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Evaluation of Stormwater Quantity and Quality Control through Constructed Mini Wet Pond: A Case Study

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***Abstract*—**One of the Best Management Practices (BMPs) promoted in Urban Stormwater Management Manual for Malaysia (MSMA) published by the Department of Irrigation and Drainage (DID) in 2001 is through the construction of wet ponds in new development projects for water quantity and quality control. Therefore, this paper aims to demonstrate a case study on evaluation of a constructed mini wet pond located at Sekolah Rendah Kebangsaan Seksyen 2, Puchong, Selangor, Malaysia in both stormwater quantity and quality aspect particularly to reduce the peak discharge by temporary storing and gradual release of stormwater runoff from an outlet structure or other release mechanism. The evaluation technique will be using InfoWorks Collection System (CS) as the numerical modeling approach for water quantity aspect. Statistical test by comparing the correlation coefficient (R^2), mean error (ME), mean absolute error (MAE) and root mean square error (RMSE) were used to evaluate the model in simulating the peak discharge changes. Results demonstrated that there will be a reduction in peak flow at 11 % to 15% and time to peak flow is slower by 5 minutes through a wet pond. For water quality aspect, a survey on biological indicator of water quality carried out depicts that the pond is within the range of rather clean to clean water with the score of 5.3. This study indicates that a constructed wet pond with wetland facilities is able to help in managing water quantity and stormwater generated pollution at source, towards achieving ecologically sustainable development in urban areas.

***Keywords*—**Wet pond, Retention Facilities, Best Management Practices (BMP), Urban Stormwater Management Manual for Malaysia (MSMA).

I. Introduction

MALAYSIA is striding to upgrade the social well-being of its urban citizens with program such as alleviating ever-increasing flash flood, water shortages and pollution problems. The particular issues being focused upon are stormwater management and drainage practices.

In stormwater management, controlling water quantity and stormwater generated pollution at source need to be focused towards achieving ecologically sustainable development and the health of the economy in urban areas like Kuala Lumpur or Penang in Malaysia [1]-[3]. In line with this, one of the efforts under the Government of Malaysia is the publication of the "Urban Stormwater Management Manual for Malaysia (MSMA)" by the Department of Irrigation and Drainage Malaysia in 2001 [4] and [2].

MSMA promotes the concept of stormwater management at source (i.e. within the catchment) and essentially involves runoff quantity and quality management through Best Management Practices (BMPs) [4] and [5]. BMPs in stormwater management involve detention and retention techniques, which include provision of detention and retention facilities such as dry and wet detention ponds, infiltration trenches, groundwater recharges, porous pavements for infiltration and provision of rough surface to retard flow reaching the watercourse and to decrease the peak flow of runoff [4].

A constructed mini wet pond is considered a type of wetland by referring to the definition of Ramsar Convention [6] which means "an areas of marsh, fen, peatland or water; whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water where the depth of which at low tide does not exceed 6 meters." and may include "riparian and coastal zones adjacent to the wetlands or island or bodies of marine water deeper than 6 meters at low tide lying within." It is a constructed pond that maintains a permanent volume of water incorporated into the design [7]. Soil utilized for the constructed pond must have the ability to store a standing pool of water and regulated by outlet device to discharge flows at various water depths and peak rates [8]. The depth of the pond is usually limited to 1.5-3 meters to avoid thermal stratification [7].

This study will be a case study on the evaluation of the initiatives to manage stormwater quantity and quality through the construction of wet ponds in a new development projects. It aims to show how a detention facility where in this study a constructed mini wet pond which is classified as a small scale on-site storage with off-line storage facilities can be used to reduce peak discharge by the temporary storage and gradual release of stormwater runoff by way of an outlet structure. Apart from the water quantity assessment, a water quality evaluation on the ability to manage and control the pollutants was as well assessed.

II. Study Site

The study site is a mini wet pond constructed within the school compound at Sekolah Rendah Kebangsaan Seksyen 2, Puchong, Selangor as shown in Fig. 1. The construction of

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pond was completed since August 2004. It is located just in front of the main stormwater drain near the main entrance of the school. The selection of site is based on the current drainage system of the school where the runoff will flow from the school buildings and football field to the constructed pond before entering into the main stormwater drain.

