Application of SWMM for Urban Stormwater Management: A Case Study with Modelling

[1]Lai S.H., [2]Ab. Ghani A., [3]Zakaria N.A., [4]Leow C.S., [4]Chang C.K., [4]Yusof M.F.
[1]Senior Lecturer, River Engineering and Urban Drainage Research Centre (REDAC), Engineering Campus, University Sains Malaysia (USM), 14300, Nibong Tebal, Penang, Malaysia, Email: redaclai@eng.usm.my
[2]Professor and Deputy Director, REDAC, Engineering Campus, USM, 14300, Nibong Tebal, Penang, Malaysia, Email: redac02@eng.usm.my
[3]Professor and Director, REDAC, Engineering Campus, USM, 14300, Nibong Tebal, Penang, Malaysia, Email: redac01@eng.usm.my
[4]Research Officer, REDAC, Engineering Campus, USM, 14300, Nibong Tebal, Penang, Malaysia.

ABSTRACT
This paper presents the design of stormwater facilities for a frequently flooded urban catchment according to the new Stormwater Management Manual produced by the Department of Irrigation and Drainage Malaysia (DID). Various measures are included in the design for quantity and quality control, including engineered waterway, outlet control, constructed wetland, pumping station, and etc. The proposed improvement works and design is simulated and analyzed using InfoWorks CS software, also presented is the simulated results for the existing drainage system in the catchment for comparison. The results obtained from calibrated model show that under the existing conditions, the whole catchment area is subjected to frequently flood of up to 2 m depth at downstream. Surprisingly, with some channel and culvert upgrading according to the criteria in SWMM, the results obtained show that the proposed design is able to handle the worse flooding scenarios (100-year ARI rain coincide with spring high tide), and therefore solving the flooding problems in the study area. The water quality in the study area is expected to be further improved with the construction of the designed wetland.

1 INTRODUCTION

Urbanization and the increase in impervious surfaces typically associated with urban development have consistently been shown to result in degraded aquatic ecosystems. These effects are a function of increased stormwater runoff volumes, surface erosion and pollutants loading across a watershed due to the efficient routing of stormwater off impervious surfaces and into a storm sewer system that ultimately discharges into a receiving water body. These elevated volumes impact stream ecosystems through amplified flow rates which increase bed and bank erosion, rapid and efficient pollutant transport and an increase in nuisance flooding in urban watersheds.

In Malaysia, frequent occurrences of flash flood in urban areas have resulted in an average loss of RM 100 million a year (DID, 2000). Department of irrigation and Drainage Malaysia (DID) estimates that RM 10 billion (reported in News Straits Times, June 22, 2000) is required to upgrade the conventional drainage system made up of concrete channels and channelized rivers to overcome the pollution and flash flood enigma. With the present conventional drainage system, new development means new and bigger monsoon concrete drains are required to be built at the downstream areas. Similarly the receiving river at the downstream end will need new flood mitigation project involving straightening, widening and deepening destroying the natural conditions including flora and fauna. Therefore there is a need to seek for a holistic and sustainable solution, not only to mitigate existing flood problems but also to prevent the occurrence of such problems in new area to be developed.

In order to overcome the above problem, The Department of Irrigation and Drainage Malaysia (DID) produced a new urban drainage manual in 2000 (DID, 2000), known as Stormwater Management Manual or SWMM to account for the quantity and quality of stormwater runoff, and the amenity value of surface water in the urban environment. The new manual emphasized on the use of Best Management Practices (BMPs) such as “control at source” approach to achieve “Zero Development Impact Contribution”, and ensures that the final discharge from a sustainable urban drainage system will not pollute rivers, nor create flooding within the study or downstream areas. This study aims in exploring and promoting the practical effectiveness and application of SWMM in urban stormwater management..

2 DESCRIPTION OF THE STUDY AREA

The study area reported in this paper is located at Peringgit Town in Melaka Tengah District of Melaka state, Malaysia with a catchment area of 133.5 ha. This area is surrounded by housing estates and villages, including Kg. Durian Daun Dalam, Kg. Mata Kucing and Taman Cempaka as shown in Figure 1.

