Impact of Heavy Rainfall Cause by Climate Change on Urban Area in Bangkok, Thailand

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***Abstract*— This paper describes benchmark testing of two-dimensional (2D) hydraulic models (Nays2D Flood) in terms of their ability to simulate surface flows in a densely urbanized area. The model are applied to a 22.595 km2 urban catchment within the city of Whattana – Klongtoey Districts. The purpose of this research is to study the capacity of current drainage system by Nays2D Flood. It is used to simulate a flood event that occurred at this site on 16th May, 2017, There was rain 90 millimeters within 3 hours which caused flooding in some area. And adapted to simulate under heavy rainfall cause by climate change. An identical numerical grid describing the underlying topography is constructed for model, using a DEM (Digital Elevation Model) from Land Development Department (LDD) and grouping building in study area. Procedure is commencing by studying existing drainage system, The calibration of parameter which effect on simulation model such as, a runoff coefficient = 0.35, a coefficient of Manning's n = 0.02. The result show that the terrain data available from DEM systems are sufficiently accurate and resolved for simulating urban flows. The existing drainage system could not achieve the design rainfall. Case of present, flooding in Asokmontri Sukhumvit and Rama 4 road, depth of flood 15-20 centimeters, and duration about 1-3 hours. Under projected climatic change scenarios, the results of flood depths, duration and areas are increased from present condition more than 1.0 - 3.0 times in the study area.**

Keywords—heavy rainfall; climate change; urban area

I. INTRODUCTION

Floods occur on a more frequent base than ever before. Due to climate change weather patterns change and rain intensity increases. Climate change also influences rainfall events. This causes increasing rainfall to flood more often. The increasing amount of rain is problematic especially in urban areas, which drainage system can often not handle this large amount in a short time.

Bangkok area is urbanization near coast and land below mean sea level, so a little rain may cause severe problems for certain city areas. When floods occur they create a great disturbance in the daily life. Roads can get blocked, people can't go to school or work. The economic damage is high but the number of casualties is usually very low, because the nature of the flood. The water slowly rises, when the city is on flat terrain the flow speed is low and rise is relatively slow.

With the current rate of climate change these extreme situation will occur more often in the future. The increasing rain intensity will cause city drainage system will not be able to handle the large amount of water. This will lead to more floods. This threat will become major in the future but one thing that does not change is the location of these urban areas in these dangerous areas. It is estimated that the population is still growing rapidly in urban areas, which will cause that an increasing number of people will be at risk in the future.

II. DATA PREPARATION AND SEMULATION

A. Data Preparation

Nays2D Flood is a 2-dimensional, flood flow simulation modeling for simulating. We implemented the Digital Elevation Model (DEM) form Land Development Department (LDD) 5 m resolution but it is not coverage the study area. So we interpolated the DEM data by Arc GIS and then we converted the DEM data to point and calculated coordinates X,Y (Fig. 1). And then we edited elevation of DEM in the main canals (Saen Seap, Tan, and Phra Khanong) and Chao Phraya River by use water level from Department of Drainage and Sewerage (Fig. 2). When we modified the DEM data from Arc GIS, we prepared the DEM to .tpo file for Nays2D Flood model.

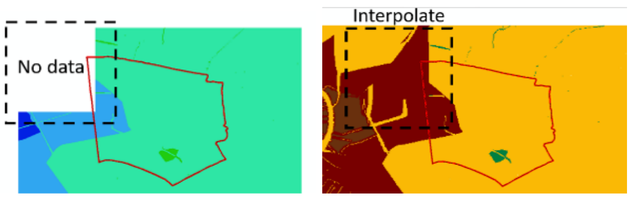

Fig. 1. The DEM data (left) Original DEM data, (right) Interpolate DEM data,

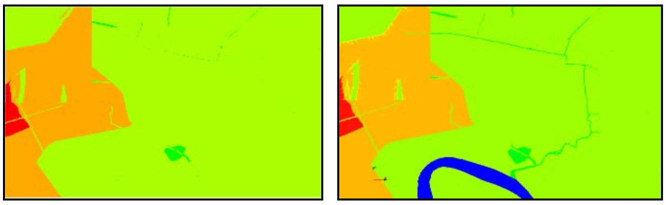

Fig. 2. The DEM interpolate (left) DEM without canal and river, (right) modified DEM to have main canals and river

We made building block grouping by Arc GIS from building blocks data with aerial photo scale 1:4,000 from Department of City Planning Bangkok Metropolitan Administration (CPD). For the background image we used an image obtained from CPD too (Fig. 3).

