

URBAN FLOOD MITIGATION AND PREVENTION USING THE MIKE 21 MODEL: A CASE STUDY OF NAKHON RATCHASIMA PROVINCE, THAILAND

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Abstract

Nakhon Ratchasima Province has suffered from several severe urban floods during the past 4 decades. Particularly, an urban flood occurred on 18th October, 2010 that resulted in loss of life and affected physical, social, economic, and environmental features. Therefore, this study attempts to apply a new advanced 2D hydrodynamic model, MIKE 21, to simulate the urban flood event in 2010 with actual conditions for urban flood mitigation and prevention in Mueang district of Nakhon Ratchasima Province. The specific objectives are: (1) to identify the optimum parameters of the MIKE 21 model for urban flood simulation; (2) to characterize the urban flood event in 2010 and its severity; and (3) to identify the minimal cut-off inflow for urban flood mitigation and prevention in the future. Three main components of the research methodology were here implemented and included: 1) data collection and preparation; 2) simulation of the urban flood in 2010 and classification of its severity; and 3) an urban flood scenario simulation for flood mitigation and prevention.

The main land use class in 2010 of the study area by visual interpretation of multi-temporal remotely sensed data was agricultural land which covered an area of 239 sq. km or 60.19% of the area; the minor land use class was forest land which covered an area of 2.19 sq. km or 0.55%. By validation of the simulated urban flood in 2010 with the actual flood map of GISTDA and by comparison with known locations of the flood recorded in 2010 from both various government agencies and a ground survey in 2014, the normal Manning's M number was determined as the optimum value for urban flood simulation by the MIKE 21 flow model and it was used to quantify the urban flood information (extent, depth, velocity, and duration) for the flood severity classification and economic value loss assessment. The dominant land use classes affected by the maximum extent of the urban flood on 24th October, 2010 were agricultural land and urban and built-up areas that covered an area of 76.89 sq. km or 86.62% and 7.74 sq. km or 8.72% of the study area, respectively. The total economic value loss according to the compensation rates of the Office of Insurance Commission and the cabinet resolution of the Thai government on

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August 25th, 2011 was about 73,516,541,689 baht. Furthermore, the urban flood simulation for flood mitigation and prevention revealed that when the historical discharge in 2010 at the Kud Hin water gate was reduced by 60% or to a discharge rate of less than 17.82 m³/s, it could mitigate urban flooding and when the discharge was reduced by 67% or to a discharge rate of less than 14.70 m³/s, it could prevent urban flooding in Mueang district.

Keywords: MIKE 21 model, urban flood simulation, urban flood severity classification, Nakhon Ratchasima Province

Introduction

Urban flooding is one of the natural hazards that can cause great damage to physical, social, economic, and environmental features, in particular the loss of properties and human lives. Shepherd (2007) defined urban flooding as an overflowing of a great body of water over land in a built-up area which is not usually submerged. Urban flooding is caused by land which loses its ability to absorb rainfall and a poor drainage system. In general, urbanization is a major cause of the decrease in the ability of natural terrain to absorb water. During periods of urban flooding, streets can become swift moving rivers, while basements can become death traps as they fill with water (Ghosh, 2006). The urbanization process is the main change to the water balance and results in an increase in the production of superficial runoff and also creates a physical flow obstruction through the construction of road networks. Although a city can influence a change in the runoff pattern within the city itself, it also changes the whole river system downstream, including surrounding areas (Miguez and Magalhes, 2010). In addition, the main causes of urban floods include changes in precipitation attributed to climate change, changes in surface runoff influenced by urbanization, and features of urban areas suffering from flood damage (Toda, 2007).

Nakhon Ratchasima Province has suffered from several severe urban floods during the past 4 decades: in 1978, 1996, 2002, and 2010 (Weeraya and Jirawat, 2012). Particularly, an urban flood occurred on 18th October, 2010 that resulted in loss of life and affected physical, social, economic, and environmental features (Table 1). The flood was caused by the amount of rainfall with more than 110 mm on 15th October, 2010 over

Mueang district, Nakhon Ratchasima Province. Meanwhile, Lam Takhong reservoir that was designed to store water and control the amount of water flow to downstream areas was over its water storage capacity (10.3 million cu. m). Thus, the reservoir had to immediately drain the water volume to downstream areas of Mueang district. Furthermore, the main rivers, including the Lam Takhong and Lam Boriboon Rivers, were shallow and had been intruded on by people along the riverbanks.

Therefore, this study attempts to apply a new advanced 2D hydrodynamic model called MIKE 21 to simulate the urban flood event in 2010 with the actual conditions for urban flood mitigation and prevention. The objectives of the study are: (1) to identify the optimum parameters of the MIKE 21 model for urban flood simulation; (2) to characterize the urban flood event in 2010 and its severity; and (3) to identify the minimal cut-off inflow for urban flood mitigation and prevention in the future.

Materials and Methods

Study Area

The study area is situated over the lowest part of the Lam Takhong watershed and covers an area of 397.24 sq. km. It mostly covers the whole territory of Mueang district where the central business district of Nakhon Ratchasima Province is located in the center of the study area (Figure 1).

Research Methodology

The research methodology and its workflow consists of 3 components: (1) data collection and preparation; (2) the urban flood in the 2010 simulation and its severity

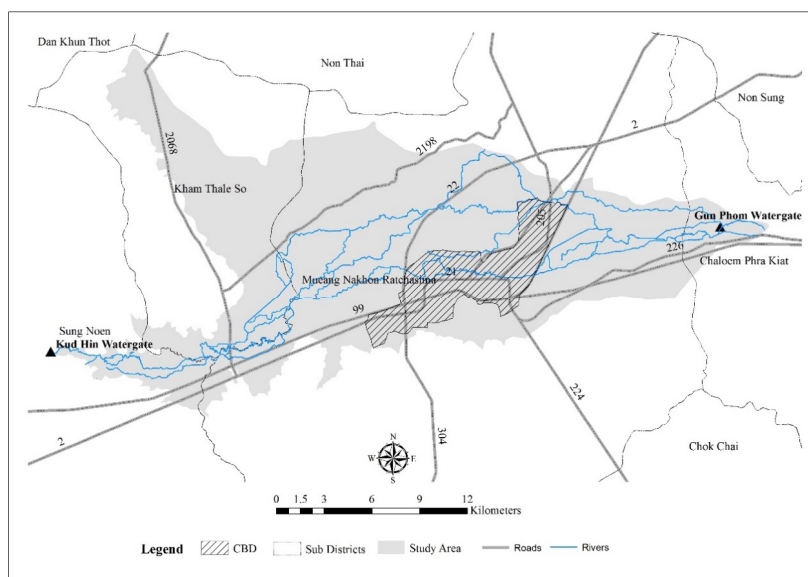


Figure 1. Study area and its administration boundary over the Lam Takhong watershed

Table 1. Mueang district flood damage in October, 2010

Feature	Flood damage
Physical	16 Government units, 13 Hospitals, and 2 Reservoirs
Social	8 Deaths, 2 Injuries, and 24,785 Households
Economic	Transportation, Markets, Industries and companies
Environmental	Landscape

Source: Mueang Nakhon Ratchasima District Office (2010).

