Modeling Bio-Ecological Drainage System – A Case Study with Storm Water Management Model

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Abstract The Bio-Ecological Drainage System (BIOECODS) is designed to characterise the element of storage, flow retarding and infiltration engineering. The Storm water Management Model (XP-SWMM) is used to model and simulate the hydrologic and hydraulic of BIOECODS. The characteristic of the catchment and system components of BIOECODS which include bio-ecological swale, dry pond and bio-ecological pond system have been modeled in the XP-SWMM using the link-node concept. The frequent storm of minor event with 60 minute duration and 10 year ARI has been used as a basis to gauge the performance of BIOECODS. The modeling and simulation indicate that the feature and characteristic of BIOECODS has been satisfactorily represented in the XP-SWMM model. The simulation results show that Bio-Ecological Drainage System exhibits the environmentally friendly drainage system.

INTRODUCTION

The urbanization and industrialization in the river basin is rapid with large portions of agricultural and ex-mining land being converted for urban use. Growing demand to spur the economy is transforming the landscape for residential, commercial, industrial and institutional used. As a result of the extensive development, river basin being subjected to river over-bank floods, flash floods that afflict clogged drainage systems and river environment degradation. This prompted the authority to adopt a new concept in the planning and management of urban storm water runoff. The alternative concept which is newly introduces nationally is based on control at source. The water quantity control is derived from multiple combinations of drainage system components which include an element of infiltration engineering, storage and flow retarding facilities.

The planning of storm water system needs to be undertaken in a safe and ecologically sustainable manner. Many of our rivers, lakes and coastal waters are currently degraded by urban storm water, due to excessive flows, poor water quality, and removal of riparian vegetation and destruction of aquatic habitats. The new approach is to broaden the storm water management to minimize the impact of urban storm water towards degradation of receiving water body. In order to meet the water quality control criterion, the storm water runoff is treated from the source and the treatment facility is optimized according to the train of treatment concept inherent in Best Management Practice (BMP).

The Bio-Ecological Drainage System (BIOECODS) is a pilot project which meets the requirement of Storm Water Management Manual (MSMA) which is designed for water quantity and quality control. BIOECODS has been constructed at Engineering Campus, Universiti Sains Malaysia, Nibong Tebal, Pulau Pinang. BIOECODS forms an alternative to storm water management practice and built in environmentally friendly manner.

Site of BIOECODS

The site enclosed in an area of 320 acres in Seberang Perai Selatan; located 1.5 km north-east of Pekan Parit Buntar; 2.0 km south-east of Pekan Nibong Tebal; and 1.5 km north-west of Pekan Bandar Baru. The main river in the area is the Krian River which drains into the South Strait. The site is located near the bank of Krian River. Typical feature for the rivers in Seberang Perai is subjected to tidal influence which is seriously effected area near the river mouth. The low lying area couple with tidal influence has impaired the discharge of storm water into the river. This has resulted of water logged in the drainage system within the area and deteriorated quality of water permanently present in the drain. Therefore, it is desirable to explore the alternative environmentally friendly drainage system to address the inherent problems in the area.

In its pre-development state, the Engineering Campus site is covered with palm oil plantation estate. The site is characterised by flat topography at average ground level of +0.7m. A network of earth drain is used for the irrigation in the plantation area with water level in the drain is normally near the ground surface. This denotes the ground water surface is at an average level of +0.7m. The high ground water level in the area is typical pre-requisite for palm oil plantation. The imported fill is used to raise the construction platform level of the site to +2.44m. The environmental impact due to development is minimised by preserving the existing condition in some area of the site. The clearing of the palm oil tree and earth filling is undertaken at designated area where roads and buildings to be constructed.

