SWE-04

ESTIMATION OF FLOOD DAMAGES ON NAMPHONG RIVER BY HEC-RAS

*Nareth NUT[1] and Vichian PLERMKAMON[1]
[1]*Department of Agricultural Engineering, Khon Kaen University*
123 Khon Kaen University, Mittaphap Road, Khon Kaen 4002, Thailand
Corresponding author: nareth NUT. E-mail: nareth_nut2005@yahoo.com

Keywords: Nam Phong River, Flood Damage, Return Period, HEC-RAS model

ABSTRACT

Floods are regularly happening in the urbanizing Nam Phong watershed, the northeastern region of Thailand. The lower Phong Basin area regularly goes more or less under water every year in monsoon due to lack of flood protection and limited resources [4]. The damage of flood normally courses property losses, houses and land use change to the lowland in the flood prone area. The objectives of the study were, 1) Determine the flood frequency and flood zoning of the Nam Pong River at a return period of 5, 10, 25, 50, and 100 years, 2) Mapping the flood damage from the simulation varied with the different return periods. In this paper, the estimation of flood damage based on various return periods on Nam Pong watershed (2993.95 km^2) was carried out by 1D hydrodynamic simulation with HEC-RAS model which the runoff was simulated by the SWAT model for 10-year rainfall records (2000–2010), the Gumbel's method had been used to analyze the flood frequencies with various return periods and the water released from Ubolratana dam were also analyzed as scenarios for inputting to the HEC-RAS model. The simulation of inundated area was conducted using hydrodynamic program HEC-RAS.4.1 for the flood of 5, 10, 25, 50 and 100-year return periods. The simulation has revealed that the percent of flood damage is 20%, 23.2%, 27.8%, 34.3%, and 38.5% at return period 5, 10, 25, 50, and 100 years, respectively. The various flood damage mappings were prepared according to the simulation result using the software ArcView. The map showed that the flood damage with 50 and 100-year return periods had affected moderately to the agricultural and urban area. In the future, these two maps should be helpful in raising awareness of flood damages and in assigning priority for emergency preparedness in the affected area.

INTRODUCTION

Flood is common phenomenon happing annually at the Low portion of Phong Basin, which the Namphong River is joined with some tributaries flowing into it, and occasionally the large amount of water has been released from Ubolratana Dam at the upstream river during flooding occurrence to prevent from dam damage or collapse. The problem is mainly confined to landslides, debris flows and river bank undercutting, whereas in the low lying areas the floods generally overflow the bank and cause bank erosion, inundation and agricultural fields are filled with sediments every year during the monsoon (Junly- October) in the numerous streams and rivers. On the other hands, one definition of a flood is a flow rate greater than common discharge rates in rivers. It has a limited duration and the water overflows the natural river's bed, occupies the lowlands and lands near the rivers and has financial and human damages [1].

Floodplain in Lower Phong Basin is still in a very rudimentary stage and no serious concern on comprehensive flood damages. Most of the flood protection works are carried out at the local level without preplanning and without considering the problems at the river basin scale. Traditionally individuals and communities have been left to develop their own strategies for minimizing the effects of floods, so due to limited resources and lack of knowledge, many householders are not able to protect their property or possessions from floods.

Floodplains and regions near rivers, where social and economic activities take place due to their special conditions, are always in danger of flooding. Determining the amount of flood advance and its height with respect to ground surface elevations, and finding flood characteristics with different return periods (known as "flood zoning") have tremendous importance. Flood zoning is considered a prerequisite for sustainable development within the limits of flood prone rivers, because it determines the type of development, construction criteria, basis for the ecological and environmental effects, and the amount of investment risk.

