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Phosphorus management in the Baltic Sea – historic evidence and future options

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Summary

Phosphorus being one of the essential elements for all forms of life is also a finite resource. The extensive use of Phosphorus in anthropogenic activities has lead to concentrations in surface waters causing eutrophication. The Baltic Sea being a semi enclosed water body and a good example of eutrophication has been chosen as model basis. The magnitude of phosphorus use in Riparian States and the total loads to the sea is investigated using a systems analysis approach. In this thesis the phosphorous flows were examined using substance flow analysis of two types of systems: anthropogenic system and a sub basin system. The anthropogenic system presents the flows and stocks of phosphorus within processes with phosphorus utilization within each Riparian country and the total load of phosphorus to the Baltic Sea. The sub basin system models individual sub basins to determine the total input of phosphorus and the resident stocks of phosphorus in sea water and biomass. Based on the sub basin a hypothesis is formulated to determine the fate of phosphorus in the sea and the identify sinks of phosphorus.

Hypothesis: *The inflow of phosphorus into the Baltic Sea is not coupled with an increase in phosphorus stock but result in a high sedimentation rate. The sub basins represent phosphorus exporters to other neighboring basins.*

Within the anthropogenic system, agriculture and food market posses the largest flows and stocks of phosphorus. While the largest loads from the anthropogenic systems are from agricultural run off and waste water discharge. Poland is found to have major share in this contribution of phosphorus flows to the Baltic Sea.

The sub basin Baltic Proper contains the largest stock of phosphorus among all the other sub basins. The test of the hypothesis hold true and sediments of the Baltic Sea have been recognized as major sinks of phosphorus.

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List of abbreviations

1) ADP- Adenosine diphosphate
2) ATP- Adenosine triphosphate
3) BSEP- Baltic Sea Environmental Proceedings
4) BSW- Baltic Sea watershed
5) CSO- Combined sewage overflow
6) CSS- Combined sewage system
7) DNA- Deoxyribose nucleic acid
8) MFA- Material Flow analysis
9) RNA – Ribose nucleic acid
10) SFA- Substance Flow analysis
11) **1^0 WWTP**- Primary waste water treatment plant
12) **2^0 WWTP-** Secondary waste water treatment plant
13) **3^0 WWTP**- Tertiary waste water treatment plant

Chapter 1. Introduction

1.1 Background

1.1.1 Phosphorus and its essential role

Phosphorus is required by all known forms of life for their growth and functioning. It is present in every living cell in the form of amino acids, RNA and DNA as well as in the energy carriers ATP/ADP. Phosphorus is also a major structural component of bones and teeth in animals. In plants, phosphorus plays an important role during photosynthesis by storage of energy in high energy phosphate bonds. Phosphorus enters the plant through root hairs and root tips whereas animals assimilate the phosphorus through food. Furthermore, phosphorus is used in numerous products like detergents, fireworks, semiconductors etc. About 95% of the world's total phosphorus production is used in agriculture through fertilizers, pesticides and animal feed (Jasinski, 2012). The use of these products and their increasing demand calls for more and more extraction of phosphorus. The global annual increase in use of phosphorus fertilizers since year 2008 has been 2.7% per year (Smil, 2009). This can be explained by the changing structure of cultivation of crops and increase in population. Phosphorus is a non renewable mineral and the sole source of virgin phosphorus is the earth's crust which contains upto 71 billion tons of potential world reserves of phosphate rock (Jasinski, 2012). The world production of rock phosphate in 2011 was 0.19 billion tons and according to USGS it is to increase by 20 % in 2015. Accelerating the use of virgin phosphorus will eventually lead to depletion. (Antikainen, 2007). It has been predicted that if this increasing trend continues the rock phosphate reserves will only last until 70-100 years from now (Smil, 2009).

The exhaustion of resources is one of the two major threats associated with phosphorus. The second important issue is the impact of phosphorus on aquatic systems where it is creating serious disturbances in the natural ecosystem. The causes and effects of which are discussed in the following section.

1.1.2 Eutrophication

Accumulation of phosphorus occurs in agricultural soils due to over-fertilization of cultivated land and rearing of farm animals on pasture land. Phosphorus is also retained in the waste treatment systems where household waste consisting of phosphorus rich excreta and detergents, food wastes and industrial waste from food processing, paper and pulp and chemical industries is released and further treated. This terrestrial phosphorus attains the aquatic environment by surface run-off from agricultural soils, discharges of waste water from municipal and industrial sources.

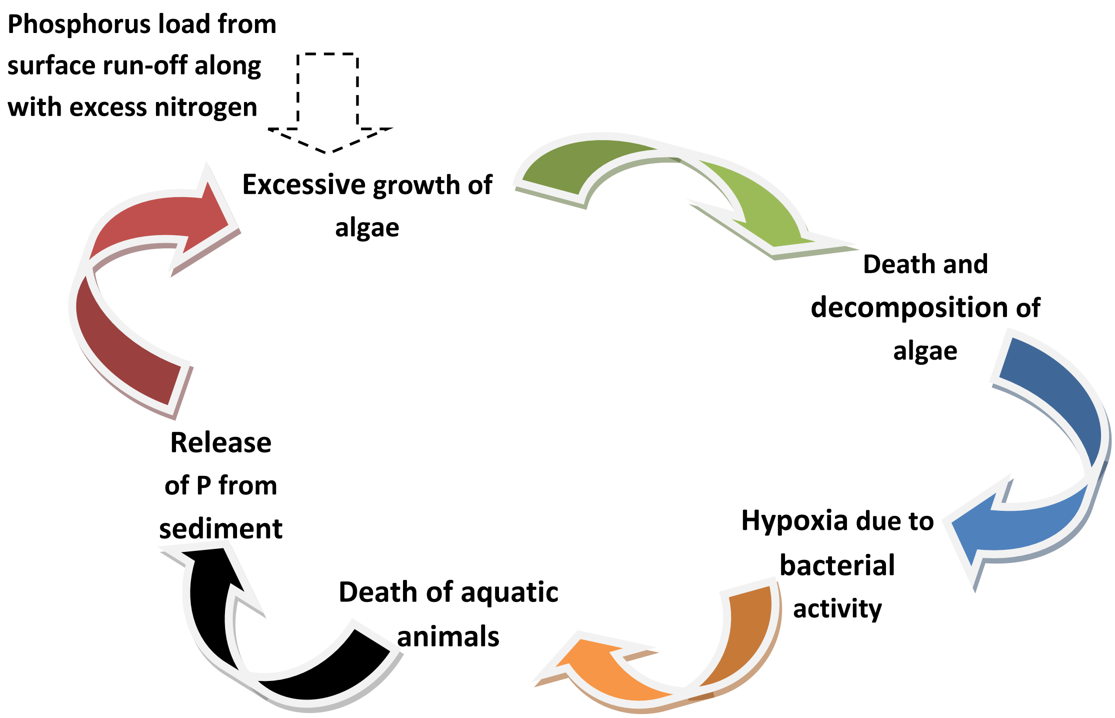

Figure 1: Schematic eutrophication process driven by phosphorus.

Excess of phosphorus coupled with excess nitrogen in aquatic systems can trigger conditions characterized by increased algal growth and reduced oxygen levels known as eutrophication. The abundance of nutrients as nitrogen and phosphorus provide the growth factors and cause an increase in aquatic vegetation like algae and phytoplankton. This vegetation decomposes after its death which results in an increased bacterial activity utilizing the dissolved oxygen in the water. This bacterial activity and resulting anoxic conditions are harmful for survival of the marine life.

This serious problem not only affects the biotic environment but also reduces the aesthetic value of any aquatic ecosystem. The stepwise process of eutrophication driven by phosphorus is shown in Figure 1.

The release of phosphorus from the sediments is driven by the anoxic condition in the bottom layer of the water body. This phosphorus in turn triggers the growth of algae and the viscous cycle continues to run. The water turbidity also increases during eutrophic conditions making it difficult for solar radiation to penetrate the water column.

1.1.3 The Baltic Sea watershed

Due to the fact that the Baltic Sea is a semi enclosed brackish water body and a good example of eutrophic conditions, it was chosen as a model basis. The Baltic sea is divided into six sub-basins namely the Bothnian Bay, Bothnian sea, Gulf of Finland, Gulf of Riga, Baltic Proper and the Kattegat which differ in physical and oceanographic characteristics. The Baltic Sea receives phosphorus loads from the surrounding terrestrial systems resulting in increasing concentrations of phosphorus in sea water. High population densities along the coast that are releasing waste waters into the sea and well developed agricultural sector which uses heavy doses of fertilizers are the main causes. Out of the total land area associated to the watershed, 20% is cultivated land/arable land and 6% is pasture land (Partanen-Hertell & Harju-Autti, 1999). The cultivated land and pasture land hold high concentrations of phosphorus due to fertilization of soil and nutrient rich animal excretion, respectively. Precipitation causes this phosphorus to diffuse in surface waters which eventually enters the riverine system. It has been observed that most of the nutrient loads to the Baltic Sea are discharged by the rivers from the surrounding land areas (Stålnacke, 1999). The annual load to the water body from entire surrounding area in 2000 was 41200 tonnes of phosphorus (HELCOM, 2004).

The accumulation of phosphorus and other nutrients in the water body stimulates the growth of algae. Excessive blooms of harmful algae and cyanobacteria are a major problem in the Baltic Sea. Such blooms not only lower the recreational value of the marine environment but they are also potentially toxic to other organisms to as well as humans. (HELCOM, 2009). The oxygen concentrations are depleted due to this heavy loading of nutrients (Fig 2) and continue to decrease since the 1990's (HELCOM, 2009).

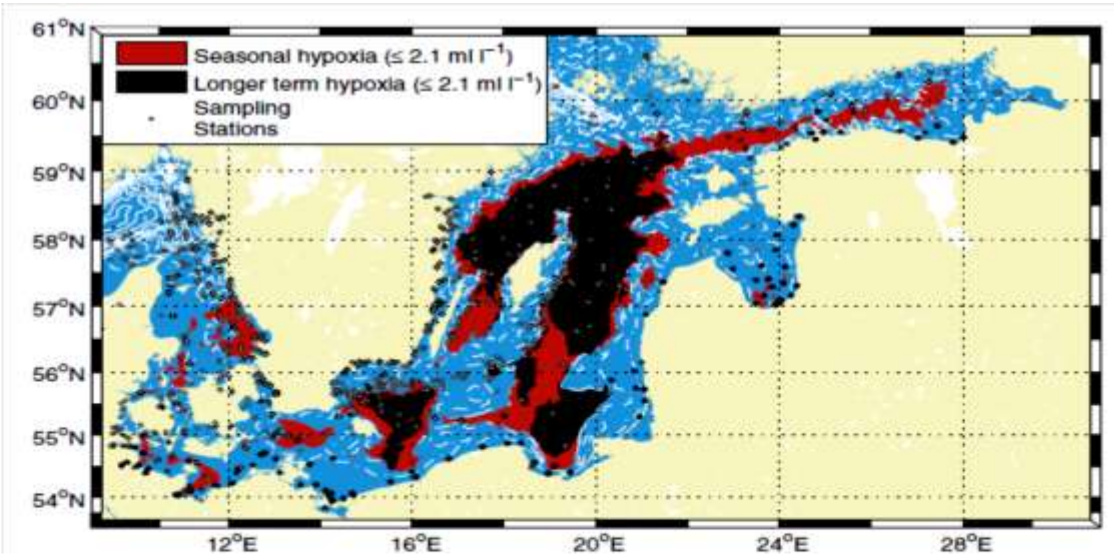

Figure 2: Map of the Baltic Sea showing hypoxic conditions with seasonal variation during year 2001-2006. Source (HELCOM, Eutrophication in the Baltic Sea – An integrated thematic assessment of the effects of nutrient enrichment , 2009)

Figure 2 gives a strong indication of eutrophic pressure in the sub-basins of the Baltic Sea. The 'long term zones', shown in black, are hypoxic throughout the year while 'seasonal zones', shown in red, are hypoxic during late summer/autumn giving the extent of the regions affected.

The riparian states along the Baltic Sea recognized this problem by the 1970s and following that, signed the Helsinki Convention, Helcom in 1974 (Lundberg, 2005) with an aim of reducing the pollution of nutrients in to the Baltic Sea. By 1980's the occurrence of eutrophication was clearer and demanded more focus. Thereafter, regular assessments of the status of the marine environment have been done by the Helsinki commission. Towards the end of 1980s, a policy perspective and recommendations to limit nutrient loading from waste water treatment plants and agricultural sites were applied. It has been observed that during the 1980s the total phosphorus loading were at a mean value of 48000 t/yr which has been reduced to 36000 t/yr during the

1990s (Bryhn, 2010). However, according to the Baltic Sea Action Plan, a reduction target of total 15000 tonnes of phosphorus has been agreed upon until 2021.

1.1.4 Current research and scope

In 2010 the Helsinki commission had launched a new project, PURE (Project on Urban Reduction of Eutrophication) to curb eutrophication and promote advanced removal of phosphorus from the municipal sewage discharge. The aim of this project is to achieve an average annual concentration of 0.5 mg phosphorus / liter in outgoing wastewaters i.e. upto 42% reduction from current concentrations. (Pure, 2011) The PURE project plans to achieve this by implementing advanced and cost effective methods for the removal of phosphorus from waste water sludge. (Pure, 2011)

Some later developments have been achieved by the Baltic nest institute developing a quantitative tool called the NANI/NAPI (Net anthropogenic nitrogen/phosphorus inputs) calculator which estimates the human induced nitrogen/phosphorus inputs to a watershed. This budgeting tool is similar to the Baltic Nest model which is a decision support system aimed at facilitating adaptive management of environmental concern in the Baltic Sea (Hong et al, 2011).

Most of the previous studies on the nutrient load of the Baltic Sea such as the Helcom's pollution load compilation reports (HELCOM, 2004), river basin in the Baltic Sea region (Nillson, 2006), total riverine loads of nitrogen and phosphorus to Baltic Sea (Stålnacke, 1999) have a holistic approach to the problem of nutrient enrichment in the Baltic Sea. But they lack a detailed and comprehensive study that explains the complex phosphorus system within the anthropogenic sectors (agriculture, food consumption, waste generation and management) within the Baltic watershed. The load oriented approach used in research so far is only able to quantify annual addition of phosphorus into the Baltic Sea, however the accumulation of phosphorus in the terrestrial region of the watershed have not been described. In order to understand the magnitude of the use of phosphorus in human activities and their interrelating processes, it is necessary to view it with a systems approach. Material Flow Analysis as a quantitative tool enables the construction of such a system that includes all the processes revolving around phosphorus and their interconnections in this study. The principle of mass balance not only determines the losses of phosphorus to the water body but also gives insight on the accumulation of phosphorus in individual processes such as agriculture, land filling, households etc.

The sub basins of the Baltic Sea and their individual watersheds of the sea have a varying degree of sensitivity to the impacts of eutrophication. This is due to large variances in e.g. topography, hydrography etc. between them. (Rönnberg & Bonsdorff, 2004) .The Baltic Sea cannot be treated as a uniform body and hence it is important to study area specific consequences of high phosphorus loads and it resulting effects. Hence it is important to analyze the phosphorus flows within different system boundaries of countries as well as sub basins.

To understand the future trends in phosphorus loading in the sea and the impacts of the historically accumulated phosphorus, it is important to calculate the total stock of phosphorus in the Baltic Sea. The water column, biomass and sediments are the media through which phosphorus accumulation takes place (Paytan & McLaughlin, 2007). The exchanges of phosphorus between the media are complex dynamics, depending on various hydrological and oceanographical factors (Bostrom, Andersen, Fleischer, & Jansson, 1998). There has been an attempt of such an analysis where a phosphorus budget of the Baltic Sea and its sub basins is constructed and the stocks and the exchanges of phosphorus between the sub-basins are quantified based on simulation models (Savchuk, 2005). However, no study has been conducted so far applying the material flow analysis methodology to explain the routes of phosphorus transport in the Baltic Sea sub basins. This thesis attempts to model the Baltic Sea sub basins and by using the mass balance principle combines with available data, calculate total stocks in water column and biomass of the sub basins of the Baltic Sea. In addition, a hypothesis has been constructed in order to answer some questions regarding the possible routes of phosphorus exchange between the sub-basins.

This thesis is in continuation with a master project where a Substance Flow Analysis model was developed for the sub region, Gulf of Riga for the year 2000 and where the phosphorus flows in tonnes of P /year were quantified (Mehta, 2011). The main sectors included in the project were agriculture, human settlements, waster water and drainage systems, solid waste treatment and the natural background. The flows related to the human settlements and waste management were well defined, however the agricultural sector needed further detailed and transparent calculations. Hence the system has been redefined to address the interaction of phosphorus in agriculture.

