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Report 364

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Table of contents

Summary

Phosphorus (P) is an essential resource for global food production. Since the introduction of phosphorus fertilizer in 1850 increasing amounts have been used in agriculture. However, the main source for fertilizer, rock phosphate, is a finite resource. Therefore, phosphorus should be used efficiently and recycling should be practised as far as possible. Unfortunately the global picture is quite in contrast with this view: losses are high, recycling is inadequate, large P deficient areas receive little or no fertilizer whereas in other regions accumulation occurs. The Netherlands is a prime example of a region where accumulation takes place.
To investigate the possibilities for a more sustainable use of phosphorus it was necessary to have a complete picture of the national phosphorus flows in the Netherlands. In this report a material flow analysis was performed by dividing the national system into a number of subsystems: agricultural subsystems (arable, grazing, intensive livestock) but also non-agricultural subsystems (food industry, non-food industry, feed industry, household, waste management, environment) were included.
Quantification of the various phosphorus flows between the subsystems was done for the year 2005 and was based on various data sources. The results showed that in the reference year 2005 a surplus of around 60 Mkg of P existed, roughly half of this amount accumulated in agricultural soil. The remaining part ended up in ground or surface water (around 7 Mkg) or was sequestered in one way or another (e.g. landfill, incineration ashes, sewage sludge etc.). Recycling from society (households and industry) back to agriculture was minimal. Options for a more sustainable use of phosphorus in the Netherlands are discussed.

1 Introduction

Phosphorus (P) is a prerequisite for life on earth being an essential constituent of compounds which play a role in various processes, including energy metabolism (ATP), genetic reproduction (DNA) and photosynthesis. Most soils have a low inherent level of plant available P and consequently this nutrient is a major growth limiting factor for plant growth.
Since the introduction of P fertilizer around 1850 increasing amounts have been used in agriculture to enhance plant production. After the depletion of guano deposits, the main source for P is now phosphate rock. Globally about 80% of mined rock is used for the production of chemical fertilizers. Rock phosphate, however, is a finite resource. Additionally, sources are located in just a few countries, of which Morocco and China are the most important. Although there is a lot of uncertainty concerning availability of deposits, it is estimated that the known reserves which can be currently exploited economically will be depleted within 100 years at the current rate of extraction. However, it is also anticipated that the consumption of P-fertilizer will increase which will accelerate depletion. Relevant factors which stimulate P-fertilizer use are i) the increase in world population, ii) a change towards an increase of meat in the diet and iii) an increase in the production of crops for bio-energy (Smit *et al.*, 2009).
There are many reasons why P is considered a valuable resource which should be used efficiently. Unfortunately, the global picture contrasts with this view: large P-deficient areas receive little or no fertilizer (Africa) whereas in various densely populated areas densely stocked with livestock accumulation of P occurs.The Netherlands, with its highly productive agriculture, is one of the regions where accumulation in the soil takes place. Importation of P containing raw materials from South America such as soy beans, the use of P fertilizer for crop production and feed additives used in animal husbandry all contribute to the large surplus. Consumption of fertilizer P in the Netherlands is often indirect, as the imported feed could not have been produced without P fertilizer. The imported P consumed by animals is excreted for the greater part in manure. Consequently, the phosphate levels in many soils in the Netherlands are high due to high annual application levels of manure, especially in the south of the Netherlands where there is a higher concentration of livestock. Some soils have reached saturation level with subsequent leaching resulting in eutrophication of surface water (Schoumans, 2004). Nationwide the annual surplus of P has led to government legislature aimed at regulating P input in agriculture.
Farmers are currently allowed to apply 85 kg of phosphate (P_2O_5) per ha on arable land and 100 kg on grassland[1]. In order to comply with European Water Directive regulations the Dutch government has indicated a further reduction in P input and also an attempt to relate phosphate application rates to the phosphate status of the soils. It is proposed that in 2015 application rates for arable land will vary from 50 – 75 kg and for grassland from 80 - 100 kg phosphate depending on the phosphate status of soils (Anonymus, 2009).
In agriculture this will lead to certain changes, one obvious consequence of the new regulations will be a reduction of manure use on arable land .
There are various scenarios or management strategies, to be considered at farm, regional or national level, which have to be explored not only in the light of the new regulations but also in anticipation of possible middle or long term shortages of phosphorus.
Questions to be asked include:

- Is it possible to reduce the dependency on mineral fertilizer P?
- What are the effects of reducing P-input in the Netherlands, particularly by lowering, or even abandoning dependency on mineral fertilizer P?
- Is it worthwhile to stimulate recycling or recovery of P from human waste, sewage sludge or slaughter waste?
- What will be the effect of new legislation (reduced P-input) on the P flows within and between various sectors of agriculture and on the national P surplus as a whole?
- What are the possibilities for manure processing?
- What are the consequences of reducing the number of animals in the country?
- How important are P additions in feed in terms of the national budget and can they be reduced?

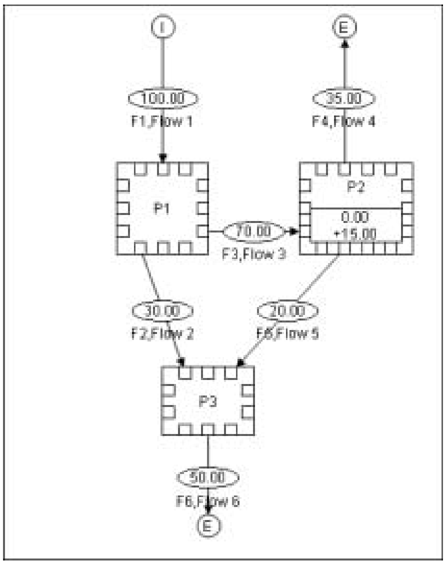
[1] In this report all values/flows are expressed as elemental P. However in agriculture P is quantified based on phosphate (P_2O_5), i.e; 1 kg P (phosphorus) = 2.29 kg of P_2O_5 (phosphate); 1 kg of P_2O_5 = 0.44 kg P.

In order to be able to explore the possibilities for improvement of the national P balance (scenario analysis), it is essential that a complete picture of phosphorus flows in the Netherlands is available (state of affairs). Levels of input and output ,together with accumulation and loss balances for the different sectors (agriculture, industry, households and the waste management sector) need to be identified and quantified. This report focuses on the elucidation of the current situation of phosphorus flows in the Netherlands. For our study, 2005 was taken as reference year since this was the most recent year with an (almost) complete dataset.

2 Materials and Methods

2.1 Material Flow Analysis

Analysis of the phosphorus flows in the Netherlands, were performed by dividing the national system into a number of phosphorus related subsystems. Available data that had been and collected was used for calculation of estimates of P flows of phosphorus within and between these subsystems. When flows of phosphorus were expected (or calculated) to be small (e.g. 0-0.4 Mkg P)[2] as well as difficult to estimate they were neglected.
The data were processed in a Material Flow Analysis (MFA)which provides a systematic assessment of the flows and stocks of materials within a system defined in space and time. This analyses links between sources, pathways and intermediates and final sinks of materials (Brunner and Rechberger, 2004). The method guarantees a systematic assessment of the flows and stocks of phosphorus, by strict application of the 'conservation of mass' principle (see Figure 2-1 for a small example). The software used was the STAN v.2 program (Cencic and Rechberger, 2008). This program visualizes flows and makes a balance of all inputs, stocks and outputs. A complete MFA forms the basis of resource, environmental and waste management, as it is considered appropriate for the analysis of the phosphorus flows in the Netherlands.
In MFA *flows* and *processes* are distinguished. A process (~subsystem) is defined as an entity where transformation, transport or storage of phosphorus occurs. Examples of *processes* in this report are Arable Land and Food Industry. Accumulation may occur within a process (e.g. in Arable soil), but there are also processes in which accumulation does not occur (e.g. the total amount of Manure in the Netherlands will not accumulate in time, the amount produced will, apart from minor storage fluctuations, have a destination: export, soil, incineration).
Flows between processes (mass per time) are calculated as million kg of phosphorus (Mkg P). As indicated above 2005 was chosen as year of reference.



The conservation of mass and MFA

A simple example is presented in Figure 2-1 where P1 and P3 are processes without accumulation or storage, P2 is a process where accumulation can occur.

Flows are indicated with F1 to F6, I and E refer to Import and Export from outside the borders of the defined system.

Assuming that the following flows are known: F1 (import to P1) = 100, F4 (export from P2) = 35, F3 (transfer from P1 to P2) = 70% and F5 (flow from P2 to P3 is 20) then it allows the following flows to be calculated: F3, F2 and F6. Also the change in storage in process P2 can be calculated and is indicated within the box (+15 units).

Figure 2-1. Example of processes and flows in the STAN software.

2.2 System boundaries

Phosphorus flows are not constrained to agriculture, in this report we focus on the P flows in the national food production and consumption chains, and include the major streams of phosphorus containing waste from civic and

[2] Mkg = million kg of P.

industrial origins. It is considered that all flows have been included, in a general net import/export flux. However, amounts of rock phosphate which is imported by Thermphos (a private company that extracts P from rock phosphate) are not included in the flux assessment since the same amount of phosphorus is later exported. The Netherlands, with its major sea port of Rotterdam, has a function in the logistics of mineral transportation, however in this report we focus only on the net national flows and therefore imported materials used to produce exported feed or food products have not been included.
Figure 2-2 shows the defined subsystems for the Netherlands along with the flows between these sub systems and import and export flows. Definition and description of the main processes and flows are given below (a process name as represented in the flow diagrams is indicated in **red**).

2.3 Agricultural land and mineral fertilizer

For agricultural land we distinguish between grassland/silage maize land and arable land. Grassland and silage maize (**Grassland& silage maize**) being defined as agricultural land grazed by animals and equal to the sum of the area of grassland including area used for silage maize production in the Netherlands. Arable land (**Arable**) is defined as land used for the growing of arable and horticultural crops excluding silage maize but including alfalfa (lucerne). Cropping areas were derived from national statistics (CBS, 2007)[3].

Influx

Major influxes come from animal manure, mineral fertilizers, composts, sugar refinery lime, waste treatment sludge and seed and plant material.
Estimates for P originating from animal manure applied to agricultural land were calculated as the difference between the sum of total P from animal excreta plus that from imported manure and the sum of exported and processed animal manure. More detail concerning the calculation of excreta P is given in the ‘animals’ paragraph. Phosphorus content in imported and exported animal manure was derived from data provided by the Central Bureau of National Statistics (CBS). It was assumed that the amount of processed manure in 2005 was negligible.
The distribution of animal manure (**Manure**) between grassland and silage maize and arable land could not be derived from CBS-data, but was estimated by using data from the BIN-farm network[4] in 2005 (LEI, 2005). The BIN-farm network is a Farm Accounting Data Network in which data from representative farms are collected and processed to estimate average farm results. Aggregated data from this network are published on BINternet (www.lei.wur.nl). This network registers P inputs from both animal manure and mineral fertilizers for dairy and arable farms. BIN-data allowed calculation of the mean ratio of P from animal manure per hectare and derivation of the amounts applied to grassland/silage maize and to arable land. This enabled extrapolation for an estimation of the amounts of animal manure , as calculated in the section animals, that could be allocated to each type of land use nationally. In 2005, there were approximately 60,000 arable and animal farms in the Netherlands. Each year, on average BIN-data was used from approximately 1450 farms (all types)

Application levels of mineral fertilizer P (**P-FERT**) on agricultural land was based on CBS data. As with animal manure, the distribution between grassland/silage maize and arable land was based on the mean application rates for grassland/silage maize and arable land registered in the BIN farm network.

For estimation of the amount of P in composts, waste treatment sludge and sugar refinery lime see sections ‘waste’ and ‘food-industry’. It was assumed that these products were predominantly applied on arable land.

Total phosphorus content in seed and plant material was calculated by multiplying the amounts of seed and plant material (KWIN, 2009) by P content (Beukeboom, 1996). Under Dutch circumstances the total amount of P in seed and plant material is greatly influenced by the amount of P in seed potatoes.

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[3] This reference included the data for 2005, the reference year.
[4] BIN is the 'Bedrijfs Informatie Netwerk, the Farm Accounting Data Network.

Outflows

The flux of P from agricultural land with harvested plant products was calculated as the product of the average yield and the P content in harvested products (Beukenboom 1996). Arable crop yields were based on annual yield statistics (CBS, 2007). Grassland crop yields were based on calculations performed by Central Bureau for Statistics (Bruggen, 2007).
Grass and maize are harvested as feed for grazing animals (see also section 'animals'). Corn cob mix is a product used as feed for pigs and beef cattle. Products from arable and horticultural land were influxes for the feed, food and non-food industry.

Leaching losses from agricultural land to surface water (**SurfaceWater**) were derived from data from the Emission Registration Collective (ERC, www.emissieregistratie.nl). Partitioning between grassland/silage maize and arable land was based on the assumption that the amount of leaching per ha is equal for both land use systems.

Table 2-1 gives a summary of inflow, outflow and data sources.

Table 2-1. In- and outflows of P on agricultural land (i.e. arable land and grassland/silage maize) according to data source.

	Type	Unit	Data source
Inflow	Animal manure	kg P	section animals
	Ratio animal manure between arable and grassland	Fraction	BINternet, www.lei.wur.nl
	Total mineral fertilizer in NL	kg P	CBS, 2007
	Partitioning mineral fertilizer between arable and grassland	Fraction	BINternet, www.lei.wur.nl
	Seed and plant material	kg	KWIN, 2009
		g P per kg	Beukenboom, 1996
Outflow	Arable crops	kg per ha	CBS, 2007
		g P per kg	Beukenboom, 1996
	Grass	kg DM per ha	Van Bruggen, 2007
		g P per kg DM	
	Leaching losses	kg P	www.emissieregistratie.nl
	Ratio leaching losses between arable and grassland	Fraction	Based on respective areas
Accumulation	Inflow minus outflow	kg P	Calculation

Reliability of data

CBS-data used in this section are considered to be reliable and (inter)nationally recognised as national data. However, yield data for arable and grassland crops are (mostly pre-harvest) estimates. They have not been cross-referenced to import, export and processing data from industries or corrected for actual harvest data. The range of error in these data remains unknown. Errors in yield will probably be compounded in the amount of products used in households as we calculated civic yield as production minus civic waste and export.

2.4 Livestock

For livestock we distinguish between grazing livestock (**GrazingAnimals**, dairy cattle, beef cattle including veal calves, sheep and goats) and intensive livestock (**IntLivestock,** pigs and poultry, including rabbits and fur animals). Veal calves have been included as grazing livestock in order to simplify the model since calves are a produce of (dairy) cattle which are grazing livestock. Therefore, there is no need for P-flow from grazing livestock to intensive livestock in the model.

Grazing livestock

Influxes

Inputs arise from feeds such as: roughages, concentrates, Corn Cob Mix (CCM) and alfalfa (Lucerne) from arable land, by-products from the food-industry and milk powder used for calves. Phosphorus in roughages flow from grassland and silage maize and arable land (via grass, silage maize and other fodder crops; see section 'agricultural land'). In the scheme (Figure 2-2) the flow of CCM and alfalfa from arable land runs via the feed industry. Therefore, there is no need for a P-flow in the scheme from arable land to grazing livestock. Phosphorus from concentrates, by-products of the food-industry, such as CCM, alfalfa and milk powder are also outflows from the feed-industry (see section 'industry').

Grazing livestock can be distinguished as two groups i.e.: grazing non-dairy livestock: beef bulls and cows, veal calves, goats and sheepor as dairy cattle, including young stock for replacement.
National statistics and figures from the Commodities Board for Animal Feed (CBS 2007, PDV) contain information on the use of feedstuffs for grazing livestock. In a study by Kemme *et al.* (2005) an estimate was made of the P-intake levels of grazing non-dairy livestock. The P-intake of dairy cattle was calculated by diminishing the total amounts with the intake of the grazing non-dairy livestock.