The most important factors affecting the intensity and flood return period in each region are: volume and time of upstream surface runoff and river or flood conditions, physical characteristics of watershed (area, morphology), hydrological characteristics of the watershed (rainfall, storage, evapotranspiration), and human activities causing and intensifying the flood flows. Investigations have shown that the cause of flood damages is neither the short-term flood return period or high flood intensity, but over use of floodplain around rivers. The management methods to decrease flood damages are divided into structural and nonstructural categories. In non-structural methods, physical structures are not used for flood management or flood protection. In structural methods, structures such as dams, embankments, flood diverting is used [9].

Johnson et al. used the HEC-RAS model to forecast and determine the limits of wetlands in the Wyoming-Gary Yule River in the U.S.A. Tate et al. (1999) combined HEC-RAS and ArcView to study the limits of the bed in the Vader Creek River in Austin, Texas, U.S.A. They found the flood zones with different return periods using the hydraulic model of HEC-RAS. Then, by making a TIN layer of the region, they transferred the results from HEC-RAS into a TIN of the region and provided the flood zones maps, water velocity in each region, and flood hazard of each section.

Azagra et al. (1999) used HEC-RAS with air photographs for flood zoning in the Vader River of Austin, Texas, U.S.A. Noori Shadkam (2001) studied different methods of management for flood control, and then by using GIS found the flood zones of the Kameh representative flood plain in Iran. Barbad et al. (2002) made flood zoning maps of the Sepid Rood River in Gilan Province, Iran, using Iranian cartographical maps of 1: 25000, cross sections measured by Iran Rasad Consulting Engineers, and ArcView, HEC-RAS and HEC-GEORAS software. They concluded that a combination of GIS and the HEC software is feasible and makes the calculations easily. Combination of ArcView and HEC-RAS provides powerful tools for planners and decision makers.

BACKGROUND THEORY

HEC-RAS Theory

HEC-RAS is an integrated system of software, designed for interactive use in a multitasking, multi-user network environment. The system is comprised of a graphical user interface (GUI), separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities. The HECRAS software supersedes the HEC-2 river hydraulics package, which was a one dimensional, steady flow water surface profiles program. The first version of HEC-RAS was released in July of 1995. Since that time, there have been several releases of this software package, including versions: 1.1; 1.2; 2.0; 2.1; 2.2; 2.21; 3.0; 3.1; and now version 4.0 in March of 2008. HEC-RAS is designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels. The current version of HEC-RAS supports Steady and Unsteady Flow Water Surface Profile calculations, perform sediment transport simulation and perform water quality simulation [15-16].

Steady Flow Surface Profiles: This component of the modeling system is used for calculation of water surface profiles for steady gradually varied flow. The system can handle a single river reach, a dendritic system, or a full network of channels. The steady flow component is capable of modeling subcritical, supercritical, and mixed flow regime water surface profiles. The basic computational procedure is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head). The momentum equation is utilized in situations where the water surface profile is rapidly varied.

Unsteady Flow Simulation: This component of the HEC-RAS modeling system is capable of simulating one-dimensional unsteady flow through a full network of open channels. The unsteady flow component was developed primarily for subcritical flow regime calculations.

Theoretical Basis for One-Dimensional Steady Flow Calculations (HEC-RAS)

Different fundamental equations used for HEC-RAS algorithm to compute water surface elevations using the standard step method for steady flow analysis are:

a. Equations for Basic Profile Calculations

Water surface profiles are computed from one cross section to the next by solving the Energy equation with an iterative procedure called the standard step method. The Energy equation is written as follows:

$$Y_2 + Z_2 + \frac{\alpha_2 V_2^2}{2g} = Y_1 + Z_1 + \frac{\alpha_1 V_1^2}{2g} + h_e \qquad (1)$$

Where:

Y_1, Y_2 = depth of water at cross sections

Z_1, Z_2 = elevation of the main channel inverts

V_1, V_2 = average velocities (total discharge/total flow area)

α_1, α_2 = velocity weighting coefficients

g = gravitational acceleration

h_e = energy head loss

A diagram showing the terms of the energy equation is shown in Fig.1.

