Implementation of Nays2DFlood Modeling for Integrated Floodplain/Stromwater Management : Case Study in Sukhumvit Area, Bangkok, Thailand

Sanit Wongsa*
dept. Civil Technology Education, FIET
King Mongkut’s University of Technology Thonburi
Bangkok, Thailand
sanit.won@kmutt.ac.th

Varameth Vichiensan
dept. Civil Engineering
Kasetsart University
Bangkok, Thailand
fengvmv@ku.ac.th

Napaporn Piamsa-nga
dept. Water Resources Engineering
Kasetsart University
Bangkok, Thailand
fengnpr@ku.ac.th

Shinichiro Nakamura
dept. Civil Engineering
Nagoya University
Nagoya, Japan
shinichiro@civil.nagoya-u.ac.jp

***Abstract*—Flooding in urban areas is an inevitable problem for many cities in the world. In Thailand, Bangkok has serious problems related to urban flooding. The situation was highlighted in October 2018, when residences experienced ankle to knee-deep flood water on the streets. Daily activities in parts of the city were nearly paralyzed and heavy traffic jams occurred due to stagnant water on the streets. The study has depended on a combined approach of physically based modeling and GIS. The architecture of the software consists of 3 functions: pre-processor, post-processor, and solver. Nays2DFlood is a flood flow analysis solver that relies on unsteady 2-dimensional plane flow simulation using boundary-fitted coordinates1 as the general curvilinear coordinates. The urban drainage is structured by Nays2DFlood software for the basis of two networks, one simulating the two-dimension free-surface flow over the streets and one for the pumping/canal/pipe system. The interaction between street and pumping/canal/pipe system is modeled in a simple way. In 2017, ADAP-T project carried out a pilot study about urban flooding and adaptation modeling for Sukhumvit area, Bangkok Metropolitan. This study is performed as an extension and improvement of pilot study in terms of analyzing drainage system on effect of flood hazard, vulnerability, risk map and adaptation under the issue of climate change in Sukhumvit area, Bangkok, together with suggestion of alleviation scenarios to relieve flood problems.**

***Keywords*— urban flooding; climate change adaptation, iRIC software**

I. INTRODUCTION

Bangkok Metropolitan Administration (BMA) has experienced water logging for the last few years. Even a little rain may cause severe problems for certain city areas, which are inundated for several days. The water depth in some areas may be as much as 20-50 cm, which creates large infrastructure problems for the city and huge economical losses in production together with large damages of existing traffic system, infrastructures, properties and goods. The BMA is protected from river flooding by an encircling embankment. Most of the time during the monsoon season, the water level in the Chao Phraya River remains about 2-3 m higher than the water level inside the city area, consequently the city drainage depends very much on the water levels of the peripheral river systems. The situation becomes worse when monsoon runoff generated from short duration and high intensity rainfall combines with high water level in river system. The main causes of floods in BMA can be classified into two types. The first one results from high water level of Chao Phraya River, canals system and the other caused by heavy rainfall. Thailand Great Flood in 2011 were caused by 5 tropical storms, resulting heavy rainfall occurred in upper and mid-Chao Phraya River Basin and the built-up areas of the city. The severe water logging in October 23, 2018 was originated from local high intensity rainfall, insufficient drainage capacity and garbage clogged the drainage system (*Fig. 1*)

Fig. 1. Flooded in Bangkok: originated from local high intensity rainfall. (https://www.google.com/search?q=ขยะน้ำท่วมกรุงเทพ).

II. DESCRIPTION OF THE SYSTEM

The BMA has been struggling to divert floodwater out of the city because its water drainage system was developed mainly for handling localised flooding caused by heavy rainfall, not massive flood water from the upstream areas.

Fig. 2. Bangkok's and Area-13 water drainage system (Department of Drainage and Sewerage: DDS).

