4.5.3 Verification of HD Model

The same dataset during 2003 to 2005 that were used for verification of MIKE11 NAM model were used to verify the MIKE11 HD model. The develop MIKE11 HD model was used to simulate water levels of the 2003 to 2005 verification periods using the parameters derived from the calibration period. The verification results show in **Figure 4.5-3** are evident that the simulated water levels of the S.4B station correspond to the observed data. Errors estimation between the simulated and observed water levels were also performed and the results were presented in **Table 4.5-3**.

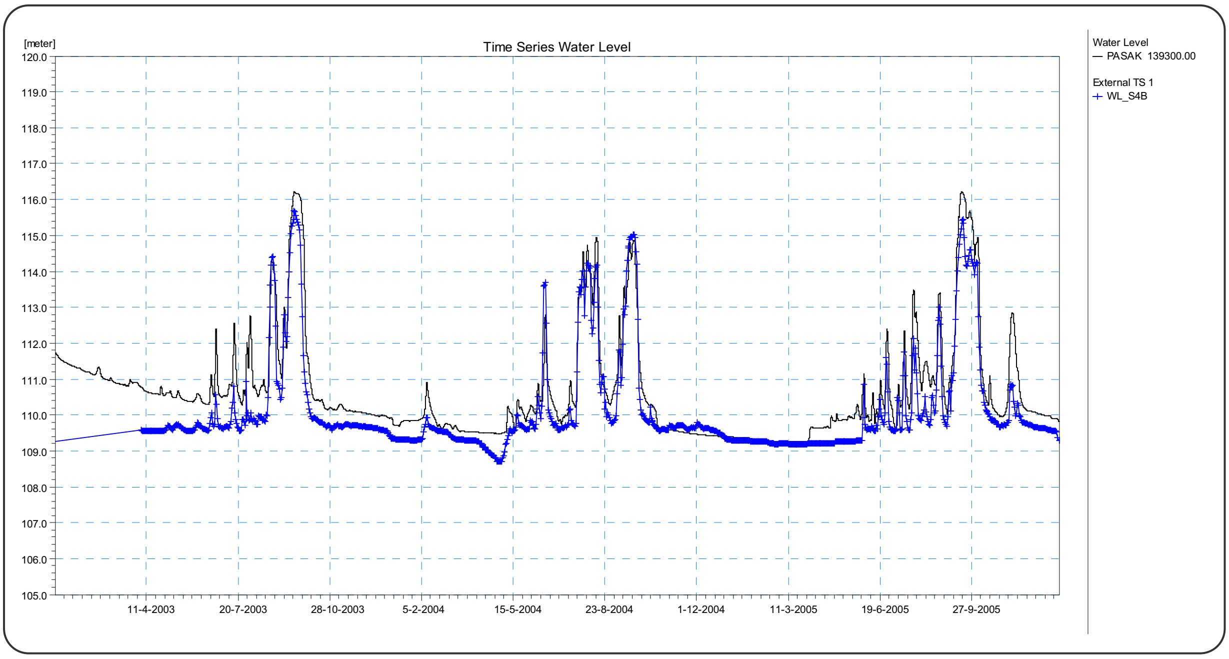


Figure 4.5-3 Comparison between Estimated and Observed Water Level of A. Muang Phetchaboon (S.4B) Sub-catchment (MIKE11 HD: Verification)

Table 4.5-3 Errors Estimation of the MIKE11 HD Model Verification

Period	Duration (days)	Statistical Comparison				
		Peak			Volume Error (%)	Correlation Coefficient, R^2
		observed	modeled	Error (%)		
1/5/2003 - 31/10/2003	183	115.69	116.204	0.445	0.757	0.884
1/5/2004 - 31/10/2004	183	115.01	114.94	-0.061	0.276	0.925
1/5/2005 - 31/10/2005	183	115.45	116.215	0.662	0.603	0.945
1/1/2003 - 31/12/2005	1,095	115.69	116.215	0.454	0.439	0.891

4.5.4 Application of HD Module

The calibration and verification results of the developed HD model are acceptable according to the outcomes presented in sections 4.4 and 4.5. The developed HD model was then used to simulate water levels along the river network of the Upper Pasak river basin during the flooding events of the year 2002, 2006 and 2007. The simulated water levels along the Upper Pasak river network calculated from the developed HD model were input to the MIKE11 GIS module to generate flood maps of the Muang Phetchaboon district. Details of these are presented in the next section.

4.6 MIKE11 GIS Module Development

The objective of developing MIKE11 GIS model is to generate and display output of MIKE11 in a meaningful easily understood formats for use in the flood management planning process. In this study, the MIKE11 GIS has been used to produce two types of flood maps. These are flood depth maps and flood duration maps. Steps used for developing MIKE11 GIS model are as follow.

4.6.1 Preparation of Topographic Map

As mentioned in section 4.1.3, MIKE11 GIS is based on a bi-directional data exchange between MIKE11 and ArcView, therefore it is necessary to develop based maps for use to create topographic map of the study catchment. The more details of the topographic map, the more accuracy of the flood map could attain. In this study, the twenty-two 1:50,000 topographic maps with 20 meters contour interval and the field surveying of flood risk areas of the Upper Pasak river basin prepared for "*The installing of a hydrometeorology telemetering system: phase III project*" of TMD were used for flood hazard modeling. Ground elevation data were used as input data to build the DEM of the study catchment. The DEM with 2-meter contour intervals were used in the analysis. The errors of this DEM do not exceed 1 meter. This DEM was used as a basic data to generate flood inundation map of the Muang Phetchaboon district. The generated DEM of the Muang Phetchaboon is shown in **Figure 4.6-1.** Note that in the study of PASCO, ground elevation data with 10- meter interval contour line available from RTSD were used. The 250- meter DEM was interpolated from this data and used for the flood depth extraction in their study. The DEM data used by PASCO were interpolated from the 10- meter interval contour line while the DEM data used in this study were interpolated from the 5-meter interval contour line. The DEM data used in the present study are the most precise that are available at the moment. These available DEM data are sufficient and precise enough to use for flood depth evaluation.

However, it is desirable to use more precise DEM data (say centimeter vertical accuracy in relative terms) if available in the future.

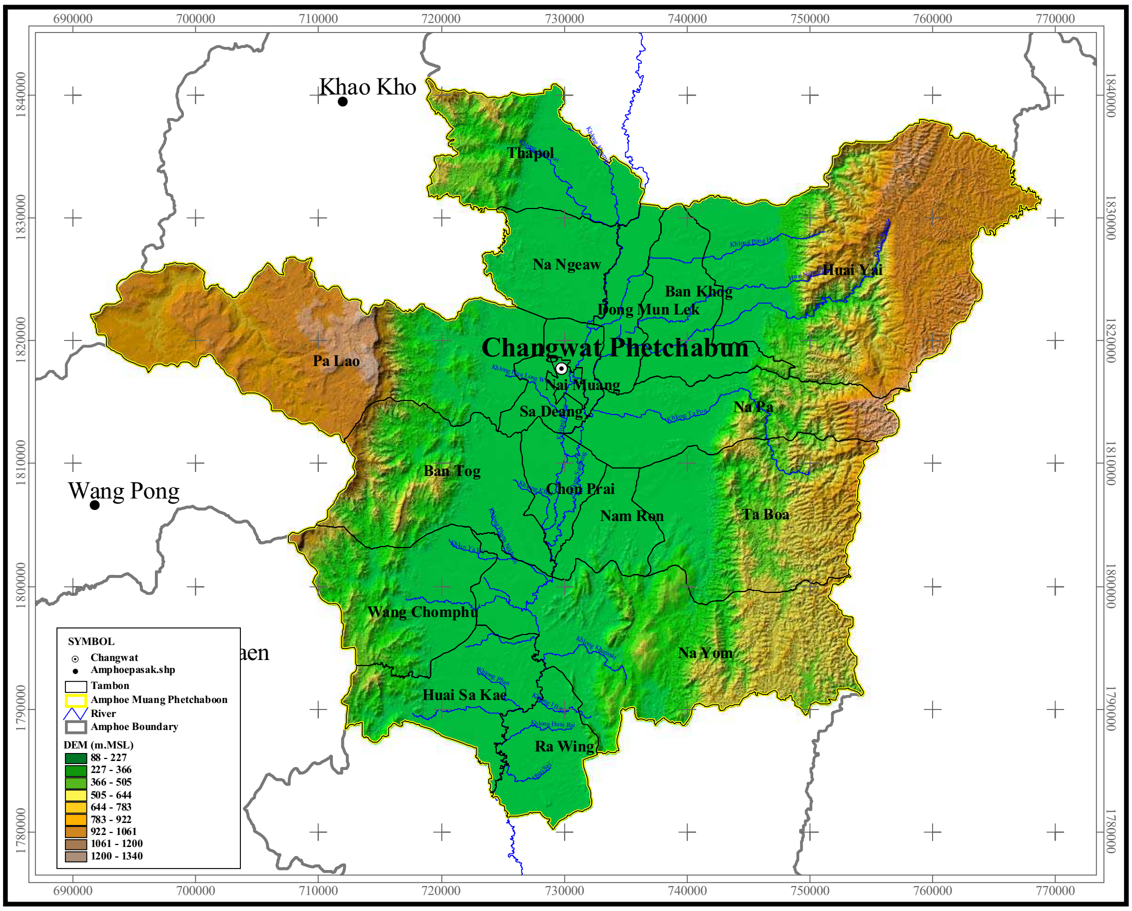


Figure 4.6-1 Digital Elevation Model, DEM of the Muang Phetchaboon District

4.6.2 Flood Mapping

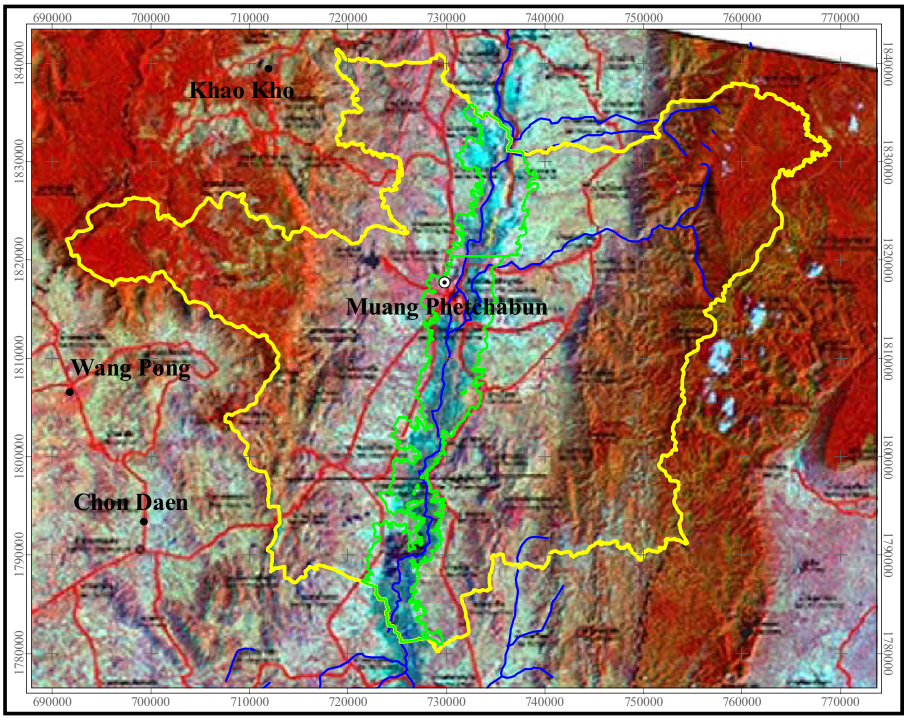
Development of flood map using MIKE11 GIS requires information from a MIKE11 model (river network), MIKE11 flood simulations and the DEM. Water levels and discharges from MIKE11 results files were input into MIKE11 GIS. Based on the discrete information from MIKE11, MIKE11 GIS constructs a grid based water surface and compares this data with the developed DEM to produce flood depth and duration mapped surfaces. To validate flood simulation model, we compare the flood depth maps of the three flood events generated from MIKE11 software package (MIKE11 NAM, MIKE11 HD and MIKE11 GIS) with the available flood extent maps with the satellite images acquired on the same date**. Table 4.6-1** shows lists of available satellite images that were used for model evaluation.

Table 4.6.1 Lists of Available Satellite Images used for Model Evaluation.

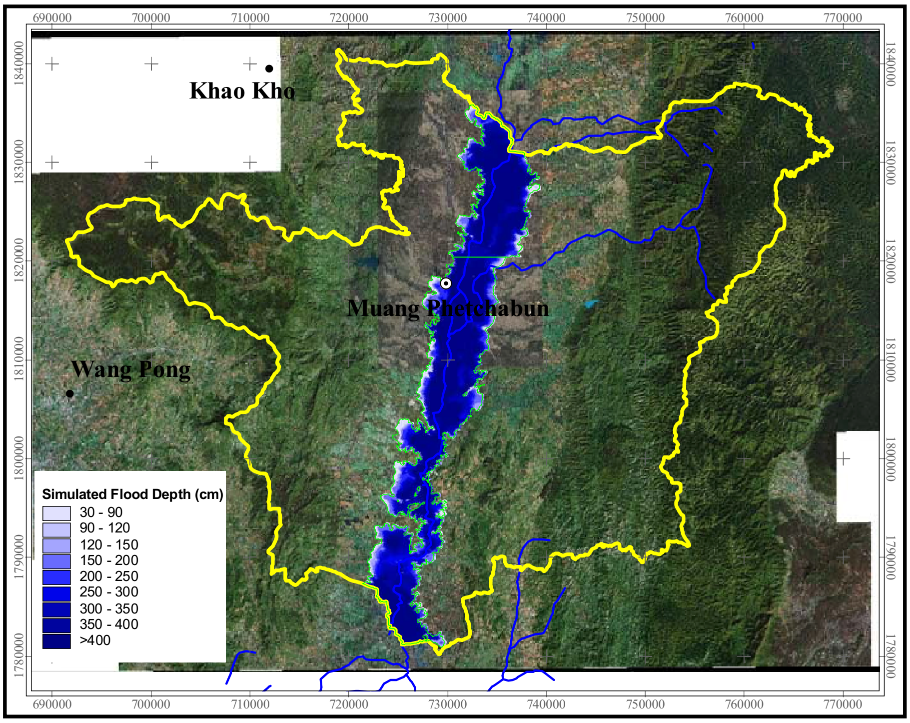
Flood Events	Satellite Image
20 Aug – 22 Oct 2002 (calibration)	Radarsat 10 September 2002 06:06 am
3 Sept – 10 Oct 2006 (verification)	Radarsat 1 October 2006 11:22 am
14 Sept – 22 Oct 2007 (verification)	Radarsat 12 October 2007 06:12 am

The flood mapping simulation of the 2002 flood event was conducted for calibration of MIKE11 GIS. Flood mapping of flood events of 2006 and 2007 were used for verification of MIKE11 GIS module. Comparison between the simulated flood maps of the three flood events and the corresponding satellite images are presented in **Figures 4.6-2 to 4.6-4,** respectively.

Only three interpreted satellite images are available during the study period as shown in Figures 4.6-2 to 4.6-4. Based on these interpreted images, it is difficult to compare modeled flood depths and flood depths illustrated in the satellite images. However, based on "*visual inspection*" the simulated flood extents obtained from the model are comparable to flood locations shown in the satellite images. Therefore, we considered that the developed flood modeling can be used to produce flood maps corresponding to different weather scenarios. Production of these flood maps will be used for identify flood hazard zones of the study area. The production of flood hazard map is presented in the next chapter.



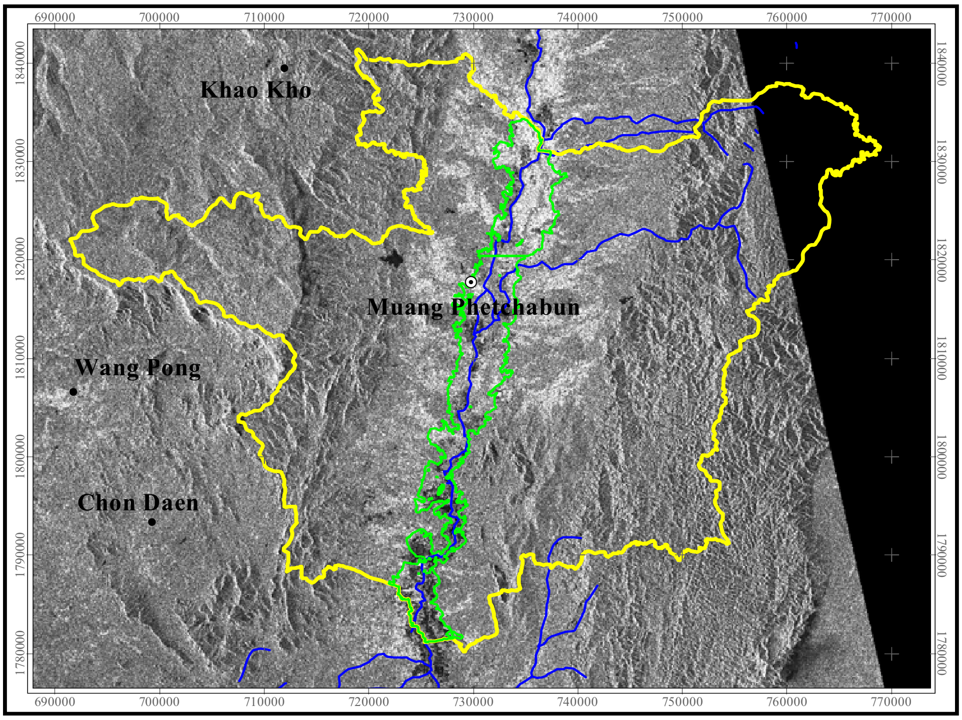
Radarsat 10 September 2002 06:06 am



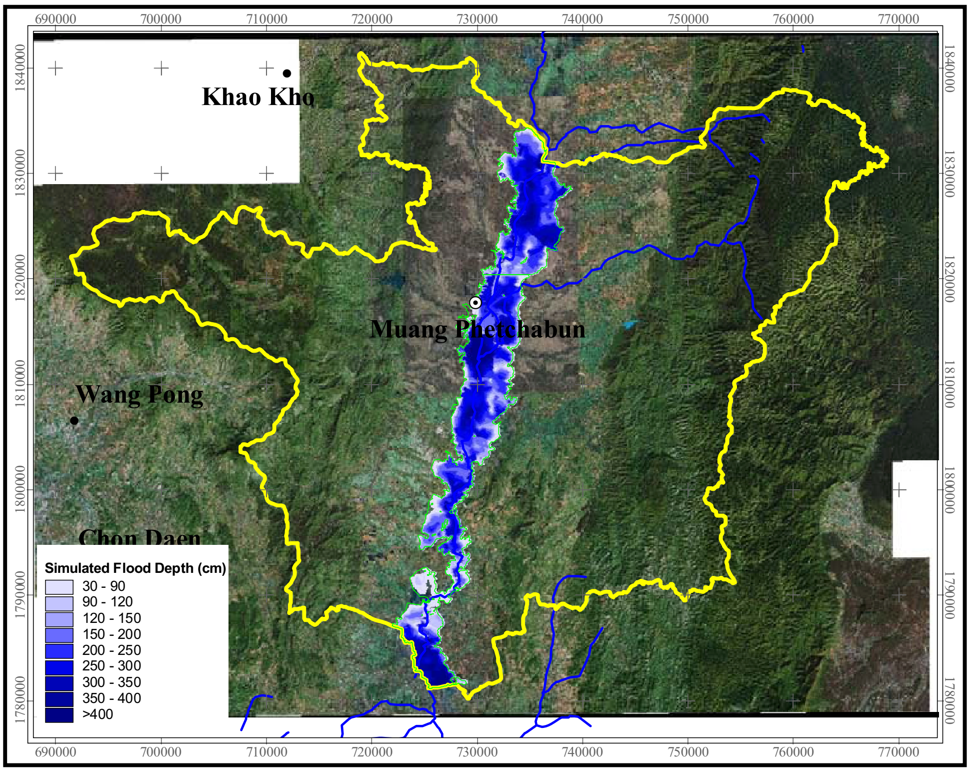
MIKE11 GIS Simulated Flood Depth on 10 September 2002 06:06 am