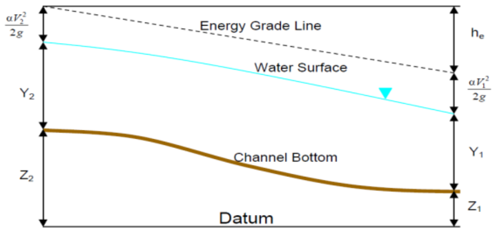


Fig. 1 Representation of Terms in the Energy Equation

The energy head loss (h_e) between two cross sections is comprised of friction losses and contraction or expansion losses. The equation for the energy head loss is as follows:

$$h_e = L\overline{S}_f + C\left|\frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g}\right| \qquad (2)$$

Where:

L = discharge weighted reach length

$\overline{S}_f$ = representative friction slope between two sections

C = expansion or contraction loss coefficient

The distance weighted reach length, L, is calculated as:

$$L = \frac{L_{lob}\overline{Q}_{lob} + L_{ch}\overline{Q}_{ch} + L_{rob}\overline{Q}_{rob}}{Q_{lob} + Q_{ch} + Q_{rob}} \qquad (3)$$

Where:

L_{lob}, L_{ch}, L_{rob} = cross section reach lengths specified for flow in the left overbank, main channel, and right overbank, respectively

$\overline{Q}_{lob}$, $\overline{Q}_{ch}$, $\overline{Q}_{rob}$ = arithmetic average of the flows between sections for the left overbank, main channel, and right overbank, respectively

b. Cross Section Subdivision for Conveyance Calculations

The determination of total conveyance and the velocity coefficient for a cross section requires that flow be subdivided into units for which the velocity is uniformly distributed. The approach used in HEC-RAS is to subdivide flow in the overbank areas using the input cross section n-value break points (locations where n-values change) as the basis for subdivision. Conveyance is calculated within each subdivision from the following form of Manning's equation (based on English units):

$$Q = KS_f^{1/2} \quad (4)$$

$$K = \frac{1.486}{n} AR^{2/3} \quad (5)$$

Where:

K = conveyance for subdivision

n = Manning's roughness coefficient for subdivision

A = flow area for subdivision

R = hydraulic radius for subdivision (area / wetted perimeter)

The program sums up all the incremental conveyances in the overbanks to obtain a conveyance for the left overbank and the right overbank. The main channel conveyance is normally computed as a single conveyance element. The total conveyance for the cross section is obtained by summing the three subdivision conveyances (left, channel, and right).

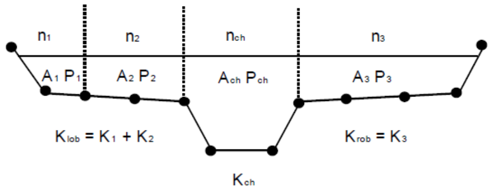


Fig. 2 HEC-RAS Default Conveyance Subdivision Method

METHODOLOGY

Study Area

This research conducted in Nam Pong River watershed located in the northern part of Thailand bordered with Udon Thani, Mahasarakham, Chaiyaphum and Nong Bua Lamphu provinces. The area of study is approximately 2993.95 km^2 (fig.3).The lower part consists mainly of paddy fields, agricultural land, factories and is more heavily populated. The land surface in the watershed is generally undulating and sloping towards the east and southeast. The elevation of the relatively flat area around the reservoir is about 190 m. The western watershed, from which the Namphong and the Nam Phrom originate, consists of many mountain ranges with an average elevation of 900 m, and up to 1,300 m at Phu Kradung [6]. Geographic location of the study area is in between Latitude N 16^0 23' 39" to N 16^0 46' 37" and Longitude E 102^0 36' 22" to E 102^0 57' 51".

Cross-section Preparation for River and Floodplain

The 103-surveyed cross-sections obtained from the study area along the Namphong River had been input to HEE-RAS for channel geometry drawing to perform steady flow calculation. SWAT model using 10-year-daily rainfalls from 2000-2010 had been used to simulate peak flow from the whole watershed area, which was divided into 14 sub-watersheds, to calculate flooding events with 5 different return periods: 5, 10, 25, 50 and 100-years by Gumbel's Distribution method.