1.2 Aim of the study

The objective for the master thesis is to systematically analyze the anthropogenic phosphorus cycle in the Baltic Sea watershed and the impact of this cycle on the movement of phosphorus in Baltic Sea. Two different systems will be constructed , first one to determine the extent of phosphorus use in the countries in the catchment area of the Baltic Sea and the second one to determine the accumulation of phosphorus in the Baltic Sea system. The country specific system will consist of flows and stock of phosphorus within human consumption and use, whereas the Baltic Sea-sub basin system will quantify the stocks of phosphorus in the sub basins of the sea. The aquatic sub basin system also aims to comment on the intermixing of phosphorus within the different biotic and abiotic components of the system as well as with the adjacent sub basins. The sub basin system receives an inflow of phosphorus from the country specific system and the stocks of phosphorus in sea are sensitive to this inflow. To understand the dynamics of intermixing, a hypothesis has been developed. The flows and stocks of phosphorus in the sub basin system will be quantified for the year 2000 and 2006 to observe the differences in the quantities of phosphorus. The hypothesis is based on this difference of quantities in the flows and stocks of phosphorus in the sub basin system.

Hypothesis:

The inflow of phosphorus into the Baltic Sea is not coupled with an increase in phosphorus stock but result in a high sedimentation rate. The sub basins represent phosphorus exporters to other neighboring basins

The analysis of the two systems and the test of the hypothesis will be used to answer the following questions.

- What are the major anthropogenic flows of phosphorous entering the Baltic Sea? How different are they from one associated country to the other? What is the proportion of the total loads from terrestrial systems to the residing stock of phosphorus in the sea water?
- What are the areas with high phosphorus use, where the phosphorus loads within the riverine watershed can be reduced and how?
- How can we explain the fate of phosphorus after its entry into the sea ,by applying the principle of mass balance?
- By determining processes that use virgin phosphorus, how can the reduction of this virgin phosphorus be achieved? What are the different possibilities and challenges in doing so?

Chapter 2. Materials and Methods

2.1 Material Flow Analysis

Material flow analysis (MFA) is a is a systematic assessment of the flows and stocks of materials within a system defined in space and time (Bunner & Rechberger, 2003). This methodology connects the source of materials with their pathways to the final state or sink of the material within a system boundary. This boundary can consists of geographical borders (countries, cities, river basins) or a limited area of interests (manufacturing unit consisting of processes like transportation, waste management etc.). The system can be characterized by applying the mass balance principle on the inputs, output or stocks of any process. MFA is used in a variety of environmental-engineering and management applications, including environmental-impact statements, remediation of hazardous-waste sites, design of air-pollution control strategies, sewage-sludge management etc (Bunner & Rechberger, 2003). One variation used in MFA terminology is Substance Flow Analysis (SFA) which is the assessment of the stocks and flows of specific substances. The term material refers to goods or products whereas a substance can be an individual element or compound.

The most relevant aspect of this methodology is the ability to model systems with a basis of managing resources and wastes to identify the accumulations of substances in the environment. Identification of the major flows and stocks can help to set the priority regarding measures for resource conservation and waste management. One such example is the study conducted by the International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria. Stigliani et al assessed the flows of some pollutants in the Rhine river basin and identified the major sinks and sources of heavy metals. They concluded with some measures regarding the future management of these pollutants (Stigliani et al, 1992).

The substance chosen for this particular thesis project is Phosphorus and the boundary is the Baltic Sea watershed where the flows and stocks of Phosphorus are analysed to identify major flows within the anthorpogenic activities and the resulting effect on the water body.

2.2 Definition of terms

The MFA terminology and some other terms used in the report have been briefly listed below.

1) **Process** is defined as a transport, transformation, or storage of materials. The processes can be natural or man-made such as storage of carbon in forest or transport of waste through waste management chain. (Bunner & Rechberger, 2003)
2) **Stocks** are defined as material reservoirs within a system and have a physical unit of kilograms. Stock of a process is where the mass is stored. (Bunner & Rechberger, 2003)
3) **Net stock addtition** is the annual accumulation of materials in the given process within the system. (Hinterberger, Giljum, & Hammer, 2003)
4) **Flow** (mass per time) link the processes with each other. The flows entering a process are called inputs and the ones exiting are called outputs. The flows across the system boundaries are called exports and imports. (Bunner & Rechberger, 2003)
5) **Baltic Sea watershed or drainage basin** is the extent of land area where the surface water from precipitation converges into the Baltic sea. The Baltic Sea watershed is shared by 14 countries, Sweden, Finland , Russia and Poland having the largest share.
6) **Sub basin** is a small watershed or drainage basin within the Baltic sea and is geographicaly and oceanographically distinguished from the rest of the sub basins. Baltic Sea is made up of six main sub basins viz. *Bothnian Bay, Bothnian Sea, Gulf of Finland, Gulf of Riga, Baltic Proper, and Kattegat*.
7) **Country segment** is the land area of each country falling under the Baltic Sea watershed.
8) **Anthroposphere** of the Baltic Sea watershed is the area inhabited by humans for their use and activities such as agriculture, settlements, food consumption, waste management etc. The anthroposphere interacts with and impacts the lithosphere, hydrosphere and atmosphere.

2.3 System definition

This thesis analyzes two systems and their phosphorus flows that are quantified based on two different approaches. The first being the country wise approach where the aim is to quantify the phosphorus flows within each country and the total phosphorus entering the Baltic Sea from that country segment. The second approach aims to model each sub basin in a system and calculate phosphorus flows between the sub basin, its sediments and the corresponding countries.

2.3.1 Country wise approach

This approach focuses on phosphorus flows and stocks between human driven processes within a country. Agriculture, industry and households are the three main areas where phosphorus is consumed and surface runoff, land filling and waste effluents are three main ways through which phosphorus is lost in the environment. The variation in demographics, agricultural practices and industrial structure of each country within the Baltic Sea watershed results in a greater variation in the individual contribution to the phosphorus loadings to the Baltic Sea. This approach enables the allocation of phosphorus loadings of Baltic Sea to individual countries rather than treating all countries as one. The 'anthropogenic system' is constructed using this approach and it will be analyzed for all the countries of the Baltic Sea watershed.

2.3.2 Anthropogenic systems of the Baltic Sea watershed

An individual anthropogenic system described above consists of all the major processes that use phosphorus including the agriculture and animal husbandry, household consumption, waste water management and solid waste management within each country. The Baltic Sea watershed is formed by 15 countries which contribute to the phosphorus flows to the Baltic Sea. These countries are Sweden, Finland, Russia, Latvia, Lithuania, Estonia, Denmark, Germany and Poland. The countries that do not surround the Baltic Sea but fall under the drainage basin are Belarus, Ukraine, Czech, Slovakia and Norway. The system boundary is defined as the border of the segment of each country that falls under the Baltic Sea drainage basin. The proportion of land area under the watershed for each country varies from about 4% to 98% (HELCOM, 2004) . According to the land area and population densities, varying percentages of population from each country have been considered. Total consumption of phosphorus for plant and animal production and the resulting loss of phosphorus from soil have been quantified. The total phosphorus in paper production, food production, consumption and waste generation of the segments of each country were quantified. The waste management system comprises of four types of treatment methods along with some fraction of waste being reused. The river system is described as the network of streams and river that drain the water into the sea. The phosphorus from agricultural soil and waste water outlets enters the river system and is further carried to the Baltic Sea. Therefore the flow from the river system to the Baltic Sea is the total phosphorus load of each country under the Baltic Sea watershed.

The total amount of phosphorus is expressed as thousand tonnes per year for the year 2000. Net stock addition is expressed as thousand tonnes. The overview of the system with the processes and their interconnecting flows is displayed in Fig.3

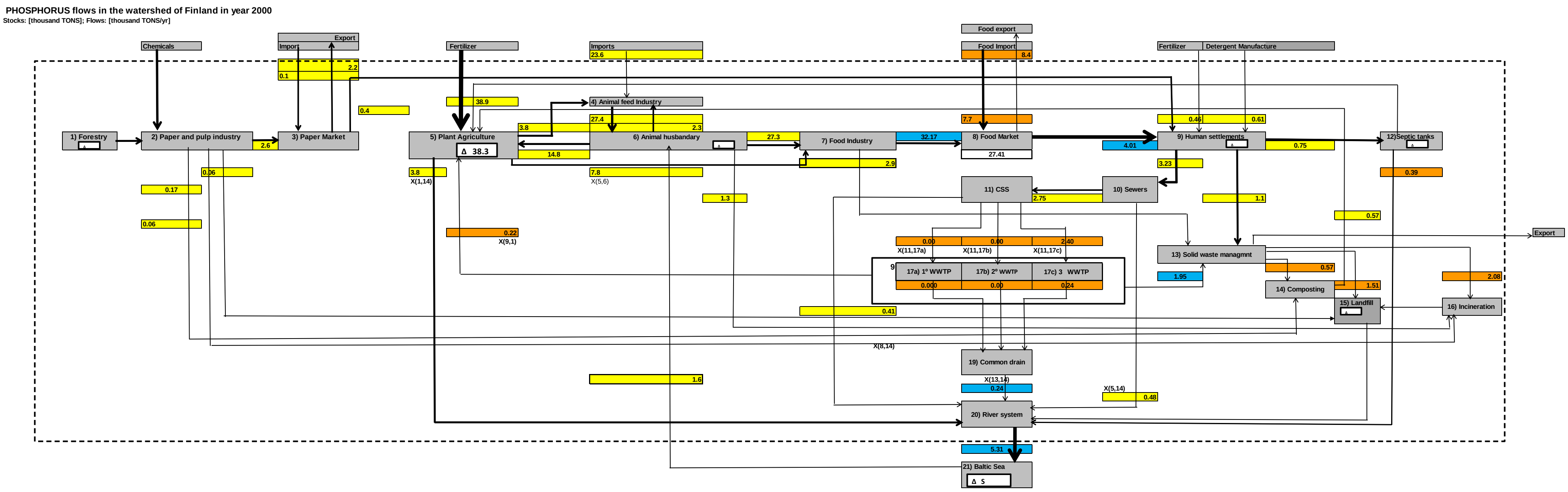

Figure 3: System diagram of the anthropogenic flows within the Finland for year 2000.

2.3.2 Sub basin approach

This approach unlike the country wise approach focuses on the individual sub basins of the Baltic Sea and its interaction with phosphorus. The main aspect of this approach is the land water interface through which the sub basin imports phosphorus from corresponding anthropogenic systems. The sub basin system is analyzed to identify the phosphorus stock in the water body and distinguish the sub basins from it phosphorus retaining capacity. The characteristic of each sub basin to store phosphorus in the water column or sediments will also be assessed. This approach also enables to determine relation of the total stock with the total annual imports of phosphorus in the Baltic Sea.

2.3.3 Sub basin system

Based on the sub basin approach this system aims to connect each sub basin of the Baltic Sea to the corresponding anthropogenic system of the countries by annual phosphorus flows. A sub-basin can bear imports of phosphorus from more than one country releasing phosphorus from its processes. The system boundary is defined by the perimeter of the sub basin of the sea. Five sub basins of the Baltic Sea (Bothnian Bay, Bothnian Sea, Gulf of Finland, Gulf of Riga and Baltic Proper) were modeled into individual sub basin system. The ratio of the stock in the water body to the total annual phosphorus inputs was also calculated. The sub basin consists of four main processes within the boundary. The water column has been divided into sub processes as coastal waters with (1) depth less than 100m and (2) deep waters with depth more than 100m. The sediment and the total biomass are two other processes that represent storage of phosphorus. The biomass has an uptake of phosphorus from the water column and stores phosphorus in the organisms. The sediment has a net stock addition of phosphorus via the deposition of dead organic matter from the total biomass. The system has an exchange of phosphorus with the neighboring sub basin in the form of export/import of phosphorus from the system. Although these flows have not been quantified due to the complex dynamics of nutrient exchange between sub basins, the hypothesis test will comment on possible routes of exchange. The phosphorus flows are expressed as 10^3 tonnes/ year and the stock are expressed as 10^3 tonnes for the year

2000 and 2006. Fig. 4 represents the Bothnian Sea sub basin with Sweden and Finland as the corresponding countries.

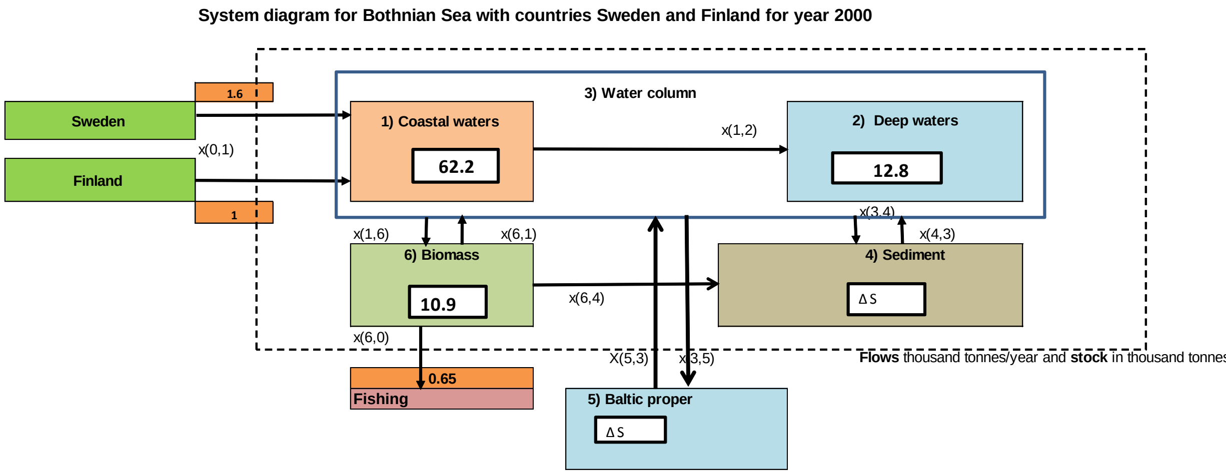

Figure 4: System diagram for sub basin system showing land water interface flows.

2.4 Major processes and interconnecting flows

After having discussed the system boundaries in the previous section, the main processes and flows within the systems are described below.

2.4.1 Anthropogenic system

Plant agriculture and animal husbandry

These processes represent the activity of cultivation of food crops rearing of livestock. The plant agriculture receives an input of phosphorus through fertilizers, manure and seeds. The fertilizer application is done only on the arable land which does not include pasture or grazing land. The crop production is used for two purposes: human food consumption and animal feed. The cultivated soil accumulates phosphorus due to the continuous application of fertilizers. The crop production suitable for human consumption is further processes at the food industry. Some losses of phosphorus from soils occur due to surface run off, further entering the riverine system.

The animal husbandry process receives phosphorus inputs through animal feed. Part of this phosphorus is assimilated in the animal body and the rest is lost through excretion. The phosphorus containing excreta from livestock is applied to the crop land as manure. The animal produce of milk and eggs are further processed and available for human consumption. The meat production included in the flow from animal husbandry to food industry consists of dressed meat. The slaughter waste is sent for incineration and bone meal, fish meal is used as manure. The fish production flow is drawn from the Baltic sea to the animal husbandry.

Paper and pulp industry and market

This process carries out the production of paper and board from wood. It receives phosphorus through raw materials of wood and chemicals. The wood is supplied by the process forestry where logging of wood takes place. The processing of wood into paper releases solid waste as well as liquid waste containing phosphorus. These wastes are composted, incinerated or treated in waste water plants. The paper market in the system receives the produce of the paper industry and an import of phosphorus through paper. Part of the domestic paper production is exported and the rest is available for human consumption.

Food industry and market

This process involves the processing and packaging of the plant and animal produce. It is assumed that all the agricultural output is processed before human consumption. The food industry generates waste water and solid organic waste which is further treated, composted or incinerated. The food market receives processed foods from the food industry and import of food. The market also exports fraction of the domestic food production. The food market is a stock of phosphorus from which the households get their required amount of phosphorus in food.

Human settlements

The human settlements can be defined as households and their vicinity. This process has a main function of food consumption and sanitation which results in 2 types of waste generation i.e. Solid waste and waste water. Another aspect considered in this process is the use of fertilizers for household gardens etc. The urban human settlements release the sewage water in the common drain where it is further treated in municipal sewage treatment plants. The storm water containing traces of phosphorus is also collected and driven into the municipal sewage treatment plant. The solid waste generated from households is composted, incinerated or land filled.

