

การสร้างแบบจำลองท่งน้ำท่วมของลุ่มน้ำเลยด้วยโปรแกรม HEC-RAS

Loei River Basin Floodplain Modelling using HEC-RAS

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บทคัดย่อ

การสร้างแบบจำลองท่งน้ำท่วมเป็นวิธีวิเคราะห์สภาพพลศาสตร์การไหลในลำน้ำและพื้นที่ริมฝั่งที่ใช้กันแพร่หลาย การศึกษาที่ใช้โปรแกรม HEC-RAS ในการสร้างแบบจำลองสภาพการไหลของลุ่มน้ำเลยในช่วงน้ำหลาก ข้อมูลทางภูมิศาสตร์ที่ใช้ประกอบด้วยและโครงสร้างชลศาสตร์และหน้าตัดลำน้ำ 1552 หน้าตัด มีช่วงลำน้ำตั้งแต่ปากน้ำเลยลงสู่โขง ที่กม.ลำน้ำ 0+500 ที่สถานี Kh.97 กำหนดเป็นเงื่อนไขขอบเขตท้ายน้ำ ไปถึง กม. 155+600 ที่สถานี Kh.61 สะพานบ้านแก่งบง เป็นเงื่อนไขขอบเขตด้านเหนือน้ำ ส่วนข้อมูลการไหลที่ใช้ได้แก่ gage hydrograph, rating curve ที่นำมาแปลงเป็น flow hydrograph โดยมี lateral inflow จากลำน้ำสาขาที่สถานี Kh.77 (น้ำทบ) Kh.105 (น้ำปวน) Kh.78 (น้ำฮวย) และ Kh.86 (น้ำหมาน) เป็นข้อมูลอนุกรมเวลาในช่วงน้ำหลากของแต่ละปี ตั้งแต่ พ.ศ. 2549 ถึง 2556 เกณฑ์การประเมินแบบจำลองพิจารณาจากค่า Root Mean Squared Error (RMSE) ซึ่งบ่งบอกถึงค่าความคลาดเคลื่อนในการพยากรณ์และสัมประสิทธิ์สหสัมพันธ์ (r) ของค่าระดับน้ำที่วัดจริงกับที่วิเคราะห์ได้จากแบบจำลองการเปรียบเทียบแบบจำลองใช้ข้อมูลน้ำท่าปี พ.ศ. 2556 โดยการปรับค่า Manning's n ที่ให้ค่า RMSE ต่ำที่สุดพบว่าค่า n ของลำน้ำเท่ากับ 0.040 และของท่งน้ำท่วมเท่ากับ 0.080 เป็นค่าที่เหมาะสมกับแบบจำลอง การสอบทานแบบจำลองใช้ข้อมูลน้ำท่าปี 2549 – 2554 พบว่า ค่า RMSE ณ สถานี Kh.58A มีค่าระหว่าง 0.387-1.152 และ RMSE ณ สถานี Kh.28A มีค่าระหว่าง 0.204-0.676 ค่าสัมประสิทธิ์สหสัมพันธ์ของสถานี Kh.58A และ Kh.28A มีค่าเฉลี่ยของทั้ง 6 ปี เท่ากับ 0.951 และ 0.946 ตามลำดับ จะเห็นได้ว่าแบบจำลองทางคณิตศาสตร์นี้มีความคลาดเคลื่อนต่ำและมีสัมประสิทธิ์สหสัมพันธ์สูง จึงเป็นแบบจำลองที่สามารถนำไปใช้พยากรณ์สถานการณ์น้ำท่วมได้เป็นอย่างดี

คำสำคัญ: แบบจำลองท่งน้ำท่วม HEC-RAS ลุ่มน้ำเลย แบบจำลองทางคณิตศาสตร์ การไหลแบบไม่คงตัว