Calibration for roughness coefficient

The roughness coefficients, which represent the surface's resistance to flow and are integral parameters for calculating water depth, were initially estimated using the Chow classification. Chow (1959) provides the most thorough set of roughness values for various surface materials to date, including descriptions and photographs to help in estimation of suitable values. The Manning's coefficients used for different zones of the Namphong River varies between 0.025 and 0.060. Flood inundation results are derived separately for each cross section in the main channel. It is generally accepted that the reliability of application of any conceptual and even physically based model depends much on the success of the calibration process used to identify values for the model parameters [5].

Model parameters can largely be divided into two categories [7]: (i) parameters that can be directly inferred from observation, such as area, extent, depth, volume etc., and (ii) parameters that cannot be directly observed at the model scale and will need to be estimated, such as roughness. Manning roughness coefficient *n*, together with the channel geometry is considered to have the most important impact on predicting inundation extent and flow characteristics. Therefore, the focus of this section is the calibration of the roughness coefficients. Most of the methods from literature for estimating roughness values are useful in establishing the range of roughness values for a river reach. Calibrated roughness values are, however, effective at the reach scale [4]. Calibration is an inverse problem associated with identification, and is used to determine unknown constants or parameters in a model. Calibrating the Namphong River model roughness values involved running the hydraulic model several times and changing the Manning roughness coefficients, first estimated from Chow tables, until the best fit between the simulated and observed water level and water extend is found. The river cross sections were divided into three zones for calibration: Left bank, main channel and right bank.