Table 2. Data collection and preparation and their sources

Data collection	Data preparation	Source
Digital Elevation Model (DEM), 2002	Missing data checking	Ministry of Agriculture and Cooperatives
Land use data, 2008	Land use data in 2010 interpretation based on land use data of LDD and multi-temporal remotely sensed data and intensive field survey in 2014	Land Development Department (LDD)
World View-II Imagery, 2012		Nakhon Ratchasima Municipality Office
THEOS Imagery, 2010		
SPOT-5 Imagery, 2008		
Administrative boundary, 2008	Topology verification	Nakhon Ratchasima Municipality Office
Lam Takhong watershed, 2010	Topology verification	Geo-Informatics and Space Technology Development Agency (GISTDA)
GISTDA flood map in 2010	Data checking	Lam Takhong Operation and Maintenance Project
Discharge, 2010	Data checking	Thai Meteorological Department
Water gates, 2010	Data checking	
Precipitation, 2010	Data checking	
Evaporation, 2010	Data checking	

classification; and (3) an urban flood scenario simulation for flood mitigation and prevention (Figure 2).

Component 1: Data Collection and Preparation

The required input data include remote sensing, GIS, hydrology, and meteorology data which were collected and prepared in advance (Table 2). In practice, multi-temporal imageries with very high spatial resolution from SPOT-5 in 2008, THEOS in 2010, and

World View-II in 2012 are visually interpreted to determine the land use types in 2010 at Level I and II based on the land use data in 2008 from the Land Development Department (LDD). In addition, urban and built-up areas are further interpreted with an intensive ground survey at Level III with details for the total economic value loss (EVL) assessment. Here, the key elements of image interpretation which include location, size, shape, shadow, tone and color, texture, pattern, height and depth, and site/situation and association (Lillesand *et al.*,

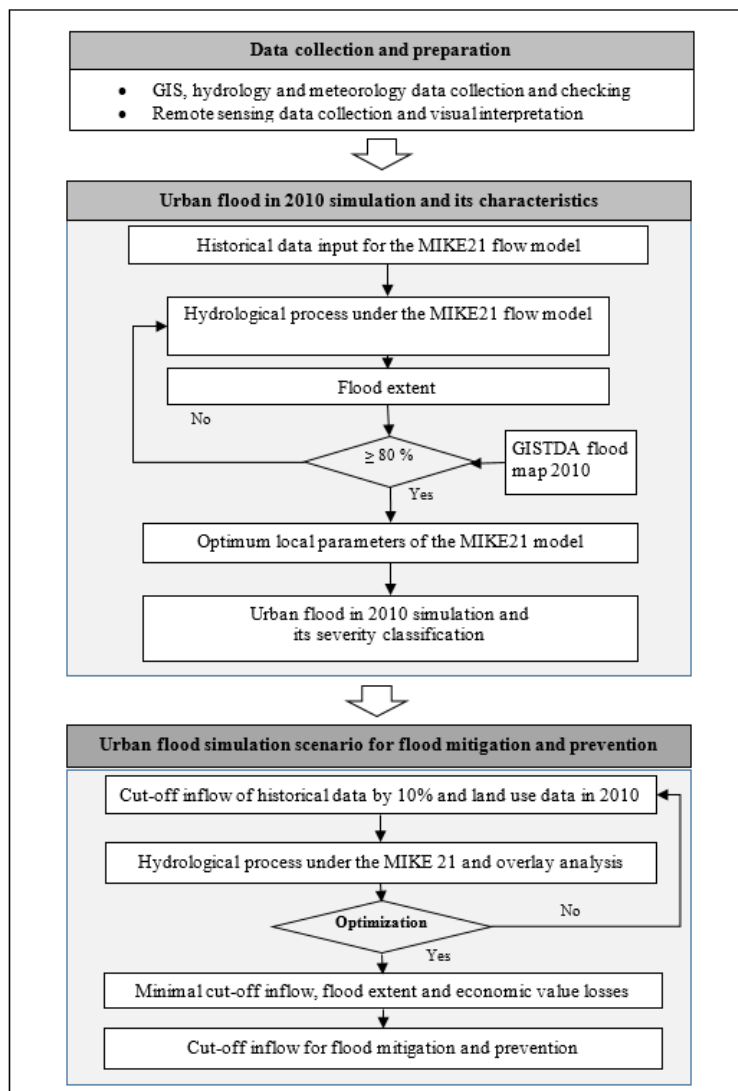


Figure 2. Schematic workflow of the research methodology

2004; Jensen, 2007) are applied to delineate the land use classes in 2010 with an intensive field survey in 2014 (Table 3).

Component 2: Urban Flood in the 2010 Simulation and Its Severity Classification

The MIKE 21 flow model is a modeling system for 2D free-surface flows. It can be used to simulate a wide range of hydraulic and related items, including tidal exchange and currents, storm surges, heat and recirculation, water quality, and urban floods. The flow

model has been successfully applied for flood simulation in various basins by many researchers, including Tennakoon (2004); Wang and Hartnack (2006); Chen (2007); Syme (2008); Patro *et al.* (2009); Filipova *et al.* (2012); and Weeraya and Jirawat (2012).

In principle, the conservation of mass and momentum integrated over the vertical describe the flow and water level variations that are applied in the MIKE 21 flow model (DHI Water & Environment, 2011) as:

Table 3. Land use classification system and compensation rates

Land use classification			Compensation rates (baht/sq. m)
Level I	Level II	Level III	
Urban and built-up area	City and Commercial	Commercial building with 1 floor	3661
		Commercial buildings with 2 floors	6978
		Commercial buildings with 3 floors	6595
		Commercial buildings with 4 floors	5912
		Shopping mall with 1-3 floors	11669
	Residential	Concrete and wooden house	9577
		House with 1 floor	9330
		House with 2 floors	10619
		Townhouse with 2 floors	7824
		Townhouse with 4 floors	6177
		Dormitory/Condominium with 4-5 floors	9191
	Institutional	Office building with 1 floor	9330
		Office building with 2-3 floors	9988
		Office building with 4-5 floors	9883
		Office building with 6-9 floors	9492
	Industrial	Small industrial and warehouse	6278
		Large industrial (more than 10,000 m ²)	8866
		Large warehouse	5579
	Transportation	Building and car park	6881
		Road	6881
		Railway station	6881
	Others	Recreation and green area	No compensation
		Golf course	No compensation
		Cemetery	No compensation
Agricultural land	Paddy field		1.38875
	Field crop		1.96875
	Perennial trees		3.18625
	Orchard		3.18625
	Horticulture		3.18625
	Pasture		1.96875
Miscellaneous land			No compensation
Forest land			No compensation
Water body			No compensation

Continuity equation:

$$\frac{\partial \zeta}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = \frac{\partial d}{\partial t} \quad (1)$$

Momentum equation in the x direction:

$$\begin{aligned} \frac{\partial p}{\partial t} + \frac{\partial}{\partial x} \left(\frac{p^2}{h} \right) + \frac{\partial}{\partial y} \left(\frac{pq}{h} \right) + gh \frac{\partial \zeta}{\partial x} + \frac{gp\sqrt{p^2+q^2}}{c^2 h^2} - \\ \frac{1}{\rho_w} \left[\frac{\partial}{\partial x} (h\tau_{xx}) + \frac{\partial}{\partial y} (h\tau_{xy}) \right] - \Omega q - fVV_x + \\ \frac{h}{\rho_w} \frac{\partial}{\partial x} (p_a) = 0 \end{aligned} \quad (2)$$

Momentum equation in the y direction:

$$\begin{aligned} \frac{\partial q}{\partial t} + \frac{\partial}{\partial y} \left(\frac{q^2}{h} \right) + \frac{\partial}{\partial x} \left(\frac{pq}{h} \right) + gh \frac{\partial \zeta}{\partial y} + \frac{gq\sqrt{p^2+q^2}}{c^2 h^2} - \\ \frac{1}{\rho_w} \left[\frac{\partial}{\partial y} (h\tau_{yy}) + \frac{\partial}{\partial x} (h\tau_{xy}) \right] + \Omega p - fVV_y + \\ \frac{h}{\rho_w} \frac{\partial}{\partial y} (p_a) = 0 \end{aligned} \quad (3)$$

