THE USE OF A MICRO–INTERACTIVE MODEL FOR THE DESIGN & SIMULATION OF STORMWATER DRAINAGE SYSTEMS UNDER TROPICAL CLIMATE

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ABSTRACT

The rapidly growth of development in the urban areas has caused the imbalance of the stormwater management in Malaysia. As natural areas are built up and paved over by urbanization, the infiltration of rainfall into the ground is reduced and stormwater flows are quickly generated. The present "Conveyance-Oriented Approach" practice, which is to quickly dispose the storm water from urban areas into rivers, has lead to downstream flooding in major cities. With the newly implementation of Urban Stormwater Management Manual for Malaysia (MSMA), this rapid disposal method is being replaced with a new integrated approach known as Storage-Oriented Approach. This approach takes into account of quantity, quality and amenity unlike the Conveyance-Oriented Approach which only focusing on quantity control.

The Storage-Oriented Approach has guide towards an innovative Sustainable Urban Drainage Systems (SUDS) in the country. Bio-Ecological Drainage System (BIOECODS) which comprises swales, underground detention, dry ponds and wetlands have successfully controls the volume of runoff and improves water quality by storage and biofiltration, before the water flow into the rivers. This new system has been implemented at pilot study area at Engineering Campus of Universiti Sains Malaysia, Pulau Pinang.

In an effort to improve the effectiveness of this system, several of simulation has been conducted. This paper focuses on the design, analysis and simulation of the BIOECODS by using Micro-Interactive Design of Urban Stormwater Systems model (MIDUSS 98). This software provides a decision support system for drainage engineers involved in the design of stormwater management facilities. Runoff modelling is versatile and involves a variety of methods for storm description, rainfall loss estimation and overland flow routing.

In view of the fact that MIDUSS 98 is one of the economical programs to simulate rainfall-runoff, this programs model is adaptable to runoff simulation, which provides a decision guide for sizing conveyance, detention and groundwater recharge elements in the drainage network of a stormwater management system. The modeling results have shown attenuation of the runoff generated from the developed area using BIOECODS.

Keyword: Stormwater Management; Bio-ecological Swale; MIDUSS 98; Detention Storage; Design; On-site Controls; Urban Hydrology

INTRODUCTION

As a result of urbanization, stormwater runoff flow rates and volumes are significantly increased due to increased impervious land cover and the decreased availability of depression storage. These increased flows are conveyed to natural watercourses, which are not adapted to the larger runoff events and their increased frequency of occurrence. The resulting effects are increased frequency of flooding occurring downstream of urban drainage systems as well as the increased potential for stream bank erosion due to high flow velocities, which can degrade water quality in general and contribute to drastic changes in streambed. Moreover, increased flow rates and changes in streambed threaten the ecosystem of the receiving waters. This effect is amplified if the stormwater runoff is itself polluted. It is also noted that the large percentage of impervious surfaces such as roads, parking lots, roof and etc. in an urban landscape contributes to another form of pollution (Mohd Sidek et al, 2002).

Traditionally, stormwater management for most developments and local councils has meant collecting runoff into an open concrete drain and then conveying the concentrated flows away from the site. Over a century of this design philosophy has had impacts on watersheds in developed areas such as downstream flooding and pollution. The severity and frequency of flooding increases with traditional stormwater management because the volume of runoff is concentrated and because the time it takes the storm flows to reach a waterway is significantly decreased. In addition, stormwater runoff can be contaminated by sediments and other pollutants, which can accumulate and degrade water quality in downstream areas. Pollutants can come from a variety of sources such as roadways, residential housing, and agriculture and can include sediments, fertilizers, petroleum products and heavy metals.

Recently, the non-traditional approach to the management of stormwater is based on a philosophy of minimizing the impacts of stormwater runoff and reducing non-point sources of water pollution by minimizing the generation of stormwater runoff at the source areas and by implementing best management practices to reduce the impacts of pollutants may have in any stormwater runoff generated. Specific implications of this philosophy include emphasis on source controls in Stormwater Management, transition from traditional “hard” infrastructures (drain pipes) to green infrastructures and needs for infrastructure maintenance and rehabilitation. Stormwater management extends beyond just remedial technologies by combining technology, environmental policies and public participation. An integrated approach to stormwater management needs to begin with each development prior to concentration and discharge of stormwater off-site. Management of stormwater on-site or “control-at source” approach will minimize the risk of flooding by minimizing the volume and peak of runoff and reducing non-point source water pollution in the watershed through more environmentally-friendly and more sustainable drainage systems.