BMA invested heavily in its water drainage infrastructure after 1983 when major flooded hit the city. Since then, canals and tunnels have been dug, retention ponds designated, and pump stations constructed to help drain the flood water. The water drainage system is based on a polder system, where dykes are built around the city, and floodwaters are directed to the sea by pumps, water drainage canals and tunnels (*Fig. 2*). Polder systems have been developed mainly in inner Bangkok, the western side of the city, and the eastern side. In inner Bangkok, a large polder has major roads and railways cutting through the Ramkhamhaeng and Phetchaburi areas, acting as its main dykes. The polder is divided into more than 20 sub-polders where drainage canals and tunnels and pumps help drain water out from the protected areas inside them. On the eastern side, His Majesty the King's dyke (RAMA IX), which runs north to south, and around 20 retention ponds help retain up to 6 MCM of flood water before it is pumped out and drained to the sea at the Gulf of Thailand. Giant tunnels have also been installed to help speed drainage. The western side has a network of dykes along the Chao Phraya, Mahasawas and Bangkok Noi canals preventing flooding from flowing into the protected areas inside the dykes. This study focus on water management in Area-13 (Sukhumvit-North sub-polder), which includes the most important commercial areas of BMA, hence most of areas are impervious. Collected storm water from each sub-catchment is drained by sewer pipes/canals to Saen Saep, Ton and Phra Kanong canals and finally it is drained to main river system by pumps and canals at the basin in front of the sluice gate.

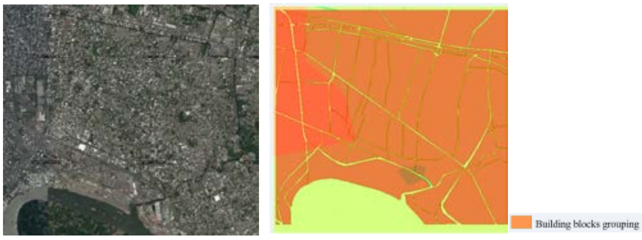


Fig. 3. DEM with canals, roads and sewer system in Area-13 (Sukhumvit-North sub-polder).

DEM represents land elevation data, which are crucial for estimating storage volume of surface flooding. In addition, result presentation in form of flood inundation map are performed based on application of iRIC Software, ArcGIS and Google Earth. Hence, the quality of the output depends on the quality of the DEM. Available DEM from pilot project was 30 m resolution from Land Development Department (LDD), which is too rough for urban flooding analysis as the dimension of typical features in the city are around 5-20 m. By using DEM 30 m resolution, which cannot cover significant details in study area, it may lead to inaccurate results. Establishing new DEM with the resolution of 5 m, which yield sufficient accuracy is performed based on the application of iRIC software. For simulating real-life situation of urban flooding, the major canals, roads, pumps and sewer system where floods occur are included in the DEM (*Fig. 3*).

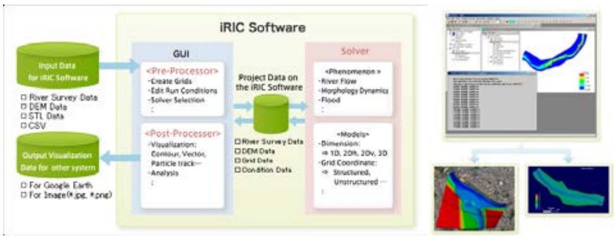


Fig. 4. The architecture of a iRIC software (http://i-ric.org/en/).

III. iRIC SOFTWARE AND MODEL SETUP

A. iRIC Software

The iRIC software is public domain interface for calculating flow, sediment transport and morphodynamics in rivers and other geophysical flows. This interface is completely free to any users and includes 13 models ranging from simple one-dimensional models through three-dimensional models. The Nays2DFlood, which is one of the models enclosed in the iRIC system, is a flood flow solver developed by iRIC [1]. Tools for creating these systems are supplied in iRIC webpage [2], [3]. This model can be used in a general, non-orthogonal coordinate system with adaptable grid. The architecture of a iRIC software consists of 3 functions: pre-processor, post-processor, and solver. (*Fig. 4*). Pre-processor is for creating calculation lattices and setting calculation conditions, hydrologic conditions, calculation methods. Calculation lattices can be created from survey data such as river survey data and DEM data. Post-processor is for visualization and analysis of calculation results. Visualization of calculation results can be used for purposes such as creation of vector, contour, and other diagrams, as well as creation of graphs. Nays2DFlood is a flood flow analysis solver that relies on unsteady 2-dimensional plane flow simulation using boundary-fitted coordinates1 as the general curvilinear coordinates.

