Flood control and loss estimation for paddy field at midstream of Chao Phraya River Basin, Thailand

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Flood control and loss estimation for paddy field at midstream of Chao Phraya River Basin, Thailand.

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Abstract. 2011 Thailand flood has brought serious impact to downstream of Chao Phraya River Basin. The flood peak period started from August, 2011 to the end of October, 2011. This research focuses on midstream of Chao Phraya River Basin, which is Nakhon Sawan area includes confluence of Nan River and Yom River, also confluence of Ping River and Nan River. The main purpose of this research is to understand the flood generation, estimate the flood volume and loss of paddy field, also recommends applicable flood counter measurement to ease the flood condition at downstream of Chao Phraya River Basin. In order to understand the flood condition, post-analysis is conducted at Nakhon Sawan. The post-analysis consists of field survey to measure the flood marks remained and interview with residents to understand living condition during flood. The 2011 Thailand flood generation at midstream is simulated using coupling of 1D and 2D hydrodynamic model to understand the flood generation during flood peak period. It is calibrated and validated using flood marks measured and streamflow data received from Royal Irrigation Department (RID). Validation of results shows good agreement between simulated result and actual condition. Subsequently, 3 scenarios of flood control are simulated and Geographic Information System (GIS) is used to assess the spatial distribution of flood extent and reduction of loss estimation at paddy field. In addition, loss estimation for paddy field at midstream is evaluated using GIS with the calculated inundation depth. Results show the proposed flood control at midstream able to minimize 5% of the loss of paddy field in 26 provinces.

1. Introduction

The Chao Phraya River Basin is normally divided into upstream (Northern Thailand), midstream (Nakhon Sawan) and downstream (Chao Phraya Delta) according to hydrological features (fig. 1). In the midstream of the Chao Phraya River Basin, Ping River, Yom River and Nan River flow down from the mountainous areas of Northern Thailand and converge at Nakhon Sawan. Bhumibol Dam (reservoir capacity of 13.5 billion m³) was constructed on Ping River and Sirikit Dam (reservoir capacity of 9.5 billion m³) was constructed on Nan River for irrigation, power generation and flood control purposes. A total of five dams were constructed for Ping River, Wang River and Nan River watersheds and contributes to 25 billion m³ reservoirs capacity [13]. Komori et al. (2012) concluded the 2011 flood was caused by increased rainfall by 143% over doubled runoff during rainy season rainfall during 1982 – 2001. Moreover, 5 typhoons made landfall in Thailand, which strongly influenced the rainfall. The flood destroyed the water gates and broke levees, especially at the left bank of the upper Chao Phraya Dam, which led to uncontrollable flooding. Thai government intends
to build Kaeng Suea Ten Dam (reservoir capacity of 1.15 billion m$^3$) on Yom River to increase the total capacity in the country. However, the plan was against by the residents and to be constructed. Limited studies were conducted on the midstream of Chao Phraya River Basin. Oki (2012) clarified and analyzed on the flood damage in the downstream of Chao Phraya River Basin. However, flood condition of midstream was not clarified in details. Kwak et al. (2012) estimated total flood volume in Chao Phraya River Basin by using modified remote sensing indices to near-real-time Moderate Resolution Imaging Spectroradiometer (MODIS) images and flood inundation level (FIL) model with the Digital Elevation Model (DEM). It studied flood condition using static method; however, this research will use hydrodynamic simulation method to understand the flood condition.

The Ministry of Finance (2012) reported the total damage and losses from the 2011 floods in Thailand amounted to USD 46.5 billion. Table 1 shows the damage and losses for agriculture sector. The Ministry of Finance (2012) defines crop damages as damage to farm machinery such as tractors, plows, threshers and farm tools. The damage to the farm machinery and losses in 26 provinces for crops were USD 0.2 billion and USD 1 billion, respectively. From table 2, it is able to understand the total losses to rice of 26 assessed provinces are estimated to be roughly USD 0.8 billion. The total loss includes 3 components, which are total production losses, higher production costs and losses due to forced early sale. Flood damage is divided into 2 categories, tangible damage and intangible damage. Intangible damage includes negative psychological impact such as depression and health. Tangible damage is subdivided in to direct damage and indirect damage. Direct damage is measureable and often referred to as the damage. Indirect damage is not physical but subsequent negative effect on economic activities (JICA). This study will use hydrodynamic simulation method to examine the flood condition at the midstream area of Chao Phraya River Basin, particularly paddy field by GIS. The aim is to understand the economic impact of the flood on the paddy field in midstream region. The direct damage for paddy field is calculated by formula (1). Different scenario of flood control at 3 rivers – Nan River, Yom River and Ping River were simulated and the loss estimation of paddy field was analysed. Ultimately, some effective mitigation measures are recommended.