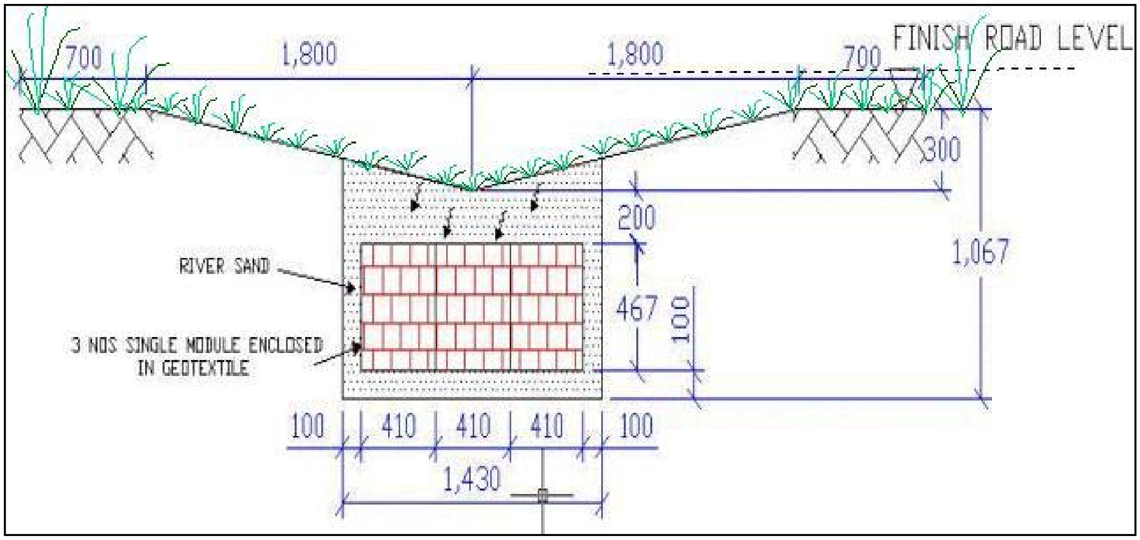

Figure 1: Bio-Ecological Swale.

Concept of BIOECODS

The BIOECODS is a drainage system which exhibits the concept of control at source. The system component is designed to incorporate the concept of infiltration engineering, storage at source and flow retardation. BIOECODS is functioned to provide optimal flood protection by controlling storm water quantity and improved storm water quality. The system component of BIOECODS includes swale for flood water conveyance, dry pond for on-site detention to manage storm water at source and bio-ecological pond system. Perimeter swale is a smaller capacity conveyance which takes storm water from roof of the building. The storm water flowing in the perimeter swale is conveyed into bio-ecological swale (Figure 1) which is designed for a higher flow. The swale built for BIOECODS is a double layer of surface swale and a sub-surface drainage module overlaid with a layer of sand. The surface swale is a soft lined channel with gentle slope, a form of flow retarding facility. The sub-surface drainage module is enclosed with a permeable hydro-net and a layer of sand. The storm water from the surface swale infiltrates into the sub-surface drainage module through a layer of topsoil and river sand. This is a pre-treatment device which removes pollutant mainly particulate material by filtration and sorption to filter material.

