CHAPTER III

MODEL DEVELOPMENT

This chapter describes the methodology of the research in each part; data preparation, modeling and simulation, decision scenario testing. Both spatial data and attribute data are required to study the fate and transport of phosphorus and cadmium in the basin. Fertilizer utilization and distribution determine the availability of phosphorus and cadmium in top soil, Substance Flux Analysis (SFA) method is applied to estimate the availability and spatial distribution of phosphorus and cadmium on the watershed surface. Their transport amount via surface runoff and sediment flow is then estimated using AnnAGNPS and TREX models respectively. Both spatial and attribute data, input and results are stored and displayed in GIS ArcView to facilitate scenario analysis and decision making.

3.1 FERTILIZER UTILIZATION AND DISTRIBUTION

The pollutant loads from the catchments on a cell-by-cell basis are important input to spatially distributed pollutant transport models. Therefore the loads need to be estimated as accurately as possible.

There are several methods available that can be used to refine estimates of phosphorus and cadmium loading. For this research, the model used should be able to determine the problem-causing mechanism in an operational fashion in the sense of having low data demand and being easy to construct and run in practice. Substance Flux Analysis (SFA) was selected in this research because SFA uses an input-output analysis of material or substance compared to Life Cycle Analysis (LCA) (Curran, 1996), which focuses on the function of a product, not on the amount of the product. Material Flow Analysis (MFA) (Leontief, 1966) treats the system as a blackbox whereas SFA tracks the processes within the system. The Partial Economic equilibrium Analysis (PEA) (Cropper and Oates, 1992) method not only tracks the process within the system, but also performs an economic analysis making it a more complex method. Therefore, in this study, SFA is used to refine the previously available estimates of loading. This will be then facilitating the modeling effort by improving the quality of the major input to non-point source pollution transport models.

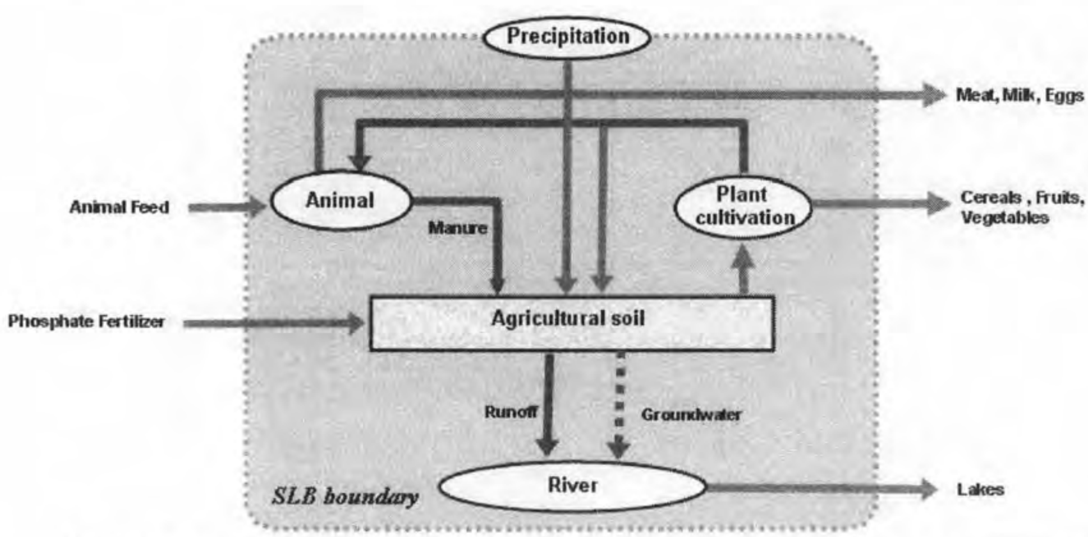
As a first step, the method is applied to the whole basin as a lumped system for evaluating the applicability of the method. A total of 86 interviews covering all of the 3 provinces including farmers, fertilizer resellers, cooperatives, and government officials were carried out. Thirty-five fertilizer samples were also collected from wholesalers, resellers and farmers for laboratory testing of phosphorus and cadmium amounts.

Accumulation of phosphorus and cadmium on agricultural soil via phosphate fertilizer, feed for swine, manure from swine farming, and precipitation was considered potentially significant. Phosphorus and cadmium stored in soil can be taken up by plants, released to air, leached to groundwater, and/or washed off by surface runoff. Losses of phosphorus from agriculture leaching into groundwater are only trace amounts (ACIAR, 1998) and are below detectable limit even in predominantly agricultural regions. Previous studies have also found that levels of cadmium in lower soil layers are below detection limit (Arrykul, 1991). However, runoff due to rain events can be a main carrier of phosphorus and cadmium transport from the system. The only significant pathways leading to the lake are runoff and direct precipitation on the surface of the lake.

A general framework for SFA consists of four steps (Lassen and Hansen, 2000 and Brunner and Rechberger, 2003): *1) define goal and system definition; 2) system analysis; 3) inventory, evaluation of data, and calculations; and 4) interpretation of the results*:

1) Goal and System Definition

The goal is to obtain reliable estimates of phosphorus and cadmium loading to Songkhla Lake via surface runoff from the catchments of the basin. The system for this study is the catchment area of Songkhla Lake. Though the catchments may have other land uses, this study focuses only on agricultural land use. The spatial boundary for the study is the physical boundary of the catchments with a total land area of 7,687 km^2. The time boundary for this study is the one-year period of 2004. Goods containing phosphorus and cadmium, which passed through relevant processes in the SLB over the one-year period of 2004 were examined (Figure 3.1). Entry of phosphorus and cadmium into agricultural soil was considered to be potentially significant via: 1) phosphate fertilizer (Emsong, 1999a, Sompongchaiyakul, P., 2005); 2) feed for swine (LDO, 2002 and REO 12, 2002a); 3) manure from swine farming (Kornegay and Harper, 1997 and NRC, 1998); and 4) precipitation (Srimechai, 1992, Ramessur, 2000; WRM, 2002; and Lawlor and Tipping, 2002). The soil within SLB can be described as being of moderate to poor fertility and poorly drained (EmSong, 1999b).



Legend: arrows represent flows; box, sub-system; ellipses, processes and a dash line, boundary.

Figure 3-1 SLB Boundary

3.1.1 System analysis

In general, the soil in peninsular Thailand was found to have relatively low phosphorus content: 2-3.5 mg/kg of available phosphorus and 39-162 mg/kg of total phosphorus. A slightly higher level of phosphorus, 145-238 mg/kg of total phosphorus has occasionally been found, with content decreasing with soil depth. The majority of the phosphorus in these soils (48 - 71%) is organic (Onthong, 1999) and is therefore not available for plant uptake. There are many emission pathways for phosphorus and cadmium into the environment. Phosphorus and cadmium stored in soil can be taken up by plants, released to air, leached to groundwater, and washed off by surface runoff.

The source of phosphorus for plant growth is present as orthophosphate in soil. Agricultural crops generally take up only 5-10% of phosphorus applied as fertilizer in the first year, with uptake gradually decreasing in the following years (Greenwood *et al.,* 1980). Plant refuse within the area is also used as animal feed (LDO, 2002) and as manure. Runoff in the SLC is estimated as 4.896×10^9 m^3/y (REO 12 and OEPP, 1997). Phosphorus and cadmium losses through runoff were calculated using an average content of 0.3 mg/l for phosphorus (Phutmongkhon *et al.*, 2000), and 0.0005 mg/l for cadmium (Hat-Yai Nakhon Municipality, 2003). Runoff due to rain event can be the main carrier for transporting phosphorus and cadmium for the system through overland flows and rivers.