Abstract

Floodplain modelling is one of the hydraulic analyses that is generally used for simulation of the dynamics of flow in the river and its overbank areas. This study employed HEC-RAS Program as a tool to model the flows in Loei River Basin, during the flood events. The geometric data includes a reach with 1552 cross-sections, and hydraulic structures. The river reach ranges from station Kh.97, the outlet to Mekong, at km.0+500 as a downstream boundary condition to station Kh.61, Kaeng Bong Bridge, at km.155+600 as an upstream boundary condition. The flow data includes gage hydrographs and Rating curves, that were transformed to flow hydrographs. The lateral inflows from tributary stations include Kh.77 (Nam Tob), Kh.105 (Nam Puan), Kh.78 (Nam Huai), and Kh.86 (Nam Man). The time-series data cover selected periods during the floods of 2006 to 2013. The model was evaluated by Root Mean Squared Error (RMSE) that indicates errors of forecasting, and the Correlation Coefficient (r) of the measured data and the model's outputs. The data from 2013 were used for model calibration to get the optimum values of Manning's n that yield the lowest RMSE. The values of n in the channel and the floodplains were 0.040 and 0.080, respectively. The verification of the model with flow data from year 2006-2011 shows that RMSE at Kh.58A ranges from 0.387-1.152 and RMSE at Kh.28A ranges from 0.204-0.676. The average values of Coefficient of Correlation at Kh.58A and Kh.28A are 0.951 and 0.946 respectively. Low level of errors, and high level of Coefficients of Correlation indicate that this mathematical model of Loei River Basin can be used as a good predictor for flood events.

Keywords: floodplain modelling, HEC-RAS, Loei river basin, mathematical model, unsteady flow

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Introduction

Flooding is one of the natural disasters that causes major damages to people and their properties. The severe 2011 flood in Chao Phraya river basin of Thailand was described as the worst flooding of the country in terms of the amount of water and people affected¹. Tropical climate was the cause of seasonal flash-flooding in various regions of Thailand, including the North, the central plains, the coastal hillsides, and the Northeast. Several drainage control measures have been implemented but are still inadequate to prevent flood damages, especially in rural areas. In small and remote river basins, such as Loei River Basin, the lacks of proper management and technology were the causes of damage that could otherwise have been prevented. One of the techniques that can help predict the flash flood in certain areas is the simulation of the flood using mathematical models. The model could help us learn in advance how the flood would affect certain areas before it actually happens.

This study focuses on making a mathematical model of Loei River Basin, using HEC-RAS program. The program was developed by U.S. Army Corps of Engineer, and has been widely used throughout the world. The geometry and flow data are collected and prepared for the hydrodynamic analyses. The model was also calibrated and verified to evaluate its accuracy, by comparing the time series of the simulated floods and the observed ones. By simulating the flood events for various inflow situations, the model could be used as a flood predicting tool that can help us plan and provide proper measures to reduce the damages. It can help determining potential flood elevations, depths, and the area of inundation².