As a result of undersized local internal drains and culvert, low-lying platform level in the Study Area, tidal effects, lack of maintenance for the existing drainage system caused by shrubs, sludge and rubbish, flash floods occur in most parts of the study area whenever it rains heavily for duration more than 2 hour. The incident of flash flood has caused extensive damage to property and interruption to daily activities in the study area. In addition, the contribution of grey water from existing residential areas has caused degradation of water quality in the existing water body, and therefore stormwater management facilities are needed to counter for the flooding faced by the population in this area and to ensure clean discharge water to Melaka River.

3 CONCEPTUAL DESIGN

Proper improvement works and designed (Figure 2) have been carried to rectify the situation as well as to enhance stormwater management in the study area. The proposed improvement works include waterway upgrade with necessary bunding, culvert upgrade, outlet control structures for drains connecting to main waterway, pumping station to discharge water into Melaka River, and constructed wetland for water quality control. The proposed upgrades are designed to work collectively to contain and mitigate flood water during minor and major events.

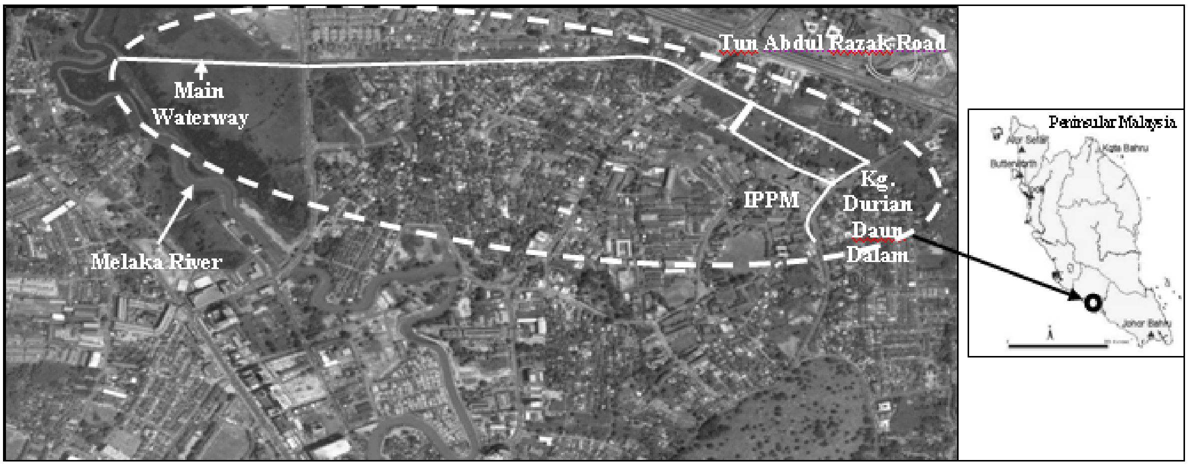

Figure 1. Satellite image of the study area

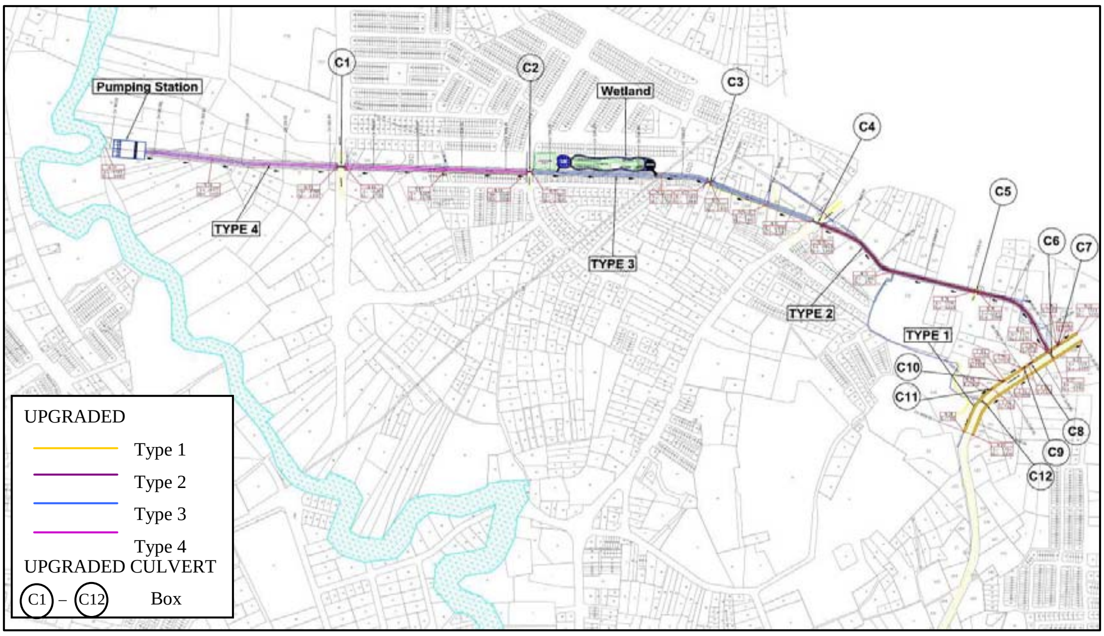

Figure 2. Key layout for proposed drainage system in the study area

The drain upgrade is suggested as shown in Table 1, in which the whole main waterway is divided into several sections of upgrading scheme to cater different volume of runoff. The shapes of new engineered waterway are designed as trapezoidal to obtain the required drain capacity, a side slope of 1:1 is selected along the waterway due to limited space available for upgrading work. Homogeneous shape is proposed to avoid complication during construction, and to avoid flow obstruction at joints of different drain types. A typical cross section for the proposed waterway is shown in Figure 3.

Table 1. Cross section detail for waterway upgrade

Drain type	Bottom Width (m)	Average Depth (m)	Side Slope H:V	Channel Gradient	Capacity Q (m^3/s)