$$\text{one type of damage} = \text{area} \times \text{yield} \times \text{farm gate price} \times \text{damage rate}$$  \hspace{1cm} (1)

**Fig. 1** Chao Phraya River Basin in Thailand (source: CTI, 1999)
Table 1 Agriculture sector - Damage, losses and needs in USD, millions (source from Ministry of Agriculture and Cooperatives, Thailand)

<table>
<thead>
<tr>
<th>Sub-sector</th>
<th>Disaster Effects</th>
<th>Ownership</th>
<th>Needs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Damage</td>
<td>Losses</td>
<td>Total</td>
</tr>
<tr>
<td></td>
<td>Public</td>
<td>Private</td>
<td>~6 mths</td>
</tr>
<tr>
<td>Agriculture</td>
<td>154</td>
<td>927</td>
<td>1,081</td>
</tr>
<tr>
<td>- Food crops</td>
<td>150</td>
<td>808</td>
<td>957</td>
</tr>
<tr>
<td>- Perennial crops</td>
<td>5</td>
<td>119</td>
<td>124</td>
</tr>
<tr>
<td>Livestock</td>
<td>10</td>
<td>83</td>
<td>93</td>
</tr>
<tr>
<td>Fisheries</td>
<td>4</td>
<td>25</td>
<td>28</td>
</tr>
<tr>
<td>Cross cutting sector</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>323</td>
<td>1,962</td>
<td>2,285</td>
</tr>
</tbody>
</table>

Table 2 Agricultural Sector - Estimated losses in 2011-2014 by commodity in USD, millions (source from Ministry of Agriculture and Cooperatives, Thailand)

<table>
<thead>
<tr>
<th>Crop</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>794</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sugar cane</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fruit trees</td>
<td>7</td>
<td>57</td>
<td>36</td>
<td>14</td>
</tr>
<tr>
<td>Flowers</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Maize</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Livestock</td>
<td>60</td>
<td>23</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Poultry</td>
<td>35</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Swine</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cattle</td>
<td>22</td>
<td>23</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fisheries</td>
<td>25</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Tilapia</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Catfish</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Shrimp</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Striped</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>snakehead fish</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>905</td>
<td>80</td>
<td>36</td>
<td>14</td>
</tr>
</tbody>
</table>

2. Simulation of Flood Scenario at Study Area
Fig 2 shows the location of midstream of Chao Phraya River Basin, Nakhon Sawan. Those labeled in red are gauging stations. Nan River and Yom River converge at gauging station N. 67. Ping River and Nan River converge before reaching gauging station C. 2. Streamflow data of these gauge stations are received from Royal Irrigation Department (RID). Data of gauging stations at upper reach are used as input parameters for model, such as P. 7A, Y. 17 and N. 7. Data of gauging stations at lower reach are used for validation, such as N. 67 and C. 2. Simulation of 2011 Thailand flood event is done with MIKE Flood, a Hydraulic Model from Denmark Hydraulic Institute (DHI). The hydrodynamic and rainfall parameters data are obtained from RID. Cross section data are provided by The International Symposium on Geohazards and Geomechanics (ISGG2015) IOP Publishing IOP Conf. Series: Earth and Environmental Science 26 (2015) 012022 doi:10.1088/1755-1315/26/1/012022
Centre for Water Hazard and Risk Management (ICHARM) and source of bathymetry data is Shuttle Radar Topography Mission (SRTM) with the resolution of 90m.

2.1. Field Survey at Nakhon Sawan
Flood marks investigation was conducted in the area of Nakhon Sawan from September 27 to 29, 2012, by measuring rod. The targeted areas were the riverbanks, natural banks, back marshes, narrow segments and others. Some measured flood marks are out of study area, as a result, a total of 8 flood marks are used for validation (fig. 4). Information such as starting date of floods, the flow direction of floods, living condition during floods and awareness of floods were collected through the interview with the residents.