Total feed intake of pigs was assumed to contain CCM and concentrates. The intake of CCM by pigs was calculated from the total yield (see arable land) minus the intake of beef bulls. Figures for the total intake of concentrates by pigs are provided by national statistics. (CBS, 2007).
Total intake of poultry was assumed to contain only concentrates. Figures for the total concentrate intake of poultry are provided by national statistics.(CBS, 2007).

In order to enable the study of future scenarios, the intake of all animals has been calculated per animal, so that, for instance when investigating the effect of a change in animal numbers this will have a direct effect on feed intake.

Outflows

Outflows are animal products and manure. Grazing animals produce milk, wool and meat, pigs produce meat and poultry products include eggs and meat. Fur production has been neglected because this only represents a very small amount of P (0,02 Mkg P in total liveweight).
National *milk* production is based on details of factory deliveries registered in the national statistics. Milk sold at the farm gate as fresh milk or dairy products has also been neglected as this too represents a very small part (< 1%) of the total production(www.prodzuivel.nl). Milk fed directly to the calves represents an internal on-farm P flow which eventually ends up in meat or manure of calves and has therefore not been calculated separately. Phosphorus outflow from milk is calculated by multiplying the total milk deliveries to the factory with default values for P content in milk (Bannink *et al.*, 2010).

The national *wool* and *egg* productions are known from available national statistics (CBS)

Meat production from beef bulls and cows, veal calves, sheep and goats has been derived from the number of production places in the stables where the animals are housed and compared with total meat production (both in national statistics). Annual meat production per production place has been derived from Kemme *et al.* (2005).

Meat production from intensive livestock has been recorded in national statistics (CBS, 2007).
Dairy cattle meat production has been derived from the number of milking cows, the weight of the animals (both CBS, 2007) and the replacement percentage of the milking cows. Replacement percentage being estimated from the number of calves and heifers.
Numbers of born calves was calculated, assuming that all milking cows produce one calf per year. Calves, not used for replacement, are assumed to have been reared for veal production. According to CBS statistics, P import through veal calves can be compared to the number of calves required to fill the places, available for veal production according to CBS. These figures are comparable..

P excretion in animal manure is taken to be the difference between intake in feedstuffs and output with animal products. Grazing animals, excrete part of the manure at pasture and this is not stored. It is assumed that all excreta from sheep and goats and 20% from dairy cattle is excreted at pasture. The estimate (20%) for dairy cattle is based on:

- Some dairy cattle are housed throughout the year and 83% graze (LEI, BINternet).
- Dairy cattle only graze in summer : 45% of the year (estimation).
- Approximately 56% of the national dairy herd overnight indoors (LEI, BINternet): 50% of the manure outside
- Approximately 28% of the national dairy herd overnight outside , and come in to be milked: 90% of the manure outside

Consequently 83% * ((56%*50%) + (28% * 90%)) * 45% = 20%

Influxes for grazing livestock must mathematically be equal to their outflow because we defined the manure as the difference between intake and production. Therefore, it is assumed that the annual amount of P in grazing animals remains stable .

In Table 2-2 the in- and outflows are summarized and data sources revealed.

Table 2-2. In- and Outflows of P for livestock according to data source.

	Type	Unit	Data source
General	Animal places for grazing and intensive livestock	Number	CBS, 2007
Inflow	Roughages for pigs (CCM)	Kg per animal place per year g P per kg	CBS, 2007; Van Bruggen, 2005
	Roughages for grazing non dairy livestock (beef bulls and cows, veal calves, sheep and goats)	Kg per animal place per year g P per kg	Kemme *et al.*, 2005
	Roughages for dairy cattle (grass, silage maize, alfalfa)	Kg per animal place per year g P per kg	CBS, 2007; calculation, cross checked with Van Bruggen, 2005.
	Concentrates for pigs and poultry	Kg per animal place per year g P per kg	CBS, 2007; Van Bruggen, 2005
	Concentrates for grazing non dairy livestock	Kg per animal place per year g P per kg	Kemme *et al.*, 2005
	Concentrates for dairy cattle	Kg per animal place per year g P per kg	CBS, 2007; calculation, cross checked with Van Bruggen, 2005.
	By-products of food industry for pigs	Kg per animal place per year g P per kg	Van Bruggen, 2005
	By-products of food industry for fattening bulls	Kg per animal place per year g P per kg	Kemme *et al.*, 2005
	By-products of food industry for dairy cattle (total by-products minus intake pigs and fattening bulls)	Kg per animal place per year g P per kg	CBS, 2007; calculation, cross checked with Van Bruggen, 2005.
	Milk powder for veal calves	Kg per animal place per year g P per kg	Kemme *et al.*, 2005
	Milk powder for dairy calves (total milk powder for calves minus intake veal calves)	Kg per animal place per year g P per kg	CBS, 2007; calculation
Outflow	Milk, eggs, wool	Kg or number per year g P per kg	CBS, 2007 a.o. Van Bruggen, 2005
	Meat of pigs and poultry	Kg per animal place per year g P per kg	CBS, 2007; www.pve.nl Van Bruggen, 2005
	Meat of grazing non-dairy livestock	Kg per animal place per year g P per kg	Kemme *et al.*, 2005
	Meat of dairy cattle	number of animals kg per animal g P per kg	Calculation, explanation in text a.o. Van Bruggen, 2005
	Excretion (= manure), inflow minus outflow	Kg P per year	calculation
	Distribution over storage and pasture of excretion	Fraction	LEI, 2005.
Accumulation	Inflow minus outflow must be zero	Kg P per year	calculation

Reliability of data

In 2005 the import of feed compounds was published on the internet for the last time by PDV (Commodities Board for Animal Feed). Thereafter PDV refrained from publishing these data. Feed imports combined with the figures for domestic production of arable crops were used to calculate the production of concentrates. The partitioning of feed over the animal types were estimated based on results of detailed studies, mentioned in Table 2-2. However, the consequences of an improper partitioning are small for this study because a balanced method has been used: what

goes in, must come out. Only partitioning over types of manure could be affected by feed partitioning over animal types. No relationship has been used between feeding and production levels.
Product output is considered to be reliable: milk production is limited by quota and deliveries to the dairy industry are registered, meat and egg production is monitored and published by the commodities board for Livestock, Meat and Eggs (PVVE).
Figures for P levels in feed additives have been derived from CBS data (CBS, 2008). No exact content or amount has been found in literature or other sources. The CBS data, reported an amount of 7 Mkg of P, without decimals implying that the deviation of this is ± 0.5 Mkg P.
Figures for P content of milk are reliable (Bannink *et al.*, 2010). Milk P content was determined in samples taken five or six times within a period of three weeks on 16 participant farms of project 'Cows and Opportunities' .Average P milk content was 0.94 g P per kg milk. The variation was about 16% between individual measurements. Between-farm variation was similar. Farm averages compared favorably to the overall average. This indicates that the P content of each individual measurement can differ greatly from the overall average yet increasing numbers of farms and measurements will improve accuracy.
There is a discrepancy in the dairy boards' figures for in- and output of P in the dairy industry (www.prodzuivel.nl). Using the average P content and the P content of products www.foodsel.com, input exceeds output. Therefore, the amount of P used for milk powder in 2005 was 1.4 Mkg P and the amount of milk powder (P content 5.9 g P per kg) produced was 0.9 Mkg P. During the powdering process, no milk is supposed to be lost. According to the statistics no losses were mentioned but a personal communication from J. Petraeus (Friesland Campina) indicated that 0.5-0.9 Mkg P was wasted and 0.4-0.8 Mkg P removed as salt. This salt is often used by other industries or is waste. It remains unclear where P flows end up in the dairy industry. This would probably need separate investigation to determine more exactly how and where P flows in the dairy industry.
The P content of animals has not been measured recently. There is a possibility that the ratio of bone to meat has changed during the years. This would have consequences for P content of the whole animal as P is mainly stored in the bones. Any fault in P content of animals would subsequently influence the amount of P in manure because of the balance method. Subsequently, this also influences estimates for P in bones which is seen as the difference between total P amount minus meat and intestines.

2.5 Industry

For the sector industry we discern feed, food and non-food industry.

*Feed industry (**Feed_Ind**)*

Inflows are products from arable land (e.g. cereals and grain maize, from domestic and foreign origin), imported feed compounds, by-products of food industry (beet pulp from sugar production, barley from brewing, potato fibers from starch production), feed additives and milk (milk powder for calves). Generally, P amounts are calculated by multiplying amounts (CBS, 2007; PDV, 2007) with P contents (CVB, 2007).
Feeds for pigs and poultry are enriched with phosphorus additives, derived from CBS-data for national usage (CBS, 2008).

Outflows from the model include concentrates for domestic use (grazing and intensive livestock), by-products of the food industry, milk powder and waste. By-products are often directly sold from the food industry to farmers or intermediates. In the model they are directed from the food industry through the feed industry in order to simplify the flow diagram. The outflow of concentrates is based on the same CBS data as that used for concentrates in the section animals and therefore similar.
The feed industry also produces feed for export. Raw materials and produced feed are, as with mineral fertilizer, not taken into account in the in- and outflow of the feed industry and for Dutch imports and exports since we were unable to find data to quantify these flows.

*Food industry (**Food_Ind**)*

Inflows include milk, meat producing animals, eggs, edible arable and horticultural products and fish, from domestic and imported origins.

The flow of products into the food industry were calculated as:

- Milk (and dairy products) from grazing livestock plus imports minus milk for calves
- Animals for meat originating from grazing and intensive livestock and imports
- Eggs originating from intensive livestock and imports
- Edible arable products for food industry from arable land and imports
- All edible horticultural products and imports
- Domestic fish (caught and bred) and imports

The amount of P was calculated as in the agricultural section excluding fish. This P count was performed by multiplying the amounts with figures for P content (www.foodsel.com).

Outflows include food for domestic use, exported food, exported living animals, by-products of the food industry for feed and waste material.

The calculation from animals to meat included:

- Animal weight multiplied by an animal specific efficiency factor for slaughter (personal communication C. van Vuure, Vion)
- Rest from carcass, the rest was used for pet food (intestines) or. car seats (hide), bone chips for porcelain, fertilizers, feed and pet food (mainly exported).
- From carcass to meat was calculated as carcass weight multiplied by an animal-specific efficiency factor for cutting out (personal communication C. van Vuure, Vion).
- The remainder comprises of bones.

Most of the bones are exported for different purposes (personal communication C. van Vuure, Vion).
In the Netherlands the bones of pigs are pre-processed by putting them into hot water. The clean bones are chipped and approximately 25% of these chips are exported to France for gelatine production. Process leftovers, which contain the P, are used for fertilizers and raw materials for feed. Approximately 50% of the chips is exported to England (after glue production) for the production of porcelain (bone china). A further, 23% is sold in Europe as raw materials for feed and 2% as raw material for fertilizer.
The skull and spine of bovines are destroyed (incinerated) , together with untimely deceased animals by Rendac. This is to prevent spreading of BSE ('mad cow disease'). This represents 20% of the total live-weight of the animal. The remainder is processed to meat and bone meal and exported for pet food and fertilizer.
Approximately 80% of the poultry bones contain little crude ash and are exported as pet food, other bones (approximately 20%) containing higher levels of crude ash are exported as fertilizer.
Figures for P content of living animals have been derived from Van Bruggen (2007) and the P content of meat from www.foodsel.com. The amount of P in bone and organs was calculated as the difference between P in living animals and P in meat.Animals that die because of diseases or accidents are incinerated by Rendac (Rendac, 2008).
The production of beer from barley, sugar from sugar beets and starch from potatoes are processes providing P-free products. All P from these arable products are assumed to be in the by-products that are directed to the feed industry.

*Non-food industry (**NonFood_Ind**)*

Inflows include all non-food arable and horticultural products and wool, from domestic and foreign origins. Generally, P was calculated by multiplying amounts by P content. In addition to agricultural products, P in dishwasher detergent is an important inflow.
Outflows include non-food products for domestic use and export and waste material.
In general the flow balance (inflow minus outflow) for all industries must be zero, since itis assumed that no accumulation takes place and there are no stock changes within the industry itself.

Table 2-3. In- and outflows of P for food, feed and non-food industry according to sources.

Industry	Type	Unit	Data source
Inflow Food	Meat from poultry, pigs and grazing cattle, domestic production	Kg per year g P per kg	Calculation in section animals
Food, feed and non food	Arable crops (food, feed and non-food): domestic production	Kg per year g P per kg	Calculation in section arable land
Food and non food	Eggs, wool, dairy: domestic production	Kg per year g P per kg	Calculation in section animals
Food	Fish from the ocean	Kg per year g P per kg	CBS, 2007 www.foodsel.com
Food, feed and non food	Import of meat, arable crops, eggs, wool, dairy, fish	Kg per year g P per kg	CBS, 2007 www.foodsel.com
Food	Import of living animals	Kg per year g P per kg	CBS, 2007 Section animals
Food	Dead animals to incineration	Kg per year g P per kg	Rendac, 2008 Section animals
Feed	Import animal feed	Kg per year g P per kg	CBS, 2007 CVB, 2007
Feed	P addition to animal feed	Kg P per year	CBS, 2008
Non food	P in detergent for dishwashers	Kg P per year	Pers. comm. Thermfos
Outflow Food	Meat, eggs, dairy, fish for export	Kg per year g P per kg	CBS, 2007 www.foodsel.com
Food	Meat, eggs, dairy, fish for domestic use	Kg per year g P per kg	Calculation www.foodsel.com
Food	By-products from food industry to feed industry	Kg per year	Calculation: all P in beets, barley for beer and starch potatoes
Food	Pet food, domestic use and export	Kg P per year	Calculation: all organs from slaughtered animals; pers comm. C. van Vuure, VION
Food	Bones, export for fertilizer, feed, pet food and porcelain	Kg P per year	Calculation: all bones from slaughtered animals; pers comm. C. van Vuure, VION
Food	Products from dead animals to cement production	Kg P per year	Rendac, 2008 ;pers comm. C. van Vuure, VION
Food	Waste from dairy industry	Kg P per year	Pers comm. J. Petraeus, Campina
Food, feed, non food	Waste water from industry	Kg P per year	Calculation in section waste
Feed	Animal feed for domestic use	Kg P per year	Calculation in section animals
Non food	P in detergent for dishwashers	Kg P per year	Pers. comm. Thermphos
Accumulation	Inflow minus outflow must be zero	Kg P per year	Calculation

Reliability of data

The input from products within this section are as reliable as the production in the sections animals and arable land. Output is taken as the difference between input and waste. The amount of P in waste has been estimated and therefore may be erratic. This will be assessed later in the section on Waste.

The number of dead animals is considered reliable. Dead animals are processed by only one firm in the Netherlands (Rendac) as this is obliged by law. This firm publishes data on numbers, types and weight of dead animals they collect and the products (Rendac, 2008).
It is known that coca cola is acidified with 0.54 g phosphoric acid per liter (www.cocacolanederland.nl). In the Netherlands about 100 L of soft drink is consumed per person annually. Assuming a quarter of the annual consumption to be coca cola, which is probably an overestimation, nationwide 0.2 Mkg phosphoric acid =~ 0.06 Mkg P would be consumed. This flow has been neglected.

2.6 National import and export

Data for import and export of (agricultural) products have been derived from national statistics (CBS, 2007). Some have been calculated using supply/balance tables (self sufficiency tables). Feed compounds were derived from the feed statistics of the commodities board for animal feedstuffs (www.pvd.nl). National imports and exports have already been declared in other sections.