1	2	1.5	1:1	1:1000	5.91
2	3	2.1	1:1	1:1000	15.29
3	3	2.3	1:1	1:1000	22.74
4	5	3.0	1:1	1:1000	33.59

The major outlet of the study area shall be controlled by outlet control structure. Such structure ensures efficient discharge as well as prohibiting water of receiving water body (backwater) from entering the drainage system. Every major drain outlet within the catchment will be equipped with flap gate as control structure.

Calculation and analysis using data collected have shown that most culvert crossings within the study area are incapable of efficiently conveying stormwater. The culverts often create bottle neck and backwater effect in the system, which eventually leads to flood. Therefore, it is proposed that all the round culverts with in the study area to be replaced by box culverts, and the existing under designed box culverts to be upgraded to an appropriate dimension based on calculation and computer analysis.

In this study, pumping system is recommended as a suitable option to discharge water from the existing channel to Melaka River. The existing discharge point is situated near to river mouth of Melaka River and is subjected to tidal effect. Hence the efficiency of existing system is greatly compromised especially when tailwater level is high (high tide). MBMB (2007) revealed that during a 100-year ARI event for Melaka River, water level in the river could rise to RL +2.480m (coinciding with mean high water spring tide), which could easily submerge much of the study area. The introduction of Melaka River Barrage to boost boating activity will ensure water level behind the gates are constantly maintained between RL +1.0m and RL +1.4m, which is almost the same as the mean high water spring tide (RL +1.21m) level.

The anticipated high tailwater after the barrage construction will permanently reduce the efficiency and capacity of existing channel. With proper segregation however, the channel efficiency can be maintained with the introduction of a pumping station. The pumping station is equipped with 5 pumps with a total capacity of 18.5 m^3/s. The proposed pumping regime is given in Table 2, whereas Figure 4 shows the mass curve routing diagram for the pumping station.