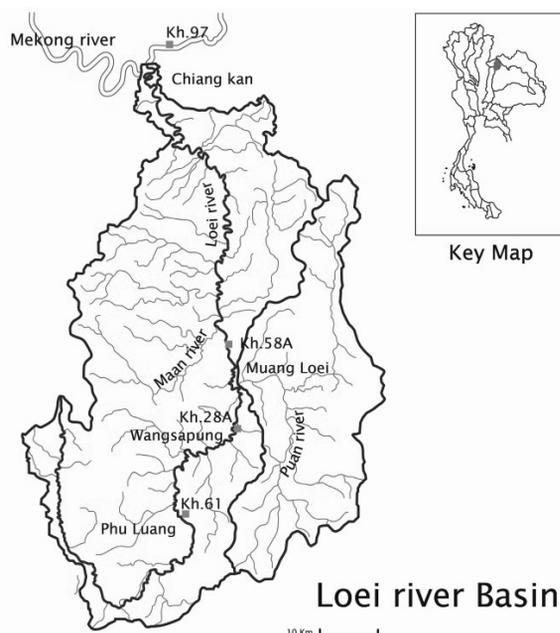


Figure 1. Loei river basin map

Loei River Basin

Loei River Basin is the most important basin in the province of Loei, economically and socially. The basin total area is 3,964.35 km². It covers 34.6% of the province's total area or 60% of the province's agricultural area. Major urban areas of the province, including Muangloei, Wangsapung, Chiangkan, and Phuluang, are located on the riverside of Loei River. Majority (53%) of the provincial population lives in the basin. Major flood events in the past, caused severe economic and social damages to people who live by the river. The major one in 2002, covering 101 km², caused 313 million baht of damages and affected 166,517 people.

Loei River is a tributary of Mekong River; it joins Mekong at Baan Kok Maad, Chiang Kan district. It begins in Phu Luang Wildlife Sanctuary. There are 147 tributaries; the main ones include Nam Tob, Nam Puan, Nam Huai, Nam Man, and Nam Phu. Loei River is a steep and relatively short river with a length of 231 km, so it is likely for the flash flood to occur due to heavy rains³. There are several reasons for this. Deforestation in recent years reduces infiltration and percolation and increases surface runoffs. Changes of land use in urban areas can cause flow obstructions in the channel and reduce the flow capacity. The feather-like shape and steep slope of the basin cause rapid flood due to the storm. The increase

of water level of Mekong at the downstream end of the basin creates backwater in the channel and causes flood especially in river mouth areas. Due to these reasons, when there is heavy rain, the flood is likely to occur. Without proper control and mitigation plan for major events, flash-floods in Loei River could be a threat that bring tremendous damages to the province and its people.

Materials and Methods

The study is based mainly on the hydraulic analysis of the flow in Loei River, by creating a mathematical model in HEC-RAS program. Figure 2 illustrates the procedure by which this study used to develop the one-dimensional hydrodynamic model of Loei River Basin.

The model in this study involves analysis of the flows and water levels in open channels and estuaries using HEC-RAS program version 4.10. The program is capable of analyzing both steady and unsteady flow, as well as sediment transportation and water quality⁴. Geometric data with 1554 cross-sections were prepared and entered. Flow data were obtained from historical record as hourly gage hydrographs at five major tributaries and converted to flow hydrographs by rating curve equations of each station. The simulations of the flow in the main reach of Loei River during the flood periods were unsteady flow analysis.

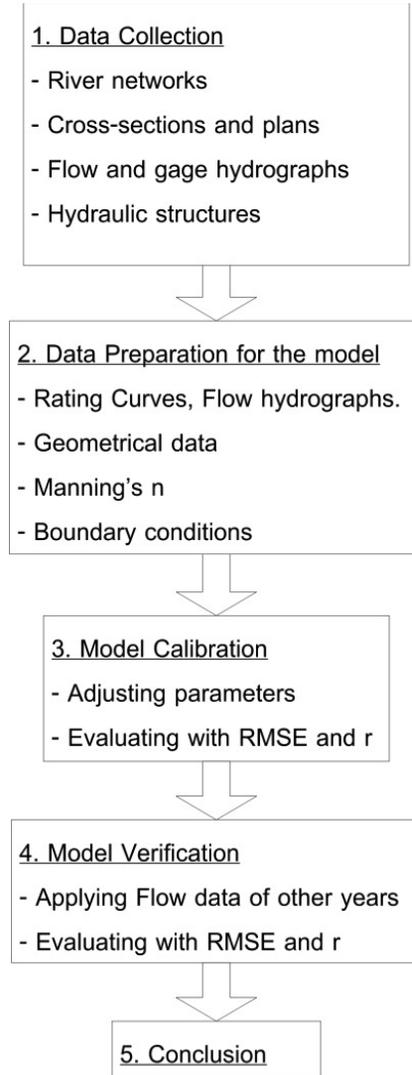


Figure 2 Procedure of Making Loei River Basin Mathematical Model

For unsteady flows, the program employs Saint Venant's equations that include two equations⁵ the continuity equation and the momentum equation:

Continuity equation

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} - q_1 = 0 \quad \frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} - q_1 = 0 \quad (1)$$

where A is the cross-sectional area, t is the time period, Q is the flow, x is the distance along the river, and q₁ is the lateral flow per unit length.