2.2. Calibration of Modelling
The flowchart of modelling is shown on fig. 5. Nedbør-Afstrømnings-Model (NAM) Rainfall-Runoff model in MIKE 11 (DHI.co) is used for simulating 1D hydraulic modelling of rivers condition in study area. Rainfall data in year 2011 for upper reach of Nan River, Ping River and Yom River are used. Streamflow data for gauging stations Y. 17, N. 7 and P. 7A are used as inflow boundary type for upper reach in model. Projection of the model has defined as Universal Transverse Mercator (UTM) North 47 and cross sections are defined in each river with at least 7 cross sections on it. The simulation period for MIKE 11 is from April 1 to December 31, 2011 as limited streamflow data obtained from RID. SRTM is used as bathymetry for MIKE 21 in 2D modelling. It was interpolated into resolution of 100m from 90m to have a smooth running of simulation. Finally, both 1D and 2D are coupled in MIKE FLOOD to simulate the flood generation. In the consideration of running time and quality of result, simulation period is focused from August 1 to December 30, 2011 with time step interval of 15 seconds. In this model, Manning M is used as bed resistance and only parameters from main rivers (Nan River, Yom River, Ping River and Chao Phraya River) are included as limited data obtained. Simulation model did not include the consideration of small streams around those main rivers.
2.3. Validation and Discussion of Simulation Result

The result of simulated streamflow is validated with data received from RID such as data at gauging stations N. 67 and C. 2. Fig 6 shows the differences of streamflow before and after confluence of Nan River and Yom River by the comparing the combination data at gauging stations Y. 17 and N. 7, and N. 67. The simulated result at gauging station N. 67 was validated with RID data. From RID data, the flood condition before gauging station N. 67 is more serious then after as it showed a difference of nearly 63 hundred million m$^3$ occurred. These flood amount flows into lower area, small streams and flood plain before reaching gauging station N. 67 and caused the flood condition eased after gauging station N. 67 at a streamflow less than 2000 m$^3$/s. Dotted line in fig 6 represents the result of simulation at gauging station N. 67 and it showed about 10 hundred million m$^3$ differences compared with RID data from August 1 to October 31, 2011. This study focused on the main river and the flood volume could flow into the small streams of the Nan River which may contribute to the observed differences.

Harmless streamflow limit for gauging station C.2 is 4000m$^3$/s [5]. In fig.7, RID data at gauging station C. 2 shows streamflow increases gradually from August to October 2011 and reaches flood peak which over the harmless streamflow limit after September 21. The total flood amount at gauging station C. 2 shows a big difference compared with gauging station N. 67. This is caused by flood amount before gauging station N. 67 returned and flowed back into Chao Phraya River (gauging station C. 2). It is the main reason of the flood peak occurred from September 21 to the end of
October, 2011. When compared the simulated result from MIKE Flood with the RID data, it shows the same pattern of flow although it does not rise smoothly as RID data. Simulated result presented pulsed undulations wave due to limitation of data and variable parameters, which is discussed in the end of this section. The different flood volume between simulated result and RID data is about 3 hundred million m$^3$. In other words, flood volume at gauging station C. 2 has only 3 hundred million m$^3$ which were affected by small streams surrounding it. The flood volume at gauging station C. 2 could be mitigated under the harmless limit if the flood returned volume is control at the upper reaches of Nan River and Yom River.
The flood inundation from the simulated result has validated with measurement of flood marks at Nakhon Sawan (fig 8). Among 8 investigation points (IP) (fig 4), the IP 1, IP 2 and IP 6 are matched with difference of + 0.5m. However, the resolution of SRTM has limited accuracy and could affect the simulated result. IP 3 falls into dry area in this model because the location is near to dike as in SRTM. IP 7 showed a difference of + 1m near to the Chao Phraya River. Therefore, the location of IP 7 in this model might be the other side of the warehouse. Furthermore, the IP 4 and IP 5 at Bung Boraphet area have a difference of + 2m. It might be affected by the water level of Bung Boraphet in SRTM. As this simulation model did not include the consideration of small streams around those main rivers. Therefore, the result of flood extent is smaller than RID in this study. Total flood volume calculated in simulated result is about 3600 million m$^3$. The estimation of flood volume of RID by spatial analyst in ArcGIS is about 4300 million m$^3$. Thus, the small streams of the main river may contribute to the differences of 700 million m$^3$.

2.4 Error Propagation

RRMSE for streamflow data at Obs. C2 was calculated using formula (1) with the period of every ten days from August 1 to October 20 using the streamflow generated from simulation. The result is shown as fig. 9. Although chart was not smooth, however all of value was less than 1.4 m. The most accurate period of data happened in the end of September and this might be caused by similar flood distribution generated from simulation with the RID data.