Stormwater Management is applied through specific measures, which are arranged in certain sequences (called treatment trains). Various terminologies were developed for such measures, including Best Management Practices (BMPs) in the USA, Alternative Techniques (AT) in France or, more recently, Sustainable Urban Drainage Systems (SUDS) in the UK (McKissock et al., 2001). There are many kinds of sustainable drainage systems in the world such as Howland swale, bio-retention, bio-filter and other drainage systems with the objectives to convey, slow down the runoff and reduce the pollution problems. One of the kind sustainable urban drainage systems is the Bio-Ecological Drainage Systems (BIOECODS) to manage the runoff in a very sustainable way by combining the conveyance, storage, infiltration and purification. The BIOECODS is the example of local 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. Surface water drainage methods that take account of quantity, quality and amenity issues are collectively referred to as BIOECODS. 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 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 (Mohd Sidek et. al, 2002).

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. Therefore, it is very important to carry out simulation study of the existing BIOECODS using existing available software such as MIDUSS’98 and XP-SWMM to simulate the performance of the systems under different type of rainfall intensity.

This paper reports on the modelling of a Bio-Ecological Drainage Systems (BIOECODS) at Engineering Campus, Universiti Sains Malaysia, Penang. A computer model was developed to simulate outflow from the BIOECODS using the Stormwater Software Package MIDUSS98. MIDUSS’98 combines runoff simulation with a set of design tools which serves as a decision support system package for sizing conveyance; detention and groundwater recharge elements in the drainage network of a stormwater management scheme. BIOECODS was simulated using the simulation of rainfall based on single event on a catchment with known physical properties. This allows the designer to estimate the response of the drainage systems to a historic or hypothetical rainfall. If the catchment is to be modified to represent construction or modification of some facility for stormwater management, successive runs of the simulation model allow design modifications to be made and tested on trial and error basis.

SITE DESCRIPTION

The site is located at Universiti Sains Malaysia (USM) Engineering Campus in Mukim 9 of the Seberang Perai Selatan District, Pulau Pinang. It lies at about latitudes 100º 29.5’ South and 100º 30.3 North and between longitudes 5º 9.4’ East and 5º 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 USM Engineering Campus 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 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 stormwater before it leaves the campus. Some roads are drained into large swales which provide attenuation of run-off and enhanced treatment prior to convergency to the community treatment facilities. This system was designed to combine infiltration, delayed flow, storage and purification as pre-treatment of stormwater before discharging to the 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, this increase runoff lags time, increase opportunities for pollutant removal through settling and biofiltration, and reduce the rate and volume of runoff through enhanced infiltration opportunities (Mohd Sidek et. al., 1997).