The catchment areas comprises of 2 blocks of school buildings and 20% from the total area of football field besides the school building which gives the total catchment areas at 0.58 hectare (Fig. 2).

Fig. 1 The constructed mini wet pond located at Sekolah Rendah Kebangsaan Seksyen 2, Puchong, Selangor

Fig. 2 Catchments of the constructed mini wet pond

III. Wet Pond Design

Swinburne method for flood control can be applied to estimate the Permissible Site Discharge and Site Storage Requirement, and further sizing of the pond [4]. Due to the constraints of space in the school, the total area of the pond designed and constructed is approximately 100m^2.

The runoff and daily losses of this project is estimated using Thorntwaite & Mather water balance model which is a daily rainfall runoff model [9]. The daily evaporation is estimated using Penman method [10]. For this project, daily evaporation is ranging from 5 to 10mm while recession constant is 0.9 to 1.0.

The wet pond is divided into five main components which are catchment area, inlet, shallow zone, deep zone and outlet. Rainfall and stormwater from drains will be diverted into the pond through drain sumps and 2 inlet perforated pipes. Runoff from catchment will flow into the shallow zone until it reaches the height of gabion in the center of the pond. The excess water from the shallow zone will then flows into the deep zone. The runoff will be kept in the deep zone until it reaches the weir height before flowing into the monsoon drain in front of the school. Table I shows the main components.

TABLE I
Main Component of Wet Pond

Component	Descriptions
Inlet	The inlet of the pond consists of a weir, 2 unit of 6 inches perforated pipes and 3 units of 10 m sub-soil drain in order to divert the runoff into the constructed wet pond during low and high flows.
Shallow Zone	It is about 0.3 m in depth and it is separated from deep zone by a gabion weir structure in the pond at 0.2 m in height.
Deep Zone	It is designed to have 0.3 to 1.2 m in depth. However, it is reduced to maximum height of 0.9 m after considering the safety factor of the school children. Initially, the base of pond is layered by impermeable material of High Density Polyvinyl Liner, but it is later concreted and topped up with top soils in the bottom of ponds due to leakage problem. The pond is planted with aquatic flora such as water lily (lotus). It serves an aesthetical value to all the students.
Outlet	The outlet structure or weir is a layer of aggregate with 0.6 m width and 0.3 m depth. It is used to discharge runoff from deeper zone to the main monsoon drain.

IV. Methodology

A. Water Quantity

1. Model Set-up

InfoWorks Collection System (InfoWorks CS) developed by Wallingford Software Ltd. is used in building the model and simulate the constructed mini wet pond in reducing peak discharge. It is formally named as Hydro Works. InfoWorks CS can support up to four different system types, which are divided to wastewater, stormwater, combined or other within any one model. This software also integrate with Geographic Information System (GIS) environment in ArcGIS ArcView, ArcInfo or MapInfo where all layers can be viewed, imported and exported in GIS format [11].

The basic inputs into the software are rainfall and water level data, catchment characteristic (area, slope and land uses) as well as drainage system characteristic (location and dimension of drainage). For rainfall and water level data, a telemetry station has been installed from January 2005 to March 2006 at the wet pond. The rainfall gauge installed is the HOBO rain gauge with 0.2 mm each tipping, while, HOBO 12 bit Electronic Data logger with ultrasonic sensor was installed to obtain water level data. The rainfall and water depth shared the same master database to send, captured and stored the water depth data every 1 hour. Anyway, the data of 15 minutes interval can be retrieved at site for further analysis. Fig. 3 shows the rainfall and water level stations installed.

Besides, a topographic survey of the wet pond was carried out on 4 and 5 October 2005. Through the topographic survey of the spot heights, a Digital Elevation Model (DEM) is generated using GIS software, ArcGIS version 9.2. Fig. 4 shows the DEM of wet pond.