The following symbols are used in the equations:

- $h(x, y, t)$ is the water depth (m)
- $d(x, y, t)$ is time varying the bottom elevation (m)
- $\zeta(x, y, t)$ is the surface elevation (m)
- $p, q(x, y, t)$ are the flux densities in the x- and y-directions ($\text{m}^3/\text{s}/\text{m}$)
- $C(x, y)$ is the Chezy resistance coefficient ($\text{m}^{1/2}/\text{s}$) $= \frac{1}{n} R^{2/3}$
- R is the hydraulic radius (m)
- n is Manning's n number $= \frac{1}{M}$
- M is Manning's M number
- g is the acceleration due to gravity (9.8 m/s^2)
- $f(V)$ is the wind friction factor
- $V, V_x, V_y(x, y, t)$ are the wind speed and components in the x- and y directions (m/s)
- $\Omega(x, y)$ is the Coriolis parameter, latitude dependent (s^{-1})
- $p_a(x, y, t)$ is the atmospheric pressure ($\text{kg}/\text{m}/\text{s}^2$)
- ρ_w is the density of water (kg/m^3)
- x, y are the space coordinates (m)
- t is time (s)
- $\tau_{xx}, \tau_{xy}, \tau_{yy}$ are the components of effective shear stress

In practice, the required input data of the MIKE 21 flow model include a digital elevation model (DEM), precipitation, discharge, watershed boundary, water gates used to simulate the flood's extent, water depth, velocity, and flood duration with an optimum local parameter. For running the model, bathymetry has to be created using the DEM as the first step in order to define the new working area and its management for flood simulation. Then, basic required input variables/parameters which include module selection, simulation period, boundary, source and sink areas, flood and dry areas, initial surface elevation, eddy viscosity, and resistance (Manning number) are entered into the model for urban flood simulation. Herein, Manning's η or bed roughness according to land cover types is considered as the main parameter to calibrate the model for an optimum local parameter of the model identification for urban flood simulation. It is a friction that causes the water to flow faster or slower, and which affects the water level's increase or decrease (DHI Water & Environment, 2011). The Manning's M number is the inverse of the conventional Manning's η as $M = 1/\eta$. In this study the Manning's M number of specific land use types is adopted from Chow (1959), Syme (2008), and Kalyanapul *et al.* (2009) and systematically assigned into 3 groups: minimum, normal, and maximum values for the model calibration, as summarized in Table 4.

The simulated flood area from the MIKE 21 model by each Manning's M number is assessed for accuracy with the actual flood map in 2010 from GISTDA as reference data. The overall accuracy, flood detection rate, and false alarm rate are calculated based on the contingency table basis, as suggested by Wang *et al.* (2008), as below:

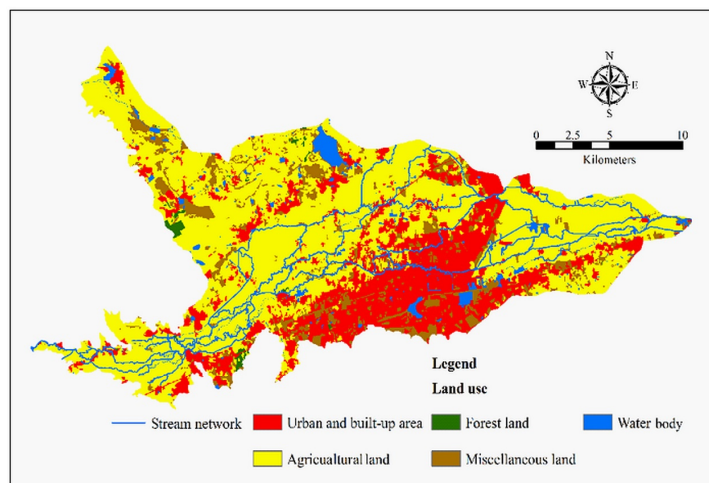
$$\text{Overall accuracy} = \frac{(A+D)}{(A+B+C+D)} \quad (4)$$

$$\text{Flood detection rate (omission error)} = \frac{A}{(A+B)} \quad (5)$$

$$\text{False alarm rate (commission error)} = \frac{C}{(C+D)} \quad (6)$$

Table 4. The Manning's M values of specific land use types for model calibration

Land use types	Manning's M group		
	Minimum	Normal	Maximum
Building	14.75	19.75	24.75
Road	71.00	71.00	71.00
Aquaculture	28.57	75.19	100.00
Abandoned field crop	88.50	88.50	88.50
Abandoned paddy field	88.50	88.50	88.50
Animal farm house	3.03	3.03	3.03
Field crop	2.78	25.00	33.33
Horticulture	22.22	22.22	22.22
Orchard	2.78	2.78	2.78
Pasture	3.08	3.08	3.08
Perennial trees	2.50	2.50	2.50
Rice paddy	5.48	22.00	40.00
Dense forest plantation	5.00	5.00	5.00
Disturbed deciduous forest	5.00	5.00	5.00
Cemetery	88.50	88.50	88.50
Garbage dump	88.50	88.50	88.50
Golf course	2.72	2.72	2.72
Grass	2.72	2.72	2.72
Landfill	88.50	88.50	88.50
Marsh and swamp	11.63	11.63	11.63
Pit	28.57	28.57	28.57
Recreation and green area	24.75	24.75	24.75
Shrub/Scrub	2.50	2.50	2.50
Water body	28.57	75.19	100.00



Distribution of 5 main land use classes in 2010 by visual interpretation based on 4 districts (sq. m)

Land use level I	Kham Thale So	Sung Noen	Mueang Nakhon Ratchasima	Chaloem Phra Kiat
Urban and built-up area	7,671,875	1,551,250	86,045,625	1,666,250
Agricultural land	68,013,750	15,740,000	146,266,250	9,085,000
Forest land	1,177,500	17,500	994,375	-
Miscellaneous land	10,048,125	298,750	26,926,875	1,137,500
Water body	3,712,500	1,128,750	14,806,875	955,000
Total	90,623,750	18,736,250	275,040,000	12,843,750

Figure 3. Distribution of 5 main land use classes in 2010 and its area

where,

(A) is the amount of true flood cells, i.e., cells simulated as flooding and which agree with the reference map;

(B) is the amount of false flood cells, i.e., cells simulated as non-flooding but which disagree with the reference map;

(C) is the amount of false flood cells, i.e., cells simulated as flooding but which disagree with the reference map; and

(D) is the amount of true non-flood cells, i.e., cells simulated as non-flooding and which agree with the reference map.

When the results of overall accuracy are equal to or more than 80%, the simulated flood by the MIKE 21 flow model is accepted due to strong agreement between both the simulated and reference data. The derived accuracy by each Manning's M dataset is then evaluated to identify an optimum local parameter of the MIKE 21 model for urban flood simulation and is then applied to simulate the flood's extent, depth, velocity and duration for the urban flood severity analysis and economic value loss assessment. In this study, the physical urban flood severity by depth and velocity are classified according to the flood severity classification of Chen (2007). Meanwhile, the urban flood duration is analyzed by a combination of the daily flood extent during the simulation period (14th-27th October, 2010) using the raster calculation under the Environmental Systems Research Institute's ArcMap software to extract the occurrence of flooded areas in the number of days (1 to 14 days). In addition, the flood's extent, depth, velocity, and duration data are overlaid with the interpreted land use map in 2010 to analyze their effect and to assess the EVL according to the compensation rates of the Office of Insurance Commission (OIC) and the cabinet resolution of the Thai government on August 25th, 2011.

