CHAPTER IV

MODEL CALIBRATION AND VALIDATION

This chapter describes the model calibration and validation results obtained from the simulation. The lake drainage area is divided into 8 sub-watersheds based on the best fit delineation results. Models were developed from each sub-watershed. Each model is then calibrated with runoff of both wet season and dry season and sediment loss for the entire year. After calibrating until satisfaction, the model then is used to predict the amount of phosphorus and cadmium. The results are compared to field measurement. If the results are satisfactory, the model is then applied to predict the amounts from the sub-watershed.

4.1 ANNAGNPS AND TREX MODEL CALIBRATION AND VALIDATION

4.1.1 Data used for calibration and validation

The model parameters subjected to calibration were hydraulic conductivity, soil erodibility, flow resistance, crop management factor and chemical distribution coefficients. Overall model sensitivity envelope bounds were estimated from the combination of individual parameter values causing the largest increase (upper bound) or decrease (lower bound) in model response. Upper bound conditions occurred for maximum surface runoff, maximum soil erosion, and minimum chemical partitioning. Lower bound conditions occurred for minimum runoff, minimum erosion, and maximum partitioning. The calibration criterion was accepted when the phosphorus and cadmium values from model generated and measured values were different within a range of 8 to 20 percent relative error. The calibrated model was then used to generate output. The obtained results were compared with the measured values used for validation for the validation data period. The data for calibration was taken from Sae-Eong *et.al.,* (2002). A total of 20 locations were sampled for soil randomly covering SLB to study the pH, phosphorus and metal concentrations (Figure 4-23 and 4-24). The data for validation was taken from Suviboon, (2006) and LDD, (2006). A total of 212 and 12 locations were sampled randomly covering SLB to study the spatial variability of phosphorus and cadmium concentrations in surface soil in SLB respectively (Figure 4-23 and 4-24).

4.1.2 Model Calibration

In previous studies, the AnnAGNPS model was calibrated by varying model parameters such as average land slope, slope shape factor, average field slope length, average channel slope, average channel side slope, Manning's roughness coefficient for channels and impoundment factor in the hydrologic characterization for a particular cell or a subcell based on measured data and parameters from the field or suitably taken from the literature. The sediment yield estimation was improved by varying the cropping factor (C) in the USLE and the hydrologic shape factor (Perrone and Madramootoo, 1997). The other soil erosion coefficient such as soil erodibility factor (K), practice factor (P), surface condition constant, and soil texture for a particular cell or subcell are assigned according to the field observation or analyses based on the observed data or suitably taken from the literature. The nutrient yields generated by the watersheds were calibrated by defining a user assigned factor representing the decay of the nutrients within the cells and specifying fertilizer contents during the event. The calibrated cropping factor (C) values over the watershed varied from 0.001 (for fertile forest) to 1.00 (for bare land). Chemical oxygen demand was not calibrated due to non availability of data. Similary, the TREX model was calibrated by varying model parameters such as soil erodibility, the cropping factor (C), the land management practice factor (P), effective hydraulic conductivity (K_h), flow resistance (Manning n) and the partition (distribution) coefficient (log K_d).

In this study, the model parameters subjected to calibration were hydraulic conductivity, soil erodibility, flow resistance, crop management factor and chemical distribution coefficients. Calibrated model parameters values are shown in Table 4-1. Model sensitivity was explored by parameter perturbation as part of calibration efforts. Hydraulic conductivity (K_h) is a property of soil or rock, which describes the ease with which water can move through pore spaces or fractures. Soil erodibility (K) is an estimate of the ability of soils to resist erosion, based on the physical characteristics of each soil. It indicates how likely a soil is to erode based on its physical and chemical properties. Generally, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion. Manning's roughness coefficient (Manning's n) is the resistance of the bed of a channel to the flow of water in it. The crop management factor (C) estimates the reduction of soil loss from land cultivated under specified vegetative, residue, and management conditions as compared to clean-tilled, continuous fallow conditions. The distribution coefficient is the ratio of the sum of the concentrations of all forms of the compounds (ionized plus unionized) in each of the two phases. Several studies have correlated observed the chemical partition coefficient (K_d) values for cadmium with soil characteristics. Anderson and Christensen (1988) found that pH was the most influential factor in controlling the distribution of cadmium in soils. From the test run, it was found that upper most sensitive parameters in the hydrologic model were the effective hydraulic conductivity (K_h) and flow resistance (Manning,n). The upper most sensitive parameters for the sediment transport model were typically the soil erodibility (K) and crop management factor (C). The upper most sensitive parameter for the chemical transport model was the chemical partition coefficient (K_d). The pH of Songkhla lake basin is highly variable ranging from less than 4.22 to more than 6.27 (Sae-Eong *et al.*, 2002). Over this pH range, partition coefficients (log K_d) for cadmium can vary more than a factor of three (in log space). Direct simulation of pH as a model state variable was not feasible. To nonetheless account for pH dependence of the partition coefficient, a distribution coefficients used for cadmium is log K_d ,Cd = 2.34 was selected (Peter *et al.*, 2003 and Velleux *et al.*, 2001). During calibration, these parameters were varied within acceptable ranges representing the uncertainty of each parameter. Overall model uncertainty envelope bounds were estimated from the combination of individual parameter values causing the largest increase (upper bound) or decrease (lower bound) in model response. Upper bound conditions occurred for maximum surface runoff, maximum soil erosion, and minimum chemical partitioning. Lower bound conditions occurred for minimum runoff, minimum erosion, and maximum partitioning. A summary of the upper and lower bounds of each parameter is shown in Table 4-1. The calibration was accepted when the phosphorus and cadmium values from model generated and measured values differed within the range of 8 to 20 percent relative error. Figure 4-1 illustrates the steps taken during calibration. The AnnAGNPS model was initially run and by varying the calibrated parameters until the values of phosphorus and cadmium at the calibration points falls within 8-20% relative error. The calibrated parameters were then exported in ASCII format and used in TREX to generate cadmium results.

Table 4-1 Summary of calibrated model parameter values

Parameter	Range	Description
Hydraulic conductivity (K_h) (m/s)	1.5×10^{-6}	Sandy loams
	$1.5 \times 10^{-6} - 2.0 \times 10^{-6}$	Gravelly sandy loams
	$1.5 \times 10^{-6} - 2.8 \times 10^{-6}$	Pits and dumps
	$1.0 \times 10^{-6} - 1.5 \times 10^{-6}$	Diggings and tailings
Soil erodibility (K) (ton/acre)	0.02 - 0.03	Sandy loams
	0.05 - 0.15	Gravelly sandy loams
	0.02	Pits and dumps
	0.02 - 0.64	Diggings and tailings
Manning's roughness coefficient	0.45	Forest
(Manning, n)	0.30 – 0.45	Shrub and grassland
	0.15	Bare rock/sand
	0.05 – 0.15	Urban/commercial
	0.08 – 0.18	Channel bed
Crop Management Factor (C)	0.0-0.001	Fertile Forest
	0.001-0.02	Meadow, Dry Forrest, Peat
	0.02-0.03	Mangroves and rice fields
	0.03-0.05	Deciduous forest
	0.05-0.10	Orchards
	0.10-0.20	Horticultural and Field
	0.25-0.30	Pine tree
	0.30-0.60	Housing/Mixed farming/beach
	0.60-1.00	Abandon land/mine/open

From figure 4-2, the hydraulic conductivity (K_h) is relatively high in throughout the watershed, where the area is utilized for cropping also it was found to be relatively high near rivers. From figure 4-3, soil erodibility (K) was found to be high when the area is slope e.g. near the hills on the west side of SLB, together with areas with diggings and tailings. Figure 4-4 shows that flow resistance (Manning,n) is high on the west side and lower towards the lake. Figure 4-5 shows that a relatively low value of crop management factor surrounds the lake.

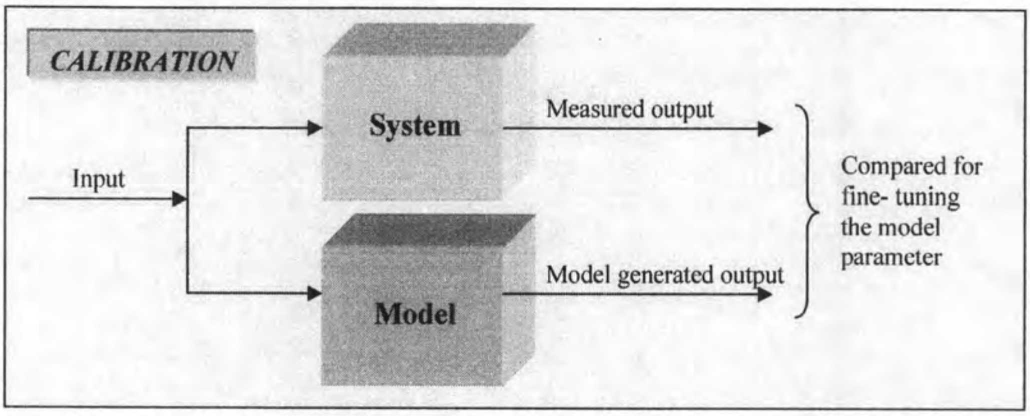

Figure 4-1 Steps during calibration

Parameters of the model are perturbed until an acceptable difference between measured (Sae-Eong *et.al.*, 2002) and model-generated output is obtained. Calibration points for phosphorus are shown in Figure 4-23. Calibration data was from year 2002. Calibration points for cadmium are shown in Figure 4-24. Being able to compare points within the watershed is an advantage of using spatially distributed parameter models. Only a single outlet point can be compared if lumped models were used.