Momentum equation

$$\frac{\partial Q}{\partial t} + \frac{\partial QV}{\partial x} + gA \left(\frac{\partial z}{\partial x} + S_f \right) = 0 \quad (2)$$

where V is the velocity, g is the gravitational acceleration, and S_f is the frictional slope.

The program uses implicit finite difference scheme to solve the one-dimensional unsteady flow equations simultaneously. This allows the information from the entire reach to influence the solution at any one point. As a result, the time step can be significantly larger than the case of explicit scheme⁶.

Geometric Data

The model of Loei River basin includes one main reach, i.e., Loei River, with inflows from the upstream boundary and lateral inflows from its tributaries, as shown in Figure 3. The model requires sets of geometric data to perform the analysis as follows:

1. River Network. There is one main reach of Loei River ranging from km.0+500 (downstream boundary condition) to km.155+600 (upstream boundary condition), with the length of 155.1 km.

2. Boundary Conditions. The upstream boundary condition is the inflow at the Kh.61, located at Kaeng Bong bridge, Phuluang. The downstream boundary condition is the stage hydrograph at the Kh.97 station in Mekong River, by the mouth of Loei River.

3. Testing Stations. There are two stations to be used to test the accuracy of the model: Kh.28A station at Na Lak bridge, Wang Sapung, located at km.111+600 and Kh.58A station at Fag Loei bridge, Muang, located at km.81+100.

4. Cross-sections. The model comprises 1552 cross-sections, placing every 100 m. along the entire length of the reach. Each includes 10-30 stations laying out the shape of its channel and overbanks.

5. Inline Structures. There are 5 main bridges that are close to the urban areas along the river.

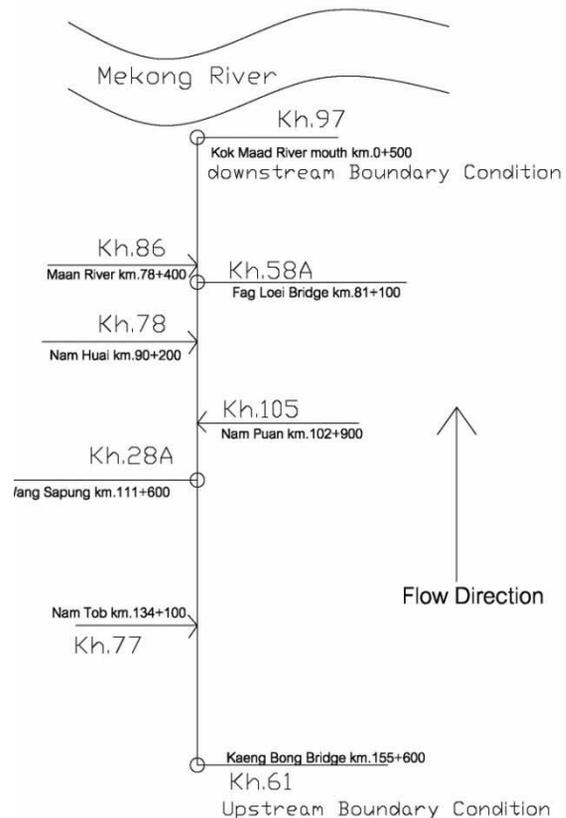


Figure 3 Schematic Model of Loei River Basin Flow Data

All Flow data were obtained from historical data recorded at each station by the Ministry of Royal Irrigation. In order to study the floodwave during flood periods, the model requires sets of flow data in time-series, that represent the hydrologic and hydraulic information of the basin. The period of study ranges from 2006-2013, but the data used for the analysis were the times that flood waves occurred in each year, for example, in 2006, the flood wave occurred from 0:00 of October 2nd to 23:00 of October 26th, covering 25 days. The periods start shortly before the front face of the wave, past its peak, until the water level lowers back to normal. The flow data used for the model includes the followings:

1. Inflow at upstream boundary condition. The model uses hourly flow hydrographs derived from gage hydrographs at Kh.61 during selected flood periods of each year.

