An Application of Urban Water Modeling toward Pluvial Flooding Assessment in Urban Area under Climate Change

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Abstract

The flooding in the Bangkok city became more frequent due to overpopulation, urbanization, unplanned development and climate change. These phenomena was not only damage organisms and environment but also impact economy, health, social and transportation. In urban areas, flooding was caused by several reasons: the rise of the water level in the river through the city high tides for coastal cities, poor operation of drainage system, and each of drainage systems maintenance etc.

Flood management required an understanding of the causes and adaptation in order to take appropriate measures by decreasing percentage of imperviousness in urban area. Thus, it could be taken to reduce the impact of floods. The most important tool needed for decreasing percentage of imperviousness in urban area are sustainable urban drainage system tools. These could provide effective tools to reduce impact of floods.

The main objective of this study is to analyze the effect of decreasing percentage of imperviousness at Sukhumvit area, Bangkok, Thailand for the latest urban drainage modeling software. Comparing the result of each amount of decreasing percentage for a suitable value of the present condition. These effects of decreasing percentage of imperviousness at Sukhumvit area, Bangkok, Thailand are helpful for the urban pluvial flood control. Moreover, these are solution for the urban development planning in future.

Keywords: Flooding, Drainage system, Infiltration, urban

1. Introduction

Bangkok is the capital city of Thailand. The area is 1568.74 square kilometers or 605.7 square miles. Bangkok is located in the Chao Phraya River basin and Chao Phraya River split down the middle of city. The ground level is between +0.00, +2.00 m. above mean sea level. Nowadays, Bangkok has flooding regularly and more impacts to residential than the past because Bangkok has rapid urbanization, impact from change of upstream condition in the northern part of Thailand, insufficient drainage capacity, tidal effect, land subsidence from groundwater consumption and climate change. These can causes urban flooding in Bangkok area.

Urbanization is the process of turning green field sites into developments. For example, building in the countryside. Infiltration is rainfall soaking into the ground and eventually ending up in rivers over a period of days. Once the site has been developed and the site is now impermeable so the rainfall becomes surface runoff quickly without soaking into the ground to get to the rivers in hours or even minutes. These make the hydrograph to peak higher and sharper (more water in less time) and flooding occurs.

Climate change is making weather less predictable, rains more uncertain and heavy storm rainfalls more likely. The unpredictability of rainfall can be caused by flooding in urban areas. Urban floods are a great disturbance of daily life in the city. Roads can be blocked, people can't go to work or to schools. The economic damages are high but the number of casualties is usually very limited, because of the nature of the flood. The water slowly rises on the city streets. When the city is on flat terrain the flow speed is low and you can still see people driving through it. The water rises relatively slow and the water level usually does not reach life endangering heights.

In the central part of Bangkok, Sukhumvit area, is a representative of urbanization. Bangkok metropolitan administration (BMA) has department of drainage and sewerage (DDS) working on flood problem in Bangkok. Several studies from DDS have shown that drainage capacity of the existing system is still not perfect enough. In Sukhumvit area has primary drainage system from surrounded canals and the secondary drainage system inside area. Therefore, when the water level in primary drainage system around this area is getting higher, the secondary drainage system will have problem to drain water out.

The study in Sukhumvit area by using modelling tool and analyze the decreasing percentage of imperviousness can show the capability of infiltration effect to the urban area. These can help to reduce impact of floods in the urban area. Moreover, this study will concern only about adaptation of urban drainage system from impact of climate change by applying some of adaptation into the model and find out which one can perform well in the area and which alternative of adaptation can reduce peak of rainfall more or less.

2. Research Objectives

The main objective of this research is to analyze effect percentage of decreasing imperviousness at Sukhumvit area, Bangkok, Thailand and comparing the result of each amount of decreasing percentage for a suitable value of the present condition.

