CHAPTER 4

RESULTS AND DISCUSSION

The results of this study are presented in quantitative frameworks as Excel spreadsheets and flow diagrams. The fluxes of P and Cd in SLC were computed and are presented in various units, depending on their implications and contexts, including t/y, g/cap/y, kg P/km^2/y, and g Cd/km^2/y. The larger unit, tons per year, is intended to show the total content of these substances passing through the SLC. The per capita unit, grams per capita per year, is used to signify the amount of substances generated by each person in SLC. The area-based unit, grams or kilograms per square kilometer per year, denotes the ecological footprints of P and Cd contamination in the agricultural land area of 5,691.4 km^2 or in the total catchment area of 7,534 km^2.

4.1 Entry of P and Cd into Agricultural Soil

Entry of P and Cd into agricultural soil was considered 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.

4.1.1 Phosphate fertilizer

It has been estimated that around 55,307 tons of chemical fertilizer were applied to the SLC agricultural soil in 2002 (Srisai, 2002). Information on chemical fertilizers obtained through interviewing SLC wholesalers was confined to 8-24-24, 13-13-21, 15-15-15 and 16-16-16 grades; their combined entry into the SLC amounted to around 4,965 t/y (Appendix C). Other grades of fertilizers were also used, but their contents were not analyzed here. P contents in the grades investigated were 9.8, 6.4, 6.8, and 7.3%, respectively; Cd contamination in phosphate fertilizer (P_2O_5) were 1.4, 1.4, 30.1, and 1.4 mg Cd/kg, respectively (Sae-Eong *et al.,* 2002). Most raw materials for fertilizers in Thailand, including rock phosphate, are imported from foreign sources, with variable Cd contaminations, such as Korea, Germany, Romania and Norway (Agriculture Economy Office, 2002). Consequently Cd contamination in fertilizers can vary widely.

On the basis of annual consumption of fertilizer entering the SLC agricultural soil, P content was found to be around 5,297 t/y or 703 $kg/km^2/y$ and Cd contamination in phosphate fertilizer (P_2O_5) was approximately 0.37 t/y or 50 $g/km^2/y$ (Appendix D). This suggests that fertilizer applied to SLC soil is relatively clean with respect to Cd. This is lower than limiting values in several countries, such as Australia, Japan, Germany, Belgium, and Austria (Al-Shawi and Dahl, 1999). European fertilizers were found to contain Cd contamination at the level of 60 mg/kg of P_2O_5 (Davister, 1996). In most countries efforts have been made over recent year to change the sources of phosphate rock materials used for phosphate fertilizer so as to result in lower Cd concentrations. This seems likely to continue (Syers and Cisse, 2001).

4.1.2 Feed for swine

The number of swine raised in the SLC is 226,390 heads (Appendix E). Most of them are in the U-Tapao sub-basin, Pa-Phayom sub-basin and Sating-Pra peninsular (LDO, 2002 and REO 12, 2002a). Typically, one cycle of swine—from birth until slaughter—takes about 120 days. During this period swine are raised from 4 to 100 kilograms in body weight (NRC, 1998). The total feed required for these swine is estimated to be around 41,905 t/y. The total consumption of P by swine is approximately 200 t/y, assuming average P concentration in the intake is 7 g/head/d (NRC, 1998). The maximum tolerable level of dietary Cd is 0.5 ppm (NRC, 1980). The content found in most feeds for domestic animals ranges between 0.18-0.32 ppm (NRC, 1980). The maximum value, 0.32 ppm, has been used to estimate the Cd content in total swine feedstuff in this study, resulting in a value of 0.013 t/y (Appendix F).

4.1.3 Manure from swine farming

A study by Kornegay and Harper (1997) indicated that swine utilized 20-50% of P (NRC, 1998) in feed and excreted the remainder in manure. The maximum P content (assuming the maximum P uptake of 80% from feed) from swine manure as a direct input to soil can thus be estimated as 160 t/y. Cd content in swine manure was found to be 0.32 ppm (NBP, 2000) giving a total input of around 0.011 t/y (Appendix G). This indicates that the Cd contents of the feed intake and the manure are almost equal. Such findings are in agreement with the results of a survey conducted by the Food and Drug Administration which found that the Cd levels in a market basket of dairy products were 0.005 ppm in meat and 0.0093 ppm in poultry (Mahaffey *et al.,* 1975). It has been reported that most men ingest around 25-75 μg Cd/d, but the WHO (1975) recommends that the daily intake of Cd should be below 60-70 μg Cd/d (WHO, 1992). The dietary intakes of Cd of Thai adults in the Bangkok area and in Ubonratchathani province were 0.016 and 0.015 mg/cap/d, respectively (Suprapan, 1991 and Suphanithasnaporn, 1995). Given its toxicity and the risk of dispersal into the environment in cases when manure is used as soil supplement, the use of potentially Cd contaminated materials should be properly controlled and monitored.

4.1.4 Precipitation

Average precipitation in the SLC is 1,880 mm/y (EmSong, 1998) and P concentration in the precipitation is around 0.03 mg/l (Srimechai, 1992). Thus the P loading from precipitation is estimated at 321 t/y or 43 kg/km^2/y (Appendix H). The range of atmospheric P input in different areas can vary widely, from 5 kg/km^2/y to over 100 kg/km^2/y (Ryden *et al.,* 1973). In general Cd content in the atmospheric is very low, except at locations close to smelters or other significant industrial and urban emission sources. Only 2% of SLC area is settlement soil and the catchment does not accommodate any intensive industrial zones. Cd 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). If a concentration of 0.01 μg/l is assumed on the basis of these reports, Cd contamination resulting from precipitation will be around 0.11 t/y.