The rural settlements that are not connected to the municipal sewage treatment treat the sewage in septic tanks where it is digested and brings about phosphorus reduction from waste water. The solid residue/sludge from this digestion is either collected and treated at the solid waste management or is applied to agricultural land.

Waste water treatment

The waste water treatment comprises of a numerous process involving collection of waste water, treatment and release. There are two types of waste water treatment in this system. One is the industrial waste water treatment and the other municipal sewage treatment plant (STP).

The sewage from human settlements is collected and carried to the combined sewage system by sewers. The network of sewers being of old construction, some leakage of phosphorus through waste water occurs here which enters the surface water bodies. A combined sewer system is a sewer that accepts storm water, sanitary water/sewage and channels the waste waters into treatment plants. Under certain wet weather conditions, however, these sewer systems can become overloaded and release some of the untreated combined waste streams, these are known as combined sewer overflows (CSOs). The CSOs are releasing into surface water streams accounting for loss of phosphorus from this process.

The treatment plants carry out different chemical, physical and biological treatment on the waste water to reduce the phosphorus from incoming waste water. This consists of primary, secondary and tertiary treatment plants where the reduction potential of each type of treatment varies with countries and population connected to each type of treatment plant. The phosphorus in the sludge is separated during this process and the outflow of treated water contains the remaining phosphorus. This treated water is directly released into the riverine system through the common drain.

Solid waste treatment

This sector represents the different processes of solid waste treatment such as composting, incineration and landfill. This group of processes receives organic waste from households, sludge from waste water treatments plants and solid waste from paper industry. In addition to this it also receives waste from the food industry which can be mainly comprised of high risk slaughter waste. There are different methods used for the disposal and end treatment of solid waste. The composted organic waste is used back for agricultural applications. The residue from incineration is mostly land filled, however some fraction is used for agriculture applications. Some of the waste is also exported to other countries.

Riverine system

The losses of phosphorus from above processes of agriculture, food and paper industry, waste treatment are collected by the riverine system which includes the streams and rivers converging into the Baltic Sea. These sources of phosphorus can be the treated drainage from urban and rural households, agricultural runoff, untreated wastewater from household and industries, leaching from landfills etc.

2.4.2 Sub basin system

Water column

This process consists of two sub processes, the coastal waters and the deep waters. The coastal water process represents the volume of water within the shallow coastal areas with depth less than 100m. This process receives an input of phosphorus from the anthropogenic system, therefore has a higher concentration of phosphorus in water. On the other hand, the deep waters represent the volume of water within the deep areas with depth more than 100m. The deep waters receive an input of phosphorus from the coastal waters.

The water column has an input of phosphorus from the sediments and the adjacent sub basin. The output from the water column is the phosphorus uptake by the biomass.

Biomass

The biomass consists of all organisms present in the sub basin system. This consists of all types of flora and fauna of the sea water. The phosphorus input to this process is from the water column through the assimilation process. The phosphorus in dead biomass forms the output of this process which is then added to the sediments.

Sediments

Sediments are a mixture of organic and inorganic particles that settle at the bottom of the sub basin. The sediments have two phosphorus inputs, one from the biomass in the form of dead decaying matter and the second one from the water column. Under anoxic conditions the sediments release phosphorus into the water column.

2.5 Model approach and parameters

2.5.1 Anthropogenic system

Plant agriculture, animal husbandry, food industry and food market

The fertilizer consumption of each country segment has been calculated using the total fertilizer consumption per country and the total area of arable land. The total plant production and animal production have been calculated using per capita productivity derived from FAO Stat data. The import and export of food products have also been calculated using per capita quantity using the percentage of population residing in each country segment. The total phosphorus from all agricultural products has been calculated using the total quantities of goods and phosphorous content of different goods. The stock of food market is calculated by mass balance (Table 1). The agricultural runoff have been calculated using data from the fourth pollution compilation load (Helcom 2000)

Paper and pulp industry

The total production, import and export of paper and board per country have been calculated using data from FAO stat (Food and agricultural organisation of united nations, 2012). The production of paper per capita has been calculated to obtain the total paper production in each country segment. Using the phosphorus content of paper the total phosphorus flows in the paper industry have been calculated (Table 1).

Human settlements and Municipal waste water treatment

Per capita consumption of phosphorus via food, detergents and garden fertilizers have been used to obtain the input flows to human settlements. The leakage from the waste water collection system has been calculated using total percentage losses from each process. By using the amount of population connected to each primary, secondary and tertiary treatment facilities and their respective reduction capacities the phosphorus content of the treated water has been calculated.

The flows from the Solid waste management and its different processes have been calculated based on country specific methods of treatment and disposal (Table 1).

Table 1. gives a complete list of parameters used for the calculation and their data sources.

Table 1. List of parameters used for calculation and their data source.

Flow	Parameter	Data source
X(2,3) X(0,3) X(3,0)	Paper production, import and export	(FAO Statistics, 2000)
	Phosphorus content of Paper	(Antikainen, Haapanen, & Rekolainen, Flows of nitrogen and phosphorus in Finland—the forest industry and use of wood fuels, 2004)
X(2,10) X(2,11)	Waste production and management of paper industry	(Monte, Fuente, Blanco, & Negro, 2009)
X(0,5)	Fertilizer consumption per country	Refer. Excel sheet 'Fertilizer'
	Total arable land per country	(UNEP Grida Arendal ,2006)
X(5,7) X(5,4) X(6,7) X(0,8) X(8,0)	Plant production, Animal production, total production from food industry, Import and export of food	(FAO Statistics, 2000), Food Balance sheets
	Phosphorus content of crops and animal products	(Hong et al, 2011)
X(3,8) , X(8,10) , X(8,16)	Waste management of food industry waste	(Swedish Environmental Protection Agency, 2005)
X(4,19)	Agricultural run-off	(HELCOM, 2004)
X(8,9) X(0,9a) X(0,9b)	Human consumption of phosphorus in food and detergents	(Karin Emilsson, 2007)
X(9,10) X(10,11)	Sewage collection and leakage from Sewers and CSS	(Sægrov, 2011)
X(11,12)	Sewage treatment plant	(BNI, 2000)

X(9,14)	Household Waste production	(Binder, Baan, & Wittmer, 2009)
Sub system approach		
X(0,1)	Total phosphorus loadings from anthropogenic system	(HELCOM, 2004)
S1, S2	Phosphorus stock in water column	Calculated using transect method. Refer 2.5.2
S6 , X(6,5)	Total stock of phosphorus in biomass and fish extraction	Refer Appendix 1

Percentage population in Baltic Sea watershed used for all calculations				
Country	**Total population in 2000**	**Population in Baltic Sea Watershed (BSW)**	**% in BSW**	**% of Arable land in BSW of all land use types**
Latvia	2374000	2028000	85.4	0.048
Finland	5173000	4906870	94.9	0.067
Sweden	8860000	8274000	93.4	0.077
Poland	38433000	38000000	98.9	0.41
Lithuania	3501000	3501000	100.0	0.085
Estonia	1370000	1370000	100.0	0.031
Russia	146670000	9028000	6.2	0.082

2.5.2 Sub basin system

Phosphorus loadings

The flows of phosphorus between the countries and the receiving sub basin have been obtained using data from the Fourth Pollution Load Compilation report published by Helcom (HELCOM, 2004). The report gives information on the contribution of each country in phosphorus loading to multiple sub basins. Hence the receiving sub basin will have as many phosphorus flows as the countries lying in its own drainage basin. For e.g. the Bothnian Bay has a phosphorus input from both Finland and Sweden. The values given in the report include all the losses of phosphorus from different processes within the anthropogenic systems of countries.

Quantification of phosphorus stock in sub basin

The physical characteristics of each sub basin have been described by (Al-Hamdani & Reker, 2007) and the data on area and volume of water has been extracted from the same. In order to calculate total amount of phosphorus in water column the concentrations of phosphorus in the water body have been taken from the ICES oceanographic database. (ICES, 2012). There is a high degree of change in phosphorus concentrations of sea water depending on the distance from coast, depth of sea etc. Averaging the phosphorus concentration from all stations will result into erroneous values, hence a transect method has been used to classify the sea area into different depth and the choice of sampling stations have been made accordingly. The first step in using this method was to determine the area of the low depth coastal areas and deep sea areas of the sub basin with. An interactive GIS map developed by Helcom was used to calculate coastal area and deep sea area of each sub basin. This was achieved by manually drawing polygons over the depth contours distinguishing areas with depth lower than 100m and the remaining sea area with depth higher than 100m. The area of each polygon was then calculated. Fig. 6 displays the map with depth contours and the polygon showing deep sea areas.

The oceanographic data is obtained by a compilation of phosphorus concentrations from 30 to 40 sampling stations across the sub basin area. Based on the depth and the geographical location of the station, an average of 15 concentrations of phosphorus from different sampling stations was used. The choice of sampling station was done by construction three transect lines along the area the sub basin and selecting data from the stations lying on the transect line. Each transect line has on an average five sampling stations. The average phosphorus concentration of coastal waters was calculated using concentrations from stations having a depth less than 100 m and a deeper area with a depth more than 100 m. Fig 6 presents the transect lines with stations constructed on the Bothnian Bay exemplarily. Each station is named with the code used in the ICES database.

Table 2. provides a list of all stations used for the Bothnian Bay and their geographical locations, depth and phosphorus concentration used for the calculation. This method reduces upto an extent, the uncertainty of using average values because of its specific selection of data

Figure 5 : Snapshot of the deep sea areas marked using the Helcom GIS interactive map. (Helsinki Commision, 2011)

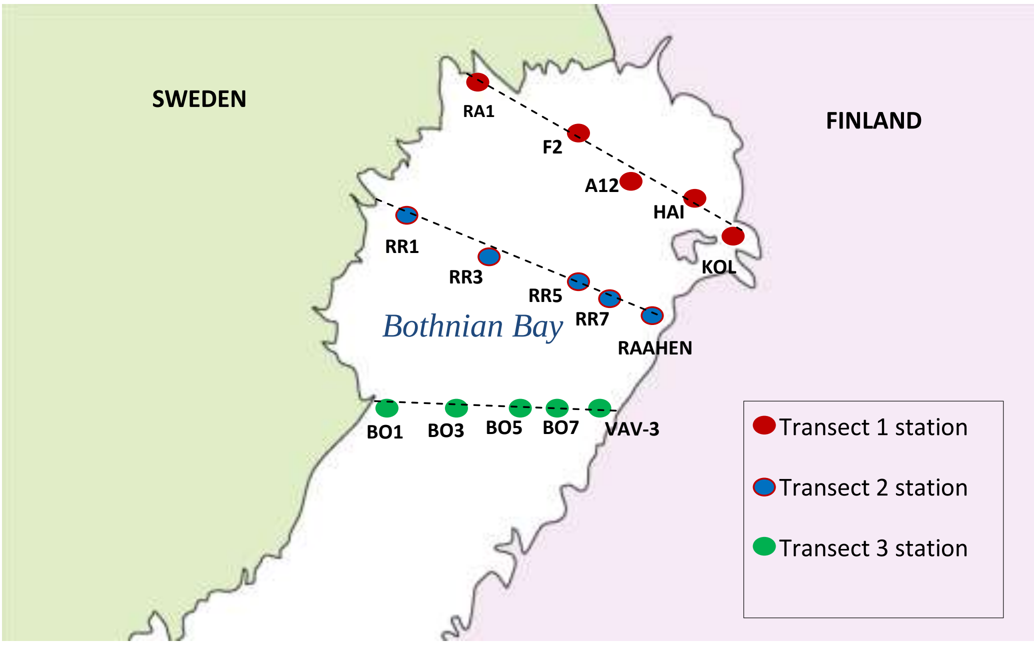

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Figure 6 : Showing the transect method used for calculation of average phosphorus concentrations.

This method has been repeated for the other four sub basins and on an average 15 sampling stations from each sub basin had been chosen. In this section only the Bothnian Bay has been mentioned exemplarily. The same methodology has been applied to the rest of the sub basins. The list of station and their detailed information for all other sub basins has been given in the Appendix 1.

Table 2. List of sampling stations of the Bothnian bay and their geographical location, depth and phosphorus concentration.

Bothnian Bay					
Transect 1					
Station name	**Depth (m)**	**Latitude**	**Longitude**	**Total P conc. In umol/l Year 2000**	**Year 2006**
RA1	9	65.8	22.37	0.35	0.1
F2	115	65.4	23.47	0.05	0.22
A12	60	65.2	23.8	0.22	0.22
Hailuodon	15	64.96	24.45	0.19	0.2
Kolmikulma	47	65.39	25.27	0.26	0.26
Transect 2					
RR1	85	64.9	21.86	0.11	0.22
RR3	100	64.93	22.35	0.05	0.2
RR5	70	64.8	23.17	0.11	0.21
RR7	40	64.73	23.82	0.15	0.21
Raahen	15	64.7	24.34	0.21	0.2
Transect 3					
BO1	80	64.42	21.85	0.15	0.3
BO3	110	64.3	22.34	0.1	0.24
BO5	50	64.18	22.9	0.13	0.3
BO7	25	64.13	23.21	0.21	0.17
LE-2	18	64.12	23.47	0.16	0.12

Chapter 3 Results

3.1 Anthropogenic system

All flows and stocks of phosphorus in the anthropogenic systems of Finland, Sweden, Estonia, Latvia, Lithuania, Russia and Poland have been quantified based on the model approach described in the previous section. The results are divided into six sections: Plant agricultural and animal husbandry, food market and household consumption, municipal waste water collection and treatment, solid waste management and total loads. Fig. 7 to Fig. 13 present system diagrams with the flows and stocks of phosphorus in the year 2000 for all countries. Table 3 to Table 8 gives a detailed overview of all the major flows and stocks of phosphorus within the defined systems.

3.1.1 Plant agriculture and animal husbandry

All the major flows and stocks in the agriculture sector within each country are summarized in Table 3. **383100** tonnes of phosphorus in fertilizers is applied on arable land of all countries among which Poland alone consumes **70%** of this total phosphorus fertilizer consumption. The total phosphorus in animal manure is **169600** tonnes and here again Poland having the highest share of manure application on arable land.

In 2000, **48%** of phosphorus from fertilizers was found in the total crop production, **3%** lost in agricultural run off and the remaining **49%** phosphorus was accumulated in agricultural soil. Another major input to the agricultural processes is phosphorus in animal feed which accounts for a total of **314000** tonnes of phosphorus where Sweden, Finland and Poland consuming **90%** of the total sum of all countries. On an average, animal feed industry has a return of **16 %** phosphorus from animal husbandry in other forms of feed such as bone meal, fish meal etc. Poland has the highest phosphorus in animal production in 2000 with a value of **132000** tonnes which equals to **53%** of the total sum of all countries. Sweden and Finland rank 2nd and 3rd in the animal production of phosphorus.

Estonia, Latvia and Russia have a **net stock reduction** of about **1190 - 50** tonnes of phosphorus in soil whereas, Poland has a net stock addition of **243000** tonnes in agricultural soil.

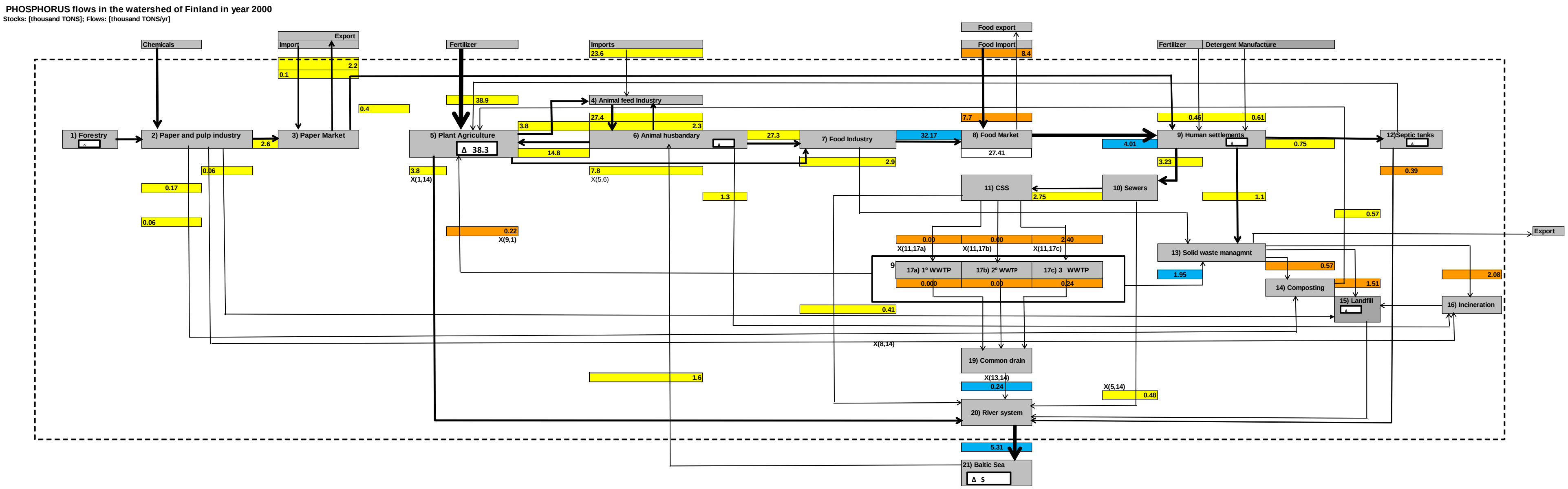

Figure 7 : System diagram with all flows and stocks of phosphorus in Finland in year 2000.