Changwat
Amphoe
Amphoe Muang Phetchaboon
Stream
Simulated Flood Extent

Figure 4.6-2 Simulated Flood Mapping of 2002 Flood Event



Radarsat 1 October 2006 11:22 am



MIKE11 GIS Simulated Flood Depth on 1 October 2006 11:00 am

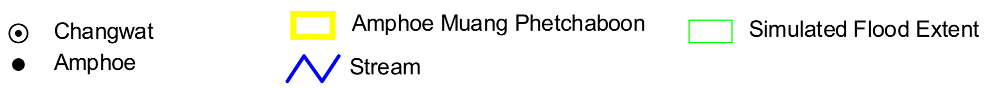
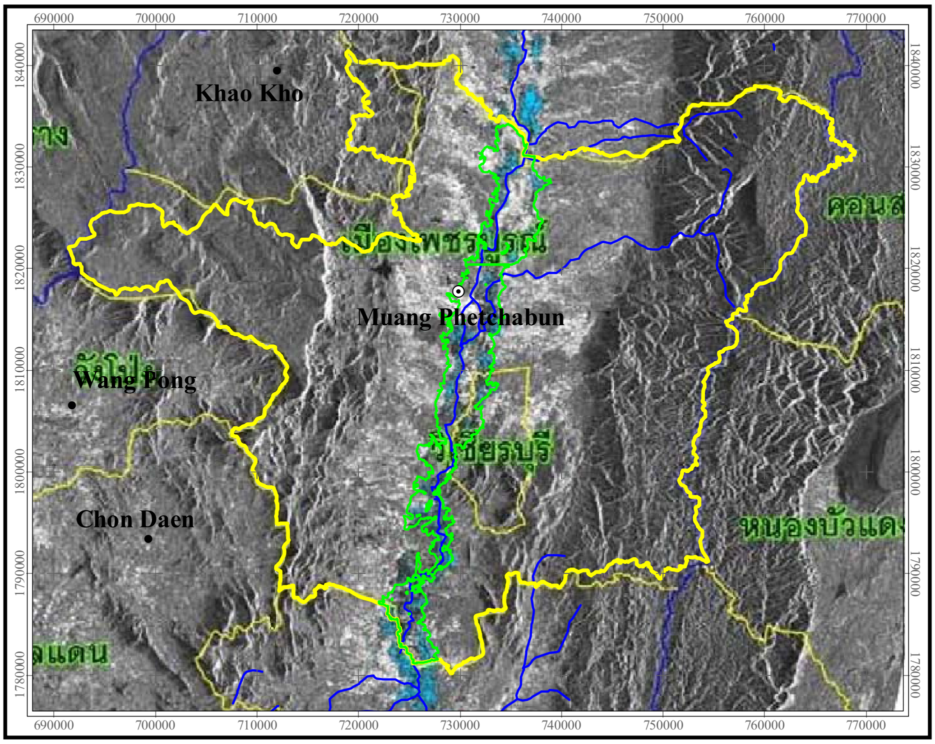
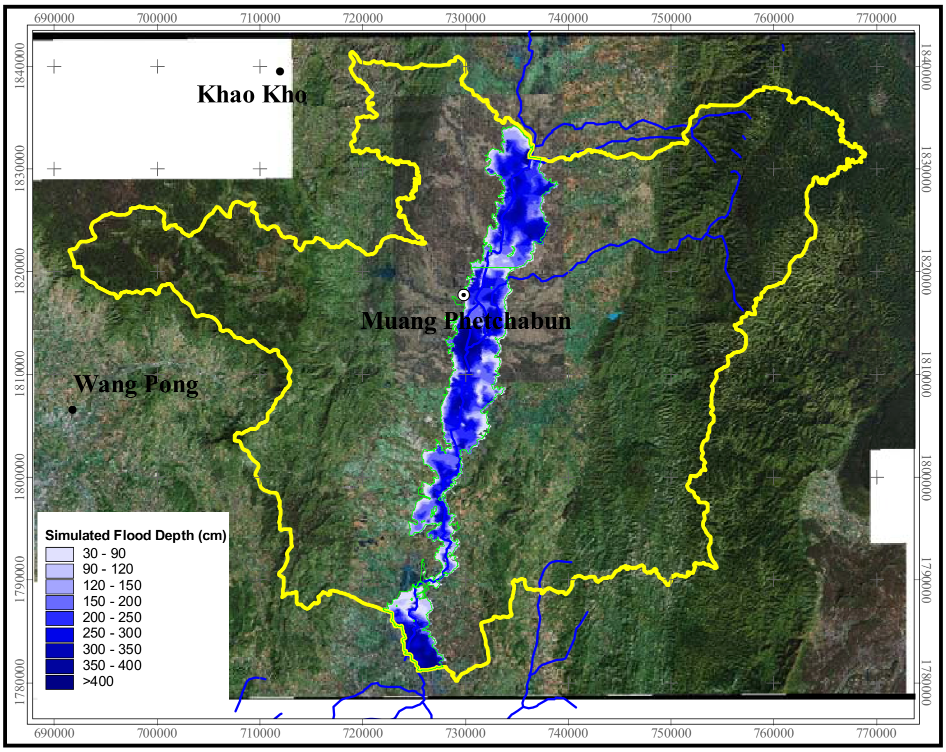


Figure 4.6-3 Simulated Flood Mapping of 2006 Flood Event



Radarsat 12 October 2007 06:12 am



MIKE11 GIS Simulated Flood Depth on 12 October 2007 06:00 am

Changwat
Amphoe
Amphoe Muang Phetchaboon
Stream
Simulated Flood Extent

Figure 4.6-4 Simulated Flood Mapping of 2007 Flood Event

Chapter 5

Flood Map Production

Chapter 5

Flood Map Production

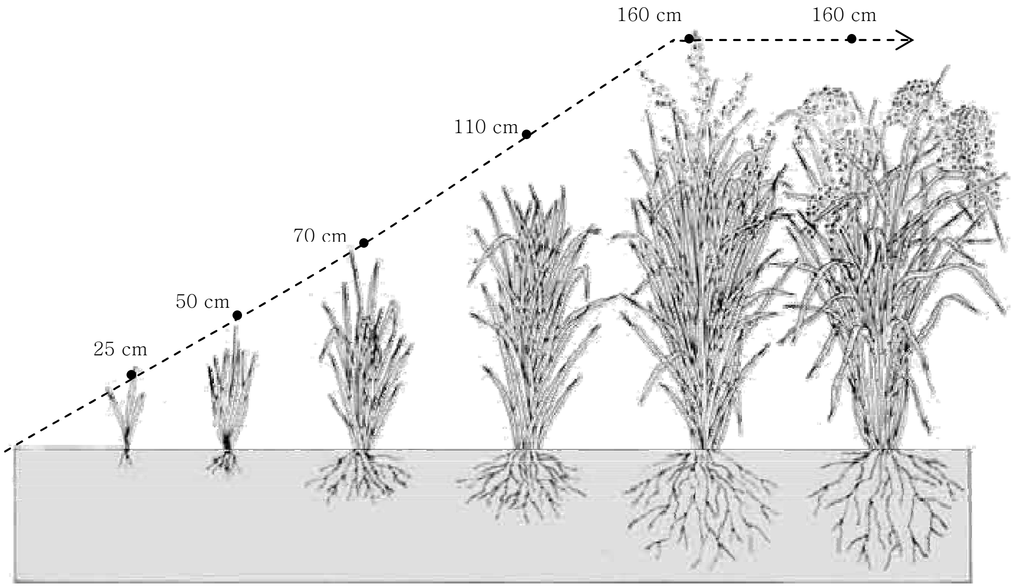
The developed flood model was used to simulate inundation patterns for different flood scenarios. The simulated inundation pattern includes flood extent, depth and duration of flood plain of the Upper Pasak river basin, which particular focus on the Muang Phetchaboon district.

Two sets of flood risk map were produced in this study. The first set of flood risk maps were generated using the maximum annual rainfall and streamflow data while the second sets of flood risk map were simulated using the weekly percentile of rainfall and streamflow values. The purpose of developing flood risk maps based on annual maximum data is to use for flood insurance of rice crop failure while the weekly flood risk maps are recommended to use for rice crop growing management. The annual maximum rainfall and streamflow data of the rain gauge and river gauge stations located within the study catchment were used to design combined flood hazard scenarios at different return periods. These combined flood hazard scenarios were used to represent the most crucial weather severity at different levels that cause flood in the study area. Rainfall and streamflow data at different percentiles of the rain gauge and river gauge stations mentioned above were used to design combined weekly flood scenarios. The combined weekly flood scenarios that designed based on 50th, 75th and 95th percentiles data were considered to represent low, moderate and high levels of weather severity that occurred in the past. Any inundation area that are caused by the 50th, 75th and 95th percentiles of designed combined weekly flood scenarios are considered as high, moderate and low flood risk zones, respectively. Flood loss criteria that were used to generate these two sets of flood risk map were given below.

5.1 Flood Loss Criteria

From the discussion with BAAC and the rise experts from the Rice Department, it has been found that the possible rice crop cycles of the study area can be up to 4 cycles as details presented in Chapter 2 (Table 2.2-4). According to the information presented in Table 2.2-4, flood depth and duration that inflicts on rice crop failure for each rice crop growth stage can be summarized as presented in **Table 5.1-1**. This information was used to define the critical flood depth and duration criteria that cause rice crop failure in the study area. Note that, generally rice crop can be overthrown because of flash flood causing damages for all growth stages. The information presents in Table 5.1-1 does not include rice crop damage due to flash flood.

Table 5.1-1 : Flood depth and duration inflict rice crop failure



Growth Stage	June	July	Aug	Sep	Oct	Nov	Dec
	Seeding	**Transplant**	**Tillering**	**Booting**	**Flowering**	**Reproductive (Grain Filling)**	**Harvesting day**
Rice Height (cm)	0-25	25-50	50-70	70-110	110-160	160	160
Critical Water Depth (cm)	25	25	40	70/ 20*	160	160	160
Critical Flooding Duration (days)	> 3	> 3	> 4	> 4	> 4	> 4	> 4

Source: From the discussion with BAAC and the rice experts of the Rice Department
* The critical water depth during the first two weeks of September is 70 cm while the last two weeks is 20 cm, respectively.

Since the critical flood depth and duration that cause rice crop failure are varied according to rice growth state. Thus, flood maps were produced according to different critical flood loss criterion of each critical month.

5.1.1 Flood Loss Criteria for Producing Flood Hazard Zone Map

According to critical flood loss information presented in **Table 5.1-1**, flood maps corresponding to the combined maximum flood scenarios at 2-, 5-, 10-, 20-, 50- and 100- year return periods were produced based on 4 different critical flood loss criteria. The 4 critical flood loss criteria were:

(i) Critical flood depth is greater than or equal to 40 cm with duration longer than 4 days

(ii) Critical flood depth is greater than or equal to 70 cm with duration longer than 4 days

(iii) Critical flood depth is greater than or equal to 20 cm with duration longer than 4 days

(iv) Critical flood depth is greater than or equal to 160 cm with duration longer than 4 days

Twenty-four flood maps were simulated according to the combined maximum flood scenarios (6 return periods multiplied by 4 critical flood loss criteria). Generating flood hazard maps for different critical flood loss criteria will allow users to be able to select which flood loss criteria fit to their crop calendars.

It is to be noted that, the flood hazard maps generated using the combined maximum flood scenarios provide the maximum inundation patterns of the study area. This is because the designed maximum 4-day rainfall patterns and the designed maximum flow patterns of the highest flood risk month (September) were used to represent rainfall and streamflow at different return periods. Appling these flood hazard maps to other periods which are not the maximum period might cause an overestimation of inundation pattern. To address this problem, additional flood risk maps for different time windows during the critical months need to be produced. Details of critical flood loss criteria for use to generate flood risk maps at different time window, so called "*weekly flood risk maps*" are given next.

5.1.2 Flood Loss Criteria for Producing Weekly Flood Risk Map

The designed weekly rainfall patterns during August to November of 5 rain gauge stations and designed weekly streamflow patterns of the S.3 station at 50th, 75th and 95th percentiles as presented in section 3.4.4 were used as combined weekly flood scenarios to produce weekly flood risk management maps. The critical flood depth and duration criteria presented in Table 5.1-1 were used to generate weekly flood risk maps. Summaries of the proposed critical flood depth and duration criteria for each time window (weekly) during the critical months are below.

- **August**: *critical flood depth is greater than or equal to 40 cm with duration longer than 4 days*
- **September#1**: *critical flood depth is greater than or equal to 70 cm with duration longer than 4 days (the first two weeks of September)*
- **September#2**: *critical flood depth is greater than or equal to 20 cm with duration longer than 4 days (the last two weeks of September)*
- **October and November**: *critical flood depth is greater than or equal to 160 cm with duration longer than 4 days*

5.2 Production of Flood Hazard Zone Map

5.2.1 Simulation of Maximum Inundation Patterns

The combined maximum flood scenarios at different return periods as proposed in section 3.4.3 were used to simulate maximum inundation patterns of the study area. **Figures 5.2-1 to 5.2-6** show the maps of simulated flood extent of more than 4 days inundated area at different return periods. Statistical summary of inundated area with flood depths are greater than 40, 70, 20 and 160 cm and duration more than 4-day (according combined maximum flood scenarios at different return periods) of each Tumbol of the Muang Phetchaboon district are presented in **Tables 5.2-1 to 5.2-4**, respectively.

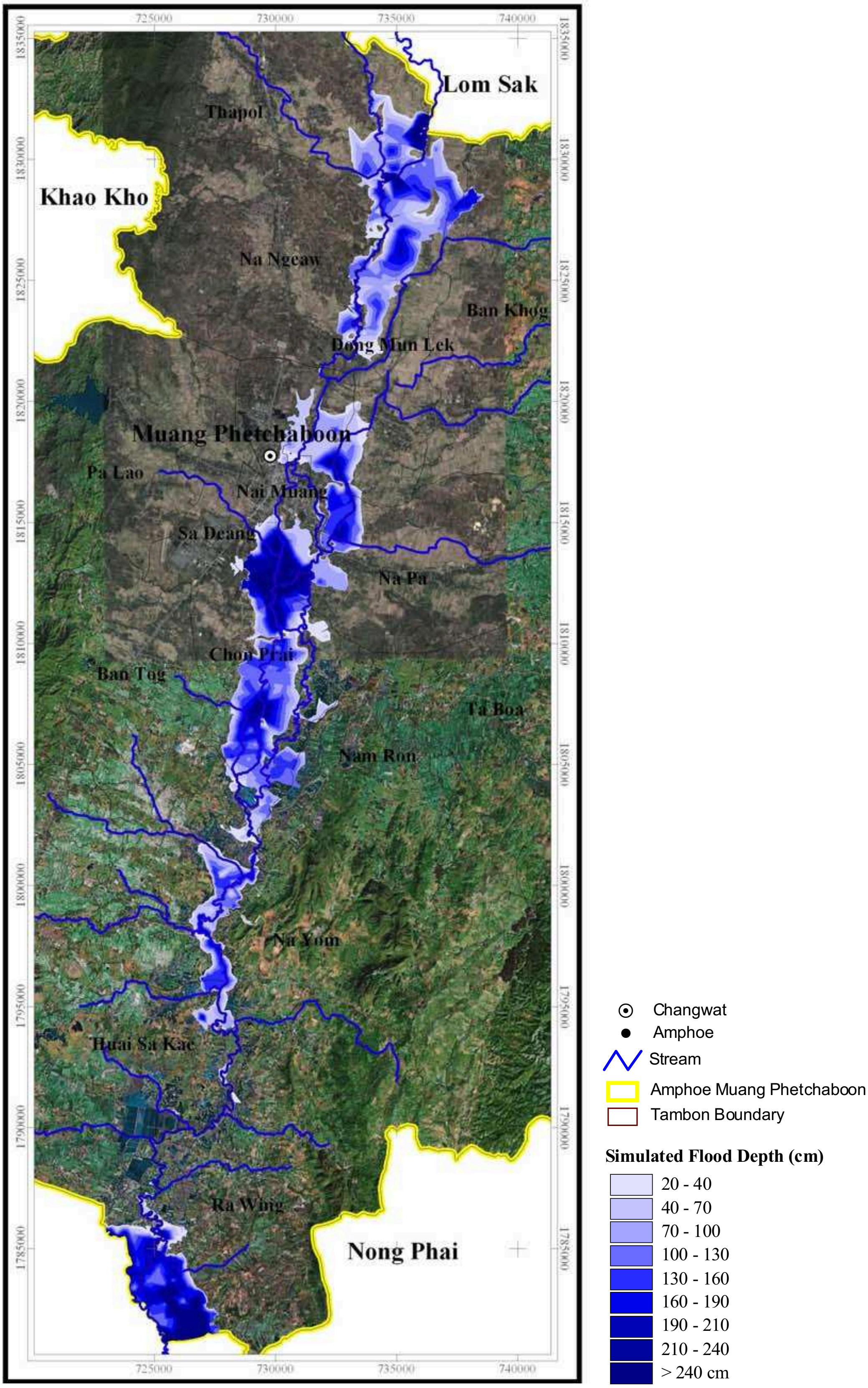


Figure 5.2-1 Map of Simulated Flood Extent of More Than 4 Days Inundated Area

(According to 2-Year Return Period of Combined Maximum Flood Scenario)

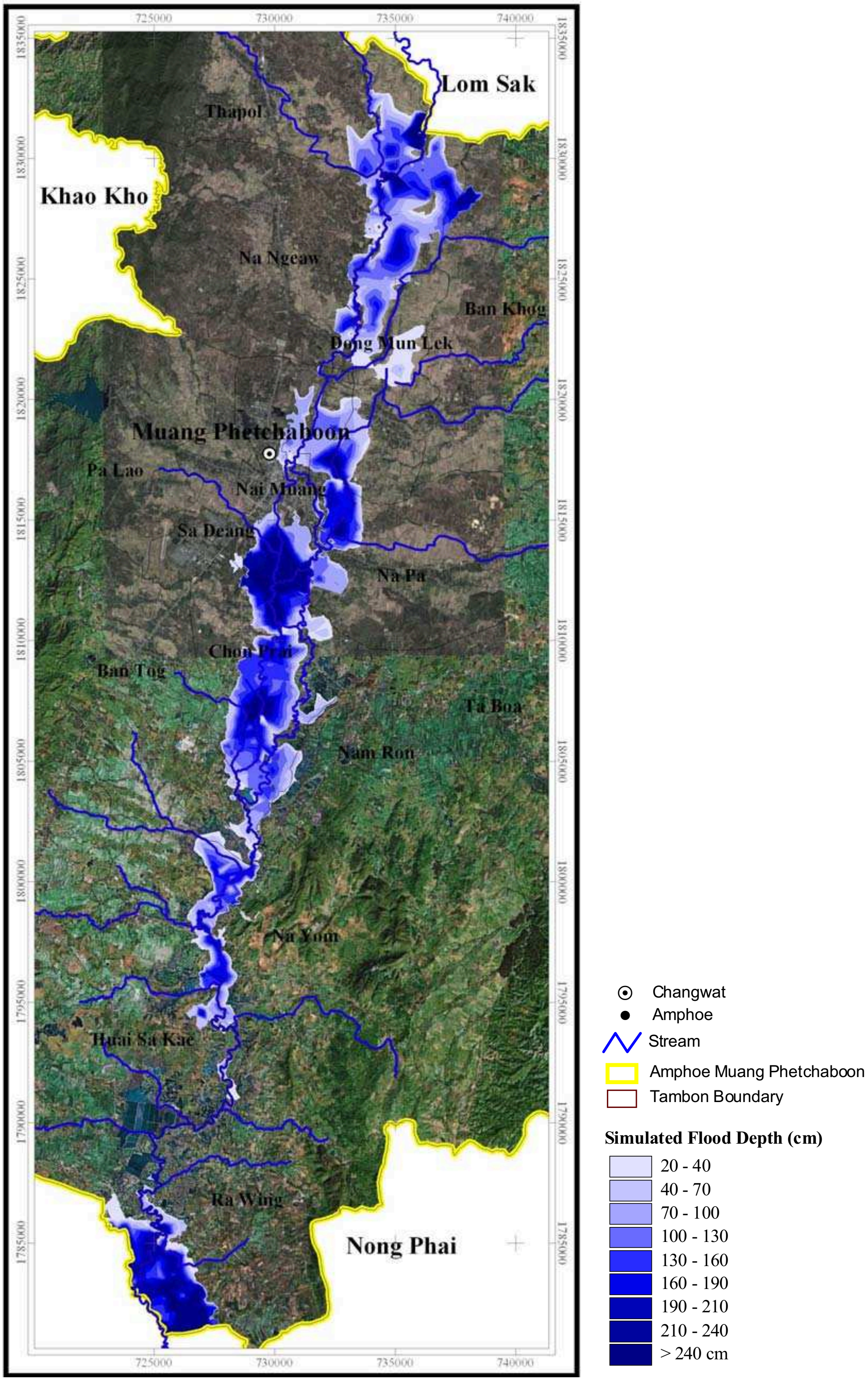


Figure 5.2-2 Map of Simulated Flood Extent of More Than 4 Days Inundated Area (According to 5-Year Return Period of Combined Maximum Flood Scenario)