4.2 Accumulation of P and Cd in Agricultural Soil

The soil within SLC can be described as being of moderate to poor fertility and poorly drained (Appendix I) (EmSong, 1999b). In general, the soil in peninsular Thailand was found to have a relatively low P content: 2-3.5 mg/kg of available P and 39-162 mg/kg of total P. A slightly higher level of P, 145-238 mg/kg of total P, has occasionally been found, with content decreasing with soil depth. The majority of the P in these soils (48 - 71%) is organic (Onthong, 2002) and is therefore not available for plant uptake. A study conducted by Sae-Eong *et al.* (2002) revealed that the P content in the SLC upper-soil layer (0.2 meters) was an average of 95 mg/kg of available P. The presence of total P content in SLC soil was estimated to be 248.7×10^3 tons. In the same study, the Cd content in the SLC upper-soil layer was found to be 0.024 mg/kg (Sae-Eong *et al.,* 2002), which could result in Cd accumulation in soil of around 63 tons (Appendix J). Another study found soils in each region of Thailand to contain 1-76 mg P_2O_5/kg of available P, and 0.001-0.294 mg Cd/kg (Primsirikul and Matoh, 2003 and Pongsakul and Attajarusit, 2002). Soils in other parts of the world were found to contain between 0.06 and 1.1 mg/kg (averaged 0.53 mg/kg) of Cd (Kabata and Pendias, 1992). This indicates that the Cd content in the SLC soil is relatively low. The low amount of Cd in the soil could possibly be due to low soil pH (Primsirikul and Matoh, 2003; Pongsakul and Attajarusit, 2002 and Sae-Eong *et al.*, 2002). Acid soil will probably increase the ability of P and Cd to harm organisms through enhanced leaching of these substances, thereby decreasing soil adsorption ability and increasing plant availability. The adsorption capacity of the soil will typically decrease two to three fold per unit decrease in pH. Therefore the potential hazard in soil is dependent on both the amount of P and Cd contamination in products applied to the soil and the characteristics of the soil itself (Baccini and Brunner, 1991 and Taylor, 1997).

4.3 Emission Pathway of P and Cd

There are many emission pathways for P and Cd into the environment. Substances stored in soil can be taken up by plants, released to air, and leached to the hydrosphere (canals and groundwater). Contamination in groundwater will result in accumulation, while in surface water the two substances will be flushed to lakes by runoff.

4.3.1 Plant cultivation

The source of P for plant growth is present as orthophosphate in soil. Agricultural crops generally take up only 5-10% of P applied as fertilizer in the first year, with uptake gradually decreasing in the following years (Greenwood *et al.,* 1980); 90% of P uptake originates from residual P in soil. P from freshly applied fertilizer cannot compensate for a low soil P status (Johnston *et al.,* 1986), since in general more than 80% of the applied P becomes immobile and unavailable for plant uptake due to adsorption, precipitation, or conversion to the organic form (Holford, 1997). P emitted from soil to plant uptake was therefore computed on the assumption that 10% of the P from phosphate fertilizer, manure and precipitation is readily available. Thus, P emitted from soil through plant uptake was estimated to be 578 t/y (Appendix K). However, there are wide variations in the uptake capacity depending upon plant species, varieties, the tissue type taking up the substance, and soil characteristics (Isermann, 1990). The plant uptake of Cd was not computed in this study, because the required data was not available. However, Cd may be easily mobile, since Cd uptake is greater at lower soil pH, lower soil organic matter and higher soil temperature (Tjell *et al*., 1983 and Louekari, 1996).

4.3.2 Losses of P and Cd through runoff

Runoff in the SLC is estimated as 4.896 x 10^9 m^3/y (REO 12 and OEPP, 1997). Contaminant losses through runoff were calculated using an average content of 0.3 mg/l for P (Phutmongkhon *et al.,* 2000), and 0.0005 mg/l for Cd (Hat-Yai Nakhon Municipality, 2002). A P concentration of 0.02 - 0.1 mg/l is generally considered to be at the eutrophication limit (Pierzynski and Logan, 1993; Sharpley *et al.,* 1994 and Lory, 1999). However, other factors also play a significant role in the initiation of the eutrophication process. The amount of P and Cd inputs to surface runoff which can pass through the lake were estimated to be around 1,469 and 2.5 t/y, respectively (Appendix L). Although the relationship between soil and runoff has not been quantified over the wider area, it has been found that the potential for P and Cd loss in runoff increases as soil accumulates (Isermann, 1990 and Brookes, 1997). It should be noted that one fertilizer application could contribute more P and Cd to surface water than do all other causes throughout the entire year. Furthermore, the production of manure and frequent lack of disposal management procedures, also contribute to the problem. Good soil erosion control practice can prevent excessive quantities of P and Cd from entering streams, particular in agricultural areas.