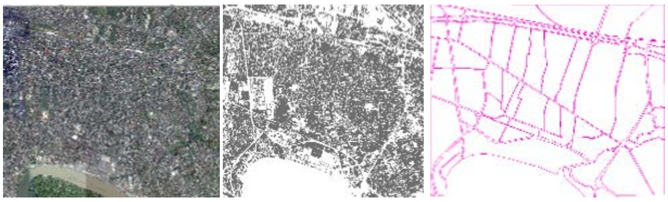

Fig. 3. Grouping building blocks Preparation (left) Aerial photo, (middle) Building blocks, (right) Building blocks grouping

For model calibration and study the characteristic features of urban flood in study area. We used the 15 minute interval rainfall data from automatic rain gauge stations with the maximum rainfall in the study area. On 16th May, 2017, we used rainfall data recorded at D29, with the maximum rainfall 25.5 mm and the total rainfall 93 mm (Fig. 4).

And validation by another heavy rainfall event. We used rainfall data recorded on 14th October, 2017 at E40 station, with the maximum rainfall 32 mm and the total rainfall 162 mm (Fig. 5).

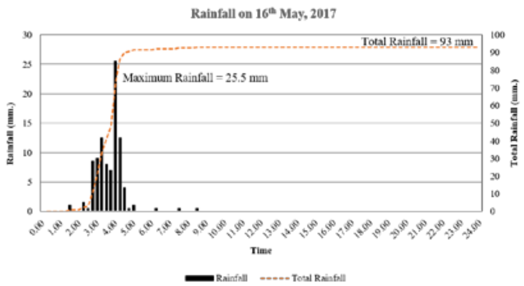

Fig. 4. Rainfall of rain gauge station on 16th May, 2017.

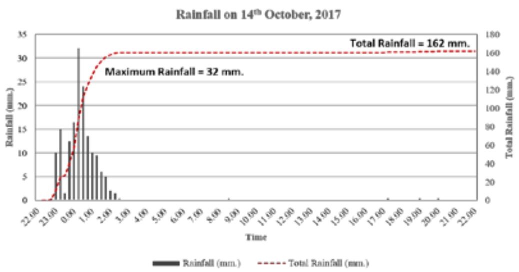

Fig. 5. Rainfall of rain gauge station on 14th October, 2017.

For the calibration of flood duration and areas at 4 locations was 1) Asok Montri, 2) Phrompong, 3) Ekamai and 4) Khlong Toei. We checked with flood reports from DDS and News from websites were available the data for validated of simulations for both of events.

Urban pluvial flood models for each pilot location and further testing of these the improved rainfall estimates and forecasts resulting from Gumbel Distribution Method for calculate all IDF curves. We used the series of annual maximum rainfall at 15, 30 mins 1, 2, 3, 6, 12 and 24 hrs of rainfall durations about 60 stations. Design storm depths associated with duration of 15 minutes for 16 years (2000 – 2015) and return period were calculated for historic observations at stations [1]

For sewers and pumps we used the information from DDS and we were setting the discharge and position by Nays2D Flood model (Fig. 6).