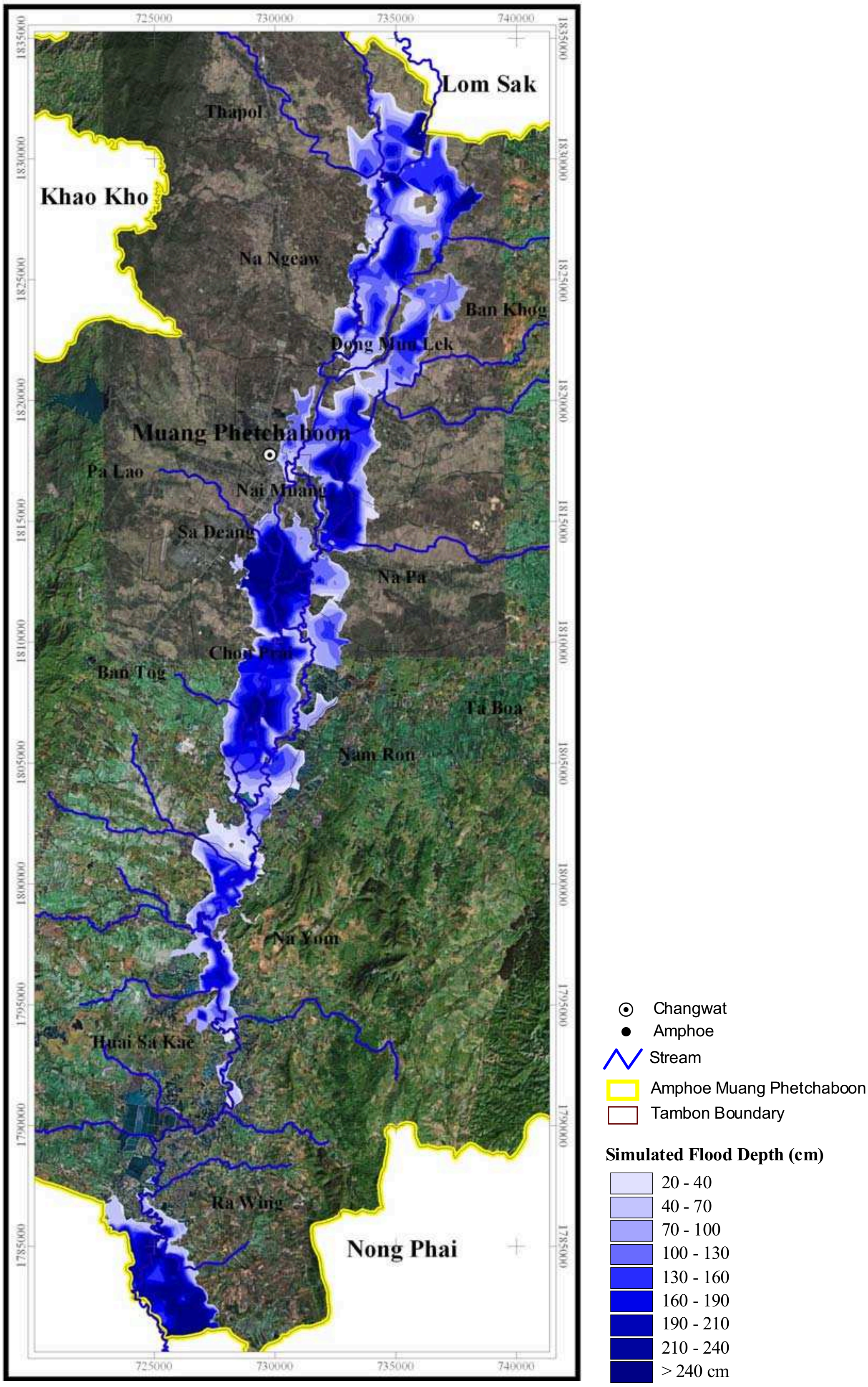


Figure 5.2-3 Map of Simulated Flood Extent of More Than 4 Days Inundated Area (According to 10-Year Return Period of Combined Maximum Flood Scenario)

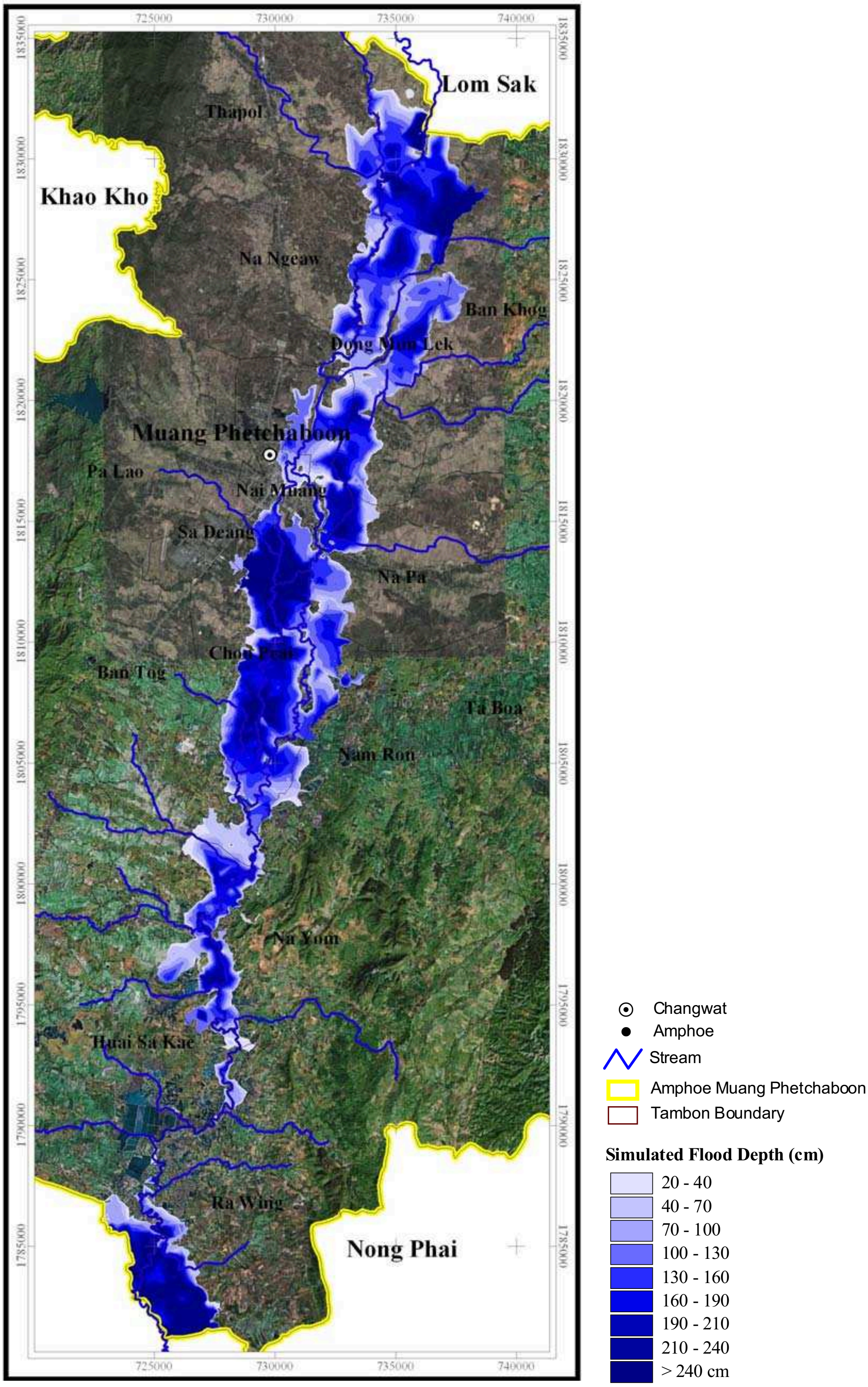


Figure 5.2-4 Map of Simulated Flood Extent of More Than 4 Days Inundated Area (According to 20-Year Return Period of Combined Maximum Flood Scenario)

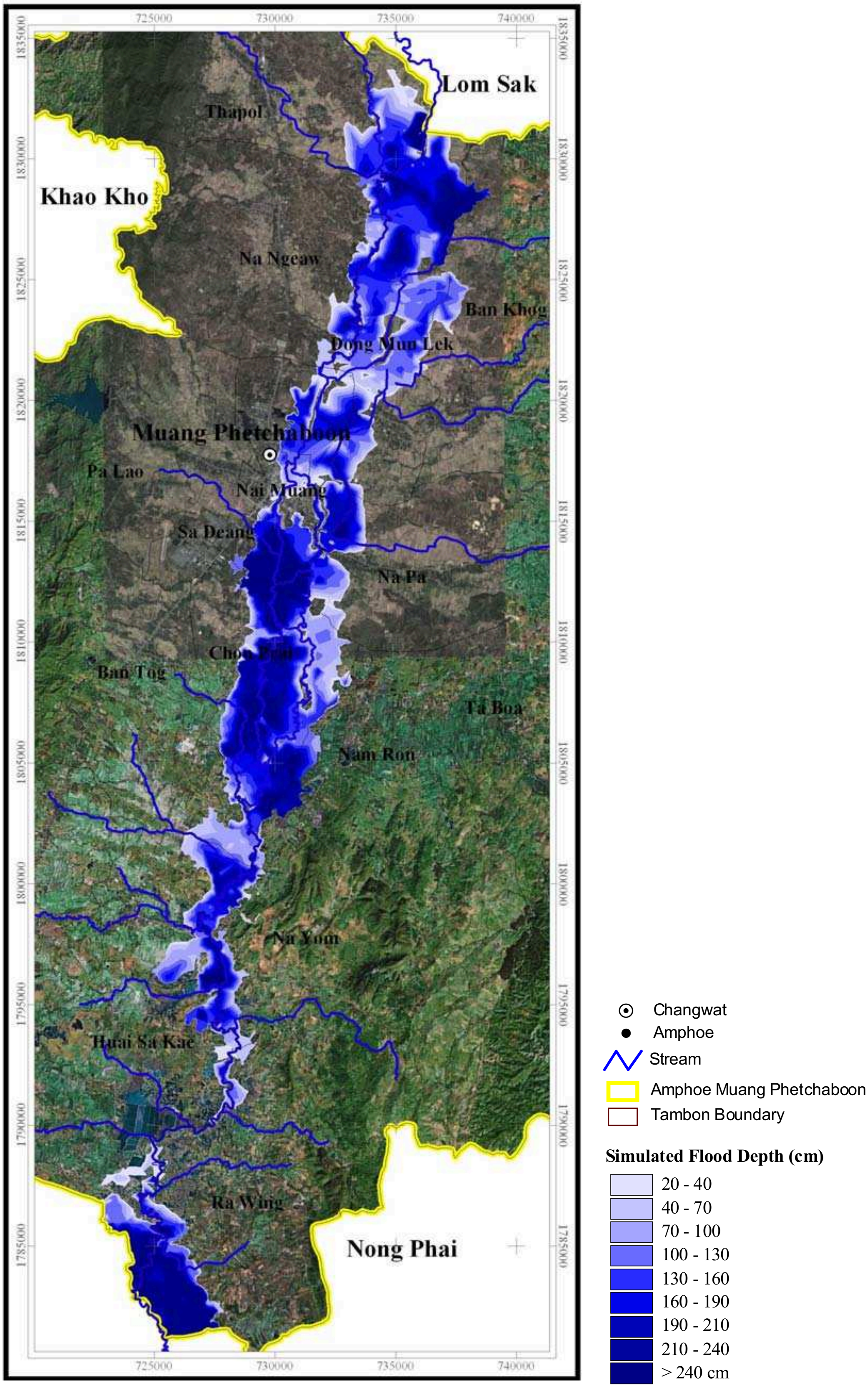


Figure 5.2-5 Map of Simulated Flood Extent of More Than 4 Days Inundated Area (According to 50-Year Return Period of Combined Maximum Flood Scenario)

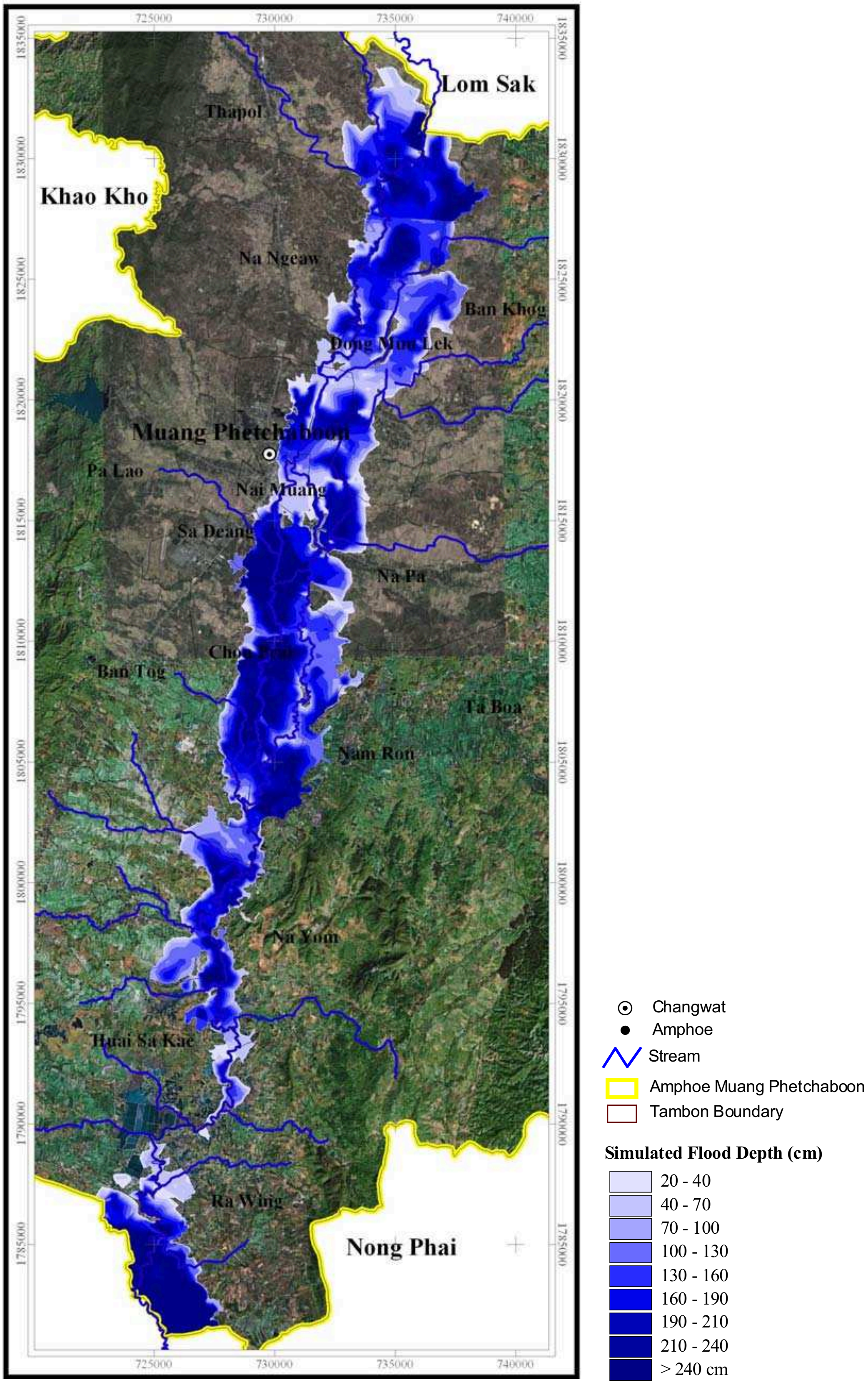


Figure 5.2-6 Map of Simulated Flood Extent of More Than 4 Days Inundated Area (According to 100-Year Return Period of Combined Maximum Flood Scenario)

Table 5.2-1 Statistical Summary of the Flood Mapping Result According to Combined Maximum Flood Scenario for 40-cm Critical Flood Depth

	Item	Return period of Combined Maximum Flood Scenario					
		2 Yrs	5 Yrs	10 Yrs	20 Yrs	50 Yrs	100 Yrs
1.	Maximum Water Level at S.4B (m.AD)	9.31	9.53	9.76	10.09	10.41	11.21
2.	Inundation Area (sq.km) *						
	- Tambol Thapol	5.96	6.49	6.71	7.53	8.26	9.31
	- Tambol Huai Yai	-	-	-	-	-	-
	- Tambol Dong Mun Lek	16.61	19.10	29.08	32.79	31.42	33.22
	- Tambol Ban Khog	0.93	1.03	2.66	3.22	3.27	3.78
	- Tambol Na Ngeaw	2.96	3.53	4.08	4.55	5.53	5.78
	- Tambol Pa Lao	-	-	-	-	-	-
	- Tambol Sa Deang	12.84	13.86	15.24	15.60	16.63	18.25
	- Tambol Nai Muang	0.45	0.74	1.02	1.70	2.31	3.55
	- Tambol Na Pa	4.43	4.96	6.33	7.64	6.24	6.59
	- Tambol Ban Tog	0.44	0.95	1.51	3.22	3.76	3.95
	- Tambol Chon Prai	19.53	21.92	25.43	28.99	29.99	31.05
	- Tambol Ta Boa	-	-	-	-	-	-
	- Tambol Nam Ron	0.67	0.59	0.75	2.00	3.26	4.25
	- Tambol Wang Chomphu	-	-	-	-	-	-
	- Tambol Na Yom	6.48	7.71	9.04	11.39	12.95	14.08
	- Tambol Huai Sa Kae	4.28	4.86	5.99	6.81	7.90	9.27
	- Tambol Ra Wing	9.00	9.68	10.44	10.99	11.95	13.85
	Total	84.57	95.41	118.28	136.42	143.46	156.95
3.	Inundation Depth (cm)						
	- Average Flood Depth	135.36	142.38	146.81	160.35	170.36	177.74
	- Minimum Flood Depth	41	41	41	41	41	41
	- Maximum Flood Depth	554	573	590	615	647	672

* Flood depth is higher than 40 cm.

Table 5.2-2 Statistical Summary of the Flood Mapping Result According to Combined Maximum Flood Scenario for 70-cm Critical Flood Depth

Item		Return Period of Combined Maximum Flood Scenario					
		2 Yrs	5 Yrs	10 Yrs	20 Yrs	50 Yrs	100 Yrs
1.	Maximum Water Level at S.4B (m.AD)	9.31	9.53	9.76	10.09	10.41	11.21
2.	Inundation Area (sq.km) *						
	- Tambol Thapol	4.96	5.43	5.61	6.47	7.09	7.69
	- Tambol Huai Yai	-	-	-	-	-	-
	- Tambol Dong Mun Lek	13.57	15.39	25.06	30.51	28.87	30.63
	- Tambol Ban Khog	0.89	1.03	2.50	2.98	2.97	3.37
	- Tambol Na Ngeaw	2.10	2.48	2.99	3.52	4.26	4.62
	- Tambol Pa Lao	-	-	-	-	-	-
	- Tambol Sa Deang	8.89	12.40	14.21	14.41	15.36	16.40
	- Tambol Nai Muang	0.22	0.34	0.68	0.98	1.52	1.95
	- Tambol Na Pa	4.06	4.58	5.38	6.49	5.31	5.77
	- Tambol Ban Tog	0.10	0.27	0.50	1.24	2.89	3.68
	- Tambol Chon Prai	16.88	18.95	22.46	27.20	28.16	30.04
	- Tambol Ta Boa	-	-	-	-	-	-
	- Tambol Nam Ron	0.46	0.28	0.46	1.33	3.13	4.03
	- Tambol Wang Chomphu	-	-	-	-	-	-
	- Tambol Na Yom	4.82	6.20	7.33	9.50	11.17	12.80
	- Tambol Huai Sa Kae	3.43	3.92	4.77	6.09	6.90	8.02
	- Tambol Ra Wing	8.36	8.89	9.19	10.24	10.98	11.71
	Total	68.74	80.15	101.13	120.98	128.62	140.72
3.	Inundation Depth (cm)						
	- Average Flood Depth	153.51	158.78	162.22	173.60	183.52	191.92
	- Minimum Flood Depth	71	71	71	71	71	71
	- Maximum Flood Depth	554	573	590	615	647	672

* Flood depth is higher than 70 cm.

Table 5.2-3 Statistical Summary of the Flood Mapping Result According to Combined Maximum Flood Scenario for 20-cm Critical Flood Depth

	Item	Return Period of Combined Maximum Flood Scenario					
		2 Yrs	5 Yrs	10 Yrs	20 Yrs	50 Yrs	100 Yrs
1.	Maximum Water Level at S.4B (m.AD)	9.31	9.53	9.76	10.09	10.41	11.21
2.	Inundation Area (sq.km) *						
	- Tambol Thapol	6.70	7.19	7.39	8.29	9.40	10.27
	- Tambol Huai Yai	-	-	-	-	-	-
	- Tambol Dong Mun Lek	18.44	22.92	30.49	33.40	32.69	34.40
	- Tambol Ban Khog	0.93	1.03	2.67	3.24	3.53	4.09
	- Tambol Na Ngeaw	3.68	4.10	4.52	4.96	6.03	6.36
	- Tambol Pa Lao	-	-	-	-	-	-
	- Tambol Sa Deang	13.89	14.62	15.79	16.55	17.82	19.33
	- Tambol Nai Muang	0.68	0.98	1.43	2.17	2.79	4.12
	- Tambol Na Pa	4.62	5.17	6.98	7.89	6.85	7.35
	- Tambol Ban Tog	1.01	1.70	3.15	3.70	3.95	4.11
	- Tambol Chon Prai	21.39	23.41	26.36	29.51	30.61	31.46
	- Tambol Ta Boa	-	-	-	-	-	-
	- Tambol Nam Ron	0.75	0.89	1.16	2.37	3.34	4.32
	- Tambol Wang Chomphu	-	-	-	-	-	-
	- Tambol Na Yom	7.43	8.53	9.80	12.45	13.44	14.51
	- Tambol Huai Sa Kae	4.64	5.80	6.52	7.45	9.43	10.55
	- Tambol Ra Wing	9.69	10.45	10.77	11.54	12.42	14.89
	Total	93.86	106.79	127.03	143.52	152.30	165.76
3.	Inundation Depth (cm)						
	- Average Flood Depth	124.97	130.48	138.81	153.93	162.24	169.94
	- Minimum Flood Depth	21	21	21	21	21	21
	- Maximum Flood Depth	554	573	590	615	647	672

* Flood depth is higher than 20 cm.