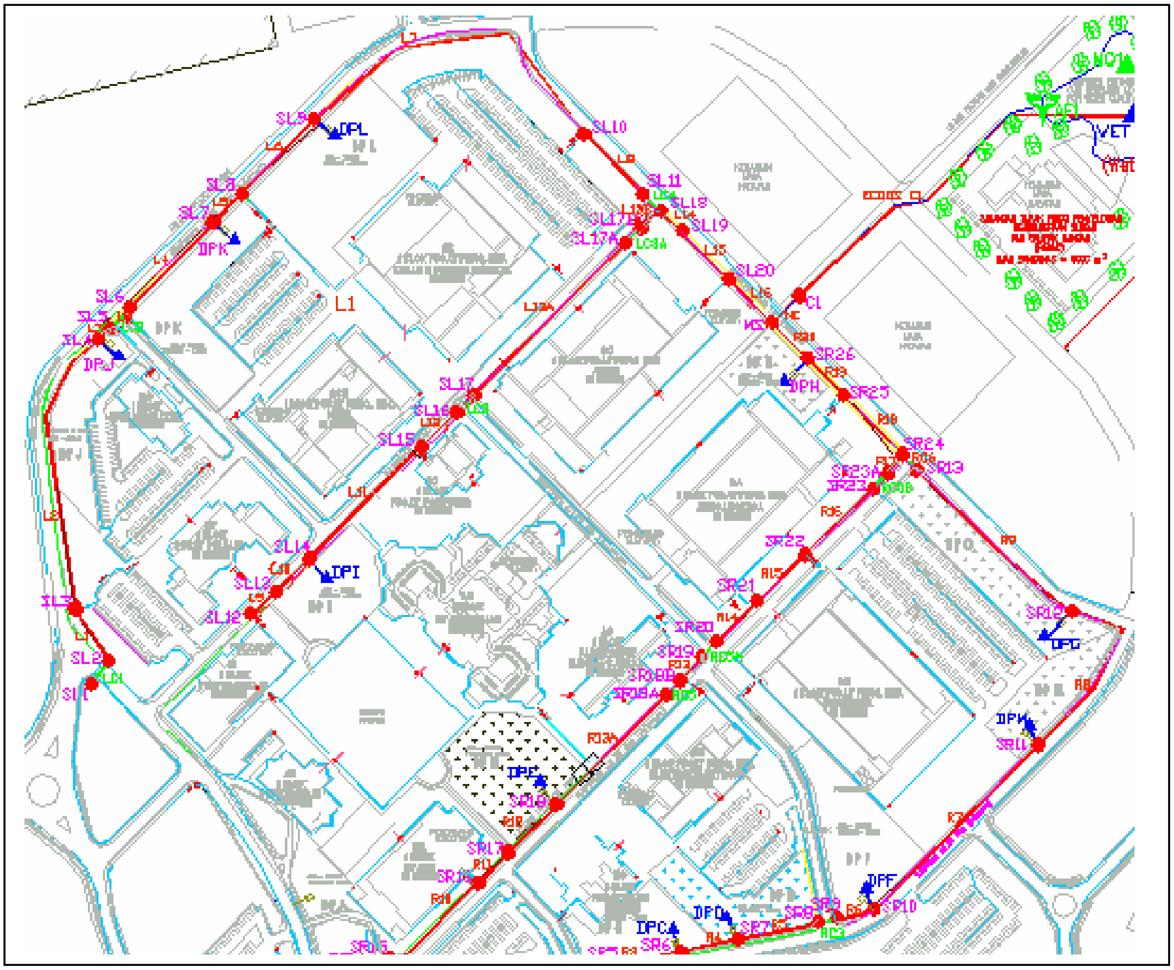

Figure 2: The Engineering School Sub-Catchment

Dry pond is a detention device design to store excess storm water in the development area. This is a multi-functional facilities blended with the landscape for optimum land use. Dry pond facility is an area with shallow depression which can retent water up to maximum depth 150mm. Sub-surface storage module is placed underneath the dry pond and connected to the sub-surface module of the swale. 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 bio-ecological pond system is a community facilities which include the 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 bio-ecological pond system is strategically placed at the downstream end of the BIOECODS to optimise and effectively attenuate and treat storm water runoff generated from the Engineering Campus development area.

The main sub-catchment of the Engineering Campus contains the Administrative Centre, Engineering Schools (e.g. Civil, Mechanical, Electrical, Chemical and Aerospace), Lecture

Theatre and Language Centre. This sub-catchment is referred to as Engineering School sub-catchment (Figure 2). The storm water generated on this sub-catchment flows into wet pond which is located at the downstream, prior discharging into detention pond. The wet pond will serve as a monitoring station where the instrumentation will be installed to measured the hydraulic, hydrologic and water quality parameters. The second sub-catchment contains the student hostels and cafeteria. This sub-catchment is referred to as Student Hostel sub-catchment. This sub-catchment is located further downstream of the first sub-catchment and near the vicinity of the bio-ecological pond system. The excess storm water generated from this sub-catchment is discharged in detention pond via bio-ecological swale.

The combine operation of swale, dry pond and bio-ecological pond system will effectively reduce the post-development peak discharge to pre-development level. The operation of these devices is integrated with the element of storage, flow retarding and infiltration engineering. In gauging the effectiveness of the system component of the BIOECODS, Storm Water Management Model (XP-SWMM) is used for the evaluation.

Modeling of BIOECODS

The Storm Water Management Model (XP-SWMM) is used to model the hydrologic catchment processes and simulate the hydraulics of BIOECODS. The link-node model of XP-SWMM is used to represent the characteristic of the catchment and drainage system of BIOECODS. A link represents a hydraulic element of flow in the system where the model offers many different types of conduits for simulation. A node represents the junction of hydraulic elements (links) and can be assigned with a particular contribution area (watershed) associated with the drainage system. The storm water runoff hydrograph generated from sub-area enters the drainage system through the node. The node can also represent a storage device such as pond or lake, or a point junction to represent a point of change in channel or conduit geometry, or a boundary condition in the model.