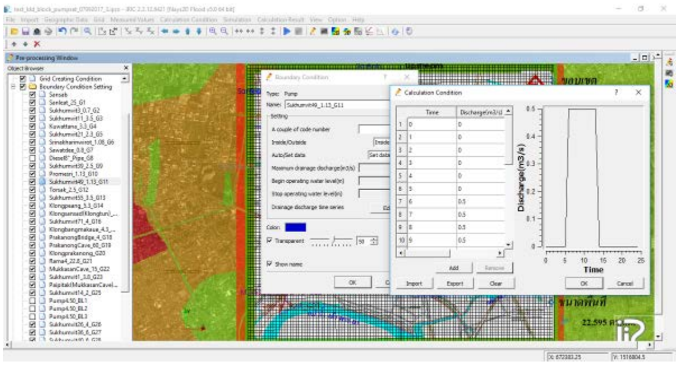

Fig. 6. iRIC Nays2D flood-solver window: Setting pumps and sewers data.

B. Model Setup

The Nays2DFlood, which is one of the models enclosed in the iRIC system, is a flood flow solver developed by iRIC [2]. Tools for creating these systems are supplied in iRIC webpage [3], [4]. For model simulation, analyzed area 42.25 km^2 grid size 5 m, 10 m and 15 m with totaling of 1,442,401, 423,801 and 177,141 grids were adopted.

This study used time step Δt = 0.05s manning's roughness n_m = 0.02 and runoff coefficient C = 0.8. The model were calibrated by a heavy rainfall event occurred on 16th May, 2017 and validated by another heavy rainfall on 14th October, 2017.

For the analysis of impact, we used the flood simulation result on 16th May, 2017 compared with the result of heavy rainfall cause by climate change. The overall workflow of flood simulation is show in Fig. 7.

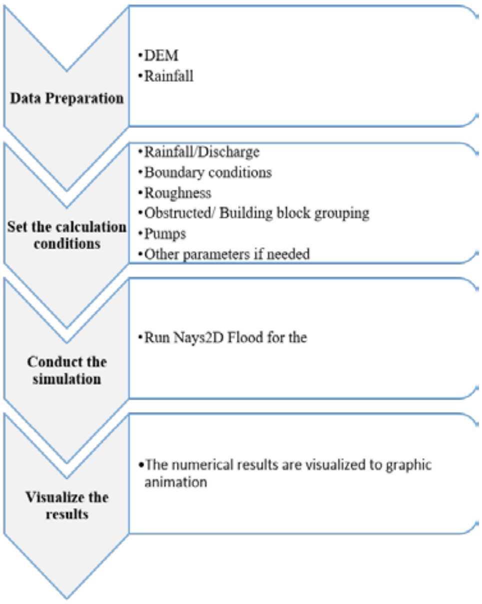

Fig. 7. Procedure for operating the Nays2D Flood solver with iRIC.

C. Model Equations

The model employs time stepping with a choice of differencing schemes for advection of momentum, including the upwind scheme and the CIP (Cubic Interpolated Pseudo-Particle) scheme [4]. The water surface elevation is calculated using a successive relaxation technique. In order to consider the effects of roads and buildings on flood analysis, the governing equations of previous Nays2DFlood have been modified to express effects of obstructions by building and road against two-dimensional water flow. In numerical model, the governing equations for a two-dimensional plane flow field are written in a general, non-orthogonal coordinate system. However, we can rewrite the continuity and *x-y* momentum equations here in an orthogonal coordinate system for simplicity, and can be written as following [5], [6],

$$\frac{\partial h}{\partial t} + \frac{\partial \gamma_x hu}{\partial x} + \frac{\partial \gamma_y hv}{\partial y} = q_{in/out} \tag{1}$$

$$\gamma_v \frac{\partial uh}{\partial t} + \frac{\partial \gamma_x hu^2}{\partial x} + \frac{\partial \gamma_y huv}{\partial y} = -\gamma_v hg \frac{\partial H}{\partial x} - \frac{\tau_x}{\rho} - hR_x \tag{2}$$

$$\gamma_v \frac{\partial vh}{\partial t} + \frac{\partial \gamma_x huv}{\partial x} + \frac{\partial \gamma_y hv^2}{\partial y} = -\gamma_v hg \frac{\partial H}{\partial y} - \frac{\tau_y}{\rho} - hR_y \tag{3}$$