Fig. 3 Rainfall and Water Level Station

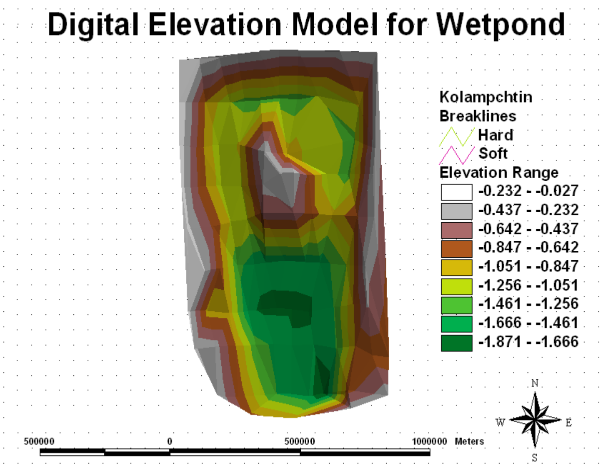


Fig. 4 DEM of wet pond

ArcGIS ArcInfo 9.2 and Microsoft Excel are applied to analyze the raw and simulated data, respectively. The simulations were run by having the basic input data to get the water depth or runoff as output. It is then calibrated with the water level observed data at site. Two rainfall events were used to calibrate and one event for verification of the model. Model calibration is a process of adjusting parameter so that the simulated result is suited with observed data with minimal errors [12]. Model verification is an approach to determine whether the developed model describes the behavior of the real system for event not being used during the model calibration [13]. It involves the comparison between the observed data and simulated output from the models. For verification purposes, both graphical and statistical tests were conducted. The statistical criteria used were namely, correlation coefficient (R^2), mean error (ME), mean absolute error (MAE) and root mean square error (RMSE). The calibrated and verified model was then applied to simulate the scenario of the impact of constructed wet pond to minimize the peak discharge. The numerical model was built using InfoWorks CS is shown in Fig. 5.

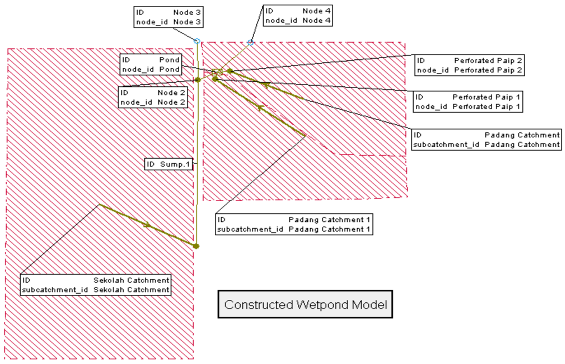


Fig. 5 Numerical model of wet pond using InfoWorks CS

2. Model Calibration and Verification

From the model calibration and verification, it shows that the model provides reasonable results in simulating the changes in flow and volume of flow. For this study, we have selected 2 events of rainfall which are the highest rainfall intensity recorded on 26 February 2006 (1-year Average Recurrence Interval, ARI) and moderate rainfall intensity recorded on 28 March 2006 (3-months ARI) for calibration purposes. For verification, event on 29 March 2006 (2-months ARI) is used. Figs. 6 to 8 illustrate that the simulated results are very close to the observed data in all simulated results for three sets of data on 26 February 2006 (calibrated event), 28 March 2006 (calibrated event) and 29 March 2006 (verified event). All events are in the range of 90% confident level. The comparison between the observed and simulated scenarios for both calibrated and verified models show good agreement and satisfactory mean square errors (R^2) are more than 0.9 as shown in Table II.