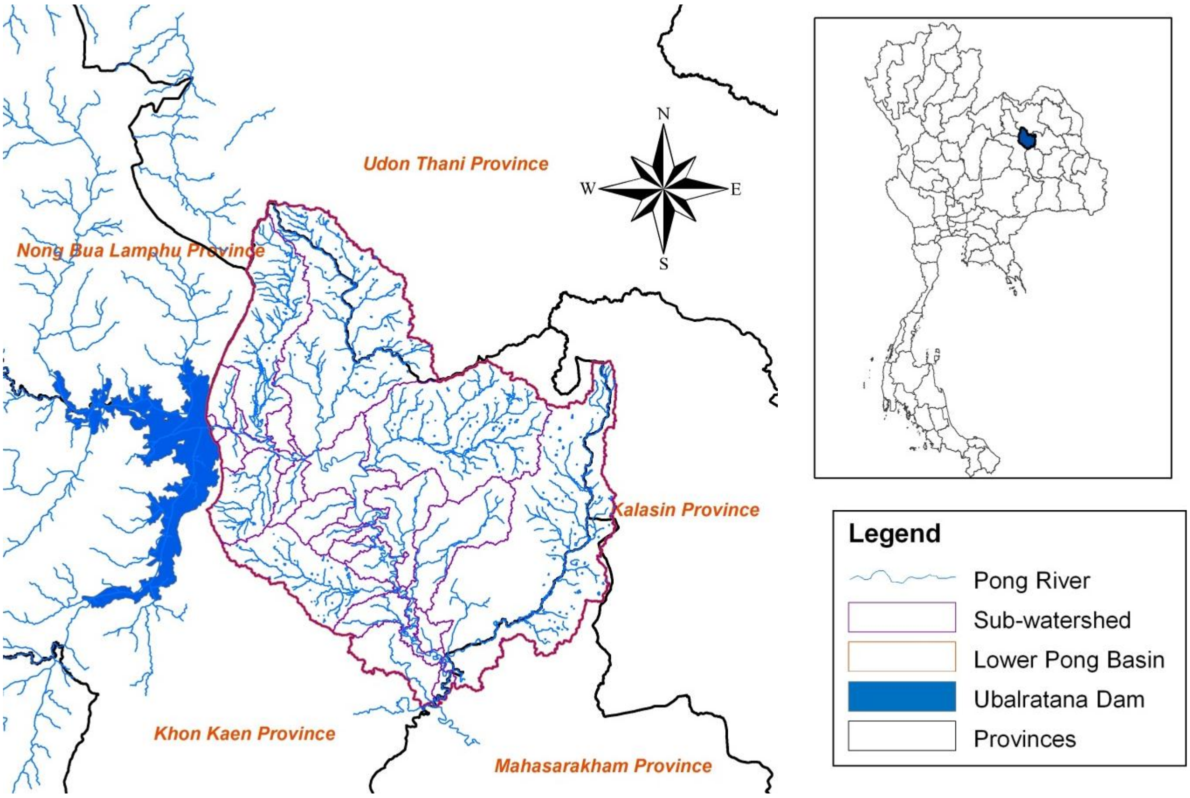


Fig.3 Location of the study area

Table 1: Characteristics of the 14 catchments used in this study (Wongsasri., S, 2012)

Namphong River	Tributary Name	Cat. Size (KM^2)	Annual Maximum Discharge (m^3/s)										
			2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Upper Reach	Huai Chot	33.97	6.81	7.62	6.20	8.68	11.17	6.18	16.63	27.26	19.21	8.27	6.18
	Huai Khum Mum	241.08	51.41	60.77	34.68	55.98	81.39	34.66	123.80	189.90	130.30	49.08	34.30
	Huai Sai	6.75	11.74	5.26	9.18	15.16	5.14	17.24	30.85	21.59	10.05	5.45	6.75
	Huai Suea Ten	527.73	111.40	106.30	108.30	161.40	140.60	105.50	109.10	169.70	121.50	117.60	114.30
	Huai Yang 1	108.45	23.99	22.60	22.43	26.09	37.05	22.39	54.39	84.67	60.88	28.05	22.03
Lower Reach	Huai Hin Lat	20.15	7.23	5.91	5.91	5.95	8.09	5.92	5.99	9.09	7.14	7.56	5.90
	Huai Kao Khot	102.24	45.89	42.54	42.61	42.57	48.03	42.67	43.08	43.40	45.06	43.27	42.54
	Huai Nong Pla	153.14	44.93	41.10	68.36	40.87	51.76	41.24	42.36	56.98	46.54	42.43	41.31
	Huai Pha Khue	83.59	32.12	26.25	25.21	30.03	40.37	23.94	25.47	25.03	33.12	26.33	27.75
	Huai Plalai	46.89	33.70	27.33	27.30	26.97	36.26	26.63	26.83	27.02	27.65	27.67	26.86
	Huai Sai Bat	697.98	155.50	153.70	478.00	165.50	193.30	155.00	168.00	191.30	205.80	160.50	154.60
	Huai Siao	412.52	84.45	44.89	118.40	151.50	185.80	54.25	123.80	140.70	130.40	74.89	108.80
	Huai Yai	175.85	61.31	44.63	45.79	49.99	69.21	43.97	44.04	44.71	95.75	45.30	46.27
	Huai Yang 2	47.65	12.94	11.03	11.04	14.39	15.38	11.19	15.82	22.52	16.23	17.89	12.64

Flood Frequency Analysis

Flood frequency analyzed by using Gumbel's Distribution method with 10-year rainfall records simulated by SWAT model which divided the study area to 14 sub-watersheds (see table.1) with the daily model calibration from 2004-2007 (R^2=0. 93) [10] to determine the flooding zone occurrence varied with the different return period of 5 year, 10 year, 25 year, 50 year and 100 years.

Flooding Zone Mapping

Flooding map, which can provide information including the past flood track records, flood anticipation, potential evacuation routes, evacuation places, etc. to the local residents, is indispensable for emergency response and for long-term flood disaster management [10]. In this study, a flood zoning map was prepared using the inundation status, which was found from hydrologic simulation.