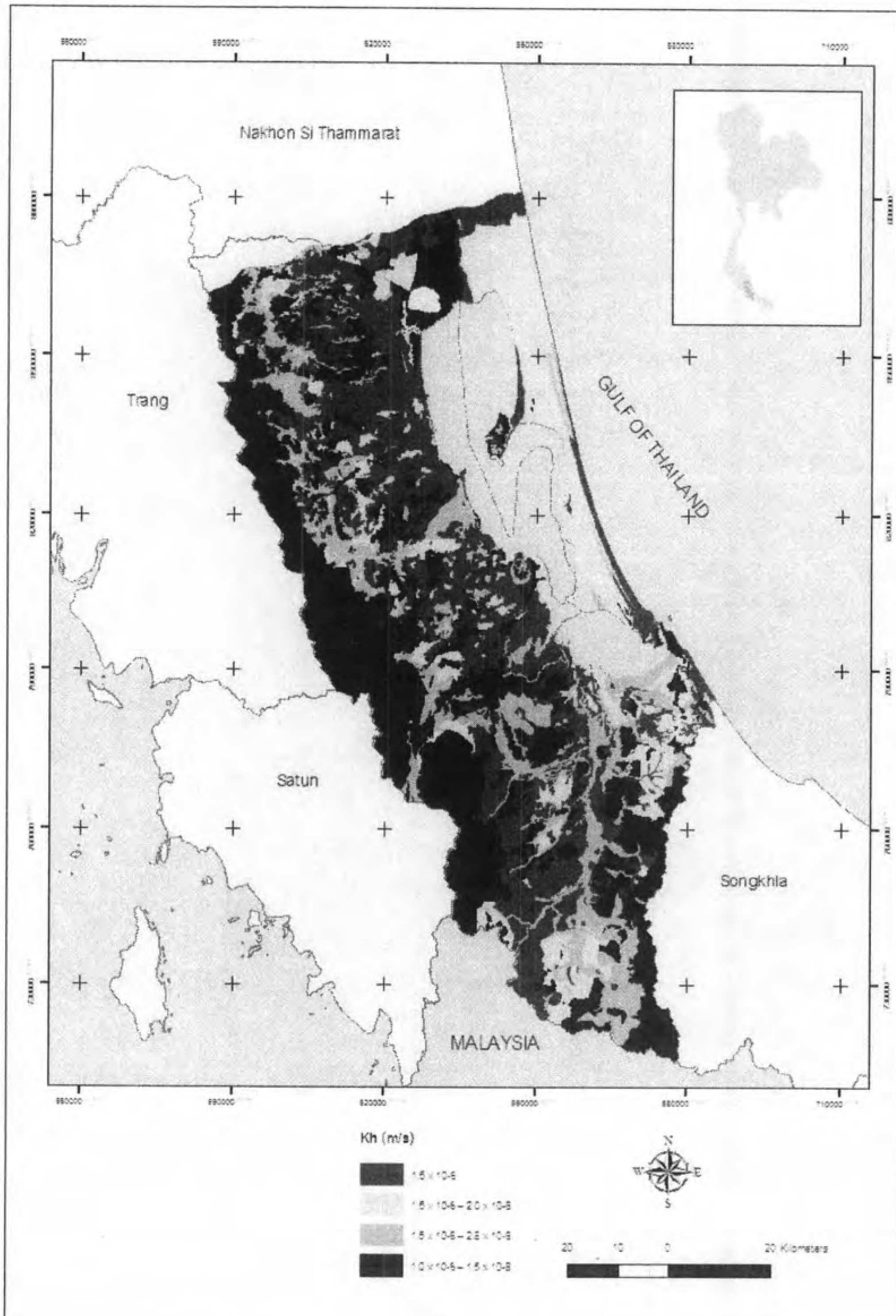

Figure 4-2 Hydraulic conductivity (K_h) calibrated values

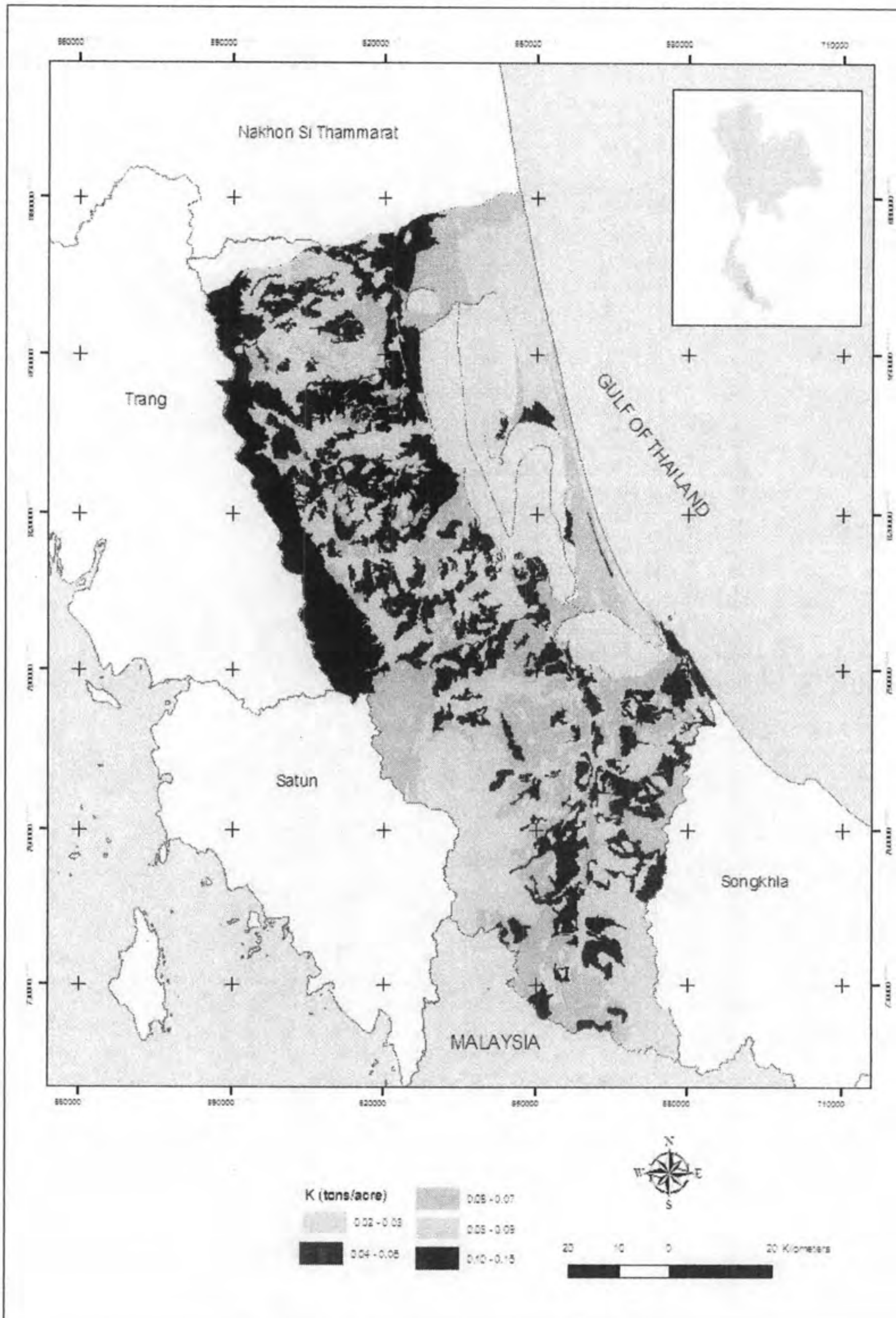

Figure 4-3 Soil erodibility (K) calibrated values

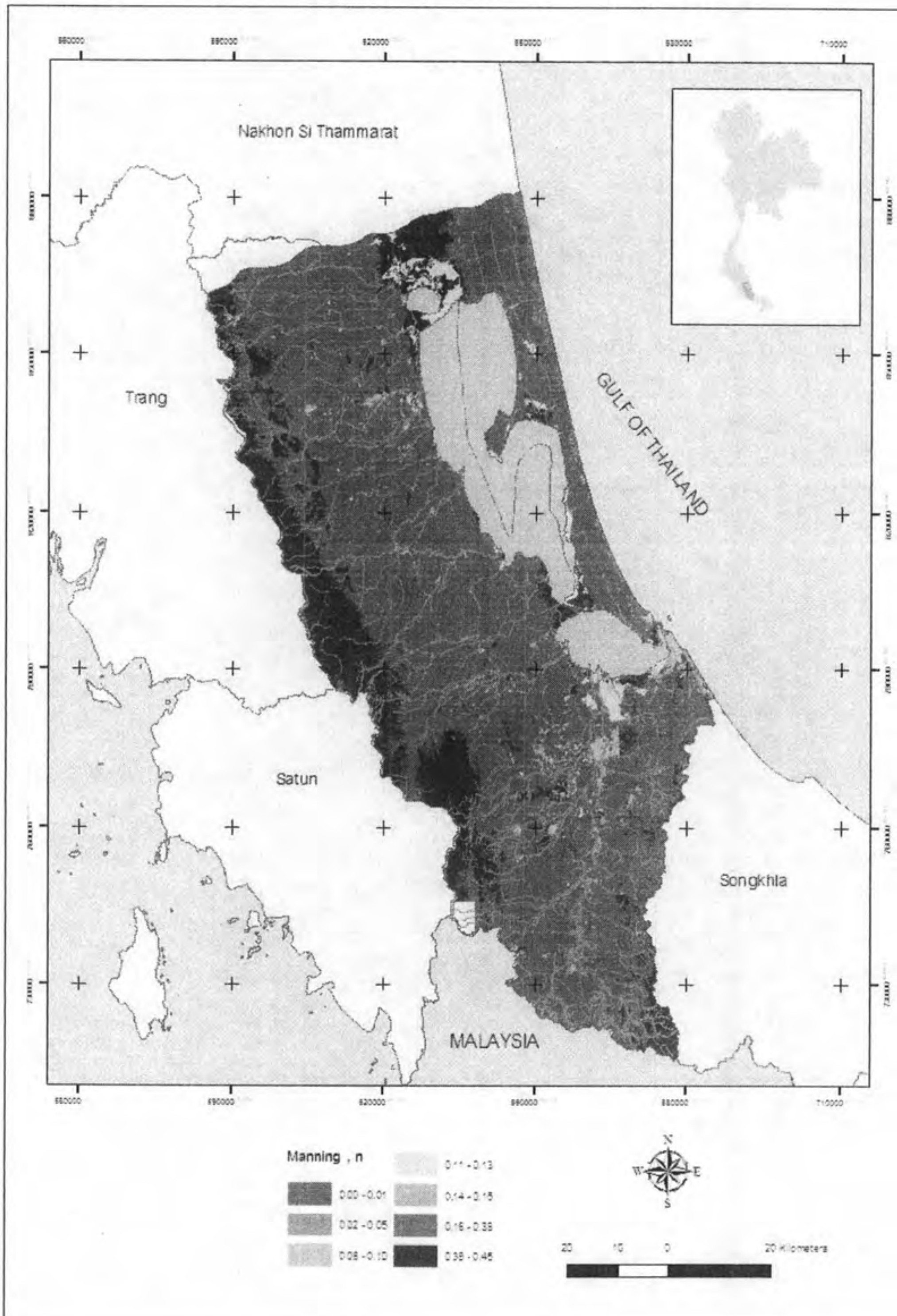

Figure 4-4 Manning's roughness coefficient (Manning, n) calibrated values

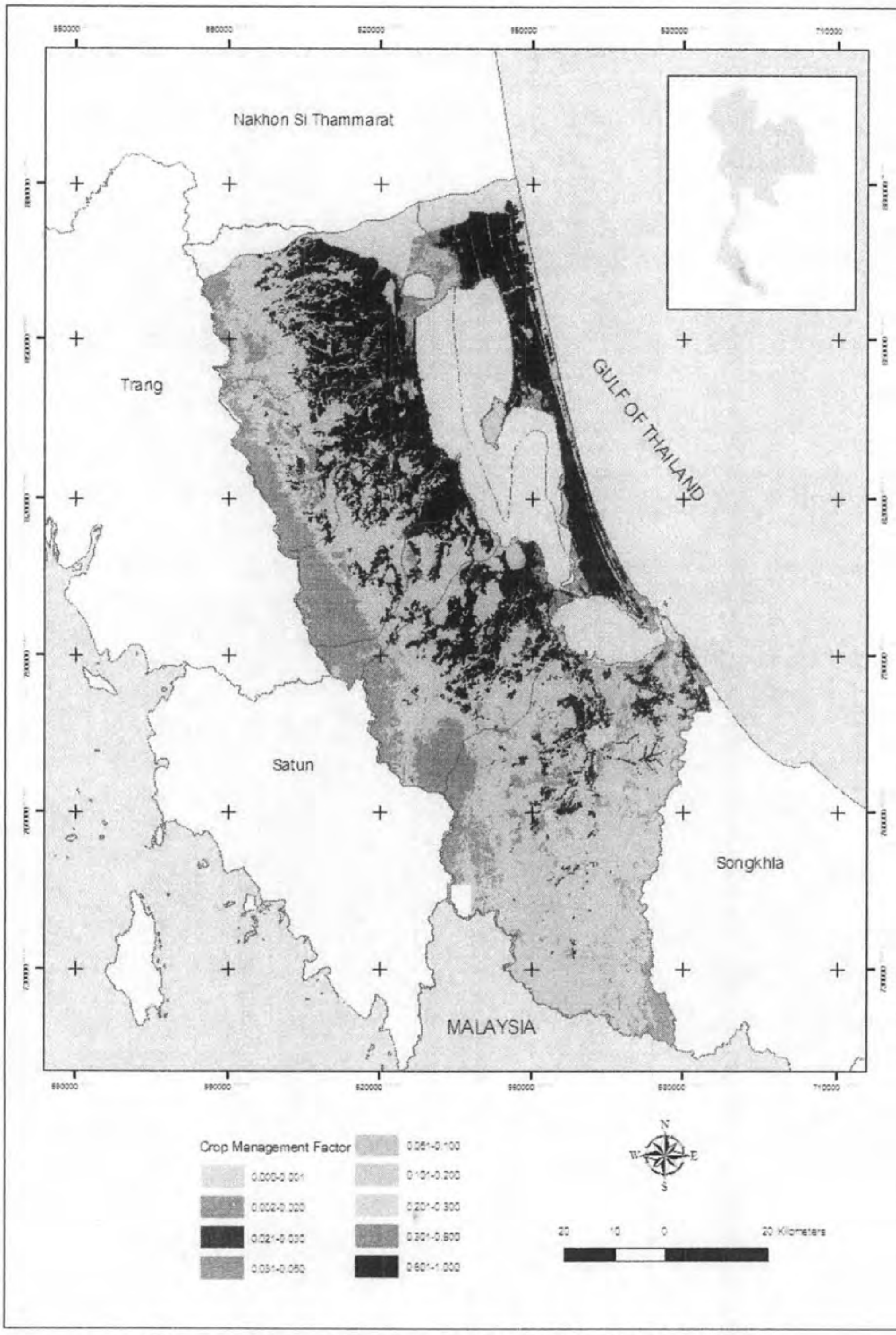

Figure 4-5 Crop Management factor (C) calibrated values

4.1.3 Model Validation

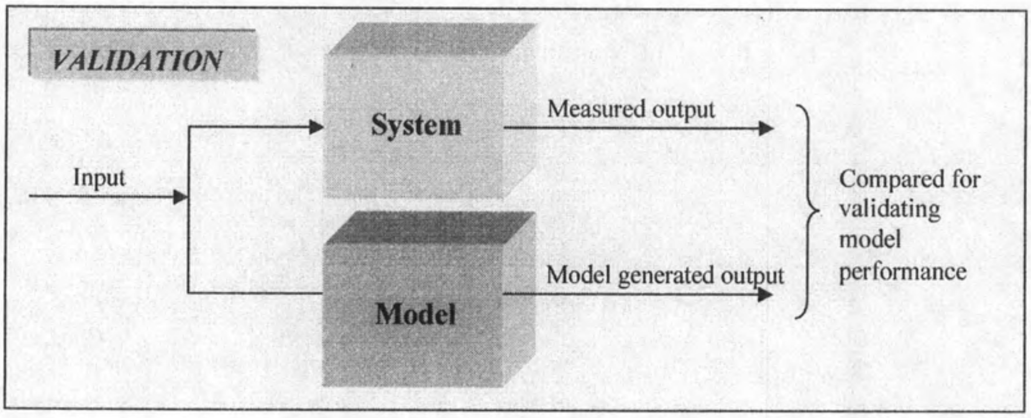

Figure 4-6 Steps during validation

The validation procedure is shown in Figure 4-6. The model is run here with the calibrated parameters to compare the performance of the model with measured data (Suviboon, 2006; LDD, 2006). Validation data was from year 2006. Validation points for phosphorus are shown in Figure 4-23. Validation points for cadmium are shown in Figure 4-24.

