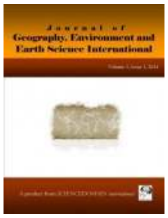

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Applying PCSWMM for Stormwater Management in the Wat Phnom Sub Catchment, Phnom Penh, Cambodia

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: Wat Phnom sub catchment in Phnom Penh, Cambodia, is highly susceptible to flash flooding during rain events. The objective of this study is to determine where wastewater and stormwater in the Wat Phnom area are discharged and to determine the hydrological and hydraulic functionality of the drainage system in the area. This specific subcatchment has not been included in previous drainage system modelling of Phnom Penh.
Place and Duration of Study: Phnom Penh, Cambodia, 2014.
Methodology: In this study, PCSWMM was selected to do the model simulation. Rainfall events for May 23rd, 2014 and 3 design storms of rainfall (2 year, 5 year, and 10 year return periods) were developed to drive the model. The Sensitivity-based Radio Tuning Calibration (SRTC) tool was used for model calibration with the depth of water at junction WL16 for the May 23rd, 2014 event. SRTC provides fast calibration for any model size or model complexity and calibrates to multiple objective or response functions simultaneously by filters to find matches for specific calibration locations. Consequently, PCSWMM can be employed as a useful tool to examine the hydrological

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and hydraulic performance of the drainage system with different rainfall design storms to provide information for stormwater management.

Results: This study confirmed that the Wat Phnom sub catchment is a part of the area which transfers water to the Boeng Cheng Ek wetland. There are two sub catchments within Wat Phnom (Sub catchment No. 1 and No. 5) which had particularly high runoff, and four specific nodes were particularly sensitive to flash flooding.

Conclusion: The drainage system is not sufficient to handle rainfall exceeding a 2 year return period, where surface flooding could occur for duration of up to 2 hours.

Keywords: Stormwater management; modeling; urban flooding; PCSWMM; Phnom Penh.

1. INTRODUCTION

Stormwater management is essential because combined sewage flooding related to insufficient drainage can result in flooding damage and impact public health [1]. Waste and pollution transported by stormwater results in qualitative and quantitative problems, affecting public health especially sanitation and hygiene and quality of the environment. Stormwater runoff contains sediment which fills drainage ditches and channels, resulting in flooding [2-6]. Sufficient and efficient stormwater management remains a challenge in both developed and developing countries [7-10] such us Malaysia [11], Cambodia [12], and United States [13,14].

Phnom Penh, the capital city of Cambodia (population 1.5 million, 2009) is located on a flat alluvial plain at the western bank of the confluence of the Tonle Sap River and Mekong River [15]. It is serviced by a combined sewer system [12,15]. For a number of reasons, including financial constraints, 80% of the original sewer system has been damaged and is not currently functioning well [12]. The drainage system is not functioning well due to clogging during stormwater collection that causes frequent flooding on the roads during the rainy season [15]. In addition, the city developed with little planning or control, resulting in flooding problems, squatter problems along drainage ways, increasing wetland in-fill, and poor urban infrastructure [16,17]. The sewer system itself frequently cannot handle the high intensity monsoon rains and street flooding occurs [18]. As a result, the city suffers from habitual inundation and poor environmental conditions caused by stagnant wastewater in lowland areas. These are serious constraints to the residents' living environment as well as social and economic development, not only in Phnom Penh City but also the whole country in general because similar conditions occur in other urban areas of Cambodia [19].