TABLE II
STATISTICAL ANALYSIS FOR CALIBRATED AND VERIFIED EVENT

Statistical Test	26 February 2006 (Calibrated Event)	28 March 2006 (Calibrated Event)	29 March 2006 (Verified Event)
Mean error (ME)	-0.002	-0.005	-0.002
Mean absolute error (MAE)	0.008	0.012	0.011
Root mean square error (RMSE)	0.012	0.017	0.006
Correlation coefficient (R^2)	0.903	0.910	0.941

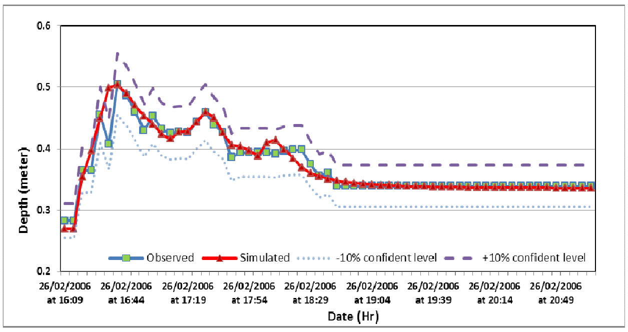


Fig. 6 Calibrated event on 26 February 2006

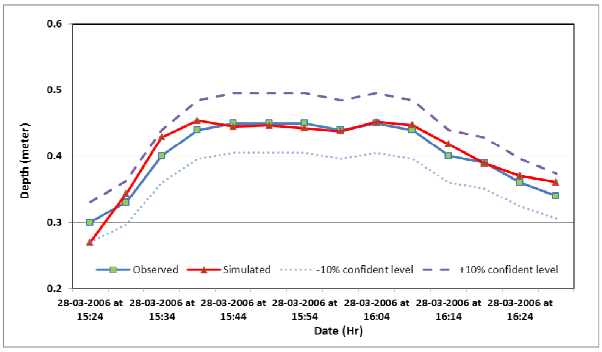


Fig. 7 Calibrated event on 28 March 2006

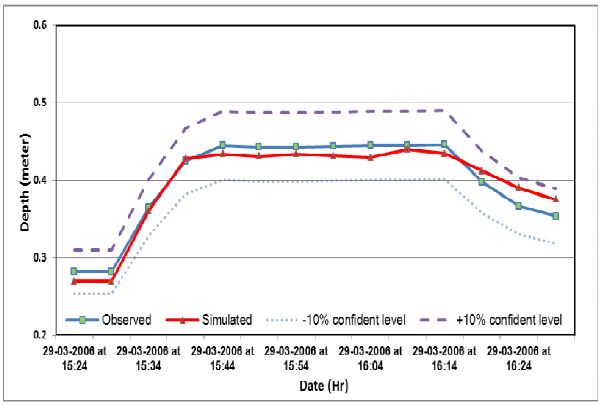


Fig. 8 Verified event on 29 March 2006

B. Water Quality

Apart from the water quantity aspect, the water quality of constructed wet pond is also evaluated by using the Biological Water Quality Index which referred to the existing Guidelines to Freshwater Invertebrates of Ponds and Streams in Malaysia [14]. In most of the case studies, chemical analysis are valuable and necessary to assess on the water quality status of certain streams or lake, but the concern is not only the contamination, but more on the effects of their concentrations on organisms living in the pond or streams [15]. Macro invertebrates are valuable indicators of the health of aquatic environments and they are typically found on the bottom of a stream or lake and do not move over large distances [16] and [17]. Therefore, they can portray the status of the quality of lake water in general.

A survey is carried out on 26 March 2007. The basic equipment and its function are as Table III.

TABLE III
BASIC EQUIPMENT AND ITS FUNCTION

Equipment	Function
Aluminium tray	To fill pond water
Square net/spoon	To collect the animals
Small white dish	To put the animal for further examination
Magnifying glass	To examine the collected animals

The procedures to carry out the survey are as the following:

a) Choose a site and collect animals from different spots in the area,
b) Fill a large aluminum tray with pond water,
c) Place a large square net to disturb the pond bed in front of the net and empty the debris collected in the net into the tray,
d) Look carefully for any movement in the water when all is settled,
e) Spoon an animal gentle into a small white dish,
f) Look at the water with a magnifying glass and examine the name of the animals using the guidelines,
g) For the animals on the water surface, scoop them up directly with a net.