4.1.4 Results of Klong Pa Payom & Thanae sub-watershed

The calibration result for Klong Pa Payom & Thanae sub-watershed outlet is shown in table 4-2 and 4.3. AnnAGNPS and TREX results for wet season runoff shows an over prediction of 4.70% and 1.35% respectively. It is better than the dry season, in which over prediction was 13.68% and 8.75%. The sedimentation loss results were also over predicted by 11.48 and 19.62 % respectively. Calibration results of phosphorus and cadmium is shown in table 4.3. Validation results of phosphorus and cadmium is shown in table 4.4, and presented in Fig. 4.7 and Fig 4.8. A relative error for phosphorus and cadmium were found between 1.0 - 2.8% and 12.1 - 91.4% respectively. Phosphorus concentration becomes higher when traveling from west to east. Cadmium concentration becomes higher when there is a merging of streams.

Table 4-2 Calibration results of Klong Pa Payom & Thanae sub-watershed

(a) Dry season runoff calibration result

Runoff (MillionM^3)	**Dry Season**	
	Simulated	**% Error**
AnnAGNPS	11.53	13.68
TREX	24.56	8.75
Observed	22.58	

(b) Wet season runoff calibration result

Runoff (MillionM^3)	**Wet Season**	
	Simulated	**% Error**
AnnAGNPS	260.42	4.70
TREX	252.09	1.35
Observed	248.74	

(c) Yearly sediment loss calibration result

Sediment Loss (Tons/Year)	**Simulated**	**% Error**
AnnAGNPS	627,874	11.48
TREX	673,716	19.62
Observed	563,202	

Table 4-3 Calibration results of phosphorus and cadmium in Klong Pa Payom & Thanae sub-watershed

Coordinate		P Observe (mg/kg dry soil)	AnnAGNPS	% Error	Cd Observed (µg/kg dry soil)	TREX	% Error
X	Y						
603518	870385	90.24	97.56	8.1	11.40	13.65	19.7
591472	858500	163.80	169.02	3.2	1.00	1.27	27.3
608681	860549	99.17	107.41	8.3	1.00	1.13	12.5
618842	854909	149.08	158.86	6.6	3.85	5.07	31.6
622982	845712	278.50	285.10	2.4	1.00	1.34	34.5
603809	839676	143.78	157.45	9.5	4.73	5.13	8.4
620393	849499	45.55	49.13	7.9	2.11	3.10	46.7
671040	874728	95.47	102.41	7.3	88.95	120.65	35.6
593514	846287	253.05	277.75	9.8	1.26	1.70	34.6
593510	844419	243.64	266.80	9.5	1	1.11	11.4

Note: X and Y are coordinates in WGS84 system zone 47

Table 4-4 Validation results of phosphorus and cadmium in Klong Pa Payom & Thanae sub-watershed

Coordinate		P Observe (mg/kg dry soil)	AnnAGNPS	% Error	Cd Observed (µg/kg dry soil)	TREX	% Error
X	Y						
602505	843105	6.80	7.10	4.4	14	27	91.4
610339	846075	23.80	25.41	6.8	14	17	23.4
614042	851878	5.79	7.09	22.5	14	20	46.3
602763	854165	6.52	7.18	10.1	14	23	62.5
619524	855775	24.54	28.97	18.1	14	22	59.3
608113	857246	9.65	9.55	1.0	14	22	55.5
621867	858308	11.39	12.54	10.1	14	22	57.0
614311	863762	14.52	15.76	8.5	14	17	18.9
609840	865181	9.56	10.48	9.6	14	16	14.2
595904	864993	13.46	14.52	7.9	14	26	88.6
603475	867671	43.53	55.87	28.3	14	16	12.1
610144	868090	3.19	3.48	9.1	14	16	13.6
597712	852643	7.50	8.73	16.4	14	25	75.4
616740	869060	29.54	31.19	5.6	14	20	45.9
613099	870858	4.41	4.50	2.0	14	16	13.4

Note: X and Y are coordinates in WGS84 system zone 47

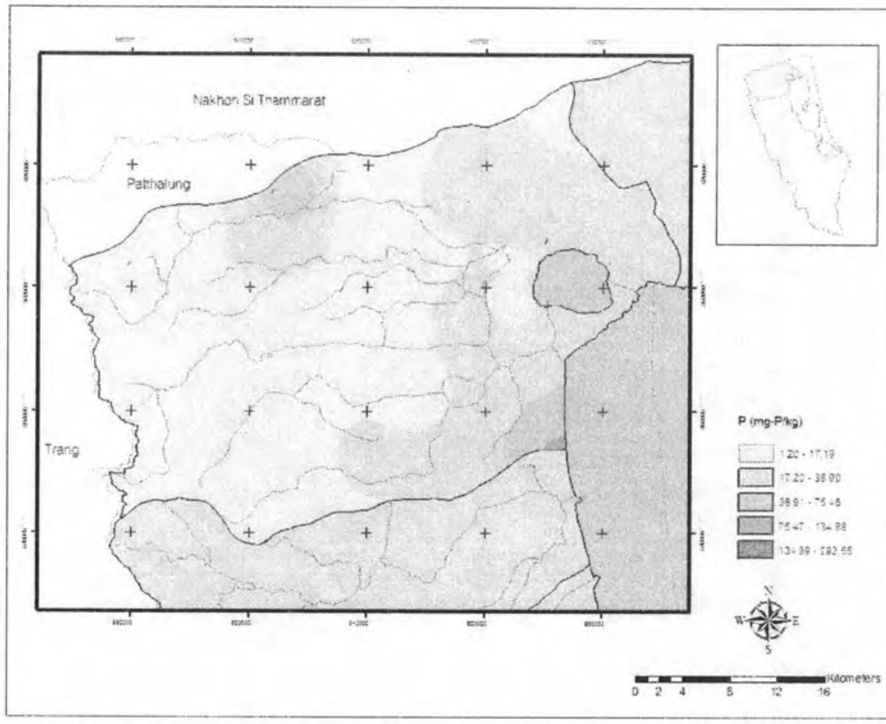

Figure 4-7 AnnAGNPS result of Klong Pa Payom & Thanae sub-watershed

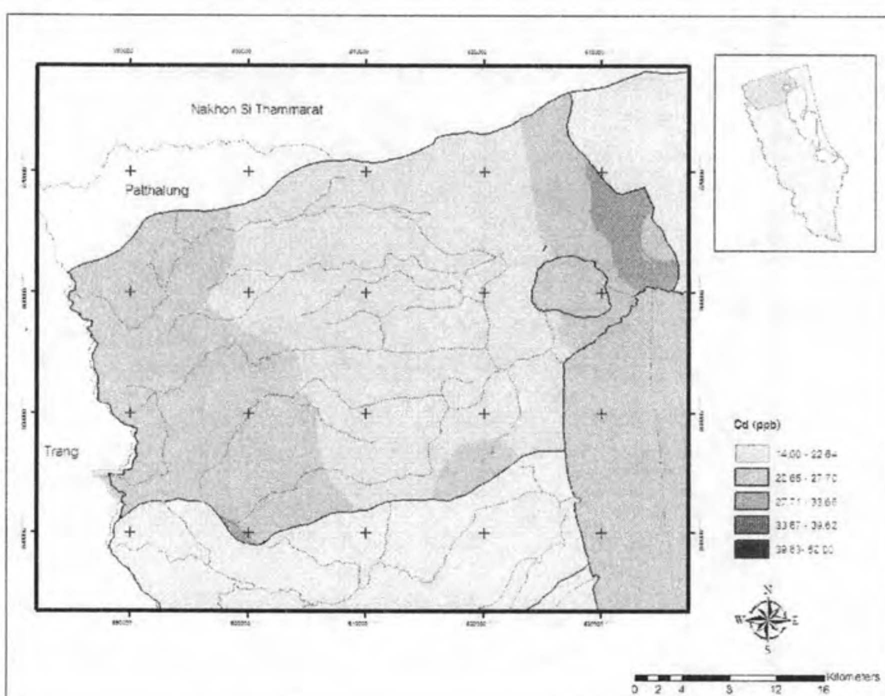

Figure 4-8 TREX result of Klong Pa Payom & Thanae sub-watershed

4.1.5 Results of Nathom sub-watershed

The calibration result for Nathom sub-watershed outlet is shown in table 4-5.and 4-6. AnnAGNPS and TREX results for wet season runoff shows an over prediction of 13.16% and 4.70% respectively. It is better than the dry season, in which over prediction was 29.43% and 13.90%. The sedimentation loss results were over predicted by 27.46 and 6.61% respectively. Calibration results of phosphorus and cadmium are shown in table 4.6. Validation results of phosphorus and cadmium are shown in table 4.7, and presented in Fig. 4.9 and Fig 4.10. For validation results, a relative error for phosphorus and cadmium were found between 0.1 – 23.3% and 22.9 – 108.9% respectively. Phosphorus concentration becomes higher when traveling from west to east. High cadmium concentration was found to be located next to the lake; the land use is broadcasted transplanted paddy field.

Table 4-5 Calibration result of Nathom sub-watershed

(a) Dry season runoff calibration result

Runoff (MillionM^3)	**Dry Season**	
	Simulated	**% Error**
AnnAGNPS	12.49	29.43
TREX	10.99	13.90
Observed	9.65	

(b) Wet season runoff calibration result

Runoff (MillionM^3)	**Wet Season**	
	Simulated	**% Error**
AnnAGNPS	106.34	13.16
TREX	98.39	4.70
Observed	93.97	

(c) Yearly sediment loss calibration result

Sediment Loss (Tons/Year)	**Simulated**	**% Error**
AnnAGNPS	826,060	27.46
TREX	690,894	6.61
Observed	648,082	

Table 4-6 Calibration results of phosphorus and cadmium in Nathom sub-watershed

Coordinate		P Observe (mg/kg dry soil)	AnnAGNPS	% Error	Cd Observed (µg/kg dry soil)	TREX	% Error
X	Y						
620157	838958	80.83	85.70	6.0	54.01	80.83	49.7
600234	827030	74.15	78.97	6.5	3.42	4.21	23.1

Note: X and Y are coordinates in WGS84 system zone 47

Table 4-7 Validation results of phosphorus and cadmium result in Nathom sub-watershed

Coordinate		P Observe (mg/kg dry soil)	AnnAGNPS	% Error	Cd Observed (µg/kg dry soil)	TREX	% Error
X	Y						
609418	831385	9.47	11.28	19.1	15	28	85.5
603562	834820	10.48	10.24	2.3	15	24	62.6
598381	836482	5.33	5.92	11.1	15	31	105.4
595762	838114	13.41	13.73	2.4	15	29	93.3
604774	838106	5.88	6.57	11.7	15	30	102.8
610023	826099	16.27	15.89	2.3	15	27	81.1
613852	830000	8.64	10.09	16.8	15	19	26.0
618322	831385	6.16	6.76	9.7	15	31	107.1
619147	829465	25.00	27.61	10.4	15	25	69.0
609668	834055	8.35	7.96	4.7	15	20	32.5
616348	838360	12.38	15.26	23.3	15	18	22.9
620904	841739	22.14	24.93	12.6	15	31	108.9
626723	845173	100.00	100.09	0.1	15	19	29.7