3.1.2 Inventory, evaluation of data and calculations

Phosphorus and cadmium through each product and process line, represented in the flow diagram need to be estimated (Fig 3-1). Data from various sources, both primary and secondary, will be compiled to establish a database of sources, amounts and stock values of phosphorus and cadmium in the system products and processes. The information obtained from the calculated data will be evaluated and interpreted for use in the transport modeling. Quantities of phosphorus and cadmium consumed in the products and processes of the SLB are shown in Table 3.1. Phosphorus and cadmium in product and processes are shown in Tables 3.2 and 3.3 respectively. The information was then integrated with data on concentrations of substances recorded in the SLB.

1) Phosphate fertilizer

Application of phosphate fertilizers could increase significant amount of cadmium content of many agricultural soils because they came from phosphate rock, in which cadmium is a common content. The use of cadmium-containing fertilizers is frequently referred as the primary source for the increase of cadmium content in soils over the past 20 to 30 years in Europe (Davister, 1996). The amount of phosphorus entering system by phosphate fertilizer was calculated by first identifying the fertilizer utilization in each province shown in Fig. 3-2 and Fig. 3-3.

$$Fertilizer\ utilization = Area*Application \qquad (3\text{-}1)$$

where: Area = Planting area for crop (acre)

Application = Fertilizer application rate in each crop (kg/acre/year)

Then, the amount of phosphorus and cadmium is calculated based on laboratory analysis for each fertilizer;

$$Substance\ Flow = Fertilizer\ utilization * Substance\ concentration \qquad (3\text{-}2)$$

where: Fertilizer utilization = Amount of fertilizer applied in the area (ton/year)

Substance concentration = Concentration of substance of interest (%)