RESULTS

Flood Frequency Analysis

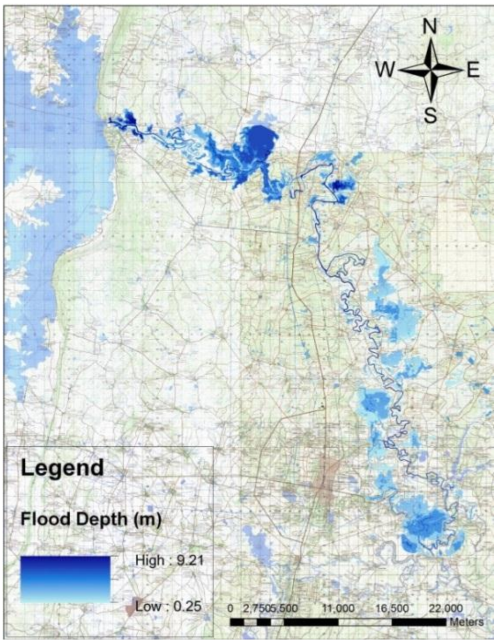
Flood frequency analyses (see table 2) were carried out with peak discharge data for 10 years (2000–2010) by the Gumbel's Distribution method. The maximum water level was calculated for flood of 100-year return period and assigned at upstream and at downstream as boundary condition which were 7.85 and 5.45 m, respectively. Initial flow 100 m^3/s and released flow 464 m^3/s from Ubolratana dam was given as initial condition. With this consideration, inundation depth was calculated with DEM 5m resolution. Then, these data were exported to the ArcView.

Table 2 Flood frequency analysis by Gumbel's Distribution method for 10-year rainfall records (2000-2010)

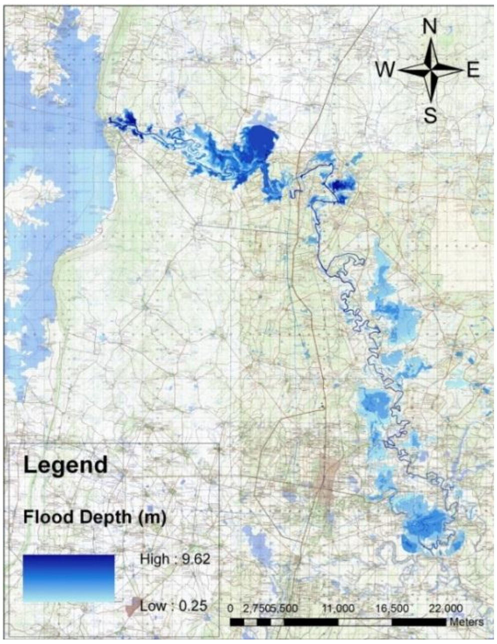
Namphong River	Tributary Name	Annual Peak Flow (M^3/S)	X Average	St.D	β	u	Return Period of Flood Frequency Analysis				
							5 YR	10 YR	25 YR	50 YR	100 YR
Upper Reach	Huai Chot	27.26	11.29	6.88	5.37	8.19	16.24	20.27	25.36	29.14	32.88
	Huai Khum Mum	189.9	76.93	50.34	39.25	54.28	113.15	142.61	179.83	207.44	234.84
	Huai Sai	565.1	12.58	8.10	6.31	8.94	18.41	23.15	29.13	33.58	37.98
	Huai Suea Ten	169.7	124.15	22.77	17.76	113.91	140.54	153.86	170.70	183.19	195.59
	Huai Yang 1	84.67	36.78	20.90	16.30	27.37	51.82	64.05	79.51	90.97	102.35
Lower Reach	Huai Hin Lat	9.09	6.79	1.11	0.87	6.29	7.59	8.24	9.06	9.67	10.27
	Huai Kao Khot	48.03	43.79	1.79	1.40	42.98	45.08	46.13	47.45	48.44	49.41
	Huai Nong Pla	68.36	47.08	8.74	6.81	43.15	53.37	58.48	64.94	69.73	74.48
	Huai Pha Khue	40.37	28.69	4.90	3.82	26.49	32.22	35.09	38.71	41.40	44.07
	Huai Plalai	36.26	28.57	3.24	2.53	27.11	30.90	32.79	35.19	36.96	38.73
	Huai Sai Bat	478	198.29	94.55	73.72	155.74	266.31	321.63	391.53	443.38	494.85
	Huai Siao	185.8	110.72	42.80	33.37	91.46	141.51	166.55	198.19	221.66	244.96
	Huai Yai	95.75	53.72	16.19	12.62	46.44	65.37	74.84	86.81	95.68	104.49
	Huai Yang 2	22.52	14.64	3.49	2.72	13.07	17.16	19.20	21.78	23.70	25.60