2. Lateral Inflow. There are four lateral inflows from the main tributary junctions: Nam Tob (Kh.77) at km.134+100, Nam Puan (Kh.105) at km.102+900, Nam Huai (Kh.78) at km.78, and Nam Maan (Kh.86) at km.78+400.

3. Gage at downstream boundary condition. The model use gage hydrograph of Kh.97 in Mekong River as a downstream boundary condition. The station is close to the mouth of Loei River where it meets Mekong.

4. Rating curves. Each station in the model includes a set of flow-gage relationship data that constitutes the Rating curves. The flow data from the field are mainly gage hydrographs, that needs to be changed to flow hydrographs with the Rating curves. However, when dealing with large amount of data it is more accurate and convenient to derive each graphical Rating curve into an equation. The rating curve equation⁷ is shown below:

$$Q = P(G - e)^b \tag{3}$$

where Q is the flow rate, G is the gage. The parameters P , e and b are needed to be found by curve fitting and trial & error methods.

When the rating curve equations of each station are laid out, the flow rate then can be calculated from gage data, instead of reading the flows from the rating curve graphs. This method is helpful and time-saving when dealing with gage and flow hydrographs that contain thousands of data points.

Results

Model Calibration

Model calibration was carried out to obtain optimal values of the parameters. In this study the parameters used for calibration are the Manning's n 's, for channel (n_c) and two river banks (n_r). However, the channel roughness has more effect on the overall flood discharges than does the overbank roughness⁸so the calibration was done with n_c before n_r .The unsteady flow simulation in subcritical flow condition was set for the analysis. The hourly flow data of year 2013 was used for the calibration, including boundary conditions and lateral inflows. Its time span starts from 0:00 of October 13th to 23:00 of October 30th. The analysis was performed with a 20-min. time step. Two gage stations, Kh.58A and Kh.28A, were selected for the comparison between the measured gage hydrographs and the result from the analysis. These two stations are

located in major urban areas of Muang Loei and Wansapung, the most populous cities in the province. RMSE (Root Mean Squared Error) and Coefficient of Correlation were used as the criteria for model evaluation. RMSE represents the error due to the difference between the calculated and the measured gages. It can be obtained from the following equation:

$$RMSE = \sqrt{\left(\frac{\sum(g_m - g_c)^2}{n}\right)} \tag{4}$$

where g_m is the recorded gage, g_c is the calculated gage, and n is the number of data. The Coefficient of Correlation (r) represents the correlation between the two values, and can be calculated from the following equation:

$$r = \frac{\sum(g_c - \bar{g}_c)(g_m - \bar{g}_m)}{\sqrt{\sum(g_c - \bar{g}_c)^2 \sum(g_m - \bar{g}_m)^2}} \tag{5}$$

where \bar{g}_c is the average of calculated gages, \bar{g}_m is the average of the measured gages, g_c is the calculated gage, and g_m is the measured gage.

The result shows that the optimum n_c is 0.040 and n_r is 0.080, because they yielded the lowest RMSE at the two stations. Figure 4 compares the calculated gage hydrographs from the model and the measured gage hydrograph at station Kh.58A.