There are some error propagation effects in this study. Differences could be seen in flood volume, streamflow, pulsed undulation flood wave, and flood inundation depth between observed and simulated flood marks. These differences between observed and simulated results could be induced by various artificial structures such as man-made structures, micro topography, variables of rainfall volume, lacking of cross sections along rivers, which have possibilities to affect the dynamics of flood wave, particularly when the flood depth became low. Due to data constraints, small streams, which played crucial role to affect flood condition, are excluded in this model. Therefore, the simulated result tends to be underestimated, compare to actual extent. The simulation could be enhanced if more details of data obtained such as streamflow of small streams, details field survey of cross sections, better resolution imagery for bathymetry and including details artificial structures along rivers such as weirs and culverts.
3. Economic Impact Analysis for Rice field

The loss estimation on paddy field is evaluated using ArcGIS after validation of the simulation result of 2011 flood is conducted. Spatial distribution of flood extent area in simulated result is smaller than the real flood condition because of model’s variable uncertainty, simulated result is compared with RID flood coverage and the different of loss estimation will be used in section 5 to include flood coverage affected by small streams and flood returned.

CTI. (1999) stated upstream of Chao Phraya is dominant by traditional rice field with some High Yielding Variety (HYV). Therefore, the calculation of the loss analysis will be based on 70% of traditional variety and 30% of HYV. The farm gate price is calculated referring to farm price index stated in bank of Thailand and land use data of Year 2010 is used for loss analysis. This study used Japan flood mitigation manual (table 3), which is used by CTI. (1999) to estimate loss rate in Japan International Cooperation Agency (JICA report).

\[
RRMSE = \sqrt{E\left[\left(\frac{Q_s(t) - Q_o(t)}{Q_o(t)}\right)^2\right]}
\] (1)

Fig. 9 RRMSE for streamflow data at Obs. C2 in the period of every 10 days.
4.0 Result and Discussion of Loss Estimation

4.1 Comparison with the Loss Estimation in rice field with World Bank Report

The original result of simulation is used to calculate the losses in rice field. Fig.10 shows the flood area with inundation depth value in August 6, September 21 and October 15 for the original result from simulation. The starting of flood event, which is August 6, has flood extent area about 574 km², and 40% is covered on rice field. When the flood expands till September 21, the flood extent area is about 1844 km² and 35% of total spatial extent is covered on rice field. The widest flood extent happened on October 15, which is about 36% covered on rice field while the total flood area is about 2217 km². Within these 3 months, more than 60% of inundated area is covered on rice field. The losses in rice field for October is near to USD 0.1 billion. World Bank report shows total losses is about USD 794 million for 26 provinces. Thus, the percentage of losses in study area is nearly 25% of total losses in 26 provinces.

When the flood spatial distribution of simulated result and RID are compared as shown in fig. 11, rice field area covered by RID is about 25% more than simulated result. When calculation of loss estimation is done, it shows RID has 7.4% more than simulated result on October 15. Thus, 7.4% is added for loss estimation in different scenarios of simulated result, which is considered loss in flood area caused by small streams and flood returned. Result of loss estimation will be discussed in section 4.2.

![Fig. 10 Spatial distribution of flood extent area in 3 months from original result of simulation](image-url)
4.2 Comparison with different scenario of flood condition

In this research, 3 scenarios quantified the benefits of flood control operation on existing reservoir and its potential to minimize flood risk. Parameters of streamflow data are modified in each case of scenario to predict conditions and effects when flood is under controlled at midstream. The hydraulic model is run repeatedly for each of the scenario cases with variable parameters. Condition of each scenario describes in table 4, each scenario has 3 cases. The baseline of model (original) for comparison is validated model as discussed in section 2.3. In order to choose the most applicable measures to control the flood condition, changes of streamflow along rivers and flood distribution are compared.