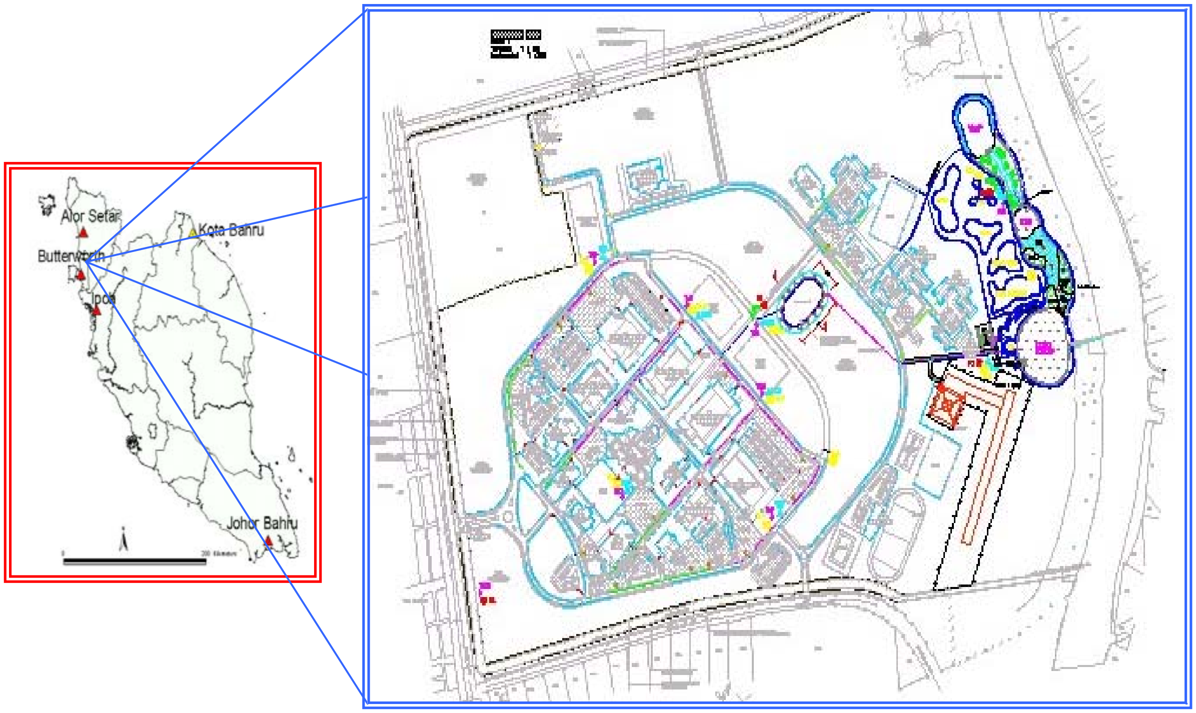

Figure 1.0 – Pilot study area at USM Engineering Campus

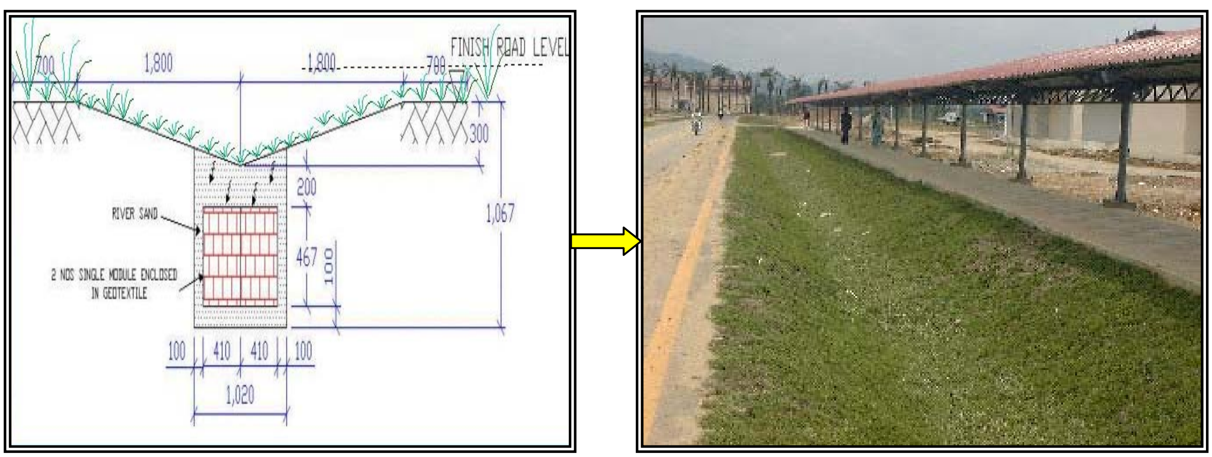

Figure 2.0: BIOECODS cross section and the completed BIOECODS

THE STORMWATER MODELLING PROGRAM MIDUSS98

The MIDUSS 98 program is an interactive computer simulation and urban stormwater drainage design program. It has been designed to be user-friendly with the simulation and design module integrated within a single program. Figure 3.0 shows the position of MIDUSS in relation to a number of similar type computer programs in the market.

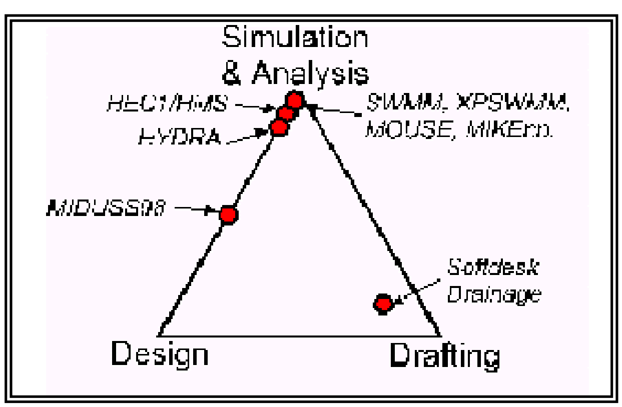

Figure 3.0 – MIDUSS 98 in relation to similar type computer programs (Smith, 2001)

MIDUSS has a "Design Storm" module to compute the design storms used to generate the runoff hydrographs from a catchment. The runoff hydrographs are generated from the "Hydrology/Catchment" module of the program using the inputs from the "Design Storm" module. The runoff hydrographs are then used by the "Design" Module to compute for the size of the chosen urban stormwater management facility. The following are the facilities available in the "Design" module:

- Pipes (part full or surcharged)
- Channels (trapezoidal or up to 50 points complex cross-section)
- Pond (4 types)
- Diversion
- Exfiltration trench

The MIDUSS "Design Storm" module has a customized Malaysia storm estimation module. Figure 4.0 shows a customized Malaysia "Design Storm" module. The estimation of the design storm and temporal rainfall patterns for any storm in Malaysia can easily be calculated using the commands in the customized module.