3. Research Methodology

3.1 Study area

In this study, an urban area was selected to apply the urban drainage model using the rainfall forecast results to simulate and predict flood situation. At present, levees with 100-year return period are being constructed along the river to prevent river and tidal flood. The main remaining cause is the heavy rainfall over the city. The drainage system in Bangkok is old and designed for 2 and 5-year return periods, which may not be adequate for stormwater in extreme events. The polder system has been proposed by NEDECO

(Netherlands Engineering Consultants) in order to provide adequate pumping capacity for each several areas in the city. At present, there are 15 polders in the primary drainage of Bangkok as summarized by DDS (1996). Each polder has its own drainage, so-called secondary drainage system. Sukhumvit catchment is the one of them. Sukhumvit catchment is very highly urbanized area and one of the central business districts of eastern Bangkok, located in inner part of Bangkok in the right side of Chao Phraya River. It has an area of 24 km2 with population density of 8,400 person/km2. It is bounded by canals and the Chao Phraya River. Average elevation of the Sukhumvit area is 0.4 to 1.0m above mean sea level (MSL). Maximum levees elevation along klong Sean Seap and klong Tan/Phra Khanong are approximated as 1.2m MSL. This catchment is a flat plain. Although, this area could be prevented from flooding caused by overflow from the Chao Phraya River in 1995 and 1996, stormwater is difficult to be drained out by gravity into existing canals. Pumping stations are necessarily needed as main drainage structures.

3.2 Rainfall runoff model

In urban hydrologic models, mathematical equations primarily simulate rainfall loss and runoff routing. The loss equations are responsible for estimating the loss of rainfall due to infiltration and depression storage whilst routing equations transform the effective rainfall to a runoff hydrograph based on catchment characteristics. The loss and routing are simulated at the same time. The general process is to remove the loss from the total rainfall and then simulate the routing process. There are a number of hydrologic modelling approaches such as the time-area method and kinematic wave method (O'Loughlin and Stack 2003; MIKE URBAN 2014). These methods use different theoretical concepts to integrate peak attenuation and travel time of runoff due to the storage action of the catchment and the drainage channels. Time-area method has been widely used in hydrologic research due to its ability to simulate urban catchments compared with other methods. Therefore, the theory of the time area method is discussed in this section. The time-area routing models can simulate the flow at the outlet of a catchment based on the variation of contributing area with time. The time-area curve can calculate the runoff hygrograph for a simulated catchment and given rainfall event. The method is illustrated in Figure 1.

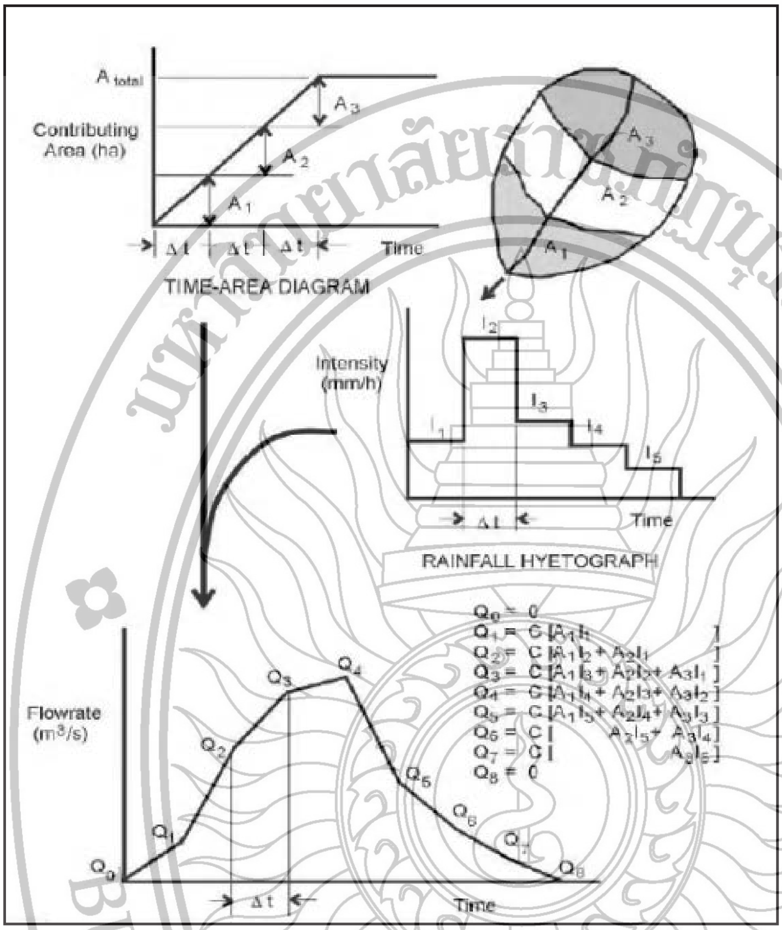

Figure1. Time-area method

The peak discharge is the sum of flow contributions from the subdivisions of the catchment defined by time contours, which are lines of equal flow-time to the catchment outlet where the peak discharge is required. The time-area curve is obtained based on the time of concentration which can be defined as the time taken for the flow from the most remote part of the catchment to reach the outlet. The variation of the cumulative time-area curve with distance from the outlet depends on the shape and surface characteristics of the catchment. That means that the time-area curve can be drawn as a concave, convex or linear shape.