4.3.3 Groundwater

Around 6%, or 113 mm/y, of SLC precipitation enters the groundwater aquifer (Arrykul, 1991). The documents reviewed suggest it has long been considered that losses of P from agriculture leaching into groundwater are trace amounts (Marien, 1997 and Brookes, 1997). ACIAR (1998) found that P loadings in shallow and deep wells in the Rataphum sub-catchment (part of the SLC), which is a predominantly agricultural region, were lower than the detectable limit (< 0.15 mg/l) using the Ascorbic Acid Method.

Some of the sandy soils in the SLC are vulnerable to leaching (Srisutasinee, 2001) given that the soil is acidic, with pHs ranging between 3.60-5.67 (Pongsakul and Attajarusit, 2002 and Sae-Eong *et al.,* 2002). Unfortunately, previous studies found that levels of Cd which have leached out into lower soil layers were lower than the detection limit of the analytical instruments used (Arrykul, 1991; Thongyai, 1992 and Meesin, 1995). Although the chance of groundwater contamination by P and Cd appears low, the consequences of such contamination would be serious and thus the risk should not be ignored.

4.4 Waste Emission Flows of P and Cd

4.4.1 Landfills

Data regarding P and its components in landfills in municipalities and sanitary districts in southern Thailand has been compiled and analyzed by Thongnark (1997); and the Cd content in Hat-Yai landfill has been studied by Pan Engineering Ltd. Part. (2002). These studies revealed that composition of southern Thailand's MSW was 65% food waste, 17% paper, 15% plastic, and 13% other waste types. Around 35% of this was recyclable (Thongnark, 1997). Most of this MSW was produced from domestic sources at a rate estimated to be 0.7 kg/cap/d (wet weight) (Appendix M), with 48.6% moisture content (Thongnark, 1997 and REO 12, 2000). It has been found that of the total MSW generated in the SLC, approximately half (representing 395 t/d) is disposed of in municipal landfills (REO 12, 2002b; Ban-Phru Muang Municipality, 2002 and Sadao Muang Municipality, 2002). The total MSW which has accumulated in landfills to date is approximately 1.98 x 10^6 tons (Appendix N), assuming these inputs of waste have remain constant. The average P content in MSW was 0.1% of wet weight (Thongnark, 1997). On the basis of these figures estimated P inputs to landfill are 144 t/y, with a P stock of around 1,980 tons (Appendix N), with measurement of Cd not yet documented. A study of leachate from Hat-Yai landfill and a study of leachate from the storage pool at the disposal site of the Bangkok Metropolitan Administration, where it was found that not detected within the detection limit of the instruments used (i.e., lower than 0.03 ppm) (Thapanandana, 1992 and Pan Engineering Ltd. Part., 2002). Low Cd contents in leachate would also be expected if disposal sites have been properly managed.

4.4.2 Waste Water Treatment Plants (WWTP)

At present there are two municipal WWTPs in operation in the SLC: the Hat-Yai Nakhon Municipality treatment plant and the Songkhla Nakhon Municipality treatment plant. The Hat-Yai WWTP has an average capacity of 52,000 m^3/d. The plant consists of a series of stabilization ponds and a constructed wetland (Hat-Yai Nakhon Municipality, 2002). The Songkhla WWTP is an aerated lagoon system with an average capacity of around 6,000 m^3/d (Songkhla Nakhon

Municipality, 2003). Average P and Cd contents in the influent entering the Hat-Yai WWTP are 1.5 and 0.006 mg/l respectively. These are approximately halved after treatment to 0.8 and 0.003 mg/l before the effluent drains into natural watercourses (Hat-Yai Nakhon Municipality, 2002). Based on actual flow rates of the Hat-Yai Nakhon Municipality and Songkhla Nakhon Municipality treatment plants, and assuming equal concentrations, the total amount of P and Cd in the influent entering the WWTPs was estimated to be 33 and 0.1 t/y; and in the effluent, 16 and 0.06 t/y respectively (Appendix O).

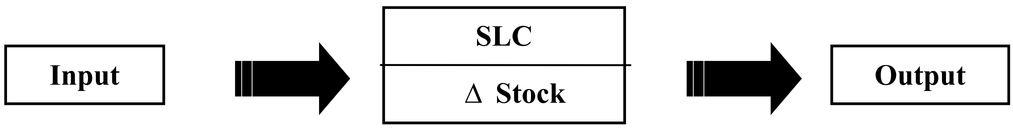
4.5 Predicting Future Emissions of P and Cd

Prediction of future emissions of P and Cd is based on the characteristics of current stocks. At present, approximately 248.7 x 10^5 tons of P has accumulated in cultivated soil; this will have doubled in 43 years assuming that all inputs remain constant (phosphate fertilizer: 5,297 t/y; precipitation: 321 t/y; and swine feed components ending up in manure: 160 t/y). The current level of Cd in cultivated soil is approximately 63 tons, which will double in 129 years assuming that all total inputs remain constant (phosphate fertilizer: 0.49 t/y; precipitation 0.11 t/y; and swine manure; 0.01 t/y). The current level of P which has accumulated in SLC landfills is around 1,980 tons. P stored in landfills will have doubled in approximately 14 years, assuming that domestic MSW is buried in landfills at a rate of 395 t/d, and that the P content in MSW remains constant at around 144 t/y.

4.6 Flow Diagrams for P and Cd

The flow diagrams presented here are simple models that necessarily required a number of assumptions to be made alongside the use of research data and calculations. The transfer of substances along the pathways is complex for some products, and there is a severe shortage of information. In addition, limited time did not allow an exhaustive data search to be conducted. This analysis is therefore only an important preliminary step towards a better understanding of the fate of P and Cd in products and processes.