A constructed wetland is proposed for water quality treatment for the catchment. The wetland is designed with a forebay and micropool. The wetland will treat water on low flow up to 3-month ARI event. This is achievable by proper inlet control structure. Figure 5 presents the layout of the proposed wetland system.

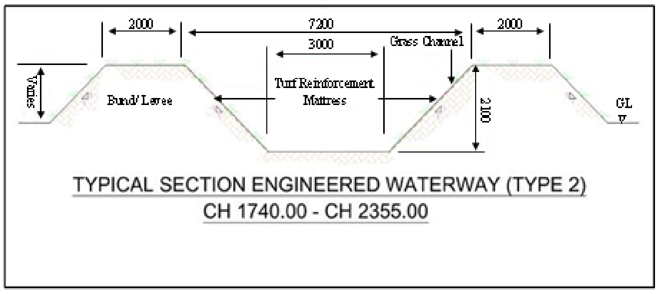

Figure 3. Typical cross section and bund structure

Table 2. Pumping regime for proposed system

Pump No.	Pump Capacity	On Level m (m^3)	Off Level m (m^3)
1	1.75	0.00 (3637)	-0.54 (0)
2	1.75	0.50 (9833)	-0.25 (1518)
3	5.00	1.00 (19074)	0.25 (6472)
4	5.00	1.50 (31081)	0.75 (14227)
5	5.00	2.00 (45180)	1.25 (24639)