Import

Imported products comprise:
Meat, fish, eggs, wool, milk and other dairy products, arable and horticultural products, feed compounds, feed P additives and mineral fertilizer.

Mineral fertilizer is defined as the net use in the Netherlands. The Netherlands has a mineral fertilizer industry that imports mining products, processes them and exports fertilizer. These amounts of P have not been included in our flow model. The same procedure was used for feed: import refers to the net domestic usage. All imported products are assessed in other sections of the model, the section import adds them together.

Export

Exported products from both domestic production and imported products include:
Meat, fish, eggs, wool, milk and other dairy products, bones, arable and horticultural products.
All exported products are assessed in other sections of the model, mainly in the section on the industry, the section export adds them together.

2.7 Household and Waste management

Phosphorus enters the household (**Household**) area from the food and the non-food industry (detergents for dish washers; no reliable data were available for this flow, a large variation is mentioned, we decided to estimate this flow at 1 Mkg of P (pers. com. Willem Schipper, Thermphos) and leaves the household as waste (human waste, food residues etc.).
We assume that the P stock in the human body does not change within each year. One potential flow of P from households would be deceased people. The population of the Netherlands (16 million people) combined with an average death rate of 1/70 (people die at an average age of 70) and assuming that one person weighs on average 80 kg with a P content similar to a pig (5.4 g P per kg live weight), the estimated annual flow of P to the environment would be 0.1 Mkg P. A relatively small amount even if the death rate doubles or halves, therefore this flow was neglected in the calculations although the whole population represents approximately 7 Mkg P based on these assumptions.

2.8 Waste management

Waste management (from household, food and feed industry as shown in Figure 2-2) has been considered as a single process (**WASTE**) with several sub processes which are illustrated in Figure 2-3.

Organic waste from Industry (**OrganicWastefromIndustry**)

Inflows

This process was devised to accumulate waste products from Food-, Feed- and the Non-food industry. P in waste flows from these industries and eventually ends up in the sewage sludge of industrial wastewater plants. The amount of P in plant influent (see below) was divided between the three industries proportional to the amount of P processed in these industries (being 49%, 49% and 2% for Food, Feed and non-Food respectively). Further, an important flow was the amount of P from deceased animals processed exclusively by Rendac. Most if not all of this source is used as input for the cement industry.

Outflows

- Untimely deceased animals (Rendac), the phosphorus of which, after incineration ends up in the cement industry
- A greater part of P ends up in the sludge of wastewater treatment plants, as industrial waste (**IndWWTP**).
  A proportion of the industrial P enters communal wastewater treatment plants (**WWTP**)

CBS data on *industrial* sewage sludge are available, however the P-content is not mentioned. Geraats *et al.* (2007) discuss the P-content of *communal* sewage sludge. Depending on the method of calculation a percentage of 3.4 or 2.2% was estimated. Arbitrarily, 2.2% on dry weight basis was assumed for the P-flow of sewage sludge from industrial wastewater plants. The inflow of phosphorus to the treatment plants was then calculated by assuming the same efficiency as for communal wastewater plants (82%, Geraats *et al.* (2007)). The difference between influent and effluent is then considered the P-load to surface water (**SurfaceWater**).
Industrial sewage sludge (**SludgeIND**) is either incinerated, input for the feed industry, input from arable land to landfill or is exported. These flows were calculated based on CBS data for 2005.

*Household waste (**HHwaste**)*

The phosphorus entering the household accumulates in waste, assuming that (almost) no accumulation occurs in the household area. Phosphorus leaves the household via the sewage system, as input for compost production (GFT; Vegetable, Fruit and Garden waste) or to landfill/ incineration plants.
The input (influent) and output (effluent) to communal wastewater treatment plants are based on recent research (Geraats *et al.*, 2007) and CBS data. Geraats *et al.* (2007) acknowledge an inconsistency in the data with respect to the efficiency of P removal from wastewater plants. We calculated the P- input to wastewater treatment plants as P-content of the sewage sludge by assuming a high removal rate. The difference between influent and effluent is assumed to be the P-load to surface water. The P containing sewage sludge (**SludgeHH**) is seen as an input for several processes: landfill or incineration plants (**ToLandfill**), export (**ExpWaste**) or the cement industry (**CementInd**). The flows were calculated based on CBS data for civic sewage sludge in 2005 .
The amount of household P which eventually ends up in compost is calculated based on Anonymus (2006). The P-flow to landfill/ incineration plants was calculated as the difference between input into the household and the (estimated) input to WWTP minus input for composting, assuming no accumulation occurs in the household area.
In Figure 2-2 the process **LOST P** can be identified, as indicating the amount of phosphorus which is not recycled to agriculture or elsewhere. It comprises phosphorus containing products that are incinerated (the P-rich ashes are not used as nutrients), taken to landfill, or used as input in non-agricultural processes such as the cement industry.

Reliability of data

There are several uncertainties. The CBS data only give P contents of sewage sludge for communal wastewater treatment plants and not for industrial plants, we assumed as described in the preceding text that the P – content of industrial sludge is lower than that of household sludge.
The flow from household to landfill/incineration plants is a *calculated* residual flow, assuming that no accumulation occurs and other flows are assessed accurately (in which case these flows might already be subject to large errors).
For the time being it is assumed that the amount of P that ends up in compost from industrial organic waste is negligible.

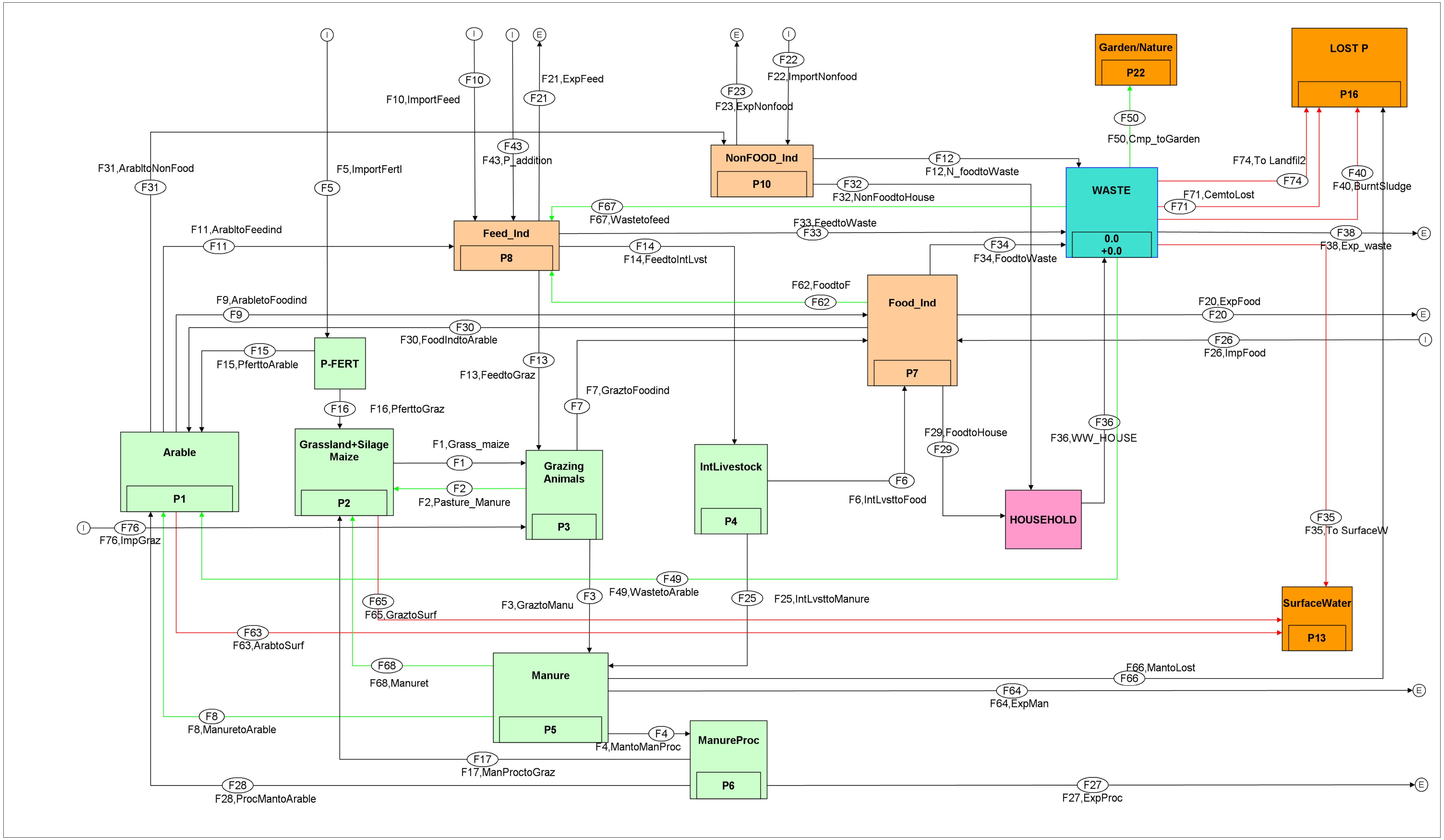

Figure 2-2. *Flows of Phosphorus in the Netherlands. Processes (subsystems) are indicated as squares. E= Exported P, I= Imported P. Flows are identified by name and number (e.g. F1, Grass_maize is the flow from Grassland & silage maize to Grazing animals). More information is available in Appendices I and II.*

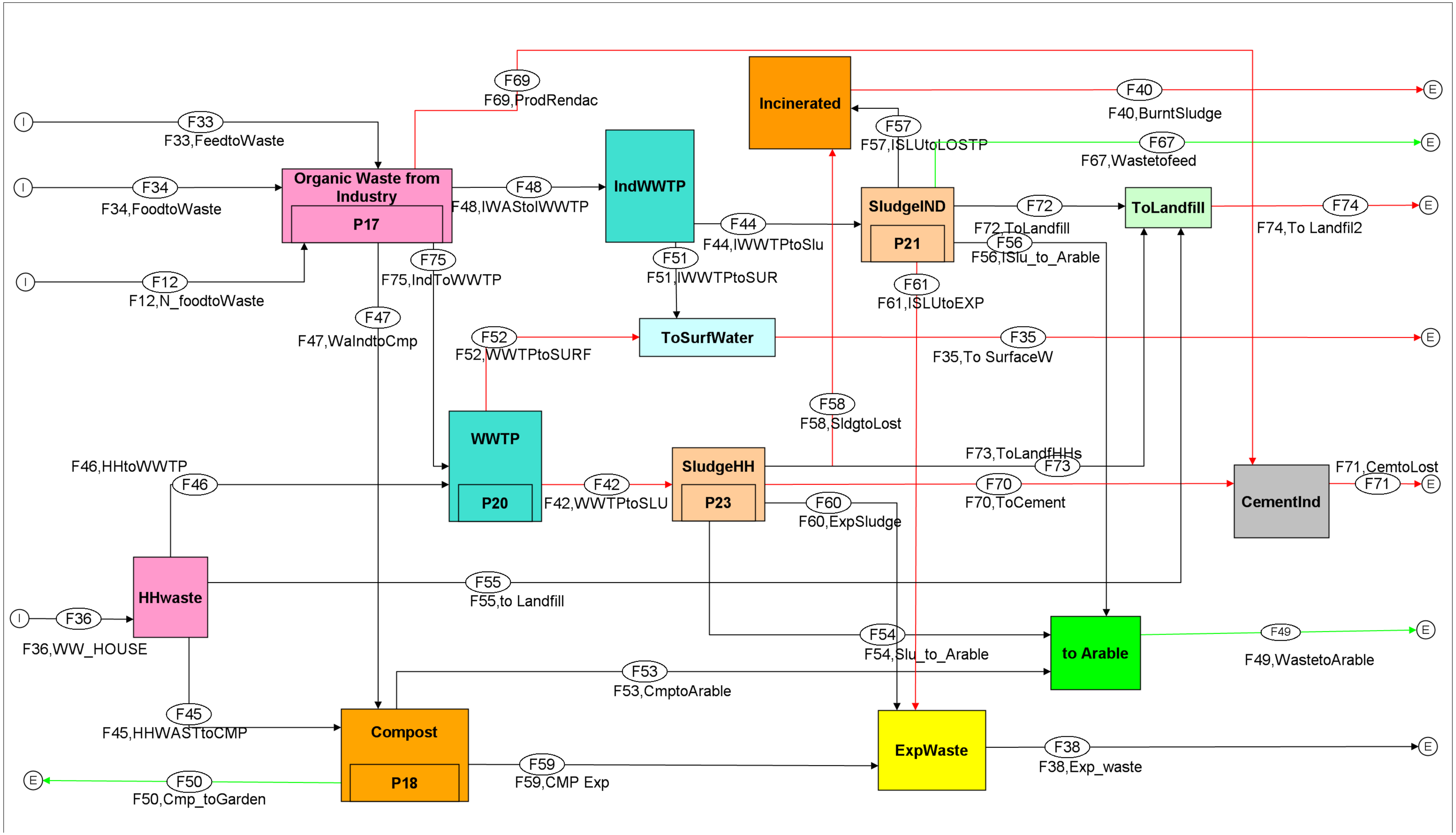

Figure 2-3. *Flows of phosphorus within the WASTE subsystem.*

3 Results

All quantified P-flows are visualized in Figure 4-1 and Figure 4-2. The latter graph refers to the complete Dutch waste management, including household and industry. The thickness of the lines (flows) is proportional to the quantity of the flow. Thus allowing for immediate identification of the most important flows in the Netherlands, e.g. feed.

3.1 Agricultural land

Table 3-1 provides an overview of the amounts of P flowing into and from agricultural land in the Netherlands.

Grassland and silage maize

Total annual P influx is 64 Mkg P presented as the sum of P in animal manure (52 Mkg P) and mineral fertilizers (12 Mkg P). Total outflow through grass and silage maize is 39 Mkg P. Leaching losses to surface water have been estimated at 3 Mkg P (www.emissieregistratie.nl) and allotted to arable land and areas of grassland and silage maize according to acreage, which results in 2 Mkg P for grassland and silage maize. This results in an accumulation in soil of 23 Mkg P, as the total area of grassland and silage maize in the Netherlands amounts to 1,2 million ha (CBS, 2007) the annual accumulation amounts to 19 kg P/ ha.

Arable land

Total P inflow is 24 Mkg P (i.e.37 kg P/ha, 0.663 million ha arable land). The main inputs are animal manure (12 Mkg P) and mineral fertilizers (9 Mkg P). A minor proportion (4 Mkg P) originates from by-products from the food-industry (sugar factory lime), compost, sludge from wastewater treatment and seeds and transplants. Total outflow with harvested products is 15 Mkg P (= 22 kg P/ha),consisting of 8 Mkg to the food industry of which 6 Mkg of P is contained in crops used by the feed industry and 1 Mkg P to the non food industry. Leaching losses to surface water have been estimated at 1 Mkg P. In 2005, this resulted in an accumulation of 8 Mkg P (= 13 kg P/ha) in arable soil.

The results show that there is considerable soil accumulation on agricultural land: above 30 Mkg P i.e. 17 kg P per ha annually. This value compares favourably with the ERC-value of 37 Mkg P (www.emissieregistratie.nl). Accumulation has already exceeded the input with mineral fertilizer (21 Mkg P in total) considerably. Leaching from agricultural land (3.3 Mkg P) contributes approximately 50% to the total annual emission to surface water (7 Mkg P) ,the remainder being non-intercepted phosphorus from communal and industrial wastewater treatment plants.