Note: X and Y are coordinates in WGS84 system zone 47

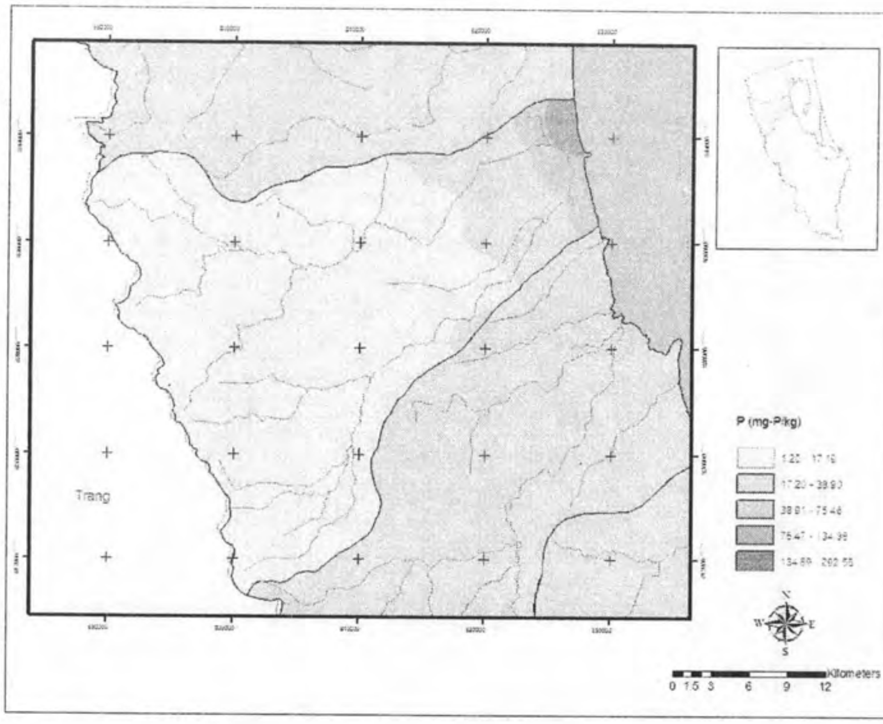

Figure 4-9 AnnAGNPS result of Nathom sub-watershed

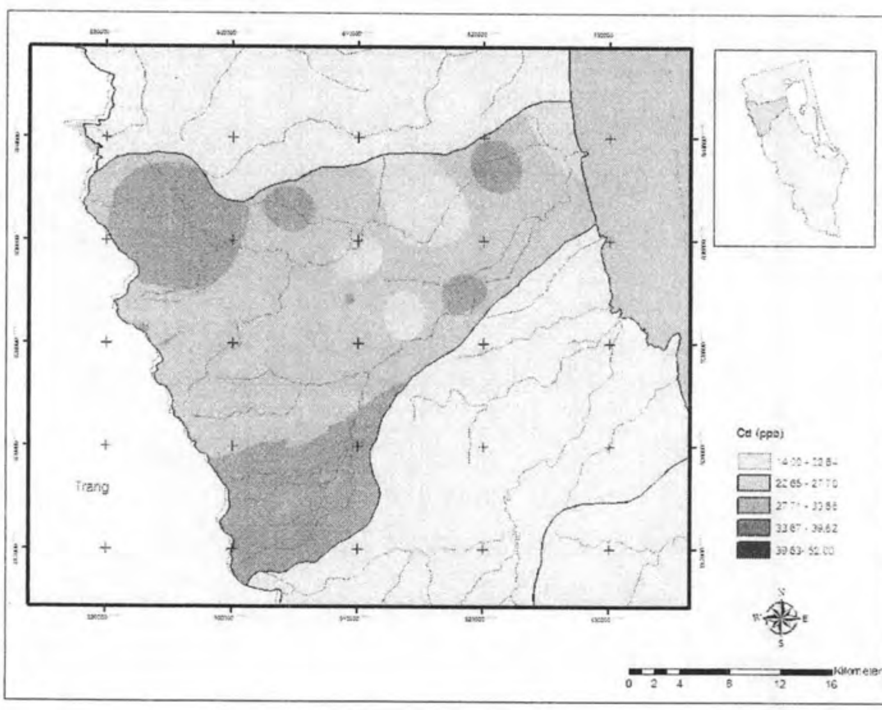

Figure 4-10 TREX result of Nathom sub-watershed

4.1.6 Results of Tachiad sub-watershed

The calibration results for Tachiad sub-watershed outlet is shown table 4-8 and 4.9. AnnAGNPS and TREX results for wet season runoff shows an over prediction of 11.19% and 4.07% respectively. It is better than the dry season, in which over prediction was 35.19% and 7.36%. The sedimentation loss results were over predicted by 11.56 and 17.14% respectively. Calibration results of phosphorus and cadmium are shown in table 4.9. Validation results of phosphorus and cadmium are shown in table 4.10, and presented in Fig. 4.11 and Fig 4.12. For validation results, a relative error for phosphorus and cadmium were found between 2.3 – 29.8% and 31.8 – 104.1% respectively. Phosphorus concentration becomes higher when traveling from west to east. Cadmium concentration was found to be located next to the lake, but relatively low when compared throughout the basin.

Table 4-8 Calibration result of Tachiad sub-watershed

(a) Dry season runoff calibration result

Runoff (MillionM^3)	**Dry Season**	
	Simulated	**% Error**
AnnAGNPS	32.54	35.19
TREX	25.84	7.36
Observed	24.07	

(b) Wet season runoff calibration result

Runoff (MillionM^3)	**Wet Season**	
	Simulated	**% Error**
AnnAGNPS	300.50	11.19
TREX	281.29	4.07
Observed	270.29	

(c) Yearly sediment loss calibration result

Sediment Loss (Tons/Year)	**Simulated**	**% Error**
AnnAGNPS	431,784	11.56
TREX	453,388	17.14
Observed	387,045	

Table 4-9 Calibration results of phosphorus and cadmium in Tachiad sub-watershed

Coordinate		P Observe (mg/kg dry soil)	AnnAGNPS	% Error	Cd Observed (μg/kg dry soil)	TREX	% Error
X	Y						
626047	831916	203.95	219.76	7.8	89.83	107.87	20.1
621294	825593	141.38	145.65	3.0	26.05	27.39	5.2
629653	824156	54.82	55.71	1.6	45.75	52.23	14.2
607199	798854	28.18	28.24	0.2	1.86	2.78	49.4

Note: X and Y are coordinates in WGS84 system zone 47

Table 4-10 Validation results of phosphorus and cadmium in Tachiad sub-watershed

Coordinate		P Observe (mg/kg dry soil)	AnnAGNPS	% Error	Cd Observed (μg/kg dry soil)	TREX	% Error
X	Y						
609732	811996	6.62	7.42	12.1	18	30	64.1
619847	815177	6.25	7.21	15.4	18	30	68.3
621524	815465	9.83	10.82	10.1	18	35	93.1
620850	817659	10.11	13.12	29.8	18	29	60.2
617794	821354	5.61	7.09	26.4	18	26	43.4
615379	821600	7.26	7.25	0.1	18	35	92.8
621042	826062	16.08	18.71	16.4	18	26	42.2
632823	826624	9.65	10.75	11.4	18	24	32.0
615890	801606	25.52	26.39	3.4	18	25	38.7
615400	802891	5.16	5.28	2.3	18	25	37.8
617541	805980	2.72	2.83	4.0	18	37	104.1
618660	807635	4.78	5.64	18.0	18	35	93.4
615872	811445	8.72	9.53	9.3	18	31	74.7
625507	815950	8.44	9.04	7.1	18	36	100.2
633857	819820	18.38	21.75	18.3	18	24	31.8
627229	820070	12.76	14.67	15.0	18	36	101.0
624359	820322	15.85	17.65	11.4	18	27	50.3
627897	823462	3.38	3.60	6.5	18	25	36.8
620595	798348	9.00	10.70	18.9	18	34	86.3
621183	800952	12.57	13.95	11.0	18	24	33.6
623048	801794	3.66	4.22	15.3	18	31	70.3

Note: X and Y are coordinates in WGS84 system zone 47

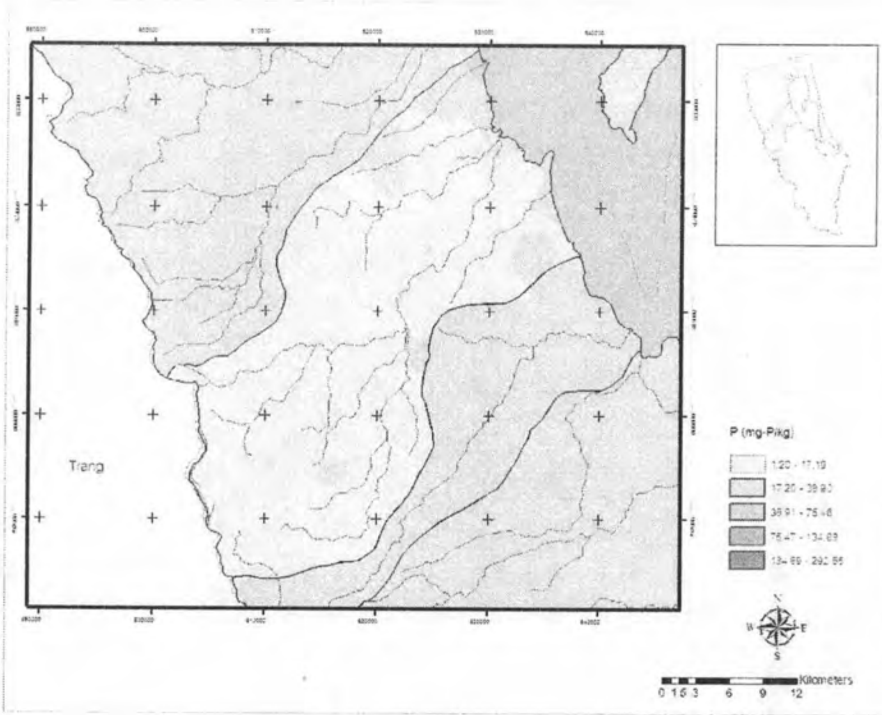

Figure 4-11 AnnAGNPS result of Tachiad sub-watershed

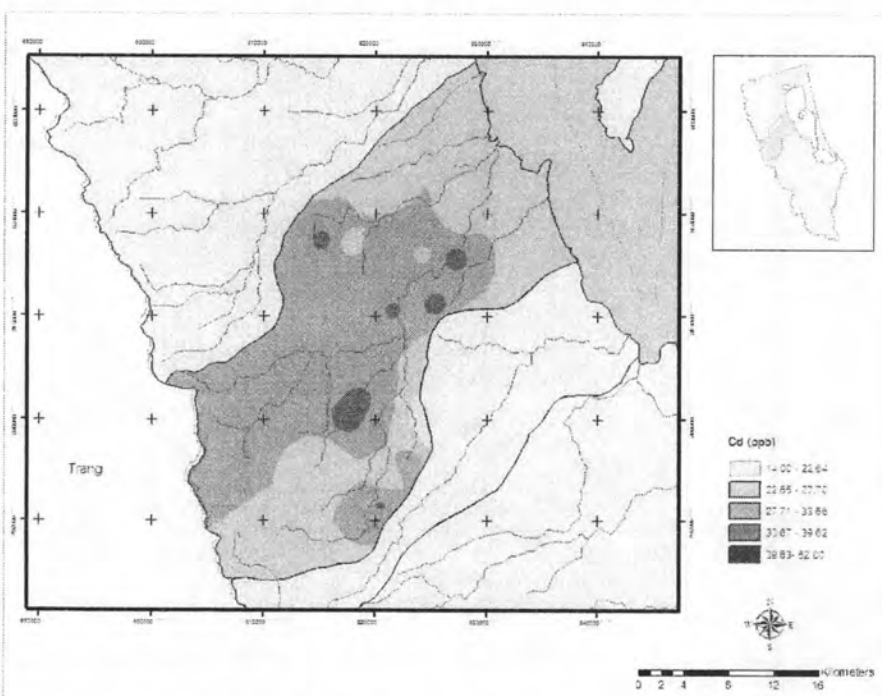

Figure 4-12 TREX result of Tachiad sub-watershed

4.1.7 Results of Pa Bon sub-watershed

The calibration results for Pa Bon sub-watershed outlet is shown table 4-11 and 4-12. For AnnAGNPS, the wet season runoff shows an over prediction of 8.21%. It is better than dry season in which over prediction was 28.57%. For TREX, the dry season runoff shows an over prediction of 5.61%. It is better than wet season in which over prediction was 18.23%. The sedimentation loss results were over predicted by 6.35 and 16.11% respectively. Calibration results of phosphorus and cadmium are shown in table 4.12. Validation results of phosphorus and cadmium are shown in table 4.13, and presented in Fig. 4.13 and Fig 4.14. For validation results, a relative error for phosphorus and cadmium were found between 0.3 – 18.5% and 13.7 – 104.9% respectively. Similar to the previous watershed results, phosphorus concentration becomes higher when traveling from west to east. Cadmium concentration was found within the area that has mixed orchards and paddy fields.