The Japanese International Cooperation Association (JICA) has played an important role with technical support to the Phnom Penh municipality to formulate their master plan on flood protection and urban drainage improvement. The project "Flood Protection and Drainage Improvement in the Municipality of Phnom Penh" was begun in 1999 and mainly focused on a feasibility study of improving the drainage system in Phnom Penh municipality [15]. In 2006, JICA launched Phase II of the flood protection and drainage improvement project in Phnom Penh which mainly focused on a small part of the city including the Wat Phnom area, Central Market Area and Royal Palace and National Museum [19]. The main activities of this project were development of revetment works, drainage pipe and side ditch improvement, pumping station and underground reservoir formation, and interceptor development [13]. In recent work, JICA aimed to increase protection against floods having up to a 2-year return period. A planning scale of management with drains designed to handle a 2-year flood probability is targeted, with inundation depths of 20 cm within 1 to 2 hours; If this is achieved, the frequency of flooding will be reduced, and flood damage by more than a 2-year flood probability will be mitigated [19]. In the JICA work, the MOUSE model was used to simulate surface flooding in the targeted area but the report does not show detail about flow in conduits, runoff, depth of water in conduits or flood and depth of water in nodes. To address these gaps in model output and assessment, we used PCSWMM to explore flooding conditions for the Wat Phnom sub catchment area.

The Personal Computer Stormwater Management Model (PCSWMM, running the United States Environmental Protection Agency SWMM5 engine) is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity from primarily urban areas [20]. The Stormwater

Management Model (SWMM) was first developed in 1971 and has undergone several major upgrades since then. It has been used throughout the world for planning, analysis, design, management and litigation related to stormwater runoff, combined sewers, sanitary sewers, and other drainage systems in urban areas, with many applications in non-urban areas as well [21]. Running under Windows, SWMM provides an integrated environment for editing study area input data, running hydrologic, hydraulic and water quality simulations, and viewing the results in a variety of formats including conveyance system maps, time series graphs and tables, profile plots, and statistical frequency analyses. SWMM accounts for hydrologic processes that produce runoff from urban areas which include time-varying rainfall, evaporation, rainfall interception, infiltration of rainfall, percolation of infiltrated rainfall, and exchange between groundwater and the drainage system [21]. In addition to modeling the generation and transportation of runoff flows, SWMM can be used to estimate the production of pollutant loads associated with this runoff, as well as generate loads in wastewater flows. It is recognized as a productive and cost effective tool for urban storm water management in many countries around the world such as United States [22], Russia [23], Costa Rica [24], Thailand [25,26], and also Cambodia [16,17,27].

A recent study for Phnom Penh applied PCSWMM to estimate contaminant loads in the sewer system for a range of storm intensities and suggested that the Boeng Cheung Ek wetland was effective in treating municipal waste [16,20,27]. However, modeling efforts utilized in those studies did not include the Wat Phnom sub catchment. The current study aims to determine and evaluate hydrology and hydraulic functioning of the sewer system in the Wat Phnom basin using actual rainfall and under rainfall event design storms using PCSWMM.

2. RESEARCH METHODS

2.1 Sub Catchment Delineation

Boundaries of the catchment area initially were adopted from the MOUSE model which was applied by JICA, [19]. Sewer system maps from JICA (2006) and the Department of Public Work and Transport (DPWT) (2010) were subsequently employed to extract detailed sewer information related to invert elevation, geometry, flow direction, and pipe length [28]. Based on the collected information, sub catchments were delineated based on Ikonos satellite images (2005) and Google Earth images (2014). The final sub catchment boundaries were validated by field observation during a rainfall event on May 7th, 2014. In particular, it was noted that the northern part of the sewer system flows directly to the Tonle Sap River while the southern part flows to the Boeng Cheung Ek wetland. Five sub catchments were identified (Table 1 and Fig. 1).

Compared with the MOUSE model boundaries some differences were found in sub catchment No. 2. Several sewers flow directly to the Tonle Sap River and did not contribute to sub catchment No. 2.

2.2 Data Collection and Processing

Rainfall data were collected from a tipping bucket rain gauge (Davis Model 7852) with a tip sensitivity of 0.2 mm of rainfall installed at Wat Ounalom (X: 113404, Y: 1045547) . This location was selected due to availability, security for equipment, and proximity to the study area. Rainfall data were converted to rainfall intensity with a five minute time step in order to drive the PCSWMM model. A rainfall event on May 23rd, 2014 (18.2 mm) was used to calibrate the model while an event on May 22nd, 2014 (depth13.8 mm) was used for model validation. Design storms of rainfall were developed based on probable rainfall in hourly rainfall adopted from JICA, [15] as in Table 2. The curve pattern of each design storm and the 23 May calibration event can be found as in Fig. 2 while the rainfall pattern for the validation event is shown in Fig. 3.