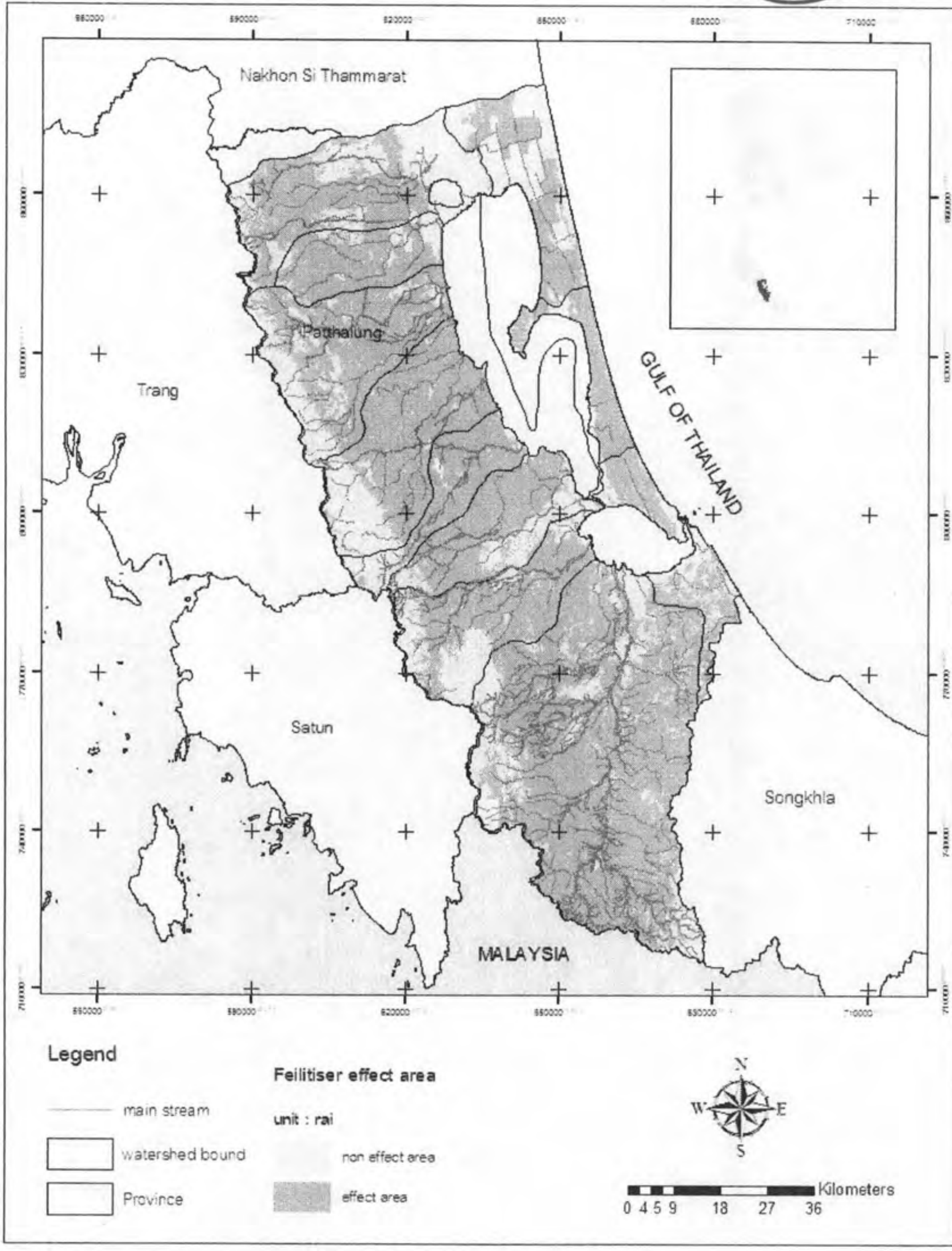


Figure 3-2 Plantation area

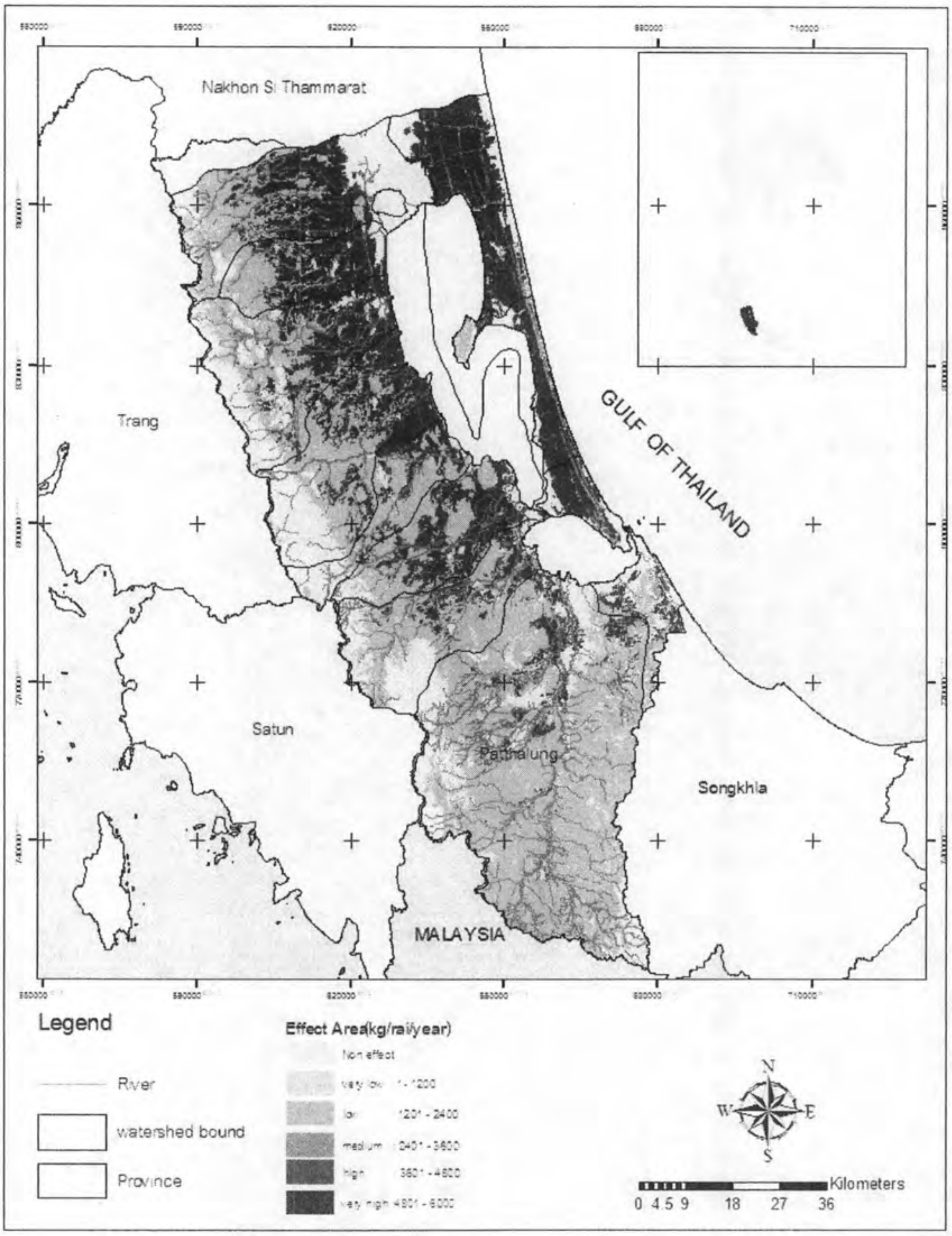


Figure 3-3 Fertilizer utilization

2) Feed and manure from swine farming

Most animal feeds require additional phosphorus from supplemental sources. The major types of phosphorus supplement are calcium phosphates, ammonium phosphates, sodium phosphates, and phosphoric acid (NRC, 1980). Syers and Cisse (2001) reported that metals are not always as well absorbed as soluble forms in swine. Thus, phosphorus and cadmium entering the system by feed in swine is calculated by multiplying the number of swine in the area with the amount of feed consumed and the amount of phosphorus and cadmium in the feed. A study by Kornegay and Harper (1997) indicated that swine utilized 20-50% of phosphorus in feed and excreted the remaining amount in manure. Phosphorus and cadmium in manure is then calculated from the number of swine multiplied by the average manure produced per animal and the amount of phosphorus and cadmium in the manure.

3) Precipitation

In general, cadmium content in atmosphere is very low except at certain locations close to smelters or some significant industrial and urban emission sources. In SLB area, only 2% of it is settlement soil and there is no intensive industrial zone in the catchment. Cadmium contents have been found in precipitation elsewhere, for example Malaysia, (<1 μg/l), Japan (300 μg/ml), Northern England (0.01μg/l), and Mauritius (ND < 90 μg/ml) (Ramessur, 2000; WRM, 2002; and Lawlor and Tipping, 2002). Phosphorus and cadmium from precipitation is calculated by multiplying an average precipitation rate with the area and the phosphorus and cadmium in the precipitation.

4) Accumulation of phosphorus and cadmium in agricultural soil

The soil within SLB can be described as moderate to poor fertility and poorly drained. In general, the soil in peninsular Thailand was found to have relatively low phosphorus content: 2-3.5 mg/kg of available phosphorus and 39-162 mg/kg of total phosphorus. A slightly higher level of phosphorus, 145-238 mg/kg of total phosphorus, has occasionally been found, with decreasing content with soil depth. The majority of phosphorus in these soils (48-71%) is organic (Onthong *et al*., 1999) and is therefore not available for plant uptake. Amount of phosphorus and cadmium in agricultural soil is calculated by multiplying the soil mass with the phosphorus and cadmium contents in agricultural soil.

5) Plant cultivation

The source of phosphorus available for plant growth is present as orthophosphate in soil. Cultivated crops generally take up only 5-10% of phosphorus applied as fertilizer in the first year, with gradually decreasing uptake in the following years (Greenwood *et al.*, 1980) and 90% of phosphorus uptake by plant comes from residual phosphorus in soil. Phosphorus from freshly applied fertilizer cannot compensate for a low soil phosphorus status (Johnston *et al.*, 1986), since in general more than 80% of applied phosphorus becomes immobile and unavailable for plant uptake due to adsorption, precipitation, or conversion to organic form (Holford, 1997). Plant debris within the area is used as animal feed (LDO, 2002) and as manure. Phosphorus and cadmium going to cultivated plant is calculated from the total phosphorus/cadmium entering the agricultural soil multiplied with the amount uptake by plant.

6) Losses of phosphorus and cadmium through runoff

Phosphorus and cadmium in the river is calculated by multiplying the quantity of SLB surface water runoff with the phosphorus/cadmium in the surface water runoff. Runoff in the SLB is estimated as 4.896 x 10^9 m^3/year (REO 12 and OEPP, 1997).

The planting area for crops in each province is shown in Table 3.4. A compilation of fertilizer used for each crop is shown in Table 3.5. Calculation of fertilizer utilization based on Eq. 3.1 and Eq. 3.2 is shown in Table 3.6.

Table 3-1 System parameters and their characteristics

Product / Process	Consumption/Quantity	Unit	Reference
1. Chemical fertilizer			
- 8-24-24, 13-13-21, 15-15-15 and 16-16-16 formula	4,965	t/y	Sareewatthanachai, 2003
- other formulae	55,307	t/y	Srisai, 2002
2. Number of swine	226,390	head	LDO, 2002 and REO 12, 2002a
3. Feed for swine	1.5	g/head/d	NRC,1998
4. Precipitation	1,880	mm/y	EmSong, 1998
5. Agricultural soil area	5,691	km^2	ICSLB, 2002
6. Runoff	$4,896 \times 10^6$	m^3/y	REO 12 and OEPP, 1997

Table 3-2 Phosphorus in product systems and processes

Product / Process	Content / Conc.	Unit	Reference
1. Chemical fertilizer			
- SLC: 8-24-24, 13-13-21, 15-15-15 and 16-16-16 formula	9.8, 6.4, 6.8, and 7.3, respectively.	%	Sae-Eong *et al.*, 2002
2. Feeds for swine			
- general	7	g/head/d	NRC, 1998
3. Manure from swine farming	50 - 80	%	NRC, 1998
4. Precipitation			
- Agricultural areas of Amphoe Hat-Yai, Songkhla	0.03	mg/l	Srimechai, 1992

Product / Process	Content / Conc.	Unit	Reference
5. Agricultural soil			
- major soil in Thailand	1 - 76 (available P)	mg/kg	Primsirikul and Matoh, 2003
	38 - 1,137 (total P)	mg/kg	
- Peninsular Thailand	2 - 3.5 (available P)	mg/kg	Onthong, 1999
	39 - 238 (total P)	mg/kg	
- SLC	24 - 288 (total P)	mg/kg	Sae-Eong *et al.*, 2002
6. Plant cultivation			
- general	5 - 10	%	Greenwood *et al.*, 1980
7. Runoff			
- Klong U-Tapao	0.002 - 0.40	mg/l	Phutmongkhon *et al.*, 2000
- Klong Ranot	3.91 - 6.53	mg PO_4/l	Phutmongkhon, 1994
- Rajjaprabha Dam Reservoir			
0-25 m	ND - 0.36	μM	Sompongchaiyakul and
> 25 m	0.14 - 0.68	μM	Ridchuayrod, 2003
- Tapi-Pumduang basin	< 0.01 - 0.18	mg/l	PCD, 2000