Flooding zone mapping

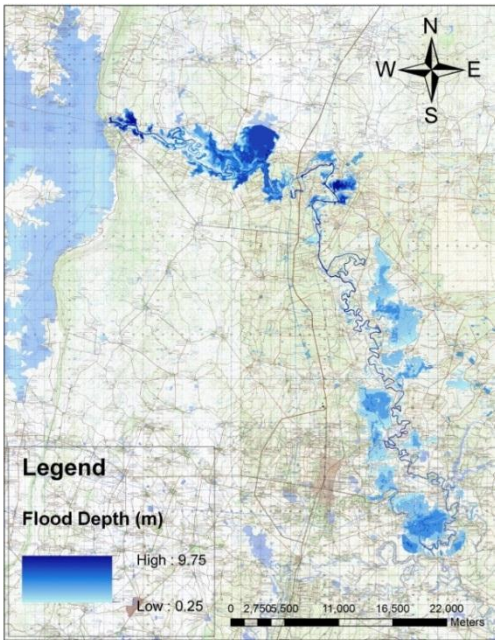
Flood zoning maps had been determined by using the water depth and flood extend to show on topographical map compering with actual flood map from Thailand Flood Monitoring System. The result showed that the depth of the flood were varied from 0.25-9.21 m, 0.25-9.62 m, 0.25-9.75 m, 0.25-9.87 m, comprising with various return period: 5 years, 25 years, 50 years, and 100 years, respectively.