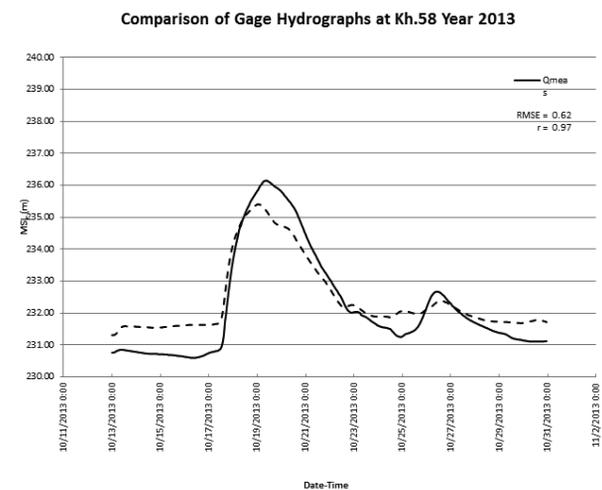


Figure 4 Comparison of Gage Hydrograph from the model and from field measurement at Kh.58A during the 2013 flood wave.

Model Verification

The model was verified with different sets of flow data of the basin. The hourly flow data during the flood period of each year, from 2006-2011, were used for the analysis. They were chosen from different dates and time spans, depending on when the flood waves came. The following are the flow periods of each year:

- year 2006, from 0:00 of October 2nd to 23:00 of October 26th
- year 2007, from 0:00 of August 6th to 23:00 of August 16th
- year 2008, from 0:00 of September 11th to 23:00 of September 24th
- year 2009, from 0:00 of October 10th to 23:00 of October 20th
- year 2010, from 0:00 of July 30th to 23:00 of August 8th
- year 2011, from 0:00 of October 13th to 23:00 of October 30th

The result from the model were gage hydrographs of each period. They were compared with the measured gage at the two stations, Kh.58A and Kh.28A, to find RMSE and Coefficient of Correlation.

Table 1. RMSE and Correlation Coefficients (r) of the gages at station Kh.58A and Kh.28A

| Year | Station Kh.58A | | Station Kh.28A | |
|------|----------------|-------|----------------|-------|
| | RMSE | r | RMSE | r |
| 2006 | 1.152 | 0.977 | 0.204 | 0.999 |
| 2007 | 0.921 | 0.938 | 0.651 | 0.950 |
| 2008 | 0.387 | 0.969 | 0.672 | 0.931 |
| 2009 | 0.568 | 0.940 | 0.272 | 0.966 |
| 2010 | 0.679 | 0.952 | 0.397 | 0.923 |
| 2011 | 0.979 | 0.932 | 0.676 | 0.910 |

As shown in Table 1, the RMSE's at Kh.58A range from 0.387-1.152, while those at Kh.28A range from 0.204-0.676. In general, the RMSE's at Kh.58A are higher than those at Kh.28A, The Correlation Coefficients at Kh.58A range from 0.938-0.977, while those at Kh.28A range from 0.910-0.999, with no obvious trend. However, the high values of Correlation Coefficients at both stations

indicate that the model yields the calculated values that match the measured data.

Discussion and Conclusion

The model's n parameters are 0.040 for the channel and 0.080 for the floodplain. These values are higher than those from other studies of floodplain models. For example, Nan⁹ River's n equals 0.035, and Klong Suan Mark¹⁰ River's n ranges from 0.028-0.030. For Tapi River in India, the n value of 0.030 was used in a study.¹¹

However, it is suggested that⁴the value of n for the clean and winding channel with some pools and shoals may range from 0.033-0.045, and 0.035-0.080 for the floodplain with brush. So, the n values from this study are in reasonable range. It was also found that the RMSE's at Kh.58A station are generally higher than those at Kh.28A station because Kh.58A is located far downstream from Kh.28A. As a result, there are more causes at Kh.58A that could raise errors to the calculated gages than those at Kh.28A. Lastly, the high value of Coefficients of Correlation between the model's outputs and the recorded values indicates that the model can predict the flood situations in Loei River Basin well.

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