CHAPTER 3

METHODOLOGY

The investigation tool used to examine P and Cd flows in this study was the SFA technique. The determination of a balance for these substances included examination of their inputs into the regional economy, their uses in certain goods and the associated flow processes, and the various emission routes within the SLC. These emission routes included both dispersed emissions associated with substance uses (e.g., Cd contamination in phosphate fertilizer dispersed over agricultural areas) and point source emissions associated with waste disposal (e.g., leachate from landfill). An understanding of mechanisms which might result in problems in the future was developed, allowing preventive strategies to be considered.

3.1 Study Area

3.1.1 General description of the Songkhla Lake Catchment

The SLC is the largest lake system located in Southern Thailand (Figure 1-1), covering a total catchment area of 8,616 km^2. The soil in the SLC examined in this study was grouped into four categories: cultivated soils (5,691.4 km^2); uncultivated soils (1,664.1 km^2); human settlement soils (176.2 km^2); and landfills (2.3 km^2). The lake itself covers an area of 1,082 km^2 (ICSLB, 2002). The study area consisted of two provinces: the entire province of Phatthalung and 12 districts in Songkhla province (Cha Na, Na Thawi, Thepha, and Saba Yoi districts were excluded). The total population of the lake basin is around 1.5 million, 73% of whom live in non-municipal areas and 27% of whom live in municipal areas (Appendix A) (NSO, 2002).

The basin consists of three inter-connected shallow lakes. Thale Noi, the northernmost lake, is a freshwater swamp of 28 km^2 connected to the middle part, the so-called Thale Luang, by three streams. Thale Luang is the largest part of the lake system. The waters of the upper part of the Thale Luang remain fresh for most of

the time while the lower part becomes brackish during the dry season. The southernmost part of the system is the Thale Sap Songkhla, or the so-called Outer Lake, which covers an area of 176 km^2. It is connected to the Thale Luang through a 260-m wide and 8.5-m deep channel, and to the Gulf of Thailand through a 420-m wide and 9.5-m deep channel (EmSong, 1999a). Tropical monsoons, with the Northeast monsoon from October to March and the Southwest monsoon from May to September, are the main climatic influences the area. Peak rainfall is observed during October and November with minimum rainfall in the dry season during April and May. Average rainfall is 1,880 mm/year with a range of 1,600-2,400 mm/year. The temperature is high throughout the year, with a daily mean value of 27°C. The maximum temperature occurs in April (28°C) and the minimum in November and December (26°C) (EmSong, 1998).

3.2 Research Approach

The SFA technique was used to assess balances of P and Cd in the SLC. These two substances have a close connection. Cd is a common contaminant of phosphate rocks, which is a commonly used raw material for phosphate products. The computation included determination of inputs of these substances into the regional economy, their uses in goods flowing through key processes, and the various emission routes in the SLC.

3.3 Methodology

The following steps were taken to generate data and undertake a SFA for P and Cd.

3.3.1 Define goal and system definition

The goal of the study

The goal of this study was to quantify the amount of P and Cd entering into, stored in, and emitted from the SLC agricultural soils.

The system definition

The spatial boundary for the study was defined as the physical boundary of the total land area in the SLC (7,534 km^2), which falls into two provinces: the entire province of Phatthalung and 12 districts in Songkhla province (Figure 1-1). The time boundary for the study represents a one year period, examining goods containing quantities of P and Cd which pass through all relevant processes in the SLC over the one-year period for the year 2002. Computation using a 1-year cycle allowed examination of the quantities of P and Cd used, estimation of the amount of substances leaving the economy in waste, determination of amounts recovered, and assessment of amounts stored in specific reservoirs (i.e., deposited in soil, landfills and similar waste repositories).

3.3.2 System analysis

This is an important preliminary step for gaining a better understanding of the flows of P and Cd from products and economic process to the environment. The system analysis was defined by the flow of P and Cd through each product and process line, which was represented by a flow diagram. It showed the input of P and Cd into the regional economy, how much was built up as stock in a year, and how much was emitted as concentrated and dispersed amounts from the economic processes that have an interface with the environment.

In this study information available from research reports, statistical records, journals etc was compiled into a spreadsheet model which corresponded to the flow diagrams (see Table 3-7 to 3-9). The information was then integrated with data on concentrations of substances recorded in the SLC, so that conclusions could be drawn on the potential for ongoing P and Cd contamination problems.