Table 3-1. Phosphorus in- and outflows (Mkg P) for agricultural land in the Netherlands.

	Grazing land	Arable land	Total agricultural land
Inflows			
Animal manure	52.5	11.5	64.0
Mineral fertilizers	11.7	9.3	21.0
Sugar factory lime		1.5	1.5
Composts		1.0	1.0
Sludge from waste treatment and other waste		0.8	0.8
Seeds/transplants		0.4	0.4
Total	64.2	24.3	88.5
Outflows			
Harvested grass and maize, roughages	39.1		39.1
Harvested grass/clover/lucerne, processed feeds	0.3		0.3
Harvested arable and horticultural products		14.9	14.9
Leaching losses	2.1	1.1	3.3
Total	41.6	16.0	57.6
Accumulation soil, total NL	22.7	8.3	30.9
Accumulation soil, kg P/ha	18.7	12.5	16.5

3.2 Animals

Phosphorus inflows by animals consist mainly of feeds (Table 3-2). For grazing animals this is largely determined by input from roughages (39 Mkg P) and purchased concentrates (17 Mkg P). A minor part originates from by-products of the food-industry, corn cob mix, milk powder and bedding material (4 Mkg P). Outflows occur via animal products (milk, meat, wool) amounting to 17 Mkg P and 44 Mkg P from manure. The amount of P in wool is small (500 kg P). For intensive livestock P inflow through feeds (concentrates) is 28 Mkg P for pigs and 16 Mkg P for poultry. P outflow with animal products is 12.5 Mkg P for pigs and 4.7 Mkg P for poultry. P outflow with manure is 16 Mkg for pigs and 11 Mkg P for poultry.
Approximately, 2 Mkg P is 'produced' by dead animals. This 'production' comes from animals that are incinerated together with high risk slaughter waste (mostly from bovines as a consequence of BSE).

The calculated estimates for P excretion correspond closely to calculations from CBS (grazing animals 43.1 Mkg P, pigs 18.3 Mkg P and poultry 11.4 Mkg P). Manure P originates primarily from grazing animals. About 20% is excreted on pastures during grazing.
The efficiency quotient for animal P, defined as output via products and input via feeds, ranged from 27% (grazing animals) to 43% (pigs).

Table 3-2. Phosphorus in- and outflows (Mkg P) for animals in the Netherlands.

	Grazing animals	Pigs	Poultry	Total
Inflows				
Roughage, grass	33.3			33.3
Roughage, maize	5.8			5.8
Roughage, other fodder crops*	0.2			0.2
Concentrates*	16.9	28.4	15.9	61.2
Organic rest products from food-industry*	2.1			2.1
Corn cob mix*	0.0	0.1		0.2
Milk powder*	0.9			0.9
Bedding material (straw etc)*	0.9			0.9
Import calves for veal	0.2			0.2
Total	60.3	28.5	15.9	104.7
Outflows				
Meat**	5.2	11.0	3.6	19.9
Milk**	10.8			10.8
Eggs**			1.0	1.0
Wool	0.0			0.0
Manure, excreted on pasture	9.3			9.3
Manure, collected in stables	34.6	16.0	11.1	61.7
Dead animals **	0.5	1.4	0.1	2.0
Total	60.3	28.5	15.9	104.6
Accumulation	0.0	0.0	0.1	0.1

** in model from feed industry to animals, to minimize flows in scheme.*
*** in model to food industry.*

3.3 Manure

Table 3-3 presents an overview of the amounts of P flowing in and out via manure produced (excreted P) on grazing land, arable land and exported manure. About 10% of excreted manure is exported.

Table 3-3. Phosphorus in- and outflows (Mkg P) via manure in the Netherlands.

Inflows	
Grazing animals*	43.8
Pigs	16.0
Poultry	10.9
Other (e.g. rabbits and fur animals)	0.2
Total	71.0
Outflows	
Grazing land*	52.5
Arable land	11.5
Exported	7.0
Total	71.0

** including manure excreted during grazing.*

3.4 Industry

Table 3-4 presents an overview of the P flows for feed, food and non-food industry under Dutch circumstances.

Feed-industry

Main P inflows come from imported feed compounds (39 Mkg P), imported arable products (12 Mkg P, e.g. cereals, grain maize) and feed additives (7 Mkg P). The contribution of products of domestic origin (10 Mkg P) to total P inflow is relatively small. Concentrates provide the main source of the P inflow (61 Mkg P, see outflows). A small P inflow (0.2 Mkg P) comes from waste. It is, however, not known what this waste material is and whether or not it is used in products. Since there is no outflow of this P, a small accumulation occurs in feed industry.

Food-industry

Main P inflows are from products of animal (46 Mkg P) and arable/horticultural origin (25 Mkg P). The major proportion of animal products (73%) is of domestic origin while approximately 70% of arable/horticultural products is imported. The amount of P in produced foods from animal and plant origin is 28 and 17 Mkg P respectively.

In- and outflow of P for animal products differ by 14 MkgP with products for human and pet consumption. This amount resides mainly in bone meal and chips exported as raw materials for fertilizer after gelatine production (ca. 3.4 Mkg P), feed (ca. 3.5 Mkg P), petfood (0.4 Mkg P) and porcelain production after glue production (3.1 Mkg P), dead animals and slaughter waste. For arable/horticultural products the difference is 4 Mkg P and leaves the food-industry mainly via by-products for animal feeds and products intended for use as fertilizer (sugar factory lime). Approximately 4 Mkg P leaves the food industry that is undistinguished whether it is of animal or plant origin.

In the food industry 41 Mkg P is of domestic origin, 28 Mkg P is imported. Approximately 25 Mkg P from food production is for domestic usage, 27 Mkg P is exported as food. 11 Mkg P is exported as bone meal for feed, fertilizer and for porcelain production. Other organic waste created by the food industry was estimated to be approximately 7 Mkg .

Table 3-4. Phosphorus in- and outflows (Mkg P) for industry in the Netherlands.

	Feed	Food	Non-food
Inflows			
Products from domestic origin			
Arable/horticultural products	5.8	7.7	1.3
Meat		21.8	
Milk	0.9	10.8	
Eggs		1.0	
Wool			0.0
By-products from food-industry	3.4		
Imported products			
Feed compounds	38.9		
Arable/horticultural products incl. stock mutation	11.5	17.0	0.4
Feed additives	7.2		
P from waste other industry	0.2		
Animals		1.4	
Meat		2.0	
Milk		4.3	
Eggs		0.2	
Wool			
Fish (directly from ocean)		1.7	
Fish (import)		1.4	
Dish washer detergent			1.0
Total	67.9	69.4	2.7
Outflows			
Domestic use			
Feed (concentrates)	61.5		
Milk powder for calves	0.9	0.9	
By-products from food-industry	2.1	3.4	
Arable/horticultural products	0.9	7.1	
Meat		2.5	
Milk for human consumption		6.8	
Eggs		0.5	
Wool			
Fish		0.8	
Pet food		0.8	
Sugar factory lime		1.5	
Seeds/transplants		0.4	
Non-food products (incl. dishwasher detergent)			1.3
Exported products			
Arable/horticultural products		10.1	
Animals		3.2	
Meat		3.8	
Milk		6.1	
Eggs		0.8	
Wool			0.0
Fish		2.3	
Pet food		0.8	
Bone meal for fertilizer, feed, porcelain and pet food		10.5	
Non-food products			1.3
Waste	2.4	3.6	0.1
Incinerated dead animals and slaughter waste		3.7	
Total	67.7	69.4	2.7
Accumulation	0.2	0.0	0.0

3.5 Households

Table 3-5 presents an overview of the in- and outflows for Dutch households. The annual P inflow of households in the Netherlands is 20 Mkg P. Most of this P inflow is from food, only 1 Mkg P comes from non food and 1 Mkg from pet food. More than half of the P inflow (11 Mkg P) is of animal origin. A further 7 Mkg P is of plant origin and 1 Mkg P is of mineral origin (dishwasher detergent).
Food entering the household area is not completely consumed. The total inflow contains also waste discarded prior to consumption, i.e. leaves and peelings from vegetables, cutting losses from meat, shells from eggs etc. Household influx also includes food discarded because it is beyond its expiry date.
We assumed that households do not accumulate P therefore all inflow leaves via household waste. Waste and waste management are addressed in a separate paragraph (3.6).

Table 3-5. Phosphorus in- and outflows (Mkg P) for Dutch Households.

Inflows	
Arable/horticultural products	7.1
Meat	2.5
Milk for human consumption	6.8
Eggs	0.5
Wool	0.0
Fish	0.8
Pet food	0.8
Non-food products (incl. dishwasher detergent)	1.3
Total	19.8
Outflows	
Wastewater treatment plant	12.4
Waste to landfill	6.2
Compost	1.2
Total	19.8
Accumulation	0.0

3.6 Waste and waste management

Industrial waste

Phosphorus levels in waste from Feed, Food and non Food industries are 2.4, 7.4 and 0.1 Mkg P respectively(see Table 3-4). Food industry waste consists of slaughter waste (3 Mkg kg) originating from animals and high risk slaughter waste which is processed by Rendac, 2.3 Mkg in the sewerage system and further processed by wastewater plants and 1.3 Mkg from the dairy industry. Waste from Feed and non-Food industry is restricted to the P in the sewerage system.

Therefore, the total amount of P from industrial waste is about 10 Mkg P. Approximately 3.9 Mkg of this eventually resides in industrial sewage sludge (which for the greater part is incinerated), the proportion of waste processed by Rendac is directly incinerated and finally ends up in the cement industry (3 Mkg), it is assumed that 2 Mkg is processed by communal wastewater treatment plants. The remainder consists of phosphorus not intercepted by industrial waste water treatment plants (0.9 Mkg). Industrial sewage sludge P (3.9 Mkg P) has according to CBS data a range of destinations: incinerator ash (0.9 Mkg), input for the feed industry (0.2 Mkg), arable land (0.8 Mkg), landfill (0.4 Mkg) and export (1.7 Mkg).

Household waste

Approximately 20 Mkg P leaves the household area as input for national waste management. We calculated the input to the communal WWTP to be around 12 Mkg P. Assuming that 1.2 Mkg ends up in compost (GFT, organic waste) the amount that goes to landfill or incineration plants must be about 6 Mkg P. As explained under Materials and Methods this constitutes a rest flow, which can be calculated assuming that no accumulation occurs in the household area. The size of this calculated flow agrees closely with the amount found by Binder *et al.* (2009) who reported that for Switzerland about 30% of household P input ends up in household refuse.

It is further assumed that most of the compost originating from households will be used on agriculture (arable land) and small amounts are exported. The P-content of communal sewage sludge (12 Mkg P) ends up as landfill (0.9 Mkg), or as input for the cement industry (0.9 Mkg) but the major part is processed by incineration plants (9.5 Mkg)

Table 3-6 provides an overview of the major flows for national waste and waste management as *a single* process (**Waste**) in the Netherlands.

Table 3-6. Phosphorus In and output from Waste in the Netherlands.

Input source	
Feed Industry	2.4
Food industry	7.4
non-Food Industry	0.1
Households	19.8
Total input	*29.7*
Output destination	
Garden/Nature	0.1
Arable	1.7
Lost P	
Landfill	7.5
Incinerated	10.4
Cement industry	0.9
Feed industry	0.2
Exported waste (sludge)	2.7
Rendac products, mainly to cement industry	3.0
Surface Water	3.5
Total output	*30.0*
Balance	0.3

3.7 National import and export

Aggregating the various sub-processes to national yields results in national import and export flows of phosphorus (Table 3-7). The main inflow of phosphorus into the Netherlands comes with feed compounds and additives (57 Mkg P), mineral fertilizer (21 Mkg P) and arable and horticultural food products (17 Mkg P). The main outflow goes through exported arable and horticultural products (12 Mkg P). Followed by bone meal (10 Mkg P), meat (7 Mkg), organic manure (7 Mkg) and dairy products (6 Mkg). This results in an accumulation of 60 Mkg P ,more than 50% (31 Mkg) of which accumulates in agricultural soil (Table 3-1), the rest is emitted to the environment (surface water, 7 Mkg) or is sequestered (landfill, incineration ashes, 20 Mkg).

Table 3-7. National import and export of P for the Netherlands, Mkg P.

	The Netherlands
Inflow	
Meat	3.4
Fish incl. directly from ocean	3.1
Eggs	0.2
Wool	0.0
Dairy products	4.3
Arable and horticultural products for food	17.0
Arable and horticultural products for non-food	0.4
Living animals for veal production	0.2
Feed compounds	50.4
P additives for feed	7.2
Mineral fertilizer	21.0
Dishwasher detergent	1.0
Total	108.2
Outflow	
Meat	7.0
Fish	2.3
Eggs	0.8
Wool	0.0
Dairy products	6.1
Arable and horticultural products for food	10.1
Arable and horticultural products for non-food	1.3
Feed	0.0
Pet food	0.8
Bone meal for fertilizer, feed, porcelain and pet food	10.5
Organic manure	7.0
Waste	2.7
Total	48.5
Accumulation	59.7

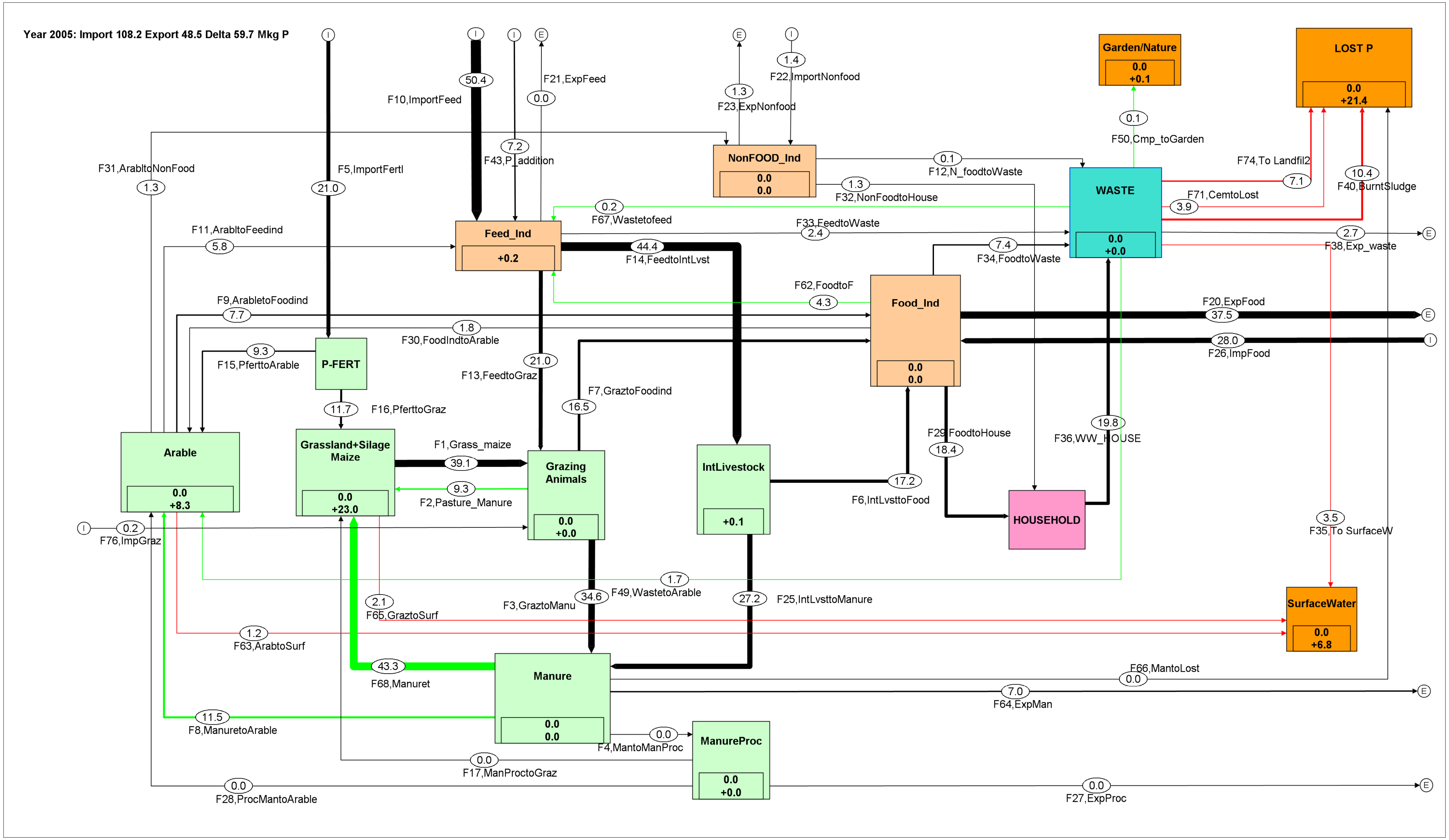

Figure 3-1. P-flows in the Netherlands, the size of the flow is indicated in the ellipse in Mkg /a of P. Accumulation of P is indicated where appropriate in the square boxes. For an explanation of flows and processes see appendix I and II.