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, h is water depth, u and v are velocities, g is gravitational acceleration, H is water level, $q_{in/out}$ is the rate of water entering or leaving ground surface per unit area, including the excess rainfall, the upstream catchments inflows, the influent and effluent of sewer networks, and the overland flow drained by hydraulic facilities, τ_x and τ_y are bed shear stress, ρ is water density, x, y and t are direction and time, respectively. A building might occupy a significant, but not full, area within a computational grid, which has similar or slightly higher size than the building scale. Neither the ground elevation nor the roof elevation is appropriate to interpret the condition. γ_x, γ_y and γ_v are the parameters for indicative of the effects of buildings against two-dimensional flow, which can be expressed as following,

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

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

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

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

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

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.

There are consisting of 4 steps for numerical model simulation. First, the calculation grids are created from DEM data are used to create a grid and to determine the attributes of each node or cell by interpolating relevant values. Second, the calculation parameters were set to the model. The conditions of study are based on real parameters. Third, model is simulating in a small time step. Finally, the numerical results are visualized to graphic animation.

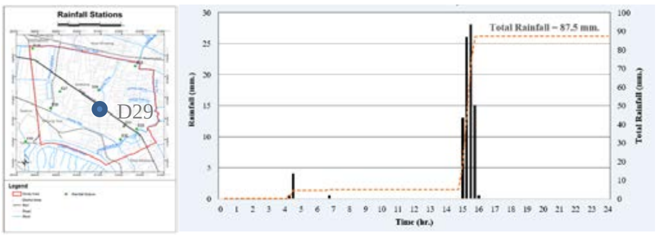


Fig. 5. Location and rainfall of D29 rain gauge station in October 23, 2018.

B. *Model Setup*

For model simulation, grid size 5m x 5m with totaling of 177,141 grids were adopted, with time step and manning's roughness parameter are Δt = 0.05s and n_m = 0.03, respectively. Geographic data are used to create a grid and to determine the attributes of each node or cell by interpolating from DEM data. For model simulation, rainfall at station D29 (Bangkok: DDS), and water level at pond/canal were adopted for input data and initial conditions, respectively. The 15 minute interval rainfall data recorded at D29 automatic rain gauge stations, extremes event during October 23, 2018, with totaling 87.5 mm are utilized to study the characteristic features of urban flood in Bangkok. Temporal changes in the short duration (less than 60 minutes), with total rainfall was 93 mm (*Fig. 5*).

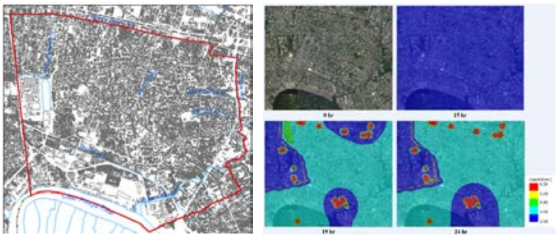


Fig. 6. Flooded area by using 5m DEM without building.

Fig. 7. Flooded area by using 15m DEM with grouping building block.

F*ig.6* shows the flood depth extent and location, which obtained from the simulation of the iRIC model by using only topography without building block, road/street and pumping station. The simulated flooding depths have been traced for several selected locations along with the available real flood marks to provide a general idea on how the simulated flood depths deviate from the real data. However, overall flood depth, areas and flow direction tends to underestimate the water depths. It was found that the differences are larger for flooded areas. For simulation with building block, it took a lot of computation times, since there are many small building blocks in computation domains. *Fig. 7* shows simulated results by grouping DEM from 5 m to 15 m and building blocks, which gives with better estimation, and more robust. It was found that the model flooded areas are similar to observe in Area-13. Therefore, DEM 15 m with grouping building blocks have been adopted in this study. The optimal value needs certain runs to tune and it differs from case to case [7].