3.3.3 Inventory and evaluation of data

It was found that different categories of data were only available for different years. For example, the concentration of Cd in phosphate fertilizer was investigated in 2002, but the corresponding figures for the concentration in animal feed were only available for the year 2001. Moreover, neither governmental bodies nor research centers had good records about the rate of increase of these substances each year. That such factors are an obstacle to the application of the SFA approach in most developing nations, compared to developed ones, is not unexpected (Baccini and Brunner, 1991; Lassen and Hansen, 2000 and Binder *et al.*, 2001). To remedy such problems the following data compilation procedure was designed.

(1) All goods and processes causing P and Cd input to the SLC agricultural soil were identified: phosphate fertilizer, feedstuff use, and precipitation.

(2) All processes through which such goods passed through the area were identified, for example fertilizer sale and distribution, rice farming, use in rubber plantations, soil accumulation, leaching to streams, and emissions to the atmosphere.

(3) Data collection was undertaken as the next step. Data regarding the P and Cd contents in different products, the amount of each product type used in the SLC, and the fate of various wastes and emissions were gathered from secondary data as well as other local and international sources (Table 3-7 to 3-9).

(4) Following data collection, a programme of interviews with fertilizer distributors was arranged. Fertilizer use is a key factor in P and Cd contamination of agricultural soils and so it was necessary to interview local distributors to collect data on consumption of fertilizer and other products important in substance flows, as government agencies have few records on such matters. Interviews were undertaken as follows:

- In order to cover a majority of fertilizer distributors, the distributors interviewed were deliberately selected from within the major commercial centers in the SLC: Muang and Hat-Yai districts of Songkhla province, and Muang district of Phatthalung province.
- Registration information on the name and address of fertilizer shops was obtained from the Partnership and Commercial Registration Bureaus in Songkhla and Phatthalung provinces.
- A walk-through survey was conducted to verify the list of dealers in case there were any discrepancies in the list.
- Only wholesale distributors were interviewed. Retail distributors were excluded to avoid double counting.
- Wholesalers were interviewed using the questionnaire presented in Appendix B.

3.3.4 Assumptions made in calculating P and Cd balances.

The limitation of available data necessitates a number of assumptions about the movements of P and Cd along the pathways. The pathways of P and Cd of some products are complex, and information about most of these pathways is lacking. In addition, limited time did not permit an exhaustive data search. Thus, assumptions, as well as adoption and adaptation of different sources of data were necessary.

(1) This study assumed a very small annual fluctuation of input, stock and output of P and Cd in the SLC. For simplicity's sake, a steady state was assumed during the span of a period of a few years. Data collected during different time periods was assumed to be applicable to the year 2002 and was applied when contemporary data was unavailable.

(2) The following data from other areas and international sources was applied to the SLC:

- Data on P in swine feeds and manure from swine farming (NRC, 1998); and P taken up during plant cultivation (Greenwood *et al.,* 2000).
- Cd in swine feeds (NRC, 1980); Cd in swine manure (NBP, 2000); and Cd in precipitation (WRM, 2002).

(3) In the absence of better information, P and Cd content were calculated to represent the worst case situation for input and output of these substances to the SLC. This assumption was made for:

- P in grades of phosphate fertilizer other than 8-24-24; 13-13-21; 15-15-15; and 16-16-16 grades; P in manure from swine farming; and P taken up during plant cultivation.
- Cd in grades of phosphate fertilizer other than 8-24-24; 13-13-21; 15-15-15; and 16-16-16 grades; and Cd in swine feeds.

(4) In the absence of better information, chosen values from the literatures were used in calculations. This assumption was made for:

- Consumption and quantities of P and Cd in the flowing products and processes: phosphate fertilizer (Sae-Eong *et al.,* 2002 and Primsirikul and Matoh, 2003); swine feeds (NRC, 1998); precipitation (Srimechai, 1992); MSW (REO 12, 2002b; Ban-Phru Muang Municipality, 2002 and Sadao Muang municipality, 2002); and WWTPs (Hat-Yai Nakhon Municipality, 2002 and Songkhla Nakhon Municipality, 2003).
- P content in swine feeds, precipitation, agricultural soil, runoff, landfills, and WWTPs.
- Cd content in swine manure, precipitation, agricultural soil, runoff, and WWTPs.