Water levels in the sewer were collected at 5 minute intervals using a Global Waters Model U16 recording level gauge (X: 492186, Y: 1279435) 5 m up stream of underground storage 5 (UGR 5) (Fig. 1). Data were downloaded every weekend. Dry weather flow patterns were developed to represent the depth of water for each hour per day. Data were collected from May 27th to June 2nd, 2014 for this purpose. Subsequently, a multiplier approach was used to represent the daily pattern of flow where a value of 1 was the average depth.

2.3 Model Calibration and Validation

Drainage systems outside of the study area were not included in the model simulations. Moreover, pumping operation was not included in the model because the actual pumping did not work. The kinematic wave approach was used for routing water as the pump was not operated. The Green Ampt equation was selected to represent infiltration, with a suction head 3.5 mm, hydraulic conductivity of 0.5 mm/h and initial deficit of 0.25. The Manning's n for the conduits was valued at 0.0251.

Table 1. Characteristics of sub catchments

Sub catchments	Cover area (ha)	Slope (%)	Impervious (%)	Pervious (%)
Sub catchment No.1	21.1449	0.1119	87.02	12.98
Sub catchment No.2	11.4661	0.1307	78.98	21.02
Sub catchment No.3	4.1976	0.0538	72.76	27.24
Sub catchment No.4	4.0626	0.0954	66.06	33.94
Sub catchment No.5	15.128	0.0602	98.48	1.52

Fig. 1. The study area of Wat Phnom's sub catchment, Phnom Penh, Cambodia

Table 2. Ground and inverted elevation of node and outfall of subcatchment

No.	Junctions	X	Y	Ground elevation (m)	Inverted elevation (m)
1	R102-3	491635	1279505	10.74	7.73
2	R102-4	491754	1279520	10.53	7.64
3	R106-4	491764	1279446	10.73	7.45
4	R108-E003	491770	1279398	11.06	7.41
5	108N-003E	492174	1279451	11.30	7.18
6	108N-003F	492181	1279441	11.30	7.18
7	R108-A001	491335	1279335	10.67	8.21
8	Outfall (1)	492224	1279442	7.60	5.6
9	Outfall (2)	492207	1279407	11.34	6.97