Table 5.2-4 Statistical Summary of the Flood Mapping Result According to Combined Maximum Flood Scenario for 160-cm Critical Flood Depth

	Item	Return Period of Combined Maximum Flood Scenario					
		2 Yrs	5 Yrs	10 Yrs	20 Yrs	50 Yrs	100 Yrs
1.	Maximum Water Level at S.4B (m.AD)	9.31	9.53	9.76	10.09	10.41	11.21
2.	Inundation Area (sq.km) *						
	- Tambol Thapol	1.01	1.27	1.40	1.94	2.75	4.23
	- Tambol Huai Yai	-	-	-	-	-	-
	- Tambol Dong Mun Lek	2.26	3.35	6.22	13.22	11.77	15.54
	- Tambol Ban Khog	0.39	0.64	0.82	1.47	1.67	1.35
	- Tambol Na Ngeaw	0.32	0.51	0.66	0.90	1.34	1.61
	- Tambol Pa Lao	-	-	-	-	-	-
	- Tambol Sa Deang	4.72	5.89	6.78	7.46	9.44	12.07
	- Tambol Nai Muang	0.13	0.13	0.16	0.25	0.32	0.44
	- Tambol Na Pa	1.46	1.83	2.51	2.85	2.90	3.41
	- Tambol Ban Tog	0.04	0.05	0.06	0.07	0.09	0.16
	- Tambol Chon Prai	4.45	6.26	9.86	14.29	17.63	19.31
	- Tambol Ta Boa	-	-	-	-	-	-
	- Tambol Nam Ron	0.05	0.06	0.07	0.22	1.85	2.34
	- Tambol Wang Chomphu	-	-	-	-	-	-
	- Tambol Na Yom	0.84	1.79	2.85	3.73	5.10	6.42
	- Tambol Huai Sa Kae	1.80	2.20	2.75	3.19	3.84	5.04
	- Tambol Ra Wing	5.98	6.88	7.40	8.11	8.61	9.29
	Total	23.45	30.87	41.54	57.69	67.30	81.21
3.	Inundation Depth (cm)						
	- Average Flood Depth	231.98	232.63	232.79	236.31	244.50	244.56
	- Minimum Flood Depth	161	161	161	161	161	161
	- Maximum Flood Depth	554	573	590	615	647	672

* Flood depth is higher than 160 cm.

Note that Figures 5.2-1 to 5.2-6 provide an overview of inundation patterns of the study area at different probabilities of occurrence while Tables 5.2.1 to 5.2.4 give details on flood depth and inundation area at different return period ofeach Tumbol. To be more practical, the study area should be separated into different flood risk levels, so call "*flood hazard zoning map*". Since the critical flood depth of rice crop growing is varied during the crop cycle (see Table 5.1.1), therefore to accommodate this fact, the flood hazard zoning maps should be produced for different time windows during the critical flooding months. Details of how these maps are generated will be presented in the next section.

5.2.2 Flood Hazard Zone Mapping

For ease of use, flood hazard map should be divided into different distinctly risk zones. The suitable criteria for defining different flood hazard zones of the study area needed to be investigated. This was performed by overlaying the simulated flood maps at the 2-, 5-, 10-, 20-, 50- and 100- year returned periods (Figures 5.2-1 to 5.2-4) of each critical flood depth as the overlapped results are shown in **Figures 5.2.7 to 5.2.10**. From these figures we have found that flood extents generated from 2-year combined maximum flood scenarios are separated from flood extents generated from other flood scenarios. The differences between flood extents generated from the 10- to 100-year return periods are very small. Based on these results, we divide flood hazard zones of the Muang Phetchaboon district into 4 zones as presented in **Table 5.2-5.**

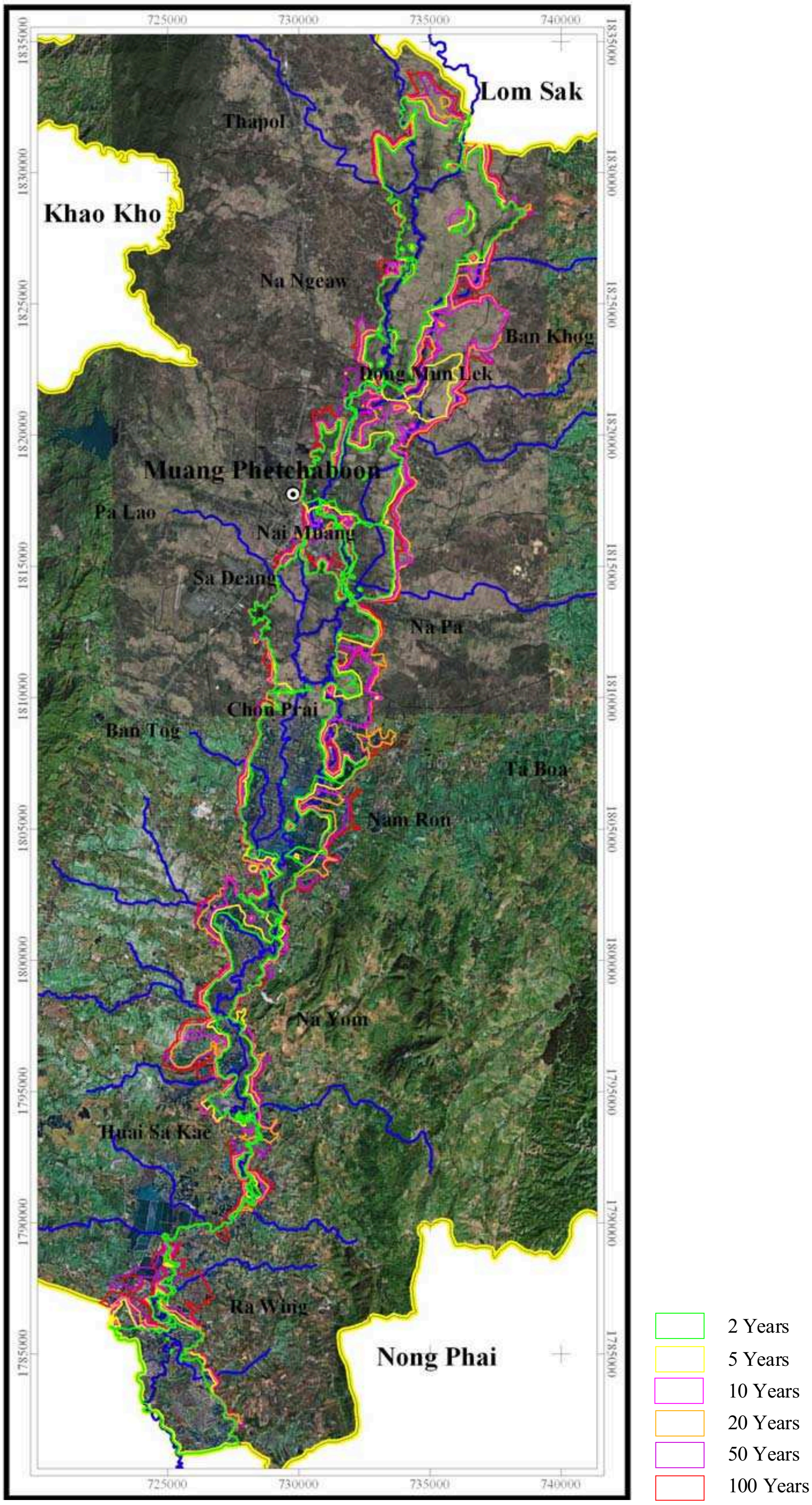


Figure 5.2-7 Flood Extent According to Combined Maximum Flood Scenarios With 20-cm Critical Flood Depth

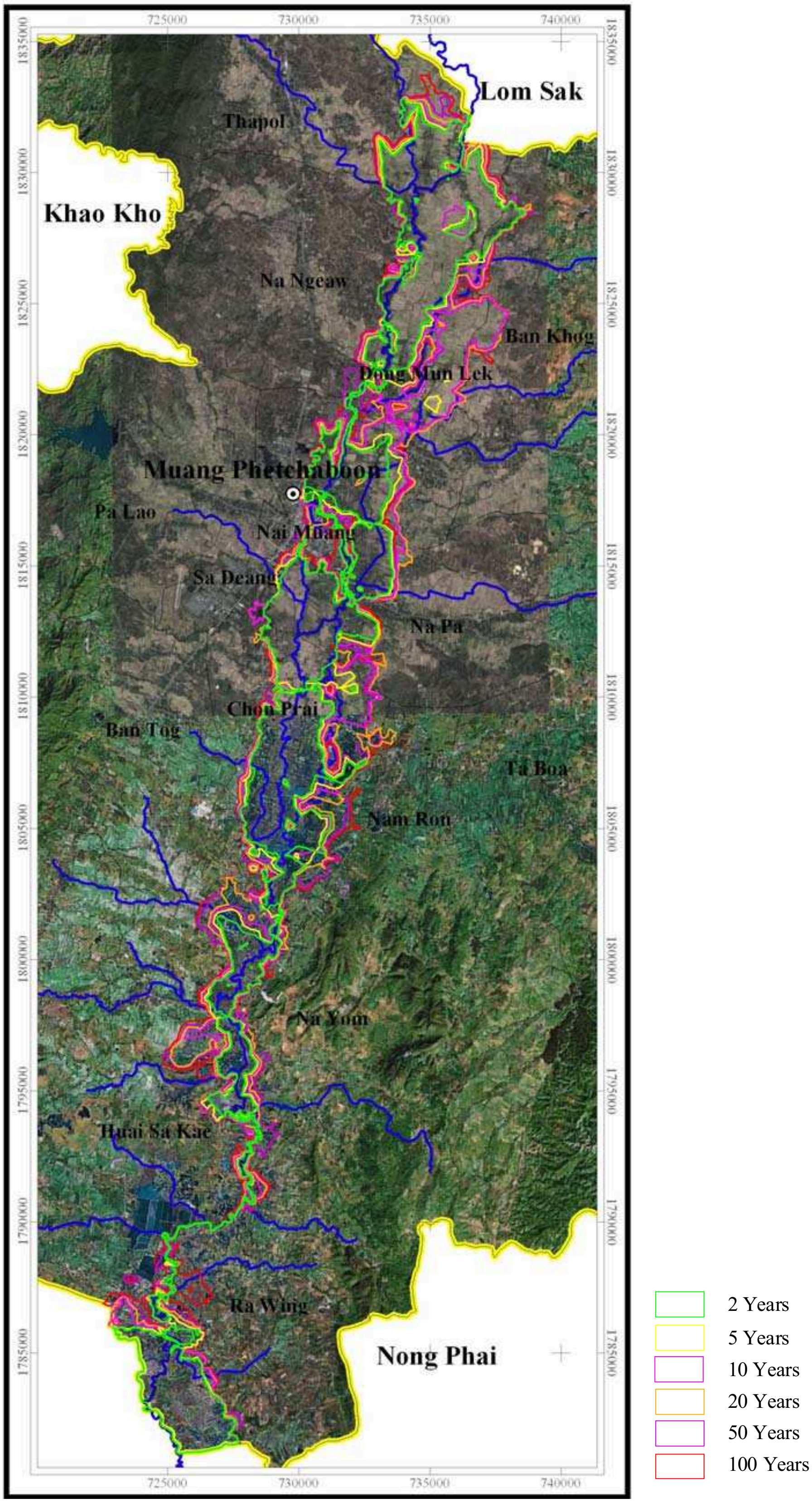


Figure 5.2-8 Flood Extent According to Combined Maximum Flood Scenarios With 40-cm Critical Flood Depth

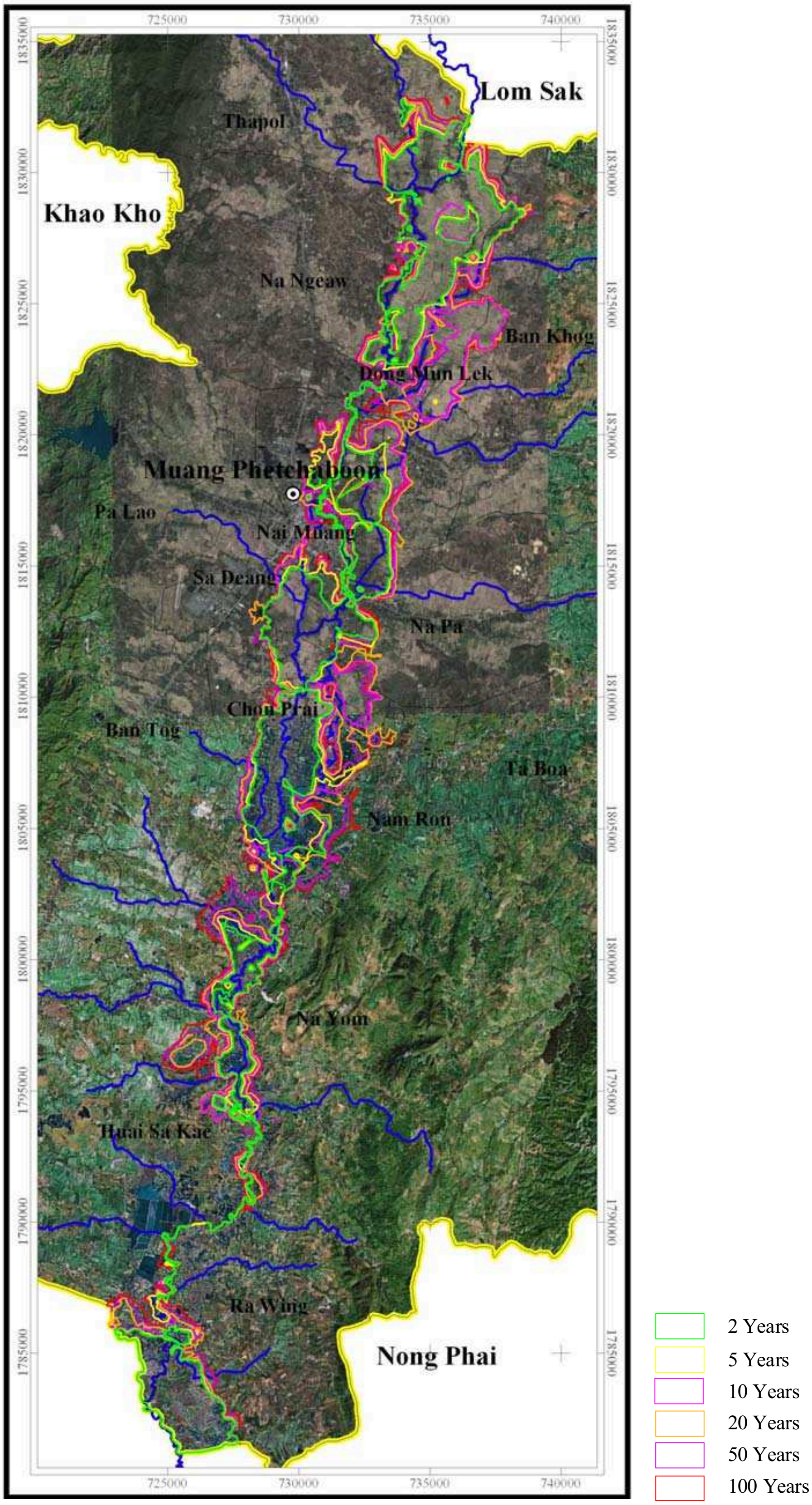


Figure 5.2-9 Flood Extent According to Combined Maximum Flood Scenarios With 70-cm Critical Flood Depth

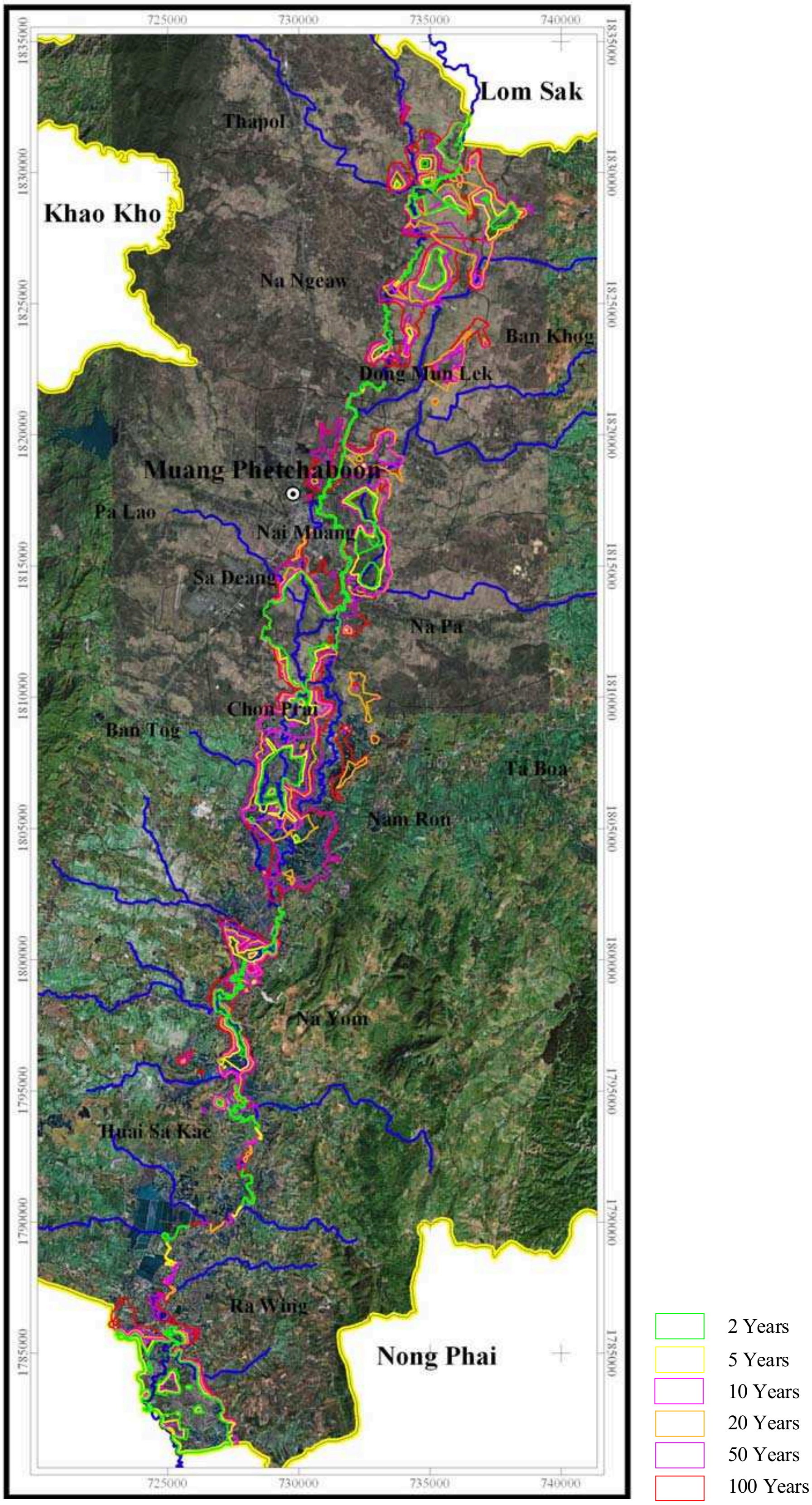


Figure 5.2-10 Flood Extent According to Combined Maximum Flood Scenarios With 160-cm Critical Flood Depth

Table 5.2-5 Criteria for Production of Flood Hazard Zone Map

Zone	Inundation area	Categories of hazard zones
1	Within 2-year return period	Very high risk
2	Between 2- and 10- year return period	High risk
3	Between 10- and 100- year return period	Moderate risk
4	Outsize 100-year return period	Low risk

The above criteria were used to develop flood hazard zone maps for different critical flood loss criteria as illustrated in **Figures 5.2-11 and 5.2-14**, respectively.