*The **yellow** color boxes are the flow quantities that are calculated using goods flows or concentrations. **Blue-** Mass balance, **Orange**- Transfer coefficient

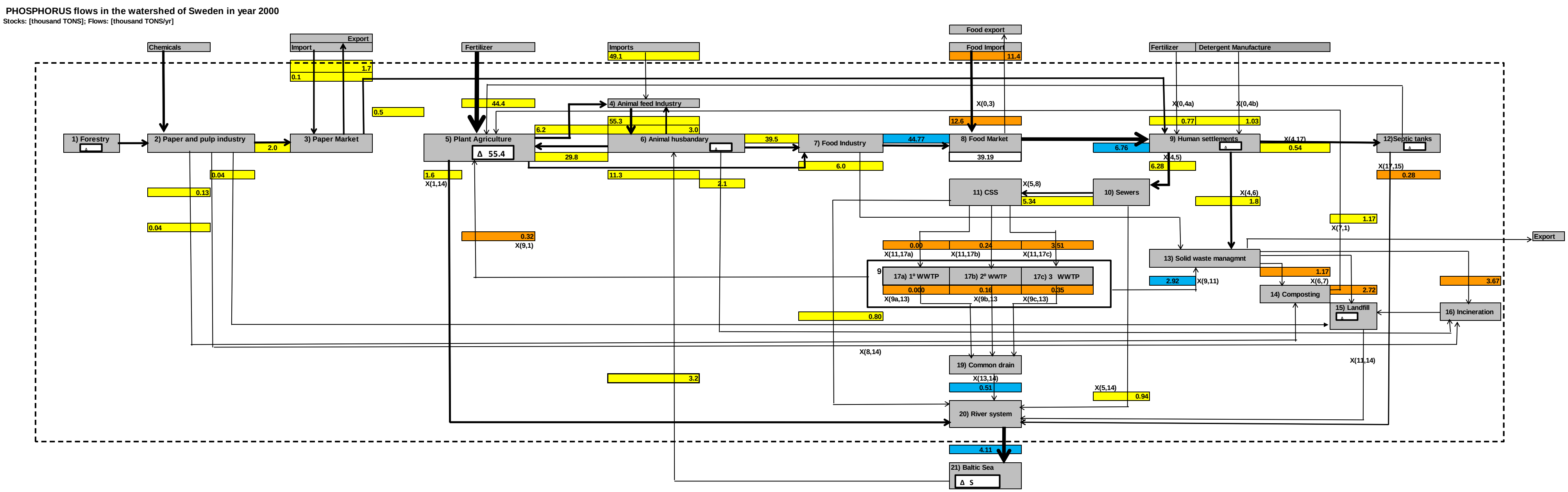

Figure 8 : System diagram with all flows and stocks of phosphorus in Sweden in year 2000.

*The **yellow** color boxes are the flow quantities that are calculated using goods flows or concentrations. **Blue-** Mass balance, **Orange**- Transfer coefficient

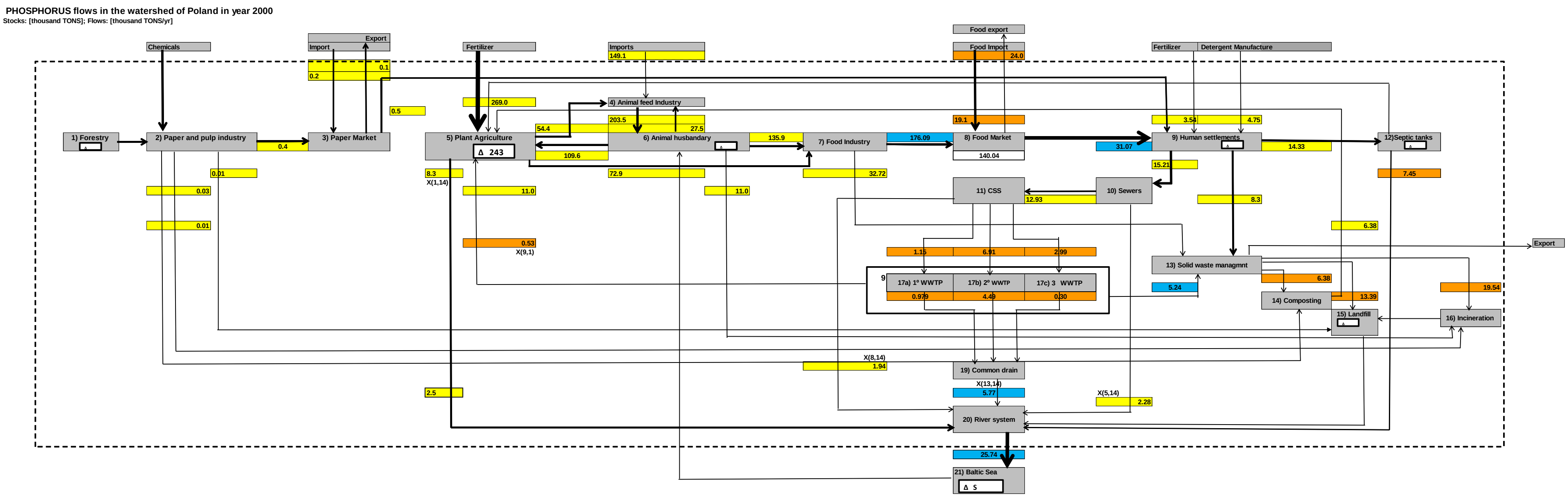

Figure 9 : System diagram with all flows and stocks of phosphorus in Poland in year 2000.

*The **yellow** color boxes are the flow quantities that are calculated using goods flows or concentrations. **Blue-** Mass balance, **Orange**- Transfer coefficient

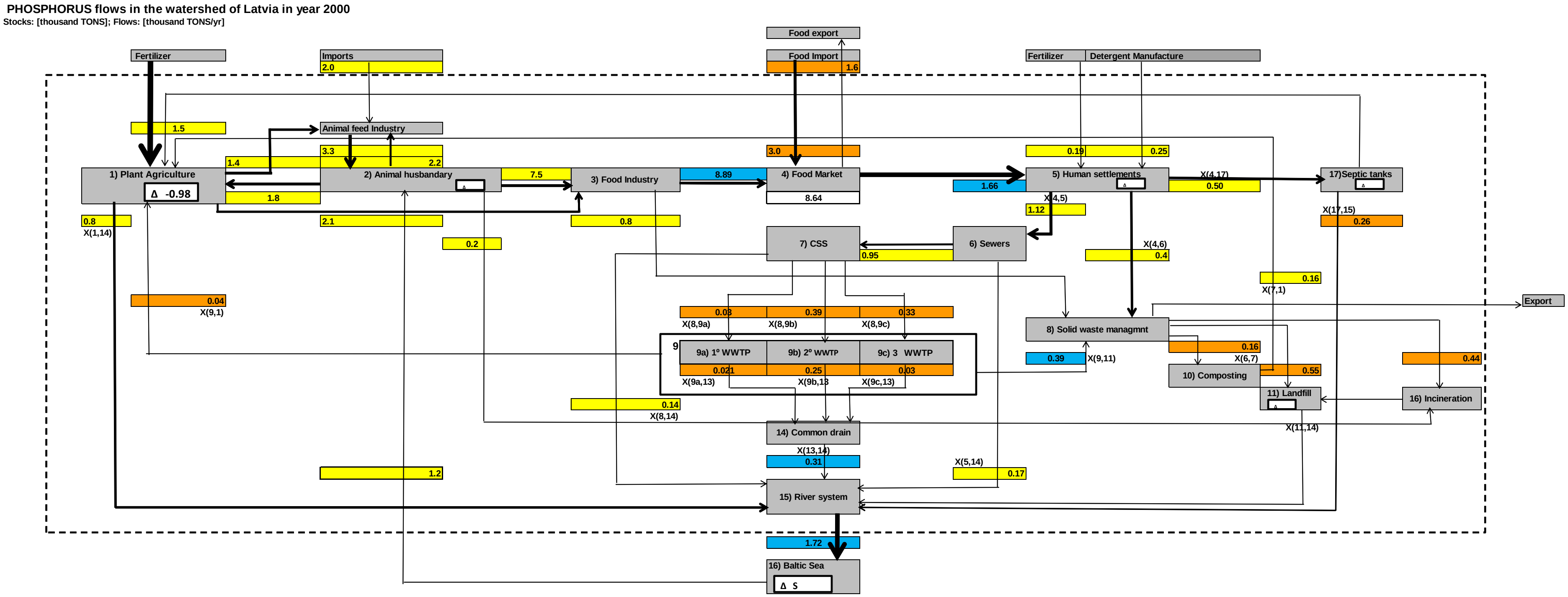

Figure 10 : System diagram with all flows and stocks of Latvia in year 2000.

*The **yellow** color boxes are the flow quantities that are calculated using goods flows or concentrations. **Blue-** Mass balance, **Orange**- Transfer coefficient

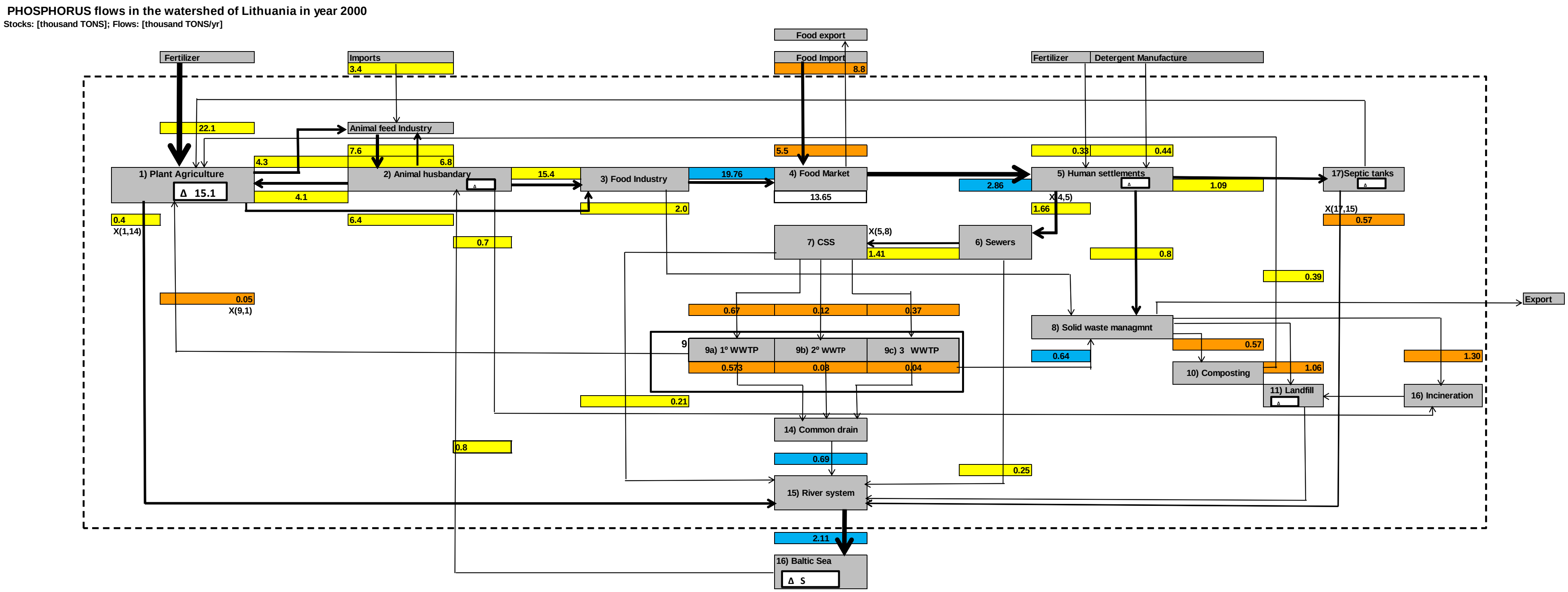

Figure 11 : System diagram with all flows and stocks in Lithuania in year 2000.

*The **yellow** color boxes are the flow quantities that are calculated using goods flows or concentrations. **Blue-** Mass balance, **Orange**- Transfer coefficient

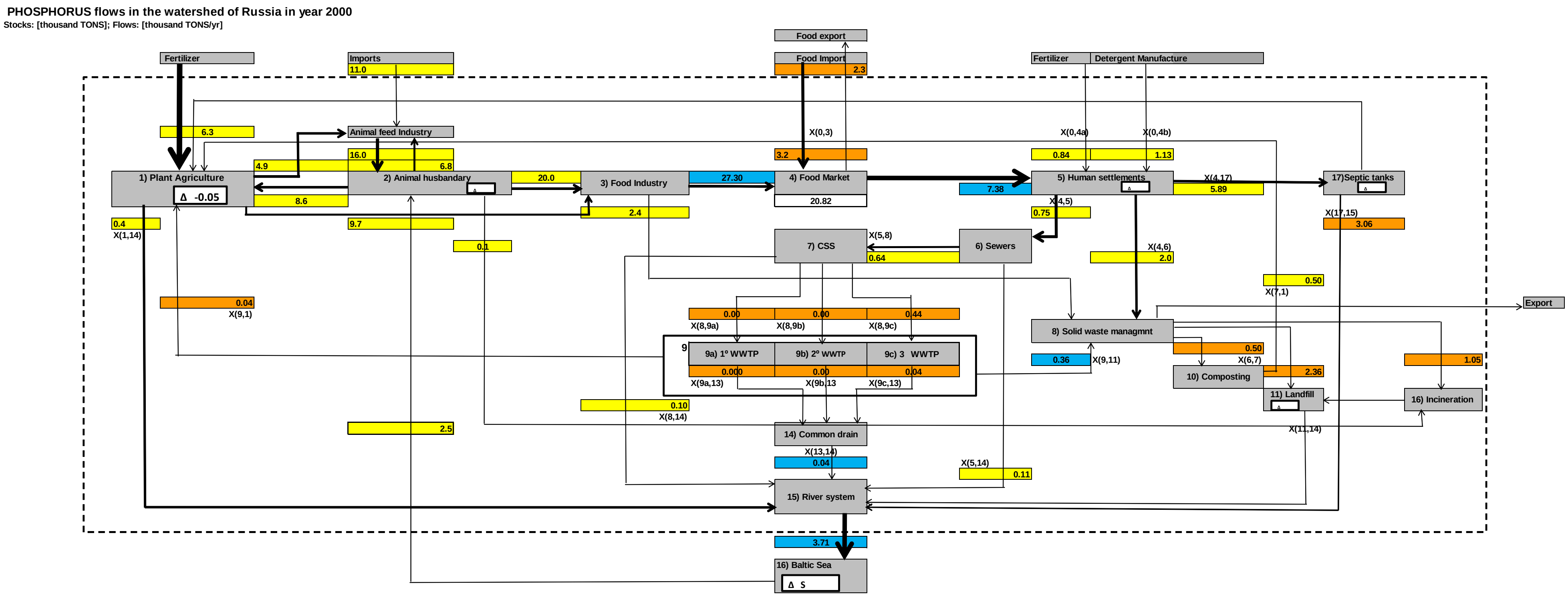

Figure 12 : System diagram with all flows and stocks of Russia in year 2000.