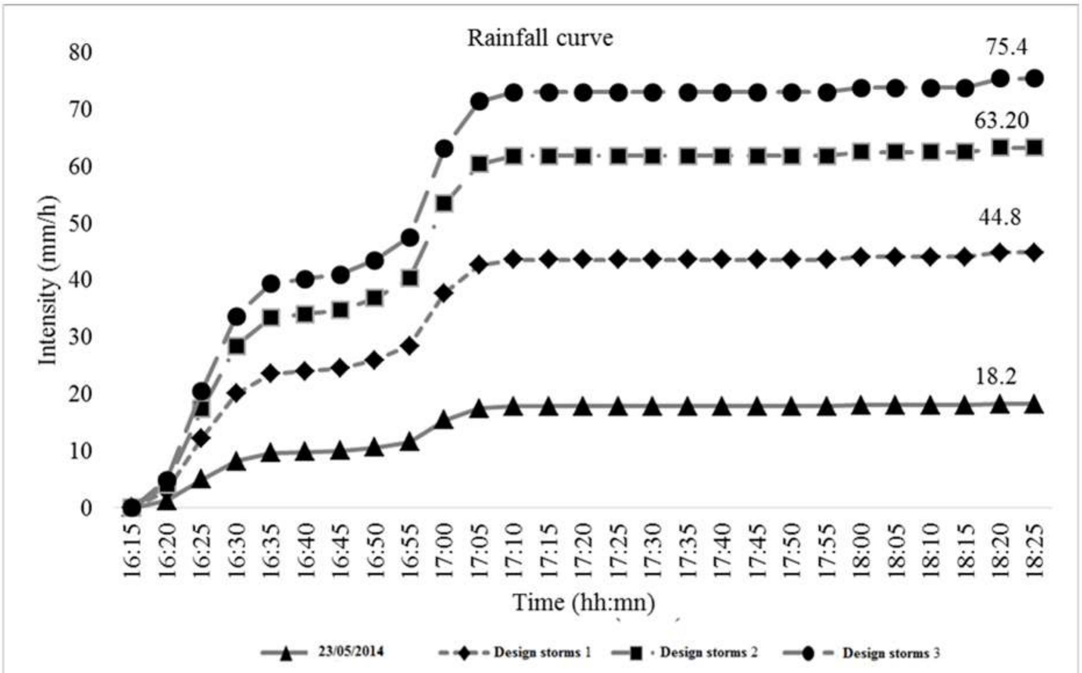

Fig. 2. Rainfall partterns of May 23rd, 2014, design storm 1 (2 years return period), design storm 2 (5 years return period) and design storm 3 (10 years return period)

Table 3. Return period of rainfall intensity defined by JICA, [15]

Return period (years)	Hourly rainfall (mm/h)
2 year	44.8
5 year	63.2
10 year	75.4

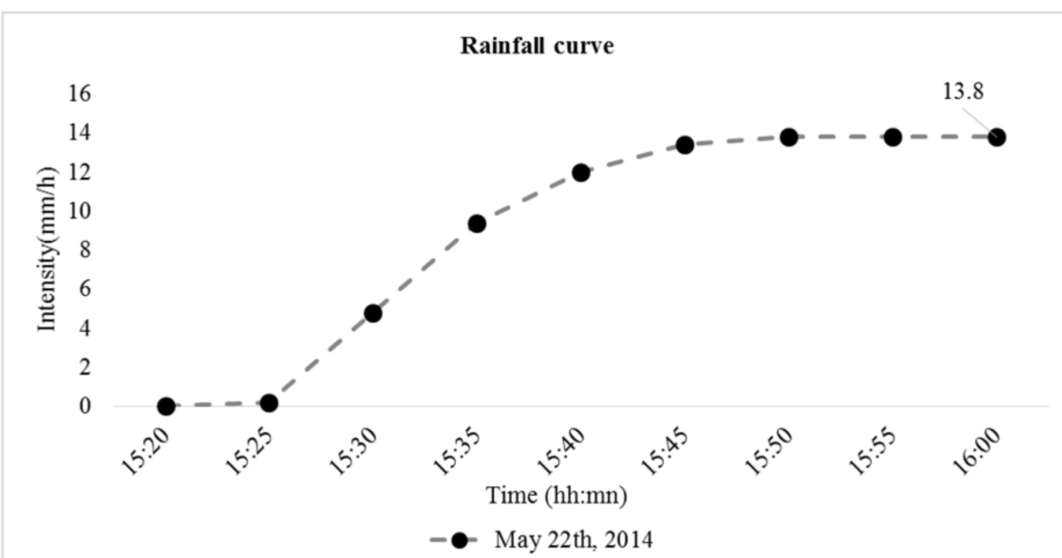

Fig. 3. Rainfall patterns of events May 22nd, 2014 used for model validation

Table 4. Result of model calibration error analysis

Equations	Model calibration error
Nash Sutcliffe Efficiency (NSE)	0.49
R-squared (R^2)	0.56
Least Squared Error (LSE)	22
Root Mean Squared Error (RMSE)	3.56

Table 5. Comparison between observed depth and simulate depth

Date/Time	Observation depth (m)	Model depth (m)	Difference%
May 22nd, 2014 15:40	0.66	0.59	10.61
May 22nd, 2014 20:10	0.75	0.62	17.33
May 22nd, 2014 21:40	0.66	0.62	6.02

PCSWMM's Sensitivity-based Radio Tuning Calibration (SRTC) tool was used in model calibration. This tool provides fast calibration for any model size or model complexity and calibrates to multiple objective or response functions simultaneously by filters to find matches for the targeted locations. The actual depth of water at node WL16 on May 23rd, 2014 was used for model calibration purposes. Sub catchment parameter inputs were selected with 30% uncertainty.