Where equation (1) is continuity equation and equation (2) and (3) are equation of motion for *x* and *y* directions. *h* is water depth, *t* is time, *u* and *v* are velocities in *x* and *y* directions, *g* is gravity accretion, *H* is water level, τ_x τ_x and τ_y are bed shear stress in *x* and *y* directions, p is water density, γ_x, γ_y and γ_v are the parameters for indicative of the effects of buildings against 2D flow.

$$\frac{\tau_x}{\rho} = c_f u\sqrt{u^2 + v^2} \tag{4}$$

$$\frac{\tau_y}{\rho} = c_f v\sqrt{u^2 + v^2} \tag{5}$$

$$hR_x = \frac{h}{2} C_d'(1 - \gamma_x)u\sqrt{u^2 + v^2} \tag{6}$$

$$hR_y = \frac{h}{2} C_d'(1 - \gamma_y)v\sqrt{u^2 + v^2} \tag{7}$$

$$C_f = \frac{g\gamma_v {n_m}^2}{h^{1/3}} \tag{8}$$

where, C_f is a drag coefficient of shear stress, n_m is Manning's roughness parameter and $C_d{}'$ is drag the ratio of a drag coefficient to typical length of building in a calculation grid.

III. RESULT AND DISCUSSION

A. Model Calibration and Validation

Model calibration and sensitivity analysis are undertaken for the 16th May, 2017 event to obtain the optimal set of parameter values for the study area. The first heavy rainfall event for calibration lasted for 2.5 hours, the peak rainfall intensity reached 25.5 mm and the precipitation accumulation for the 24 hours with 93 mm.

For the flood on 16th May, 2017, the simulation of the event agrees well with the observation. The model predicted peak flood depth is about 0.201 to 0.205 m is in agreement with the observed value from the flood event on this day at the 4 points for calibration (Fig. 8).

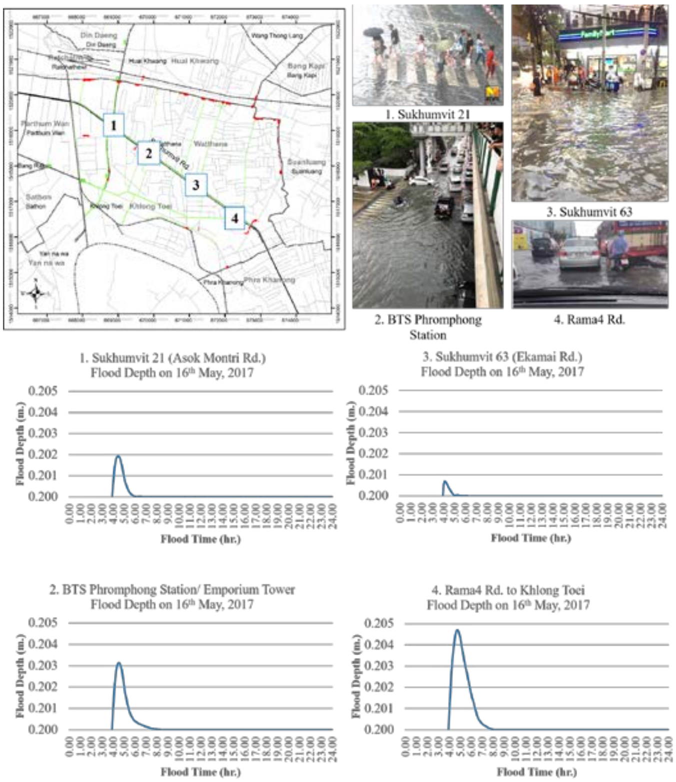

Fig. 8. Time series flood depth on 16th May, 2017. (calibration)

For the best simulation, we perform the result to the difference of computational grid size with 5 m, 10 m, and 15 m. For the grid size we considered from the wide of canals and roads/streets in the study area (5 to 15 m).

Table I. shows calculation time and the result of each run. The calculation time for the simulation using 5 m grid size is 5 times longer than 15 m grid size and 4 times longer than 10 m grid size simulation.