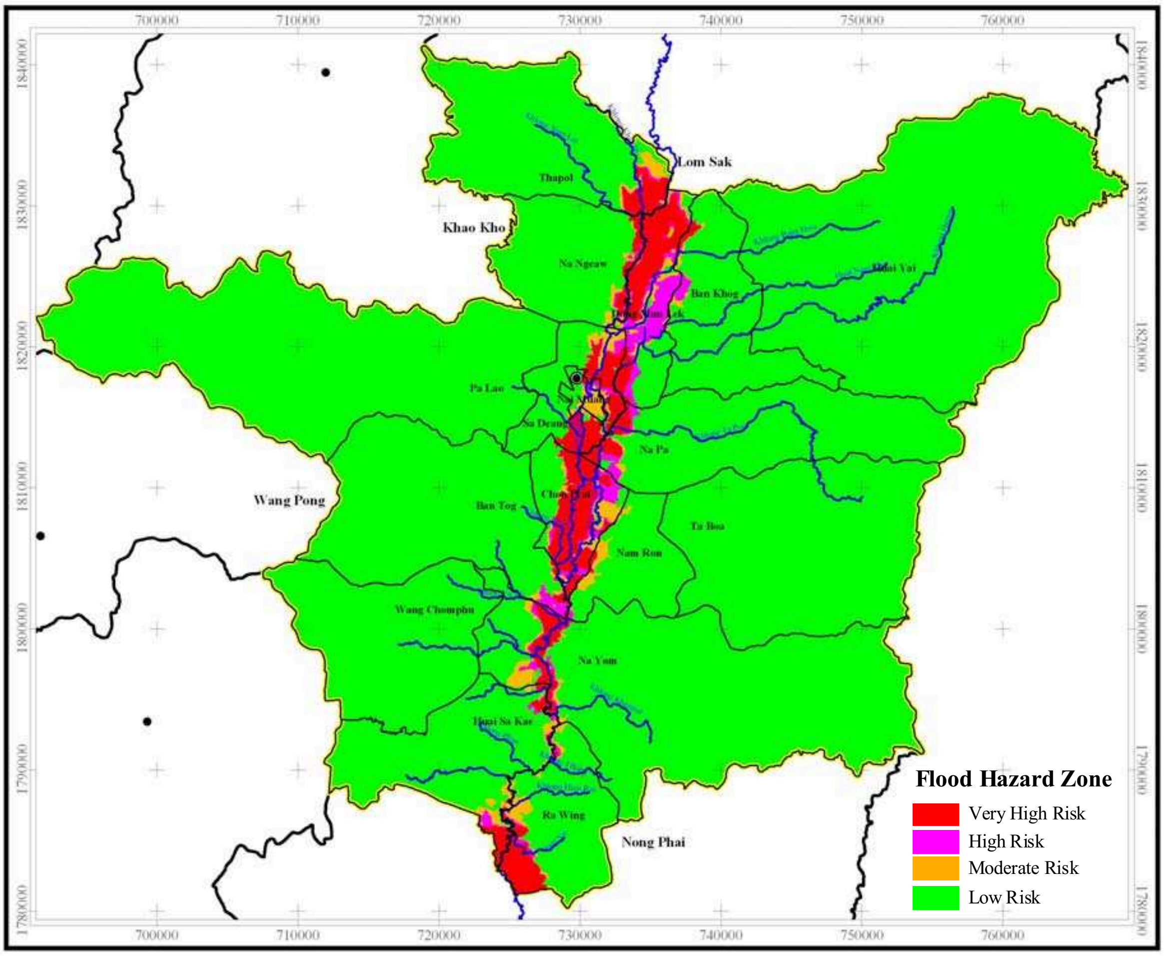


Figure 5.2-11 Flood Hazard Zone Map for Critical Flood Depth Greater than 40 cm. (August)

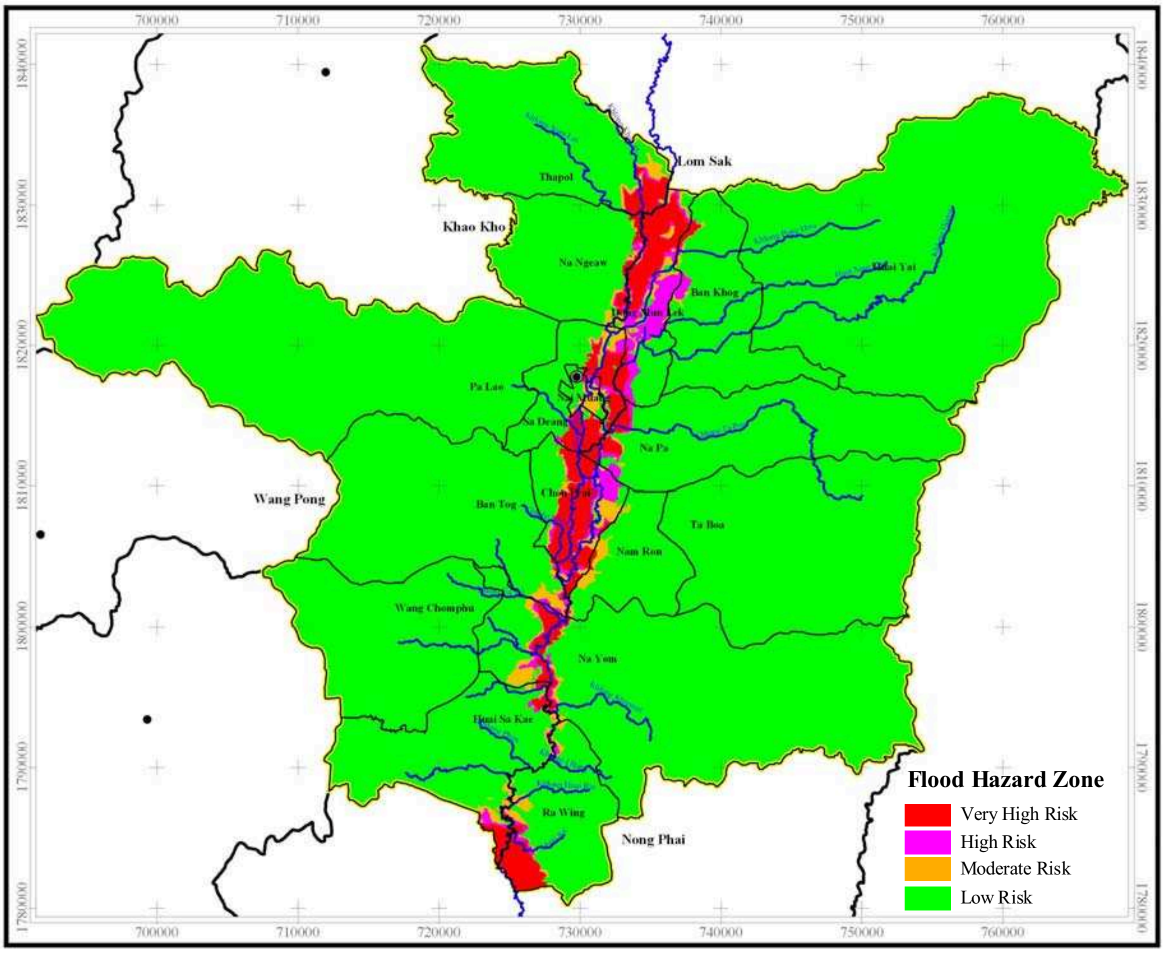


Figure 5.2-12 Flood Hazard Zone Map for Critical Flood Depth Greater than 70 cm. (1st , 2nd Week of September)

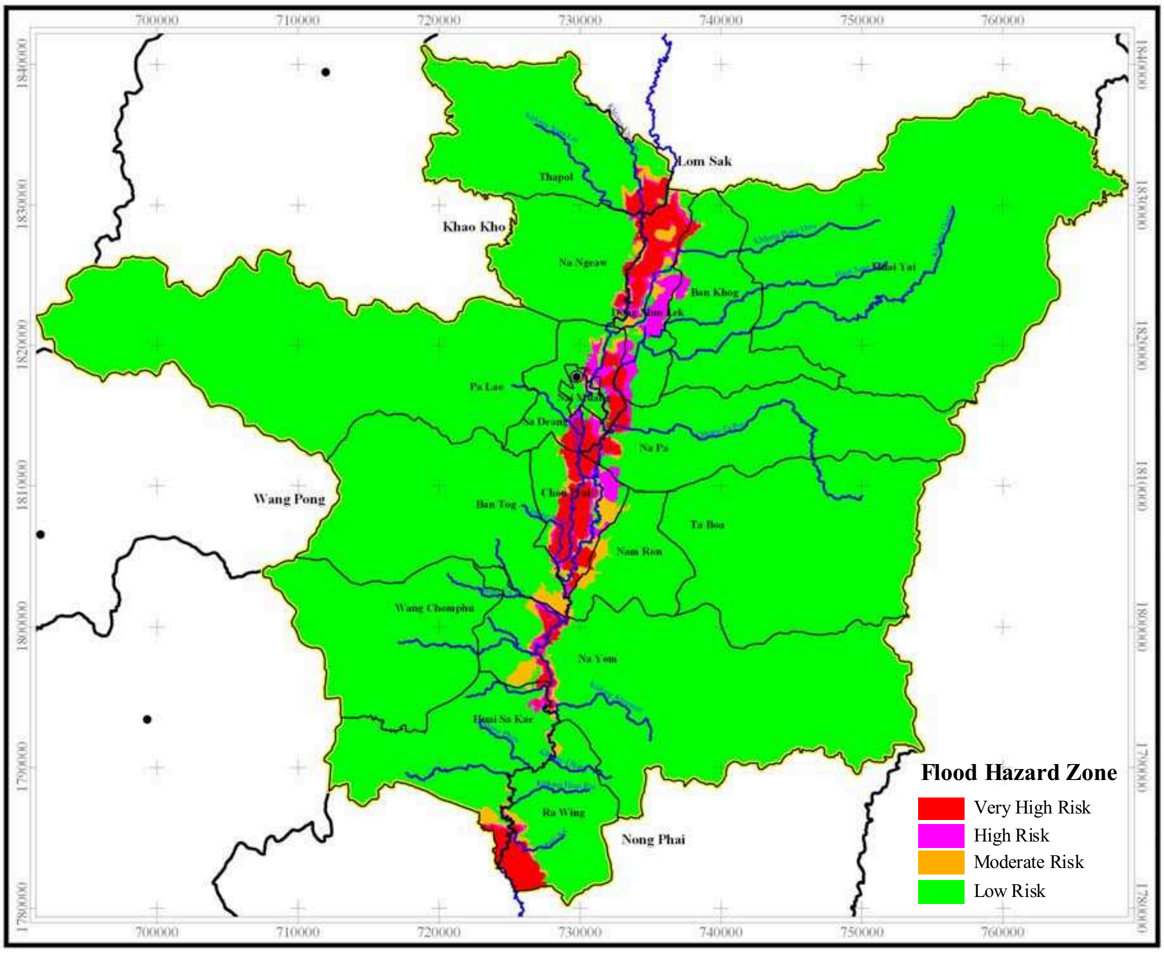


Figure 5.2-13 Flood Hazard Zone Map for Critical Flood Depth Greater than 20 cm. (3rd and 4th Week of September)

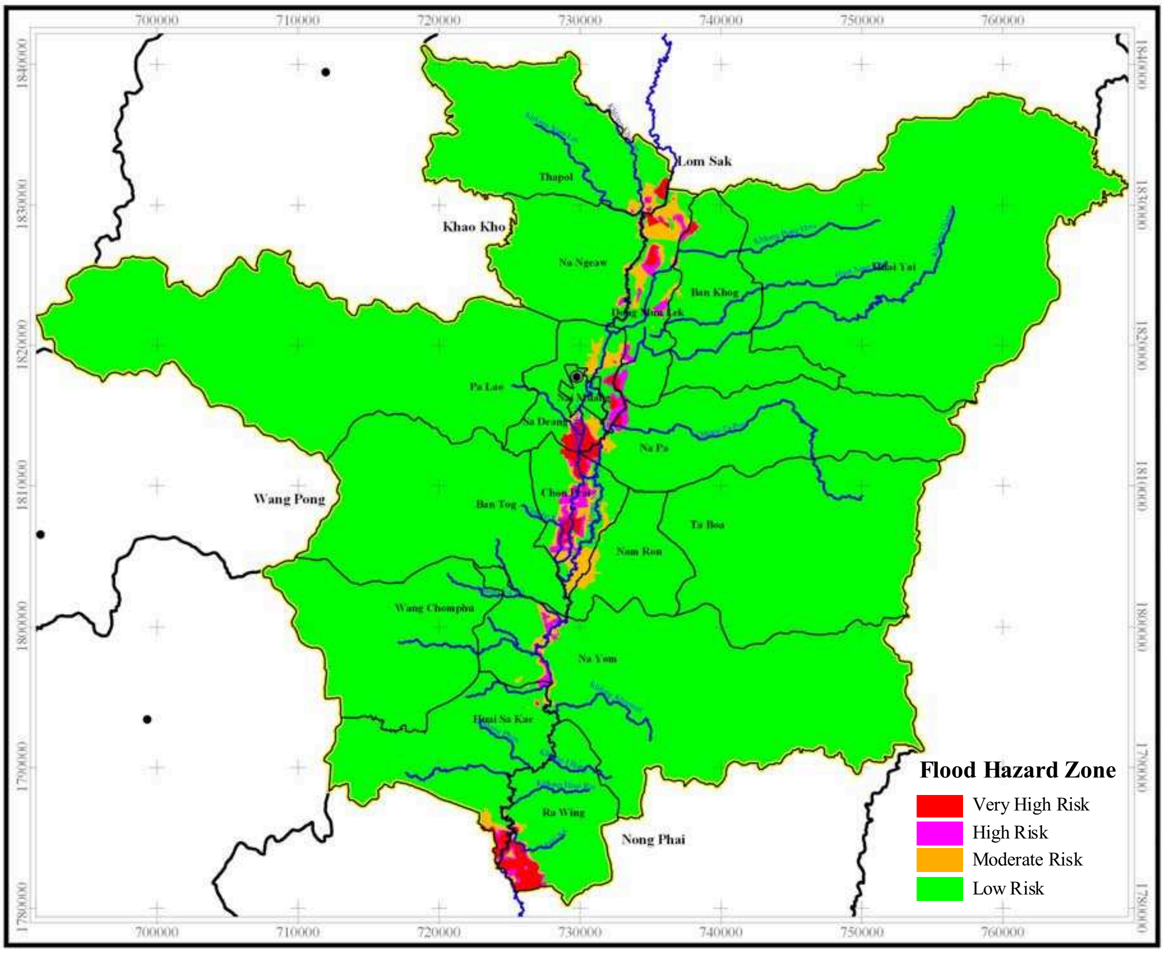


Figure 5.2-14 Flood Hazard Zone Map for Critical Flood Depth Greater than 160 cm. (October and November)

Details of flood risk assessment of each Tumbon of the Muang Phetchaboon district at different critical flood depths according to combined maximum flood scenarios were summarized in **Tables 5.2-6 to 5.2-9**, respectively. The results presented in Figures 5.2-11 and 5.2-14 and Tables 5.2-6 and 5.2-9 indicate that the flood hazard zones are varied during the critical months which are depending on the rice growth stage and hydrological condition of each period. This information can be used as indicator for evaluating insurance premium and rice crop failure claming of each area.

Table 5.2-6 Details of Flood Risk Area Corresponding to 40-cm Critical Flood Depth

Item		Flood Hazard Level				Total Area
		Very High	High	Moderate	Low	
1	Probability of Flooding	≥ 50%	49% - 10%	10% - 1%	<1%	
2	Water Level Index at S.4B (m.AD)	9.31	9.31 – 9.76	9.76 – 11.21	> 11.21	
3	Flood Hazard Zone Area (sq.km)					
	- Tambol Thapol	5.96	0.75	2.60	121.74	131.05
	- Tambol Huai Yai	0.00	0.00	0.00	379.04	379.04
	- Tambol Dong Mun Lek	16.61	12.47	4.14	14.10	47.32
	- Tambol Ban Khog	0.93	1.74	1.12	80.20	83.98
	- Tambol Na Ngeaw	2.96	1.11	1.70	70.66	76.44
	- Tambol Pa Lao	0.00	0.00	0.00	306.01	306.01
	- Tambol Sa Deang	12.84	2.40	3.02	27.17	45.42
	- Tambol Nai Muang	0.45	0.56	2.53	3.82	7.37
	- Tambol Na Pa	4.43	1.91	0.25	128.21	134.8
	- Tambol Ban Tog	0.44	1.08	2.44	153.63	157.58
	- Tambol Chon Prai	19.53	5.90	5.63	13.01	44.06
	- Tambol Ta Boa	0.00	0.00	0.00	197.61	197.61
	- Tambol Nam Ron	0.67	0.08	3.50	43.45	47.7
	- Tambol Wang Chomphu	0.00	0.00	0.00	129.56	129.56
	- Tambol Na Yom	6.48	2.55	5.05	276.10	290.18
	- Tambol Huai Sa Kae	4.28	1.71	3.28	93.71	102.98
	- Tambol Ra Wing	9.00	1.45	3.41	57.05	70.9
	Total Area	84.57	33.71	38.67	2095.05	2252

Table 5.2-7 Details of Flood Risk Area Corresponding to 70-cm Critical Flood Depth

Item		Flood Hazard Level				Total Area
		Very High	High	Moderate	Low	
1	Probability of Flooding	≥ 50%	49% - 10%	10% - 1%	<1%	
2	Water Level Index at S.4B (m.AD)	9.31	9.31 – 9.76	9.76 – 11.21	> 11.21	
3	Flood Hazard Zone Area (sq.km)					
	- Tambol Thapol	4.96	0.64	2.08	123.36	131.05
	- Tambol Huai Yai	-	-	-	379.04	379.04
	- Tambol Dong Mun Lek	13.57	11.50	5.56	16.69	47.32
	- Tambol Ban Khog	0.89	1.61	0.87	80.61	83.98
	- Tambol Na Ngeaw	2.10	0.89	1.63	71.82	76.44
	- Tambol Pa Lao	-	-	-	306.01	306.01
	- Tambol Sa Deang	8.89	5.32	2.19	29.02	45.42
	- Tambol Nai Muang	0.22	0.46	1.27	5.42	7.37
	- Tambol Na Pa	4.06	1.32	0.39	129.03	134.8
	- Tambol Ban Tog	0.10	0.40	3.18	153.90	157.58
	- Tambol Chon Prai	16.88	5.58	7.58	14.02	44.06
	- Tambol Ta Boa	-	-	-	197.61	197.61
	- Tambol Nam Ron	0.46	-0.01	3.58	43.67	47.7
	- Tambol Wang Chomphu	-	-	-	129.56	129.56
	- Tambol Na Yom	4.82	2.51	5.47	277.38	290.18
	- Tambol Huai Sa Kae	3.43	1.34	3.25	94.96	102.98
	- Tambol Ra Wing	8.36	0.83	2.53	59.19	70.9
	Total Area	68.74	32.38	39.59	2111.28	2252

Table 5.2-8 Details of Flood Risk Area Corresponding to 20-cm Critical Flood Depth

Item		Flood Hazard Level				Total
		Very High	High	Moderate	Low	Area
1	Probability of Flooding	≥ 50%	49% - 10%	10% - 1%	<1%	
2	Water Level Index at S.4B (m.AD)	9.31	9.31 – 9.76	9.76 – 11.21	> 11.21	
3	Flood Hazard Zone Area (sq.km)					
	- Tambol Thapol	6.70	0.70	2.88	120.78	131.05
	- Tambol Huai Yai	-	-	-	379.04	379.04
	- Tambol Dong Mun Lek	18.44	12.04	3.92	12.92	47.32
	- Tambol Ban Khog	0.93	1.73	1.42	79.89	83.98
	- Tambol Na Ngeaw	3.68	0.84	1.83	70.08	76.44
	- Tambol Pa Lao	-	-	-	306.01	306.01
	- Tambol Sa Deang	13.89	1.89	3.54	26.09	45.42
	- Tambol Nai Muang	0.68	0.75	2.69	3.25	7.37
	- Tambol Na Pa	4.62	2.36	0.38	127.45	134.8
	- Tambol Ban Tog	1.01	2.14	0.96	153.47	157.58
	- Tambol Chon Prai	21.39	4.97	5.10	12.60	44.06
	- Tambol Ta Boa	-	-	-	197.61	197.61
	- Tambol Nam Ron	0.75	0.41	3.16	43.38	47.7
	- Tambol Wang Chomphu	-	-	-	129.56	129.56
	- Tambol Na Yom	7.43	2.37	4.71	275.67	290.18
	- Tambol Huai Sa Kae	4.64	1.88	4.03	92.43	102.98
	- Tambol Ra Wing	9.69	1.08	4.12	56.01	70.9
	Total Area	93.86	33.17	38.73	2086.24	2252

Table 5.2-9 Details of Flood Risk Area Corresponding to 160-cm Critical Flood Depth

Item		Flood Hazard Level				Total Area
		Very High	High	Moderate	Low	
1	Probability of Flooding	≥ 50%	49% - 10%	10% - 1%	<1%	
2	Water Level Index at S.4B (m.AD)	9.31	9.31 – 9.76	9.76 – 11.21	> 11.21	
3	Flood Hazard Zone Area (sq.km)					
	- Tambol Thapol	1.01	0.39	2.82	126.82	131.05
	- Tambol Huai Yai	-	-	-	379.04	379.04
	- Tambol Dong Mun Lek	2.26	3.96	9.32	31.78	47.32
	- Tambol Ban Khog	0.39	0.43	0.53	82.63	83.98
	- Tambol Na Ngeaw	0.32	0.34	0.95	74.83	76.44
	- Tambol Pa Lao	-	-	-	306.01	306.01
	- Tambol Sa Deang	4.72	2.06	5.29	33.35	45.42
	- Tambol Nai Muang	0.13	0.03	0.27	6.93	7.37
	- Tambol Na Pa	1.46	1.04	0.90	131.39	134.8
	- Tambol Ban Tog	0.04	0.01	0.10	157.42	157.58
	- Tambol Chon Prai	4.45	5.40	9.45	24.75	44.06
	- Tambol Ta Boa	-	-	-	197.61	197.61
	- Tambol Nam Ron	0.05	0.02	2.27	45.36	47.7
	- Tambol Wang Chomphu	-	-	-	129.56	129.56
	- Tambol Na Yom	0.84	2.01	3.57	283.76	290.18
	- Tambol Huai Sa Kae	1.80	0.95	2.29	97.94	102.98
	- Tambol Ra Wing	5.98	1.42	1.89	61.61	70.9
	Total Area	23.45	18.10	39.66	2170.79	2252

5.3 Production of Weekly Flood Risk Maps

The combined weekly flood scenarios at 50th-, 75th- and 95th- percentile were input to the developed flood model to simulate weekly flood maps. Forty-eight weekly flood extent maps during August to November were simulated (16 weeks multiplied by 3 different percentiles). Note that, inundation area generated from the 50th-, 75th- and 95th- percentile of the combined weekly flood scenarios are considered to be represent high, moderate and low risk zones, respectively. The generated weekly flood maps according to the combined weekly flood scenarios at the three percentiles were superimposed. Thereafter, flood hazard zones of each week were identified based on the proposed critical flood depth and duration criteria as presented in **Table 5.3-1**. **Figures 5.3-1 to 5.3-16** are the simulated weekly flood hazard maps during the 4 critical months.