3.2 Input parameters

3.3.1 Rainfall reduction factor

Hydrological Reduction - Rainfall reduction factor, accounts for water losses caused by e.g. evapo transpiration, imperfect imperviousness, etc. on the contributing area. The value is 0.65 refer to model calibration from Loetluck (2015) in analysis of flooding in klong toei wattana polder, Bangkok using mike flood urban model.

3.3.2 Percentage of impervious area

For modelling approach, sensitivity analysis was found that the impervious area is most effective parameter for model calibration. This parameter affected directly with the water volume and also water level. In this study, the effect of infiltration adapted by decreasing percentage of imperviousness area in study area.

The previous calibration and verification model, it set the percentage of impervious surface equal 70% for all sub catchment. Thus, these three cases are created for compare the effect by varied from 70% as a normal condition, 60% for decreasing 10% and 50% for decreasing 20%.

3.3.3 Effect of infiltration and rainfall

Marselek (2000) was found that the low return period and short of rainfall significant to effect of infiltration. In this study, the rainfall events are 2 and 5 years return period with varied duration 30 minute and 1 hour.

3.3.4 Scenarios

There are two groups of scenarios. First group of rainfall is due to 2 years return period and the second is for 5 years return period with 30 minutes and 1 hour rainfall duration.

In each rainfall duration, the percentage of imperviousness area will be varied from 70% (present condition) to 60% and 50% (increase infiltration by decreasing imperviousness area)

	Return period (Tr)					
Rainfall duration	2			5		
30 minute	70% ex	60% ex	50% ex	70% ex	60% ex	50% ex
1 hour	70% ex	60% ex	50% ex	70% ex	60% ex	50% ex

4. Research Results

The results were showed according to the main objective as follows:

4.1 The effect of increase infiltration by decreasing imperviousness area varied from 70% (present condition) to 60% and 50% in difference scenarios. The selected position in study as shown lagging of flood duration and flood level were shown in Figure 2, 3, 4 and 5 below:

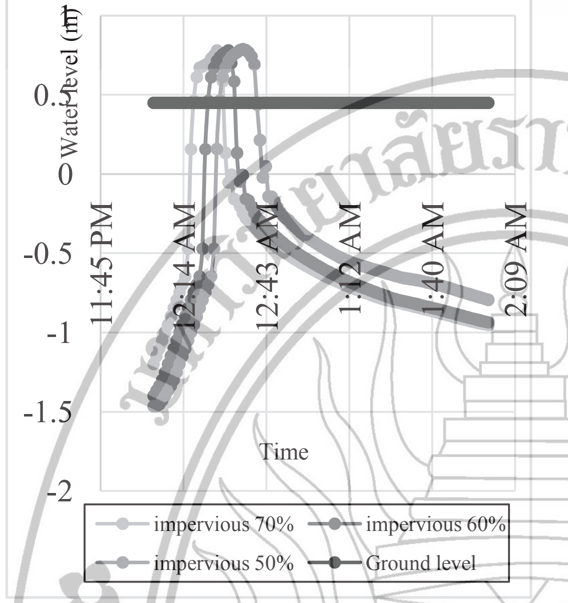

Figure 2 Case of using 2 years return period rainfall with 30 minute duration

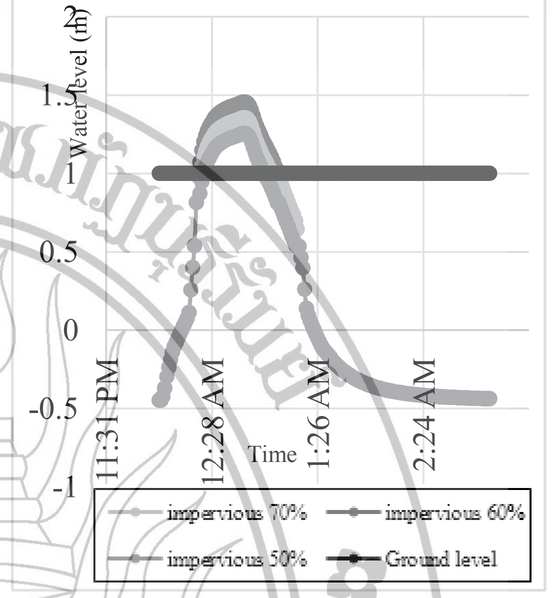

Figure 3 Case of using 2 years return period rainfall with 1 hour duration

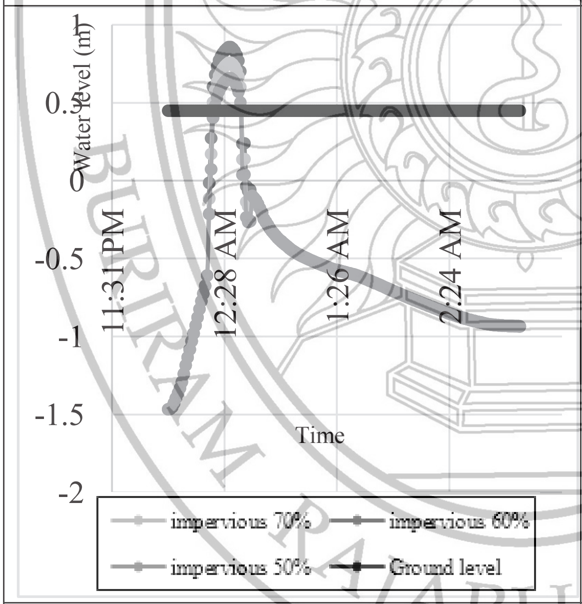

Figure 4. Case of using 5 years return period rainfall with 30 minute duration

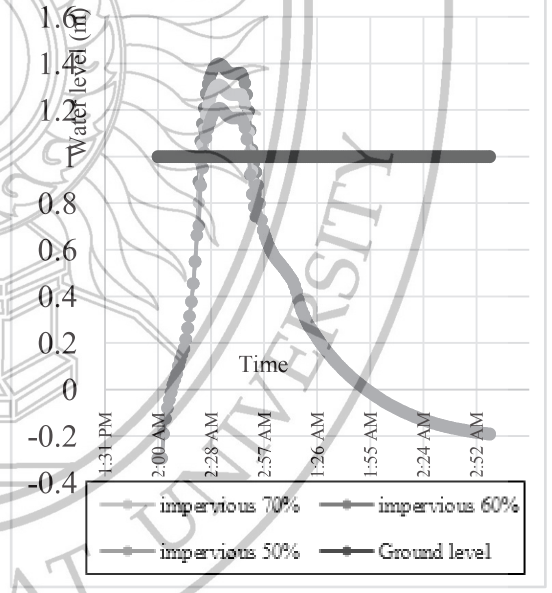

Figure 5. Case of using 5 years return period rainfall with 1 hour duration

Number of cell in difference of maximum flood level

The results present the performance of the drainage system as well as quantitative evaluation of criteria that represent the hazards associate with the events of floods. In general hazards are categorized based on the flood depth. The implication of climate change through increasing rainfall intensities in urban basin could create the hazard as a consequence of flood in socio-economic environment. The increasing extents of flood duration connote significant disturbances in socio-economic activities. The following scatter plot diagrams show the hazard in term of depth. Each point is the 2D computation cell where depth is computed. The scatter plots are considered for each return period to compare flood hazard from present to future extents. The results show number of cell from 2D flood computation comparing with difference percentage of imperviousness area in varied of rainfall event as Figure 6, 7, 8, and 9 below:

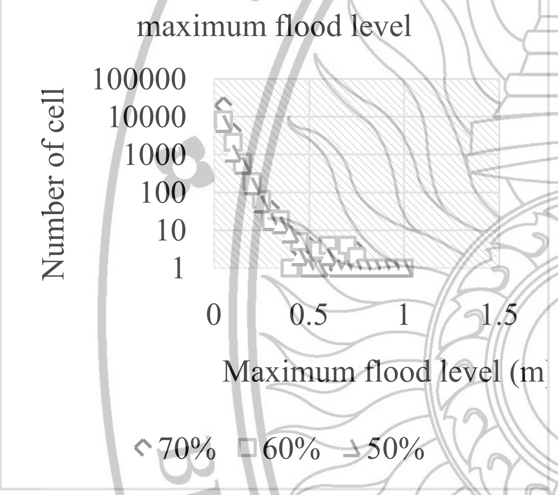 	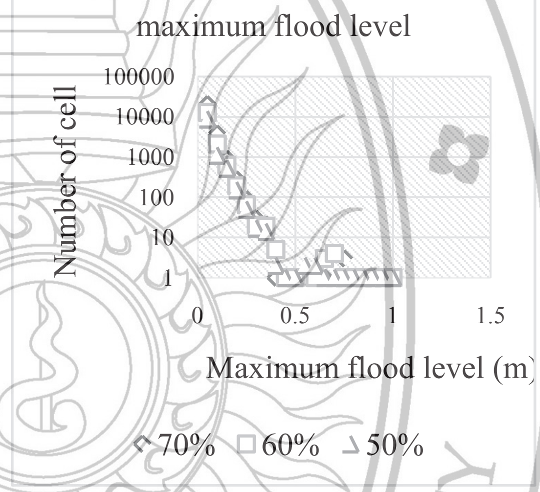
Figure 6. Number of cell in difference of maximum flood level in case of using 2 years return period rainfall with 30 minute duration	*Figure 7. Number of cell in difference of maximum flood level in case of using 2 years return period rainfall with 1 hour duration*