In this example, considering the balance of resolutions of the computation time and the inundation depth, we adopted a grid of 15 m. It is important to carry out such a sensitivity analysis in advance.

TABLE I. COMPARE THE SIMULATION RESULTS WITH GRID SIZE 5 M, 10 M, AND 15 M

Study area	**22.595 km^2 (Wattana-Khlong Toei District)**		
Analyzed area	**42.25 km^2 (6.5 km x 6.5 km)**		
Data	**Grid size**		
	15 m	***10 m***	***5 m***
Totaling of grids	177,141	423,801	1,442,401
Simulation Time	About 7 hr	About 9 hr	About 35 hr
Flood Depth	Close to the real situation	More than the real situation	More than the real situation
Flood Area	Close to the real situation	Close to the real situation	Close to the real situation
Flood Duration	Close to the real situation	More than the real situation	More than the real situation

To avoid the potential problem of model overfitting, the optimal set of parameters identified in the model calibration and sensitivity analysis for the heavy rainfall event on 16th May, 2017 is used to simulate the inundation processes of another heavy rainfall event on 14th October, 2017.

The second heavy rainfall event for validation lasted for 3 hr, the peak rainfall intensity reached 32 mm and the precipitation accumulation for the 24 hours with 162 mm.

For the flood on 14th October, 2017, the simulation of the event agrees well with the observation. The model predicted peak flood depth is about 0.202 to 0.222 m is in agreement with the observed value from the flood event on this day (Fig. 9).

For the flood depth and flood time of the inundation processes simulated by the established iRIC model for both of heavy rain fall events. The depth and duration of flood at point 4 (Khlong Toei) are longer than at point 1 (Asok Montri), 2 (Phrompong) and 3 (Ekamai) both of the simulations due to the elevations at point 4 lower than point 1, 2 and 3. If the value of rainfall are increased, the flood depth and flood durations are increased too.

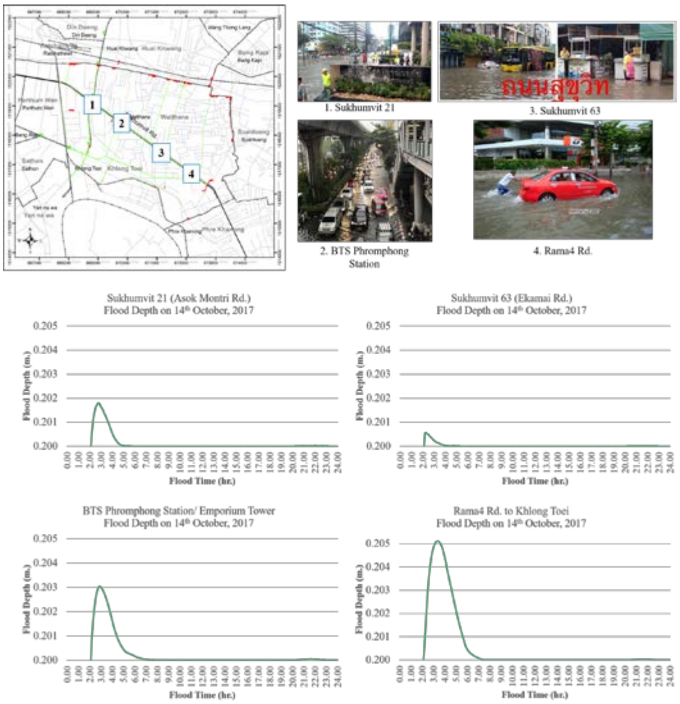

Fig. 9. Time series flood depth on 14th October, 2017. (validation)

The overall patterns of flood depth and duration in the two simulations agree well with observations.

B. Simulation Under Heavy Rainfall Event Cause by Climate Change.

The study about climate projection indicates that a likelihood of increased magnitude and frequency of hydrological extremes. Changes in extreme rainfall events will have a significant implication flood on the urban area. This study assessed the potential impact of rainfall from calculation rainfall extreme by climate change on study area.