In order to assess the water quality of the constructed pond using Biological Water Quality Index, each collected animals will be given a "pollution" scores. For instance, animals which need a lot of dissolved oxygen and cannot bear pollution may be given a higher score (10 as stated in the Guideline [14]) while those animals that may tolerate with polluted water are rated a lower score (1-2 as stated in the Guideline [14]). Each type of animals will only be counted once in the assessment and the average of the total score will be the Biological Water Quality Index. The calculation of the Biological Water Quality Index is using (1). Then the status of water quality in the wet pond is determined by comparing the Biological Water Quality Index in Table IV.

$$\text{Biological Water Quality Index} = \frac{\text{Total Score}}{\text{Number of the animal types}} \quad (1)$$

TABLE IV
BIOLOGICAL WATER QUALITY INDEX

Range of Score	Water Quality Assessment
7.6-10	Very clean water
5.1-7.5	Rather clean-clean water
2.6-5.0	Rather dirty water-average
1.0-2.5	Dirty water
0-0.9	Very dirty water

V. RESULTS AND DISCUSSION

A. Water Quantity

There are two scenarios for each events, one modeled the scenario without constructed wet pond while the other modeled scenario with the constructed wet pond. Refer to Fig. 9 for the comparison of both scenarios on 26 February 2006 and Fig. 10 for the scenarios on 29 March 2006. The results in flow differences and time to peak for both events are shown in Tables V and VI, respectively.

From both events on 26 February 2006 and 29 March 2006, it is found that there is a reduction of 11% to 15% of flow by having the constructed wet pond at site and the same scenario helps to slow down the peak flow by 5 minutes. The present study obtained a similar finding on the ability of an on-site storage or pond to attenuate peak flow as studied by [5], [18]-[20].

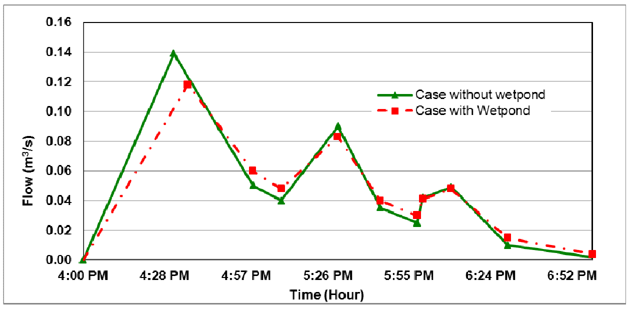


Fig. 9 Comparison case with and without constructed wet pond for calibrated event on 26 February 06

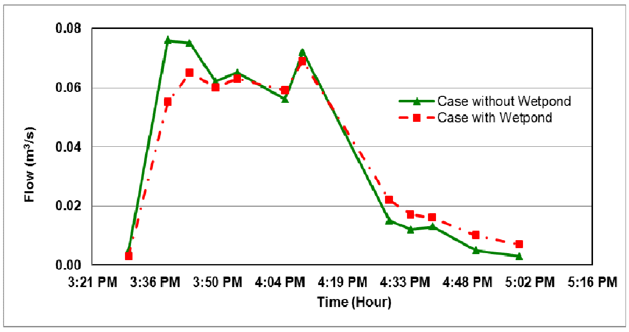


Fig. 10 Comparison case with and without constructed wet pond for verified event on 29 March 2006

TABLE V
RESULTS OF COMPARISON FOR CASE WITH AND WITHOUT CONSTRUCTED WET POND ON 26 FEBRUARY 2006

Parameter	Without Pond	With Pond	Differences
Peak Flow(m^3/s)	0.139	0.118	15 %
Time to Peak Flow	4.32PM	4.37PM	5 min

TABLE VI
RESULTS OF COMPARISON FOR CASE WITH AND WITHOUT CONSTRUCTED WET POND ON 29 MARCH 2006

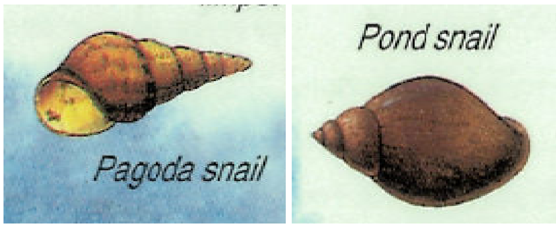
Parameter	Without Pond	With Pond	Differences
Peak Flow(m^3/s)	0.076	0.065	11%
Time to Peak Flow	3.39PM	3.44PM	5 min