The catchment processes and hydrologic component models such as infiltration, evaporation, depression storage and transformation of effective rainfall to runoff is executed in the runoff layer. The hydrologic losses are the amount of losses through depression storage and infiltration is used to compute the effective rainfall. The hydrologic losses are the volume of storm water detain in the catchment and is characterised by the land use, topography and geology of the catchment. The initial and minimum capacities (Table 1) of Horton's infiltration equation are approximated based on the site condition. These values are the minimum values of infiltration capacity for clay.

Parameter	Rate
Initial Capacity (F_o)	25.4 mm/hr
Minimum Capacity (F_c)	2.54 mm/hr
Rate of Decay (k)	0.00115 /sec
Depression Storage	25.00 mm

Table 1: Horton's Infiltration Capacity Curve

The non-linear reservoir method is used for the transformation of effective rainfall to runoff hydrograph. The overland flow hydrograph is generated by non-linear reservoir routing using Manning's equation and lumped continuity equation with depression storage and pervious and impervious area parameters. The sub-catchment width parameter is related to the collection length of overland flow and is calculated based on the watershed area. The manning coefficients for permeable area and impermeable area used in the computation for hydrologic losses are shown in Table 2. The runoff hydrograph drain into the system through the node and is routed through the bio-ecological swale in the transport layer. The manning coefficients for surface swale and sub-surface module are shown in Table 2. The bio-ecological swale is designed in two layers consists of surface swale and sub-surface module. In actual condition the storm water infiltrates from the surface swale into the sub-surface module through a layer of river sand. The bio-ecological swale in XP-SWMM is modeled with two layers or double links to represent the surface swale and sub-surface module. These links are connected to the node which represents a manhole in transport layer. The storm water drain into the sub-surface module through the node and when its capacity is reached, the water level will rise into the surface swale.

Parameter	Manning (n)
Permeable area	0.040
Impermeable area	0.013
Surface Swale	0.035
Sub-Surface Module	0.100

Table 2: Manning Coefficients.

The storm water is drained out from dry pond through the sub-surface storage module connected to the adjacent sub-surface module of the swale. However, in the XP-SWMM simulation, the storm water is drained from dry pond through orifice connected to the adjacent sub-surface module of the swale. The detention pond is simulated based on the outflow control structures shown in Table 3. The capacity for the outflow from detention pond to wetland for storm water treatment is designed for 3 month average recurrence interval (ARI). The minor and major outflow structures from detention pond to Krian River are designed for 10 year and 50 year ARI, respectively.

Outflow to Wetland (3 month ARI)	Minor Outflow (10 year ARI)	Major Outflow (50 year ARI)
4 nos PVC orifice with 50mm diameter	3 nos concrete pipe with 825mm diameter	Emergency Spillway

Table 3: Outflow Control Structure for Detention Pond

Results and Discussion

The Bio-Ecological Drainage System is designed to function as storage, flow retardation and infiltration engineering concepts. The behavior of the system is simulated with XP-SWMM. The simulation is emphasised on the impact of minor flood event on the drainage system. Hence, the basis of the evaluation is the frequent occurrence storm with design duration and average recurrence interval of 60 minute and 10 years, respectively. The performance of the drainage system is critical at the Engineering School sub-catchment and Student Hostel sub-catchment.

The XP-SWMM models store the storm water surcharge at the node until the conduit has enough capacity to convey the flow downstream. Table 4 and Table 5 show the overflow depths at Engineering School sub-catchment attain the highest depth at 60 mm at node SR2 consists of car park with flooded time of 505 minutes. The maximum depth of ponding at Student Hostel Sub-Catchment is approximately 50 mm with flooded time 460 minutes (Table 6).

The results generated from XP-SWMM modeling have given a good indication that; the model is capable of simulating the characteristic of BIOECODS consists of storage, flow retarding and infiltration engineering. The system component consists of perimeter swale, bio-ecological swale, dry pond and bio-ecological pond system capable of attenuating flood discharge and managing storm water at source. The total inflow into the detention pond consists of outflow from wet pond and discharge from Student Hostel sub-catchment is approximately 1.1m^3/s (Figures 3, 4 & 5). This is the post-development discharge which has been routed through the BIOECODS system.