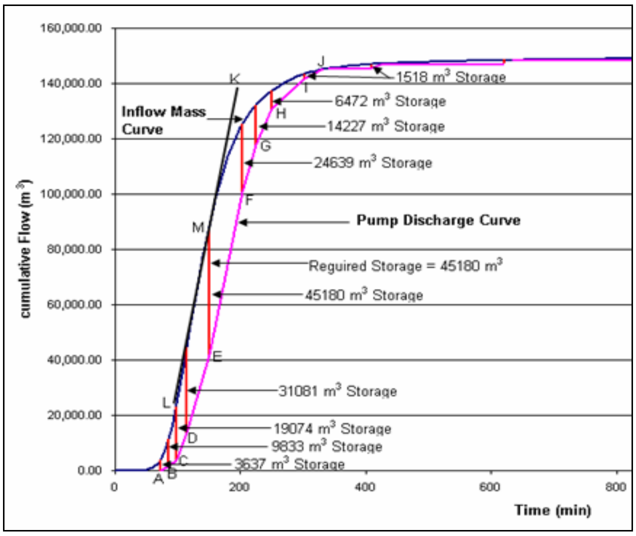

Figure 4. Mass Curve Routing Diagram

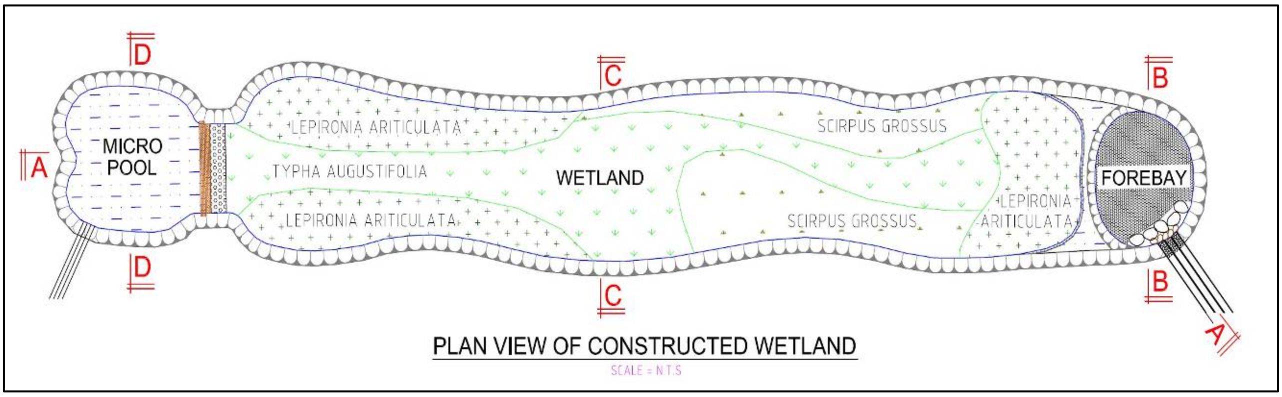

Figure 5. Proposed constructed wetland system

4 URBAN DRAINAGE MODELLING

In order to analyze the existing and proposed stormwater facilities in the study area, Computer modeling and simulation have been carried out in GIS environment using the InfoWork CS software. Figure 6 shows the delineated catchment area and the network of main drainage system involved in this study. The study area is divided into 19 sub-catchments based on the topographical conditions, surveyed data (MBMB, 2006) and drainage information obtained from inventory work.

Landuse data of the study area is mapped according to two different conditions. The existing condition is mapped on cadastral sheet based on site observation and information from Local Plan (DID, 2005). The future landuse (year 2015) condition is also digitized from the Local Plan (DID, 2005). Generally, the study area can be divided to 4 types of primary landuse including Urban, suburban, Road & Highway, and Green Area as shown in Figure 7. The soil type in most of the area is found consists of Linau Sedu Series (DID, 2005), and therefore it is assumed that the whole study area is of hydrological class C soil.

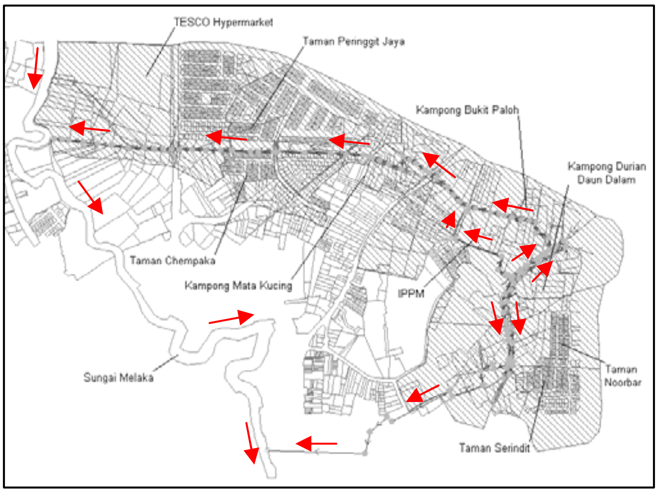

Figure 6. Delineated catchment area for the Study

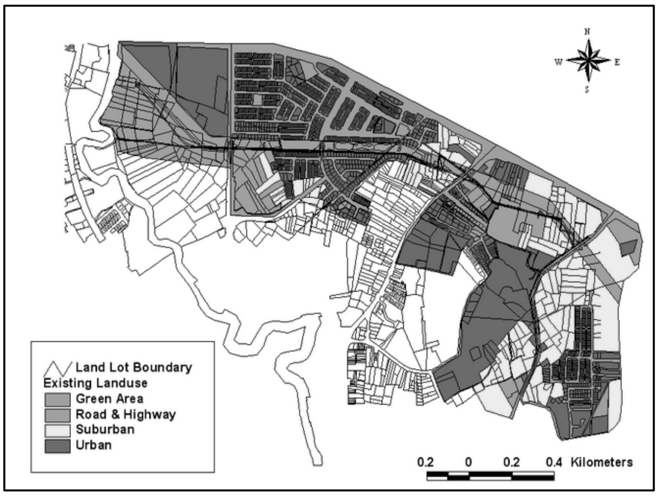

Figure 7. Digitised Existing Landuse

The rainfall-runoff model selected for this study is the Soil Conservation Service (SCS) Curve Number Method, (SCS, 1986). It has been tested to be used satisfactory in Malaysia by Hassan (2006). Table 3 gives the calibrated Curve Number used in this study. Also shown in Table 3 is the CN values obtained from SCS (1986) and Hassan (2006) for comparison. The generated runoff is routed to the connected nodes using Kinematics Wave routing. Flow in channel is routed by solving the St. Venant Equations. Figure 8 shows the results obtained from calibrated model using a 1-year ARI event. These results illustrated that the model is able to estimate the flow and flood level in the study area satisfactorily.