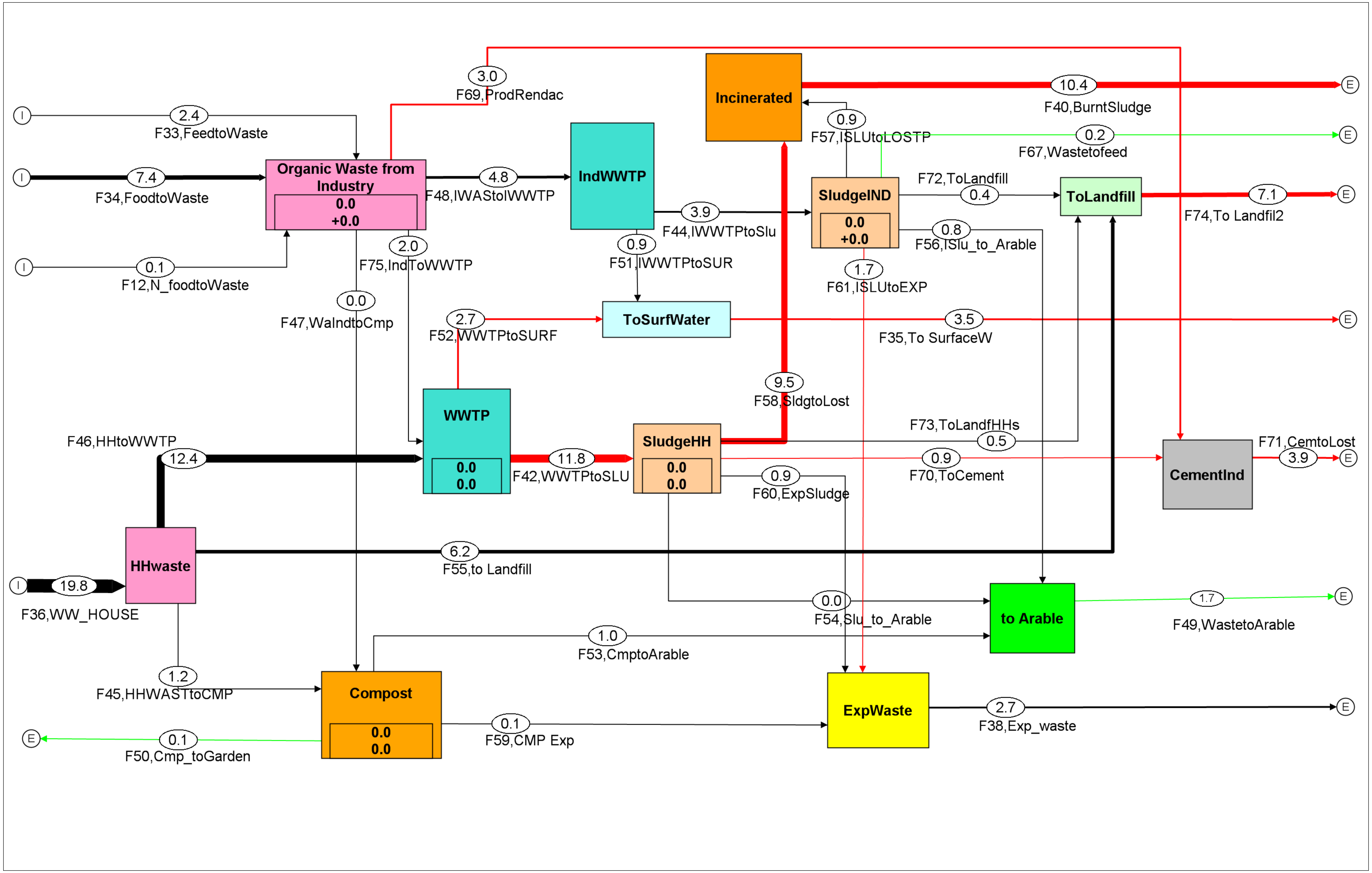

Figure 3-2. *P flows in Mkg of P/a in the sub process Waste. Accumulation of P is indicated where appropriate in the square boxes. See also Appendix I and II.*

4 Discussion

4.1 The national P-balance

For a broad overview of the national flow we have identified 5 areas of interest (Figure 4-1):

- *Agriculture:* all the basic agricultural production activities are pooled here, production of feed, food, milk, eggs, meat etc.
- *Industry.* This sector includes industrial (processing) activities in the food, feed and non-food industries.
- *Households,* comprises all processes in the household area in connection with food, detergents and other non-food products
- *Waste Sector* includes all processes to do with the disposal and treatment of wastes from industry or households
- *Environment/Sequestered* includes emission to surface waters and rivers, but also where phosphorus accumulates or is sequestered. This can take the form of landfills but also cement (one of the destinations of phosphorus in sewage sludge) and discarded incineration ashes

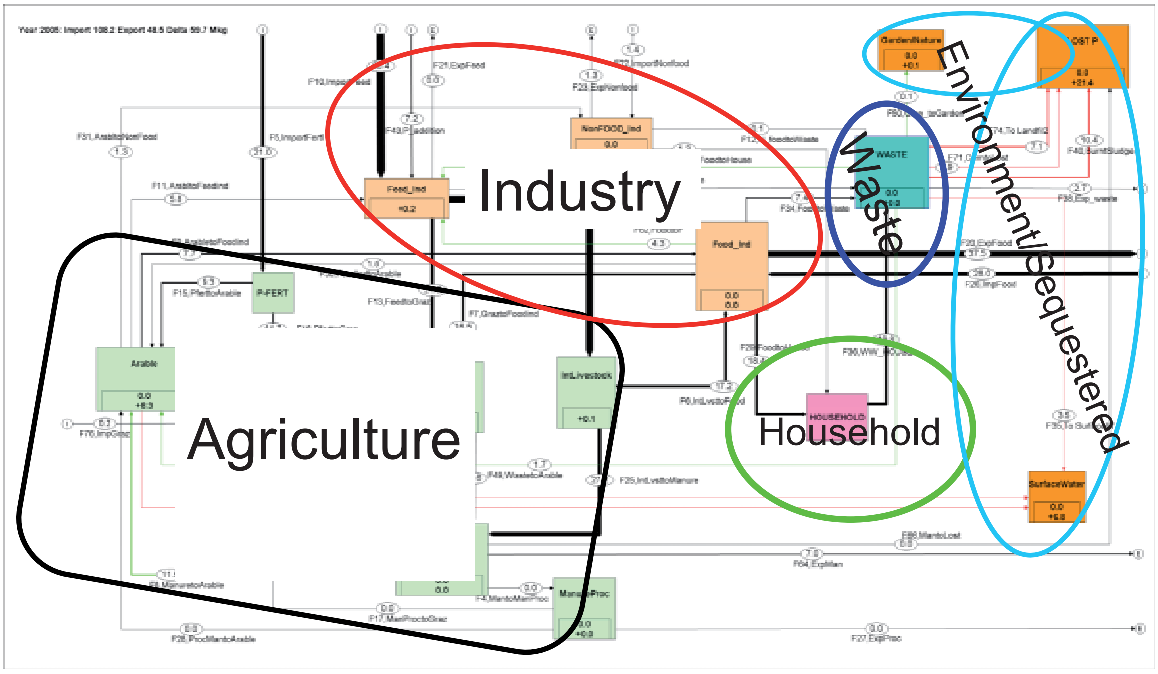

Figure 4-1. Areas of interest in the national P flow scheme.

All in and outflows of phosphorus between these areas have been calculated on the basis of the individual flows shown in Figure 3-2 accounting for national import and export of phosphorus with various compounds such as waste, food etc. Figure 4-2 depicts the main flows of phosphorus in the Netherlands and the areas where accumulation takes place. The Netherlands imports 110 Mkg P of which less than half it is exported, consequently the remainder (approximately 60 Mkg of P in 2005) remains in the country in one form or another. In the figure it can been seen that 31 Mkg accumulates in agricultural soil whereas 28 Mkg of P ends up in 'Environment/Sequestered'. Therefore, it is obvious that the 20 Mkg exported from Households is not recycled back to agriculture, only a small amount returns as compost.

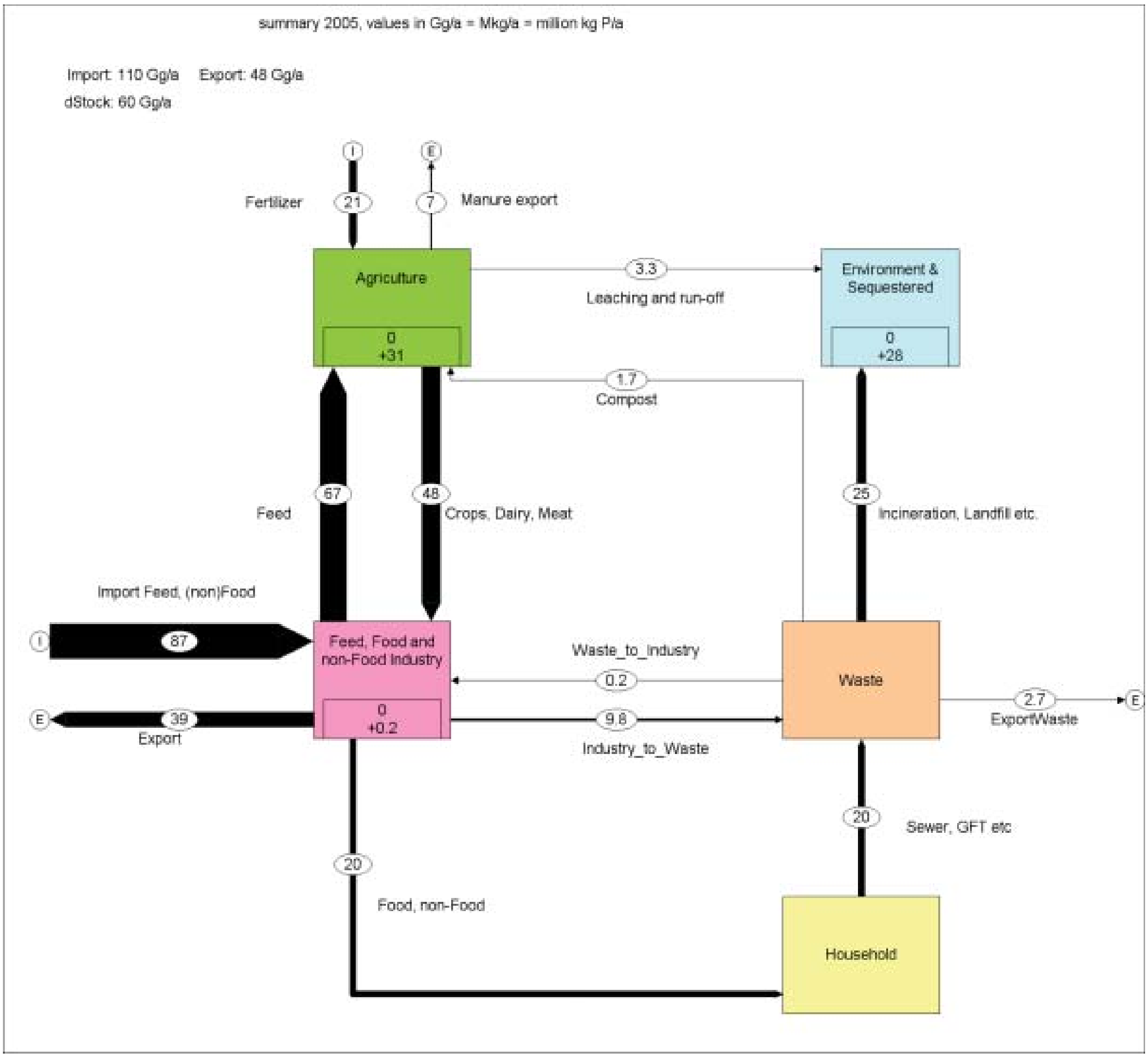

Figure 4-2. *Summarizing the main flows between agriculture, environment/Sequestered, Industry, Waste and households.*

Agriculture

Phosphorus flows in agriculture (Figure 4-2) can be characterized by a large input flow via Industry (imported feed), the return flow of products to Industry (crops, meat, milk etc) being smaller than the feed imports. Taking account of other flows an accumulation of 31 Mkg of P (half of the national phosphorus surplus) takes place in agricultural soils. The agricultural area in the Netherlands is approximately 2 Mha (including arable, grazing land, maize land, vegetables etc.) implying an accumulation per hectare of 17 kg of P/ha/annum.

Industry

Almost two-thirds of the flow into the industry is imported (Figure 4-2). More than half of this import are components for feed (50 Mkg P feed and 7 Mkg P additives). Half of the total production of the industry comes from animal feed production. The other half, comes mainly from food production. About one third of the food production is for domestic use and two thirds is exported. Approximately 15% of P inflow is waste. It is assumed that there is no accumulation or depletion in industry.

Household

Relatively small amounts of P enter the household (20 Mkg of P/annum), and of this small amount only a fraction (probably not more than 50-75%) is consumed as food. Whereas phosphorus enters the household via food and detergents, it leaves the households with sewerage (63% of the output), refuse to landfill/incineration (31%) and food residues, kitchen and garden waste destined for compost (6%) (Table 4-1). These figures agree reasonably well with Swiss data, 63%, 26% and 10%, for household waste, landfill and GFT respectively. (Binder *et al.*, 2009).
The data (taken to be the difference between food entering the household and leaving via the sewers i.e. consumed food + detergents) suggest that a large fraction of the food entering the household is not consumed but ends up in household refuse. Considering the fact that currently all solid waste from Dutch households is incinerated this implies that nearly all the phosphorus entering the household is not returned to agricultural production areas.

Table 4-1. Input and output of phosphorus to and from Households in the Netherlands (in Mkg of P).

Household		Products		
In	Industry	Food (animal)	11.4	57%
	Industry	Food (veg.)	7.1	36%
	Industry	Non-Food (cleaning products)	1.3	7%
		Total	*19.8*	*100%*
Out	Waste	Sewage	12.4	63%
	Waste	Landfill/Incineration	6.2	31%
	Waste	Compost	1.2	6%
		Total	*19.8*	*100%*

Waste Industry

Two-thirds of the waste that is processed comes from households and one-third comes from industry (Table 4-2). In total, almost 30 Mkg of P was processed by the Waste sector in 2005. On the output side, recycling to Agriculture is almost negligible and the main output flows to the Environment & Sequestered sector (25 Mkg of P).