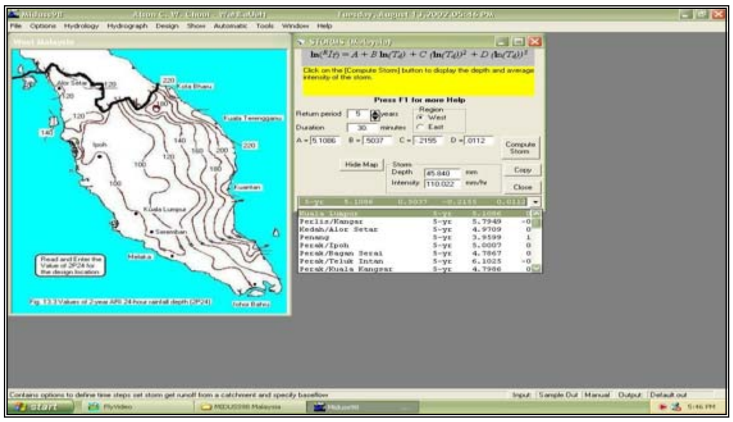

Figure 4.0: Customized Malaysia Design Storm in MIDUSS98

The application of MIDUSS 98 has been developed over many years of professional practice and most recently application in Belleville, Ontario to 400ha catchment to assign cost sharing among two municipalities (Smith, 2001). The introduction of the new Urban Stormwater Drainage Design Manual for Malaysia (DID, 2001) requires drainage engineers in Malaysia to have a paradigm shift in their approach to urban stormwater drainage design. Instead of using the simple, manual-based, rational method equation, the Manual requires the engineers to use computers in their analysis in order to increase their productivity and thus stay competitive in the market place. MIDUSS 98 will able to help the drainage engineers in Malaysia meet the new 2001 DID Manual requirements, in particular in achieving Best Management Practice in stormwater management.

RESULTS AND DISCUSSIONS

Input Data for Sub Catchment Node

This research will cover the total area approximately of 320 hectares at USM, Pulau Pinang. As for that, the catchments area has been divided into 80 sub catchments areas where represented as node. The total catchment area is subdivided into a series of sub catchments, each of which generates an overland flow or runoff hydrograph. The hydrograph is assumed to enter the drainage network at a particular point or node associated with the sub-catchment. The drainage network is assumed to be a tree so that each node can have any number of inflow links but only one outflow link. For this reason, each link is given the same number as the node at its upstream end. These sub-catchments are processed in order, starting at the upstream limit of drainage branches and working in the downstream direction as shown in Figure 5.0.

Input Data for Swales Link

As the sub catchment has been defined, BIOECODS is used as a functional of link where connecting all this sub catchment or nodes. Principally, there are four types of grass swales are been utilized namely Type A, Type B, Type C and Perimeter swales. In the perspective view of promoting the Best Management Practice (BMP), all the parameters are determined to fulfill in accordance to the Manual Saliran Mesra Alam (MSMA). At this point, the input parameter measure are been categorized into two approaches. This is inclusive of the Hydrology mode which consists of numerous Sub Catchment function as node. Then, follow with the Hydraulic mode which is consisting of various types of swales where functional as link to each node.

Parameters Used for Sub Catchment Node

The Sub Catchment Node which play the role as Hydrology mode take into consideration of rainfall, define time parameters, storm design and catchment command. In this study, the rainfall parameter is defined to cater minor storm system with 10 years average recurrence interval and time interval of 60 minutes. The range of storm length and hydrograph is to be assumed maximum at 180 minutes and 1500 minutes respectively. Given that the MIDUSS 98 permitted to the design storm using Malaysian Polynomial Approximation of IDF Curves, the coefficients for IDF equation of Bagan Serai, Perak has been employed as this station is the nearest to the study area. In the catchment command section, Linear Reservoir Routing Method is used to determine the Inflow and Outflow Hydrograph and Horton equation was employed to determine the infiltration development. The schematic diagram for the nodes and link for this project can be seen in Figure 5.0. Meanwhile, the parameters used for Sub Catchment Node can be referred in Table 1.0.

Parameters Used for Swales Link

The determination of swales size design needs to take into consideration of the basewidth of the swales. This is to harmonize the size of the geostrip or module below the swales to encourage better results of infiltration rate. For the swale to perform adequately as a biofilter, the basewidth with the range 0.6m ≤ b ≤ 3.0m design criteria are recommended (DID, 2001). Table 2.0 shows the detail parameters used for swales link.