The pathways show the flow of P and Cd inputs to outputs reading from left to right across the diagrams, in some cases summarized along the top. The major emissions to the hydrosphere are at the bottom, and storage on agricultural land is shown in a column in the middle. Flow diagrams for P and Cd in the SLC agricultural soil are similar for both substances and are shown in Figures 4-2 to 4-10.



$\sum Input$ $\Delta\ Stock \pm \left(\sum Input - \sum Output\right)$ $\sum Output$

Figure 4-2 : Flow Model Based on the Mass Balance Principle

Figure 4-2 shows the principle of the mass balance, which is based on the input, stock, and output of the system. Substance quantities can change over time but the objective of the system is to maintain the balance between input and output. The input of substance should not exceed the output and dispersion into the environment should be avoided by keeping the substance stored in the economic system.

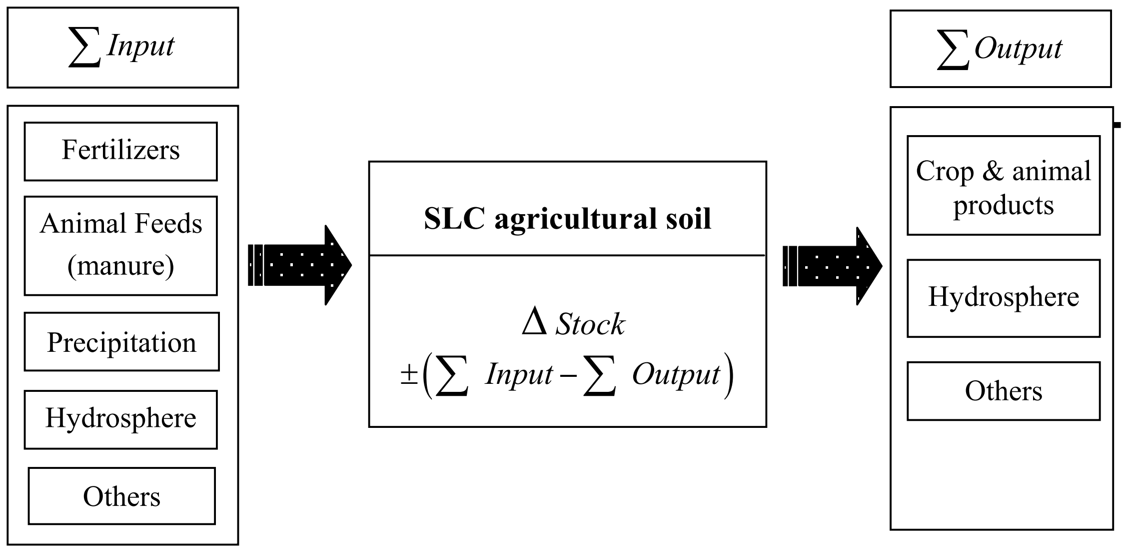


Figure 4-3 : Identified sources of phosphorus and cadmium contained in goods and processes passing through the Songkhla Lake Catchment system.

Figure 4-3 defines where the input and output of the two substances under analysis enter and leave the system and shows that they can be stored in agricultural soil.

Figure 4-4 defines the P and Cd content in each product and process under four categories of SLC land use. These flows are presented as draft findings which can be adapted over time as further information becomes available.