Table 4-2. Phosphorus flows in the Dutch Waste sector (in Mkg of P).

Waste sector			
	System	Products	
In	Household	Sewage, Compost, Landfill	19.8
	Industry	Waste (from Feed, Food and non-Food industry)	9.8
		Total	*29.6*
Out	Export	Exported sludge and compost	2.7
	Industry, Household	Reused in industry	0.2
	Agriculture/gardens	Compost, used in agriculture	1.8
	Environment/Sequestered	Sewage sludge (+ Incineration), Landfill, Cement Industry, Surface Water	24.9
		Total	*29.6*

Environment & Sequestration

Half of the national surplus accumulates in agriculture, while the other half accumulates in the system Environment & Sequestration (28 Mkg of P/a). Table 4-3 also shows that approximately 7 Mkg of P ends up in the water system (groundwater, rivers, lakes etc.). Half of which, 3.5 Mkg of P, originates from the effluent of industrial or communal wastewater treatment plants (which have an average efficiency of 80%) and 3.3 Mkg P originates from leaching and runoff from agricultural land. The table shows that the remainder of the P accumulation in this sector (21 Mkg of P) is sequestered.

Table 4-3. Phosphorus flows in the Environment/Sequestered sector.

Environment/Sequesterd				
	Sector	Products		
In	Waste	Effluent wastewater treatment plants	3.5	
	Agriculture	Leaching and runoff	3.3	
		Total to Surface water		*6.8*
	Waste	Incinerated sludge	10.4	
	Waste	Input for cement industry	3.9	
	Waste	To Landfill/Incineration	7.1	
		Total Sequestered		*21.4*
		Total		*28.2*

4.2 Losses and accumulation

The fact that in the Netherlands approximately 28 Mkg isn't recycled to agriculture contributes to an apparent low efficiency for 'fertilizer/mine to fork'. Cordell *et al.* (2009) mention that worldwide only 20% of the annual P fertilizer application ends up in food. However, this does not necessarily mean that 80% is lost for agriculture. Therefore we will briefly summarise the different kinds of losses in the chain ranging from P-deposit, mining, fertiliser, food to human excreta. In Table 4-4 we mention first *Direct losses:* immediate losses which cannot return to the agricultural cycle, i.e. losses by erosion, leaching and runoff, which end up in the sediments of the oceans and are impossible to mine again. These types of losses also include substantial mining losses (Villalba *et al.*, (2008).

The second category is '*Potentially recoverable*: P-flows produced by society, such as sewage sludge, which are not returned to agricultural fields (so-called 'missed opportunities'). There are a variety of reasons why this does not happen, one being the concern of contamination with heavy metals. Instead of recycling it is incinerated. A major loss of P in the Netherlands is through the destruction of dead animals and slaughter waste, especially the P-rich bones. Because of hygiene regulations (due to BSE 'mad cow' disease), 43% of P in bones of slaughtered bovines are incinerated. Approximately, 50% of the bones from pigs are used for other purposes (e.g. the production of porcelain). In this study it was estimated that the amount of P lost for agriculture in this way could be as high as 6 Mkg of P/annum. In comparison to the total use of (imported) P-fertiliser (21 Mkg P) this is a substantial quantity.

The third category of losses which may explain the apparent low efficiency from fertilizer to consumed food is *accumulation*. Accumulation of phosphorus in soils occurs when P removal via crops (the product harvested and removed from the field) is lower than the P input (with manure, fertiliser etc.). This accumulation takes place on

various scales (national, regional, on farm), usually due to high concentrations of livestock which necessitate (costly) transport of manure to fields farther away.
Accumulation is also influenced by the special character of phosphorus in the soil (immobile, insoluble, bound to soil particles). This makes it profitable to strive for a high P-fertility of the soil, the drawback however is that this necessitates large amounts of P (compared to the annual removal through crop harvest) in order to arrive at higher P-fertility levels. Even farmers who strictly follow guidelines for P-fertilisation still accumulate soil P. In Germany, as in most other EU-countries, a recommended range of soil fertility applies. Römer (2009) concluded that *within* this recommended range, 500 kg P ha^{-1} would already be needed to bring the soil from the lowest to the highest recommended fertility level, such an amount is removed with crops only after two decades. To ensure a more efficient use of P-fertiliser he suggested a critical revision of the recommendation system. Römer also concluded that 70-80% of soils in European countries have an average or high P-status and that such locations should be able to maintain yields even without P-fertilisation and that fertilisation wil not increase yields.

Table 4-4. Types of losses which explain the apparent low inefficiency of P in the chain from mine to fork.

Type of loss	Examples
Permanent	*Losses to the environment* - Mining losses - Erosion, runoff, leaching - 'Dumping' of manure on non-agricultural areas *Sequestered or made otherwise unavailable for agriculture* - Incineration of manure - Sequestration in building materials, landfills
Potentially recoverable (due to inefficient use, unnecessary waste production or suboptimal recycling)	*Organic waste by-product losses* - slaughter waste - Food losses - Crops used for non-food purposes
Accumulation in soils (on national scale, regional scale, and even on a local scale within farms)	*Accumulation in agricultural soils* - Risk aversive fertilization - Improvement soil fertility - Concentration of livestock (too much manure for surrounding arable area) - P-recommendations for economically optimal yields

Considering the large quantities of phosphorus that are not recycled to agriculture in the Netherlands it is obvious that phosphorus is not considered a valuable and finite resource. Although it appears as if the Netherlands is less dependent on mineral P-fertiliser (because of its surplus) it must be realised that most of the P-rich feed that is imported from other countries (*e.g.* Brazil), could only be produced with the input of fertiliser itself. Therefore, Dutch agricultural activities are equally dependent on the use of mineral P-fertiliser.

4.3 Possibilities for a more sustainable use of phosphorus

Above it has been shown that the lack of sustainability in the Netherlands has many forms:

- Missed opportunities to recycle
- Accumulation of P in agricultural soil
- Emissions to the environment

To improve sustainability therefore various paths can be followed:

In Agriculture

- Livestock farming should be in balance with the surrounding area of arable land. Then the excess of animal manure will not lead to an accumulation of phosphorus in the soil and to risks (and losses) for the environment. The most drastic measure would be to reduce the number of P-excreting animals in the country in the long run. However, such a policy would have serious economic consequences. Instead the government is currently focusing on two policies:
  - Reducing P-input by imposing a so-called equilibrium fertilisation (input =~ net removal).[5]
  - Manure processing, making a less voluminous P-rich organic fertiliser (for export).
- Critical judgment of current fertiliser recommendation schemes and stimulation of implementation of the fertiliser recommendations. The potential trade-off (lower yields or crop quality) when aiming for lower phosphorus fertility levels should be quantified for various situations. Possibilities for increasing the efficiency of phosphorus fertilisation strategies within agriculture should be explored. Use of precision farming will improve the potential for efficient use of fertiliser P (*e.g.* placement of fertiliser). Additionally, this will allow consideration of differences in P-fertility within and between fields. In the Netherlands, more than 80% of the maize and arable land has a P fertility level which is deemed sufficient or more than sufficient (Schoumans, 2007).
- Critical evaluation of P-additions to feed. According to a recent desk study (van Krimpen *et al.*, 2010) for dairy and pigs there are possibilities to lower the intake of these animals by lowering the P content of raw products and roughages. For pigs this also includes the possibilities to diminish feed P additives.
- Plant breeding:
  - Breeding aimed at improvement of rooting characteristics (especially in the juvenile phase) in order to mobilize phosphorus more efficiently in the soil (Smit et al., 2010)
  - Perennial wheat (Scheinost et al., 2001)
  - It is also suggested that the use of genotypes with a low phytic acid content (so called lpa-mutants) could have a large contribution (Lott et al., 2009)

In summary it would appear that various measures are available for improvement of more sustainable phosphorus utilization, however good coordination is essential to avoid unwanted side effects, e.g. loss of soil quality due to an insufficient input of organic matter with manure.

In Recycling

- Stimulation of recycling. Besides a more efficient use of manure, efforts should be aimed at improvement of recycling of P-rich waste. Phosphorus is lost with human excreta, household waste, crop residues, slaughter waste and bones, and other organic rest. After incineration of these waste streams the P-rich ashes are usually not recycled. However, technology is now available for recycling P in sewage sludge, thereby removing heavy metals and maintaining bioavailability of phosphorus for plants (Adam *et al.*, 2009). In order to improve the recycling rate, current regulations at national and EU level will have to be critically reviewed. Incentives for recycling by the government may also be helpful.
- Recovery from wastewater, e.g. struvite. Struvite recovery technology is available, however the use of struvite as fertilizer is not yet allowed in the Netherlands.
- Recycling of phosphorus should be a key factor in new developments or trends. For example a larger global area of crops grown for energy purposes (bio fuels/bio energy crops) can stimulate the demand for P fertiliser while increasing losses through erosion. The motivation for utilization of these types of crops is the prevention of global warming, but their sustainability is dependant upon recycling of the P containing residues (in such cases the residues, or at least the nutrients, should be returned to the land where the crops were grown).
- Recycling of phosphorus will have consequences for agriculture, because in the short term the national surplus (for agriculture) will be higher. Therefore, changes must follow in one way or another, e.g. more export of manure or recycled P, less animals, less fertilizer use, less imported feed.

[5] This policy aims to achieve, e.g. for arable land, a maximum input of 60 kg P_2O_5 (~ 25 kg P /ha) per year in 2015.

4.4 Conclusions

- Figure 4-2 summarizes the flows between the main sectors. The Netherlands is a net importer of phosphorus (importing 108 Mkg of P and exporting 46 Mkg of P), leading to an accumulation of more than 60 Mkg of P/annum.
  - Approximately 31 Mkg of P of the 60 Mkg, accumulates in Agriculture. Emissions from agriculture to the environment (water) are estimated to exceed 3 Mkg of P. A further 25 Mkg of P from the Waste Industry is either sequestered or emitted to the environment (water)
- Almost half of the national import of phosphorus comes in animal feed (mainly for intensive livestock production)
- The relatively large intensive livestock sector produces substantial amounts of slaughter waste, together with the amount of phosphorus in produced manure crop P-requirements on the available arable area are exceeded.
- The P flow into households amounts to nearly 20 Mkg of P (93% food, 7% detergents). Consumed goods are directly transferred to the Waste industry in the form of various waste substances. Households are the main input P source (66%) to the Waste Industry.
- Return flows from society (Household and Waste industry) to Agriculture are almost negligible. The Waste sector produces 30 Mkg of P annually, but not more than 2 Mkg is recycled to agriculture or horticulture. Approximately, 2.7 Mkg of P is exported and more than 25 Mkg P ends up either in surface water (from wastewater plants), in incinerator ash or in cement.
- Potential recycling paths are not used (or are prohibited) for the following reasons: environmental concerns (heavy metals in sewage sludge), hygienic concerns (direct use of faeces and urine), and concerns about spread of diseases (a.o. BSE).
- In order to improve sustainable usage of phosphorus in the Netherlands the emphasis should be on a reduction of the national surplus on the one hand and increased recycling on the other. Both strategies interact but various options are available.

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5 Appendices

Appendix I. Phosphorus flows in consecutive numbering (F1- F76) in Mkg of P/annum.

Flow	Flow name	Source process	Destination Process	Mass flow [	Mass flow (calcu-lated)	Components
F1	Grass_maize	Grazeland,Grasslandland+Silage Maize	P3,Grazing Animals	39.1	39.1	grass 33.3 forage maize 5.8
F2	Pasture_Manure	P3,Grazing Animals	Grazeland,Grasslandland+Silage Maize	9.3	9.3	pasture manure (manure production sheep, 50% goat, 20% of dairy cattle)
F3	GraztoManu	P3,Grazing Animals	P5,Manure	34.6	34.6	Beef bulls 1.4; veal calves 4.0; Beef cows 0.6; 50% goat manure 0.2; 80% manure produced by dairy cattle 26.0; bedding material (straw) 0.9; horses 1.5
F4	MantoManProc	P5,Manure	P6,ManureProc	0.0	0.0	
F5	ImportFertl		P9,P-FERT	21.0	21.0	CBS data
F6	IntLvsttoFoodind	P4,IntLivestock	P7,Food_Ind	17.2	17.2	poultry meat 3.6; eggs 1.0; Rendac: poultry 0.1; pork 11.0; destructed pigs 1.4
F7	GraztoFoodind	P3,Grazing Animals	P7,Food_Ind	16.5	16.5	meat 5.2; dairy 10.8; destruction 0.5 (Rendac)
F8	ManuretoArable	P5,Manure	ARABLE,Arable	11.5	11.5	see Materials and methods
F9	ArabletoFoodind	ARABLE,Arable	P7,Food_Ind	7.7	7.7	Non-feed and non-exported arable products (cereals/corn, potatoes, sugar beet, vegetables, pulses).
F10	ImportFeed		P8,Feed_Ind	50.4	50.4	Imported feed soya 10.9 /rapeseed meal 9.4; maize gluten feed 4.1 palm kernel meal 4.0 sunflower meal 3.6 pulps 0.5 '; dairy products 1 diverse oil containing seeds (i.e. linseed)
F11	ArabltoFeedind	ARABLE,Arable	P8,Feed_Ind	5.8	5.8	arable products cereals, crop residues, alfalfa (Lucerne) and corn cob mix for feed
F12	N_foodtoWaste	P10,NonFOOD_Ind	P17,Organic Waste from Industry	0.1	0.1	Sewage sludge, see F33
F13	FeedtoGraz	P8,Feed_Ind	P3,Grazing Animals	21.0	21.0	Dairy feed concentrates 17.1; org. waste 2.12 from food (beets, beer, potatoes) + milk powder 0.9; crop residues (straw etc)0.9
F14	FeedtoIntLvst	P8,Feed_Ind	P4,IntLivestock	44.4	44.4	Pig feed concentrates 28.4; corn cob m ix for pigs 0.1; Poultry feed concentrates 15.9
F15	PferttoArable	P9,P-FERT	ARABLE,Arable	9.3	9.3	P fertilizer 9.3
F16	PferttoGraz	P9,P-FERT	Grazeland,Grasslandland+Silage Maize	11.7	11.7	P-fertilizer
F17	ManProctoGraz	P6,ManureProc	Grazeland,Grasslandland+Silage Maize	0.0	0.0	
F20	ExpFood	P7,Food_Ind		37.5	37.5	exported dairy 6.1; eggs 0.8; meat 3.8; living animals 3.2; arable products 10.1; fish 2.3, pet food 0.8; bone meal for feed and fertilizer 7.4; bone meal for