Table 3-3 Cadmium in product systems and processes

Product / Process	Contents / concentration	Unit	Reference
1. Chemical fertilizer			
- SLC : (8-24-24, 13-13-21, 15-15-15 and 16-16-16 formula)	1.4, 1.4, 30.1, and 1.4 , respectively.	mg Cd/kg	Sae-Eong *et al.*, 2002
2. Feeds for swine	0.18-0.32	ppm	NRC, 1980
3. Manure from swine farming	0.32	ppm	NBP, 2001

Product / Process	Contents / concentration	Unit	Reference
4. Precipitation			
- SLC	$1.63x10^{-4}$ - $2.23x10^{-3}$	ppm	Kanatharana and Chareonchatchai 1985
- Mauritius	ND < 90	μg/l	Ramessur, 2000
- Malaysia	< 1	μg/l	WRM, 2002
- Northern England	0.01	μg/l	Lawlor and Tipping, 2002
5. Agricultural soil			
- other parts of the world	0.06 - 1.1	mg/kg	Kabata and Pendias, 1992
- SLC	< 0.001 – 0.089	mg/kg	Sae-Eong *et al.*, 2002
- in each region of Thailand	0.001 - 0.294	mg/kg	Pongsakul and Attajarusit, 2002
6. Runoff			
- Klong U-Tapao	0.00274	mg/l	Atipairin, 1994
- Klong Wat	0.002 - 0.005	mg/l	Suwannarath, 1994
- Klong Kud, Klong Teuy, and Klong U-Tapao	ND (< 0.0005) - 0.003	mg/l	Hat-Yai Nakhon Municipality, 2003

Table 3-4 Planting area for crops having fertilizer application in 3 provinces (acre)

Sub-Province	Phatthalung	Nakhon Si Thammarat	Songkhla
Rubber	281,753	497,762	721,260
Rice	202,493	272,925	165,994
Mangosteen	6,704	30,264	1,605
Palm Oil	732	13,728	6,130
Rambutan	3,672	25,888	1,352
Durian	2,828	17,860	5,580
Longan	7,520	11,379	5,274
Pamelo	880	7,247	2,453

Source: Agricultural Provincial Office Phatthalung, 2004

Agricultural Provincial Office Nakhon Si Thammarat, 2004

Agricultural Provincial Office Songkhla, 2004

Table 3-5 Fertilizer application rate in each crop

Crop	Fertilizer Formula*	Application Rate (kg/acre/year)	Spatial Distribution in Phatthalung	Spatial Distribution in Nakhon Si Thammarat	Spatial Distribution in Songkhla
Young rubber (<6 years)	16-8-4 15-7-8	125	Pabon	Tungsong	Sadaow
Old rubber	20-8-20	250	Pabon	Chaaud	Sadaow
Rice	16-20-0	250	Muang, Kwankanoon	Haisai	Ranote, Satingpra
Mangosteen	15-15-15	250	Tamote	-	-
Palm Oil	25-7-7	125	Bangkaew	Tungsong	Klonghoikong
Rambutan	15-15-15	250	Piboon	Tasala	

Crop	Fertilizer Formula*	Application Rate (kg/acre/year)	Spatial Distribution in Phatthalung	Spatial Distribution in Nakhon Si Thammarat	Spatial Distribution in Songkhla
Durian	15-15-15	250	Piboon	Tasala	
Longan	15-15-15	125	Piboon	Tasala	
	8-24-24	125	Piboon	Tasala	
	13-13-21	125	Piboon	Tasala	
Pamelo	15-15-15	250	Kauankanoon	Hwaisai	Singhanakorn

Source: Interviewing of farmers and fertilizer dealers.

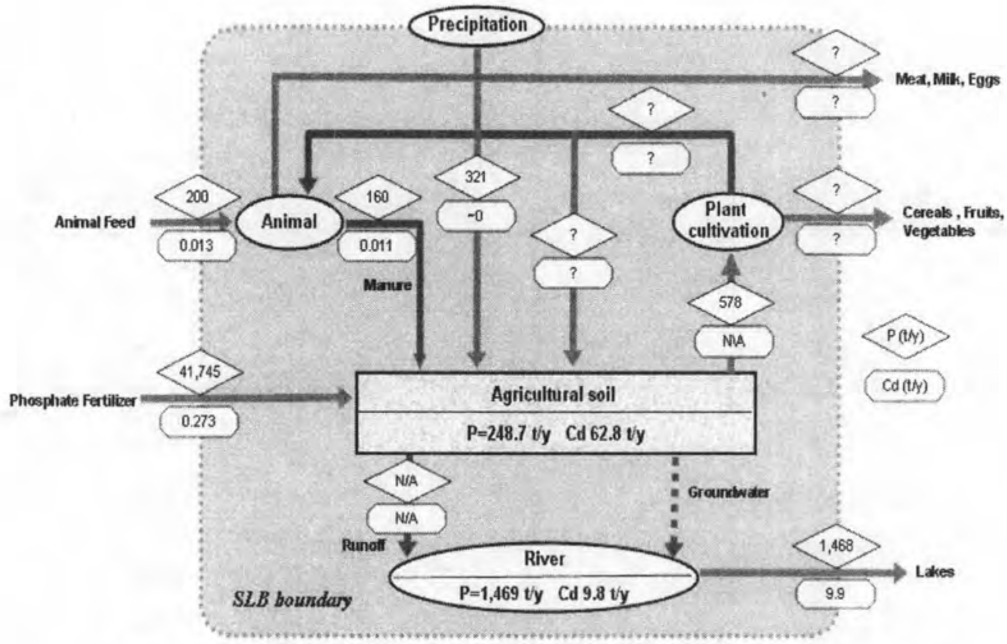
*The formula represents the value of N-P-K concentration

Table 3-6. Fertilizer utilization (ton/year)

Fertilizer Formula	Phatthalung	Nakhon Si Thammarat	Songkhla	Phosporous (Ton/year)
16-8-4	4,402	7,778	11,270	6,700
15-7-8	4,402	7,778	11,270	5,472
20-8-20	52,829	93,330	135,236	80,399
16-20-0	50,623	68,231	41,498	37,416
25-7-7	92	1,716	766	2,679
15-15-15	2,996	19,502	15,605	12,843
8-24-24	313	2,971	13,059	5,448
13-13-21	313	2,971	13,059	5,448
Total	**115,970**	**204,277**	**241,763**	**156,405**

3.1.3 Interpretation of the results

A total of 86 interviews including farmers, fertilizer dealers, cooperatives, and government officials were carried out in 3 provinces. Thirty five fertilizer samples were also collected from wholesalers, resellers and farmers for laboratory analysis of phosphorus and cadmium. The weak acid (2 M HNO_3) leaching method was used to extract metals from the fertilizer samples. Subsequently an inductively coupled plasma-optical emission spectroscopy on a Perkin-Elmer ICP-OES Optima 2000 DV instrument was used to determine cadmium. Recent cropping area and land use data was obtained from government agencies. Based on the planting area for each crop, fertilizer utilization rate for Phatthalung, Nakhon Si Thammarat, and Songkhla were 115,970, 26,556 and 241,763 ton/year respectively. This finding was similar to information obtained from agricultural fertilizer dealers and private organizations such as Bank of Agriculture and Agricultural Cooperatives (BAAC) in the provinces. Thus, 41,745 ton/year of phosphorus, and 273 kg/year of cadmium from phosphate fertilizer would be more precise values. Also, the stock calculation for phosphorus and cadmium were revised to be 248.7 and 62.8 ton/year respectively (Fig 3-4). The remaining amount of phosphorus in the system could go with soil erosion. An estimate of average rate of soil loss increased from 4.9 ton/ha*year in 1982 to 7.2 ton/ha*year in 1996 (Masaharu *et al.,* 2000, Pornpinatepong, *et al.,* 2005). Songrukkiat, (2006) reported that up to eight percent of SLB experienced a rate of soil loss of more than 5 ton/rai/year. The rate of soil loss is higher in greater slope or rubber area. A report of sediment lost in each sub watershed was recently released by the Land Development Department (Table C-3). Thus, it can be assumed that the remaining fate of phosphorus in the system could have transported with soil erosion. Phosphate contribution by urban waste water was treated as a point source to the river, however, magnitude was much lesser comparing with fertilizer application.