*The **yellow** color boxes are the flow quantities that are calculated using goods flows or concentrations. **Blue-** Mass balance, **Orange**- Transfer coefficient

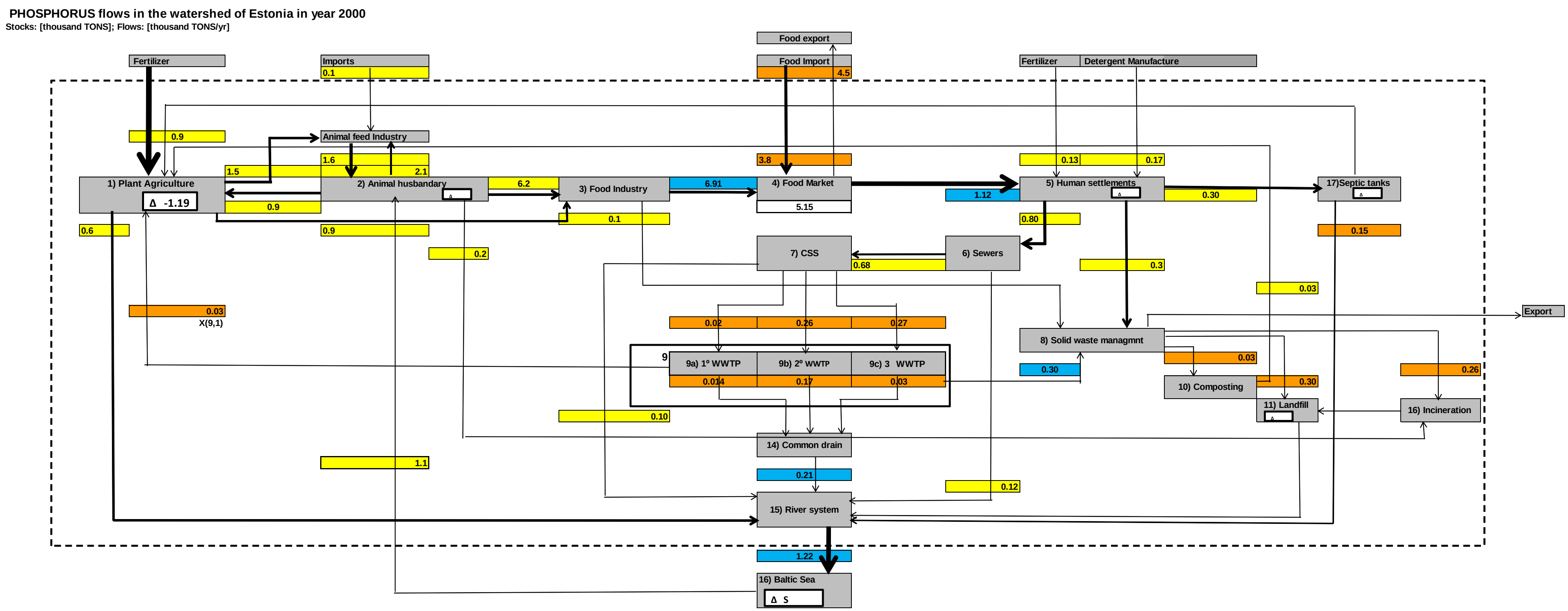

Figure 13 : System diagram with all flows and stocks of Estonia in year 2000

*The **yellow** color boxes are the flow quantities that are calculated using goods flows or concentrations. **Blue-** Mass balance, **Orange**- Transfer coefficient

Table 3. Total amount of phosphorus in flows and stocks of plant agriculture and animal husbandry in 2000

Country	Total fertilizer consumption (10^3 tonnes)	Total phosphorus in manure/animal excretion (10^3 tonnes)	Total agricultural run off (10^3 tonnes)	Total crop production (food+seed) (10^3 tonnes)	Net stock addition of phosphorus in soil	Total phosphorus in animal feed (10^3 tonnes)	Total phosphorus in animal production* (10^3 tonnes)	Total phosphorus in animal products used as feed*[1] (10^3 tonnes)
Estonia	0.9	0.9	0.6	2.4	-1.19	1.6	6.2	2.1
Finland	38.9	14.8	3.8	11.6	38.3	27.4	28.6	2.3
Latvia	1.5	1.8	0.8	3.5	-0.98	3.3	7.1	2.2
Sweden	44.4	29.8	1.6	17.5	55.4	55.3	40.3	3.0
Lithuania	22.1	4.1	0.4	10.7	15.1	7.6	14.3	6.8
Russia	6.3	8.6	0.4	14.6	-0.05	16.0	20.5	6.8
Poland	269.0	109.6	8.3	127.3	243	203.5	132.4	27.5
Total	**383.1**	**169.6**	**15.9**	**187.6**	**359.3**	**314.7**	**249.6**	**50.7**

*Slaughter waste is not included.

*[1] products such as bone meal, fish meal used as animal feed.

3.1.2 Food Market and household consumption

All the major flows and stocks in the food market and household consumption within each country are summarized in Table 4. and Table 5.

Table 4. Total amount of phosphorus in flows and stocks of food market in 2000

Country	Total food products (10^3 tonnes)	Total import of food (10^3 tonnes)	Total export of food (10^3 tonnes)	Total stock in food market (10^3 tonnes)
Estonia	6.9	3.8	4.5	5.1
Finland	32.1	7.7	8.4	27.4
Latvia	8.4	3.0	1.6	8.4
Sweden	44.7	12.6	11.4	39.1
Lithuania	18.5	5.5	8.8	13.6
Russia	27.3	3.2	2.3	20.8
Poland	172.4	19.1	24	140
Total	**310.3**	**54.9**	**61**	**254.4**

The food industry in the Baltic Sea watershed produces a total of **310300** tonnes of phosphorus as annual production in 2000. On the whole **81%** of the annual production is stored in stocks of food market.

Poland is the largest importer and exporter of food products and Sweden the second largest. Lithuania exports **45%** and Sweden exports **22%** while Poland only exports **13%** of their total food production in 2000.

The phosphorus stock in food market is highest in Poland and equals to **140000** tonnes of phosphorus in year 2000. Sweden holds the second largest food stock of **39000** tonnes.

Table 5. Total amount of phosphorus in flows and stocks of household consumption in 2000

Country	Total food consumption (10^3 tonnes) of phosphorus	Total fertilizer consumption in households (10^3 tonnes) of phosphorus	Total detergent consumption in households (10^3 tonnes) of phosphorus
Estonia	**1.1**	**0.13**	**0.17**
Finland	**4**	**0.46**	**0.61**
Latvia	**1.6**	**0.19**	**0.25**
Sweden	**6.7**	**0.77**	**1.03**
Lithuania	**2.8**	**0.33**	**0.44**
Russia	**7.3**	**0.84**	**1.13**
Poland	**31**	**3.54**	**4.75**

In 2000 the flow of phosphorus from food industry to food consumption was **31000** tonnes compared to the stock of **140000** tonnes of phosphorus in food industry in Poland. The lowest rank in household consumption of phosphorus is Estonia with only **1400** tonnes of phosphorus.

The difference between the largest consuming country to the lowest consuming country in the Baltic Sea watershed is about **96%.**

3.1.3 Waste water collection and treatment

All the major flows and stocks in the waste water collection and treatment within each country are summarized in Table 6.

The total losses from leakage during collection of waste water equals to the amount of phosphorus of the discharges from municipal waste water treatment plants (MWWTP). Out of the total phosphorus generated in sewage in all countries on an average, more than half of phosphorus is released into the Baltic Sea. The other half is retained in the terrestrial system mainly as landfills.

Table 6. Total amount of phosphorus in flows in the waste water collection and treatment in 2000

Country	Total phosphorus in sewage generation (10^3 tonnes)	Total losses in collection by leakage (10^3 tonnes)	Phosphorus in outflow of MWWTP (10^3 tonnes)	Phosphorus from septic tanks (10^3 tonnes)
Estonia	1.5	0.2	0.2	0.1
Finland	4.0	0.9	0.2	0.4
Latvia	1.6	0.3	0.3	0.3
Sweden	6.8	1.2	0.5	0.3
Lithuania	2.7	0.5	0.7	0.6
Russia	6.6	0.2	0.0	3.0
Poland	29.5	4.2	5.7	7.4
Total	**52.7**	**7.5**	**7.7**	**12.1**

3.1.4 Solid waste management

All the major flows and stocks in the Solid waste management within each country are summarized Table 7. Out of the total waste generated, **36%** is land filled, **47%** is incinerated and only **17%** is composted. The landfills have a net stock addition of **21600** tonnes of phosphorus in 2000. The largest waste producer is Poland and Sweden ranks second.

Table 7. Total amount of phosphorus in flows of solid waste management sectors in 2000

Country	Total phosphorus in landfill (10^3 tonnes)	Total phosphorus in incinerated waste (10^3 tonnes)	Total waste being composted (10^3 tonnes)
Estonia	0.3	0.2	0.03
Finland	1.5	2.0	0.6
Latvia	0.5	0.4	0.1
Sweden	2.7	3.6	1.2
Lithuania	1.0	1.3	0.5
Russia	2.3	1.0	0.5
Poland	13.3	19.5	6.3
Total	**21.6**	**28**	**9.23**

3.1.5 Total loads

All the flows of phosphorus converging into the riverine system to form a total flow of phosphorus to the Baltic Sea are summarized in Table 8.

Table 8. Summary of the total inputs of phosphorus to the Baltic sea in 2000

Country	Total agricultural run off (10^3 tonnes)	Total phosphorus from MWWTP and septic tanks (10^3 tonnes)	Total leakage from waste water collection (10^3 tonnes)	Total load to Baltic sea (10^3 tonnes) in 2000
Estonia	0.6	0.4	0.2	1.2
Finland	3.8	0.6	0.9	5.3
Latvia	0.8	0.6	0.31	1.7
Sweden	1.6	0.8	1.7	4.1
Lithuania	0.4	1.3	0.4	2.1
Russia	0.4	3.0	0.2	3.7
Poland	8.3	13.1	4.2	25.7
Total	**15.9**	**19.8**	**7.91**	**43.6**

3.2 Sub basin system

The phosphorus flows and stocks of the sub basins Bothnian Bay, Bothnian Sea, Gulf of Finland, Gulf of Riga and the Baltic Proper are presented in section **3.2.1** to **3.2.5**. The flows and stocks have been calculated for the year 2000 and 2006. Table 9 gives an overview of all the sub basins and their total stocks in thousand tonnes of phosphorus.

The largest input of **16,000** tonnes of phosphorus per year is received by the Baltic Proper sub basin in 2000. Out of the **16,000** tonnes, Poland has the highest contribution of **78%** in this input of phosphorus. The percentage of the total anthropogenic inputs to the resident stock of coastal waters is in the range **41 to 3 %** in year 2000 with Bothnian Sea being the highest and the Baltic proper the lowest. The total phosphorus output through fishing is about **4 to 6%** of the total phosphorus stock in biomass for both years.

The total anthropogenic inputs in 2006 have reduced by **35 to 16%** for all sub basins except the Gulf of Riga which has an increase of **16%** to the input of 2000. On the other hand the total stocks of phosphorus in the Bothnian Bay, Bothnian Sea and Gulf of Finland have increased by **47 to 17 %** in 2006 compared to the stocks in 2000. However the Gulf of Riga and the Baltic Proper have a reduction of **12%** and **8%** respectively.

The largest stock of phosphorus in water is in the Baltic Proper and accounts to **444,000** tonnes of phosphorus in year 2000 and **432,000** tonnes in 2006. The largest increase in stock in water column is of **47%** from the year 2000 to 2006 in the Gulf of Finland.

The detailed amounts of phosphorus within each sub basin and its processes are described in detail in the following sections.

3.2.1 Bothnian Bay

All the quantified flows and stocks of the Bothnian Bay sub basin for year 2000 and 2006 are shown in Fig. 15 and Fig. 16 respectively. Table 7 presents an overview of amount of phosphorus in stocks and flows of all processes within the sub basin.

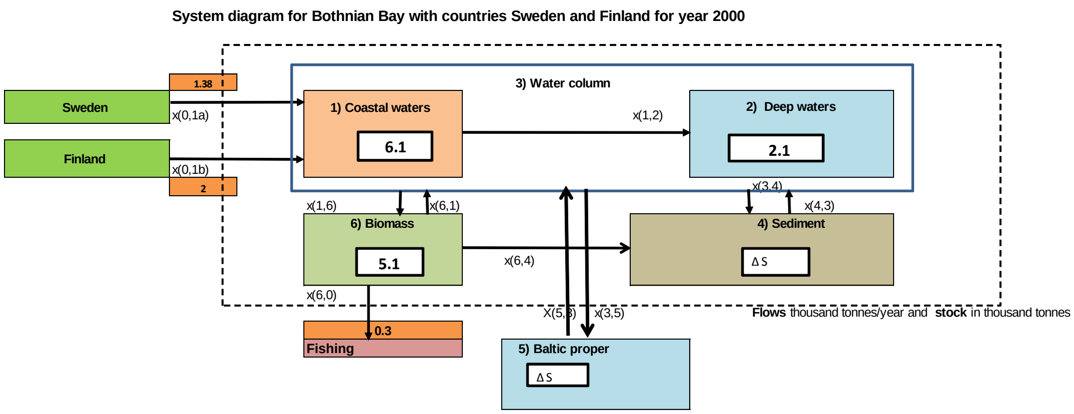

Figure 14: System for Bothnian Bay sub basin showing phosphorus flows from the corresponding countries to the total stock of the sub basin for year 2000.

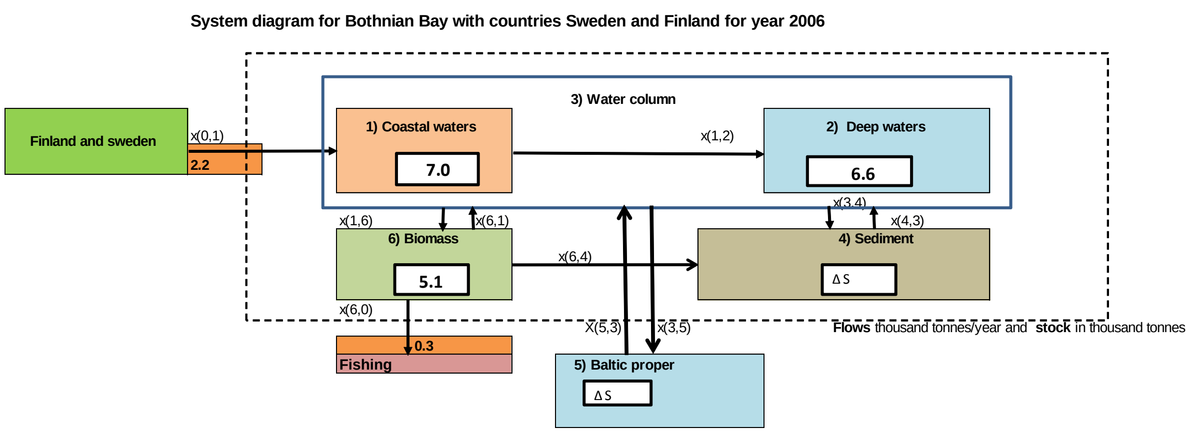

Figure 15: System for Bothnian Bay sub basin showing phosphorus flows from the corresponding countries to the total stock of the sub basin for year 2006.

In year 2000 the Bothnian Bay received an annual total import of **3300** tonnes of phosphorus which is a net stock addition to the coastal waters. Sweden contributes **40%** to the input to the Bothnian Bay and Finland the rest **60%**. This stock addition of phosphorus to the coastal waters accounts for **55%** of the total resident stock in 2000. The deep waters and the biomass have a total phosphorus stock of **2100** and **5160** thousand tonnes respectively. The total phosphorus exported via fishing from the biomass is **300** thousand tonnes which accounts for **5.8%** compared to the total stock of phosphorus in biomass of the Bothnian Bay.

In year 2006 the Bothnian Bay received an annual import of **2200** thousand tonnes of phosphorus having a decrease of **35%** from the inputs of year 2000. However the stocks of coastal waters and deep waters in 2006 have increased by **40%** compared to the stocks in 2000. It is assumed that there is no change in biomass and hence the total stock of phosphorus in biomass is **5160** thousand tonnes. The total phosphorus exported via fishing from the biomass is **300** thousand tonnes also based on the assumption that fishing rate per year of constant.

3.2.2 Bothnia Sea

All the quantified flows and stocks of the Bothnian Sea sub basin for year 2000 and 2006 are shown in Fig. 17 and Fig. 18 respectively. Table 9 presents an overview of amount of phosphorus in stocks and flows of all processes within the sub basin.

In year 2000 the Bothnian Sea received an annual total import of **2600** tonnes of phosphorus which is a net stock addition to the coastal waters. Sweden contributes **61%** to the input to the Bothnian Sea and Finland the rest **39%**.This stock addition of phosphorus to the coastal waters accounts for only **4%** of the total resident stock in 2000. The deep waters and the biomass have a total phosphorus stock of **12800** and **10900** tonnes respectively. The total phosphorus exported via fishing from the biomass is **650** tonnes which accounts for **6%** compared to the total stock of phosphorus in biomass of the Bothnian Sea.