IV. RESULTS AND DISCUSSION

A. *Simulation of October 23, 2018 Flooding (present scenario)*

All consisting conditions of major canals, roads, pumps and sewer system have been included in the model. Then, the model has been properly calibrated for the surface roughness and runoff coefficient. It was found that manning's roughness n_m = 0.03 and runoff coefficient C= 0.8 have been used in entire simulation domain. Good matching of model results and observed data ensures that the model was able to reproduce the actual flooding situation. Overall flood duration and areas at 4 selected locations ((1) Aok Montri, (2) Ekamai, (3) Phrompong and (4) Khlong Toei) are identical. But, flood depth are 4-6 cm, tends to underestimate the water depths slightly. The differences are larger at the main road, due to the different levels of traffic surface with walkways and garbage clogged the road drainage, which smaller grid sizes are required (*Fig. 9-10*).

Fig. 8. Maximum flooded area in Area-13. (Present scenario).

Fig. 9. Time series flood depth at several selected locations (Present scenario).

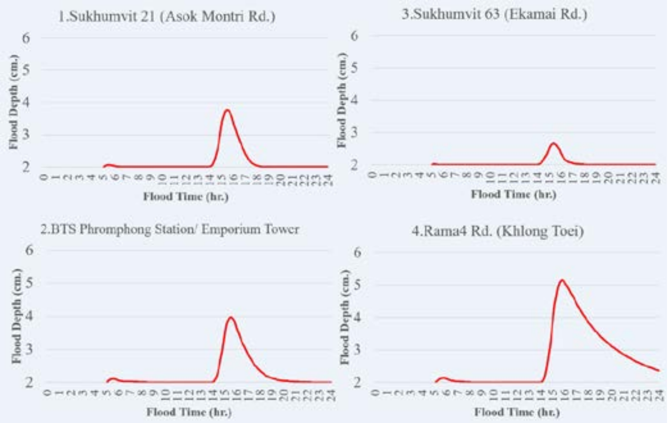


Fig. 10. Time series flood depth at several selected locations (Climate Change Scenario).

B. *Simulation of Climate Change Scenario*

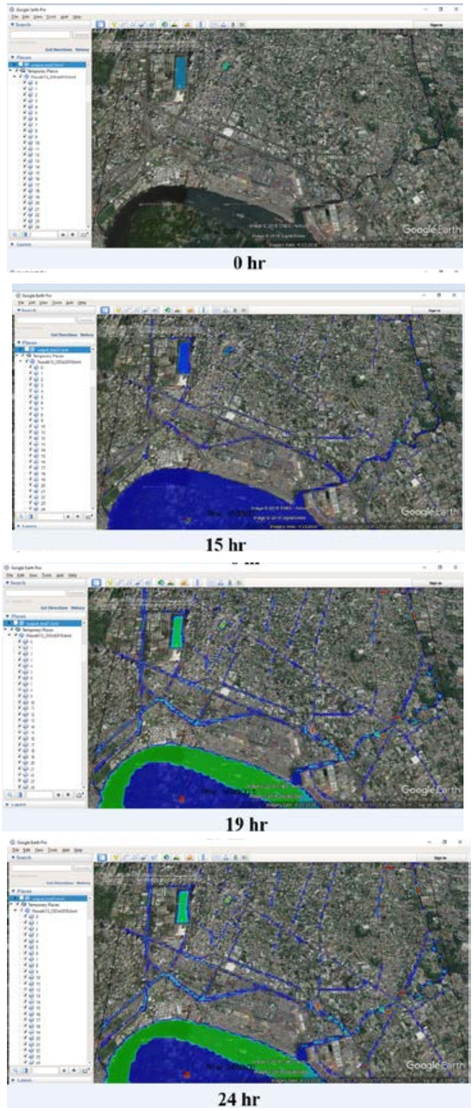
A number of future climate projections indicate a likelihood of increased magnitude and frequency of hydrological extremes. An attempt was made to identify the possible alleviation scenarios for the climate change. The drainage infrastructures in an urban area are usually designed based on the rainfall depth calculated employing statistical analyses of observed precipitation data. The rainfall depths are calculated from the historic rainfall time series without considering climate change impact. So, the designing of storm water management infrastructure based on design storm considering the assumption of non-stationary climate will not be able to manage extreme events in future climate. Changes in extreme rainfall events will have a significant implication on the design of storm water management infrastructures. This study assessed the potential impact of changed rainfall extreme on drainage systems in the BMA Area-13 sub-polder. The design storms for the study area were re-calculated from observed rainfall data and employing as time series rainfall input for the study area in present infrastructure scenario.