4.2.1. Comparison on 3 Scenarios of flood condition for losses in paddy field

Since October 15 has widest spatial distribution of flood extent, it is used to compare difference of loss estimation in rice field for scenario 1, scenario 2 and scenario 3. Fig. 12 shows the percentage of loss estimated in study area. The red line is the percentage of baseline. Based on the graph, loss is estimated in scenario 1 (Case 1a – 1c) has decreased more than 2%, which is highest compare to other scenarios. Loss estimated in scenario 2 (case 2a – 2c) has decreased more than 1% while loss estimated in scenarios 3 (case 3a – 3c) only decreased less than 1%. Therefore, controlling flood at upper reach of Nan River (scenario 1) able to reduce losses more effectively than other rivers. In contrast, controlling flood at upstream of Yom River (scenario 3) only contribute minor effect.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Case</th>
<th>River Controlled</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>1a</td>
<td>Nan</td>
<td>Reduced 10% streamflow</td>
</tr>
<tr>
<td></td>
<td>1b</td>
<td>Nan</td>
<td>Reduced 20% streamflow</td>
</tr>
<tr>
<td></td>
<td>1c</td>
<td>Nan</td>
<td>Reduced 30% streamflow</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>2a</td>
<td>Ping</td>
<td>Reduced 10% streamflow</td>
</tr>
<tr>
<td></td>
<td>2b</td>
<td>Ping</td>
<td>Reduced 20% streamflow</td>
</tr>
<tr>
<td></td>
<td>2c</td>
<td>Ping</td>
<td>Reduced 30% streamflow</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>3a</td>
<td>Yom</td>
<td>Reduced 10% streamflow</td>
</tr>
<tr>
<td></td>
<td>3b</td>
<td>Yom</td>
<td>Reduced 20% streamflow</td>
</tr>
<tr>
<td></td>
<td>3c</td>
<td>Yom</td>
<td>Reduced 30% streamflow</td>
</tr>
</tbody>
</table>
4.2.2. Comparison on 3 Scenarios of flood distribution in Paddy Field

Spatial distribution of flood extent for these 3 scenarios are used to compare before proposed a suitable flood control. Fig. 13 shows the difference of 3 scenarios in each case with different result of flood distribution. In scenario 1, the changes of flood distribution can be seen reduced 16% of coverage in case 1a. In addition, the coverage is reduced to 18% and 21% respectively in case 1b and case 1c. Thus, the more percentage of flood volume controlled at upper reach of Nan River could help to reduce 2-3% of coverage on rice field. In scenario 2, the changes of flood distribution are much wider than scenario 1. The flood coverage has 12% reduced in case 2a, 15% in case 2b and 17% in case 2c. Difference of 3 cases in scenario 2 is about 2-3%, which is similar to scenario 1. In scenario 3, the flood distribution changes is smallest compared to scenario 1 and 2. In case 3a, there is reduced 9% of coverage, which is lesser than both case 1a and 2a. Case 3b and 3c only reduced 12% and 13% of coverage respectively. Difference of each case in scenario 3 is about 1-2% only. Based on the results, Nan River is able to mitigate flood more than Ping River and Yom River. In contrast, Yom River is less effective as the river width is narrower than the other 2 rivers.
5. Proposed Flood Controlling

In the consideration of estimated loss and flood distribution on rice field, a combination of flood volume control at upstream of Nan River (20%), Yom River (20%) and Ping River (10%) is recommended. During 2011 Thailand flood, streamflow at Nan River and Yom River exceeded its capacity and flow into small streams around them, result in gauging station N.67 has lower streamflow. When flood volume is controlled at upper reaches of Nan River and Yom River, the streamflow would not exceed its capacity during the period from August to October and it flows down to downstream smoothly. As a result, higher streamflow occurred at gauging station N.67 from September and October.

Although there is about 200 million m$^3$ more than original in the period of September 21 to October 24 happened at gauging station N.67, which is location of Bung Boraphet, however the daily streamflow did not over harmless streamflow limit for N.67, which is 1500m$^3$/s. The most important is the flood returned volume from small streams to C2 reduced tremendously. When flow out from upstream to small streams decreased, the flood volume that over harmless stream flow limit also reduced indirectly.
6. Conclusions
By controlling flood volume at upper reach of Nan River helps to minimize the loss of rice field and flood extent more effectively rather than controlling flood volume at upstream of Yom River or Ping River. If flood volume is controlled at upper reaches of Nan River, Ping River and Yom River, it minimizes about 5% of total loss and reduces nearly 30% of flood extent on rice field. Result of this research shows work plan for management of major water reservoirs and formulation of water management in Thailand master plan workable, although there are some weakness such as lack of concrete proposal to compensate farmers in flood retention area and inadequate attention to the complex long-term issues of fragmented water management.

Error propagation effects between observed and simulated results are caused by limitation of data and variable parameters such as various artificial structures, micro topography, variables of rainfall volume, lacking of cross sections along rivers, which have possibilities to affect the dynamics of flood wave, particularly when the flood depth became low. The impervious surface is closely related with surface runoff. It is suggested to conduct detail field survey on cross sections along rivers and artificial structures along rivers is needed in order to improve the result of simulation. Furthermore, streamflow data for small streams in study area is needed for enhancing the result in future.

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