Table 3. Calibrated CN Value for Various Landuse

Runoff Surface ID	Description	SCS, 1986	Hassan, 2006	Calibrated CN
1	Commercial	94	90	82
2	Green Area	74	60	55
3	Residential	83	90	75
4	Road	98	90	95
5	Suburb / Village	78	65	70

According to SWMM (2000), tailwater condition is of great important to stormwater drainage design. The effects of coincident storm events in each system must be considered. Although a joint probability is recommended by SWMM (2000), insufficient information on receiving water response to various event has hindered the application of joint probability assessment. Instead, the study opt to model the worst condition, i.e. 100 year ARI event for drainage system coincide with mean high water spring tide (MHWS) in Melaka River.

The calibrated model was used to examine the hydrological and hydraulic response of the channel network for various ARI rainfall events (10-year, 50-year, 100-year, etc.) and under different conditions (existing and future conditions).These events are induced to the system to examine how it response to various possible rainfall events.

The simulations focus on MHWS scenarios as these scenarios would yield the high tailwater levels, which will cause drainage capacity to be greatly compromised. In MLWS and MSL, the concern of flooding may still occur, but is relatively less severe than that of MHWS. Generally, the results obtained from the simulation are of the same trend, but different in flood level. A sample of the result is shown in Figure 9, which presents the longitudinal section of the drainage system under the simulation of worst 100 year ARI scenario. It can be seen that under such condition, all of the area along the main waterway is subjected to flood of up to 2 m (CH2100). These areas are relatively low, as compared to the developed areas nearby (i.e. Kg. Mata Kucing and Taman Cempaka), which are mostly built on raised platforms.

The proposed system is simulated with InfoWorks CS to carry out channel routing, backwater effect analysis and to establish initial pumping regulatory scheme. 4 simulations were carried out to examine the performance of stormwater facilities in mitigating flood in the area. Table 4 sums up the simulation results. A sample of the longitudinal profile for simulation under future landuse condition is given in Figure 10 (100-year ARI). The system is designed by using future landuse as reference. It is found that stormwater runoff is well contained within the proposed channel with ample freeboard, even for major event.