Table 4-11 Calibration result of Pa Bon sub-watershed

(a) Dry season runoff calibration result

Runoff (MillionM^3)	**Dry Season**	
	Simulated	**% Error**
AnnAGNPS	7.29	28.57
TREX	5.99	5.61
Observed	5.67	

(b) Wet season runoff calibration result

Runoff (MillionM^3)	**Wet Season**	
	Simulated	**% Error**
AnnAGNPS	47.56	8.21
TREX	51.96	18.23
Observed	43.95	

(c) Yearly sediment loss calibration result

Sediment Loss (Tons/Year)	**Simulated**	**% Error**
AnnAGNPS	176,352	6.35
TREX	192,529	16.11
Observed	165,816	

Table 4-12 Calibration results of phosphorus and cadmium in Pa Bon sub-watershed

Coordinate		P Observe (mg/kg dry soil)	AnnAGNPS	% Error	Cd Observed (μg/kg dry soil)	TREX	% Error
X	Y						
630800	814959	37.22	38.99	4.7	1.00	1.40	40.0

Note: X and Y are coordinates in WGS84 system zone 47

Table 4-13 Validation results of phosphorus and cadmium in Pa Bon sub-watershed

Coordinate		P Observe (mg/kg dry soil)	AnnAGNPS	% Error	Cd Observed (μg/kg dry soil)	TREX	% Error
X	Y						
625120	810930	25.41	29.70	16.9	12	22	79.8
627817	813443	6.47	7.16	10.7	12	20	68.3
641142	808549	37.89	41.29	9.0	12	21	71.3
638831	809691	10.22	11.78	15.3	12	23	91.4
642075	812222	13.88	15.75	13.5	12	20	64.4
640442	812577	4.78	5.10	6.7	12	15	25.2
640518	815397	8.63	9.48	9.8	12	22	80.5
630721	801038	3.28	3.29	0.3	12	21	72.2
628097	803168	2.72	2.62	3.7	12	17	43.8
625641	805936	4.60	5.30	15.2	12	14	13.7
630818	807747	6.47	7.67	18.5	12	14	17.3
635347	808043	3.47	3.72	7.2	12	25	104.9
632770	809982	8.91	11.30	26.8	12	17	45.7

Note: X and Y are coordinates in WGS84 system zone 47

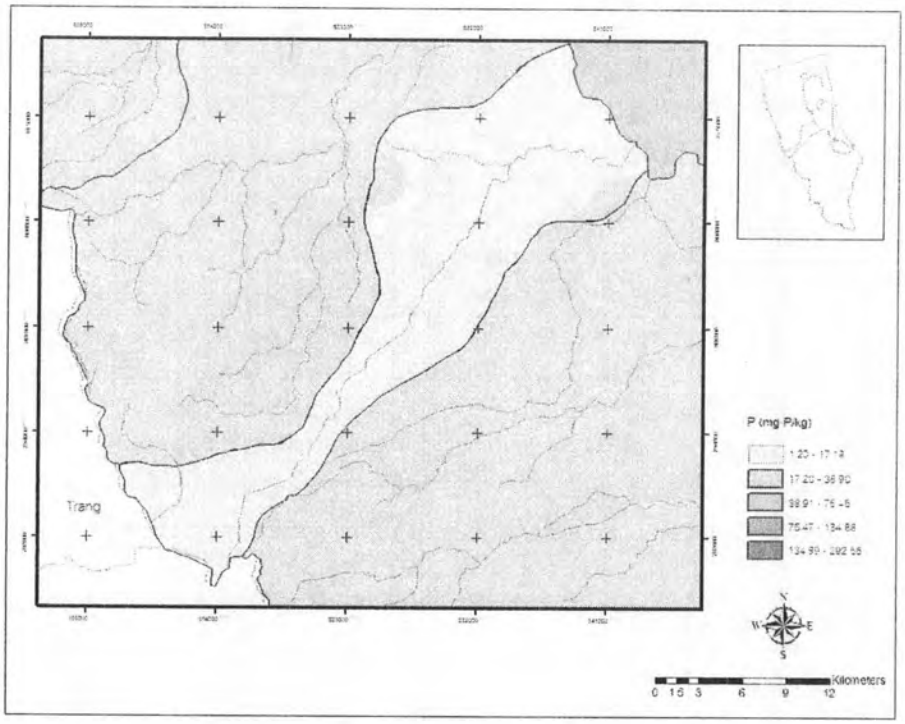

Figure 4-13 AnnAGNPS result of Pa Bon sub-watershed

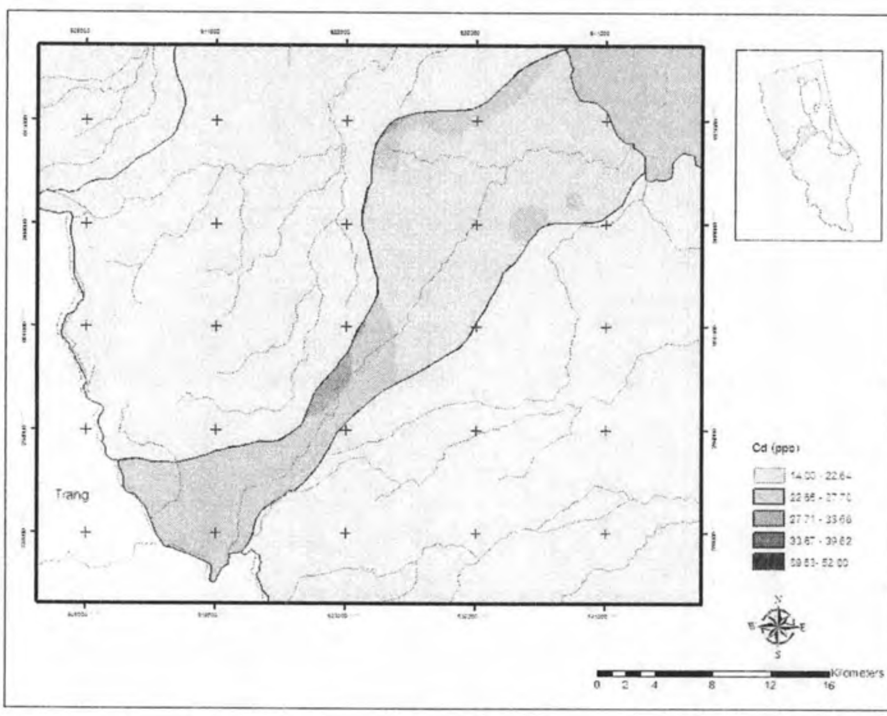

Figure 4-14 TREX result of Pa Bon sub-watershed

4.1.8 Results of Phru Poh & Rattaphum sub-watershed

The calibration results for Phru Poh & Rattaphum sub-watershed outlet is shown in table 4-14. Phosphorus and cadmium data for calibration was not available so therefore, model parameters were inserted by using other sub-watershed model parameter with similar physical characteristic. For AnnAGNPS, the wet season runoff shows an over prediction of 6.61%. It is better than dry season in which over prediction was 46.26%. For TREX, the dry season runoff shows an over prediction of 11.03%. It is better than wet season in which over prediction was 13.32%. The sedimentation loss results were over predicted by 7.72 and 13.89% respectively. Validation results of phosphorus and cadmium are shown in table 4.15, and presented in Fig. 4.15 and Fig 4.16. For validation results, a relative error for phosphorus and cadmium were found between 0.1 – 25.6% and 11.3 – 103.8% respectively. Phosphorus concentration becomes higher when traveling from west to east and higher concentration was found near the rivers. Cadmium concentration was found within the area that has mixed orchards and paddy fields.

Table 4-14 Calibration result of Phru Poh and Rattaphum sub-watershed

(a) Dry season runoff calibration result

Runoff (MillionM^3)	**Dry Season**	
	Simulated	**% Error**
AnnAGNPS	39.40	46.26
TREX	29.91	11.03
Observed	26.94	

(b) Wet season runoff calibration result

Runoff (MillionM^3)	**Wet Season**	
	Simulated	**% Error**
AnnAGNPS	202.99	6.61
TREX	215.77	13.32
Observed	190.4	

(c) Yearly sediment loss calibration result

Sediment Loss (Tons/Year)	**Simulated**	**% Error**
AnnAGNPS	39.40	46.26
TREX	29.91	11.03
Observed	26.94	

Table 4-15 Validation results for phosphorus and cadmium in Phru Poh and Rattaphum sub-watershed

Coordinate		**P Observe (mg/kg dry soil)**	**AnnAGNPS**	**% Error**	**Cd Observed (µg/kg dry soil)**	**TREX**	**% Error**
X	**Y**						
651528	789093	5.98	6.71	12.2	16	27	67.3
654264	791617	10.91	10.92	0.1	16	19	15.9
648317	799708	5.03	4.70	6.6	16	22	36.9
650429	801867	10.81	11.20	3.6	16	21	30.5
647109	779507	5.59	6.53	16.8	16	33	103.4
638212	775335	24.28	24.66	1.6	16	23	42.6
626289	779271	7.11	8.21	15.5	16	19	19.8
629481	779806	43.83	41.82	4.6	16	25	57.8
642080	780800	3.32	3.95	19.0	16	24	50.6
630827	779240	20.67	25.03	21.1	16	19	18.9
640972	784124	4.65	5.17	11.2	16	18	14.9
647066	786849	2.94	3.17	7.8	16	21	33.1
639684	787845	3.60	4.52	25.6	16	28	73.0
633947	789982	10.15	10.10	0.5	16	28	71.9
644925	790195	8.16	7.73	5.3	16	33	103.8
624637	790772	3.61	3.65	1.1	16	20	23.4
646702	792233	4.65	4.79	3.0	16	19	19.6
636267	794386	5.22	5.16	1.1	16	24	47.0
643098	796389	3.79	4.02	6.1	16	24	49.9
646627	803448	18.29	20.50	12.1	16	20	24.9
640738	805961	36.86	42.93	16.5	16	26	64.6
648502	809525	27.01	26.29	2.7	16	32	100.1
634057	793622	3.56	3.65	2.5	16	23	46.0
631062	796033	8.44	8.69	3.0	16	18	11.3
641249	800260	7.22	8.09	12.0	16	20	25.3