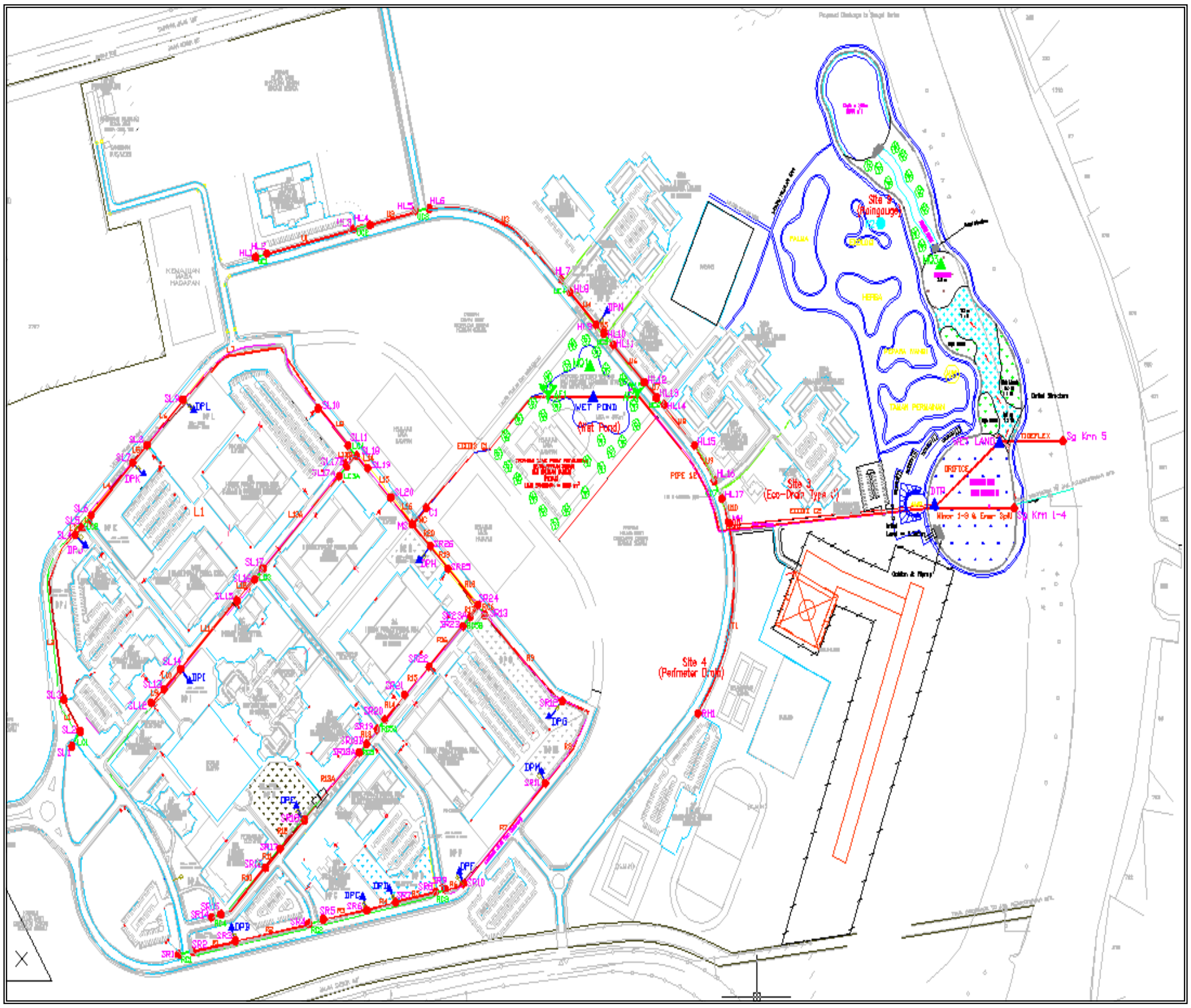

Figure 5.0: Schematic Layout of Sub Catchment Nodes and Swales Links at USM, Pulau Pinang.

Table 1.0 – Parameter used for Sub Catchment

NO	CONSIDERATION	LIMITATION	REMARKS
1.	<u>Rainfall</u> Average Recurrence Interval, ARI Time Interval	 10 years 60 minutes	 Minor Storm
2.	<u>Time Parameters</u> Time Step Maximum Storm Length Maximum Hydrograph	 5 minutes 180 minutes 1500 minutes	
3.	<u>Design Storm</u> Malaysian Polynomial Approximation of IDF Curves (Coefficients for IDF equations) (Values – a, b, c & d) Storm Descriptor	 Use Perak, Bagan Serai For 10 years ARI 010	 Value of $^{2}P_{24h}$ from MSMA (DID) Table 13.3 for $t_c < 30$ min
4.	<u>Catchment Command</u> Routing Method Pervious & Impervious Flow Length Manning Roughness Coefficient, n - Pervious - Impervious Infiltration Method Maximum Infiltration, f_o - Pervious - Impervious Minimum Infiltration, f_c - Pervious - Impervious Lag Constant, K - Pervious - Impervious Depression Storage - Pervious - Impervious	 Linear Reservoir Equal Length 0.300 0.014 Horton Equation 125 mm/hr 0 mm/hr 15 mm/hr 0 mm/hr 0.222 hours 0.050 hours 12.7 mm 1.5 mm	