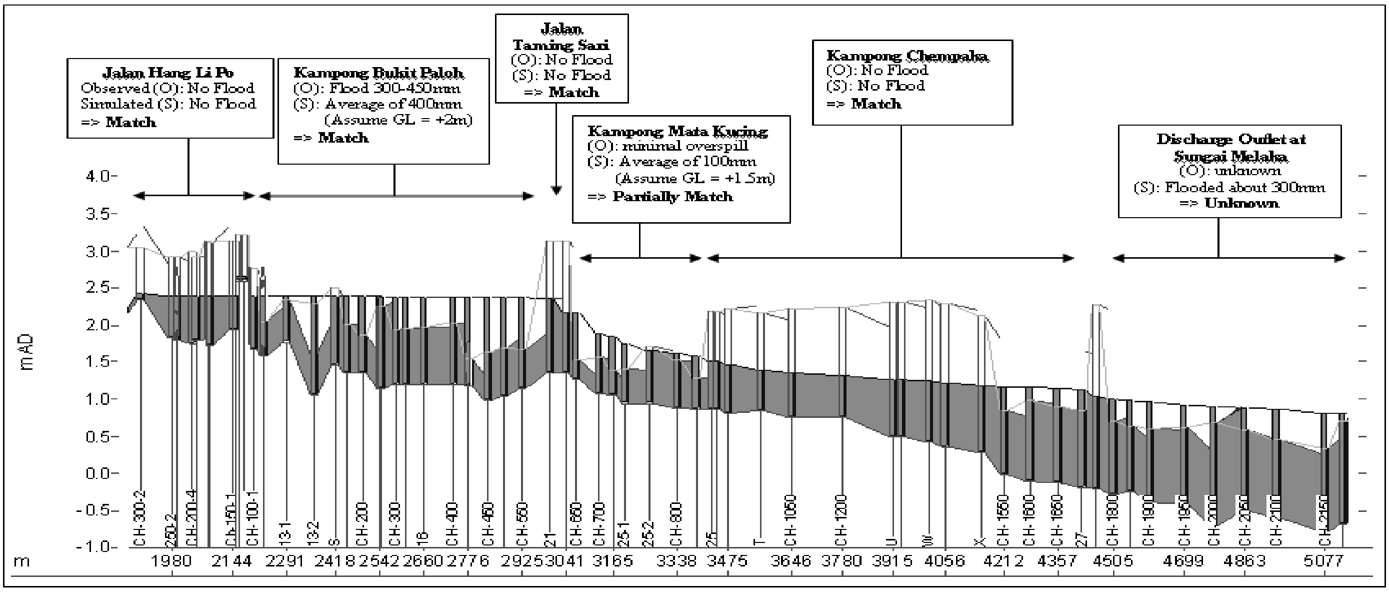

Figure 8. Longitudinal Flood Profile for Simulated 1 Year ARI Flood Event

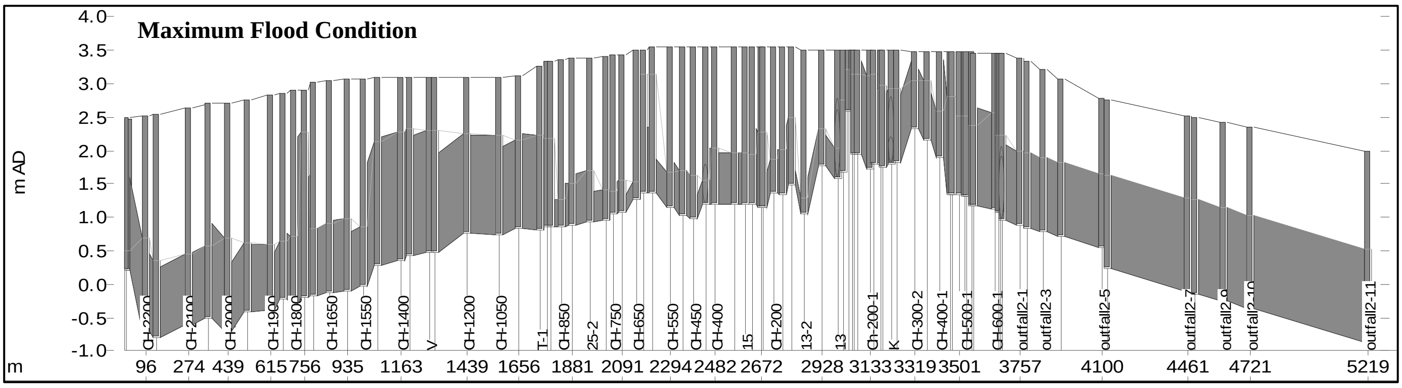

Figure 9. Longitudinal Section for Existing Drainage Network with Maximum 100 year ARI Flood Profile

Table 4. Result Summaries for Computer Modelling of the proposed stormwater facilities

Landuse Condition	Event	Total Percipitation (mm)	Total Runoff (m^3)	Total Flood Volume (m^3)	Peak Discharge (m^3/s)	Peak Velocity (m/s)	Max Water Level (msl)
Existing Landuse	Major (100 Year ARI)	217,404.40	123,977.30	0.0	17.690	1.983	2.520
	Minor (10 Year ARI)	160,173.00	79,063.80	0.0	12.359	1.772	2.126
Future Landuse	Major (100 Year ARI)	217,404.40	147,722.00	0.0	17.371	1.843	2.877
	Minor (10 Year ARI)	160,173.00	98,400.00	0.0	12.604	1.669	2.318