Legend: arrows represent flows; box, sub-system; ellipses, processes and a dash line, boundary.

Figure 3-4 SFA of phosphorus and cadmium in SLB (t/y)

Entry of phosphorus and cadmium into agricultural soil was found to be potentially significant via three products and one process line: 1) phosphate fertilizer; 2) feed for swine; 3) manure from swine farming; and 4) precipitation. These entry points are discussed below.

1)Phosphate fertilizer

This study found that approximately 562,010 ton/year of phosphate fertilizer was applied in the SLB agricultural soil in the 2004, whereas Sereewatthanachai (2003) reported only 55,307 ton/year in 2002. Information obtained through interviewing SLB dealers revealed the fertilizer formulae (N-P-K) used as 16-8-4, 15-7-8, 20-8-20, 16-20-0, 25-7-7, 15-15-15, 18-24-24 and 13-13-21. The formulae 20-8-20 and 16-20-0 were the main ones used in paddy fields and old rubber plantation. Sereewatthanachai (2003) reported that only 4 formulae which are 8-24-24, 13-13-21, 15-15-15 and 16-16-16 were used in the area while other formulae were also noted in her report without analysis. Phosphorus contents from analysis of fertilizer samples were 8.3, 6.5, 7.4, 16.8, 6.4, 13.2, 20.2, 10.1 percent, respectively; cadmium content in phosphate fertilizer (P_2O_5) were 1.5, 1.6, <1.4, <1.4, <1.4, <1.4, 7.19, 1.4 mg-Cd/kg respectively. Sereewatthanachai (2003) found that phosphorus contents in the formulae investigated were 9.8, 6.4, 6.8, and 7.3 percent, respectively; cadmium content in phosphate fertilizer (P_2O_5) were 1.4, 1.4, 30.1, and 1.4 mg Cd/kg, respectively. On the basis of annual consumption of fertilizer entering the SLB agricultural soil, phosphorus content was found to be around 41,745 ton/year and cadmium content in phosphate fertilizer (P_2O_5) was approximately 0.273 ton/year. This suggests that fertilizer applied to SLB soil is relatively clean with respect to cadmium.

2)Feed for swine and Manure from swine farming

This study found that feed for swine contributed 200 ton/year for phosphorus and 0.013 ton/year for cadmium into the system.

3)Manure from swine farming

By having the maximum of 80 percent phosphorus uptake from feed, 160 ton/year was estimated to be in manure as direct input to soil. Cadmium content in swine manure was found to be 0.32 ppm (NBP, 2000), thus giving a total input of cadmium to SLB in this study around 0.011 ton/year.

4)Precipitation

The range of atmospheric phosphorus input in different areas can vary widely, from 5 kg/km^2/year to over 100 kg/km^2/year (Ryden *et al.*, 1973). Review result from this study revealed that the average precipitation in the SLB is 1,880 mm/year (EmSong, 1998) and phosphorus concentration in the precipitation is around 0.03 mg/l (Srimechai, 1992). Thus the phosphorus loading from precipitation is estimated to be around 321 ton/year. If a concentration of 0.01 μg/l is assumed on the basis of reports mentioned, cadmium accumulation resulting from precipitation could be around 0.11 ton/year.

The result also showed that cadmium has a possibility of accumulating in the system (agricultural soil and river) due to unbalanced of input and output sources of which later could enter into other boundary (plant cultivation and animal) and could pose a risk to human by exposure. Based on SFA finding, policy setting up, for example, minimizing or controlling of cadmium entering into the system by phosphate fertilizer could be efficiently initiated in the future.

3.2 MODELING AND SIMULATION

The modeling and simulation part is used to predict the amount of phosphorus and cadmium transport through run off water and sediment. Based on the literature review, TREX is the only model which can handle metal transport via runoff. However, for nutrients transport via runoff, AnnAGNPS is the most widely used model in agricultural watersheds. Therefore, these two models are both used in this research, AnnAGNPS for predicting phosphorus transport; and TREX for predicting cadmium transport.

3.2.1 Input Data Preparation

1) Map and boundary of Phatthalung, Nakhon Si Thammarat and Songkhla province.

2) Digital Elevation Model (DEM) of Phatthalung, Nakhon Si Thammarat and Songkhla province with resolution 30mx30m and 100mx100m.

3) Accumulated rain fall, number of rainy days, and monthly average rain intensity for the past 30 years (B.C. 2517 – 2546) of every weather station located in Phatthalung, Nakhon Si Thammarat and Songkhla provinces from Thai Meteorological Department.

4) Land use of Phatthalung, Nakhon Si Thammarat and Songkhla provinces year B.C. 2543 from Land Development Department.

5) Soil and Soil shape profiles of Phatthalung, Nakhon Si Thammarat and Songkhla provinces from Land Development Department.

6) LANDSAT satellite image with 30x30m of Phatthalung, Nakhon Si Thammarat and Songkhla province year B.C. 2543.

7) Rivers and streams of Phatthalung, Nakhon Si Thammarat and Songkhla province year B.C. 2543 , from Southern Regional Geo-Informatics and Space Technology Centre, Prince of Songkla University.

8) Calibration sampling points, Fig. 3-5 (Sea-Eong *et.al.*, 2002).

9) Validation sampling points, Fig. 3-6 (Suviboon *et al.,* 2006; LDD, 2006).

3.2.2 AnnAGNPS Modeling

AnnAGNPS will be used to trace fate and transport of phosphorus in the catchments. A model is created using the following inputs;

1) Input Data Preparation including DEM 30m x 30m, Land use and Soil shape files, Land cover (crops types) & Land use practices, Fertilizer application, RUSLE file (Info/ Parameters related to crops & field operations), Climate data from local weather station.

2) Delineation of Watershed: Input requirement DEM, Processes: creation of watershed boundary and cells, Output: Cell & Reach data.

3) Extraction of Dominant Soil and Land Use ID's. Input requirement: Soil and land Use shape files. Output: Dominant Soil and Land Use ID's in each cell.

4) Enter detailed information relevant to each Dominant Soil and Land Use ID's and other required datasets in Input Editor.

GEM is used to generate climate data for AnnAGNPS in the required format, followed by executing model to generate results. The model will be calibrated using runoff, sediment loss, and historical phosphorus level and then validated with a new set of validation data, obtained results with measured phosphorus level collected from field.

3.2.3 TREX Modeling

TREX will be used to trace the fate and transport of cadmium in the catchments. A model is created using the following inputs;

1) Input Data Preparation including DEM, Land use and Soil shape files, Land cover (crops types) & Land use practices, Fertilizer application and Extraction of Dominant Soil and Land Use ID's. Input requirement: Soil and land Use shape files. Output: Dominant Soil and Land Use ID's in each cell, exported as ASCII file used as input for TREX.

2) Delineation of Watershed: Input requirement DEM 100m x 100m, Processes: creation of watershed boundary and cells, Output: Cell & Reach data. The reason for using 100m x 100m is to generate grids cells not larger than 30,000 to 50,000 grid cells in the model.