The detention pond is the community facility for water quantity control with control flow to wetland and outflow (minor and major) to Krian River. The simulation has indicated that the flow through minor and major outflow is absent and the stormwater flow from detention pond to wetland through the orifice. The wetland is connected to recreational pond through wading river, and the water level is maintained in recreational pond through outflow hydraulic structure tideflex dicharging into Krian River. This suggests that the annual volume of stormwater treated through the BIOECODS system is more than 90%. In term of water quantity control, the BIOECODS system exhibits a system of zero flow contribution to the Krian River for design storm with 60 minute duration and 10 year ARI.

Node	**Flood (m^3)**	**Catchment Area(m^2)**	**Flooding Depth(mm)**	**Flooded Time(min)**	**Remarks**
SR1	955	16700	57	595	Car Park
SR2	177	2965	60	505	Car Park
SR4	85.9	2885	30	339	Car Park
SR5	154	4823	32	299	Pusat Islam
SR8	404	10453	39	218	50% PPKEE + Car Park
SR9	188	10597	18	99.2	75% PPK Mekanikal
SR11	32.8	1992	16	36.1	DPM Road + Car Park
SR14	128	3622	35	457	C Park Beside Dewan SG
SR16	463	11405	41	423	Dewan SG + Car Park
SR17	159	3781	42	303	50% Dataran + C Park
SR19	547	14550	38	252	P Bhs + 50% D Kuliah
SR20	52	2775	19	161	PPK Aero. Car Park
SR21	295	7630	39	155	50% PPK Aero
SR22	164	4597	36	110	25% PPK Mekanikal

SR23	260	9195	28	86.6	PPK Mek. Car Park
SR25	22.3	8590	3	0	50% PPK Aero.

Table 4: Engineering School Sub-Catchment – School of Electrical Engineering (PPKEE) & Aerospace Engineering (PPK Aero.)

Node	Flood (m^3)	Catchment Area(m^2)	Flooding Depth(mm)	Flooded Time(min)	Remarks
SL3	135	4581	29	388	Pusat Pelajar Car Park
SL4	97.6	2966	33	350	Car Park & Road
SL5	770	15752	49	335	P Kesihatan & C Park
SL6	397	11700	34	203	PPK Kimia & Road
SL8	213	8961	24	135	PPKK CP+50%PPKBSM
SL10	337	12092	28	88.8	PPKBSM Car Park
SL11	143	10728	13	52.6	Road + 50% PPKBSM
SL12	394	9921	40	357	Library + B Pentadbiran
SL13	160	4199	38	263	50% Dataran
SL15	85	2420	35	206	Pusat Komputer
SL16	357	8779	41	185	50% Dewan Kuliah
SL17	30.8	3105	10	45.8	25% PPK Awam
SL19	21.9	4194	5	0.733	25% PPK Awam
SL20	22.7	8550	3	0	50% PPKA + Car Park

Table 5: Engineering School Sub-Catchment – School of Chemical Engineering (PPK Kimia) and Material and Mineral Resource (PPKBSM)

Node	Flood (m^3)	Catchment Area(m^2)	Flooding Depth(mm)	Flooded Time(min)	Remarks
HL1	195	4306	45	587	TNB + Road
HL4	458	9380	49	459	Jabatan Pembangunan
HL7	370	9500	39	173	Kafe. B + 50% D Siswa
HL10	169	4616	37	114	50% D Siswa + C Park
HL12	265	6582	40	92	Pejabat Penggawa
HL14	79.6	3098	26	59.8	50% SH3
HL15	170	4904	35	53.1	50% SH4 + Car Park
HL16	95.7	3275	29	37.4	50% SH4 + 50% SH3
HL17	32.5	19680	2	17.6	SH2 + Car Park
RH1	52.6	9849	5	27.4	Komplek Sukan + Road