This study used 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. We used the Gumbel Distribution Method for calculated 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, and return period were calculated for historic observations at station [8].

It was found that overall flood depths, duration and areas are increased from present condition more than 1.5 - 2.0 times in Area-13 (Sukhumvit-North sub-polder) areas. For flood depths in Sukhumvit21 (Asok Montri Rd.) and Khlong Toei (Rama 4 Rd.) are increased from 0.025 – 0.040 m to 0.04 – 0.06m, due to an insufficient drainage capacity of sewer and pumping systems (*Fig. 10*). The results show an increase in design storm depths under projected climatic change scenarios that suggest an update of current standard for designing is needed. A concept of applying real time control and increasing pump capacity real time/ remote control and to improve the drainage capacity locally may be used as a tool to reduce flooding. *Fig. 8* to *10* depict the generated heavy rainfall flood based on water depth for Area-13, BMA, Thailand. The condition of the improvement of present condition has a significant role on generated flood water depth and extents area. However, land-use development (urbanization) increases impervious areas and generated considerable impacts on drainage system. Rainfall events with higher intensity of climate change scenario lead to higher runoff and flood water depth. Therefore, this contributes to enlargement of the area of flood and hazard classes. Eventually, increase of development magnitude leads to boost the river flood from the main Chao Phraya and the peripheral river systems. During flood event, flood flow exceeds the river banks and overflows into the sub-polder (protection area), in this case, the characteristics of floodplain topography affects on the flood distribution.

C. Output Results to Graphics and Animation

For visualization and analysis of calculation results of iRIC software. The visualization of calculation results can be used for purposes such as creation of vector, contour, and other diagrams, as well as, creation of graphs. Furthermore, visualization results can be output to file in graphic formats such as JPG, or output to Google Earth and ArcGIS.



0 hr

15 hr

19 hr

24 hr

Fig. 11. Visualization of calculation results to Google earth.

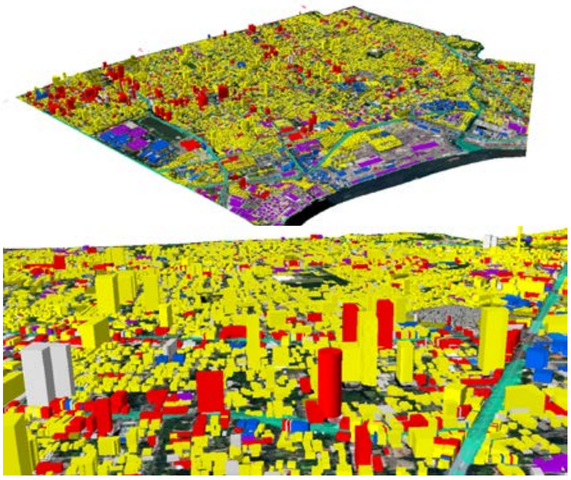


Fig. 12. Visualization of calculation results to ArcGIS.

V. CONCLUSIONS

The study of urban flooding in Area-13 (Sukhumvit-North sub-polder), BMA, Thailand by using iRIC software for the basis of two networks, one simulating the two-dimension free-surface flow over the streets and one for the pumping/canal/pipe system. This study explored the potential simulation for 2 scenarios; (1) present condition, and (2) future impact of climate change. The results show that improved the drainage capacity locally, such as, sewer and pumping systems can reduce present flood condition. For projected climatic change scenarios, it was found that overall flood depths, duration and areas are increased 150-200%. Overall, the urban storm water management infrastructures designed based on current climate condition will not be able to cope with the increased design storm depth under future climate condition, an update of current standard for designing is needed. The findings of this study would encourage municipalities and other stakeholders for considering climate change impact in planning and designing of storm water management infrastructures to ensure that they will work effectively in future. A concept of applying real time control and increasing pump capacity real time/ remote control and to improve the drainage capacity locally may be used as a tool to reduce flooding.

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