Component 3: Urban Flood Scenario Simulation for Flood Mitigation and Prevention

Under this component, the urban flood scenarios are firstly simulated at each 10% of the cut-off inflow data from the historical record in 2010 to generate the flood's extent and to evaluate the EVL. This process is operated reiterately to identify the minimal

cut-off inflow for urban flood mitigation and prevention with the optimal flood extent and EVL.

Results and Discussion

Land use Data in 2010

According to visual interpretation of multi-temporal remotely sensed data, the main land use class in 2010 in the study area was agricultural land which covered an area of 239 sq. km or 60.19% of the study area and the minor land use class was forest land which covered area of 2.19 sq. km or 0.55% of the area. The distribution of the main land use classes and the area is presented in Figure 3. It reveals that most of the main land use classes are situated in the floodplain with an average elevation at 162.27 m above mean sea level. It can be assumed that if an urban flood occurs, the most affected land use classes would be urban and built-up areas and agricultural land, especially paddy fields. The overall accuracy of the detailed land use data in 2010 using 297 stratified random sampling points was 88.39% and the Kappa hat coefficient was 88.1%. According to Fitzpatrick-Lins (1981), a Kappa hat coefficient of more than 80% represents a strong accuracy between the interpretation map and the ground reference information.

Optimum Parameters for Urban Flood Simulation by the MIKE 21 Flow Model

The results have demonstrated that 3 varying Manning's M number groups for flood simulation provided an overall accuracy higher than 80% of the acceptance value. In fact, the flood simulation with the minimum Manning's M number provided the best flood extent based on overall accuracy, flood detection rate, and false alarm rate when it was compared with the actual flood maps on 22nd and 23rd October, 2010 from GISTDA (Figure 4). However, when the simulated flood extent from the 3 groups of Manning's M numbers were validated with known locations of the flood record in 2010 from various government agencies (Tables 5 and 6) and the ground survey in 2014, it was found that the simulated flood extent using the normal Manning's M number could provide a more realistic urban flood event in 2010 than the others. In fact, it

was found the corrected flood arrival date at many important landmarks was the same as the historical flood record in 2010. For example, the flood arrived at Ban Don on 14th October, 2010, Ban Kong Yang on the 15th, V.I.P housing estate and Saint Mary's Hospital on the 21st, and Wat Taklong Kao on the 24th (Figure 5). Therefore, the normal Manning's M number has the optimum value with an overall accuracy of 81.68%, a flood detection rate of 62.39%, a false alarm rate of 15.01% on 22nd October, and an overall accuracy of 81.53%, a flood detection rate of 63.44%, and a false alarm of 15.50% on 23rd October, and it

is further applied to characterize the urban flood information (extent, depth, velocity, and duration) for the flood severity classification and total EVL assessment. The comparison of the urban flood extent on 22nd and 23rd October, 2010 by GISTDA and the MIKE 21 model with the normal Manning's M number is displayed in Figure 6.

Urban Flood Extent During 14th-27th October, 2010

The simulated urban flood extent increased intensely during 14th to 21st October, 2010 and gradually increased to reach the

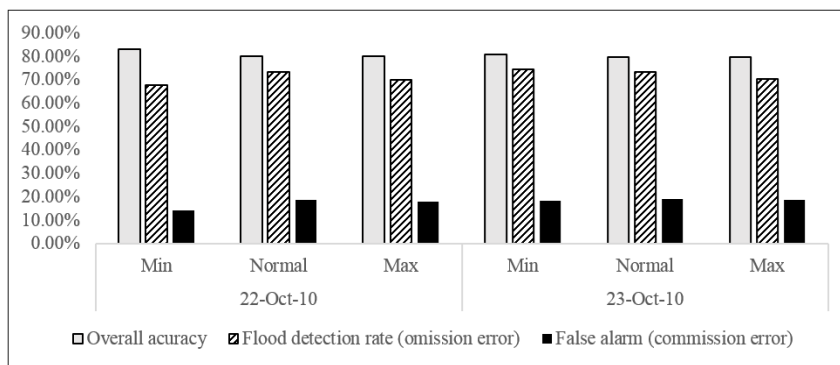


Figure 4. Comparison of overall accuracy, flood detection rate, and false alarm rate by 3 Manning's M value groups

Table 5. Accuracy comparison of 3 simulated flood extents based on 3 Manning's M value groups with flood landmark with time record in 2010

Date	No of flood landmark	Number of correction		
		By minimum value	By normal value	By maximum value
14-Oct-2010	7	5	5	5
15-Oct-2010	1	0	1	0
21-Oct-2010	2	0	2	0
24-Oct-2010	1	1	1	0

Table 6. Accuracy comparison of 3 simulated flood extents based on 3 Manning's M number dataset with flood landmark without time record and non-flood landmark record in 2010

Landmark type	No of landmark	Number of correction		
		By minimum value	By normal value	By maximum value
Flood	52	43	42	35
Non-flood	4	4	4	4

maximum flood extent on 24th October when it covered an area of 88.77 sq. km, and it then slowly decreased until 27th October when it covered an area of 82.00 sq. km. The extent of the urban flood during 14th-27th October, 2010 is comparatively displayed in Figure 7. The dominant affected land use classes based on the physical flood extent on 24th October, 2010 were agricultural land and urban and built-up areas that covered an area of 76.89 sq. km or 86.62% of the study area and 7.74 sq. km or 8.72%, respectively.

Urban Flood Depth and Its Severity Classification and Effect on Land Use

The urban flood depth during the simulated period varies from 0.10 to 3.91 m. The minimum value of the flood depth is here set at 0.10 m as a constant value to detect flood occurrence, as suggestion by the local expert of the Royal Irrigation Department (Wachirasak Pakdee, Head of the Khud Hin water gate). In this study, if the depth is less than 0.10 m, it is not considered as a flood. In general, the direction of the Mueang district urban flood in 2010



Figure 5. Historical flood record of selected landmarks from urban flood of Mueang district in 2010

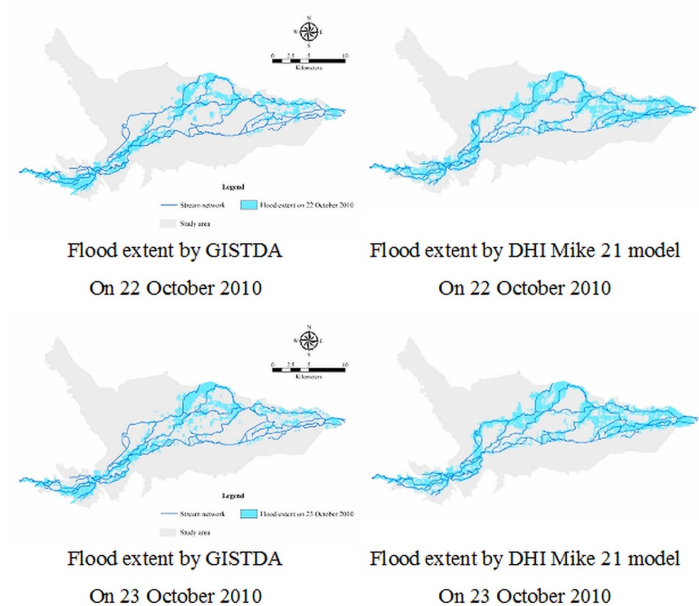


Figure 6. Comparison of urban flood extent on 22nd and 23rd October, 2010 by GISTDA and DHI MIKE 21 Model with normal Manning's M number

flowed in the same direction as the Lam Takhong River from the west at Kud Hin watgate to the east at Gun Phom water gate. A huge volume of water creates overflowing along the main stream networks. Moreover, high urban flood depths are located close to stream networks in areas of lowlying land. However, some parts of the study area also have road networks which are mostly constructed higher than the normal terrain. These roads perform as man-made barriers to prevent flood flows and they block flooded water on one side of road, e. g. road number 22

(the bypass Mitraphap road to Khon Kaen). As a result, it leads to a high flood depth near to the roads.