In year 2006 the Bothnian Sea received an annual import of **1700** tonnes of phosphorus having a decrease of **35%** from the inputs of year 2000. However the stocks of coastal waters and deep waters in 2006 have increased by **17%** compared to the stocks in 2000.

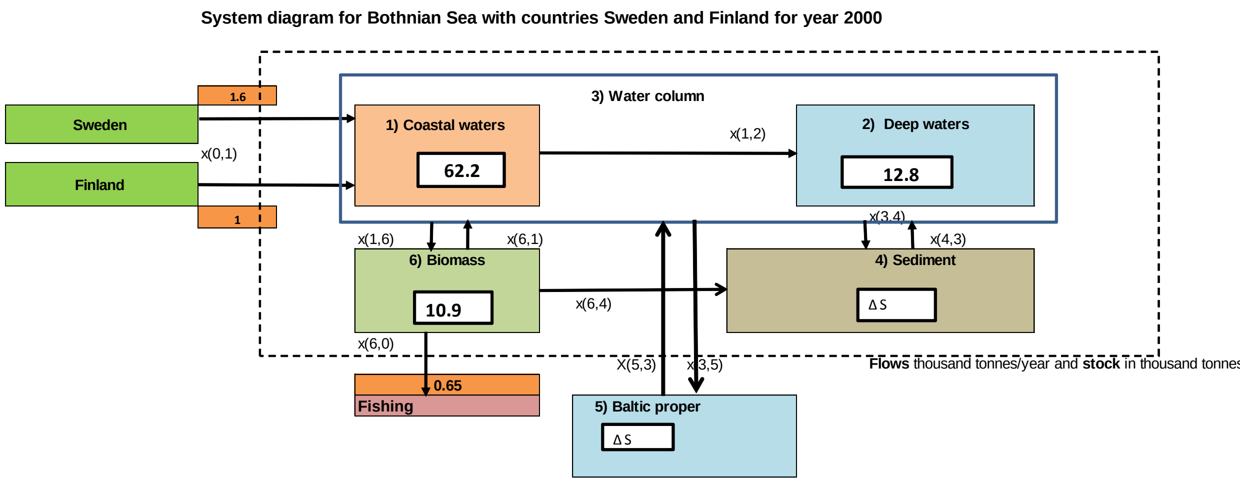

Figure 16 System for Bothnian sea sub basin showing phosphorus flows from the corresponding countries to the total stock of the sub basin in year 2000.

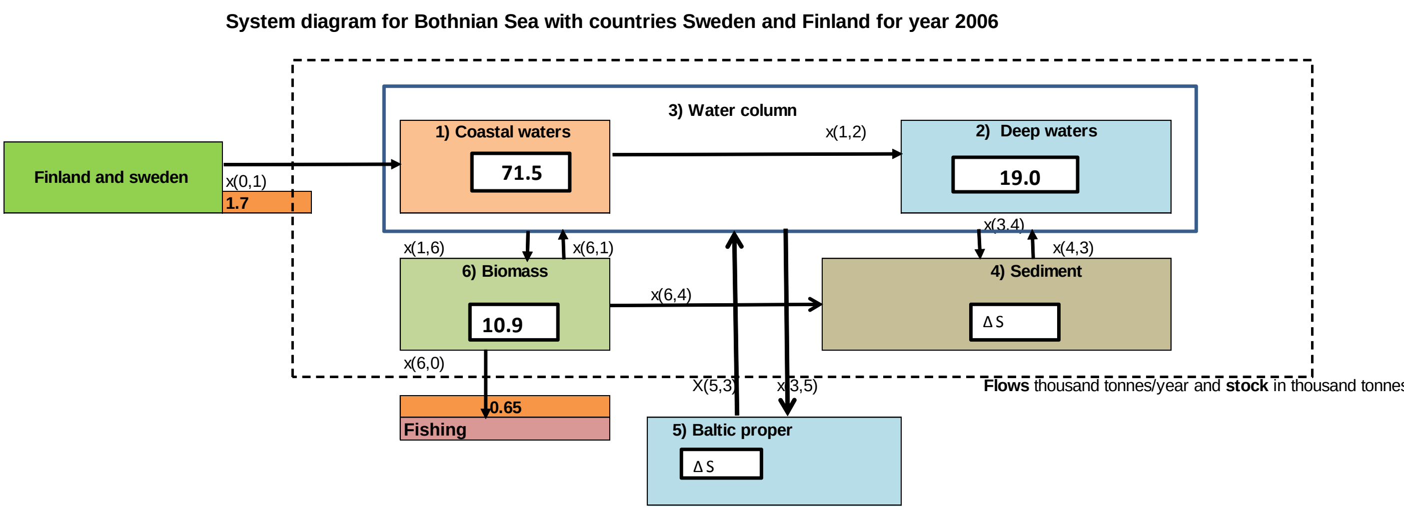

Figure 17: System for Bothnian sea sub basin showing phosphorus flows from the corresponding countries to the total stock of the sub basin in year 2006.

3.2.3 Gulf of Finland

All the quantified flows and stocks of the Gulf of Finland sub basin for year 2000 and 2006 are shown in Fig. 19 and Fig. 20 respectively. Table 9 presents an overview of amount of phosphorus in stocks and flows of all processes within the sub basin.

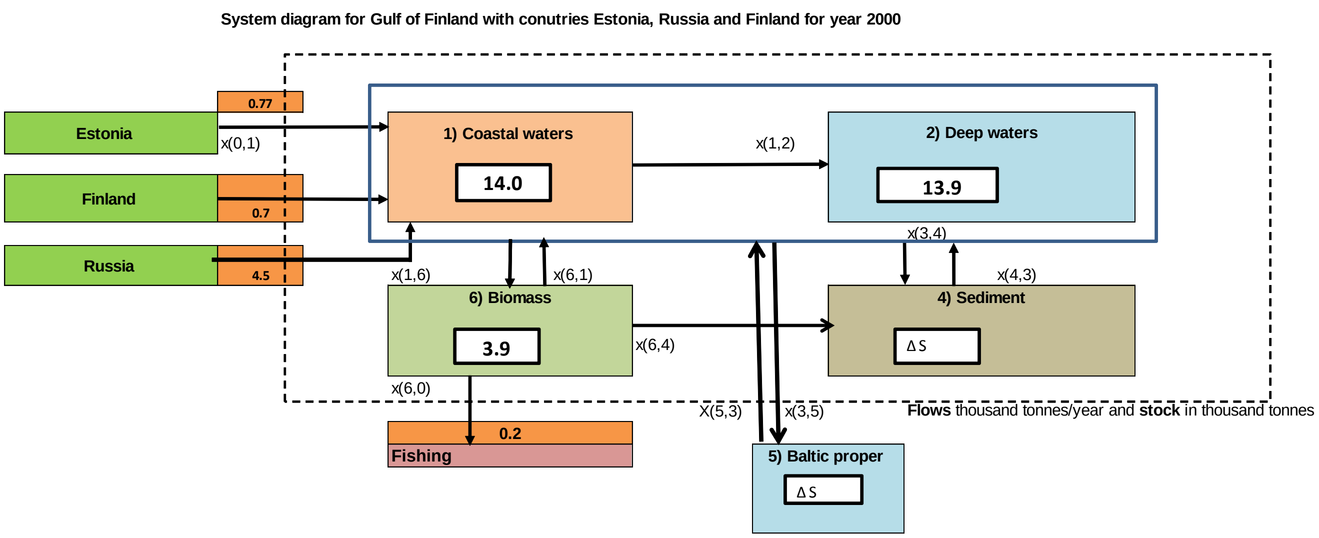

Figure 18: System for Gulf of Finland sub basin showing phosphorus flows from the corresponding countries to the total stock of the sub basin in year 2000.

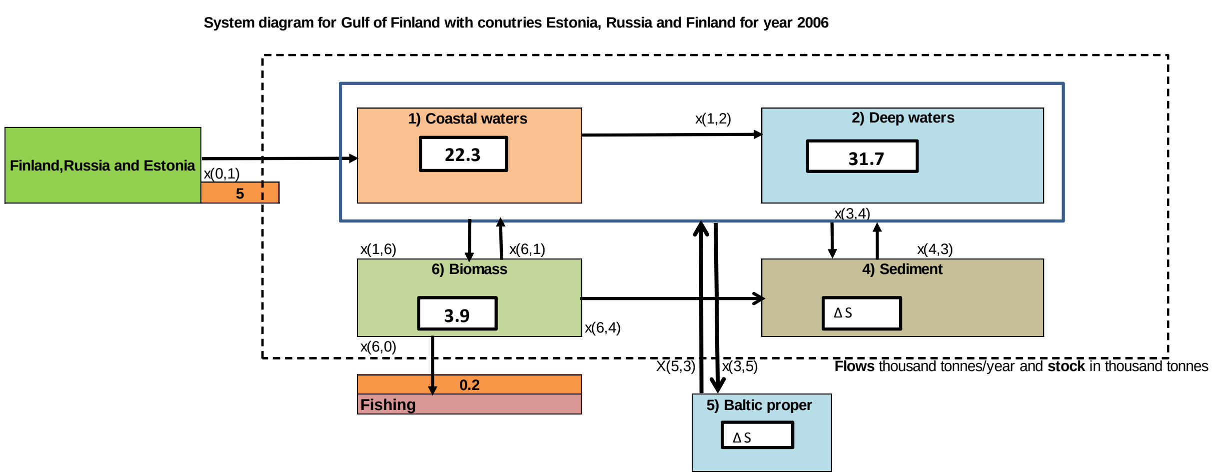

Figure 19: System for Gulf of Finland sub basin showing phosphorus flows from the corresponding countries to the total stock of the sub basin in year 2006.

In year 2000 the Gulf of Finland received an annual total import of **5900** tonnes of phosphorus which is a net stock addition to the coastal waters. Russia has the highest contribution of **76%** to the inputs. Finland and Estonia have contribution of **11**% each to the total input of phosphorus to the coastal waters. The Gulf of Finland compared to the Bothnian Sea and Bothnian Bay has a higher input from the anthropogenic system. This stock addition of phosphorus to the coastal waters accounts for **42%** of the total resident stock in 2000. The deep waters and the biomass have a total phosphorus stock of **13900** and **3900** tonnes respectively. The total phosphorus exported via fishing from the biomass is **200** tonnes which accounts for **5%** compared to the total stock of phosphorus in biomass of the Gulf of Finland.

In year 2006 the Gulf of Finland received an annual import of **5000** tonnes of phosphorus having a decrease of **16%** from the inputs of year 2000. However, the stocks of coastal waters and deep waters in 2006 have increased by **37%** and **57%** compared to the stocks in 2000. Total total stock of phosphorus in the water column of the Gulf of Finland is **54000** tonnes o phosphorus.

3.2.4 Gulf of Riga

All the quantified flows and stocks of the Gulf of Riga sub basin for year 2000 and 2006 are shown in Fig. 21 and Fig. 22 respectively. Table 9 presents an overview of amount of phosphorus in stocks and flows of all processes within the sub basin.

In year 2000 the Gulf of Riga received an annual total import of **2200** tonnes of phosphorus from the corresponding anthropogenic systems. The anthropogenic system of Latvia contributes **90%** of this total input to Gulf of Riga. This stock addition accounts for **17%** of the total resident stock in 2000. The Gulf of Riga being a shallow sub basin does not contain in deep waters. The biomass stock in the Gulf of Riga is **2200** tonnes of phosphorus. The total phosphorus exported via fishing from the biomass is **100** tonnes which accounts for **4%** compared to the total stock of phosphorus in biomass of the Gulf of Riga.

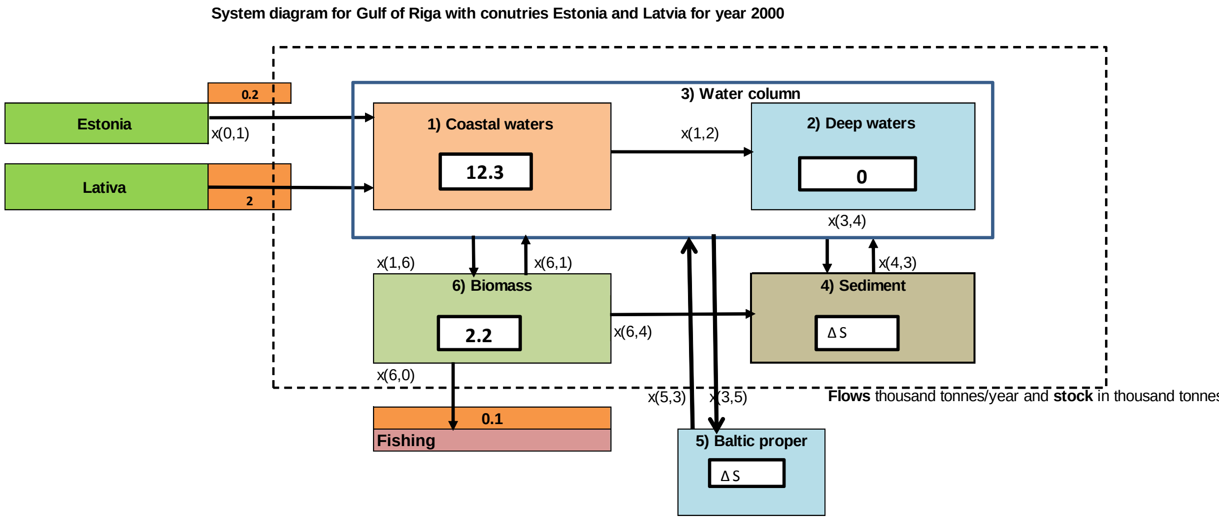

Figure 20 : System for Gulf of Riga sub basin showing phosphorus flows from the corresponding countries to the total stock of the sub basin in year 2000.

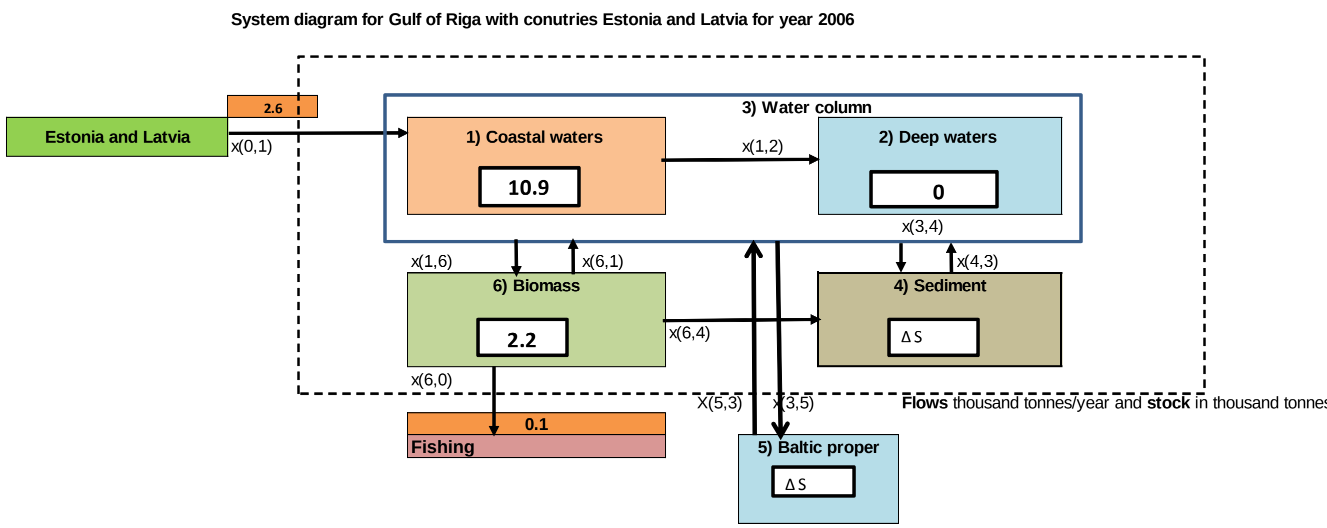

Figure 21: System for Gulf of Riga sub basin showing phosphorus flows from the corresponding countries to the total stock of the sub basin in year 2006.

In year 2006 the Gulf of Riga received an annual import of **2600** tonnes of phosphorus having an increase of **16%** from the inputs of year 2000. The stocks of coastal waters in 2006 have decreased by **12%** compared to the stocks in 2000. The Gulf of Riga unlike the Bothnian Bay, Bothnian Sea and Gulf of Finland has a reduction in stocks from 2000. The phosphorus stocks of biomass and export of phosphorus through fisheries remain the same.