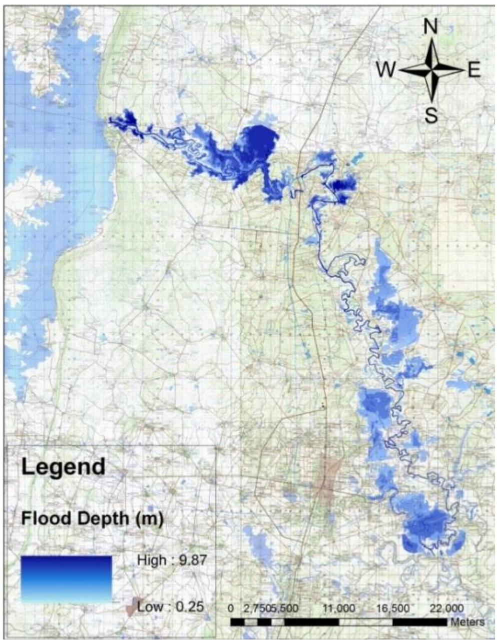
a). Flood mapping of 5-yr return period



b). Flood mapping of 25-yr return period



c). Flood mapping of 50-yr return period



d). Flood mapping of 100-yr return period

Table 3 Classification of flood damage according to land use from the study area

Land use Types (Km^2)	Total flood damage area (Km^2)									
	5 year Flood		10 year Flood		25 year Flood		50 year Flood		100 year Flood	
	Area	%	Area	%	Area	%	Area	%	Area	%
Cultivation	2.46	1.80	2.49	1.77	2.59	1.76	2.68	1.76	2.97	1.91
Forest	1.08	0.79	1.08	0.77	1.08	0.73	1.08	0.71	1.08	0.69
Miscellaneous land	21.51	15.75	21.93	15.58	23.16	15.72	23.75	15.54	24.15	15.50
Orchard	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other	0.33	0.24	0.34	0.24	0.34	0.23	0.34	0.22	0.34	0.22
Paddy field	82.80	60.62	86.40	61.37	91.19	61.91	95.36	62.37	97.39	62.48
Urban Area	0.84	0.61	0.87	0.62	0.98	0.66	1.02	0.66	1.02	0.66
Water body	27.56	20.18	27.69	19.66	27.96	18.98	28.67	18.75	28.91	18.55
Total	136.59	100.00	140.80	100.00	147.30	100.00	152.90	100.00	155.86	100.00

Flood damage analysis

The flood damages for the flooded areas were prepared by intersecting the land use map of the floodplains with the flooded area polygon simulated from HEC-GeoRAS for each of the flood event being modeled (see table 3).

This depicts of the flood damage in the particular area is in terms of the presence or the absence of flooding of a particular return period as a binary model. The assessment of the flood damage areas indicated that a large percentage (more than 60 %) of damage area lied in flood plain area i.e. paddy field followed by miscellaneous land, forest and cultivation area comprising 15%, 0.7% and 1.7% respectively

CONCLUSIONS

This study presents a systematic approach in the preparation of flood zoning and flood damage with the application of steady flow models and GIS. The major tools/models used in this method are one-dimensional numerical model HEC-RAS and ArcView GIS for spatial data processing and HEC-GeoRAS for interfacing between HEC-RAS and ArcView.

- The automated floodplain mapping and analysis using these tools provide more efficient, effective and standardized results and saves time and resources.
- The presentation of results in GIS provide a new perspective to the modeled data and this approach can facilitate a transition from a flood damage model based on the field investigation to a knowledge-based model that can be related to flood intensity.
- The visualization and the quantification of the flood damages as facilitated by this approach can help the decision-makers to better understand the problem.
- The evaluation of the damages due to the flooding was made with regard to the land use pattern in the flood areas. The evaluation of the flood area indicates that a large percentage (more than 60 %) of flooding area lies in flood plain area i.e. paddy field area and followed by miscellaneous land, forest and cultivation area, comprising 15%, 0.7% and 1.7% respectively.
- The study also made the analysis of flood damages with relation to the return period of floods and their water depth. The relationship between the flood area and discharge indicates that there is a medium rate of increase of the flood area with the increase in discharge. The examination of the flood water depth shows that most of the areas under flooding have water depth greater than 1.5m.

DISCUSSIONS

The applications of hydraulic model and GIS for floodplain analysis and mapping have been limited in countries like Thailand, where the availability of the river geometric, topographic and hydrological data are also very limited. The situation of river flooding in Thailand is also completely different, as there is much higher variation in the river flows and rivers are completely unregulated. There are very few flood control structures like spurs and dikes and the river banks and boundary lines are not clearly defined. Hence, the floodplain analysis and modeling are subject to number of new sets of constraints. This study presents an approach of conducting a similar study, within these constraints.

- HEC-RAS and ArcView GIS were the primary software packages used for this analysis. HEC-GeoRAS extension facilitates the exchange of data between ArcView and HEC-RAS.
- The spot elevations and contour line are used to prepare the digital terrain model of the study area so that it can represent the river channel and floodplains adequately.
- The flood discharge of different return period is derived by different method. For safe side the maximum of different methods are taken as flood discharge for the analysis.
- During the model run in HEC-RAS, several aspects required were careful considered.

ACKNOWLEDGMENTS

I would like to acknowledge financial support from the department of Agricultural Engineering, Faculty of Engineering, Khon Kaen University, as well as Water Resource and Environment Institute (WREI) which provided data for my research process. Moreover, I would like to deeply thank for my advisor Asst. Pro. Dr. Vichian Plermkamon for his useful guides and comments on the paper and my research processes.

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