In addition, the urban flood severity classification by depth, according to Chen (2007), showed that the major urban flood severity class was moderate and covered an area of 35.32 sq. km or 39.80% of the flooded area. Meanwhile, most of the urban and built-up areas and agricultural land that were affected had a flood depth situated in the moderate severity class with a depth between 0.4 and 1.0 m (Figure 8).

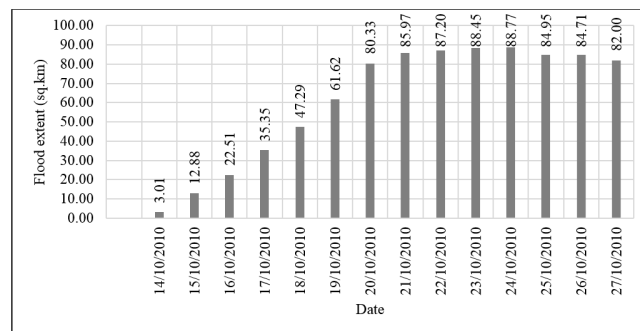


Figure 7. Area of urban flood extent during 14th – 27th October, 2010

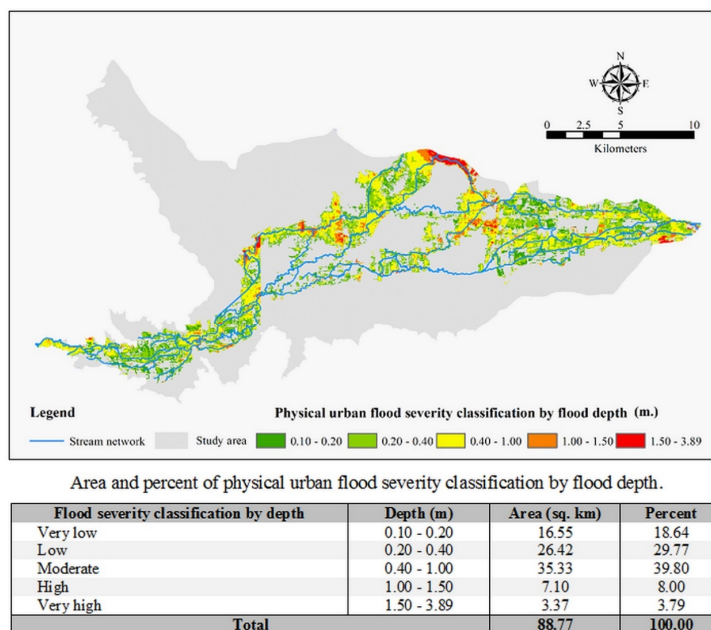


Figure 8. Distribution of urban flood severity classification and its area based on flood depth on 24th October, 2010

Urban Flood Velocity and Its Severity Classification and Effect on Land Use

The results from the hydrodynamic simulation indicated that the urban flood velocity increased from 0.00 m/s to 2.03 m/s on 19th October, 2010 and then it gradually increased to its highest value on the 22nd and 23rd October at 2.06 m/s, before it slightly decreased to 1.97 m/s on the 27th. The spatial variability of the maximum urban flood velocity was located close to the stream network and flat areas. The average urban flood velocity during the simulated period ranged between 0.22 and 0.14 m/s and that showed little

difference due to the characteristics of the study area which is mostly situated over a floodplain and terrace landform.

In addition, the urban flood severity classification by velocity, according to Chen (2007), showed that the most dominant urban flood severity class was very low and it covered an area of 72.97 sq. km or 82.21% of the flooded area (Figure 9) because the gradient of the study area is rather gentle. Most of the urban and built-up areas and agricultural land that were affected by flood velocity were

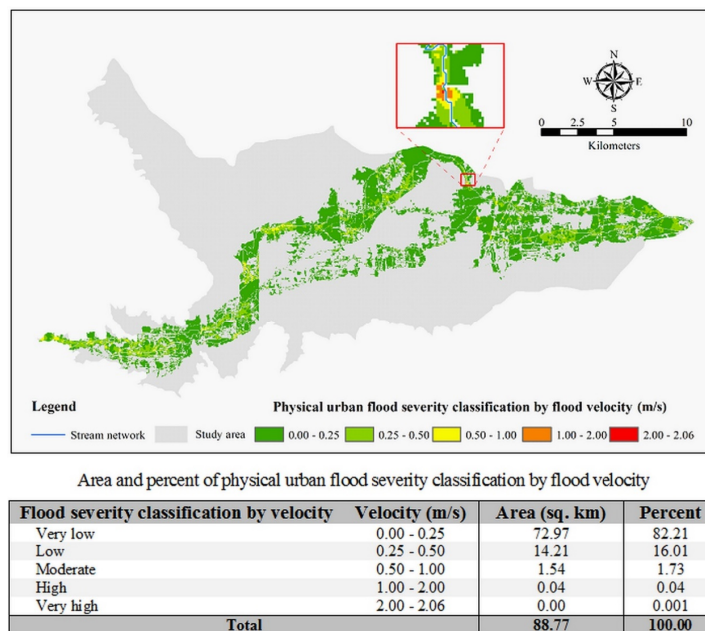


Figure 9. Distribution of urban flood severity classification and its area based on flood velocity on 24th October, 2010

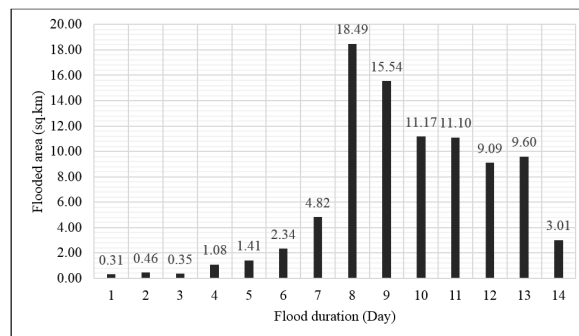


Figure 10. Area of flood and its duration

situated in the very low severity class with a velocity less than 0.25 m/s.

Urban Flood Duration and Its Severity Classification and Effect on Land Use

All 14 values of the urban flood duration with their flooded areas during the simulated period are presented in Figure 10. It revealed that the flooded areas slowly increased while the flood duration increased and it reached a maximum flood duration after 8 days and covered an area of 18.49 sq. km or 20.83% of the maximum flood extent on 24th October, 2010.

According to the urban flood severity classification by the flood duration with equal interval method, the major severity class was moderate (7-9 days) and it covered an area of 34.02 sq. km or 38.33% while the very low severity class (1-3 days) covered an area of 1.12 sq. km or only 1.27% (Figure 11). It can be seen that the direction of the movement of the flood can be used to indicate the urban flood duration classification. The very high flood duration severity class was mainly situated on the western part of the study area while the very low flood duration severity class was located on the eastern part of the study area. Most of the urban and built-up areas and agricultural land that were

affected by the flood duration are situated in the moderate severity class with a flood duration between 7 and 9 days.

Economic Value Loss Assessment

According to the detailed interpreted land use data in 2011 and their compensation rates, the total economic value loss (EVL) through compensation payments for affected urban and built-up areas and agricultural land based on the maximum urban flood extent on 24th October, 2010 was about 73,516,541,689 baht (Table 7).