B. Water Quality

There are 6 types of indicator animals obtained from the survey done and it is used to calculate the Biological Water Quality Index. Each types will be multiple with the score given in the guidelines [14] to obtained the Total Score. Results of the calculation are shown in Table VII. Figs. 11 to 14 show some of the animal considered for the calculation of Biological Water Quality Index.

TABLE VII
CALCULATION OF BIOLOGICAL WATER QUALITY INDEX

No.	Animal	Quantity	Score
1	Pagoda Snails	2	6
2	Pond Snails	2	3
3	Damselfly nymphs	1	6
4	Non-biting midge larvae	1	2
5	Swimming mayfly nymphs	1	5
6	Stonefly nymphs	1	10
	Total Score		32
	Number of animal types		6
	Biological Water Quality Index		5.3



(a) (b)

Fig. 11 (a) and (b) Pagoda and Pond Snails

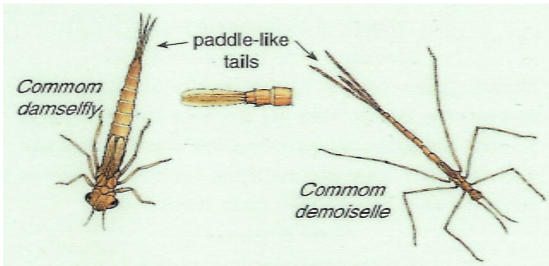


Fig. 12 Damselfly nymphs

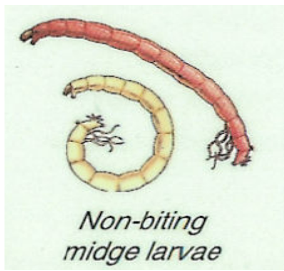
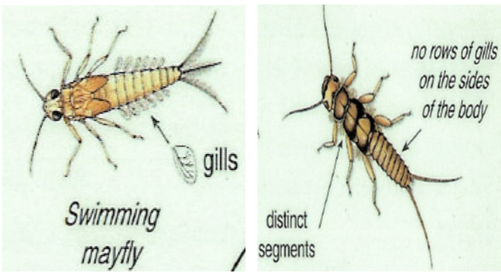


Fig. 13 Non-biting midge larvae



(a) (b)

Fig. 14 Swimming mayfly and Stonefly nymphs

From the survey, we also found others animal namely Non-indicator animals which are still not considered in the calculation of Biological Water Quality Index such as Water Measurer (Surface Living Animal), water spider (Water Spider & Water Mites), Whirligig beetle larva (Beetle Larvae), Common demoiselle (Damselfly Nymphs) and Hairworms.

The Biological Water Quality Index calculated is 5.3 which indicated that the water quality in the pond is rather clean to clean from Table IV. Anyway, the Index of 5.3 is near to the border line of 5 where it is the cutting line of rather dirty and average water quality.

VI. Conclusion

Generally, it shows that it is appropriate to evaluate the impact of wet pond provision in flow reduction using computer modeling such as InfoWorks CS. Even though the results revealed only a minimal reduction in flow but wet ponds are still advantageous to be promoted. A constructed wet pond with wetland facilities is able to help in managing water quantity and stormwater generated pollution at source, towards achieving ecologically sustainable development in urban areas like major cities in Malaysia.

In additional, wet ponds area provide an educational besides recreational benefits and it served as a high visual appeal which adds to the natural landscape for the school teachers and students in particular. The public in general can appreciate better on the impact of development on flooding, the need and the importance of stormwater management in order to sustain a better and viable environment.

The construction of wet ponds should be encouraged aligned with the recommendation of MSMA in new residential, commercial and industrial lots, government building areas, schools compound as well as public open space, recreational and sport facilities areas.

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