Table 2.0 – Parameter used for Grass Swales

NO.	CONSIDERATION	LIMITATION	REMARKS
1.	General Geostrip/ Module (Rectangular) - BIOECODS Perimeter Swale - BIOECODS Swale Type A - BIOECODS Swale Type B - BIOECODS Swale Type C Manning Roughness Coefficient, n - BIOECODS Perimeter Swale - BIOECODS Swale Type A - BIOECODS Swale Type B - BIOECODS Swale Type C	 W=0.200m; D=0.080m W=0.410m; D=0.467m W=0.820m; D=0.467m W=1.230m; D=0.467m 0.085 0.100 0.100 0.100	 W = size of the modules only (Check the size of Basewidth of Design Swales is greater than W)
2.	Channel Design Left Bank Slopes Right Bank Slopes Gradient / Longitudinal Slope Depth of Flow Velocity of Flow	 4H : 1V 4H : 1V 0.1 % ≤ 0.9 meter < 2.0 m/s	 Specification of MSMA Inclusive of freeboard 50mm
3.	Route Reach Length MuskingumRouting Parameters: - X factor - K-lag	 Length of Swale To be determine by MIDUSS 98 To be determine by MIDUSS 98	 (Refer to Input Data for Swale Link)

The simulation results are strictly based on modelling process using MIDUSS 98 v1.0. These results are accomplished and are required before any further analysis can be performed. Four scenarios have been conducted based on different parameter in order to optimize the results. Scenario 1 – FYP2 USM1i.out is used as the final output for this project and the rest of the scenarios are based on trial in order to accomplish the outmost results.

Scenario 1 – FYP2 USM1i.out

As refer to this final output, the final peak discharge prompts a tremendous result with the value of 0.666 m^3/s (Figure 6.0), which is appropriate in the research. This scenario 1 is obtained based on the updated data used in the XP-SWMM simulation which cover the school and hostel portion.

Scenario 2 – FYP1 USM1d_i_Dpond.out

This scenario 2 as shown in Figure 7.0 is obtained based on the data from the school portion only. The data has been altered in order to test the efficiency of MIDUSS 98. These alterations comprise of longitudinal slope or gradient of swales link only and the peak discharge gives a value of 2.463 m^3/s.

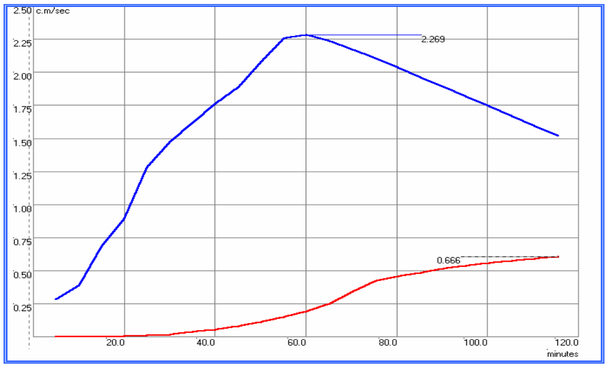

Figure 6.0 – Hydrograph (Scenario 1)

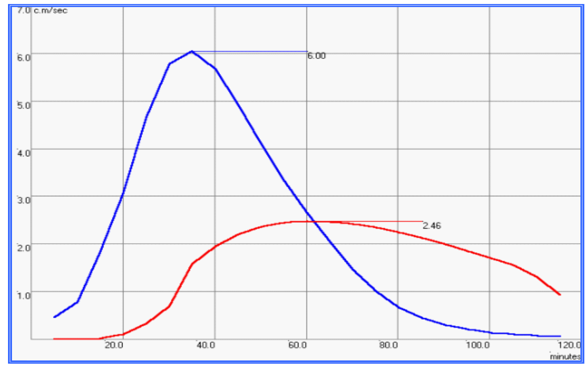

Figure 7.0 – Hydrograph (Scenario 2)

Scenario 3 – FYP1 USM1d_ii_Dpond.out

The scenario 3 is obtained based on the data cover the school portion only. The data here has been altered in order to test the efficiency of MIDUSS 98. This alteration comprise of longitudinal slope or gradient of swales link and the base width of channel. The peak discharge gives a value of 2.281 m^3/s as shown in Figure 8.0.

Scenario 4 – FYP1 USM1d_iii_Dpond.out

Lastly, scenario 4 is obtained based on the data cover the school portion only. The data here has altered and optimized in order to test the efficiency of MIDUSS 98. This maximum further alteration comprise of longitudinal slope or gradient of swales link and the base width of channel. The peak discharge gives a value of 2.278 m^3/s as shown in Figure 9.0.