Flow	Flow name	Source process	Destination Process	Mass flow [	Mass flow (calcu-lated)	Components
						bone china porcelain 3.1
F21	ExpFeed	P8,Feed_Ind		0.0	0.0	
F22	ImportNonfood		P10,NonFOOD_Ind	1.4	1.4	non-food arable products 0.4 and detergents (dish washer tablets) 1.0 see section … assumption
F23	ExpNonfood	P10,NonFOOD_Ind		1.3	1.3	exported arable products non food, such as seed potatoes etc.
F25	IntLvsttoManure	P4,IntLivestock	P5,Manure	27.2	27.2	pig manure 16.0; poultry manure 11.1 including rabbits and fur animals
F26	ImpFood		P7,Food_Ind	28.0	28.0	Dairy imports 4.3; meat 2.0; live animals 1.4; arable products/vegetables 16.9; eggs 0.2; fish 1.4; fished in ocean 1.7; stock mutation arable 0.2
F27	ExpProcManure	P6,ManureProc		0.0	0.0	
F28	ProcMantoArable	P6,ManureProc	ARABLE,Arable	0.0	0.0	
F29	FoodtoHouse	P7,Food_Ind	P11,HOUSEHOLD	18.4	18.4	meat 2.5, dairy 6.8; egg 0.5; arable products 7.1; fish 0.8; pet food 0.8
F30	FoodIndtoArable	P7,Food_Ind	ARABLE,Arable	1.8	1.8	Sugar factory lime 1.5 ; seed/plants 0.35
F31	ArabltoNonFood	ARABLE,Arable	P10,NonFOOD_Ind	1.3	1.3	arable products (all non exported non food products such as flax, bulbs and flowers, nurseries, oil seeds, caravon, minus seed/plant material)
F32	NonFoodtoHouse	P10,NonFOOD_Ind	P11,HOUSEHOLD	1.3	1.3	detergent in dishwasher (1.0); non Food AT (0.3)
F33	FeedtoWaste	P8,Feed_Ind	P17,Organic Waste from Industry	2.4	2.4	P in sewage to Ind WWTP, proportional to processed P in Food, Feed and non-Food
F34	FoodtoWaste	P7,Food_Ind	P17,Organic Waste from Industry	7.4	7.4	1.3 dairy industry; 2.3 from sewage see (to Ind WWTP, proportional to processed P in Food, Feed and non-Food); dead animals Rendac 3.7
F35	To SurfaceW	P25,ToSurfWater	P13,SurfaceWater		3.5	Calculated as F52 + F51
F36	WW_HOUSE	P11,HOUSEHOLD	P24,HHwaste		19.8	Calculated as the sum of F29 and F32
F38	Exp_waste	P27,ExpWaste			2.7	Calculated as the sum of F60 and F61
F40	BurntSludge	P28,Incinerated	P16,LOST P		10.4	Calculated, sum of incinerated sludge from industrial and communal waste water treatment plants (from CBS data)
F42	WWTPtoSLU	P20,WWTP	P23,SludgeHH	11.8	11.8	CBS data communal sludge
F43	P_addition		P8,Feed_Ind	7.2	7.2	Additives for feed intensive livestock
F44	IWWTPtoSlu	P19,IndWWTP	P21,SludgeIND	3.9	3.9	CBS data and assuming a P-content of 2.24% in the sludge
F45	HHWASTtoCMP	P24,HHwaste	P18,Compost	1.2	1.2	Calculated with data from Rapportnr. SenterNovem 3UA0607 (Vereniging Afvalbedrijven rapportnr. VA0600IIR.R) assuming a P content of 1.62 kg P per

Flow	Flow name	Source process	Destination Process	Mass flow [	Mass flow (calcu-lated)	Components
						ton in GFT compost.
F46	HHtoWWTP	P24,HHwaste	P20,WWTP	12.4	12.4	Influent of wastewater treatment, assuming an efficiency of 82%
F47	WaIndtoCmp	P17,Organic Waste from Industry	P18,Compost	0.0	0.0	
F48	IWAStoIWWTP	P17,Organic Waste from Industry	P19,IndWWTP	4.8	4.8	Calculated based on the assumption of P content of industrial sludgewith an efficiency of 82%
F49	WastetoArable	P26,to Arable	ARABLE,Arable		1.7	Calculated, the remainder of compost is assumed to be applied in agriculture (total minus exported & used in citizen garden.)
F50	Cmp_toGarden	P18,Compost	P22,Garden/Nature	0.1	0.1	Vereniging Afvalbedrijven rapportnr. VA0600IIR.R
F51	IWWTPtoSUR	P19,IndWWTP	P25,ToSurfWater		0.9	Calculated as F48-F44
F52	WWTPtoSURF	P20,WWTP	P25,ToSurfWater	2.7	2.7	P in effluent of WWTP assuming an efficiency of the plant of 82%
F53	CmptoArable	P18,Compost	P26,to Arable	1.0	1.0	Vereniging Afvalbedrijven rapportnr. VA0600IIR.R
F54	Slu_to_Arable	P23,SludgeHH	P26,to Arable	0.0	0.0	
F55	to Landfill	P24,HHwaste	P29,ToLandfill		6.2	Calculated as a rest stream
F56	ISlu_to_Arable	P21,SludgeIND	P26,to Arable	0.8	0.8	CBS data 2005
F57	ISLUtoLOSTP	P21,SludgeIND	P28,Incinerated	0.9	0.9	CBS data
F58	SldgtoLost	P23,SludgeHH	P28,Incinerated	9.5	9.5	Incinerated sludge from WWTP (CBS data)
F59	CMP Exp	P18,Compost	P27,ExpWaste	0.1	0.1	Vereniging Afvalbedrijven rapportnr. VA0600IIR.R
F60	ExpSludge	P23,SludgeHH	P27,ExpWaste	0.9	0.9	CBS data
F61	ISLUtoEXP	P21,SludgeIND	P27,ExpWaste	1.7	1.7	CBS data
F62	FoodtoFeed	P7,Food_Ind	P8,Feed_Ind	4.3	4.3	milk powder 0.9; rest beer 1.7 and sugar beet refineries 0.9, potato 0.9
F63	ArabtoSurf	ARABLE,Arable	P13,SurfaceWater	1.2	1.2	Emission registration, ratio area arable/grazing land
F64	ExpMan	P5,Manure		7.0	7.0	CBS data
F65	GraztoSurf	Grazeland,Grasslandland+Silage Maize	P13,SurfaceWater	2.1	2.1	Emission registration, ratio area arable/grazing land
F66	MantoLost	P5,Manure	P16,LOST P	0.0	0.0	
F66	MantoLost	P5,Manure	P16,LOST P	0.0	0.0	
F67	Wastetofeed	P21,SludgeIND	P8,Feed_Ind	0.2	0.2	Sludge CBS data 2005
F68	ManuretoGraz	P5,Manure	Grazeland,Grasslandland+Silage Maize	43.3	43.3	non-exported manure produced allocated to arable and grazing see section….
F69	ProdRendac	P17,Organic Waste from Industry	Process 29,CementInd	3.0	3.0	Dead animals 2.0; high risk (BSE) slaughter waste 0.9

Flow	Flow name	Source process	Destination Process	Mass flow [	Mass flow (calcu-lated)	Components
F70	ToCement	P23,SludgeHH	Process 29,CementInd	0.9	0.9	communal sludge as input for cement industry (CBS data)
F71	CemtoLost	Process 29,CementInd	P16,LOST P		3.9	Calculated, input to cement industry is lost for recycling (F69+F70)
F72	ToLandfill	P21,SludgeIND	P29,ToLandfill	0.4	0.4	CBS data 2005
F73	ToLandfHHs	P23,SludgeHH	P29,ToLandfill	0.5	0.5	see above
F74	To Landfil2	P29,ToLandfill	P16,LOST P		7.1	Calculated as the sum of F55, F73 and F72
F75	IndToWWTP	P17,Organic Waste from Industry	P20,WWTP	2.0	2.0	W. Schipper (Thermphos) pers. comm.
F76	ImpGrazAnim		P3,Grazing Animals	0.2	0.2	imported live animals mainly for veal production 0.2

Appendix II. Phosphorus flows per process in Mkg of P/annum.

Process	Flow	Flow name	Source process	Destination Process	Mass flow	Mass flow (calculated)	Data Source
Process name: Arable							
Input							
ARABLE	F28	ProcMantoArable	P6,ManureProc	ARABLE,Arable	0.0	0.0	
ARABLE	F30	FoodIndtoArable	P7,Food_Ind	ARABLE,Arable	1.8	1.8	Sugar factory lime 1.5 ; seed/plants 0.35
ARABLE	F15	PferttoArable	P9,P-FERT	ARABLE,Arable	9.3	9.3	P fertilizer 9.3
ARABLE	F49	WastetoArable	P26,to Arable	ARABLE,Arable		1.7	Calculated, the remainder of compost is assumed to be applied in agriculture (total minus exported & used in garden etc.)
ARABLE	F8	ManuretoArable	P5,Manure	ARABLE,Arable	11.5	11.5	see Materials and methods
Output							
ARABLE	F9	ArabletoFoodind	ARABLE,Arable	P7,Food_Ind	7.7	7.7	arable products cereals/corn potatoes sugar beet vegetables, pulses) not going to feed or exported
ARABLE	F11	ArabltoFeedind	ARABLE,Arable	P8,Feed_Ind	5.8	5.8	arable products cereals, crop residues, alfalfa and corn cob mix for feed
ARABLE	F31	ArabltoNonFood	ARABLE,Arable	P10,NonFOOD_Ind	1.3	1.3	arable products (all non exported non food products such as flax, bulbs and flowers, nurseries, oil seeds, caravon, minus seed/plant material)
ARABLE	F63	ArabtoSurf	ARABLE,Arable	P13,SurfaceWater	1.2	1.2	Emission registration, ratio area arable/grazingland
Process name: CementInd							
Input							
Process 29	F70	ToCement	P23,SludgeHH	Process 29,CementInd	0.9	0.9	Communal sludge as input for cement industry (CBS data)
Process 29	F69	ProdRendac	P17,Organic Waste from Industry	Process 29,CementInd	3.0	3.0	Dead animals 2.0; high risk (BSE) slaughter waste 0.9
Output							
Process 29	F71	CemtoLost	Process 29,CementInd	P16,LOST P		3.9	Calculated, input to cement industry is lost for

Process	Flow	Flow name	Source process	Destination Process	Mass flow	Mass flow (calculated)	Data Source
							recycling (F69+F70)
Process name: Compost							
Input							
P18	F45	HHWASTtoCMP	P24,HHwaste	P18,Compost	1.2	1.2	Calculated with data from Rapportnr. SenterNovem 3UA0607 (Vereniging Afvalbedrijven rapportnr. VA0600IIR.R) assuming a P content of 1.62 kg P per ton for GFT compost.
P18	F47	WaIndtoCmp	P17,Organic Waste from Industry	P18,Compost	0.0	0.0	
Output							
P18	F53	CmptoArable	P18,Compost	P26,to Arable	1.0	1.0	Vereniging Afvalbedrijven rapportnr. VA0600IIR.R
P18	F59	CMP Exp	P18,Compost	P27,ExpWaste	0.1	0.1	Vereniging Afvalbedrijven rapportnr. VA0600IIR.R
P18	F50	Cmp_toGarden	P18,Compost	P22,Garden/Nature	0.1	0.1	Vereniging Afvalbedrijven rapportnr. VA0600IIR.R
Process name: ExpWaste							
Input							
P27	F59	CMP Exp	P18,Compost	P27,ExpWaste	0.1	0.1	Vereniging Afvalbedrijven rapportnr. VA0600IIR.R
P27	F60	ExpSludge	P23,SludgeHH	P27,ExpWaste	0.9	0.9	CBS data
P27	F61	ISLUtoEXP	P21,SludgeIND	P27,ExpWaste	1.7	1.7	CBS data
Output							
P27	F38	Exp_waste	P27,ExpWaste			2.7	Calculated as the sum of F60 and F61

Process	Flow	Flow name	Source process	Destination Process	Mass flow	Mass flow (calculated)	Data Source
Process name: Feed_Ind							
Input							
P8	F11	ArabltoFeedind	ARABLE,Arable	P8,Feed_Ind	5.8	5.8	arable products cereals, crop residues, alfalfa (Lucerne) and corn cob mix for feed
P8	F43	P_addition		P8,Feed_Ind	7.2	7.2	Additives for feed intensive livestock
P8	F10	ImportFeed		P8,Feed_Ind	50.4	50.4	Imported feed soya 10.9 /rapeseed mealt 9.4; maize gluten feed 4.1 palm kernel meal 4.0 sunflower meal 3.6 pulps 0.5 '; dairy products 1 diverse oil containing seeds (i.e. linseed)
P8	F62	FoodtoFeed	P7,Food_Ind	P8,Feed_Ind	4.3	4.3	milk powder 0.9; rest flows, beer 1.7 and sugar beet refineries 0.9, potato 0.9
P8	F67	Wastetofeed	P21,SludgeIND	P8,Feed_Ind	0.2	0.2	Sludge CBS data 2005
Output							
P8	F14	FeedtoIntLvst	P8,Feed_Ind	P4,IntLivestock	44.4	44.4	Pig feed concentrates 28.4; corn cob mix 0.1; poultry feed concentrates 15.9
P8	F33	FeedtoWaste	P8,Feed_Ind	P17,Organic Waste from Industry	2.4	2.4	P in sewage to Ind WWTP, proportional to processed P in Food, Feed and non-Food
P8	F21	ExpFeed	P8,Feed_Ind		0.0	0.0	
P8	F13	FeedtoGraz	P8,Feed_Ind	P3,Grazing Animals	21.0	21.0	Concentrates to Dairy farms 17.1; org. waste 2.12 from food (beets, beer, potatoes) + milk powder 0.9; crop residues (straw etc)0.9
Process name: Food_Ind							
Input							
P7	F7	GraztoFoodind	P3,Grazing Animals	P7,Food_Ind	16.5	16.5	meat 5.2; dairy 10.8; destruction 0.5 (Rendac)
P7	F9	ArabletoFoodind	ARABLE,Arable	P7,Food_Ind	7.7	7.7	arable products cereals/corn, potatoes, sugar beet, vegetables, pulses non- feed or exported
P7	F6	IntLvsttoFoodind	P4,IntLivestock	P7,Food_Ind	17.2	17.2	poultry meat 3.6; eggs 1.0; Rendac: poultry 0.1; pork 11.0; pigs 1.4
P7	F26	ImpFood		P7,Food_Ind	28.0	28.0	Dairy import 4.3; meat 2.0; living animals 1.4;

Process	Flow	Flow name	Source process	Destination Process	Mass flow	Mass flow (calculated)	Data Source
							arable products/vegetables 16.9; eggs 0.2; fish 1.4; fished in ocean 1.7; stock mutation arable 0.2
Output							
P7	F20	ExpFood	P7,Food_Ind		37.5	37.5	exported dairy 6.1; eggs 0.8; meat 3.8; living animals 3.2; arable products 10.1; fish 2.3, pet food 0.8; bone meal for feed and fertilizer 7.4; bone meal for bone china porcelain 3.1
P7	F34	FoodtoWaste	P7,Food_Ind	P17,Organic Waste from Industry	7.4	7.4	1.3 dairy industry; 2.3 from sewage see (to Ind WWTP, proportional to processed P in Food, Feed and non-Food); dead animals Rendac 3.7
P7	F30	FoodIndtoArable	P7,Food_Ind	ARABLE,Arable	1.8	1.8	Sugar factory lime 1.5 ; seed/plants 0.35
P7	F29	FoodtoHouse	P7,Food_Ind	P11,HOUSEHOLD	18.4	18.4	meat 2.5, dairy 6.8; egg 0.5; arable products 7.1; fish 0.8; pet food 0.8
P7	F62	FoodtoFeed	P7,Food_Ind	P8,Feed_Ind	4.3	4.3	milk powder 0.9; rest flows beer 1.7 and sugar beet refineries 0.9, potato 0.9
Process name: Garden/Nature							
Input							
P22	F50	Cmp_toGarden	P18,Compost	P22,Garden/Nature	0.1	0.1	Vereniging Afvalbedrijven rapportnr. VA0600IIR.R
Process name: Grasslandland+Silage Maize							
Input							
Grazeland	F2	Pasture_Manure	P3,Grazing Animals	Grazeland,Grasslandland+Silage Maize	9.3	9.3	pasture manure (manure production sheep, 50% goat, 20% dairy cattle)
Grazeland	F16	PferttoGraz	P9,P-FERT	Grazeland,Grasslandland+Silage Maize	11.7	11.7	P-fertilizer
Grazeland	F17	ManProctoGraz	P6,ManureProc	Grazeland,Grasslandland+Silage Maize	0.0	0.0	
Grazeland	F68	ManuretoGraz	P5,Manure	Grazeland,Grasslandland+Silage Maize	43.3	43.3	non-exported manure produced allocated to arable and grazing see section….
Output							