Table 5.3-1 Criteria for Production of Weekly Flood Risk Management Map

Zone	Inundation area	Categories of hazard zones
1	Within 50th-pecentile	Very high risk
2	Between 50th- and 75th-percentile	High risk
3	Between 75th- and 95th-percentile	Moderate risk
4	Outside 95th-percentile	Low risk

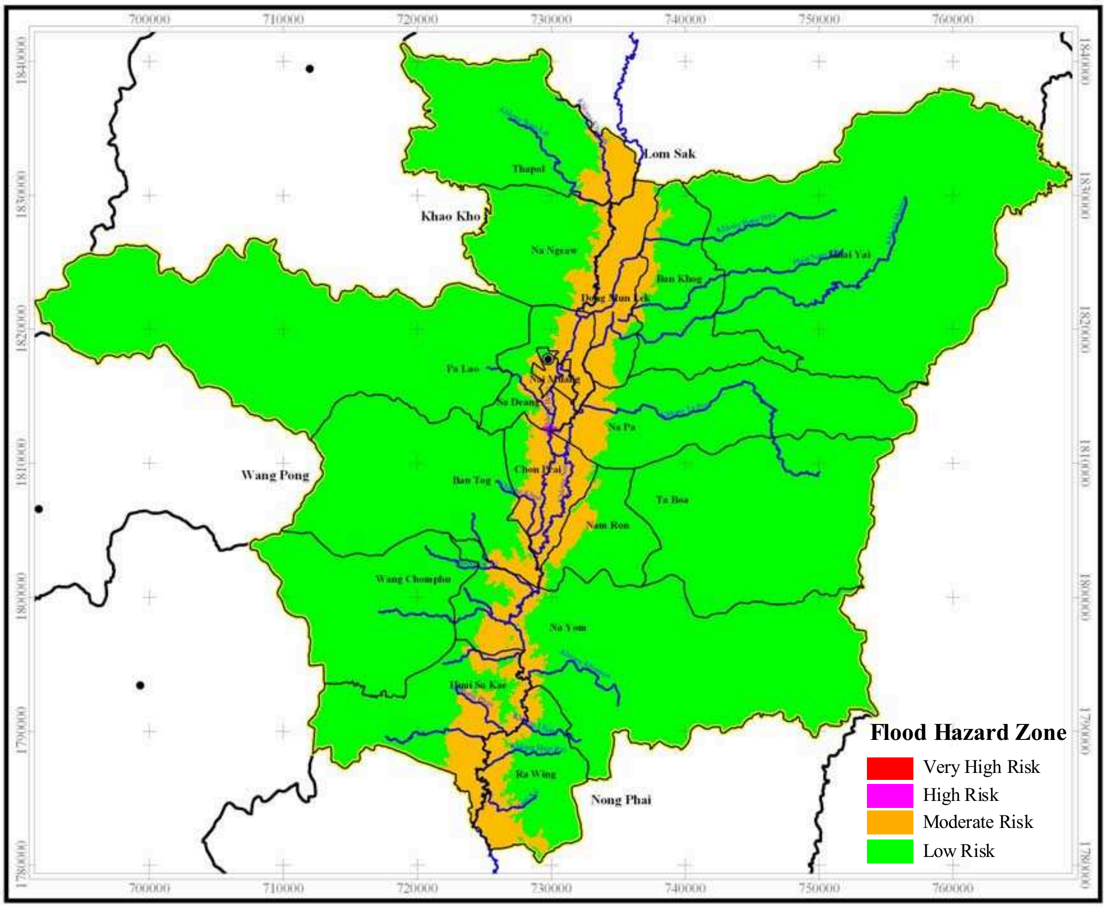


Figure 5.3-1 Flood Hazard Zone Map for 1th Week of August

(Critical Flood Depth ≥ 40 cm with Duration Longer than 4 Days)

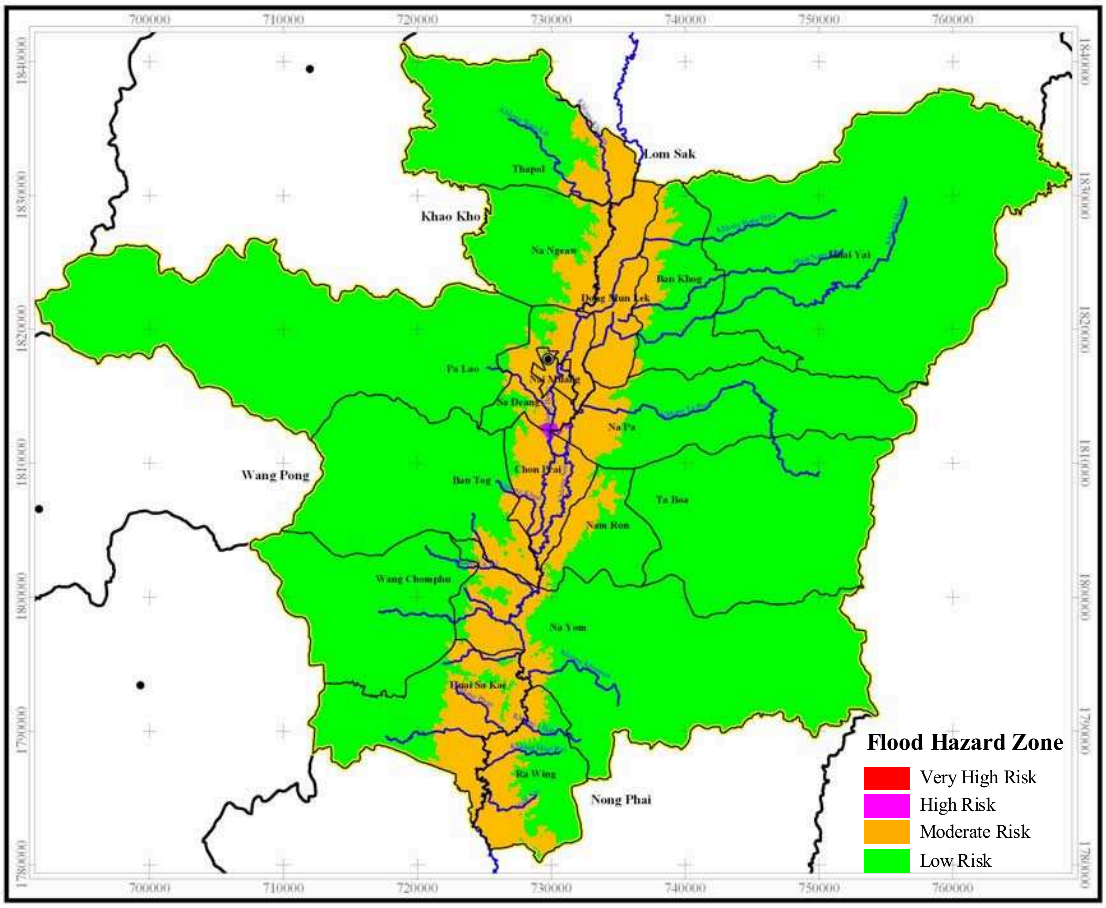


Figure 5.3-2 Flood Hazard Zone Map for 2nd Week of August

(Critical Flood Depth ≥ 40 cm with Duration Longer than 4 Days)

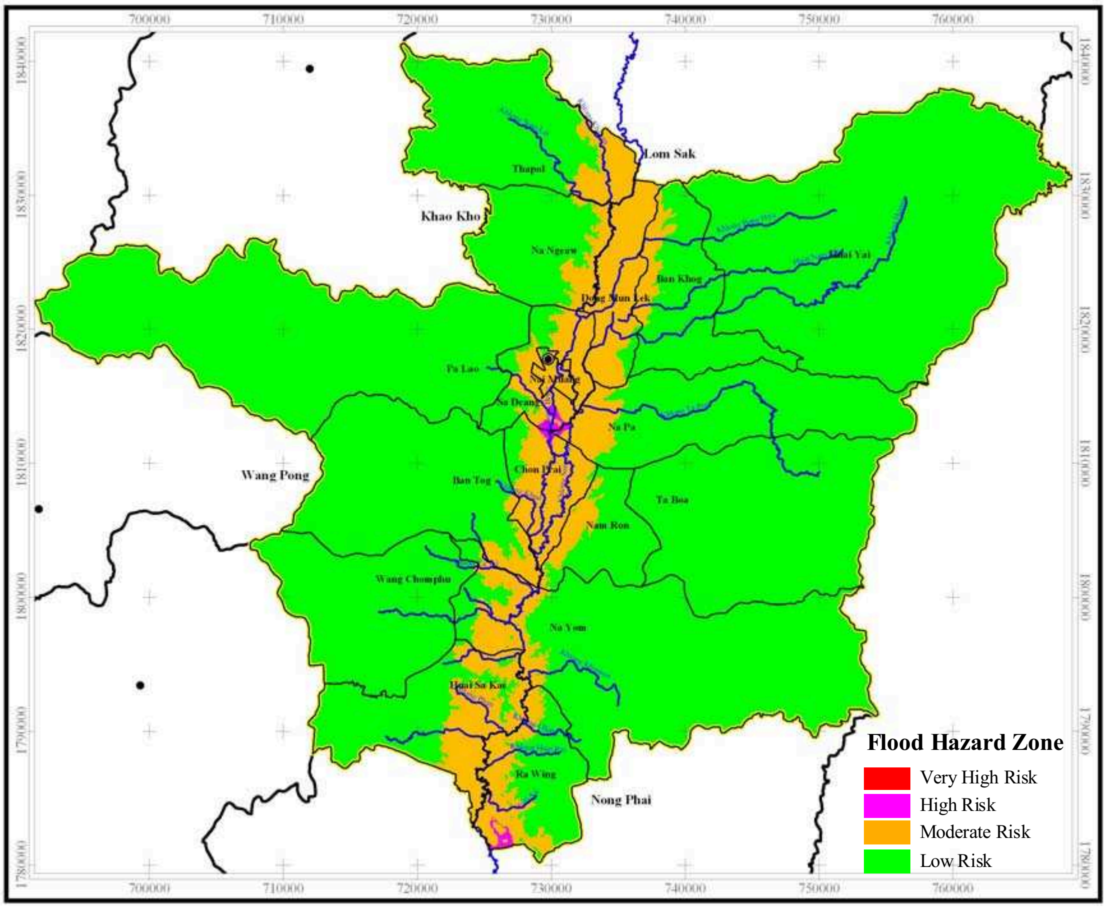


Figure 5.3-3 Flood Hazard Zone Map for 3rd Week of August

(Critical Flood Depth ≥ 40 cm with Duration Longer than 4 Days)

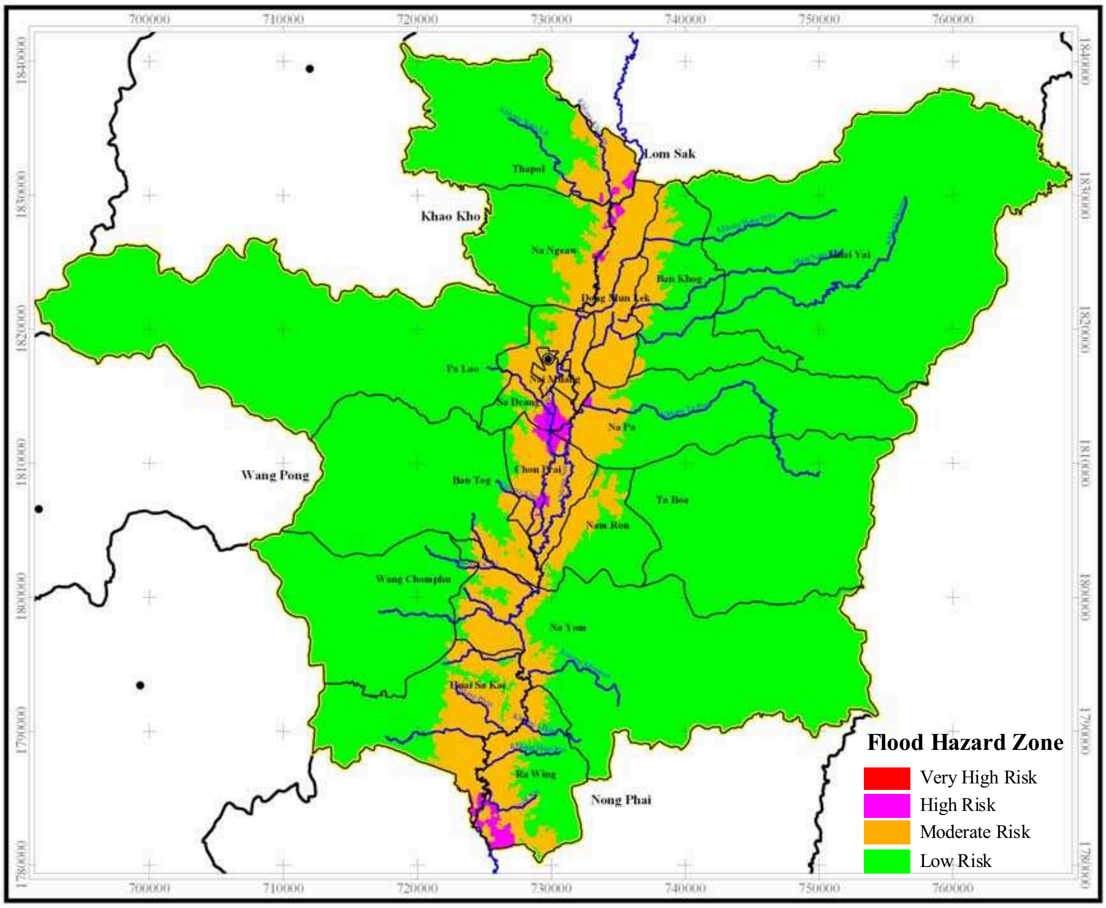


Figure 5.3-4 Flood Hazard Zone Map for 4th Week of August

(Critical Flood Depth ≥ 40 cm with Duration Longer than 4 Days)

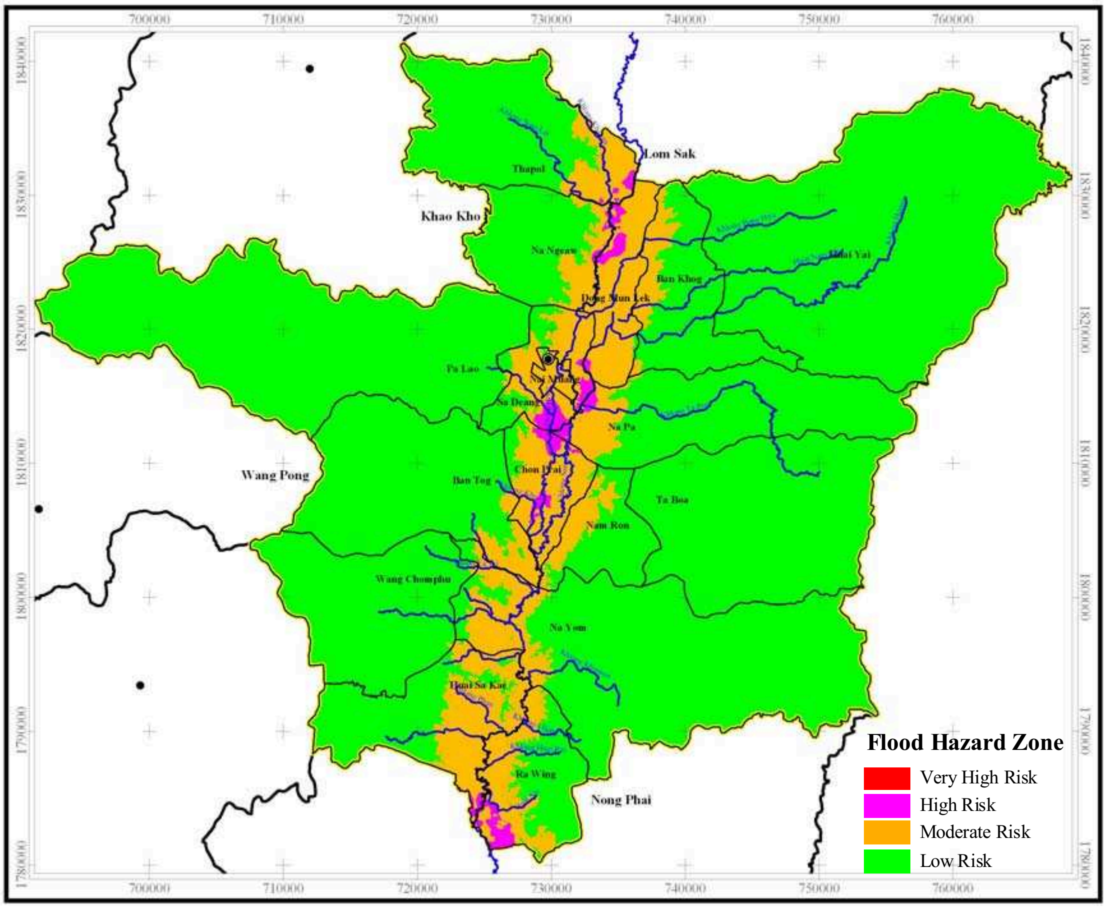


Figure 5.3-5 Flood Hazard Zone Map for 1th Week of September

(Critical Flood Depth ≥ 70 cm with Duration Longer than 4 Days)

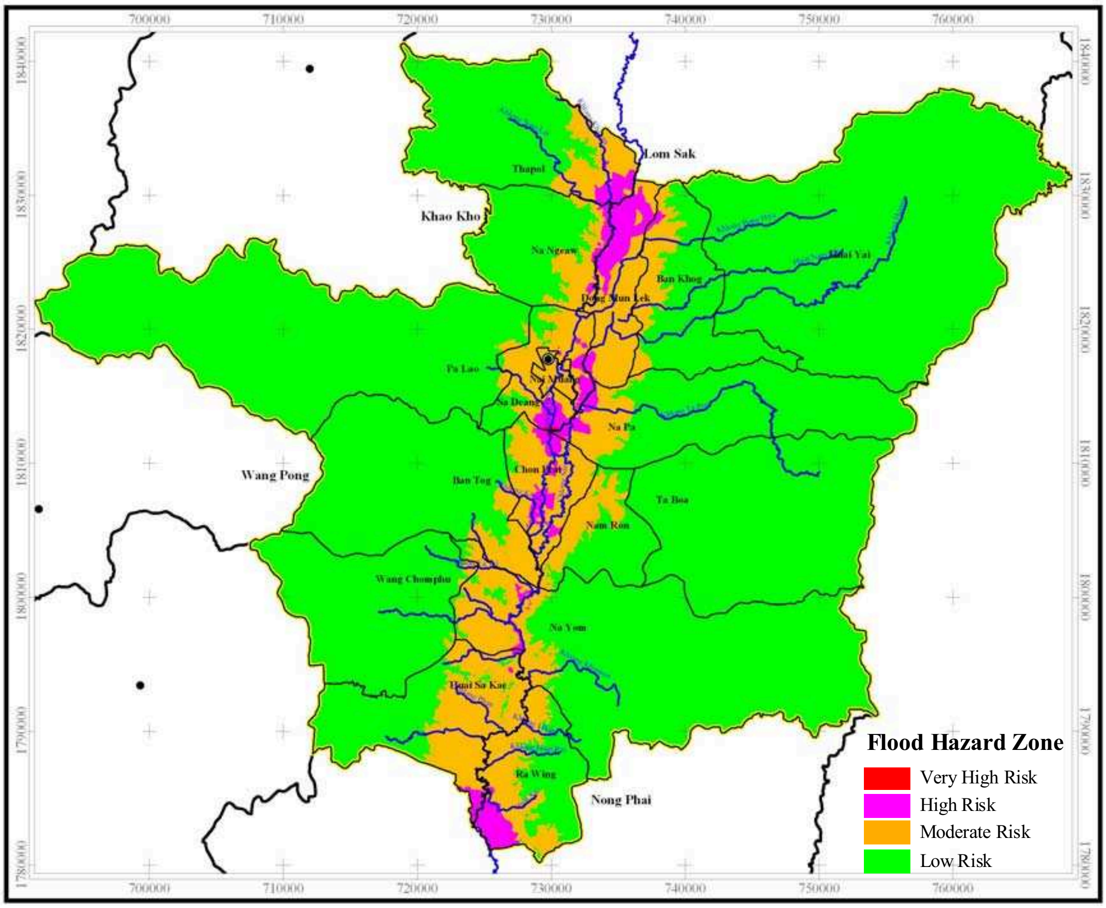


Figure 5.3-6 Flood Hazard Zone Map for 2nd Week of September

(Critical Flood Depth ≥ 70 cm with Duration Longer than 4 Days)