3.2.5 Baltic Proper

All the quantified flows and stocks of the Baltic Proper sub basin for year 2000 and 2006 are shown in Fig. 23 and Fig. 24 respectively. Table 9 presents an overview of amount of phosphorus in stocks and flows of all processes within the sub basin.

In year 2000 the Baltic Proper received an annual total import of **16000** tonnes of phosphorus which is the highest input compared to all other sub basin. The largest contributors to this input are Poland **78%** and Latvia **11%.** The stock addition accounts for only **5%** of the total resident stock in 2000. The deep waters and the biomass have a total phosphorus stock of **162,500** and **27,600** thousand tonnes respectively. The total phosphorus exported via fishing from the biomass is **1750** thousand tonnes which accounts for **6%** compared to the total extraction of phosphorus from biomass of the entire Baltic Sea.

In year 2006 the Baltic Proper received an annual import of **13400** tonnes of phosphorus having a decrease of **17%** from the inputs of year 2000. The stocks of coastal waters in 2006 remain the same as in 2000 and the stocks of the deep waters have reduced by **8%** compared to the stocks in 2000. The Baltic proper unlike the Bothnian Bay, Bothnian Sea and Gulf of Finland has a reduction in total stocks of phosphorus from 2000. The phosphorus stocks of biomass and export of phosphorus through fisheries remain the same.

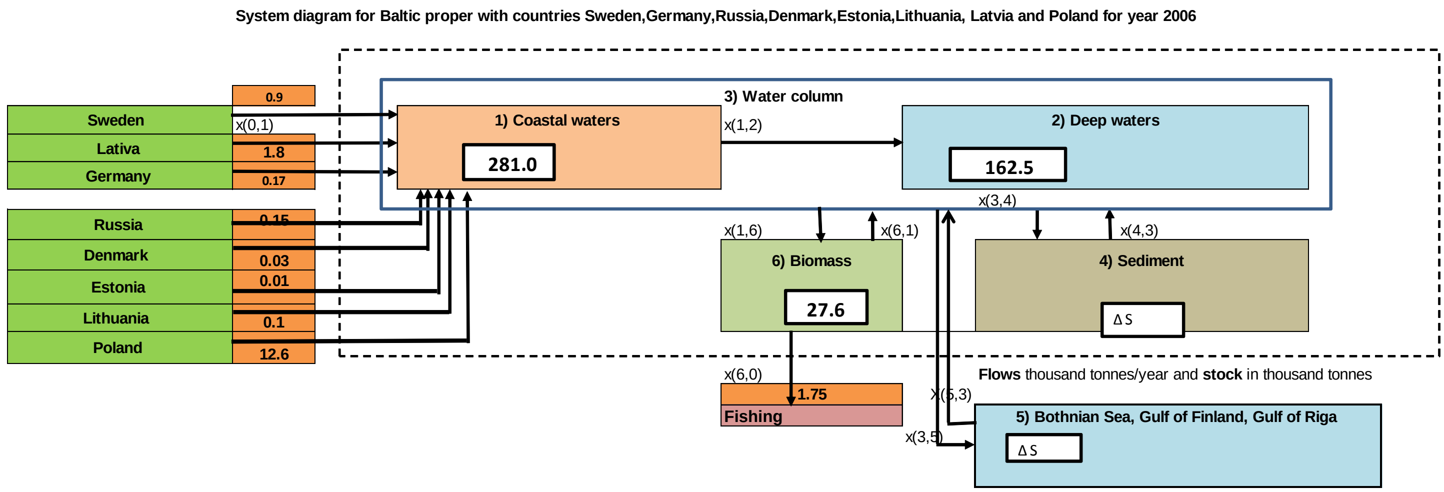

Figure 22 : System for Baltic Proper sub basin showing phosphorus flows from the corresponding countries to the total stock of the sub basin in year 2000.

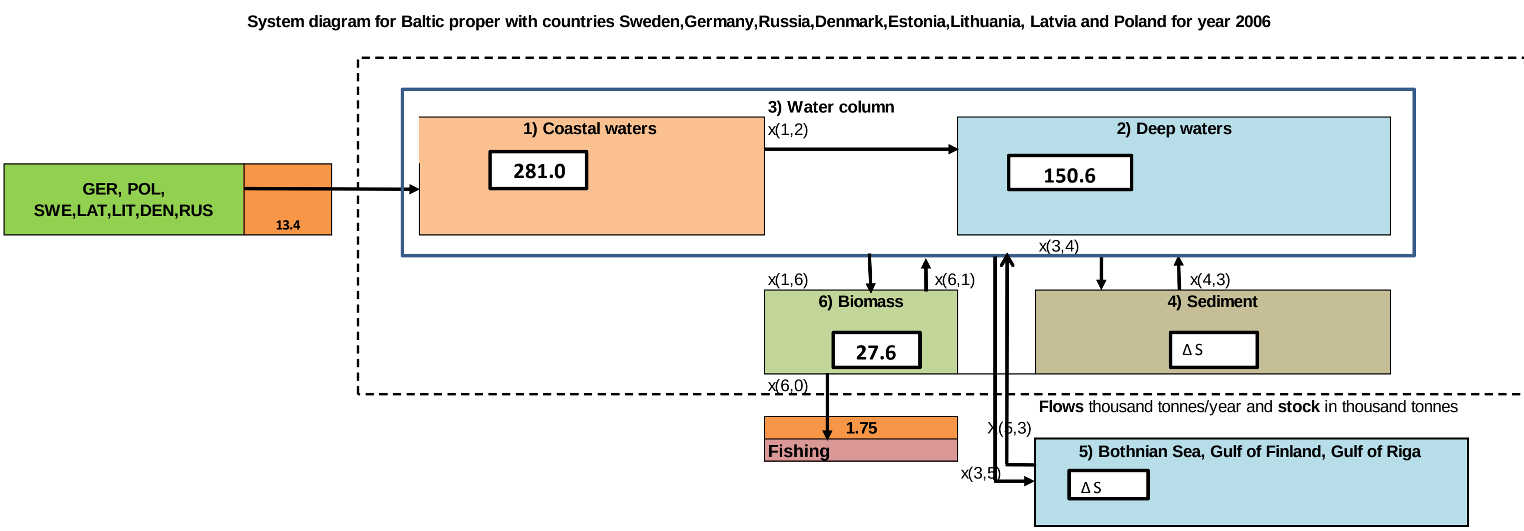

Figure 23: System for Baltic Proper sub basin showing phosphorus flows from the corresponding countries to the total stock of the sub basin in year 2006.

Table 9. Phosphorus stocks and flows within the sub basin systems

Sub basin	Total inputs from land (10^3tonnes) in 2000	Total inputs from land (10^3tonnes) in 2006	Total output of biomass to fishing (10^3tonnes)	Total stock of phosphorus in water column (10^3tonnes) in 2000	Total stock of phosphorus in water column (10^3tonnes) in 2006	Total stock of phosphorus (10^3tonnes) in biomass	% increase in stock of 2006
Bothnian Bay	3.4	2.2	0.30	8.2	13.6	5.2	40.0
Bothnian Sea	2.7	1.7	0.65	75.0	90.5	10.9	17.1
Gulf of Finland	6.0	5	0.24	27.9	53.9	4.0	48.3
Gulf of Riga	2.2	2.6	0.14	12.3	10.9	2.2	-12
Baltic Proper	16.0	13.4	1.75	444.3	432.0	27.7	-8
Total Baltic Sea	**30.3**	**24.9**	**3.0**	**567.6**	**600.8**	**49.9**	

Chapter 4 Discussion

This study not only identifies the countries playing a major role in phosphorus release to the Baltic Sea but also determines the sectors causing most impact. The flows between the processes in the anthropogenic system reveal the country profile with regards to phosphorus quantities which plays an important role in designing phosphorus reduction measures. Determining the stocks of phosphorus in the water and biomass gives information on how the Baltic Sea acts as a large sink of phosphorus and whether it can be a potential source of phosphorus in the long run.

4.1 Diversity in Phosphorous use

4.1.1 Country specific diversity in use of phosphorus.

This section attempts to answer the research question of this thesis. The results very well represent the situation of the Baltic Sea watershed in the year 2000. It is important to discuss how the countries differ with each other and how big a share they have in the total load of phosphorus to the Baltic Sea. This differentiation within the countries also helps to identify the need of reduction in most important sectors of each country instead of having a general reduction policy for the watershed area.

- What are the major anthropogenic flows of phosphorous entering the Baltic Sea? How different are they from one associated country to the other? What is the proportion of the total loads from terrestrial systems to the residing stock of phosphorus in the sea water?

The magnitude of phosphorus flows and stock in the countries in the Baltic Sea watershed vary with demographics, industrial sector, agricultural area and practices etc. Per capita quantities of phosphorus used for various activities in a country are compared in the following to describe the country profile. The largest differences are in the agricultural productivity per capita, fertilizer use and waste water treatment.

If Lithuania and Russia are compared with regards to their fertilizer use, Russia uses 28% phosphorus compared to Lithuania's total consumption. However arable land area in Lithuania is only 21% of that of Russia. This can be explained by the intense agricultural activities in Lithuania. The priority of phosphorus reduction for Lithuania lies in controlling its agricultural activities.

On the other hand, the largest flow in Russia is of the waste water discharge, since only 10% of the population was connected to a waste water treatment plant. Hence the Russian strategy to bring about phosphorus reduction would lie in improved waste water treatment as opposed to agriculture in Lithuania.

The phosphorus stocks in the food market in Sweden and Finland are observed to be huge compared to the population and total agricultural area (Table 4). This can be explained by the quantities of per capita food supply/availability quantities of these countries. Finland and Sweden has a food supply of about 5.5 kg/capita/year in 2000 from domestic supply and imports (appendix 2), whereas the dietary consumption in humans is only 0.6 kg/capita/yr (Emilsson, 2007). This large difference in production and consumption rate accounts for the stock accumulation in the food market. In order to reduce the impact from agriculture, these two countries must reduce the agriculture productivity. The need of fertilizers and animal feed will eventually reduce.

Finland, Sweden and Poland have a significant impact of phosphorus from pulp and paper industry. The wastes generated from the pulp and paper industry are in the range 0.05 to 0.3 thousand tonnes of phosphorus in 2000. The rest of the countries do not have a significant impact on phosphorus loads from paper production industry.

Poland is identified to have the highest share in all flows of the agriculture, household and the waste management industry. Being the most populous country in the Baltic Sea watershed, having the largest share of land area and intense agricultural activity explains the high amounts of phosphorus use. This suggests that Poland needs to improve phosphorus reduction from all sectors including reduction in agriculture, improved waste water treatments etc.

It can be observed that leakages occurring from the sewers and storm water overflow (Table 6) have a significant impact in phosphorus losses in the surface waters leading to the Baltic Sea.

Only improving the treatment plants will not be beneficial, therefore there is a need for some country wise targets to reduce these leakages.

4.2 Sub basins and their stocks

This section will address the following research question and discuss the test on the hypothesis formulated in section 1.2.

- How can we explain the fate of phosphorus after its entry into the sea ,by applying the principle of mass balance?

Considering an average annual input of 30 thousand tonnes from year 2000 to 2006 the stocks in entire Baltic Sea would have increased by 180 thousand tonnes in 2006. However, the stock increase has only been of **33,000** tonnes. It is known that the Baltic Sea releases 17% of total annual inputs, to the North Sea (Hille, 2005). Hence in the six years the Baltic Sea would have approximately released a total of **30,000** tonnes of phosphorus, considering an annual anthropogenic input of 30 thousand tonnes. This suggests that there is a high rate of phosphorus accumulation in the sediments of the Baltic Sea as there is no other way for phosphorus to exit the system. The rate of sedimentation in the Baltic Sea varies with each sub basin but an estimate of 0.2 g/sqm/yr have been made (Hille, 2005). The phosphorus in the sediments is adsorbed by Iron and Manganese molecules that keep it bound in the sediments. (Lehtoranta, 1997). The phosphorus from the sediments is released back into the water column during reduction of Iron oxides that bind the phosphorus. (Aigars, 2001).

It is observed that the Bothnian Sea, Bothnian Bay and the Gulf of Finland have an increase in stocks while their anthropogenic inputs have reduced by about **18 %** from 2000 to 2006(Table 7). Whereas, the Gulf of Riga and Baltic Proper have a decrease of **12** and **8%** respectively in the total stocks in 2006. This suggests that the Baltic proper and Gulf of Riga could be exporting phosphorus to the adjacent three sub basins. There are annual water fluxes exchanges within the sub basins due to varying degree of salinity, temperatures etc. (Håkanson & Bryhn, 2008). The phosphorus exchanges within the sub basin have been quantified by (Savchuk, 2005) and put forth that the Bothnian Sea, Bothnian Bay and Gulf of Finland are essential importers of phosphorus where as the Gulf of Riga and Baltic proper are exporters of phosphorus within the Baltic Sea.

Thus the hypothesis that ‘the inflow of phosphorus into the Baltic Sea is not coupled with an increase in phosphorus stock but result in high sedimentation rate .The sub basins represent phosphorus exporters to other neighboring basins’ hold true and determines that sub basins represent importers as well as exporters to other neighboring basins.

4.2.1 Sediments- A future source of phosphorus

As identified in the previous section that the sediments play an important role in phosphorus accumulation in the sub basins of the Baltic Sea. There is a fear of over saturation of phosphorus in sediments and occurrence of a high reflux of phosphorus back into the water column (Blomqvist, 2011). The Baltic Sea 2020 project has been launched with a goal of developing permanent phosphorus binding sediments in the Baltic Sea. It is proposed that the goal can be achieved by using aluminium as precipitation agent to increase the binding capacity of sediments.

These sediments could be used as large scale alternative sources of phosphorus in the future, only if a profitable method of deep sea mining is developed (Seaman, 2009). However, the deep sea mining and phosphorus bound sediments poses many challenges to the environment and human health. The sediments along with phosphorus are a sink of various heavy metals too which can interfere with the use of sediments for phosphorus extraction. (Mirja et al, 2000). Due to mining of sediment there is a possibility of diffusing the nutrient back into the water column causing an increased concentration of nutrient in the water column (Håkanson & Bryhn, 2008).

Under low oxygen conditions in the water column, the sediments release phosphorus back into the water column and if the current trends of phosphorus inputs continue, the anoxic conditions may prevail. This situation might cause high phosphorus concentrations in water causing a reinforcing loop of the eutrophication process. Mining of sediments can help reduce the phosphorus in sea bottom however there are many environmental risks involved. Therefore, there is a good scope for research and development to find feasible and inexpensive methods for phosphorus extraction from sediments.

4.3 Reduction potential

One of the research questions of this thesis aims to find out reduction potential in the anthropogenic processes and how can they be achieved. Section 3.1 presents the processes and their flows with high phosphorus use and section 4.3.1 and 4.3.2 discuss their potential to reduce the phosphorus loads. Section 4.3.3 discusses the cost effectiveness of reduction strategies.

- What are the areas with high phosphorus use, where the phosphorus loads within the riverine watershed can be reduced and how?

4.3.1 Reduction of phosphorus in agriculture.

The total inputs to the Baltic sea from agriculture run off is **15900** tonnes and is the highest input from all the other anthropogenic inputs to the Baltic Sea(Table 6). Therefore agriculture and animal husbandry are the processes with maximum reduction potential. Below are some methods or strategies that can be used for efficient use of phosphorus in agriculture.

1) Optimised fertilizer application can be done by regular soil sampling to indentify the need of fertilization and hence reducing the cost of fertilizers and accumulation of phosphorus in soil (Henriksson & Miljökonsulter, 2007).

2) Reducing the animal dietary phosphorus for farm animals that are often fed more than the recommended diets will reduce the amount of phosphorus in excretion. To increase the phytase content in feed which can help in reducing the total requirement of mineral phosphorus, the animal feed for pigs can be soaked in water. (Helcom, 2011).

3) Tilling or riparian buffer strips between agricultural land and water bodies helps in reduction of phosphorus in surface runoff. The filter strips allow infiltration of phosphorus to the root zone and nutrient uptake by plants takes place (Zaimes, 2002).

4) The biggest flow of phosphorus after the fertilizer consumption is the output from animal husbandry. Human diet in these countries containing meat and dairy is the driver for intensive animal husbandry. Having low meat diets will reduce the demand of meat production. Moving the choice of meat to poultry can also significantly reduce impacts from pigs and bovine animals.

5) It is also found that in Finland and Sweden agriculture production (plant and animal) is much higher than total dietary requirement of the population. These countries can reduce their agricultural output and lower the fertilizer consumption and agricultural run off. Reducing the agricultural output can also provide an opportunity for crop shifting and letting the agricultural land to fallow. Reuse of fallow land reduces the need of fertilization in the subsequent crops (McClinton, 2006).

