high permeability rate, water can be added during process to make sure the continuous reading happen.

i) Finally, graph infiltration rate versus time is plotted to get the infiltration curve and to determine the infiltration condition for the selected dry pond.

3.3.2 Sieve Analysis Test

Sieve Analysis is done in order to evaluate the soil textures (the size of the soil particles) and soil structure at the selected dry pond. It is done using a set of sieves with different sizes according to BS: 1337 sieve sizes (Figure 3.6).

Figure 3.6: Set of Sieves with different sizes