As a result, the most affected urban and built-up areas were concrete and wooden houses that covered an area of 5,593,125 sq. m and the compensation payment was 53,565,358,125 baht while the most affected agricultural land was paddy fields that covered an area of 68,883,750 sq. m and the compensation payment was 95,662,308 baht. Conversely, the least affected urban and built-up areas were houses with 1 floor that covered an area of 13,750 sq. m and the compensation payment was 128,287,500 baht while the least affected agricultural land was pasture that covered an area of 71,875 sq. m and the compensation payment was 141,504 baht.

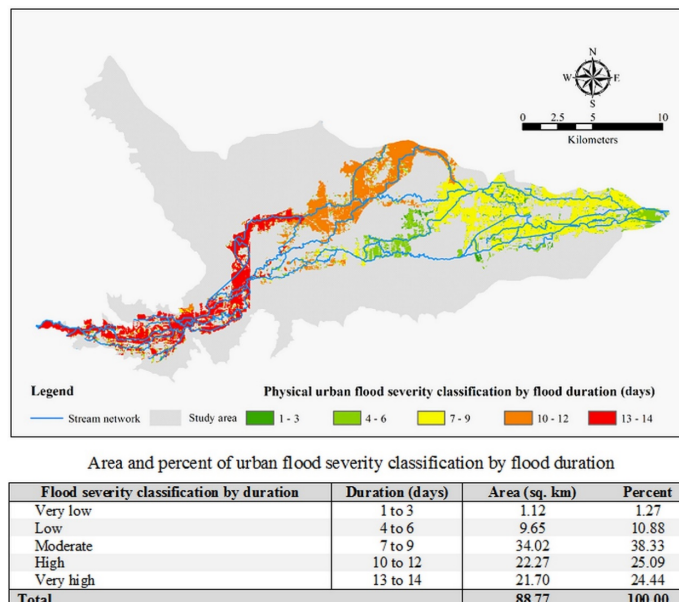


Figure 11. Distribution of urban flood severity classification by flood duration and its area

Urban Flood Simulation Scenario for Flood Mitigation and Prevention

This part is focused on the reduction (cut-off inflow) data in percentages from the historical discharge in 2010 to create the simulated urban flood scenarios for flood mitigation and prevention in the future by minimizing flood extent and total EVL. The discharge data which were used to simulate the urban flood scenarios using the MIKE 21 model are summarized in Table 8. The statistical data of the flood event according to the percentage of the reduced discharge which include the initial discharge, the urban flood extent and its changing rate, the total EVL and its changing rate, and the peak date are summarized in Table 9 and the distribution of the urban flood extent of each scenario is displayed in Figure 12.

From the results, it can be observed that the urban flood extent slightly decreased when the historical discharge in 2010 was reduced between 10% and 40%. However, the urban flood extent dramatically decreased with an accelerated rate when the historical discharge in 2010 was reduced between 40 and 60%. After that its extent slightly decreased when

the historical discharge in 2010 was reduced between 60% and 66%. Similarly, the total EVL change occurred when the discharge was reduced.

Furthermore, the dynamic change pattern of the urban flood extent (in sq. km) and total EVL (in trillion baht) and their change rates among the scenarios were similar (Figure 13). The result implies that when the urban flood extent increases, then the EVL also increases. The relationship between the simulated urban flood extent and total EVL can be confirmed by a simple linear regression analysis, as shown in Figure 14. The simulated urban flood extent (in sq. km) as an independent variable (x) and the total EVL (in million baht) as a dependent variable (y) show a positive relationship with R^2 at 99.16% as:

$$y = -19,128 + 1031.2x \quad (7)$$

Minimal Cut-off Inflow for Urban Flood Mitigation and Prevention

From the result presented in Table 9, the urban flood extent and total EVL abruptly decreased from the historical urban flood

Table 7. Total economic value loss assessment

Land use classification		Area (sq. m)	Compensation rate (baht)	Payment (baht)
Level I	Level II and III			
U	Bus station/Gasoline station	41250	6881	283841250
U	Commercial buildings with 1 floor	51875	3661	189914375
U	Commercial buildings with 2 floors	21250	6978	148282500
U	Commercial buildings with 4 floors	198750	5912	1175010000
U	Concrete and wooden house	5593125	9577	53565358125
U	House with 1 floor	13750	9330	128287500
U	House with 2 floor	807500	10619	8574842500
U	Large industrial (more than 10,000 sq. m)	393125	8866	3485446250
U	Office building with 1 floor	55625	9330	518981250
U	Office building with 2-3 floors	268125	9988	2678032500
U	Office building with 4-5 floors	36875	9883	364435625
U	Office building with 6-9 floors	93125	9492	883942500
U	Road	132500	6881	911732500
U	Shopping mall (levels 1-3)	15625	11669	182328125
U	Small industrial and warehouse	21250	6278	133407500
A	Animal farm house	47500	3661	173897500
A	Field crop	82500	1.96875	162422
A	Horticulture	5839375	3.18625	18605709
A	Orchard	1233750	3.18625	3931036
A	Pasture	71875	1.96875	141504
A	Perennial trees	93750	3.18625	298711
A	Paddy field	68883750	1.38875	95662308
Total compensation payment				73516541689

Table 8. Discharge data for urban flood simulation to mitigate and prevent flood

Date	Kud Hin Q (m ³ /s)	RQ 10%	RQ 20%	RQ 30%	RQ 40%	RQ 50%	RQ 60%	RQ 70%	RQ 80%	RQ 90%
2010-10-14	44.54	40.09	35.63	31.18	26.72	22.27	17.82	13.36	8.91	4.45
2010-10-15	49.55	44.60	39.64	34.69	29.73	24.78	19.82	14.87	9.91	4.96
2010-10-16	55.71	50.14	44.57	39.00	33.43	27.86	22.28	16.71	11.14	5.57
2010-10-17	79.93	71.94	63.94	55.95	47.96	39.97	31.97	23.98	15.99	7.99
2010-10-18	73.5	66.15	58.80	51.45	44.10	36.75	29.40	22.05	14.70	7.35
2010-10-19	67.07	60.36	53.66	46.95	40.24	33.54	26.83	20.12	13.41	6.71
2010-10-20	82.22	74.00	65.78	57.55	49.33	41.11	32.89	24.67	16.44	8.22
2010-10-21	82.22	74.00	65.78	57.55	49.33	41.11	32.89	24.67	16.44	8.22
2010-10-22	81.44	73.30	65.16	57.02	48.88	40.74	32.60	24.46	16.32	8.18
2010-10-23	77.58	69.82	62.06	54.31	46.55	38.79	31.03	23.27	15.52	7.76
2010-10-24	73.03	65.73	58.42	51.12	43.82	36.52	29.21	21.91	14.61	7.30
2010-10-25	71.53	64.38	57.22	50.07	42.92	35.77	28.61	21.46	14.31	7.15
2010-10-26	67.11	60.40	53.69	46.98	40.27	33.56	26.84	20.13	13.42	6.71
2010-10-27	68.57	61.71	54.86	48.00	41.14	34.29	27.43	20.57	13.71	6.86
2010-10-28	62.78	56.50	50.22	43.95	37.67	31.39	25.11	18.83	12.56	6.28

Note: RQ is reduce discharge

Table 9. Summary of flood extent, economic value losses, historical peak date and their scenarios

Flood event	Reduced discharge (%)	Initial discharge at Kud Hin water gate	Urban flood extent (sq. km)			Total EVL (Million Baht)			Peak Date
			Area	Change	Change rate ¹	Payment	Change	Change rate ²	
Historical	0	44.54	88.77			73,516.54			11 th date
Scenario 1	10%	40.09	86.64	2.13	0.213	71,280.60	2,235.94	223.59	11 th date
Scenario 2	20%	35.63	84.68	1.96	0.196	69,942.88	1,337.72	133.77	11 th date
Scenario 3	30%	31.18	83.5	1.18	0.118	66,724.22	3,218.66	321.87	11 th date
Scenario 4	40%	26.72	82.37	1.13	0.113	64,739.96	1,984.26	198.43	11 th date
Scenario 5	50%	22.27	51.76	30.61	3.061	27,252.91	37,487.05	3,748.71	12 th date
Scenario 6	60%	17.82	31.12	20.64	2.064	14,380.24	12,872.67	1,287.27	12 th date
Scenario 7	62%	16.93	30.42	0.7	0.35	14,014.61	365.63	182.81	12 th date
Scenario 8	64%	16.04	29.79	0.63	0.315	12,157.44	1,857.17	928.58	13 th date
Scenario 9	66%	15.15	28.87	0.92	0.46	11,297.42	860.02	430.01	13 th date
Scenario 10	67%	14.7	-	-	0	-	-	-	-

Note: 1. Change in rate of urban flood extent is change in area (in sq. km) divided by change in percentage of reduced discharge.