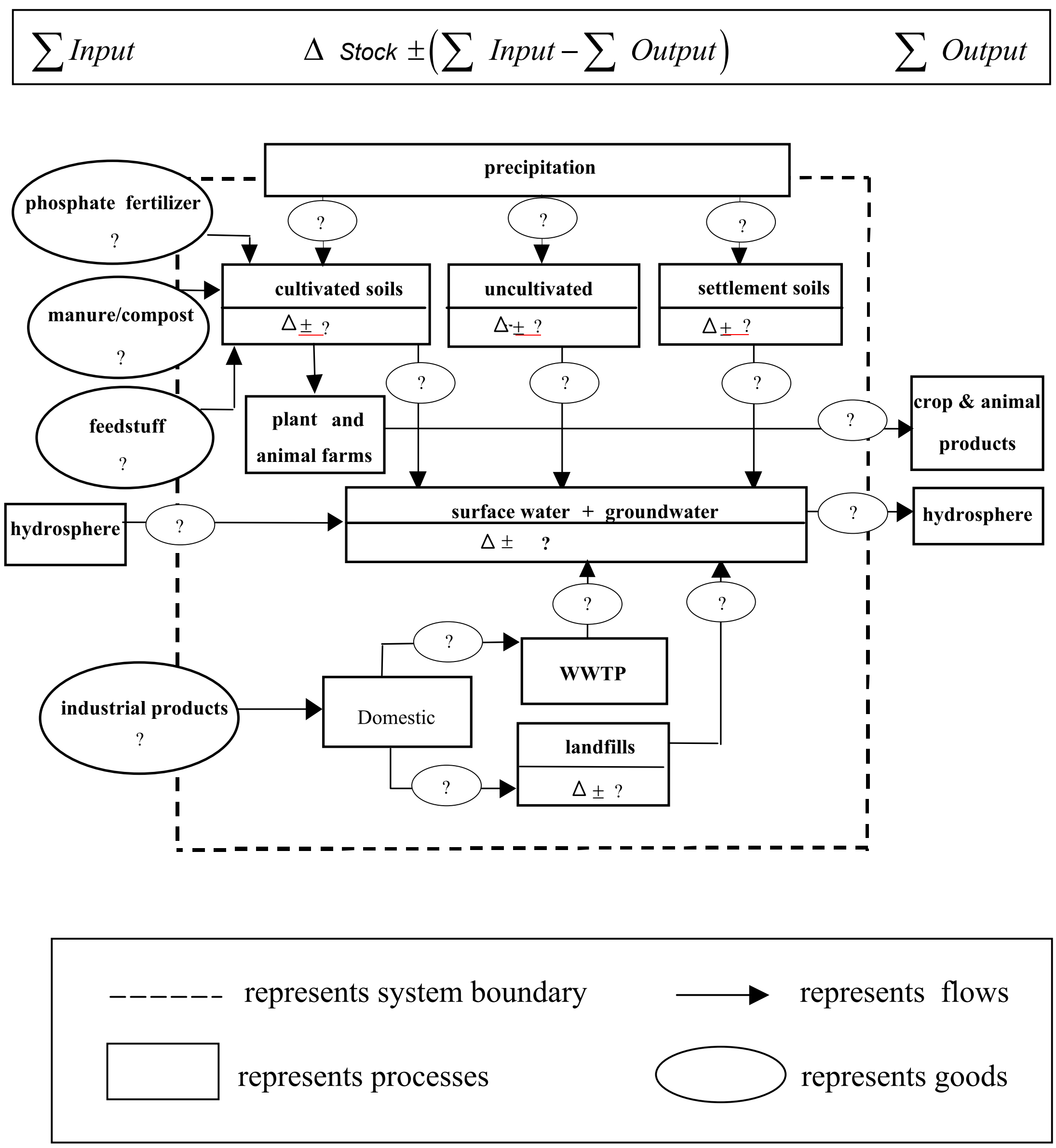


Figure 4-4: Flow diagram for P and Cd in the Songkhla Lake Catchment.

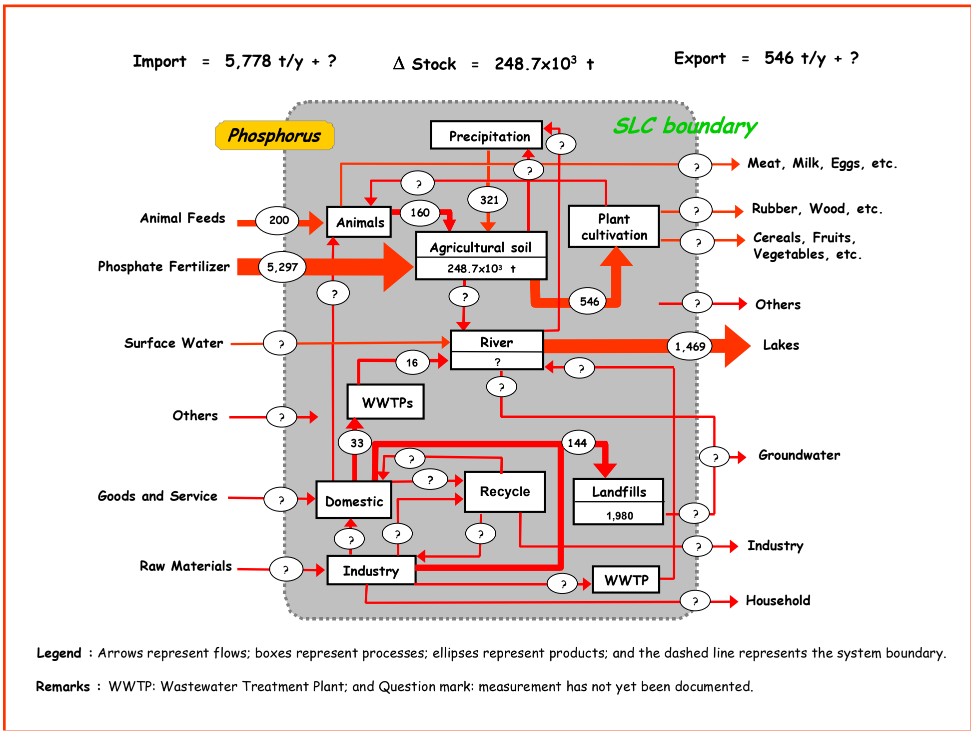


Figure 4-5 : Substance flows and stocks of phosphorus in the agricultural soil of the Songkhla Lake Catchment (t/y). The dashed line indicates the system boundary of the SLC. The width of the arrows is directly proportional to the size of the flux except for the products annotated with question marks, for which measurement has not yet been documented. Phosphate fertilizer and precipitation represent the predominant imports. Most of the P is transferred to agricultural soil and is stored almost entirely in the ploughed layer. This process has the greatest annual P stock in comparison with the other processes. A second important storage site is landfill, in which in some of the municipal solid waste is recycled or reused to produce feed for animals and/or secondary fertilizers. The most important impact with respect to the overall balance is the input to the agricultural soil, and emission flows from this source should be regarded as the hydrosphere process that causes the largest contribution to the lakes.