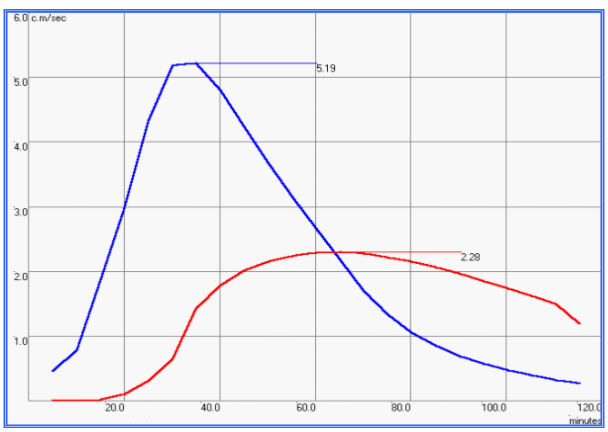

Figure 8.0 – Hydrograph (Scenario 3)

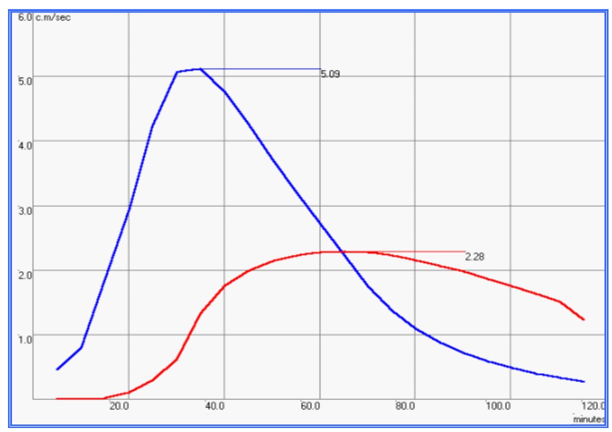

Figure 9.0 – Hydrograph (Scenario 4)

Simulation Analysis

The simulation analysis is carrying out to ensure the effectiveness and accuracy of MIDUSS 98 to model the BIOECODS. The rainfall hyetograph shows a consistent storm with a maximum intensity of 199.334 mm/hr at 25 minutes. In accordance to that, the rainfall depth gives a value of 71.6 mm. As for information, although the research site is based at Seberang Perai, Pulau Pinang, it is preferable to use the polynomial coefficient at Bagan Serai, Perak in the simulation. This is because the nearest rainfall station to USM is located at Bagan Serai, Perak.

Channel design in MIDUSS 98 performs a great job and does not offer any setback. Thus, in this section, trustworthiness of link design should not be query as comparing to Manual Computation Analysis. In order to fulfil the requirement in MSMA, at least 300 mm freeboard has been considered throughout the simulation.

The runoff storage is one of the main concern in carrying out the infiltration process in order to accomplish a great water quality. Although that storage is important, the mosquitoes breeding should not be neglected and must take into consideration. The swales should be designed for a maximum residence time of 24 hours. This will eliminate mosquito problems since mosquitoes generally require 72 hours to breed and hatch. If a site has clay soil with low permeability, the swale may require an under drain or other design adjustment to keep the maximum residence time below 24 hours. Soils with high clay content, and sandy soils, may also require soil amendments to develop a dense turf. Thus, the types of soil play an important role in order to attain perfect infiltration process. Sandy soil is always preferable when using swale and as for that, the selection of drainage system must refer to the site condition.

The length of swale will influence the storage of surface runoff. The longer the length of swale, the more storage of runoff will be accumulated. Adjacent to this, evidently the velocity of flow will manipulate the storage as well. By means of the longitudinal slope or gradient of swale will directly control the velocity of flow. Even with the difference of gradient ±0.5%, the velocity of flow will turn out significant changes. The smaller the gradient of swales by means of the larger the channel is required. However, when take into account of downstream condition, the greater the gradient of swales at upstream will cause the larger the channel is required at downstream.

The channel design in MIDUSS 98 truly turns out a first-class work. Nevertheless, during the simulation process, at least 50mm freeboard been taken into consideration as per requirement in MSMA. While in MSMA suggested the channel depth of 0.9m, it is still acceptable to use channel depth up to 1.5m as along as further safety measure been fulfil, such as installation of barrier or embed of plantation. Based on the simulation understanding, it is advisable and practical to increase the channel depth rather than increasing the base width of channel in order to accommodate more runoff and secure more land area. However, it is noticed that the increment of base width of channel will directly boost the performance of infiltration process. Therefore, again, the channel design must refer to the land area provided and site condition as well.

Although MIDUSS 98 provides Malaysia Storm Features, it is preferably to use the storm data directly from the rainfall station where located nearest to the site. With this progress, it is undeniable that the accuracy of simulation will amplify to another stage. The percentage of impervious area is the main contribution in surface runoff. The higher the percentage the greater the runoff will envelope.

Wetpond and Detention pond plays a very outmost role in controlling the runoff. This is clearly seen in the Inflow and Outflow Hydrograph where the inflow runoff of 2.269 m^3/s successfully been reduced to 0.666 m^3/s (Figure 6.0) which is perfectly appropriate to the site condition. With the percentage difference of 70.65%, this detention pond should be no difficulty playing role for the major storm up to 50 years ARI. All the routing process had been conducted show an insignificant difference between the inflow and outflow runoff except for detention pond and wetpond.