2. Change in rate of total EVL is million baht per percentage of reduced discharge.

The urban flood extent was reduced from the historical record of 88.77 sq. km at to 30.61 sq. km with a change rate of 3.061 sq.km per 1% of the reduced discharge at Scenario 5 and then 20.64 sq. km with a change rate of 2.064 sq.km per 1% of the reduced discharge at Scenario 6. Similarly, the total EVL of the historical record dropped from 73,516.54 million baht to 27,252.91 million baht with a change rate of 3,748.71 million baht per 1% of the reduced discharge at Scenario 5 and 14,380.24 million baht with a change rate of 1,287.27 million baht per 1% of the reduced discharge at Scenario 6.

After Scenario 6, there was a slight decrease in the flood extent and total EVL and the change rate. The urban flood extent was reduced from 31.12 sq. km at Scenario 6 to 30.42 sq. km at Scenario 7 and 28.87 sq. km at Scenario 9; meanwhile, the total EVL slightly

dropped from 14,380.24 million baht at Scenario 6 to 14,014.61 million baht at Scenario 7 and 11,297.42 million baht at Scenario 9. It shows a non-significant change occurring during Scenarios 7 to 9 when compared with Scenarios 5 to 6. Lastly, it was found that no urban flood occurred in the study area at Scenario 10 when the historical discharge record was reduced by 67%.

As can be seen from the results, the minimal cut-off inflow based on the historical record in 2010 for flood mitigation should be 60% (Scenario 6). At this scenario, it can reduce the urban flood extent to about 57.65 sq. km or 64.94% of the flooded area in 2010, and it can save about 59,136 million baht in compensation payments or 80.44% of the total EVL in 2010. Meanwhile, the reduction discharge from the historical record in 2010 for flood prevention should be 67% (Scenario 10).

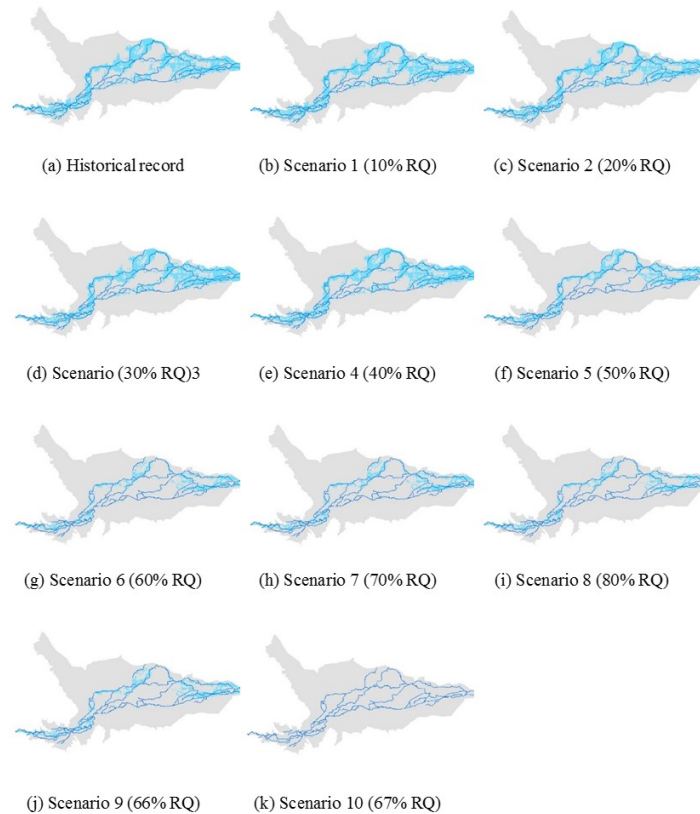
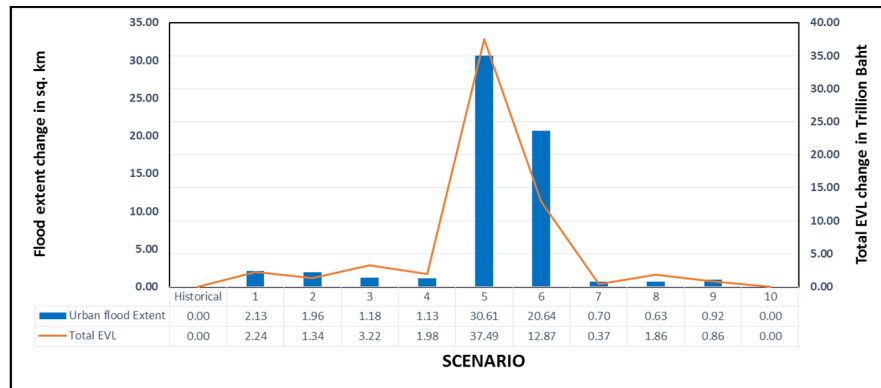
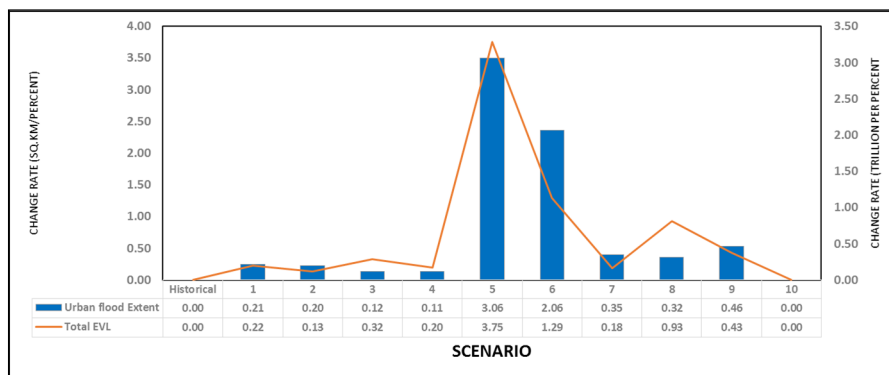


Figure 12. Distribution of simulated flood extent of historical record with scenarios



(a)



(b)

Figure 13. Dynamic urban flood extent and total EVL (a) and dynamic change rate of urban flood extent and total EVL (b) among scenearios

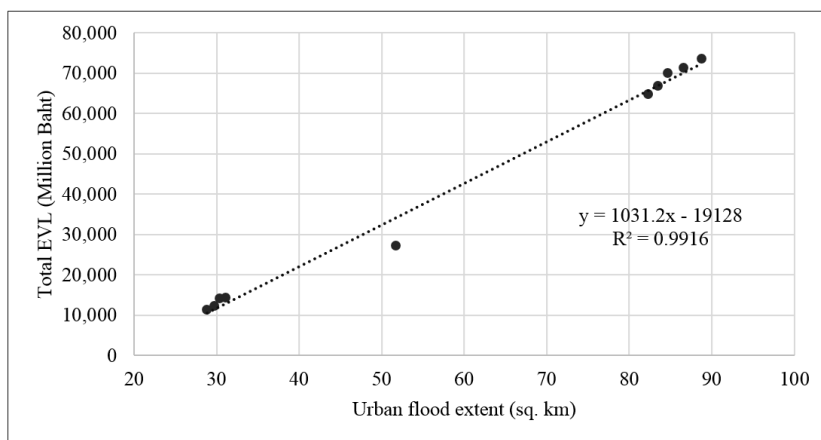


Figure 14. The relationship between simulated urban flood extent and total EVL

At this scenario, it can protect Mueang district from the urban flooding that occurred in 2010.