The rainfall were calculated from the series of annual maximum rainfall at 15, 30 mins 1, 2, 3, 6, 12 and 24 hrs of rainfall durations from 2000-2015 about 60 stations and used the Gumbel Distribution Method for calculate all IDF curves. A design storm can be represented by a value of rainfall depths or intensity (presented by IDF curves) or by a design hyetograph specifying the time distribution of rainfall during a storm. Design storm depths associated with duration of 15 minutes for 16 years (2000-2015) and return period were calculated for historic observations at station [1]

The results above show that the model works well for the heavy rainfall events in urban area. After that we simulated under heavy rainfall event cause by climate change for analyzed the impact the flood on study area.

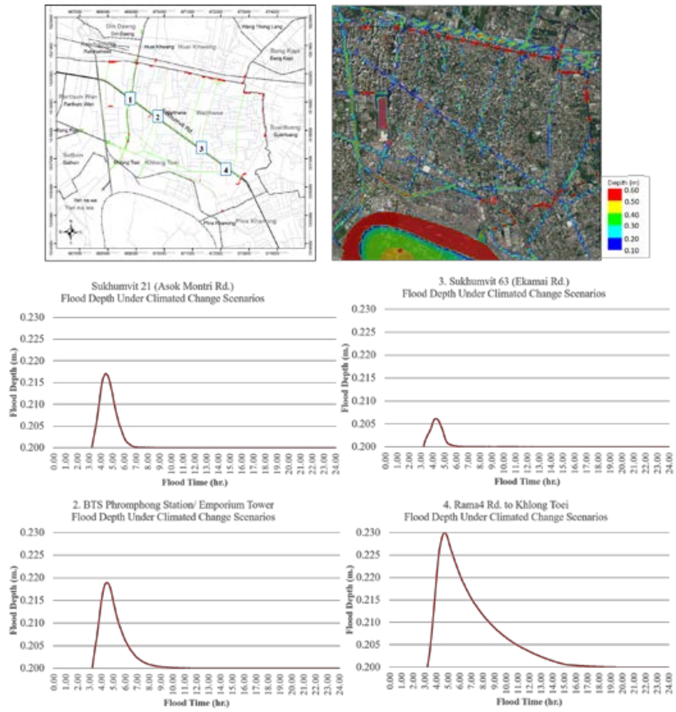

Fig. 10. Time series flood depth predict under havy rain event cause by climate change.

The Fig. 10 shows flood depth and flood time of the result from simulation under heavy rainfall event cause by climate change. For all of point, the inundated flood depths and flood durations from heavy rainfall event cause by climate change are more than the flooded in present.

C. *Impact of Flood on Study Area*

For the analysis of impact, we used the flood simulation result on 16th May, 2017 compared with the result of heavy rainfall cause by climate change.

All of 4 points with 1) Asok Montri, 2) Phrompong, 3) Ekamai and 4) Khlong Toei from the result of heavy rainfall cause by climate change have flood depth and duration more than the present scenario, especially at Khlong Toei that flood depth high to 0.23 m and flood duration more than 15 hr ,due to this point have low terrain (Fig. 11).

It was found that overall flood depths, duration and areas are increased from present condition about 1.0 - 3.0 times. For flood depths are increased from 0.201 – 0.205 m to 0.206 – 0.230 m, flood durations are increased from 1.00 – 3.30 hr to 3.30 – 15.30 hr, due to an insufficient drainage capacity of sewer and pumping systems (Table II.).

The Table III. shows flood area and flood volume are increased from present condition about 1.0 times. For flood area are increased from 709,000 m^2 to 729,000 m^2, flood volume are increased from 143,927 m^3 to 158,922 m^3 , due to the rainfall are increased from present and capacity of sewer and pumping systems still the present condition.