The results of the model runs will then be imported into GIS. The model will be calibrated using runoff, sediment loss, and historical phosphorus level and then validated with a new set of validation data, obtained results with measured phosphorus level collected from field.

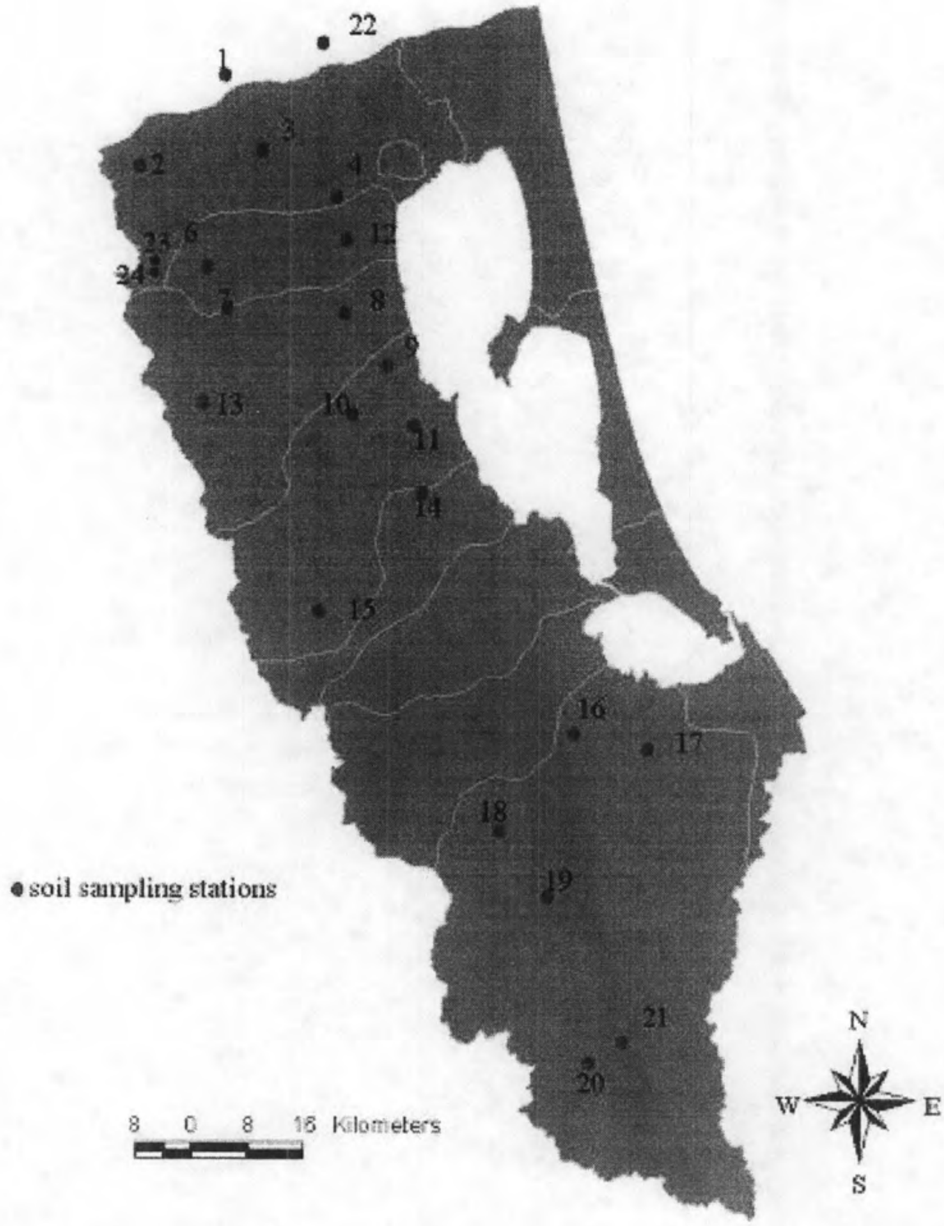


Figure 3-5 Calibration sampling points

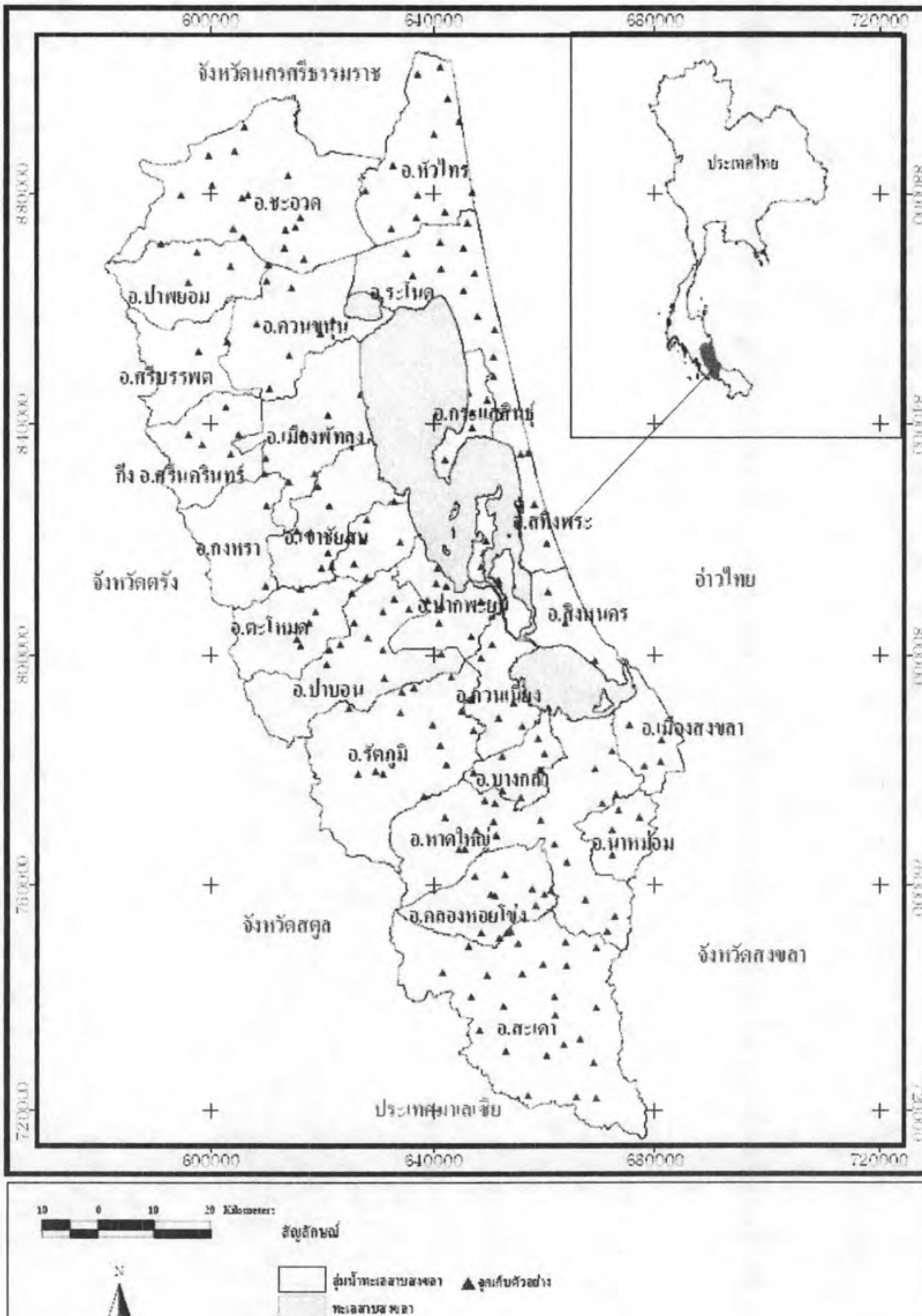


Figure 3-6 Validation sampling points

3.2.4 Model Development

A series of steps were performed when delineating watersheds or defining stream networks. Some steps are mandatory, while others are optional depending on the characteristics of the input data. Flow across a surface will always be in the steepest down slope direction. Once the direction of flow out of each cell is known, making it possible to determine which and how many cells flow into a given cell. This information can be used to define watershed boundaries and stream networks. The flowchart (Figure 3-7) shows the process of extracting hydrologic information, such as watershed boundaries and stream networks, from a digital elevation model (DEM).