Note: X and Y are coordinates in WGS84 system zone 47

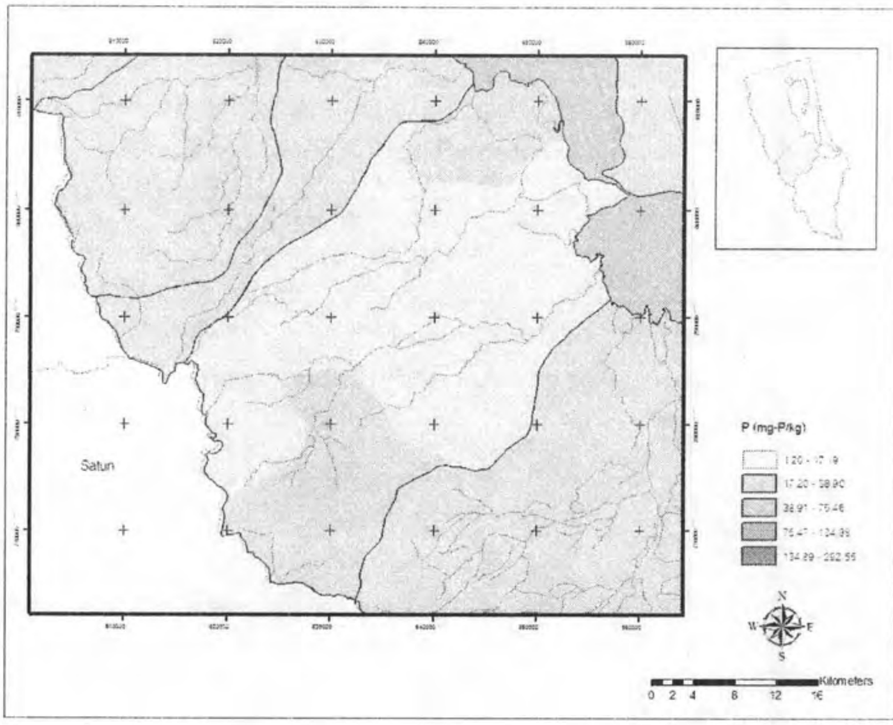

Figure 4-15 AnnAGNPS result of Phru Poh & Rattaphum sub-watershed

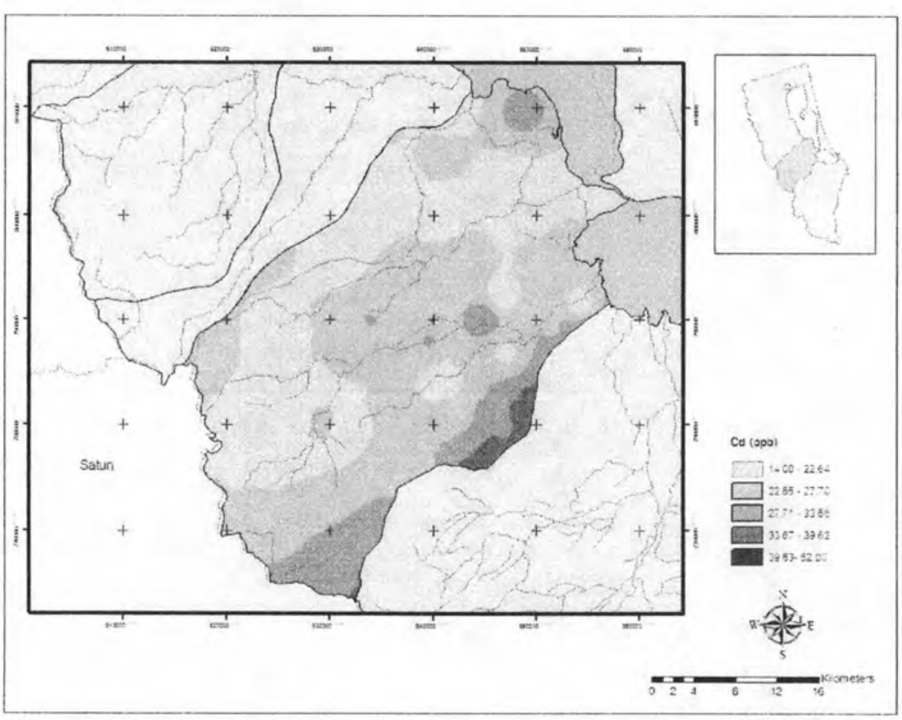

Figure 4-16 TREX result of Phru Poh & Rattaphum sub-watershed

4.1.9 Results of U-Tapao & Eastern Coast Sub Basin 4 sub-watershed

The calibration results of U-Tapao and Eastern Coast Sub Basin 4 sub-watershed outlet is shown in table 4-16 and 4-17. AnnAGNPS and TREX results for wet season runoff shows an over prediction of 9.94% and 6.82% respectively. It is better than the dry season, in which over prediction was 22.77% and 14.32%. The sedimentation loss results were over predicted by 13.58 and 7.54% respectively. Calibration results of phosphorus and cadmium are shown in table 4.17. Validation results of phosphorus and cadmium are shown in table 4.18, and presented in Fig. 4.17 and Fig 4.18. For validation results, a relative error for phosphorus and cadmium were found between 0.0 – 32.7% and 10.5 – 106.2% respectively. Phosphorus concentration becomes higher when traveling from south to north towards the lake and higher concentration was found near the rivers. Cadmium concentration was found in various areas in the sub-watershed that is used for mixed orchards and paddy fields.

Table 4-16 Calibration result of U-Tapao and Eastern Coast Sub Basin 4 sub-watershed

(a) Dry season runoff calibration result

Runoff (MillionM^3)	**Dry Season**	
	Simulated	**% Error**
AnnAGNPS	65.34	22.77
TREX	60.84	14.32
Observed	53.22	

(b) Wet season runoff calibration result

Runoff (MillionM^3)	**Wet Season**	
	Simulated	**% Error**
AnnAGNPS	314.54	9.94
TREX	305.60	6.82
Observed	286.1	

(c) Yearly sediment loss calibration result

Sediment Loss (Tons/Year)	**Simulated**	**% Error**
AnnAGNPS	862,168	13.58
TREX	816,337	7.54
Observed	759,084	

Table 4-17 Calibration results of phosphorus and cadmium in U-Tapao and Eastern Coast Sub Basin 4 sub-watershed

Coordinate		**P Observe (mg/kg dry soil)**	**AnnAGNPS**	**% Error**	**Cd Observed (µg/kg dry soil)**	**TREX**	**% Error**
X	**Y**						
652479	781907	24.05	24.43	1.6	16.11	17.15	6.4
649857	779751	74.31	76.05	2.3	40.05	49.49	23.6
641771	769116	120.84	122.02	1.0	4.64	6.30	35.8
651714	760350	58.62	62.81	7.2	5.54	7.26	31.1
654446	737358	40.96	44.35	8.3	1.21	1.72	42.4
662859	740376	288.49	316.22	9.6	8.93	10.25	14.8

Note: X and Y are coordinates in WGS84 system zone 47

Table 4-18 Validation results of phosphorus and cadmium in U-Tapao and Eastern Coast Sub Basin 4 sub-watershed

Coordinate		**P Observe (mg/kg dry soil)**	**AnnAGNPS**	**% Error**	**Cd Observed (µg/kg dry soil)**	**TREX**	**% Error**
X	**Y**						
651834	750923	3.32	3.76	13.3	25	44	77.4
648449	751837	6.83	6.63	2.9	25	40	58.8
653789	752122	35.56	40.88	15.0	25	28	10.5
658162	756697	3.22	3.06	5.0	25	44	77.7
650915	758355	2.94	3.07	4.4	25	46	84.3
659715	758564	4.55	4.83	6.2	25	36	44.4
660867	759411	3.41	3.64	6.7	25	40	60.0
657467	759656	3.98	4.65	16.8	25	30	21.0
650188	758473	2.47	2.40	2.8	25	38	52.0
652656	761888	74.53	79.29	6.4	25	40	61.6
647367	761536	8.16	8.79	7.7	25	48	93.6
652290	782414	6.07	7.44	22.6	25	44	75.4
655698	787588	9.96	12.07	21.2	25	50	99.6
672058	765286	144.42	164.08	13.6	25	29	14.4
672083	769677	64.11	75.23	17.3	25	51	106.0
677008	771650	19.73	22.88	16.0	25	42	69.7
655513	775149	1.23	1.20	2.4	25	43	72.2
659025	779877	4.55	5.09	11.9	25	29	17.6

Coordinate		P Observe (mg/kg dry soil)	AnnAGNPS	% Error	Cd Observed (µg/kg dry soil)	TREX	% Error
X	Y						
659749	782888	225.45	204.85	9.1	25	50	98.1
658646	785273	22.39	22.19	0.9	25	38	51.8
677801	780695	24.47	28.54	16.6	25	32	27.6
680888	781371	5.50	7.30	32.7	25	38	51.9
681119	785170	32.24	33.01	2.4	25	36	42.2
675191	787902	15.83	16.16	2.1	25	48	92.5
656864	723023	2.28	2.28	0.0	25	46	83.3
669104	722330	2.28	2.59	13.6	25	48	93.4
665677	722539	4.84	5.93	22.5	25	42	67.0
668700	728464	4.96	5.34	7.7	25	36	45.6
660235	729946	14.25	16.71	17.3	25	44	74.5
652806	730520	9.19	9.04	1.6	25	30	21.7
663330	731718	11.85	14.06	18.6	25	46	85.2
666181	732620	4.60	4.68	1.7	25	36	45.6
648120	734281	7.99	8.87	11.0	25	34	34.4
661869	737236	5.42	5.39	0.6	25	39	54.6
669125	738672	8.82	10.30	16.8	25	40	61.1
652409	738873	5.15	4.78	7.2	25	39	56.7
661503	740522	2.94	3.72	26.5	25	29	15.0
646600	740700	7.08	7.24	2.3	25	32	29.5
655833	744535	4.23	4.74	12.1	25	31	23.7
641377	744818	9.19	10.29	12.0	25	47	86.3
649445	744436	6.34	6.43	1.4	25	37	46.8
663813	745976	15.53	16.72	7.7	25	29	14.7
659677	746448	5.15	5.47	6.2	25	47	88.1
669299	749446	4.59	5.71	24.4	25	37	46.3
646077	749605	3.31	3.50	5.7	25	42	69.8
655204	750046	231.54	254.66	10.0	25	37	49.8
663701	750286	7.08	8.59	21.3	25	35	39.3
653165	751817	33.36	41.60	24.7	25	39	57.5
671268	752093	7.81	8.00	2.4	25	44	76.7
672432	754643	16.08	18.06	12.3	25	38	51.6
667103	757687	6.43	7.60	18.2	25	52	106.2
663789	764182	8.18	8.72	6.6	25	32	29.6
645515	766377	12.59	12.91	2.5	25	36	42.9
652125	776389	15.17	19.21	26.6	25	51	105.8
644259	766177	139.04	148.20	6.6	25	46	84.8
661679	767247	12.78	10.94	14.4	25	46	83.4
651027	768639	12.50	14.82	18.6	25	32	28.4
647393	769617	14.15	16.01	13.1	25	45	79.9
650712	770961	7.26	7.65	5.4	25	32	28.8
659214	771257	8.18	7.51	8.2	25	41	65.5
641886	771747	8.82	7.48	15.2	25	40	59.1
650821	774057	7.72	9.86	27.7	25	51	103.2
670299	774082	9.56	9.86	3.1	25	47	88.0
649006	774666	7.90	9.44	19.5	25	45	80.0

Coordinate		P Observe (mg/kg dry soil)	AnnAGNPS	% Error	Cd Observed (µg/kg dry soil)	TREX	% Error
X	Y						
672860	775823	25.82	27.00	4.6	25	49	95.8
669011	780194	8.27	9.00	8.8	25	28	13.2
673207	773068	14.98	16.25	8.5	25	29	16.2
672020	783238	8.82	9.10	3.2	25	32	28.8

Note: X and Y are coordinates in WGS84 system zone 47

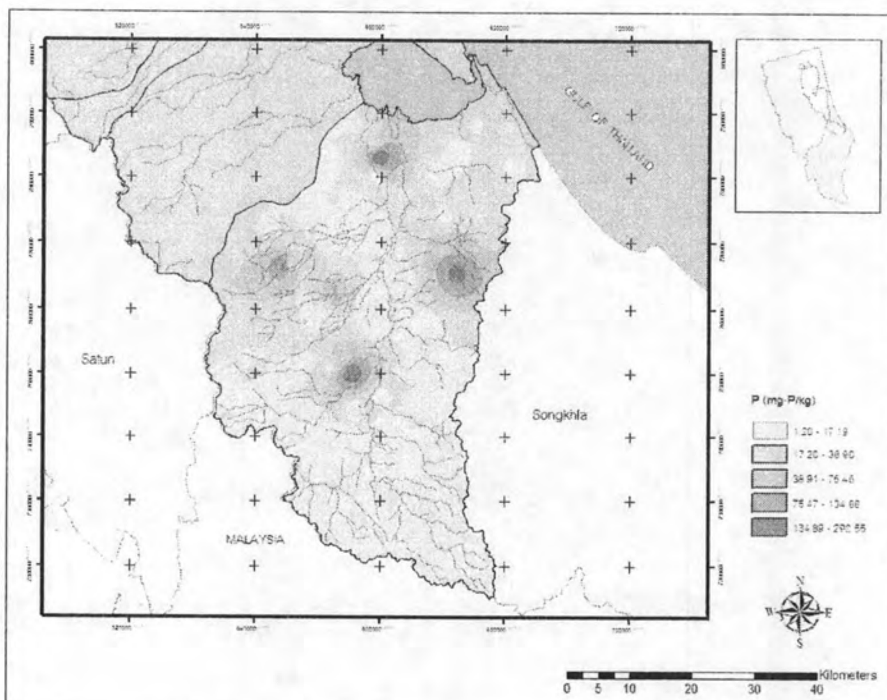

Figure 4-17 AnnAGNPS result of U-Tapao and Eastern Coast Sub Basin 4 sub-watershed