TABLE II. FLOOD DEPTH AND FLOOD DURATION

Point	Flood depth (m)			Flood duration (hr)		
	Present	***Climate change***	***Δ***	***Present***	***Climate change***	***Δ***
1	0.202	0.217	0.015	2.30	3.30	1.00
2	0.203	0.219	0.016	3.00	7.00	4.00
3	0.201	0.206	0.005	1.00	3.30	2.30
4	0.205	0.230	0.025	3.30	15.30	12.00
Avg.	0.203	0.218	0.015	2.30	7.30	5.00

TABLE III. FLOOD AREA AND FLOOD VOLUME

Flood area			Flood Volume		
Present	***Climate change***	***Δ***	***Present***	***Climate change***	***Δ***
(m^2)	***(m^2)***	***(m^2)***	***(m^3)***	***(m3)***	***(m3)***
709,000	729,000	20,000	143,927	158,922	14,995

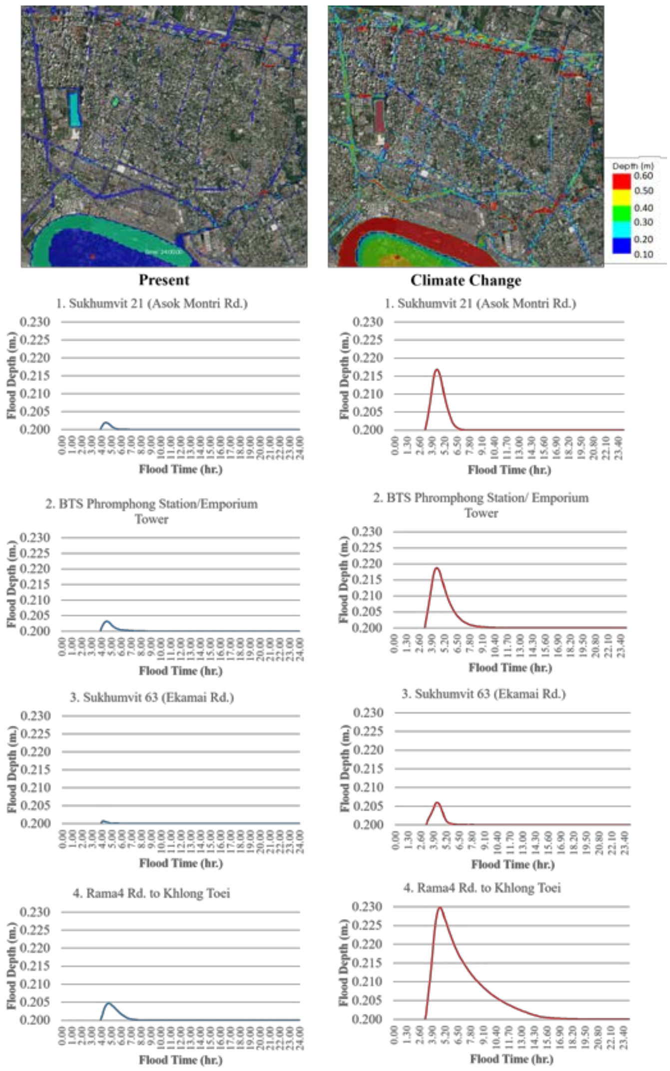

Fig. 11. Compare the flooded present with predict under havy rain event cause by climate change.

IV. CONCLUSIONS

The model is tested in a 22.595 km2 urban catchment, the downtown of Bangkok district, Thailand. While common flooding events in a natural watershed inundate large areas and last for hours and days, urban flooding event usually occur in a small or even tiny subcatchment and on discrete sites with lower elevation due to natural topology or civil engineering projects. The urban flooding events normally last for tens of minutes or hours.

The results above show that the i-RIC model could simulate for heavy rainfall events in urban area well. According to the above comparison, the result of simulation under climate change can be seen that depth and duration of flooded increased more than 1.0 to 3.0 times

The study area is one of the frequently flooded spots. It is located at a main avenue in the downtown area, and the flooding often causes serious traffic jam. So, we should study

1) The evaluation principle for hazard/risk of flood to transport and traffic for avoid or implement mitigation measures from flood in study area.

2) The impact of flood on build-up area, infrastructure, and economic in study area.

3) The method to retention the water from flood for reused in the study area.

4) The planning and designing of storm water management infrastructures for work effectively in future under climate change.

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