Table 6: Student Hostel Sub-Catchment

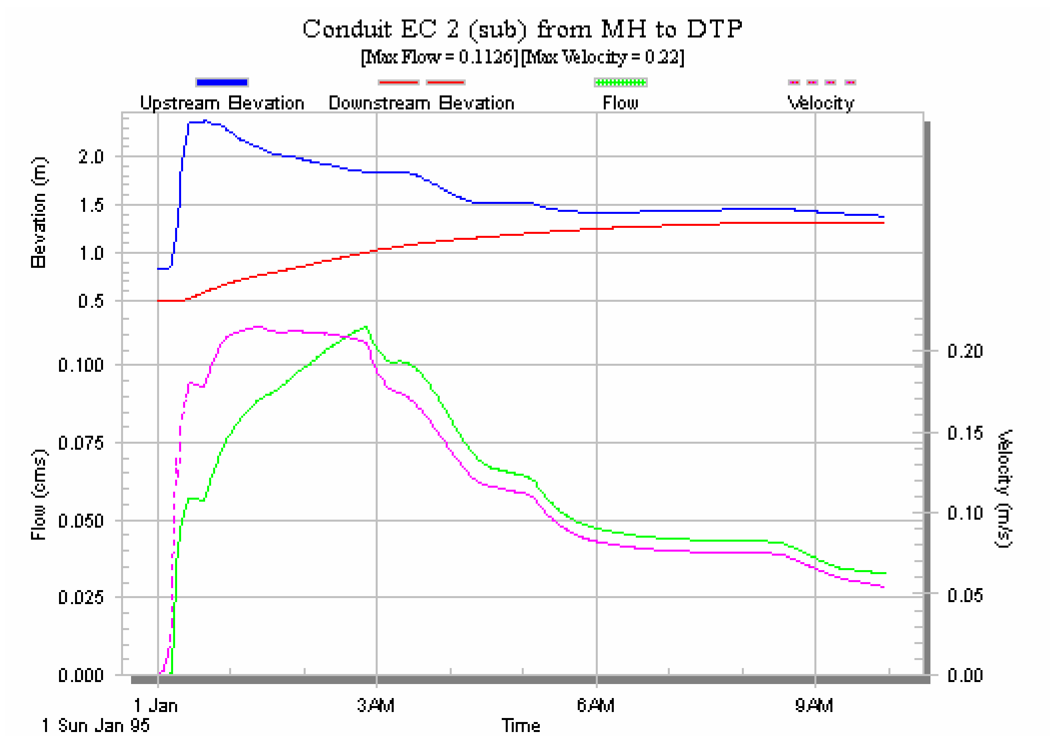

Figure 3: Flow in the Sub-Surface Module of Bio-Ecological Swale (from Student Hostel Sub-Catchment into Detention Pond)