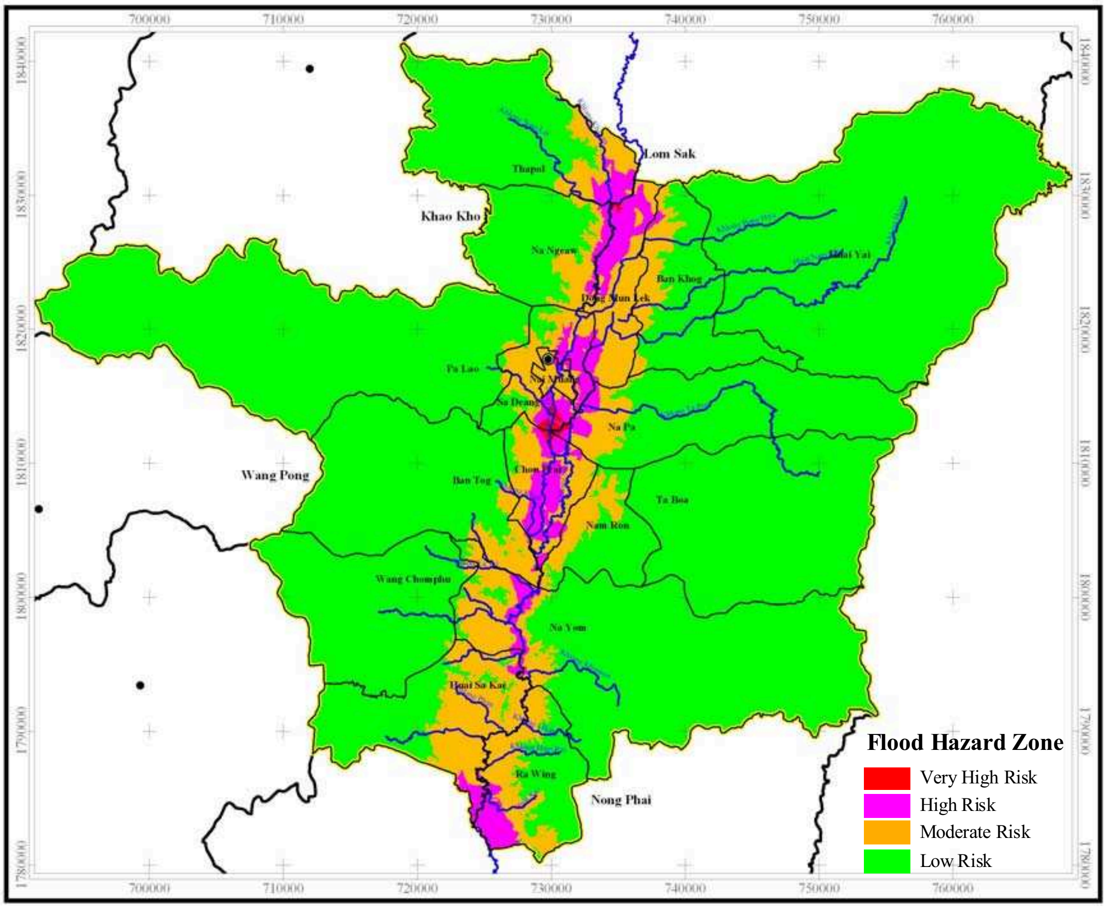


Figure 5.3-7 Flood Hazard Zone Map for 3rd Week of September

(Critical Flood Depth ≥ 20 cm with Duration Longer than 4 Days)

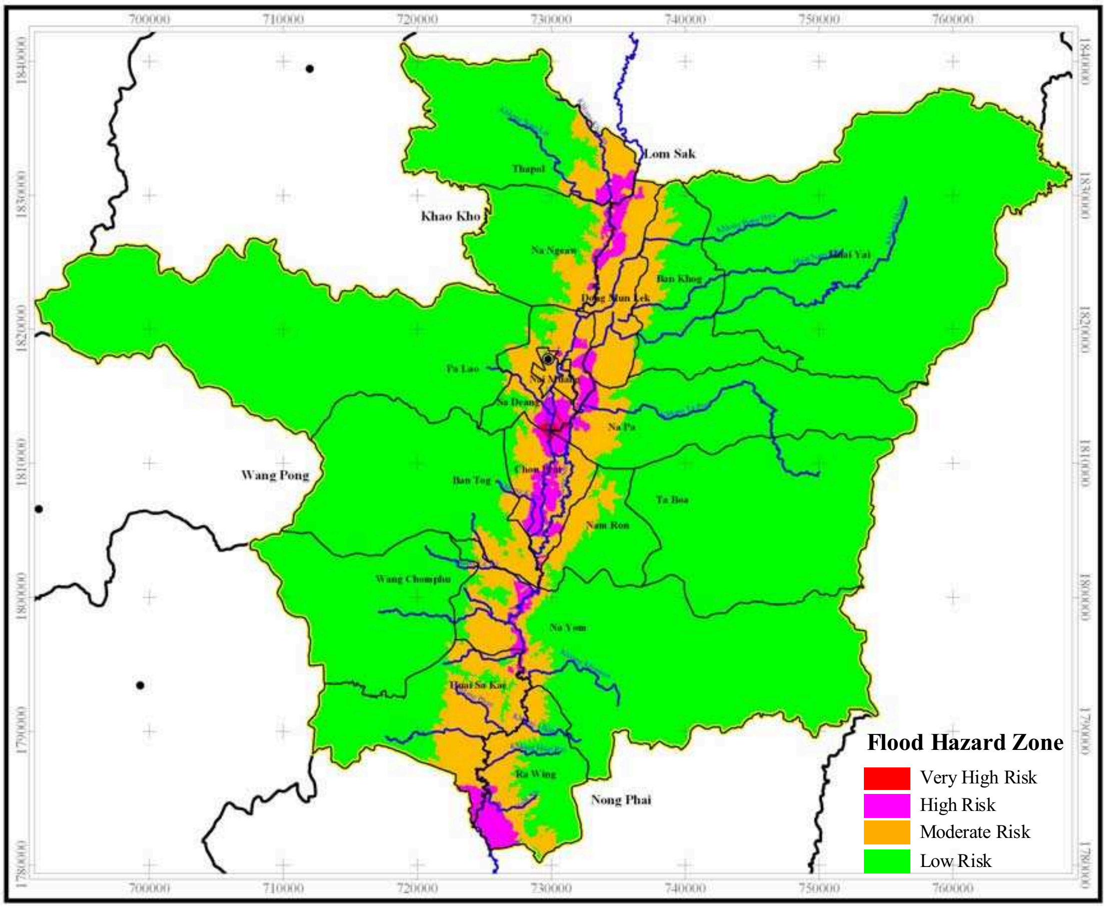


Figure 5.3-8 Flood Hazard Zone Map for 4th Week of September

(Critical Flood Depth ≥ 20 cm with Duration Longer than 4 Days)

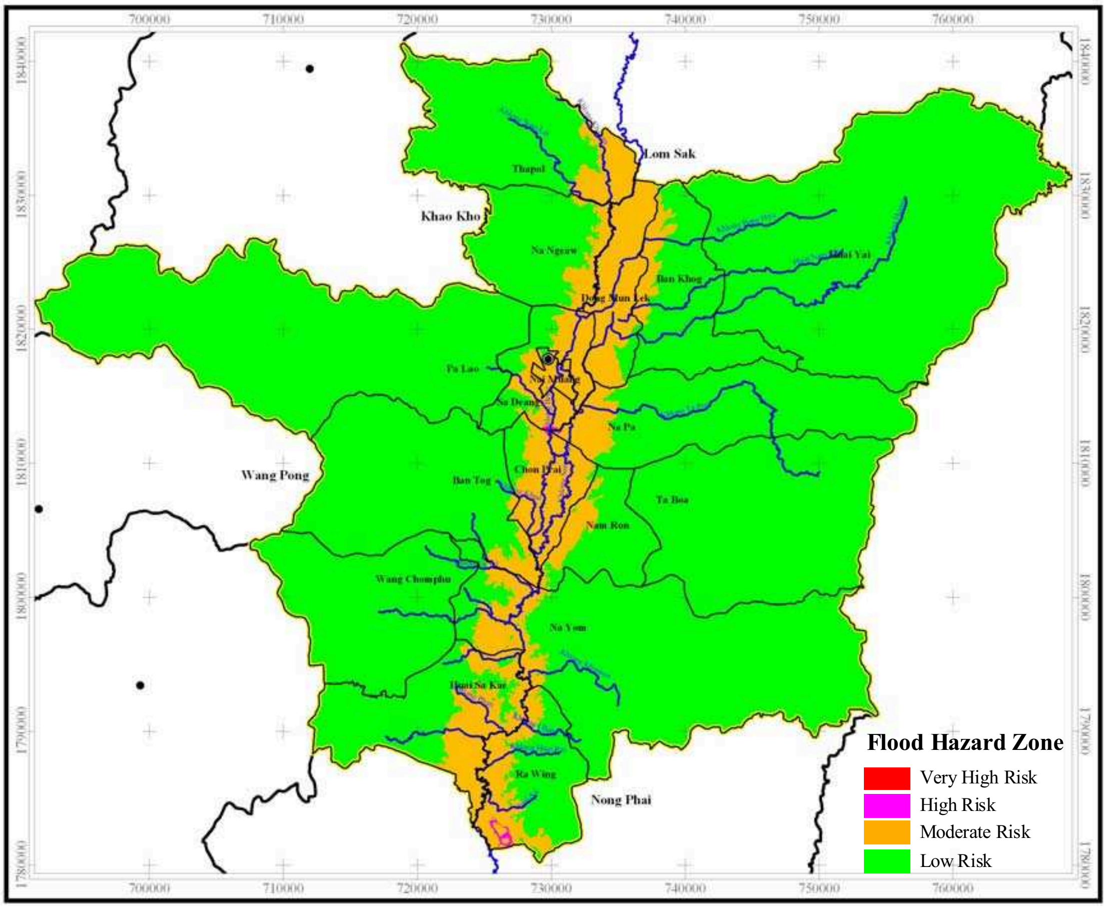


Figure 5.3-9 Flood Hazard Zone Map for 1th Week of October

(Critical Flood Depth ≥ 160 cm with Duration Longer than 4 Days)

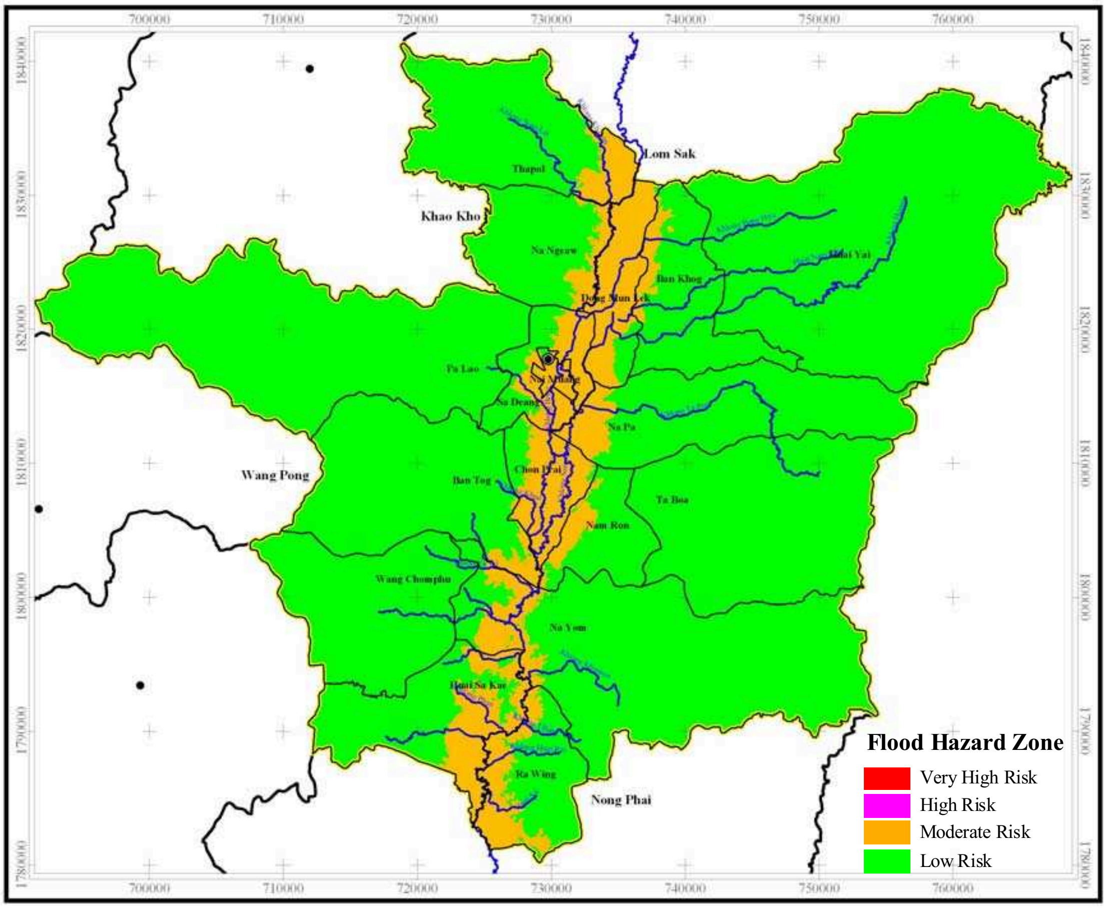


Figure 5.3-10 Flood Hazard Zone Map for 2nd Week of October

(Critical Flood Depth ≥ 160 cm with Duration Longer than 4 Days)

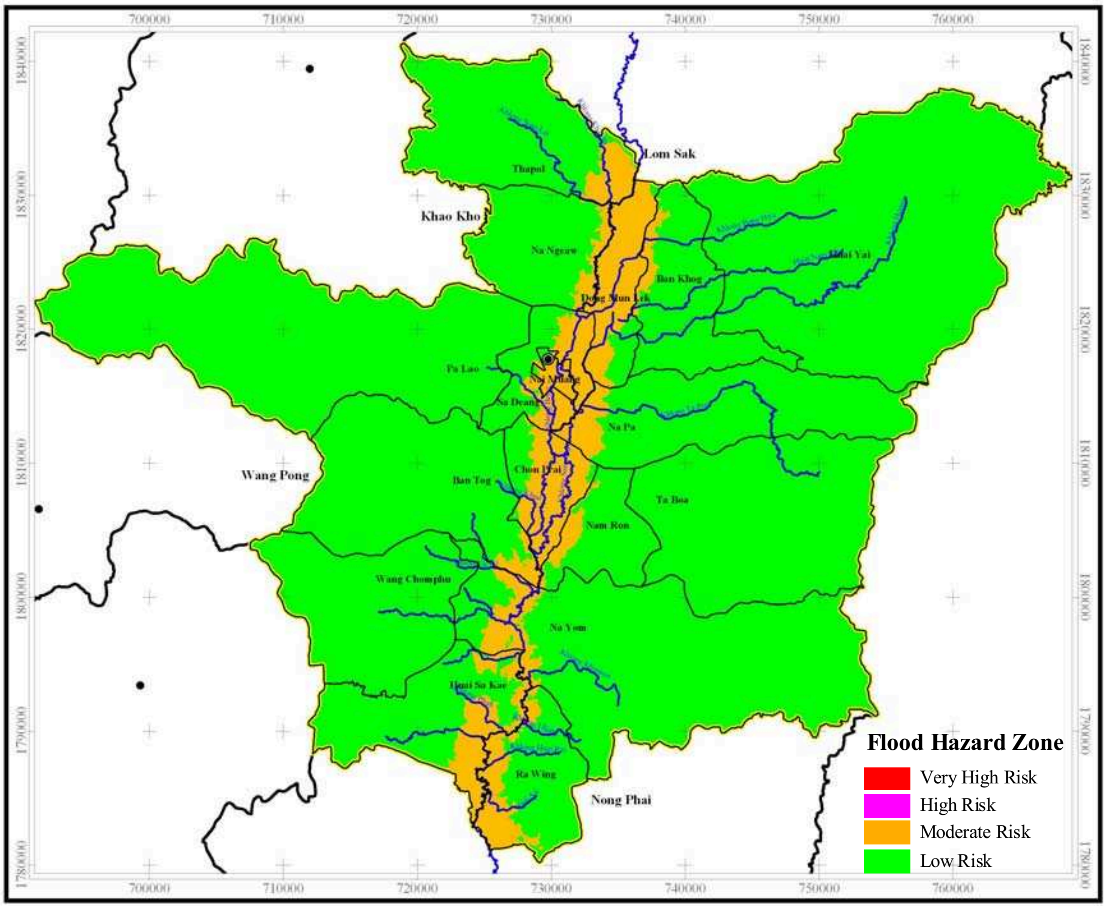


Figure 5.3-11 Flood Hazard Zone Map for 3rd Week of October

(Critical Flood Depth ≥ 160 cm with Duration Longer than 4 Days)

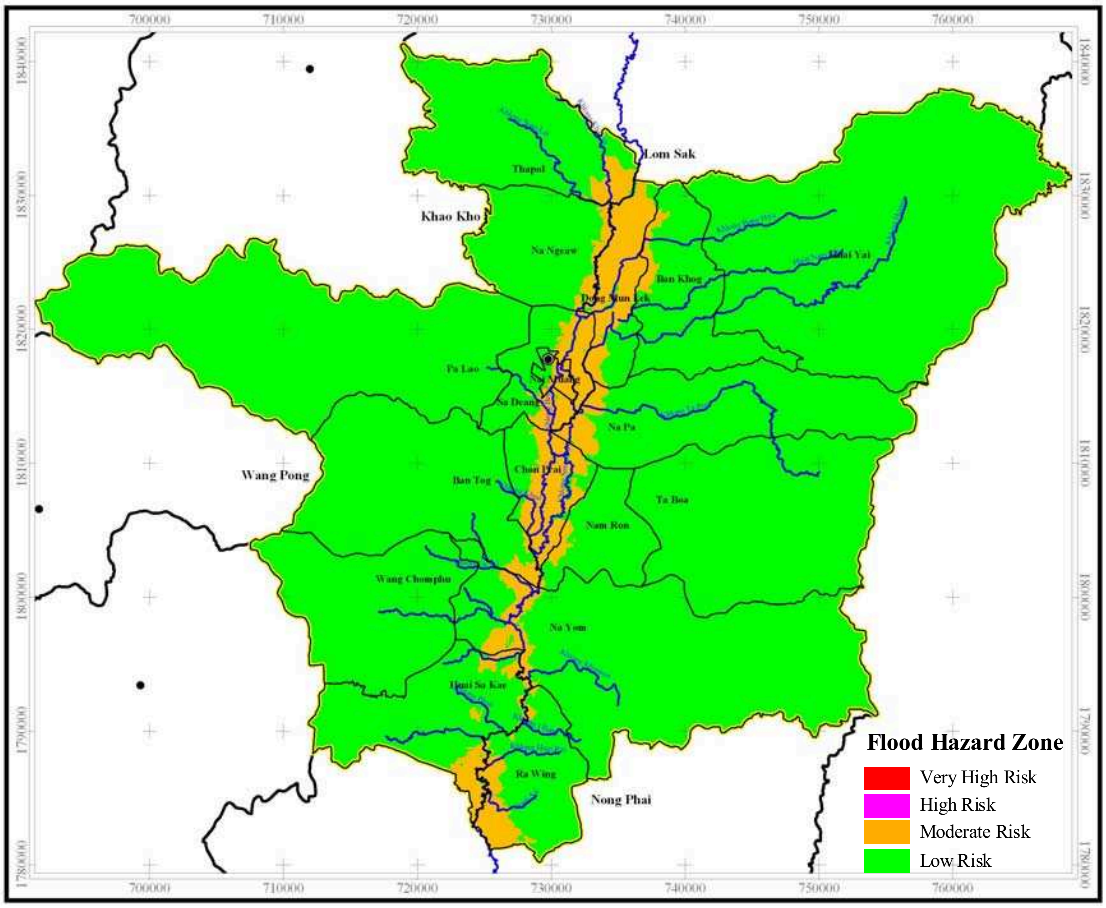


Figure 5.3-12 Flood Hazard Zone Map for 4th Week of October
(Critical Flood Depth ≥ 160 cm with Duration Longer than 4 Days)

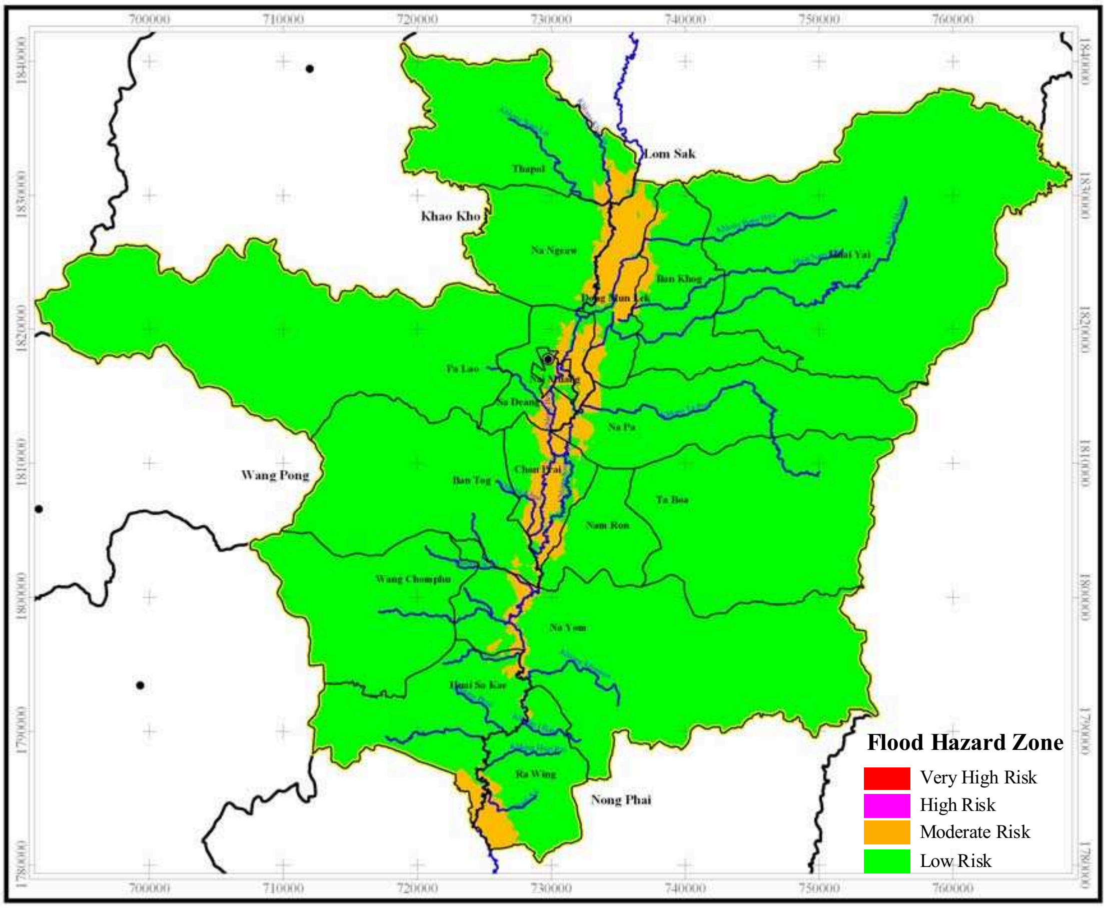


Figure 5.3-13 Flood Hazard Zone Map for 1th Week of November
(Critical Flood Depth ≥ 160 cm with Duration Longer than 4 Days)