Model validation was conducted in order to get reliable output. Water level data (WL16) on May 22nd, 2014 were selected for model validation purposes. Field observation during rainy days was conducted to help verify model accuracy. The percentage of difference between observed data and simulated data was also calculated to evaluate the error of the model.

The model was calibrated using the SRTC tool with parameter uncertainty constrained to ±30%. The Nash Sutcliffe Efficiency (NSE) was selected to assess model fit, where a value near 1 represents a better fit. In this study the NSE value was 0.49 which shows the accuracy of the model is fair (Table 4 above). However, this result is acceptable due to several factors contributing to model output errors. Firstly, the model did not include the simulation of solid waste and during our model calibration and evaluation we observed solid waste was jammed on the screening resulting in the water level at the observation point increasing sharply. Secondly, as Wat Phnom is a sub catchment of the Trabek Catchment, during this study, many sewer systems in the Trabek Catchment were under construction which might affect the hydrological and hydraulic conditions of the study sub catchment.

Model validation was developed to ensure reliable output from model. Some of the water levels at node WL16 for the May 22nd, 2014 event were utilized for single event model validation. Actual depth is compared with model estimates in Table 5 above and results are quite good.

3. RESULTS AND DISCUSSION

3.1 Dry Weather Inflow

Dry weather flow refers to the depth of water in a conduit during a dry weather day. Dry weather flow patterns exhibited some differences from a previous study by Sovann et al. [20] done in 2011 (Fig. 4). Depth of water reached a maximum at noon (Around 12:00 pm to 1:00 pm) and a minimum in the evening time (5:00 pm to 6:00 pm) (Fig. 4). The previous study identified the lowest depth at 5:00 am while the current study observed it at 6:00 pm. In addition, the previous study identified the highest depth occurring on 9:00 am while the current study found it to occur between 12:00 pm to 1:00 pm. Some possible reasons behind the difference are likely related to: (1) the locations of observation because the previous study (2011) measured flow at the down steam end of the wastewater collection system while this study measured flow at an up stream point. Moreover, it is noticed that the Wat Phnom area is more influenced by commercial activities and restaurants when people have lunch at noon and then go home at 6pm and commerce is less busy, while the previous study makes more sense in terms of a residential area. However, it is likely that a number of factors contributed to the differences observed and more study is necessary to be conclusive about which factor contributed the most to the differences observed.

3.2 Runoff

The peak runoff for the 23 May and design storm events is shown in Fig. 5. Runoff was greatest in sub catchment No.1 and No. 5 because of their large area with high percent imperviousness that results in less infiltration into the soil.

3.3 Depth in Conduit

Depth in conduit refers to depth of water during the simulation in a sewer pipe (conduit) which results from runoff. The maximum depth of water in a conduit occurred for conduit No.2, conduit No.3 and conduit No. 4 (Fig. 6). The depth of water reached 1.3m in conduits C2, C3 and C4 which is the maximum diameter for these pipes (i.e. they were running full for the design storms). Other conduits had 1.5 m diameters.