(5) The flowing assumptions were made for fertilizer use:

- It was assumed that the rate of fertilizer application by agriculturists was one half of what was recommended by government agencies (Srisai, 2002).
- Fertilizer was applied at the following rates: paddy fields - 40 kg/rai/y; rubber trees - 25 kg/rai/y; field crops and orchards - 50 kg/rai/y (Srisai, 2002).
- Information on chemical fertilizers obtained from interviews with SLC wholesalers was confined to 8-24-24, 13-13-21, 15-15-15 and 16-16-16 grade fertilizers. Other grades of fertilizers are also known to be used by farmers, and it was assumed their P and Cd contents were the maximum for these four common grades.

(6) It was assumed that one cycle of swine rearing — from birth until slaughter — takes 120 days. During this period swine are raised from 4 to 100 kilograms in body weight (NRC, 1998).

(7) P values in manure from swine farming were calculated using the maximum value from a study by Kornegay and Harper (1997) which indicates that swine utilize 20% of P in feeds (NRC, 1998). It was assumed the remaining 80% is excreted in manure.

(8) During plant cultivation it was assumed that 10% of the P from fertilizer, manure, and precipitation is taken up (Greenwood *et al.,* 1980) and that P from these sources is readily available.

(9) Data regarding P and its components in landfills was compiled for all municipalities and sanitary districts in Southern Thailand has been compiled, but Cd content in landfills was estimated on the basis of figures from the Hat-Yai Municipality landfill site.

(10) Average P and Cd content in influent and effluent from the Hat-Yai municipality WWTP was used in calculations because Songkhla Nakhon Municipality WWTP has no records for these parameters.

(11) Prediction of future emissions of P and Cd is based on the characteristics of current stocks and assumes that all inputs remain constant.

3.3.5 Concentrations of P and Cd

Concentrations of P and Cd in goods and processes which were used for the calculations in Chapter 4 were obtained from various research studies and other relevant information. Data used for calculation of quantities of P and Cd consumed in the products and processes of the SLC are shown in Table 3-7 and data used for calculation of P and Cd contents are shown in Tables 3-8 and 3-9.

Table 3-7 : Total quantities consumed for products and processes of the SLC

Product / Process	Consumption / Quantity	Unit	Reference
1. Chemical fertilizer			
- 8-24-24, 13-13-21, 15-15-15 and 16-16-16 grades	4,965	t/y	Personal interviews, 2002.
- other grades	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
7. Groundwater	113	mm/y	Arrykul, 1991
8. Landfill			
- MSW from domestic	0.7	kg/cap/d	REO 12, 2000
- MSW to SLC landfill:			
HY_{NM} (0.22 km^2)	230	t/d	REO 12, 2002b;
SK_{NM} (0.32 km^2)	85	t/d	Ban-Phru Muang
SDTM (0.15 km^2)	20	t/d	Municipality, 2002 and
BPMM (0.16 km^2)	30	t/d	Sadao Muang
PTMM (0.15 $km^{2)}$)	30	t/d	Municipality, 2002
9. WWTP			
- Hat-Yai WWTP	52,000	m^3/d	Hat-Yai Nakhon Municipality, 2002
- Songkhla WWTP	6,000	m^3/d	Songkhla Nakhon Municipality, 2003

Table 3-8 : Data for calculation of P content in each product and process studied.

Product / Process	Content / concentration	Unit	Reference
1. Chemical fertilizer			
- SLC: 8-24-24, 13-13-21, 15-15-15 and 16-16-16 grades	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
- Lago de Cidra, Central Puerto Rico	0.02	mg/l	Gins, 1998
5. Agricultural soil			
- major soil in Thailand	1 - 76 (available P) 38 - 1,137 (total P)	mg/kg mg/kg	Primsirikul and Matoh, 2003
- Peninsular Thailand	2 - 3.5 (available P) 39 - 238 (total P)	mg/kg mg/kg	Onthong, 2002
- 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	Ridchuayrod, 2003
> 25 m	0.14 - 0.68	µM	
- Tapi-Pumduang basin	< 0.01 - 0.18	mg/l	PCD, 2000
- Upper-South river basins (watershed classes 1, 2, 3, 4 and 5)	16.7; 24.5; 13.3; 10.8; and 569.2	µg/l	Wongsawasditkul, 1989
8. Groundwater			
- Rataphum sub-catchment	ND (0.15) - 0.21	mg/l	ACIAR, 1998
- Biscayne bay	0.031 - 0.032	ppm	Byrne and Meeder, 1999
9. Landfill			
- municipality and sanitary districts in southern Thailand	0.1	%	Thongnark, 1997
10. WWTP			
- SLC:			
Influent	1.5	mg/l	Hat-Yai Nakhon Municipality, 2002
Effluent	0.8	mg/l	
- Lago de Cidra, Central Puerto Rico: Effluent	0.95	kg/d	Gins, 1998

Table 3-9 : Data for calculation of Cd content in each product and process studied.