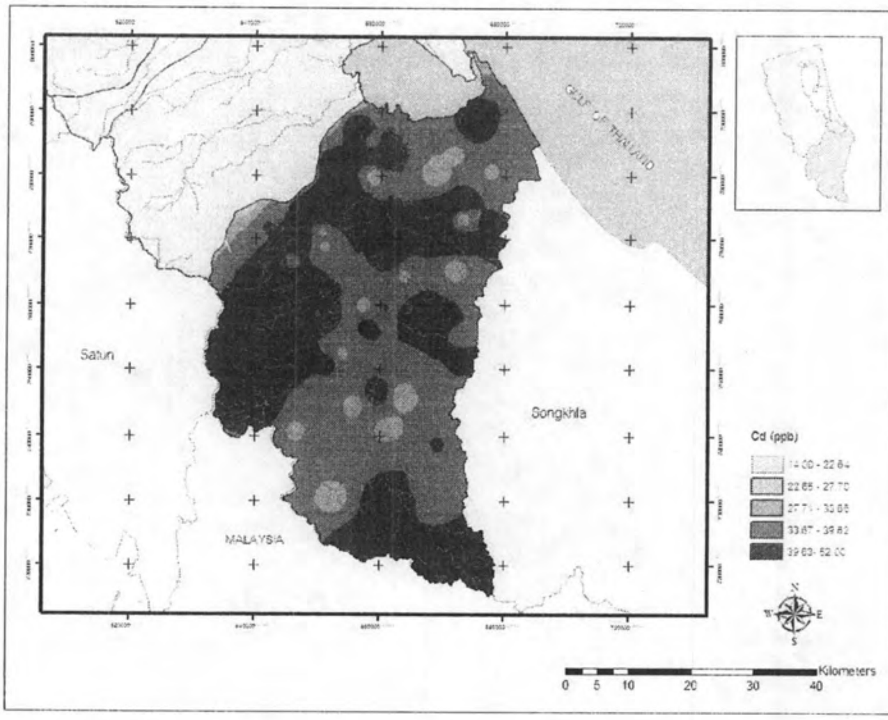

Figure 4-18 TREX result of U-Tapao and Eastern Coast Sub Basin 4 sub-watershed

4.1.10 Results of Eastern Coast Sub Basin 2 and 3 sub-watershed

There were no runoff and sediment loss data available for calibration, only observed phosphorus and cadmium within the area was available for validation. The model was created using estimates and assumptions taken from the other sub-watershed model parameter with similar physical characteristic. Validation results of phosphorus and cadmium are shown in table 4.19, and presented in Fig. 4.19 and Fig 4.20. For validation results, a relative error for phosphorus and cadmium were found between 5.4 – 23.8% and 11.2 – 92.0% respectively. Phosphorus concentration is distributed evenly throughout the sub-watershed, were mostly are paddy fields and shrimp farms. Cadmium is found mostly near paddy fields and near the rivers next to the lake.

Table 4-19 Validation results of phosphorus and cadmium in Eastern Coast Sub Basin 2 and 3 sub-watershed

Coordinate		P Observe (mg/kg dry soil)	AnnAGNPS	% Error	Cd Observed (µg/kg dry soil)	TREX	% Error
X	Y						
643619	833326	262.37	292.67	11.5	13	21	58.8
641975	833924	13.37	16.55	23.8	13	15	16.2
646823	839335	148.95	172.06	15.5	13	22	71.6
660134	819468	11.86	12.80	7.9	13	18	36.5
658092	826150	10.06	10.51	4.5	13	14	11.4
655620	834814	16.03	18.48	15.3	13	25	92.0
656790	835281	42.88	50.76	18.4	13	15	11.7
669000	799006	6.71	7.55	12.5	13	17	34.0
663536	805626	12.59	11.91	5.4	13	16	22.3
660387	811065	9.46	11.07	17.0	13	14	11.2

Note: X and Y are coordinates in WGS84 system zone 47

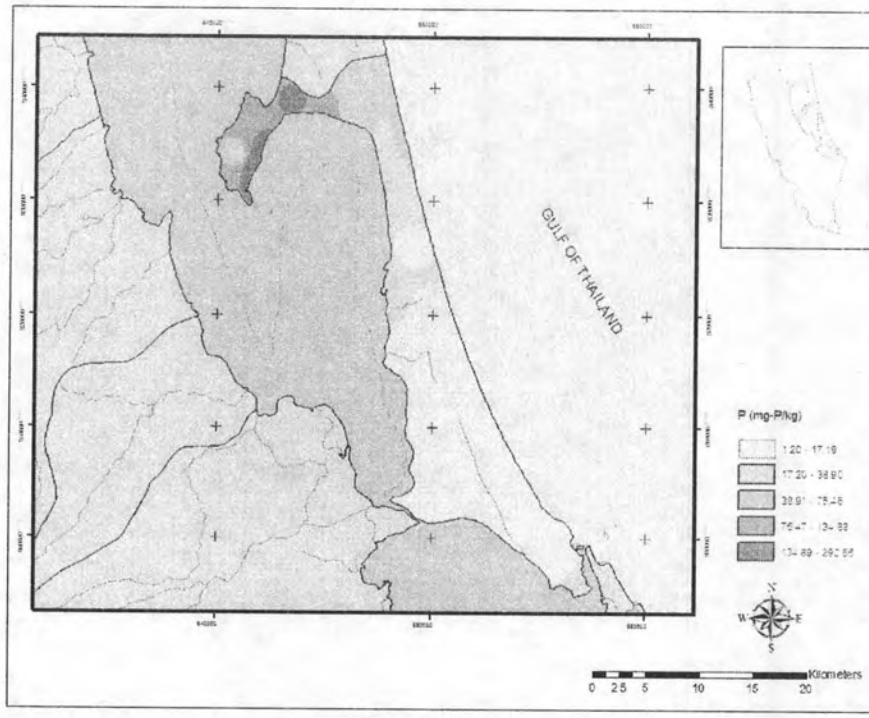

Figure 4-19 AnnAGNPS result of Eastern Coast Sub Basin 2 and 3 sub-watershed

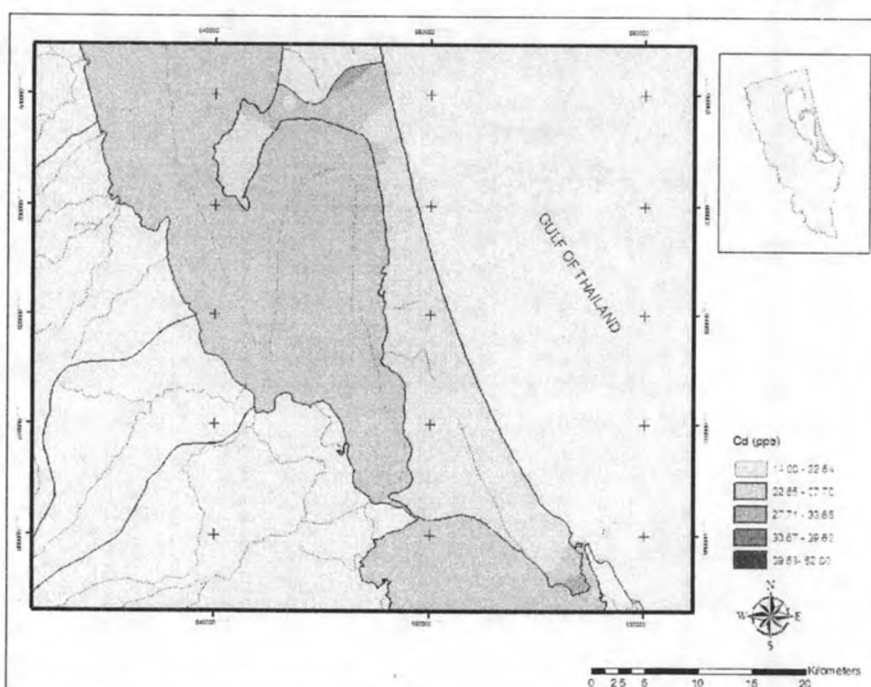

Figure 4-20 TREX result of Eastern Coast Sub Basin 2 and 3 sub-watershed

4.1.11 Results of Eastern Coast Sub Basin 1 sub-watershed

There were no runoff and sediment loss data available for calibration, only observed phosphorus and cadmium within the area was available for validation. The model was created using estimates and assumptions taken from the other sub-watershed model parameter with similar physical characteristic. Validation results of phosphorus and cadmium are shown in table 4.20, and presented in Fig. 4.21 and Fig 4.22. For validation results, a relative error for phosphorus and cadmium were found between 0.7 – 30.2% and 20.8 – 102.4% respectively. Phosphorus concentration is distributed evenly throughout the sub-watershed, were mostly are paddy fields and shrimp farms. Cadmium is found mostly near paddy fields and near the rivers next to the Gulf of Thailand.

Table 4-20 Validation results of phosphorus and cadmium in Eastern Coast Sub Basin 1 sub-watershed

Coordinate		P Observe (mg/kg dry soil)	AnnAGNPS	% Error	Cd Observed (µg/kg dry soil)	TREX	% Error
X	Y						
646833	842030	15.84	15.95	0.7	18	31	73.0
649610	844091	11.00	13.50	22.7	18	37	105.4
646245	845452	7.49	9.75	30.2	18	32	79.3
650682	848443	7.21	7.58	5.1	18	29	61.7
650551	851460	80.79	91.36	13.1	18	26	42.7
650889	856366	220.99	249.86	13.1	18	24	31.8
647742	858917	12.80	13.08	2.2	18	24	35.8
645176	863324	23.15	25.48	10.1	18	34	88.9
636115	865996	35.09	37.50	6.9	18	24	31.9
647285	866557	17.26	22.99	33.2	18	26	45.2
641240	867073	14.79	16.97	14.7	18	32	76.4
634964	869941	27.02	31.61	17.0	18	36	102.4
645365	870719	5.88	7.42	26.2	18	32	79.6
641124	871906	14.89	16.87	13.3	18	31	69.7
645928	875208	7.20	7.40	2.8	18	22	20.8
632342	874185	3.47	3.63	4.6	18	24	31.1
636675	876088	8.35	9.39	12.5	18	35	93.5
641921	876905	5.16	5.60	8.5	18	30	66.1
646778	880337	135.80	149.54	10.1	18	23	25.2