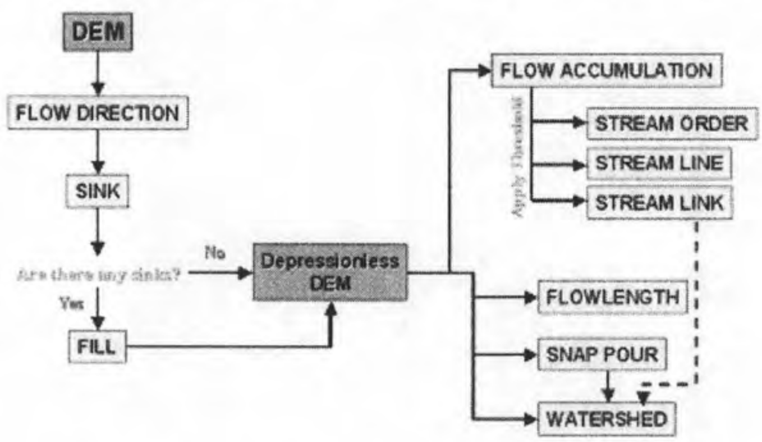


Figure 3-7 Steps performed during watershed delineation

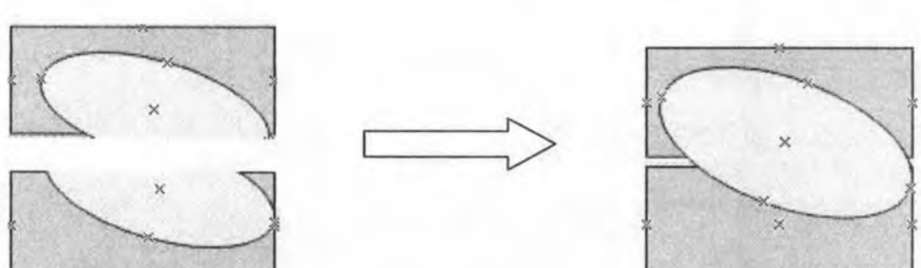


Figure 3-8 Combining watersheds

Determining how the watershed(s) is/are connected is a crucial step while developing the model. During the initial stages of model development, watershed delineation was performed. Both AnnAGNPS and TREX were designed and well tested for one watershed with one outlet. In several cases, the result of single watershed delineation was not possible from that the outlet could not be located or the watershed area coverage was not completed. However, when combining the two watersheds together, as shown in Figure 3-8, the results were found to be better. In this study, the SLB was therefore split into 8 sub watersheds upon trials of combinations of different watershed (Figure 3-9 and Figure 3-10) as follows:

1. Klong Pa Payom & Thanae sub watershed: 377 rows and 519 columns on a 100 x 100m were observed, a total of 31 links and 645 nodes.

2. Nathom sub watershed: 417 rows and 752 columns on a 100 x 100m were observed, a total of 7 links and 236 nodes.

3. Tachiad sub watershed: 308 rows and 250 columns on a 147.96 x 147.96m were observed, a total of 7 links and 139 nodes.

4. Pa Bon sub watershed: 362 rows and 365 columns on a 100 x 100m were observed, a total of 3 links and 295 nodes.

5. Phru Poh and Rattaphum: 544 rows and 982 columns on a 100 x 100m were observed, a total of 52 links and 825 nodes.

6. U-Tapao and Eastern Coast Sub Basin 4 Sub watershed: 907 rows and 1028 columns on a 100 x 100m were observed, a total of 47 links and 2315 nodes.

7. Eastern Coast Sub Basin 2 and 3 Sub watershed: 483 rows and 354 columns on a 100 x 100m were observed, a total of 1 links containing 11 nodes.

8. Eastern Coast Sub Basin 1 Sub watershed: 463 rows and 646 columns on a 100 x 100m were observed, a total of 1 links containing 45 nodes.