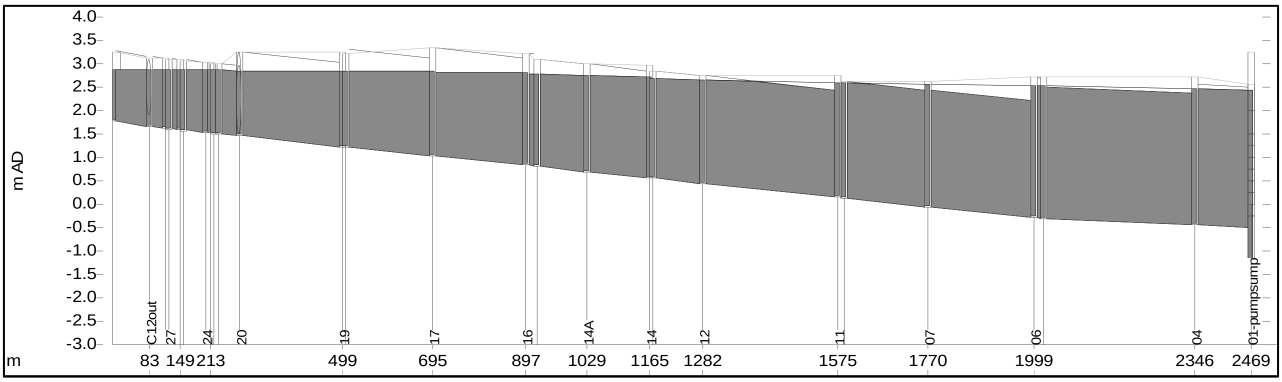

Figure 10. Maximum Water Profile for Plan A under 100 Year ARI Event and Future Landuse Condition

5 CONCLUSION

From the results obtained, it can be concluded that the proposed channel improvement works and design is able to cater for the flooding problem in the study area successfully. These results further emphasized that the BMPs and design criteria suggested in SWMM are able to solve the urban stormwater problems in terms of quantity and quality control, and it should be recommended for practical application throughout a developing country like Malaysia.

ACKNOWLEDGEMENTS

The authors are grateful to the Government of Malaysia for the financial support from the Department of Irrigation and Drainage (DID) through the research project entitled “Detailed design of stormwater management facilities from Maktab Perguruan Perempuan Malayu Melaka to Taman Peringgit Jaya“. The assistance of all staff at the DID is acknowledged.

REFERENCES

DID. 2000. *Stormwater Management Manual for Malaysia (SWMM).* Department of Irrigation and Drainage Malaysia. Malaysia Publication.

DID. 2005. *Local Stormwater Strategic Plan for Sungai Melaka Catchment.* Jurutera Perunding Zaaba Sdn Bhd & Perunding W Mokhtar, Kuala Lumpur, Malaysia.

Hassan, A.J. 2006. *River and Floodplain Modelling for the Development of Flood Risk Map: A Case Study of Sg. Selangor*. M.Sc. Thesis, Universiti Sains Malaysia, Penang, Malaysia.

Majlis Bandaraya Melaka Bersejarah (MBMB). 2006. *Proposed Improvement Drainage System from Maktab Perguruan Perempuan Melayu Melaka – Taman Peringgit Jaya, Melaka.* Melaka, O and L Jurutera Perunding Sdn Bhd, Malaysia.

Majlis Bandaraya Melaka Bersejarah (MBMB). 2007. *Cadangan Kerja-Kerja Pembersihan dan Pengindahan Sungai Melaka Fasa 3 (Parcel 4) secara ‘Design And Build’ untuk Majlis Bandaraya Melaka Bersejarah.* SMHB Sdn Bhd, Kuala Lumpur, Malaysia.

Mohd Sidek, L., Ainan, A., Zakaria, N.A., Ab. Ghani, A., Abdullah, R. & Ayub, K.R. 2004. Stormwater Purification Capability of BIOECODS. *The 6th International*

Conference on Hydroscience and Engineering (ICHE-2004), Brisbane, Australia.

Soil Conservation Service (SCS). 1986. *Technical Release 55: Urban Hydrology for Small Watershed*. United States Department of Agriculture, Washington.