6) The emerging field of organic farming can also help reduce intense phosphorus use in agriculture.

4.3.2 Improving waste water treatment.

According to levels of sewage treatment in 2004, only 50 to 70% of population of Russia, Poland, Latvia and Estonia were connected to sewage treatment facilities. Under an improved scenario with modern sewage treatment facilities, Poland and Russia will reduce 30 to 40 % of their phosphorus loads from waste water from the levels in 2004 (The Baltic Nest Institute, 2007). The scenario of improvement of sewage treatment facilities requires huge monetary and infrastructure requirements which might pose a challenge in implementation of the strategy. Under legislative pressure, such a scenario could be implemented.

In a case study in Sweden, 250 modern houses were built urine diversion toilets. The urine collected was collected in tanks used for application on farmland. This brought 99% phosphorus recovery from urine. (Schroder, 2009). This case study in Sweden is an effective method to reduce need of mineral fertilizers, however the costs in installing urine diversion toilets might be high. It can be more expensive to change current drainage system in houses to built diversion toilets. Hence this methodology can be applied to new emerging cities or towns.

4.3.3 Costs

The cost effectiveness of the phosphorus reduction strategies plays an important role in their large scale implementation. For instance, since 1995, Sweden reduced annual loads to Baltic Sea by 530 tons s at the cost of 300 Million EUR annually (Elofsson, 2010).

The choice of phosphorus reducing measures and their location in the Baltic Sea watershed can be determined from comparing overall marginal costs for reduction of phosphorus. There is a huge variation in the most cost effective method and resulting impact with the countries and sub basins of the Baltic Sea watershed. The cost of implementation of constructing riparian buffer strips in agricultural areas for Finland is 790 –855 Euro/ kg of phosphorus, while in Russia it is 190 – 280 Euro/kg of phosphorus (Gren, 2008). Although the cost of reduction in Russia is lower, the possibility of implementation is also low because only 6% of the Russian population resides in the Baltic Sea watershed. And the government efforts to invest in improving current scenario will be low.

The cost of sewage treatment for reduction of phosphorus loads can be estimated upto an average 50- 300 Euro/kg of phosphorus for all countries in the Baltic Sea watershed. The Nordic countries are more likely to invest in the improvement of phosphorus recovery, more than the Baltic States due to having a larger share in phosphorus loads and have a larger population residing in the Baltic Sea watershed.

4.4 Uncertainties and Assumptions

There are several factors in the data and parameters that can affect the present results. The uncertainties in each, the anthropogenic system and the sub basin system will vary according to the model approach parameters used. Although, overall uncertainty lies in using secondary data for e.g. phosphorus concentrations in Baltic Sea, agricultural production in countries, phosphorus content of foods and material etc.

Anthropogenic system

Calculation on the paper production, plant and animal production are based on statistical data from the Food and Agricultural organization of United Nations and the reliability is believed to be high. The human dietary consumption and consumption in detergents is mostly constant among the countries, and is therefore rather robust. The total inputs and outputs of phosphorus in agricultural and animal husbandry are derived from total country's production, import and exports. To obtain it for the fraction of country lying in the Baltic Sea watershed, they have been used as per capita quantities. The fertilizer consumption is based on the per hectare calculation. Using the per capita and per hectare parameters might have averaged regional differences in production and consumption within the country.

The phosphorus uptake in livestock is seemingly high with 35% of total phosphorus intake is assimilated in the animal body. This average was made for all categories of animals based on data from (Hong et al, 2011). However this number is confirmed by other studies as well (Weiss, 2012), (H.D., 1999).

There are some flows that have not been calculated due to unavailability of data and time plan of the thesis e.g. Exports of waste from solid waste management, use of forest resources for paper production, the amount of incinerated ash going to landfill etc. However these flows are not the largest in the defined systems and do not affect the calculations of other flows of the systems.

Sub basin system

There is low uncertainty in calculation of total phosphorus stock in water due to the use of the transect method used to determine the concentration of phosphorus in sea. The calculation of deep sea areas and coastal areas has also been done accurately by using GIS maps. Relatively large uncertainty lies in calculation of phosphorus in the biomass. There is high variation in biomass density, movement of motile organisms and abundance of species within the Baltic Sea making it difficult to obtain accurate data. Due to unavailability of data, it is assumed that the biomass stocks are constant over the years 2000 to 2006. The impact of this assumption might not be that high as biomass has not been identified as the most important sink and the hypothesis test does not discuss the stock in biomass to be influencing the phosphorus dynamics in Baltic Sea to a great extent.

4.5.1 Comparison of results with relevant studies

As mentioned in above sections that prior studies have calculated the total loads of countries to the Baltic Sea and the stocks of phosphorus in sub basins, based on model simulation and different data sources. Therefore, it is interesting to compare those results to obtain by the material flow analysis methodology.

The comparison of the phosphorus stocks in the sub basins can be made to the phosphorus budget developed by (Savchuk, 2005). The total stock of phosphorus in the Baltic Sea in 2000 calculated in this thesis is **567,000** tonnes of phosphorus in water column and **49000** tonnes in the biomass. The estimate given by (Savchuk, 2005) is close and equals to an average of **530,000** tonnes of phosphorus in Baltic Sea for 1991-1999. This estimate is based on an average of nine years which is a long span which are subject to changes. A trend has been observed in phosphorus concentrations over the last decades and there some substantial changes in phosphorus loads during the early 90s (Bryhn, 2010). In addition the biomass stock calculation has not been undertaken by (Savchuk, 2005).

The total phosphorus fertilizer consumption in Finland is comparable to an estimate made by (Antikainen, 2007). The calculated value in the system diagram for Finland in 2000 is **38,000** tonnes of phosphorus which is in the same order of magnitude to the estimate of **29500** tonnes in late 1990s, made by (Antikainen, 2007).

The total loads of phosphorus to the Baltic Sea calculated by (HELCOM, 2004) for the year 2000 are estimated to **30255** tonnes from all anthropogenic sources. The total anthropogenic loads calculated during this thesis sum up to **43600** tonnes of phosphorus in 2000. However, (Helcom, 2004) does not calculate any stocks of the processes. The flow of phosphorus from the leakage of waste water from sewers and storm overflow to the riverine system leading to the Baltic Sea might have increased amounts of phosphorus in the results of the anthropogenic systems in this study.

These phosphorus flows have first time been calculated using material flow analysis as a core and identifies all the major stocks within the Baltic Sea watershed and sub basins. This study widens the application of the MFA methodology in aquatic systems and in the land water interface. The results of this thesis provide scope in time series calculations of stocks and scenario building.

4.6 Further research and scope

This study resulted into two systems, one based on the country level flows and the sub basin stocks and flows of phosphorus. There is a need for a holistic approach based system that combines the country wise anthropogenic system and the sub basin system. The system boundary of such a system would comprise of the riparian states and the entire Baltic Se basin. The phosphorus inputs from each country to the different sub-basins and the interaction with the adjacent sub -regions form an important part of the system. Fig. 24 diagrammatically represents the proposed system of the Baltic watershed. In order to calculate the flows in sub basin watersheds various data on population density, animal density, slope, soil characteristics are needed. To be able to balance the flows between sub basins historical developments in stocks, oceanographic data and hydrographic data are also needed.

Combining anthropogenic systems and sub basin systems under one system boundary does not fit in with the current scope of the thesis, but provides opportunities for further research to understand the Baltic Sea watershed as an entire system and its interconnections.

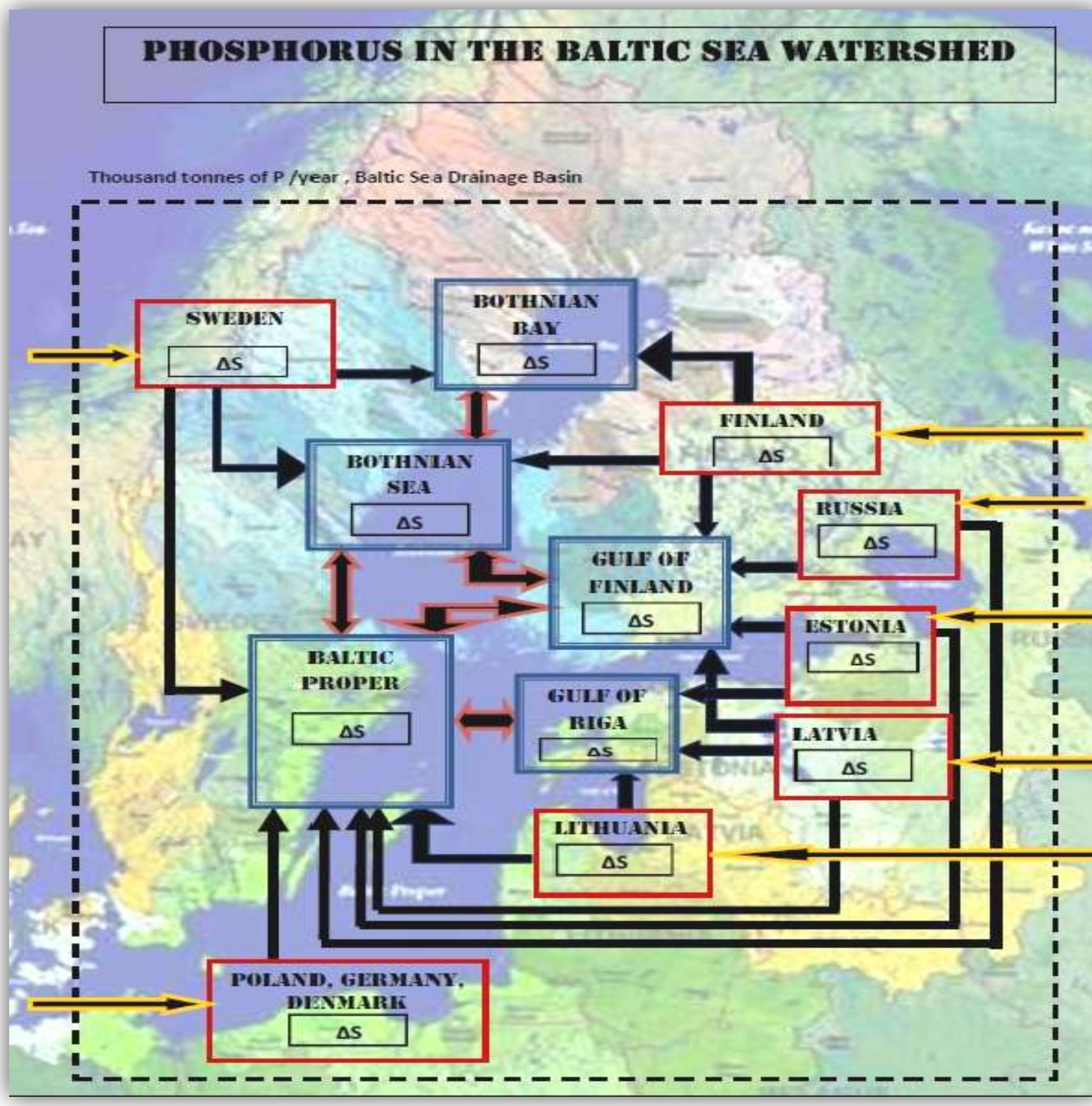

Figure 24 : System diagram of the Baltic Sea drainage basin with countries and sub-basins

4.7 Conclusion

The flows and stocks of phosphorus were studied in two different systems within the Baltic Sea watershed using Substance Flow Analysis as a research method. The first system consists of all major flows and stocks within the anthropogenic system of each country in the Baltic Sea watershed. The largest phosphorous flows identified within the anthropogenic processes were the fertilizer use and food production. The flows from the land based system to the Baltic Sea were agricultural run off and waste water discharge. The largest stocks were observed in the agricultural soil and food market. Within all the countries in the Baltic Sea watershed Poland has found out to be having the biggest share in stocks and flows of phosphorus within all sectors.

The second system consisting of individual sub basins of the Baltic Sea identifies the total inputs to each sub basin and the residing stock of phosphorus in the water column and biomass. The phosphorus extraction by fishing has also been quantified. A hypothesis has been formulated to determine the fate of phosphorus in the sea water and it has been found out that the inflow of phosphorus in the sub basin results into high sedimentation rate. The sub basin with the largest stock of phosphorus is the Baltic Proper sub basin and the sediments of the Baltic Sea have identified has large sinks of phosphorus.

This study also identifies the anthropogenic sectors and countries that posses high potential in the reduction of phosphorus use within human activities and reduce the load of phosphorus to the Baltic Sea. Some reduction strategies and the costs involved have also been discussed.

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Appendix 1

1.1 Transect method

Table 10 Phosphorus concentration for Transect method

Bothnian Sea					Year 2006
Transect 1					
N 8	25	63.49	19.82	0.28	0.4
N21	60	63.3	19.95	0.25	0.25
F18	100	63.32	20.3	0.35	0.36
VAV-12 V5	27	63.06	20.7	0.52	0.6
VAV-10 V3	10	62.94	21.26	0.4	0.47
Transect 2					
GA1	85	62.86	18.26	0.5	0.5
US2	200	62.85	18.92	0.45	0.82
US3	180	62.7	19.2	0.3	0.72
US5B	125	62.58	19.98	0.8	0.85
US7	25	62.6	20.82	0.5	0.94
Transect 3					
F64	280		18.5	0.65	1.03
MHAM	90		19.2	0.7	0.8
VARDO	30		20.12	0.75	0.65
KUML	80		20.94	0.85	0.99
UKI 170	20		21.31	0.9	0.95

Gulf of Finland					Year 2006
Transect 1					
K1	90		18.4	1.2	1.31
F40	40		28.8	1.1	1.4
C3	200		18.99	0.65	0.99
F42	65		27.46	1.3	1.24
LL3A	65		26.34	0.6	1.68
Transect 2					
UUS 30	20		25.47	1.2	1.5
LL7	80		27.83	0.8	2.4
FOE B27	80		24.35	0.7	1.5
FOE B 26	100		23.36	0.7	2.2

Gulf of Riga					year 2006
Transect 1					
137A	40		24.08	1.5	0.87
102A	40		23.6	1.5	0.99
170	10		23.48	0.9	0.9
Transect 2					
121	55		23.61	0.8	1.2
107	30		23.9	0.7	0.6
142	40		22.9	0.9	0.7
Transect 3					
125	30		23.4	0.6	0.6
111	40		22.8	0.65	0.7
123	40		23.34	0.9	0.9

Baltic proper					
Transect 1					
B1	40		17.62	0.65	**0.93**
LL23	452		18.23	2.5	**2.4**
BY30	130		19.09	0.55	**1**
BY29	180		20.32	2.5	**2.3**
BY27	160		21.56	1.5	**1.5**
Transect 2					
VISBY	30		16.83	0.95	**0.95**
BY 36	140		17.37	1.5	**1.6**
1VB 1	50		19.12	0.45	**0.45**
BY 15	230		20.05	3.2	**2.1**
Transect 3					
Ref M1V1	20		16.21	1.5	**1**
BY 39	50		16.53	1.1	**1**
PL- P3	90		17.07	1	**1.1**
PL- LP	20		17.03	0.7	**1**
FOE B21	80		18.83	0.7	**0.6**

Biomass Estimation

Basin	Percentage area of the eentire Baltic sea	Total coastal fish Kt	P Stocks in fish in thousand tonnes	Total biomass In benthic flora	Total biomass In benthic fauna	Total Biomass	Total fish catch/year
BOB	9.8	30.5	0.61	2.71	1.84	5.2	0.30
BOS	21.2	51	1.02	5.87	3.98	10.9	0.65
GUF	7.9	14.3	0.286	2.20	1.49	4.0	0.24
GUR	4.4	10.6	0.212	1.21	0.82	2.2	0.14
BAP	56.7	68.8	1.376	15.69	10.62	27.7	1.75
Total	**100.0**	**175.2**	**3.504**	**27.70**	**18.75**	**49.94503774**	**3.08**

Carbon stocks		Fauna	Flora	Unit
C:N:P ratio in Benthic marine organisms		106:16:01	106:16:10	
Total C standing stock		794.8	1174.3	1000 tonnes
C stock in moles		66233333333	97858333333	moles of C
Converting it to moles		624842767.3	923191823.9	moles of P
Total P in gram		18745283019	27695754717	g of P
Total P in thousand tonnes		**18.7452830**	**27.69575472**	thousand tonnes of P
Fishing catch per year		**3.08**		thousand tonnes of P

Data source
(Sterner et al, 2000)
(Hakanson et al, 2010)