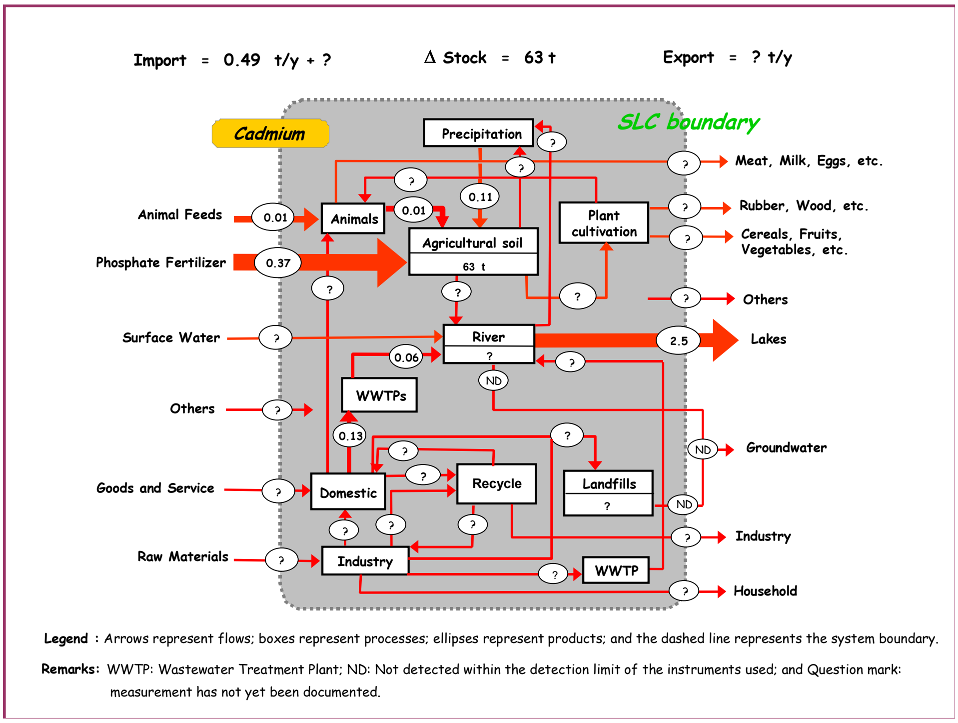


Figure 4-6 : Substance flows and stocks of cadmium in the agricultural soil of the Songkhla Lake Catchment (t/y). The dashed line indicates the system boundary of the SLC. The width of the arrows is directly proportional to the size of the flux except for the products annotated with question marks, for which measurement has not yet been documented. Phosphate fertilizer represents the predominant anthropogenic import. Most of the Cd is transferred to the agricultural soil and is stored almost entirely in the ploughed layer. This process has the greatest annual Cd stock in comparison with the other processes. The most important impact with respect to the overall balance is the input to the agricultural soil, and the emission flows from this source should be regarded at the hydrosphere process that causes the largest contribution to the lakes.

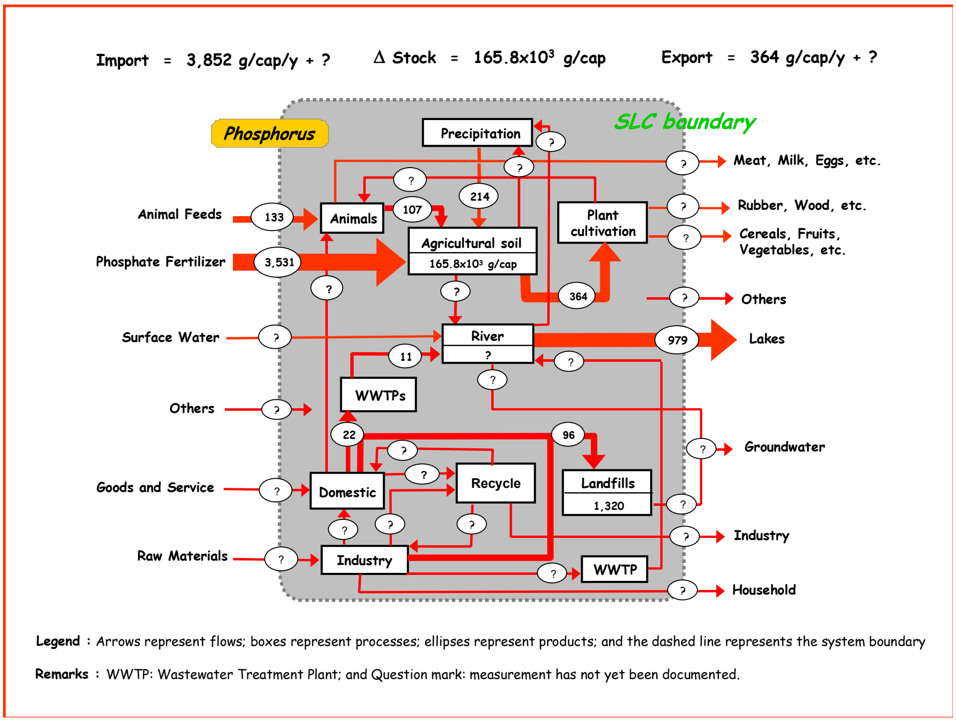
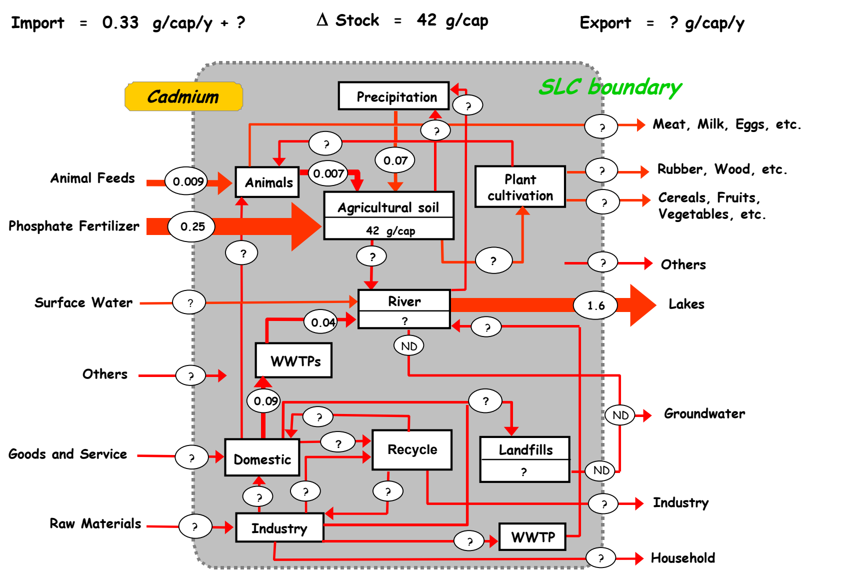