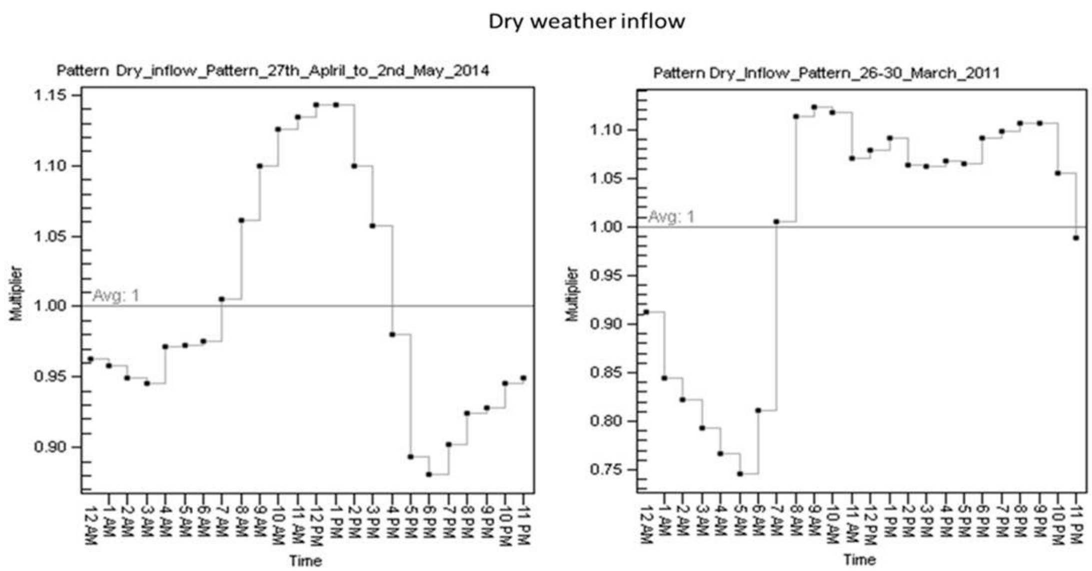

Fig. 4. Comparison of multiplier dry weather inflow pattern

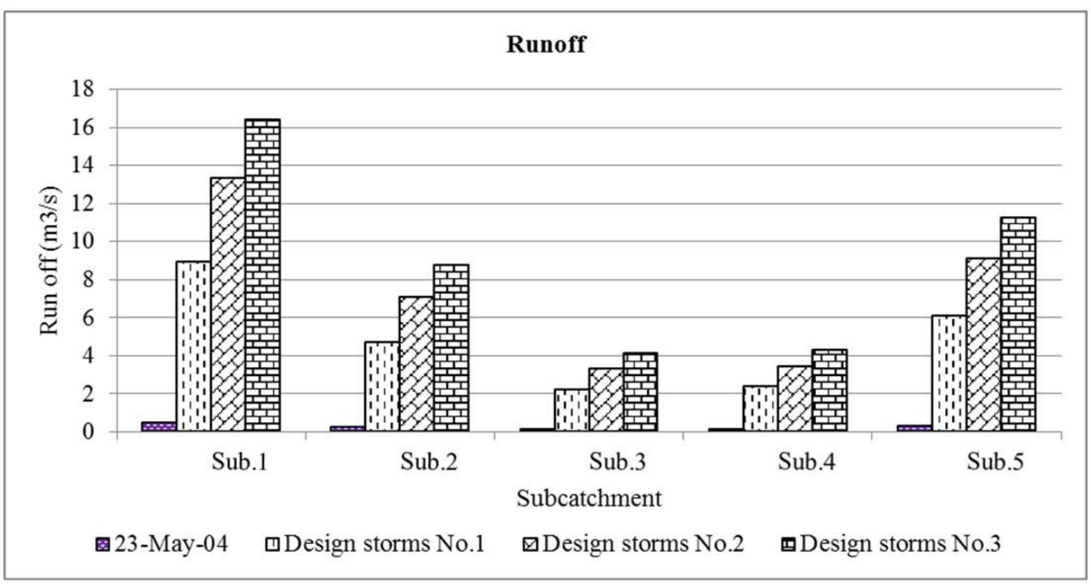

Fig. 5. Runoff from the five Wat Phnom sub catchments of the design storms

3.4 Flow

Flow refers to the flow rate of water flow in a conduit. The peak flow occurred in conduits No.7, No.8 and No. 9 (Fig. 7). Flow in these conduits was up to 5.9 m^3/s. It is noticed higher flows occur at the end of the sewer line of the whole sub catchment because water runoff from all sub catchments was collected in the line and the slope of the conduit was also high (accounting for the smaller depths of flow at these sites, Fig. 6).