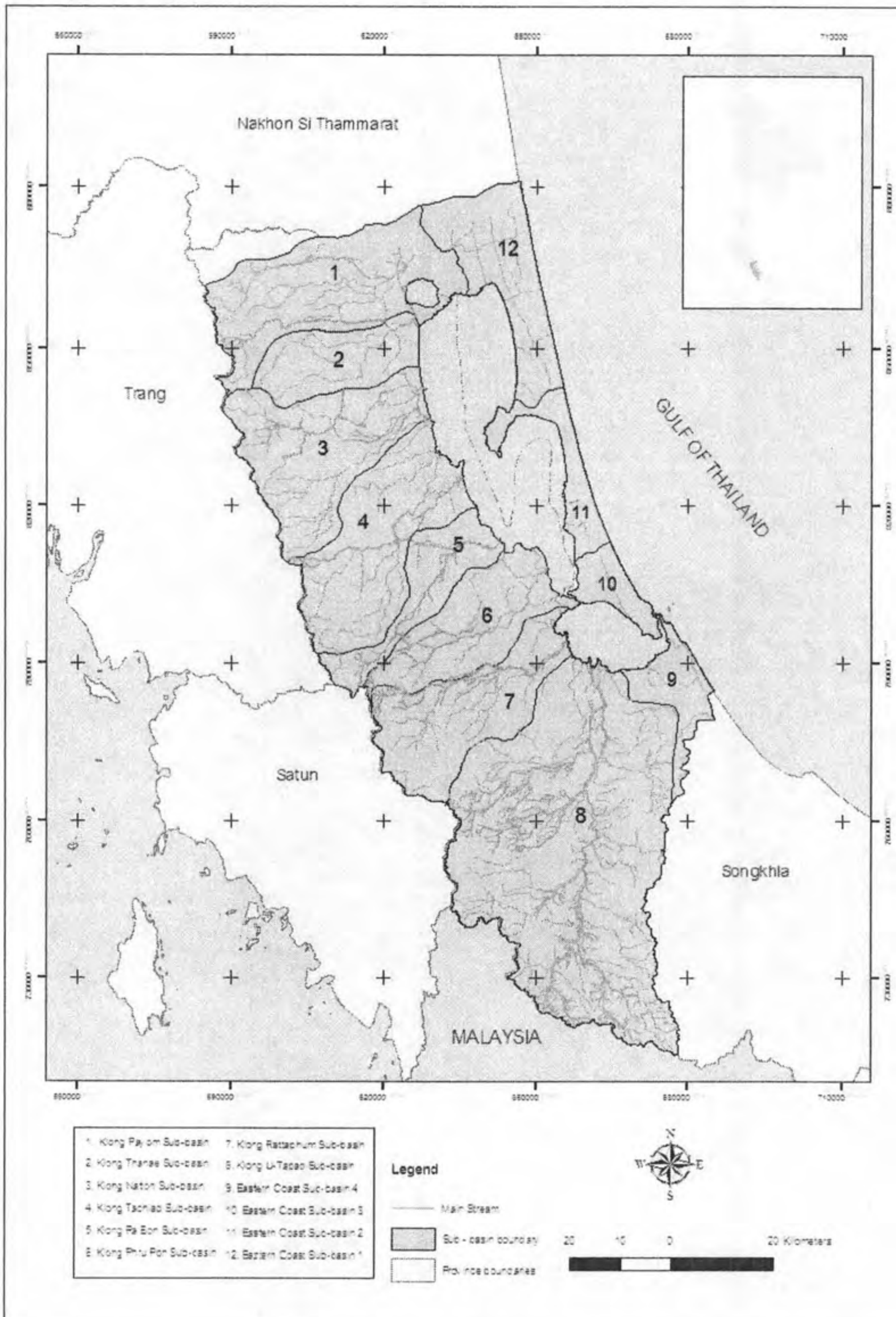


Figure 3-9 SLB divided into 12 watersheds

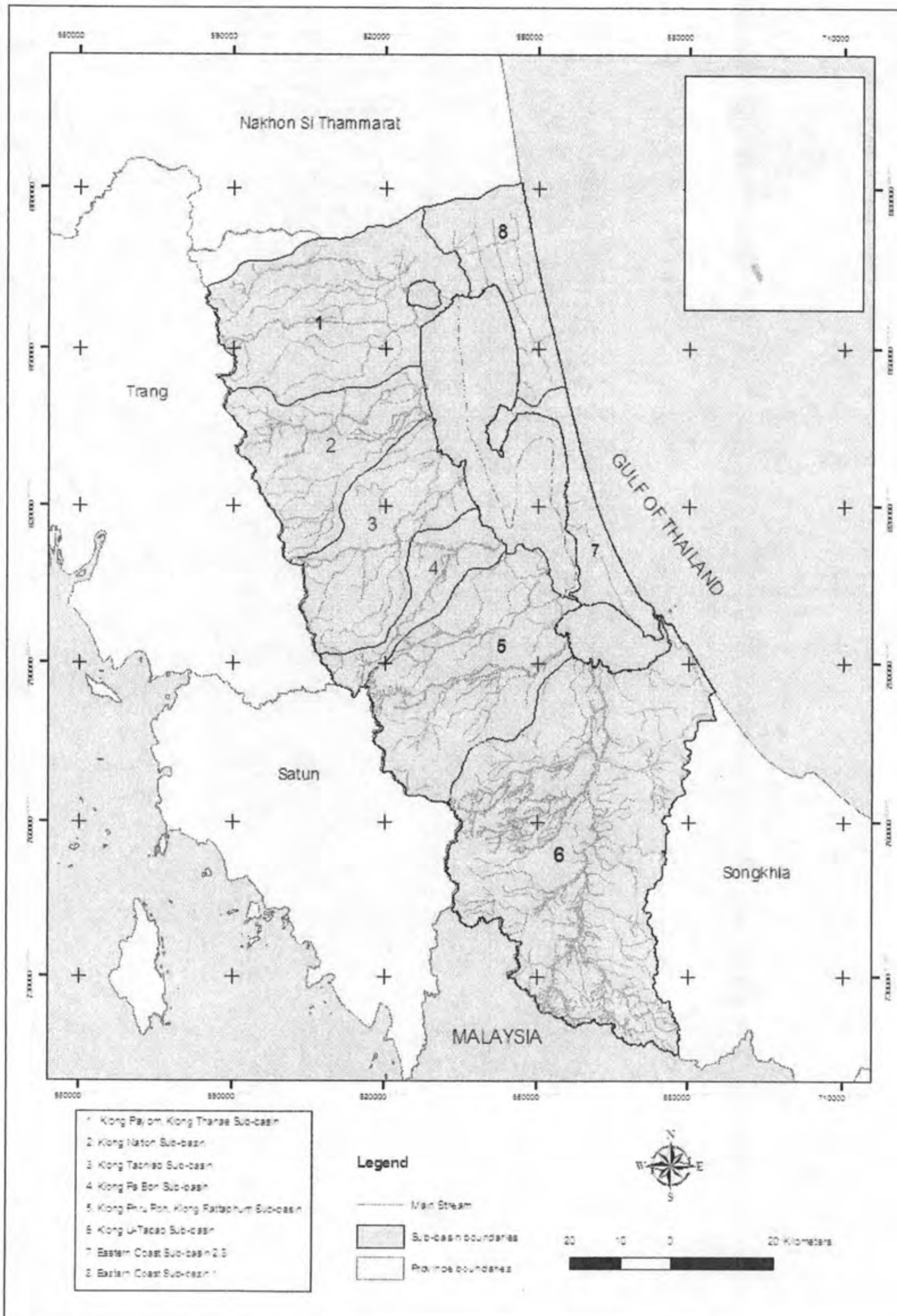


Figure 3-10 SLB divided into 8 watersheds

3.2.5 Future Scenarios for Analysis

The ultimate causes of NPS pollution from agricultural lands is excessive fertilizer usage. There are many applicable direct solutions to mitigate the problem e.g. fertilizer application can be reduced to match crop needs (Carpenter *et al.*, 1998). Various best practice managements approaches were introduced and could be applied to agricultural lands to improve such situations (Steven, 2003). Initially, the relative impact of fertilizer usage must be thoroughly understood e.g. what is the relationship between fertilizer application rate and phosphorus and cadmium loading. Remediation actions then should be well studied e.g. changes in fertilizer formula, crops grown, and soil amendment. Finally, decision making and then setting up policy should be carefully exploited and enforced. In this study, practical scenarios were studied to develop the decision support tool used to support the Songkhla Lake environmental management decision making process. Three scenarios (table 3-7) were included in the test as followed;

1) Scenario 1: Changes of fertilizer application rate. Fertilizer application rate is the amount of fertilizer used for a certain crop in a certain area at a certain time. High fertilizer application rate could be found in horticultural crops to achieve high production yield. Low fertilizer application rate could be found in field crops, rubber and palm plantations. Impact resulted from increases and decreases of fertilizer application rate should therefore be understood. This scenario should provide an understanding of the relative impact of fertilizer usage on phosphorus and cadmium loading.

2) Scenario 2: Changes of fertilizer formula. Many phosphate fertilizers have lead significant increase in the cadmium content of many agricultural soils because they are produced from phosphate rock, in which cadmium is a common content. If alternative low cadmium content fertilizers could be used as a replacement, this could lead towards lowering cadmium loading in the basin. This scenario should provide an understanding of how fertilizer formula affecting the load of phosphorus and cadmium to the basin.

3) Scenario 3: Changes of crops cultivated. The principal goal of agricultural development in each period of time normally placed an emphasis on the uplift of life quality of farmers who are the majority of Thai population. Some agency such as The Department of Agricultural Extension has one of many functions to increase farmer's potential in terms of agricultural production, processing, and value-added as well as to identify measures and guidelines for agricultural extension. Therefore, information of certain crop cultivate causing environmental impact should be acquired and understood. This scenario provides an understanding of how crops grown in the area, if changed, would impact the phosphorus and cadmium loading.

Table 3-7 Summary of future scenarios for analysis

Scenario	**Name**	**Strategy**
1	Changes of fertilizer application rate	- Increase fertilizer application rate by 10% - Increase fertilizer application rate by 50% - Decrease fertilizer application rate by 10% - Decrease fertilizer application rate by 50%
2	Changes of fertilizer formula	- Replacement of 8-24-24, 13-13-21 and 15-15-15 (high cadmium) by 15-15-15 (low cadmium).
3	Changes of crops cultivated	- Replacement of horticultural crops by rubber crop

The following steps are undertaken:

1) Perform model simulation with proposed scenarios to study the amount of phosphorus and cadmium loading.

2) Analyze the result of each scenario in order to develop management control procedures or policies to prevent and mitigate phosphorus and cadmium loading.

3) Provide recommendation and suggestion in order to manage and prevent problems that could occur in the basin in the future.