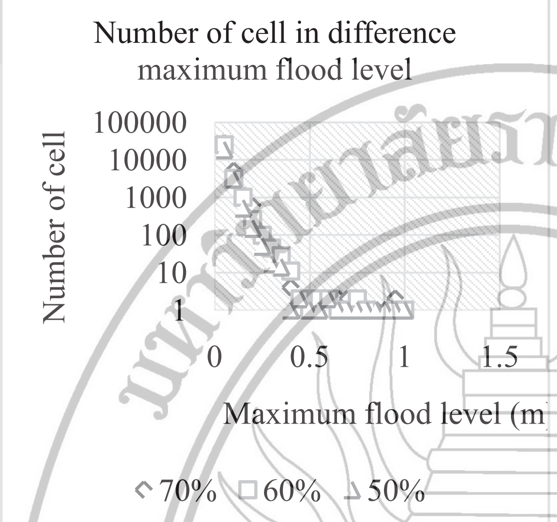

Figure 8. Number of cell in difference of maximum flood level in case of using 5 years return period rainfall with 30 minute duration

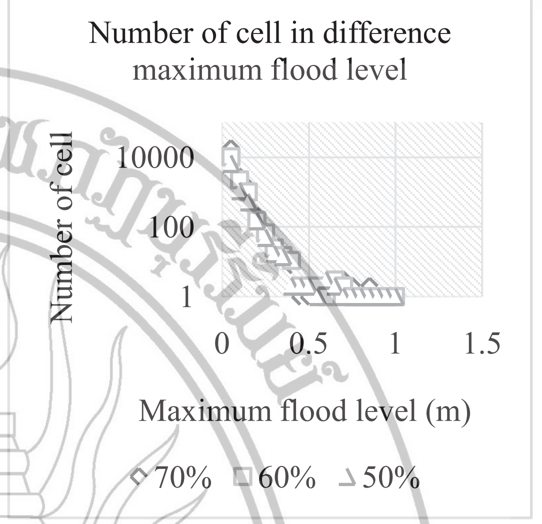

Figure 9. Number of cell in difference of maximum flood level in case of using 5 years return period rainfall with 1 hour duration

The summary of results show the changing of flood level and flood duration due to the percentage of impervious area. Figure 3, 4 and 5 show the peak of flood level is getting lower by decreasing percentage of impervious area from 70% to 60% and optimum at 50%. In addition, figure 2 shows the lag of flood duration from the effect of decreasing percentage of impervious area.

5. Conclusion

Table 2
Summary of decreasing percentage of number of flooded cell in 2D

	Return period (Tr)					
Rainfall duration	2			5		
	70%	60%	50%	70%	60%	50%
30 minute	present condition	49.67	61.83	present condition	17.85	39.22
1 hour	present condition	41.04	58.58	present condition	47.66	68.82

In conclusion, impervious area has an important impact on runoff flow. The peak of water level was decreasing compared from present condition with cases of decreasing percentage of imperviousness area. Moreover, time to peak is longer. The suitable percentage of decreasing imperviousness is 10%. It can reduce almost 50% of flooded area comparing to present condition. The percentage of impervious area should be considered for future urban planning. Thus, the impact from pluvial flooding in urban area will be lower than the present condition.

5. Recommendations

The present condition of urbanization of 70% impervious area is coming close to the saturated points regarding flooded hazards. By reducing this number at least to 60% or leading to 50% benefits in term of flood mitigation can be grained.

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