To achieve flood mitigation, the discharge at the Kud Hin water gate should be controlled and it should be less than 17.82 m³/s. Meanwhile, when the discharge at the Kud Hin water gate is equal or less than 14.70 m³/s, it can protect Mueang district from urban flooding.

Conclusions

The normal Manning's *M* number is demonstrated as the optimum value for the urban flood simulation in 2010 by the MIKE 21 model through validation of the simulated urban flood extent with an actual flood map from GISTDA with an overall accuracy greater than 80%. The urban flood simulation in 2010 can quantify the flood extent, depth, velocity, and duration for the urban flood severity classification and total EVL assessment. Meanwhile, based on the urban flood simulation scenarios, by varying the discharge record of the historical urban flood in 2010 the minimal cut-off inflow at 60% can mitigate urban flooding with the minimum flood extent and total EVL. Likewise, when the historical discharge has a cut-off at 67%, it could protect urban flooding in Mueang district. To achieve urban flood mitigation and prevention, the discharge at the Kud Hin water gate should be controlled to less than 17.82 m³/s and 14.70 m³/s, respectively. However, it requires allocating a monkey cheek to collect a huge volume of water above the storage capacity of Lam Takhong reservoir before it reaches the Kud Hin water gate, as occurred in October 2010.

References

- Chen, P. (2007). Flood impact assessment using hydrodynamic modelling in Bangkok, Thailand, [MSc. thesis]. International Institute for Geo-Information Science and Earth Observation. Enschede, The Netherlands, 61p.
- Chow, V.T. (1959). *Open-channel Hydraulics*. McGraw-Hill, NY, USA, 680p.
- DHI Water & Environment (DHI). (2011). MIKE 21 flow model: Hydrodynamic module [Computer software]. Horsholm, Denmark.
- Filipova, V., Rana, A., and Singh, P. (2012). Urban Flooding in Gothenburg - A MIKE21 Study. *Journal of Water Management and Research*, 68:175-184.
- Fitzpatrick-Lins, K. (1981). Comparison of Sampling Procedures and Data Analysis for a Land-use and Land-cover Map. *Photogramm. Eng. Rem. S.*, 55(4):475-478.
- Geo-Informatics and Space Technology Development Agency (GISTDA). (2010). Flood data of Nakhon Ratchasima Province in 2010. Geo-Informatics and Space Technology Development Agency, Bangkok, Thailand
- Ghosh, S.N. (2006). *Flood Control and Drainage Engineering*. Taylor & Francis. Abingdon, UK, 364p.
- Jensen, J.R. (2007). *Remote Sensing of the Environment: An Earth Resource Perspective*. 2nd ed. Prentice Hall, Upper Saddle River, NJ, USA, 592 p.
- Kalyanapal, A.J., Burian, S.J., and McPherson, T.N. (2009). Effect of land use-based surface roughness on hydrologic model output. *J. Spatial Hydro.*, 9(2):51-71.
- Lam Takhong Operation and Maintenance Project. (2010). Discharge data of Kut Hin Water gate in October 2010. Lam Takhong Operation and Maintenance Project, Sikhiu, Nakhon Ratchasima, Thailand.
- Land Development Department. (2008). Land use data of Nakhon Ratchasima Province. Land Development Department, Bangkok, Thailand.
- Lillesand, T.M., Kiefer, R.W., and Chipman, J.W. (2004). *Remote Sensing and Image Interpretation*. John Wiley & Sons, Inc., Hoboken, NJ, USA, 763p.
- Miguez, M.G. and de Magalhaes, L.P.C. (2010). Urban flood control, simulation and management - an integrated approach. In: *Methods and Techniques in Urban Engineering*. de Pina Filho, A.C. and de Pina, A.C., (eds). InTech, Rijeka, Croatia, p.131-160. [On-line]. Available from: <http://www.intechopen.com/books/methods-and-techniques-in-urban-engineering/urban-flood-control-simulation-and-management-an-integrated-approach>.
- Ministry of Agriculture and Cooperatives. (2002). Digital Elevation Model Data. Permanent Secretary's Office, Ministry of Agriculture and Cooperatives, Bangkok, Thailand.
- Mueang Nakhon Ratchasima District Office. (2010). Report on Mueang Nakhon Ratchasima district flood damage in October 2010. Mueang Nakhon Ratchasima District Office, Mueang, Nakhon Ratchasima, Thailand.
- Nakhon Ratchasima Municipality Office. (2010). Remote sensing dataset: THEOS Imagery, SPOT-Imagery and World View II imagery. Nakhon Ratchasima Municipality Office, Mueang, Nakhon Ratchasima, Thailand.
- Office of Insurance Commission. (2010). Manual of property damage valuation. Office of Insurance Commission, Bangkok, Thailand. (in Thai).
- Patro, S., Chatterjee, C., Singh, R., and Raghuwanshi, N.S. (2009). Hydrodynamic modelling of a large flood-prone river system in India with limited data. *Hydrol. Process.*, 23(19):2,774-2,791.

- Shepherd, W. (2007). Issues of Urban Flooding. Sheffield, UK: University of Sheffield. Available from: http://www.shef.ac.uk/polopoly_fs/1.130125!/file/Sheperd-2007.pdf.
- Syme, W.J. (2008). Flooding in urban areas - 2D modelling approaches for buildings and fences. Proceedings of the Engineers, Australia, 9th National Conference on Hydraulics in Water Engineering; September 23-26, 2008; Darwin, Australia, p. 25-32.
- Tennakoon, K.B.M. (2004). Parameterisation of 2D hydrodynamic model and flood hazard mapping for Naga city, Philippines, [MSc. thesis]. International Institute for Geo-Information Science and Earth Observation. Enschede, The Netherlands, 115p.
- Thai Meteorological Department. (2010). Nakhon Ratchasima climate data in 2010. Thai Meteorological Department, Bangkok, Thailand.
- Toda, K. (2007). Urban flooding and measures. J. Disaster Res., 2(3):143-144.
- Wang, F. and Hartnack, J.N. (2006). Simulation of flood inundation in Jilin City, Songhua River Project. Proceedings of the 4th Asia-Pacific DHI Software Conference; November 15-17, 2006; Shanghai, China, p. F - 18-F - 28.
- Wang, L., Qu, J.J., and Hao, X. (2008). Forest fire detection using the normalized multi-band drought index (NMDI) with satellite measurements. Agr. Forest Meteorol., 148:1767-1776.
- Weeraya, M. and Jirawat, K. (2012). The study of flood relief measures of upper Mun river basin in Nakhon Ratchasima by MIKE 11 Model. Proceedings of the 10th National Kasetsart University Kamphaeng Saen Conference; December 6-7, 2012; Kamphaeng Saen, Nakhon Pathom, Thailand, p. 1,699-1,705.