Note: X and Y are coordinates in WGS84 system zone 47

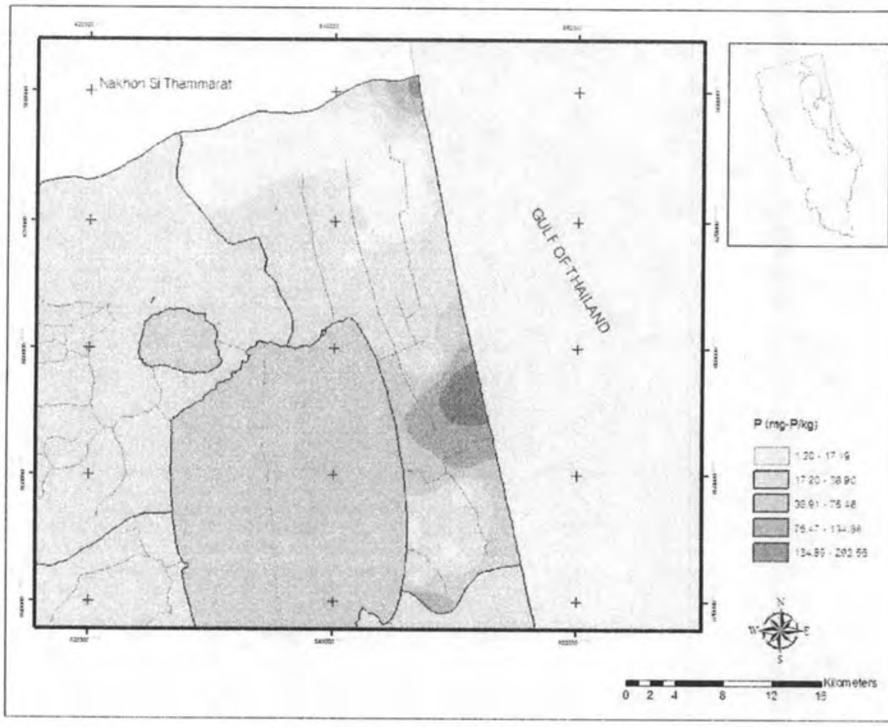

Figure 4-21 AnnAGNPS result of Eastern Coast Sub Basin 1 sub-watershed

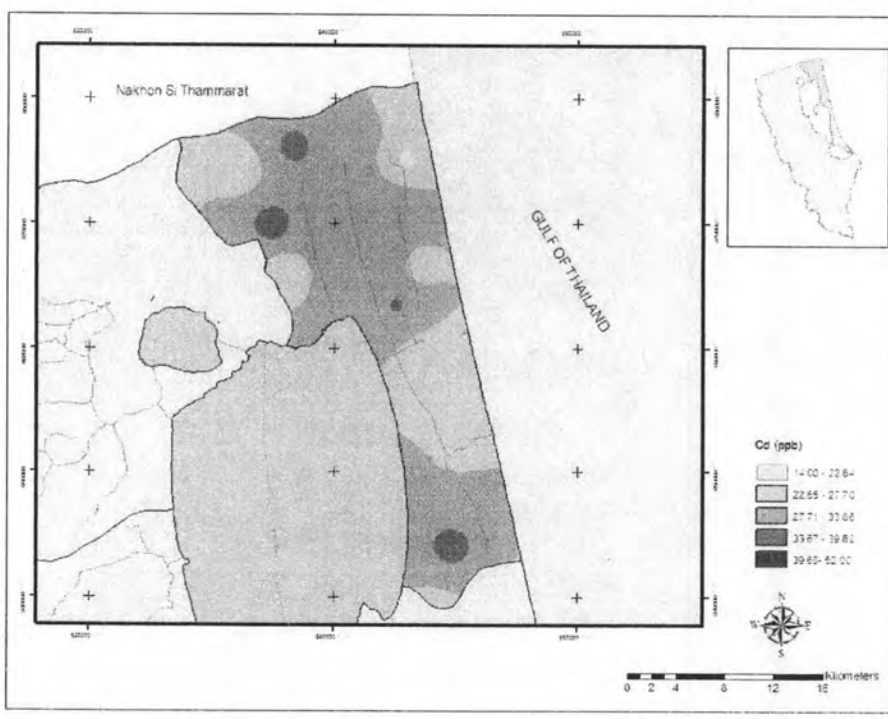

Figure 4-22 TREX result of Eastern Coast Sub Basin 1 sub-watershed

An overall picture of calibrated and validation points of the entire lake is shown in Figure 4-23 and Figure 4-24.

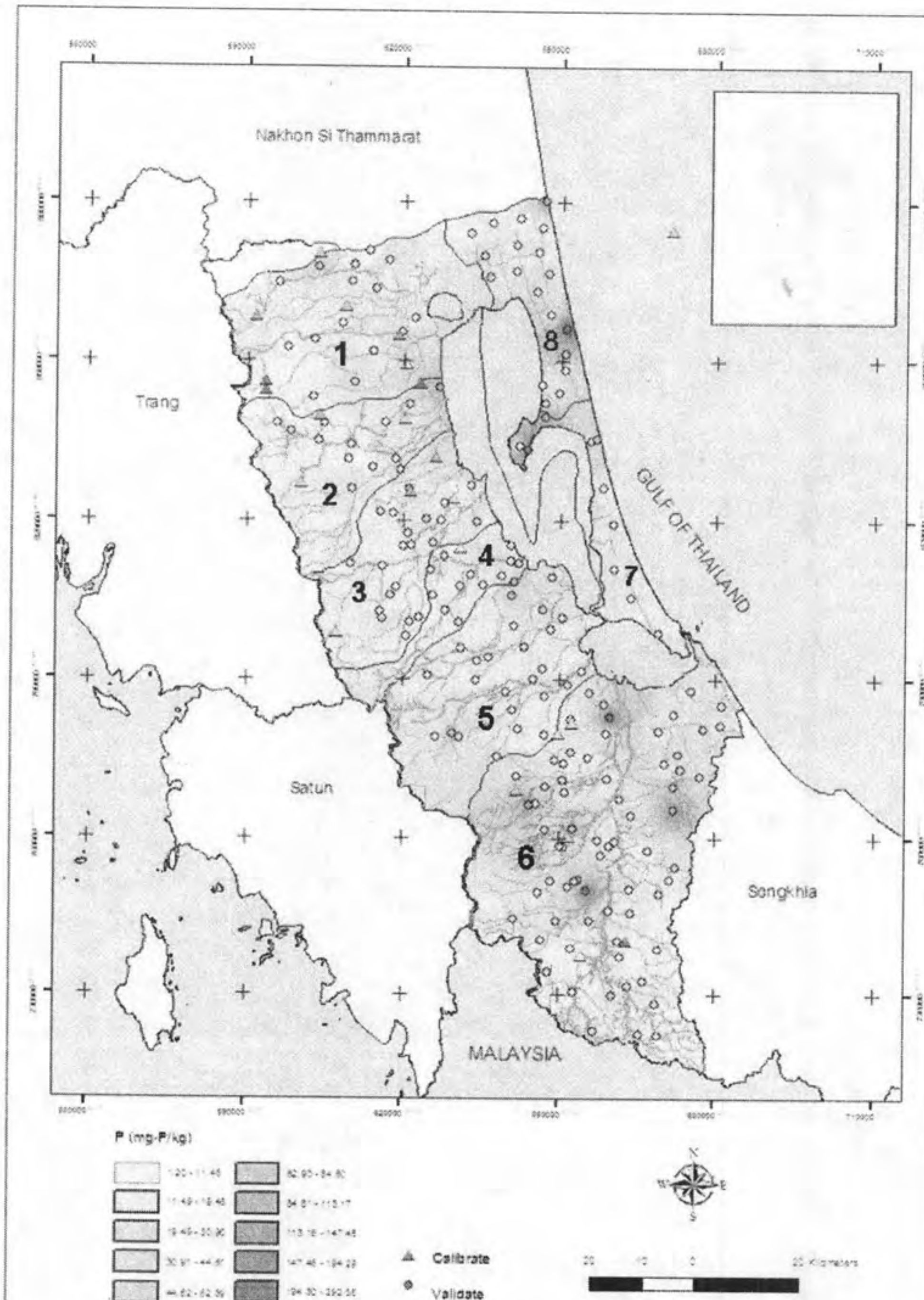

Figure 4-23 Phosphorus levels at calibration and validation points compared to model generated results

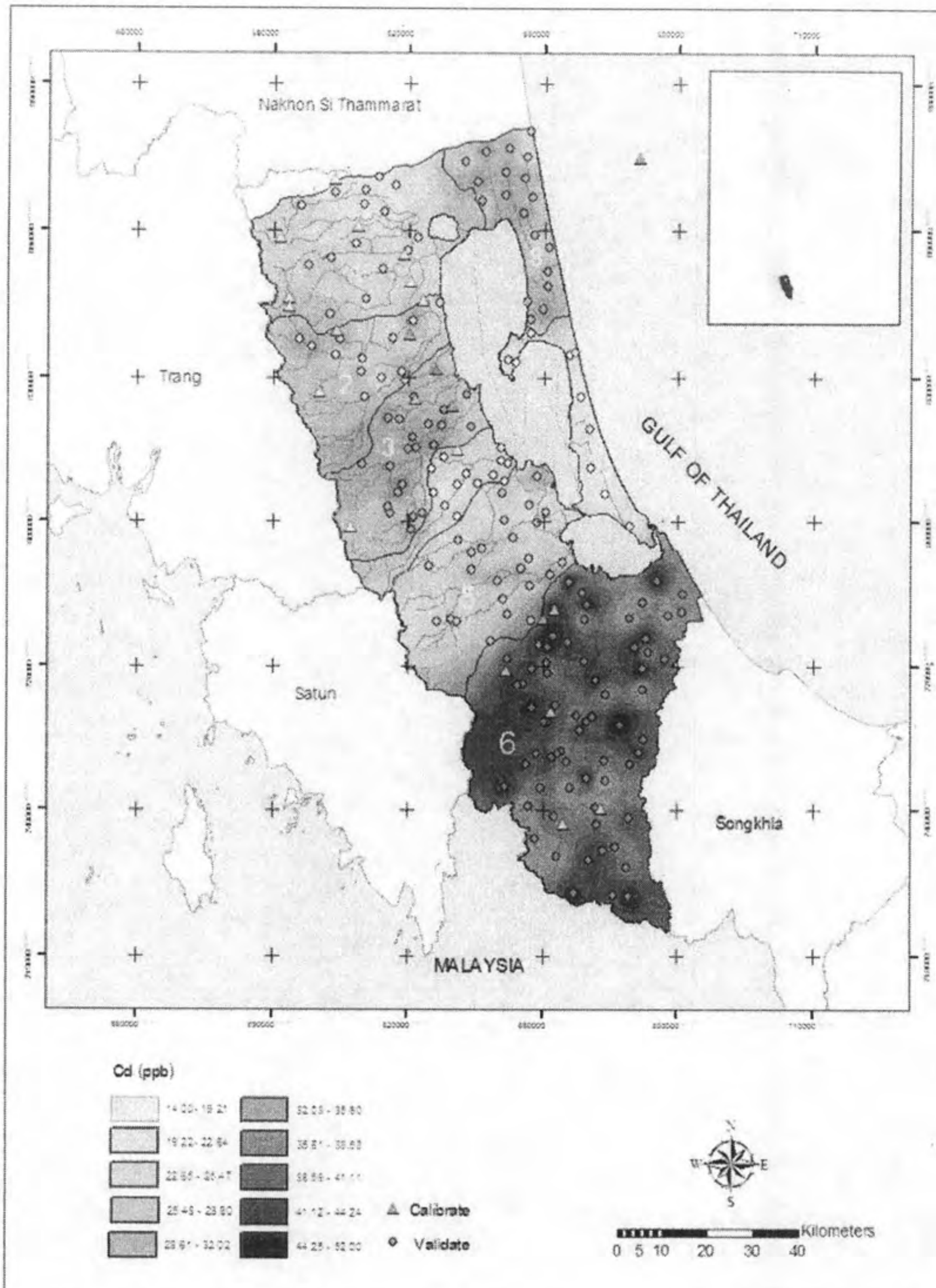

Figure 4-24 Cadmium levels at calibration and validation points compared to model generated results

4.2 PHOSPHORUS AND CADMIUM LOADING

From the simulation results, the phosphorus and cadmium contribution to the lake from each sub-watershed is summarized to find the relative loading of phosphorus and cadmium from various parts of the watershed. From Table 4-21, it clearly shows that almost one third of the phosphorus contribution occurred from U-Tapao and Eastern Coast Sub Basin 4 sub-watershed, followed by Klong Pa Payom & Thanae, Phru Poh & Rattaphum sub-watershed, with approximately equal relative contributions of 15.38 and 15.02% respectively. Similar parameters were also observed for cadmium. Recently, a study by Suviboon, (2006) and Leekpai, (2006) used analytic hierarchy process approach to identify the potential areas in SLB for phosphorus and cadmium transport via runoff. The factors in the study were runoff, soil erodibility (includes land form and slope gradient) organic matter, soil texture, land use, pH, available phosphorus and total metal. A summary of the correlation of the factors and the potential runoff is summarized in table 4-22. This study also shows that U-Tapao and Eastern Coast Sub Basin 4 sub-watershed has high runoff, horticultural crops, steep slope, high organic matter, high erosion, acidity, high clay percentage, and high total metal which lead to high potential runoff of phosphorus and cadmium similar to what is found from the model results (Table 4-21).

Table 4-21 Phosphorus and cadmium relative loading

Sub-watershed	Phosphorus (tons/Year)	Phosphorus relative loading (%)	Cadmium (kg/Year)	Cadmium relative loading (%)
Klong Pa Payom and Thanae	6,422	15.38	42	15.38
Nathom	4,194	10.05	27	9.89
Tachiad	4,263	10.21	28	10.25
Pa Bon	1,820	4.36	12	4.39
Phru Poh and Rattaphum	6,271	15.02	41	15.01
U-Tapao and Eastern Coast Sub Basin 4	14,195	34.00	93	34.06
Eastern Coast Sub Basin 2 and 3	1,876	4.49	12	4.39

Sub-watershed	Phosphorus (tons/Year)	Phosphorus relative loading (%)	Cadmium (kg/Year)	Cadmium relative loading (%)
Eastern Coast Sub Basin 1	2,704	6.48	18	6.59
Total	**41,745**	**100**	**273**	**100**

Table 4-22 Correlation of factors with potential of phosphorus and cadmium runoff

Factors	phosphorus	cadmium
Runoff	+	NA
Soil erodibility	+	+
Organic matter	+	+
pH	-	-
Clay	NA	+
Land use (C)	+	NA
Available phosphorus	+	NA
Total metal	NA	+

Notes: Compiled from Suviboon (2006) and Leekpai (2006)

+ indicates direct variation, - indicates opposite variation.