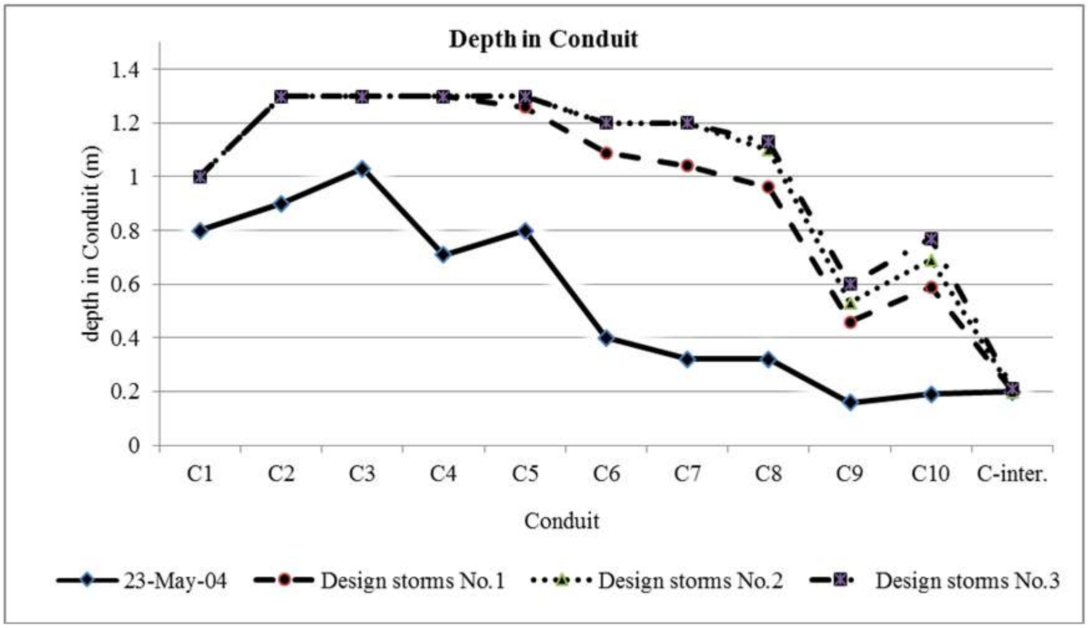

Fig. 6. Depth in conduit of Wat Phnom Sub catchment of the design storms

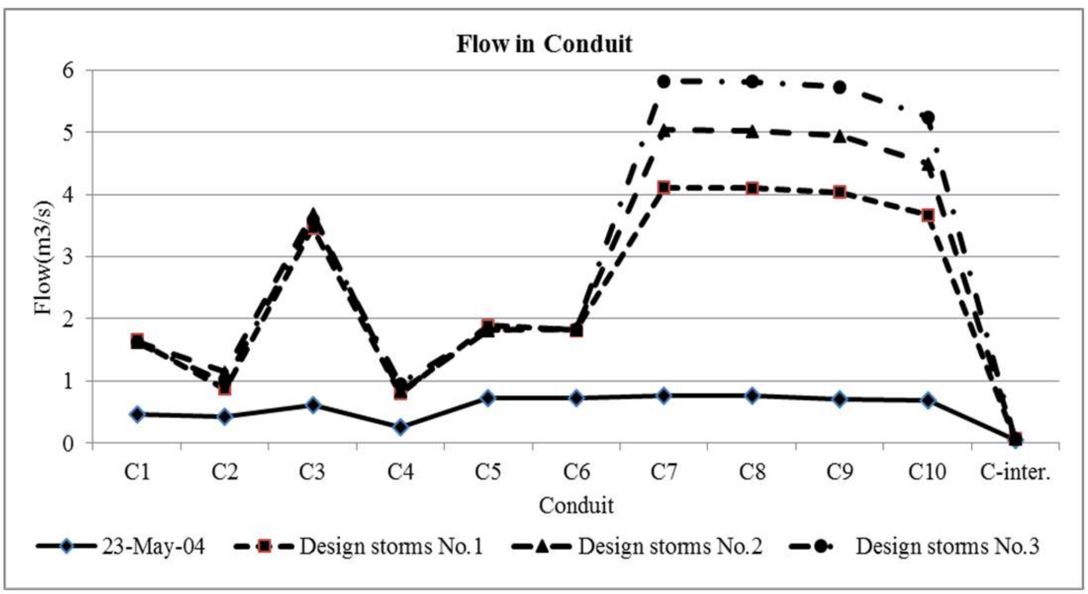

Fig. 7. Flow in conduit of the five sub catchment of the design storms

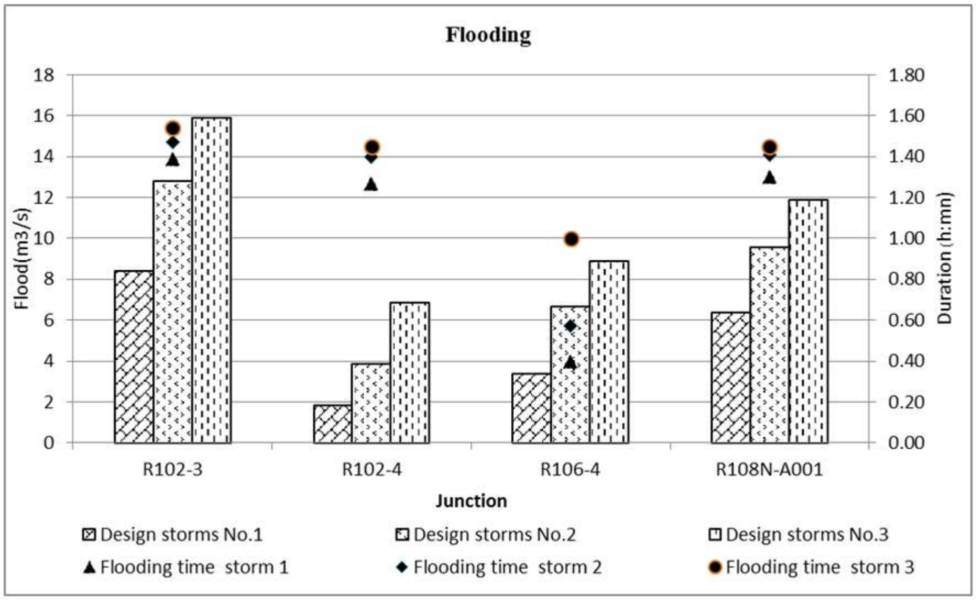

Fig. 8. Flood of four nodes with duration of flooding of the design storm

3.5 Flood

Flood at a node refers to water which overflows at the node and produces localized surface flooding. For the design storms, 4 nodes produced flooding. Node No.R102-3 had the highest flood occurrence (15.9 m^3/s) with flooding time up to 1 h: 54 mn. The four nodes often were predicted to flood because high runoff from sub catchment No.1 and No.2 was conveyed to these points directly (Fig. 8 above). Moreover, ground level at these points was lower than other nodes especially around Wat Phnom. The event on May 23th, 2014 did not produce flooding, although surcharging conditions may have occurred.

4. CONCLUSION

PCSWMM can be employed as a useful tool to examine and evaluate hydrological and hydraulic functionality of combined sewer systems under different rainfall design storms to provide scientific information for stormwater management. It was found that the Wat Phnom sewer system was able to adequately transfer water from this catchment for storms with less than a 2 year return period (or 44.65 mm/h). Moreover, 4 nodes frequently produced surface flooding with durations up to nearly 2 hours for design storms of 2 years and greater, if the pump station is not operating. This study also confirms that Wat Phnom sub catchments were a part of the area which transferred water to Boeng Cheung Ek wetland year round. The model results have identified system constraints where additional remediation could be done to reduce surface flooding. Furthermore, in order to reduce runoff and storm water flooding in the study area, based on sub catchment characteristic identities (percentage of pervious and impervious area) in each sub catchment especially S1, S2, S3 and S4 there likely is some potential to increase the pervious area by applying some Low Impact Development (LID) technology such as permeable pavers and tree box filters.

DISCLAIMER

SEAGA (Southeast Asian Geographers Association) International Conference 2014, Siem Reap, Cambodia (at Royal University of Phnom Penh), 25 - 28 November 2014.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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