Product / Process	Contents / concentration	Unit	Reference
1. Chemical fertilizer			
- SLC : (8-24-24, 13-13-21, 15-15-15 and 16-16-16 grades)	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, 2000
4. Precipitation			
- SLC	1.63×10^{-4} - 2.23×10^{-3}	ppm	Proesphichaya and Sumet, 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. Plant cultivation	-	-	-
7. Runoff			
- Songkhla Province (old tin mines)	0.1 - 0.27	mg/l	Soingoen, 1990
- 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, 2002
8. Groundwater			
- Songkhla province (old tin mines)	0.12 – 0.16	mg/l	Arrykul, 1991
- Hat-Yai basin	ND	mg/l	Thongyai, 1992
- Amphoe Hat-Yai	ND	mg/l	Meesin, 1995
- Amphoe Hat-Yai	ND – 190	mg/l	Soingoen, 1990
9. Landfill			
9.1 MSW			
- Hat-Yai Nakhon Municipality	ND		Pan Engineering Ltd, Part., 2000
- rubbish manures from Petchburi municipality	0.899	mg/kg	Isaradej, 1993.
9.2 Leachate			
- Hat-Yai Nakhon Municipality	ND		Pan Engineering Ltd., Part., 2000
- Bangkok Metropolitan Administration	ND - < 0.03	ppm	Thapanandana, 1992.
10. WWTP			
- Hat-Yai Nakhon Municipality:			
Influent	0.006	mg/l	Hat-Yai Nakhon Municipality, 2002
Effluent	0.003	mg/l	

Approximations made in the aforementioned studies were often crude, and hence could be a source of inaccuracy. Data from these studies should therefore be considered only as a starting point. The wide range of P and Cd content recorded in the different studies suggests the need for further measurements specific to the SLC situation so as to describe it more accurately. Differences in area, climate conditions, operating practices and the content of each substance might give rise to significant discrepancies in calculations of the amounts of P and Cd entering the SLC using data from different sources.

3.3.6 Formulation of balances for P and Cd

Balances of P and Cd were formulated for each of the goods going through each process (input, stock and output) using an Excel Spreadsheet. Data was acquired in various forms and was converted into standard units of P and Cd measurement in the spreadsheet (t/y, g/cap/y, kg/km^2/y of P, and g/km^2/y of Cd).

Methods used for the calculation of flows of P and Cd and balances in phosphate fertilizer, swine feeds, precipitation, agricultural soil, plant cultivation, surface runoff, MSW and WWTP effluents are shown in the appendices D, F-H, J-L, and N-O, respectively. An example of the basic calculation is shown below:

(1) Calculation of mass unit (tons):

$$Quantity\ of\ \ product\ or\ \ process \times P\ or\ Cd\ \ content \times time\ (1\ year)$$

(2) Calculation of population unit (per capita):

$$\frac{Quantity\ of\ \ product\ or\ \ process \times P\ or\ Cd\ \ content \times time\ (1\ year)}{Total\ \ population\ in\ SLC\ (\approx 1{,}500{,}000\ residents)}$$

(3) Calculation of area unit (square kilometers):

$$\frac{Quantity\ of\ \ product\ or\ \ process \times P\ or\ Cd\ \ content \times time\ (1\ year)}{Total\ area\ in\ SLC\ (7{,}534\ km^2)\ or\ total\ agricultural\ area\ (5{,}691\ km^2)}$$

3.3.7 Interpretation of the results

Interpretation of the results required evaluation of the flow charts derived from the study, based on crosschecks. The following issues were considered:

(1) The main sources of emission to the environment and losses to waste were identified.

(2) Emissions of each substance in terms of any environmental impact or sustainability indicators which may be relevant.

(3) Identification of in-depth research required to obtain further data for future investigations.