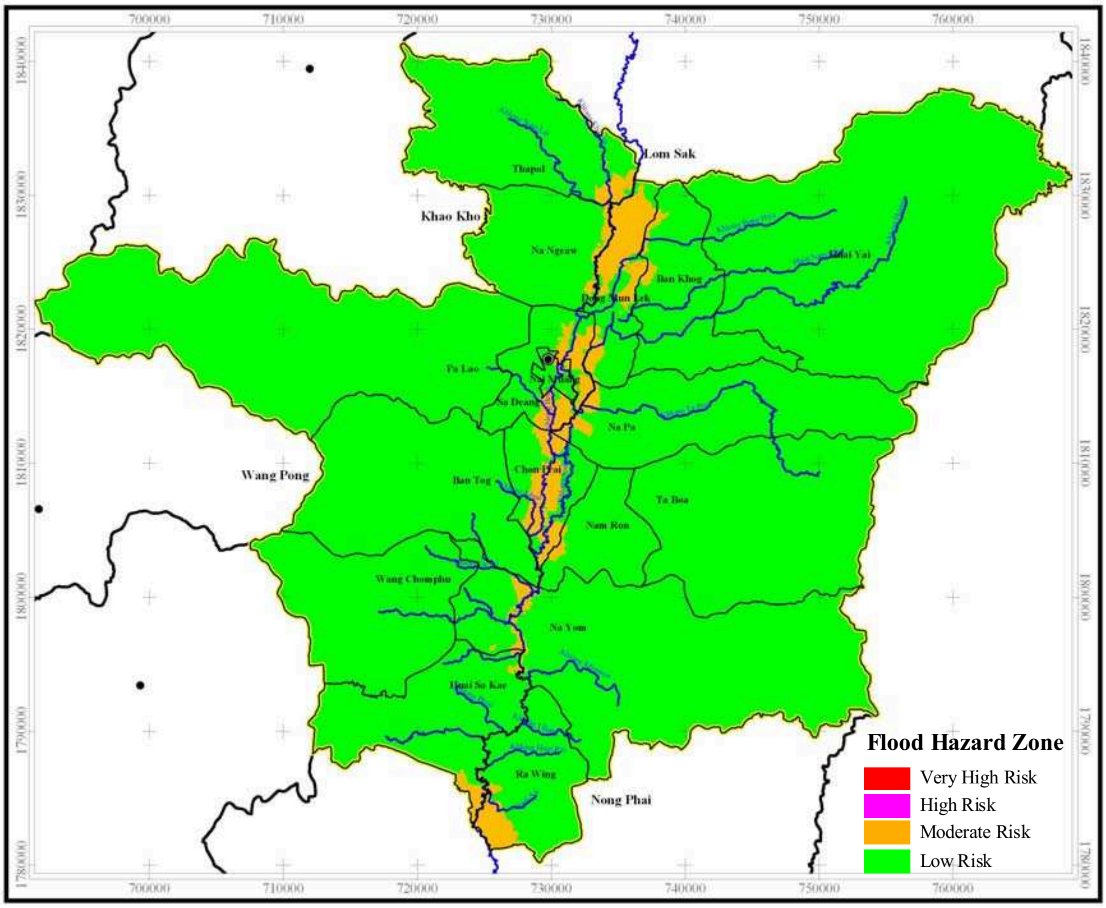


Figure 5.3-14 Flood Hazard Zone Map for 2nd Week of November

(Critical Flood Depth ≥ 160 cm with Duration Longer than 4 Days)

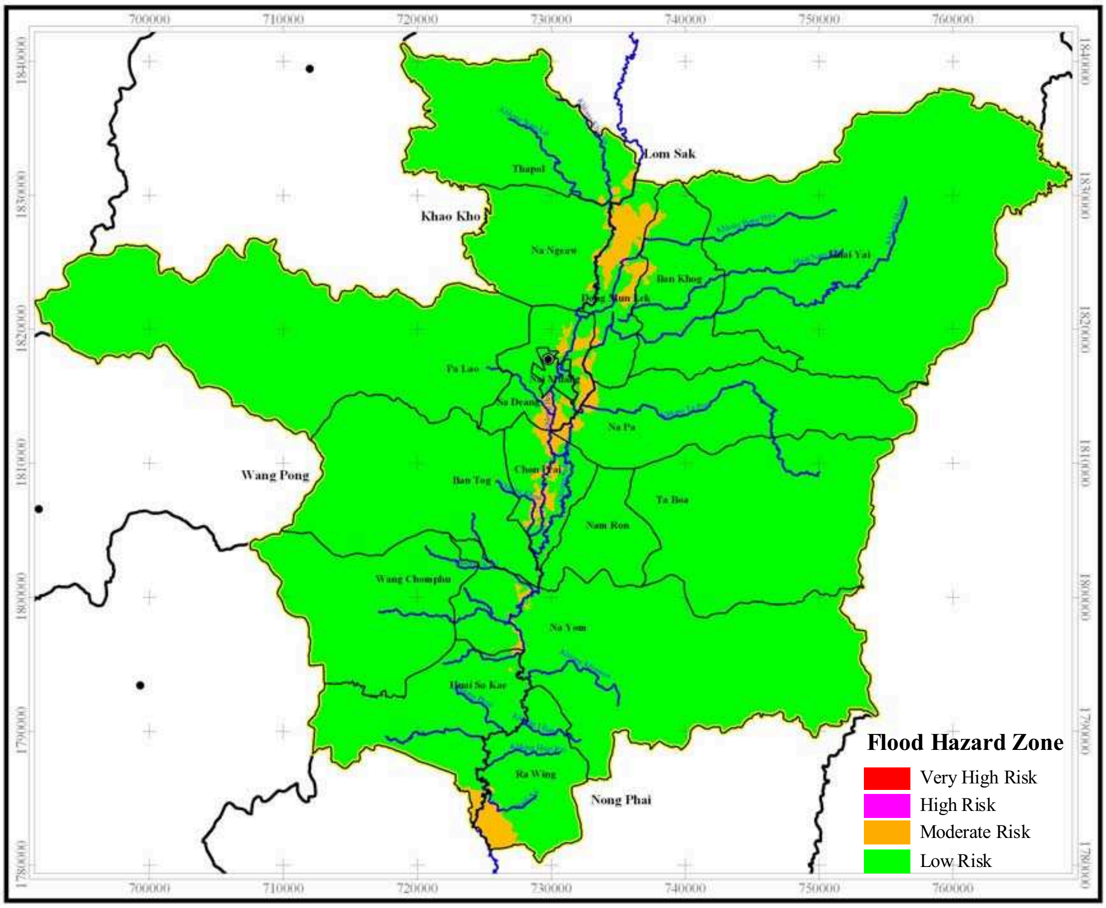


Figure 5.3-15 Flood Hazard Zone Map for 3rd Week of November
(Critical Flood Depth ≥ 160 cm with Duration Longer than 4 Days)

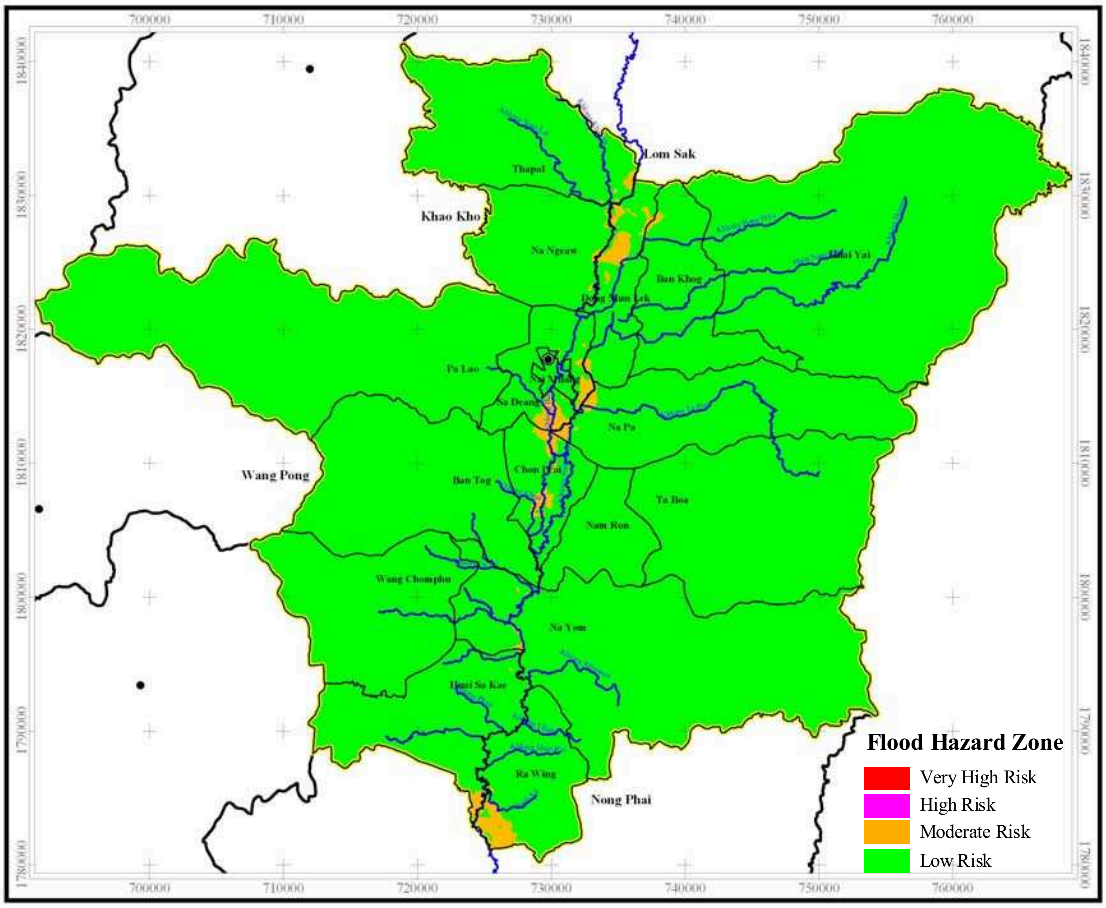


Figure 5.3-16 Flood Hazard Zone Map for 4th Week of November

(Critical Flood Depth ≥ 160 cm with Duration Longer than 4 Days)

5.4 Flood Map Implementation

5.4.1 Implementation of flood hazard zone maps

Since the combined maximum flood scenarios at different return periods that used to develop flood hazard zone maps (as presented in section 5.2.2) were derived from the annual maximum rainfall and streamflow data, hence these flood hazard zone maps provide the most severity inundation patterns that might occur in the study area at different probabilities of exceedence. Therefore, these flood hazard zone maps are recommended to use for flood insurance purpose as details below.

5.4.1.1 Evaluation of insurance premium

An insurance association or BAAC might set up an insurance premium for flood insurance of rice crop for particular area using information from the generated flood hazard zone maps. The following steps are proposed to estimate insurance premium of rice crop failure for particular area:

- The insurance association or BAAC should set up insurance premium (Bath/Rai) for very high risk, high risk, moderate risk and low risk zones. Note that the probability of flooding of the very high risk area is about 2-year return periods (probability of exceedence is greater than 50%). The insurance association might have to consider whether to include or exclude those areas from their flood insurance.
- Identify risk level of an interested area of each critical flood months based on flood hazard zone maps.
- Calculate insurance premium of each critical month
- Calculate total insurance premium for the entire crop cycle.

5.4.1.2 Rice crop failure claiming

Variations of water level at the S.4B river gauge station located in the Muang Phetchaboon district are due to high flow from the North of the basin and rainfall that occurs within the study area. Therefore, water level data at this river gauge station are proposed to use as "*Objective Flood Index*" for rice crop failure claiming according to the combined maximum flood scenarios.

The water levels at this station were simulated according to different combined maximum flood scenarios as established in Tables 5.2-2 to 5.2-5. An example for implementation of flood hazard assessment for insurance purpose is presented in **Table 5.4-1.**

Table 5.4-1 Example of an Implementation of Flood Insurance for Rice Crop Failure Using the Generated Flood Hazard Zone Maps

	Item	Flood Hazard Level			
		Very High	High	Moderate	Low
1.	Probability of Flooding	$\geq$ 50%	49% - 10%	10% - 1%	<1%
2.	Water Level Index at S.4B (m.AD)	9.31	9.31 – 9.76	9.76 – 11.21	> 11.21
3.	Flood Hazard Zone Area (Rai)				
	- August	XXX	XXX	XXX	XXX
	- September (week 1-2)	XXX	XXX	XXX	XXX
	- September (week 3-4)	XXX	XXX	XXX	XXX
	- October and November	XXX	XXX	XXX	XXX
4.	Flood Insurance Rate (Bath/Rai)	A	B	C	D
5.	Rice crop failure claiming (Bath/Rai)				
	- August				
	- September week 1-2				
	- September week 3-4				
	- October and November				

The above table can be used as follow:

1. An insurer and/or a beneficiary fill the flood insurance area corresponds to each flood hazard level (XXX) using the generated flood hazard zoning maps (Figures 5.2-11 to 5.2-14).
2. Flood insurance rate should be set for different flood hazard levels (A, B, C and D). Details on how to prescribe this insurance rate is beyond the scope of this study.
3. For simplicity, the water level at S.4B station is proposed to use as an objective index for rice crop failure claiming. For instance, if the water lever at the S.4B station is between 9.31-9.76 m, we consider that this weather event lead to high flood level of the study area. The inundation pattern of the study area is considered to be the same as the Figures 5.2-11 to 5.2-14 depending on the time of occurrence. The beneficiary who owns the land that located in the very high and high flood risk zones can claim for insurance premium.

It is important to note that the suggested ideas presented in this section can be considered as one alternative for implementation of flood insurance. It is not a final 'recipe' for the implementation of flood insurance. More insurance and underwriting issue such as insurance implementation would need some further thought of how to define exactly where individual farmer would be georeferenced (zoning for enrolment) and how losses would be measured (loss assessment zones). There could still be a lot of potential for anti-section, since risks are actually a continuum, even though there are 4 categories of flood hazard have been presented in this study. However, such considerations are beyond the scope of this study. Therefore, more considerations have to be made before implementation the produced flood risk maps.

5.4.2 Flood Risk Management for Rice Crop Growing

The generated weekly flood risk maps as presented in section 5.3 are evident that that flood hazard zones have been changed according to hydrometeorological condition and rice growth stage. According to these two factors, the most critical period of rice crop failure of the Muang Phetchaboon district is during the 2^{nd} to 4^{th} weeks of September. The generated weekly flood risk maps can be used for flood risk management for rice growing of the study area. On the other hand, weekly flood risk maps of different crops can be used as an additional information for selecting the most suitable crop for particular location.

Chapter 6

Conclusion and Recommendation

Chapter 6

Conclusion and Recommendation

6.1 Conclusions

The conclusions of this study can be summarized below.

6.1.1 Hydrological Analysis

- Three main factors that cause flooding in the Muang Phetchaboon district are (i) heavy rainfall within the vicinity of the Muang Phetchaboon district, (ii) high flows from the North of the Upper Pasak river basin, and (iii) the combination between (i) and (ii).
- The combination between high flow from the North of the basin and heavy rainfall within the vicinity of the Muang Phetchaboon district has been considered to be more realistic than the two standalone factors. Flood scenarios were designed based on the combined factors.
- The four highest flood risk months are September, October, August and November, respectively.
- Hydrometeorology condition of the study area can be represented by rainfall data recorded from the 36013, 36023, 36032, 36043 and 36141 rain gauge stations and stramflow data at the S.3 and S.4B river gauge stations. The designed flood scenarios were developed based on these data.
- Frequency analysis or return period of maximum 1-, 2-, 3- and 4-day accumulated rainfall of the above 5 rain gauge stations was performed and the return period tables were established.
- Frequency analysis or return period of annual momentary peak of discharge data of the S.3 and S.4B station was performed and the return period tables were established.

6.1.2 Designed Flood Scenarios

- Most of flood events occurred in the study area were due to 3-4 day continuous rainfall. The 4-day rainfall patterns of the 5 rain gauge stations at different return periods (2-, 5-, 10-, 20-, 50- and 100- year) were designed. Stramflow patterns at different return periods (2-, 5-, 10-, 20-, 50- and 100- year) of the S.3 station were designed by imitation of the flow pattern of the highest flood risk month of the climatological year (September 2005). The combination between designed rainfall and streamflow patterns at different return periods were used to represent combined maximum flood scenarios. These combined maximum flood scenarios were input to the developed flood modeling to produce flood hazard maps for different weather severities.
- Three different percentiles (50th, 75th and 95th percentiles) of daily rainfall at the 5 rain gauge stations and streamflow at the S.3 river gauge station during the critical 4 months were derived from the historical data. Rainfall and streamflow patterns of these stations at the three different percentiles were used to design combined weekly flood scenarios. Any inundation area that are caused by the 50th, 75th and 95th percentiles of designed combined weekly flood scenarios are considered as high, moderate and low flood risk zones, respectively. The designed combined weekly flood scenarios were used to produce weekly flood maps during the critical 4 months.

6.1.3 Flood Modelling Development

- The MIKE11 software package that includes Rainfall Runoff model, Hydrodynamic model and MIKE11 GIS model can be employed successfully to simulate inundation patterns, including flood extent, depth and duration in the flood plan.
- Calibration and verification of the developed flood model based on observed water level and discharge data was performed using the data during 2000 – 2002 and 2003-2005, respectively. The calibration and verification results confirm the capability of the developed flood model to be employed for simulating inundation patterns of the Muang Phetchaboon district.
- Validation of the developed flood model based on available satellite images was carried out. The 2002 satellite image was use for calibration while the 2006 and 2007 images were used for validation. The validation results show that flood extents generated from the model correspond well with the satellite images.

6.1.4 Flood Map Production

- Critical flood depths for rice crop are varied depending on rice growth stage as details presented in **Table 5.1**. The critical flood durations for all 4 critical months are longer than 4 days. These critical flood depths and durations were used to identify flood hazard zones based on the flood modeling results.
- Inundation patterns according to different probabilities of exceedence (2-, 5-, 10-, 20-, 50- and 100- year return periods) of combined maximum flood scenarios were simulated.
- The flood hazard zone maps for rice crop of the Muang Phetchaboon district according to different combined maximum flood scenarios were generated for each critical flood depth and duration.
- Inundation patterns of the Muang Phetchaboon district according to the combined weekly flood scenarios were simulated and used to produce 16 weekly flood risk maps during the critical periods.
- Flood risk assessments of each Tumbol of the Muang Phetchaboon district were established according to different combined maximum flood scenarios and different combined weekly flood scenarios.

6.1.5 Flood Map Implementation

- The water level data at S.4B station are recommended to use as flood index for rice crop failure claiming of the study area.
- The flood hazard zone maps generated according to combined maximum flood scenarios are recommended to use for flood insurance purpose. They can be used for estimating insurance premium and rice crop failure claiming due to flood.
- The generated 16 weekly flood risk maps during the critical months are recommended to use for flood risk management purpose. The weekly flood risk zone maps can be used by BAAC to recommend farmers whether they should grow rice in their land or not. Additionally, producing of flood zone maps at different time windows for different crops can be used as information for selecting the most suitable crop for particular area.

6.2 Recommendations

The recommendations for developing flood insurance index for other areas in Thailand can be summarized below.

- Most of the required data for flood modeling are available for this study area; however, it is desirable to use more precise elevation data. The more precise DEM data covering Thailand could be purchased from the Land Development Department, the Ministry of Agriculture and Co-operatives. These DEM data have horizontal resolution of 2 meters and vertical contour interval of 5 meters. The errors of these DEM are less than 1 meter and 2 meters for plain and hilly areas, respectively. Alternatively, more precise DEM data can also be obtained using Digital Terrain Model by LIDAR Methodology. Vertical relative accuracy of LIDAR product shall be less than 0.75 meter (RMSE) with resolution of 2.0 meters. More Detailed of this technique is presented in **Appendix B**.
- To apply the flood simulation approach presented in this study to other areas in Thailand, BAAC should start collecting satellite images that correspond to the dates of flood events occurred in different areas of the country.
- Field investigation of inundation patterns might be necessary to perform for use as other alternative to validate an accuracy of a developed flood model for a case where satellite imagery data are not available.
- Other data such as road network, water supply and drainage structures, river bank, breaking points, etc., are required to be collected for developing appropriate flood model of the interested areas.