The simulated peak discharge, Qsimulate does not offer a significant value as refer to the actual peak discharge, Qactual. This is due to the infiltrate peak discharge, Qinfiltrate only consist of small amount of infiltration rate. Therefore, the actual peak discharge is approximately equal to the simulate peak discharge as the percentage differences is less than 5%.

CONCLUSION

The MIDUSS 98 program really works and reliable to assist drainage engineers to design the hydraulic elements in a collection network of storm sewers or channels. The program does not make design decisions but rather carries out hydrological and hydraulic analyses and presents us with design alternatives. It is then left to the engineer to select values for the design variables and to decide on the acceptability of a design.

MIDUSS 98 is highly interactive in use, and able to analysis and redesign the BIOECODS components based on the concept design rainfall in MSMA. The program capable to estimate the runoff generated referring to Manual Saliran Mesra Alam (MSMA) for 10 years average recurrence interval and determine and analysis the simulated peak runoff flow. Besides, it allows engineering judgement to be exercised at all stages of the design process. Furthermore, this interaction lets to monitor each step of the process and takes corrective action in the event of an error. With most commands, data is input in response to prompts, and are free from the need to prepare lengthy data files prior to the design session.

When a design session has to be repeated with a modification such as a different storm, it is possible to use an input file which contains a log of the previous session with all the commands and the relevant data. In MIDUSS 98 this input file is in the form of a database which can be produced automatically from a previously created output file. Running MIDUSS 98 in automatic mode eliminates the need to re-enter the commands and data from the keyboard. In this mode, however, design decisions with respect to pipes, ponds, channels or diversion structures can still be altered and changes can be made to the database. The design may vary, this is important in order to provide various alternatives to the client. Although the design could differ, it is preferable and practical to perform the alteration comprise of longitudinal slope or gradient of swales link, the depth of swales and the length of swales. This is due to the modification through side slope and base width swales do not offer momentous values.

In addition, with the assistants of MIDUSS 98, BIOECODS can be design conservatively using the channel design option as taking into consideration as peak discharge with infiltration is nil. This is proven as the Qinfiltrate does not offer significant values. MIDUSS 98 is applicable to be use in design BIOECODS as the post development does not exceeding the pre development discharge 2.9m^3/s (Lariyah et. al., 2001) which preferable in MSMA. The conventional drainage system which is far beyond the limitation shows an inappropriate usage at USM.

Local experience, although limited, shows these concerns and criticisms to be unfounded. The system in USM is 10% cheaper than a conventional one. This system capable to save up to 20% of the cost (Lariyah et. al., 2001). The savings came from omitting the use of expensive concrete-lined drains. Besides that, the savings come from lowest maintenance such as grass mowing and removing of debris only rather than conventional drainage, which required high maintenance such as repairing or widening concrete drains and removing clogged trash. Instead, we have more green areas. In the long term, the new approach translates to spend on stormwater controls will avoid costly river engineering tomorrow.

This enhanced swales system promotes space-saving comparing to the ordinary swales. As the runoff will infiltrate and store within the modules, which encourage further infiltration process beneath the modules. This will definitely reduce the size of swale that eventually able to reduce the space land area comparing to ordinary swales system. Previous research had shown that the final output runoff been categorized as Class IIA (Drinking water – Class I) before releasing to Sungai Kerian which rank as Class III (Mohd Sidek et. al., 2001). Taking into consideration of quantity term and refer to the conservative design, BIOECODS capable to provide further storage of runoff than the conventional drainage system.

The research has shown findings with respect to the basic philosophy of coping with stormwater problems by means of a holistically based management, rather than continuing the traditional expansion of urban drainage systems. This research is reflected in a number of specific findings, needs or proposed actions including the following:

- Although the programs contain some drawback, nevertheless the overall performance of MIDUSS 98 is much satisfactory than some of the program exists in the market especially as comparing to the price and affordability.
- The coefficient used for Polynomial Approximation of IDF curves in the Malaysian Storm Features required an update. For instance, the coefficient for Bagan Serai, Perak is based on the old data collected from 1960 to 1983.
- Enhancement on the Malaysian Storm Features by the IDF Values Frequent Storm features (1, 3, 6 and 12 months ARI) may be suitable for determination of the water qualities.
- Development of water quality section in the program is an essential in order to promote the development of the Best Management Practices (BMPs).
- Although exfiltration trenches option is available, but it requires a range of parameter to be determine. Hence additional simplified design option such as Swale Design will be enormous.
- Study on the life cycle assessment is required in order to ensure the life span of BIOECODS where concerns such as performance of the systems, infiltration and maintenance (clogging of sand due to impurities) should not be neglected. Development of future cost maintenance will provide a great deal on estimation of the projected cost required of the systems.
- Study on the type of vegetation use as based on site condition may required in order to investigate the influence type of vegetation in the systems.

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