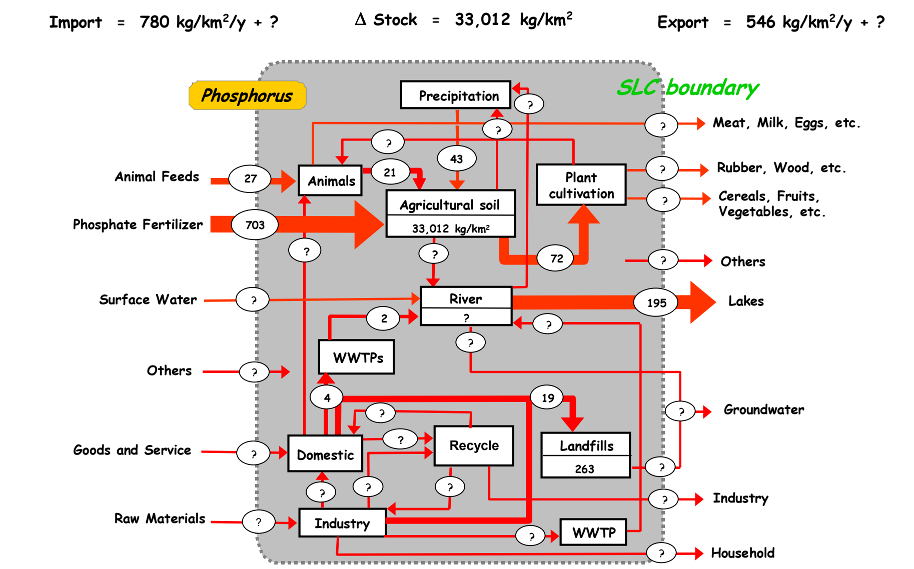
Figure 4-7 : Substance flows and stocks of phosphorus in the agricultural soil of Songkhla Lake Catchment (g/cap/y). The dashed line indicates the system boundary of the SLC. The width of the arrows is directly proportional to the size of the flux, except for the products annotated with question marks, for which measurement has not yet been documented. Phosphate fertilizer and precipitation represent the predominant imports. Most of the P is transferred to agricultural soil and is stored almost entirely in the ploughed layer. This process has the greatest annual P stock in comparison with the other processes. A second important storage site is the landfill, in which some of the municipal solid waste is recycled or reused to produce feed for animals and/or secondary fertilizers. The most important impact with respect to the overall balance is the input to the agricultural soil, and emission flows should be regarded as the hydrosphere processes that causes the largest contribution to the lakes.



Legend : Arrows represent flows; boxes represent processes; ellipses represent products; and the dashed line represents the system boundary.

Remarks: WWTP: Wastewater Treatment Plant; ND: Not detected within the detection limit of the instruments used; and Question mark: measurement has not yet been documented.

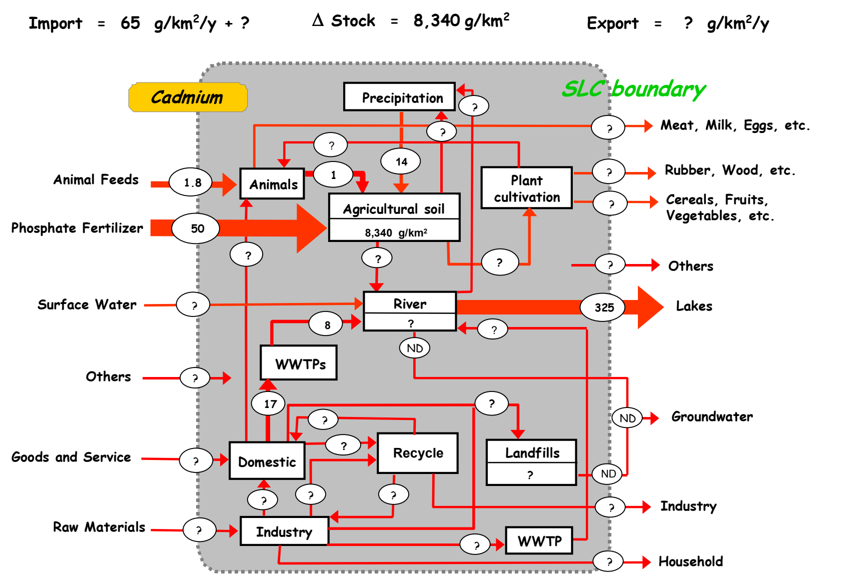
Figure 4-8 : Substance flows and stocks of cadmium in the agricultural soil of the Songkhla Lake Catchment (g/cap/y). The dashed line indicates the system boundary of the SLC. The width of the arrows is directly proportional to the size of the flux, except for the products annotated with question marks, for which measurement has not yet been documented. Phosphate fertilizer represents the predominant anthropogenic import. Most of the Cd is transferred to agricultural soil and is stored almost entirely in the ploughed layer. This process has the greatest annual Cd stock in comparison with the other processes. The most important impact with respect to the overall balance is the input to the agricultural soil, and emission flows from this source should be regarded as the hydrosphere process that causes the largest contribution to the lakes.