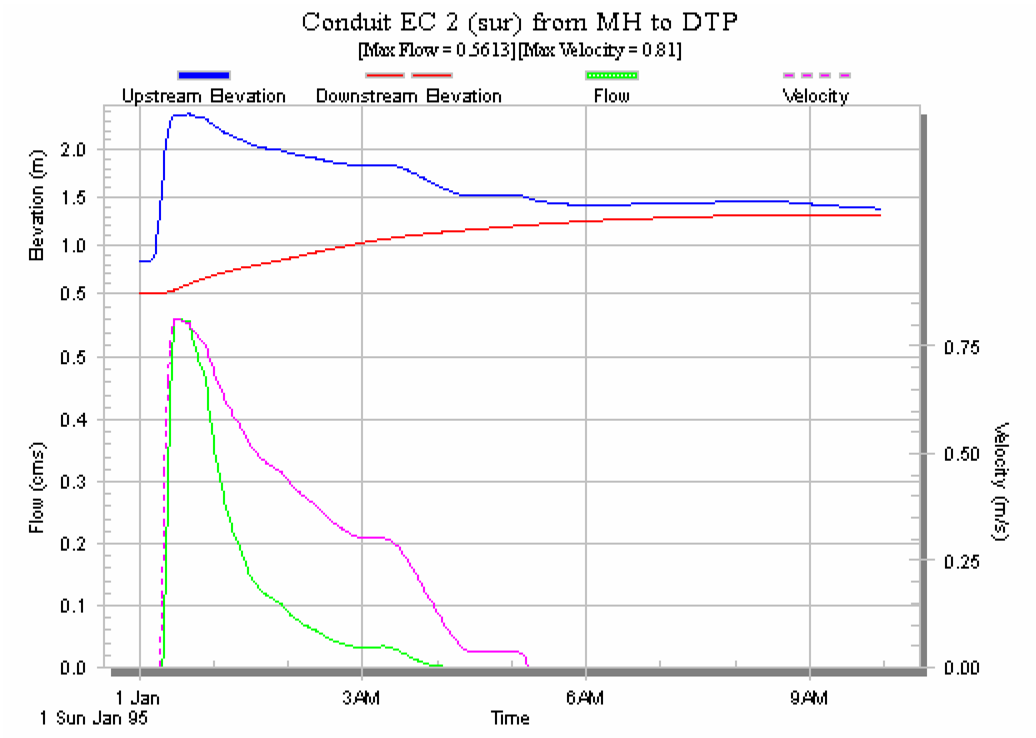

Figure 4: Flow in the Surface Bio-Ecological Swale (from Student Hostel Sub-Catchment into Detention Pond)

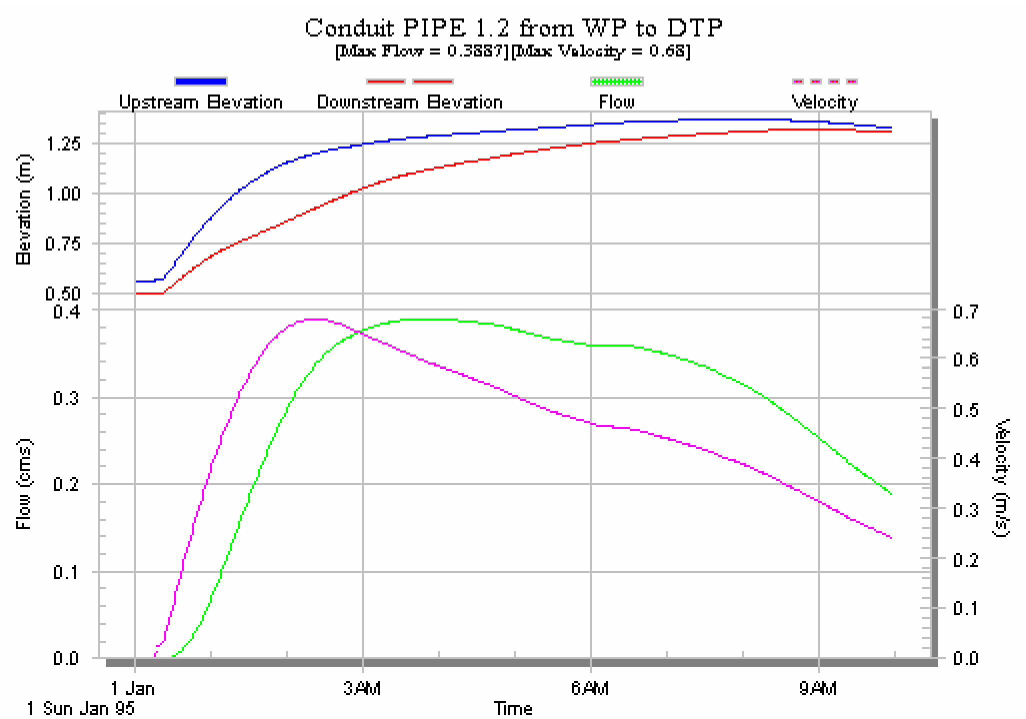

Figure 5: Flow from Wet Pond into Detention Pond

CONCLUSIONS

The urban management model such as XP-SWMM is an invaluable tool in simulating the behavior of the BIOECODS:

- provide a comprehensive environment to evaluate the Bio-Ecological Drainage System
- the system components of the Bio-Ecological Drainage System can be assessed and evaluated
- modeling enable the drainage system with storage, flow retarding and infiltration engineering to be evaluated
- the hydrologic and hydraulic analyses are readily available at any point within the Bio-Ecological Drainage System

The modeling and simulation of XP-SWMM in evaluating the BIOECODS system has generated the following findings:

- the modeling capable of simulating the characteristic of BIOECODS consists of storage, flow retarding and infiltration engineering
- the maximum surcharge at the node is 60 mm with flooded time of 500 minute which is limited ponding and within acceptable range
- in term of water quality control, BIOECODS system is capable of treated more than 90% of annual volume of storm water
- in term of water quantity control, BIOECODS system is capable of attenuate the post-development discharge to the pre-development level

The simulation of the BIOECODS with XP-SWMM is based on the parameter estimated to reflect and characterise the hydrologic and hydraulic regime at the development site.

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