Legend : Arrows represent flows; boxes represent processes; ellipses represent products; and the dashed line represents the system boundary.

Remarks : WWTP: Wastewater Treatment Plant; and Question mark: measurement has not yet been documented.

Figure 4-9 : Substance flows and stocks of phosphorus in the agricultural soil of the Songkhla Lake Catchment (kg/km^2/y). The dashed line indicates the system boundary of the SLC. The width of the arrows is directly proportional to the size of the flux, except for the products annotated with question marks, for which measurement has not yet been documented. Phosphate fertilizer and precipitation represent the predominant imports. Most of the P is transferred to agricultural soil and is stored almost entirely in the ploughed layer. This process has the greatest annual P stock in comparison with the other processes. A second important storage site is landfill, in which some of the municipal solid waste is recycled or reused to produce feed for animals and/or secondary fertilizers. The most important impact with respect to the overall balance is the input to the agricultural soil, and emission flows from this source should be regarded as the hydrosphere process that causes the largest contribution to the lakes.



Legend : Arrows represent flows; boxes represent processes; ellipses represent products; and the dashed line represents the system boundary.

Remarks: WWTP: Wastewater Treatment Plant; ND: Not detected within the detection limit of the instruments used; and Question mark: measurement has not yet been documented.

Figure 4-10 : Substance flows and stocks of cadmium in the agricultural soil of the Songkhla Lake Catchment (g/km^2/y). The dashed line indicates the system boundary of the SLC. The width of the arrows is directly proportional to the size of the flux, except for the products annotated with question marks, for which measurement has not yet been documented. Phosphate fertilizer represents the predominant anthropogenic import. Most of the Cd is transferred to agricultural soil and is stored almost entirely in the ploughed layer. This process has the greatest annual Cd stock in comparison with the other processes. The most important impact with respect to the overall balance is the input to the agricultural soil, and emission flows from this source should be regarded as the hydrosphere process that causes the largest contribution to the lakes.

The findings of this study are summarized in Tables 4-10 and 4-11, which indicate the amount of P and Cd released from each pathway. As noted above, the data used to create these estimates are very limited. The reliability of this framework can only be established at an order of magnitude level.

Table 4-10 : Summary of P flux in the agricultural soil of the SLC.

Product / Process	(t/y)	(g/cap/y)	(kg/km^2/y, SLC)	(kg/km^2/y, agri. soil)
1. Substances entering				
1.1 Phosphate fertilizer	5,297	3,531	703	931
1.2 Precipitation	321	214	43	56
1.3 Manure	160	107	21	28
Total	5,778	3,852	780	1,002
2. Substances emitted				
2.1 Erosion	?	?	?	?
2.2 Plant cultivation	546	364	72	96
3. Waste Management				
3.1 Landfills				
3.1.1 MSW by domestic	144	96	19	25
3.2 WWTP				
3.2.1 Influent	33	22	4	6
3.2.2 Effluent	16	11	2	3
Product / Process	(t)	(g/cap)	(kg/km^2, SLC)	(kg/km^2, agri. soil)
4. Storage				
4.1 Agricultural soil	248,714	165,809	33,012	43,700
4.2 Landfills	1,980	1,320	263	384

Note: Question mark = measurement has not yet been documented

Table 4-11 : Summary of Cd flux in the agricultural soil of the SLC.

Product / Process	(t/y)	(g/cap/y)	(g/km^2/y, SLC)	(g/km^2/y, agri. soil)
1. Substance entering				
1.1 Phosphate fertilizer	0.37	0.25	50	50
1.2 Precipitation	0.11	0.07	14	19
1.3 Manure	0.01	0.007	1	2
Total	0.49	0.33	65	71
2. Substance emitted				
2.1 Erosion	?	?	?	?
2.2 Plant cultivation	?	?	?	?
3. Waste Management				
3.1 Landfills				
3.1.1 MSW by domestic	?	?	?	?
3.2 WWTP				
3.2.1 Influent	0.13	0.09	17	22
3.2.2 Effluent	0.06	0.04	8	11
Product / Process	**(t)**	**(g/cap)**	**(g/km^2, SLC)**	**(g/km^2, agri. soil)**
4. Storage				
4.1 Agricultural soil	63	42	8,340	11,040
4.2 Landfills	?	?	?	?

Note: Question mark = measurement has not yet been documented.