Process	Flow	Flow name	Source process	Destination Process	Mass flow	Mass flow (calculated)	Data Source
Grazeland	F1	Grass_maize	Grazeland,Grasslandland+Silage Maize	P3,Grazing Animals	39.1	39.1	grass 33.3 forage maize 5.8
Grazeland	F65	GraztoSurf	Grazeland,Grasslandland+Silage Maize	P13,SurfaceWater	2.1	2.1	Emission registration, ratio area arable/grazing land
Process name: Grazing Animals							
Input							
P3	F1	Grass_maize	Grazeland,Grasslandland+Silage Maize	P3,Grazing Animals	39.1	39.1	grass 33.3 forage maize 5.8
P3	F76	ImpGrazAnim		P3,Grazing Animals	0.2	0.2	imported live animals mainly for veal production 0.2
P3	F13	FeedtoGraz	P8,Feed_Ind	P3,Grazing Animals	21.0	21.0	Concentrates to Dairy farms 17.1; org. waste 2.12 from food (beets, beer, potatoes) + milk powder 0.9; crop residues (straw etc) 0.9
Output							
P3	F2	Pasture_Manure	P3,Grazing Animals	Grazeland,Grasslandland+Silage Maize	9.3	9.3	pasture manure (manure production sheep, 50% goat, 20% dairy cattle)
P3	F7	GraztoFoodind	P3,Grazing Animals	P7,Food_Ind	16.5	16.5	meat 5.2; dairy 10.8; destruction 0.5 (Rendac)
P3	F3	GraztoManu	P3,Grazing Animals	P5,Manure	34.6	34.6	beef bulls 1.4; veal calves 4.0; beef cows 0.6; 50%goat manure 0.2; 80% manure produced by dairy cattle 26.0; bedding material (straw) 0.9; horses 1.5
Process name: HHwaste							
Input							
P24	F36	WW_HOUSE	P11,HOUSEHOLD	P24,HHwaste		19.8	Calculated as the sum of F29 and F32
Output							
P24	F45	HHWASTtoCMP	P24,HHwaste	P18,Compost	1.2	1.2	Calculated with data from Rapportnr. SenterNovem 3UA0607 (Vereniging Afvalbedrijven rapportnr. VA0600IIR.R) assuming a P content of 1.62 kg P per ton for GFT compost.
P24	F46	HHtoWWTP	P24,HHwaste	P20,WWTP	12.4	12.4	Influent of wastewater treatment, assuming an efficiency of 82%

Process	Flow	Flow name	Source process	Destination Process	Mass flow	Mass flow (calculated)	Data Source
P24	F55	to Landfill	P24,HHwaste	P29,ToLandfill		6.2	Calculated as a rest stream
Process name: HOUSEHOLD							
Input							
P11	F29	FoodtoHouse	P7,Food_Ind	P11,HOUSEHOLD	18.4	18.4	meat 2.5, dairy 6.8; egg 0.5; arable products 7.1; fish 0.8; pet food 0.8
P11	F32	NonFoodtoHouse	P10,NonFOOD_Ind	P11,HOUSEHOLD	1.3	1.3	detergent in dishwasher (1.0); non Food AT (0.3)
Output							
P11	F36	WW_HOUSE	P11,HOUSEHOLD	P24,HHwaste		19.8	Calculated as the sum of F29 and F32
Process name: Incinerated							
Input							
P28	F58	SldgtoLost	P23,SludgeHH	P28,Incinerated	9.5	9.5	
P28	F57	ISLUtoLOSTP	P21,SludgeIND	P28,Incinerated	0.9	0.9	
Output							
P28	F40	BurntSludge	P28,Incinerated	P16,LOST P		10.4	Calculated, sum of incinerated sludge from industrial and communal wastewater treatment plants (from CBS data)
Process name: IndWWTP							
Input							
P19	F48	IWAStoIWWTP	P17,Organic Waste from Industry	P19,IndWWTP	4.8	4.8	Calculated based on the assumed P content of industrial sludge, assuming an efficiency of 82%
Output							
P19	F44	IWWTPtoSlu	P19,IndWWTP	P21,SludgeIND	3.9	3.9	CBS data and assuming a P-content of 2.24% in the sludge
P19	F51	IWWTPtoSUR	P19,IndWWTP	P25,ToSurfWater		0.9	Calculated as F48-F44
Process name: IntLivestock							
Input							
P4	F14	FeedtoIntLvst	P8,Feed_Ind	P4,IntLivestock	44.4	44.4	
Output							

Process	Flow	Flow name	Source process	Destination Process	Mass flow	Mass flow (calculated)	Data Source
P4	F6	IntLvsttoFoodind	P4,IntLivestock	P7,Food_Ind	17.2	17.2	poultry meat 3.6; eggs 1.0; Rendac: poultry 0.1; pork 11.0; destructed pigs 1.4
P4	F25	IntLvsttoManure	P4,IntLivestock	P5,Manure	27.2	27.2	pig manure 16.0; poultry manure 11.1 including rabbits and fur animals
Process name: LOST P							
Input							
P16	F40	BurntSludge	P28,Incinerated	P16,LOST P		10.4	Calculated, sum of incinerated sludge from industrial and communal waste water treatment plants (from CBS data)
P16	F66	MantoLost	P5,Manure	P16,LOST P	0.0	0.0	
P16	F71	CemtoLost	Process 29,CementInd	P16,LOST P		3.9	Calculated, input to cement industry is lost for recycling (F69+F70)
P16	F74	To Landfil2	P29,ToLandfill	P16,LOST P		7.1	Calculated as the sum of F55, F73 and F72
Process name: Manure							
Input							
P5	F3	GraztoManu	P3,Grazing Animals	P5,Manure	34.6	34.6	Beef bulls 1.4; veal calves 4.0; Beef cows 0.6; 50% goat manure 0.2; 80% manure produced by dairy cattle 26.0; bedding material (straw) 0.9; horses 1.5
P5	F25	IntLvsttoManure	P4,IntLivestock	P5,Manure	27.2	27.2	pig manure 16.0; poultry manure 11.1 including rabbits and fur animals
Output							
P5	F4	MantoManProc	P5,Manure	P6,ManureProc	0.0	0.0	
P5	F64	ExpMan	P5,Manure		7.0	7.0	CBS data
P5	F66	MantoLost	P5,Manure	P16,LOST P	0.0	0.0	
P5	F68	ManuretoGraz	P5,Manure	Grazeland,Grasslandland+Silage Maize	43.3	43.3	non-exported manure produced divided between arable and grazing see section….
P5	F8	ManuretoArable	P5,Manure	ARABLE,Arable	11.5	11.5	see Materials and Methods
Process name: ManureProc							
Input							

Process	Flow	Flow name	Source process	Destination Process	Mass flow	Mass flow (calculated)	Data Source
P6	F4	MantoManProc	P5,Manure	P6,ManureProc	0.0	0.0	
Output							
P6	F17	ManProctoGraz	P6,ManureProc	Grazeland,Grasslandland+Silage Maize	0.0	0.0	
P6	F28	ProcMantoArable	P6,ManureProc	ARABLE,Arable	0.0	0.0	
P6	F27	ExpProcManure	P6,ManureProc		0.0	0.0	
Process name: NonFOOD_Ind							
Input							
P10	F31	ArabltoNonFood	ARABLE,Arable	P10,NonFOOD_Ind	1.3	1.3	arable products (all non exported, non food products such as flax, bulbs and flowers, nurseries, oil seeds, caravon, minus seed/plant material)
P10	F22	ImportNonfood		P10,NonFOOD_Ind	1.4	1.4	non-food arable products 0.4 and detergents (dish washer tablets) 1.0
Output							
P10	F23	ExpNonfood	P10,NonFOOD_Ind		1.3	1.3	exported arable products non food, such as seed potatoes etc.
P10	F12	N_foodtoWaste	P10,NonFOOD_Ind	P17,Organic Waste from Industry	0.1	0.1	sewage sludge, see F33
P10	F32	NonFoodtoHouse	P10,NonFOOD_Ind	P11,HOUSEHOLD	1.3	1.3	detergent in dishwasher (1.0); non Food AT (0.3)
Process name: Organic Waste from Industry							
Input							
P17	F12	N_foodtoWaste	P10,NonFOOD_Ind	P17,Organic Waste from Industry	0.1	0.1	sewage sludge, see F33
P17	F34	FoodtoWaste	P7,Food_Ind	P17,Organic Waste from Industry	7.4	7.4	1.3 dairy industry; 2.3 from sewage see (to Ind WWTP, proportional to processed P in Food, Feed and non-Food); dead animals Rendac 3.7
P17	F33	FeedtoWaste	P8,Feed_Ind	P17,Organic Waste from Industry	2.4	2.4	P in sewage to Ind WWTP, proportional to processed P in Food, Feed and non-Food
Output							
P17	F47	WaIndtoCmp	P17,Organic Waste from Industry	P18,Compost	0.0	0.0	

Process	Flow	Flow name	Source process	Destination Process	Mass flow	Mass flow (calculated)	Data Source
P17	F48	IWAStoIWWTP	P17,Organic Waste from Industry	P19,IndWWTP	4.8	4.8	Calculated based on assumption that P content of industrial sludge and an efficiency of 82%
P17	F75	IndToWWTP	P17,Organic Waste from Industry	P20,WWTP	2.0	2.0	W. Schipper (Thermphos) pers. comm.
P17	F69	ProdRendac	P17,Organic Waste from Industry	Process 29, CementInd	3.0	3.0	Dead animals 2.0; high risk (BSE) slaughter waste 0.9
Process name: P-FERT							
Input							
P9	F5	ImportFertl		P9,P-FERT	21.0	21.0	CBS data
Output							
P9	F16	PferttoGraz	P9,P-FERT	Grazeland,Grasslandland+Silage Maize	11.7	11.7	P-fertilizer
P9	F15	PferttoArable	P9,P-FERT	ARABLE,Arable	9.3	9.3	P fertilizer 9.3
Process name: SludgeHH							
Input							
P23	F42	WWTPtoSLU	P20,WWTP	P23,SludgeHH	11.8	11.8	CBS data communal sludge
Output							
P23	F54	Slu_to_Arable	P23,SludgeHH	P26,to Arable	0.0	0.0	
P23	F58	SldgtoLost	P23,SludgeHH	P28,Incinerated	9.5	9.5	Incinerated sludge from WWTP (CBS data)
P23	F60	ExpSludge	P23,SludgeHH	P27,ExpWaste	0.9	0.9	CBS data
P23	F70	ToCement	P23,SludgeHH	Process 29,CementInd	0.9	0.9	communal sludge as input for cement industry (CBS data)
P23	F73	ToLandfHHs	P23,SludgeHH	P29,ToLandfill	0.5	0.5	see above
Process name: SludgeIND							
Input							
P21	F44	IWWTPtoSlu	P19,IndWWTP	P21,SludgeIND	3.9	3.9	CBS data and assuming a P-content of 2.24% in the sludge
Output							
P21	F56	ISlu_to_Arable	P21,SludgeIND	P26,to Arable	0.8	0.8	CBS data 2005
P21	F61	ISLUtoEXP	P21,SludgeIND	P27,ExpWaste	1.7	1.7	CBS data

Process	Flow	Flow name	Source process	Destination Process	Mass flow	Mass flow (calculated)	Data Source
P21	F67	Wastetofeed	P21,SludgeIND	P8,Feed_Ind	0.2	0.2	Sludge CBS data 2005
P21	F57	ISLUtoLOSTP	P21,SludgeIND	P28,Incinerated	0.9	0.9	CBS data
P21	F72	ToLandfill	P21,SludgeIND	P29,ToLandfill	0.4	0.4	CBS data 2005
Process name: SurfaceWater							
Input							
P13	F35	To SurfaceW	P25,ToSurfWater	P13,SurfaceWater		3.5	Calculated as F52 + F51
P13	F63	ArabtoSurf	ARABLE,Arable	P13,SurfaceWater	1.2	1.2	Emission registration, ratio area arable/grazing land
P13	F65	GraztoSurf	Grazeland,Grasslandland+Silage Maize	P13,SurfaceWater	2.1	2.1	Emission registration, ratio area arable/grazing land
Process name: to Arable							
Input							
P26	F53	CmptoArable	P18,Compost	P26,to Arable	1.0	1.0	Vereniging Afvalbedrijven rapportnr. VA0600IIR.R
P26	F54	Slu_to_Arable	P23,SludgeHH	P26,to Arable	0.0	0.0	
P26	F56	ISlu_to_Arable	P21,SludgeIND	P26,to Arable	0.8	0.8	CBS data 2005
Output							
P26	F49	WastetoArable	P26,to Arable	ARABLE,Arable		1.7	Calculated, the remainder of compost is assumed to be applied in agriculture (total minus exported & used in citizen gardens.)
Process name: ToLandfill							
Input							
P29	F72	ToLandfill	P21,SludgeIND	P29,ToLandfill	0.4	0.4	CBS data 2005
P29	F73	ToLandfHHs	P23,SludgeHH	P29,ToLandfill	0.5	0.5	see above
P29	F55	to Landfill	P24,HHwaste	P29,ToLandfill		6.2	Calculated as a rest stream
Output							
P29	F74	To Landfil2	P29,ToLandfill	P16,LOST P		7.1	Calculated as the sum of F55, F73 and F72

Process	Flow	Flow name	Source process	Destination Process	Mass flow	Mass flow (calculated)	Data Source
Process name: ToSurfWater							
Input							
P25	F51	IWWTPtoSUR	P19,IndWWTP	P25,ToSurfWater		0.9	Calculated as F48-F44
P25	F52	WWTPtoSURF	P20,WWTP	P25,ToSurfWater	2.7	2.7	P in effluent of WWTP assuming an efficiency of the plant of 82%
Output							
P25	F35	To SurfaceW	P25,ToSurfWater	P13,SurfaceWater		3.5	Calculated as F52 + F51
Process name: WASTE							
Input							
P12	F36	WW_HOUSE	P11,HOUSEHOLD	P24,HHwaste		19.8	Calculated as the sum of F29 and F32
P12	F12	N_foodtoWaste	P10,NonFOOD_Ind	P17,Organic Waste from Industry	0.1	0.1	sewage sludge, see F33
P12	F34	FoodtoWaste	P7,Food_Ind	P17,Organic Waste from Industry	7.4	7.4	1.3 dairy industry; 2.3 from sewage see (to Ind WWTP, proportional to processed P in Food, Feed and non-Food); dead animals Rendac 3.7
P12	F33	FeedtoWaste	P8,Feed_Ind	P17,Organic Waste from Industry	2.4	2.4	P in sewage to Ind WWTP, proportional to processed P in Food, Feed and non-Food
Output							
P12	F50	Cmp_toGarden	P18,Compost	P22,Garden/Nature	0.1	0.1	Vereniging Afvalbedrijven rapportnr. VA0600IIR.R
P12	F49	WastetoArable	P26,to Arable	ARABLE,Arable		1.7	Calculated, the remainder of compost is assumed to be applied in agriculture (total minus exported & used in horticulture.)
P12	F40	BurntSludge	P28,Incinerated	P16,LOST P		10.4	Calculated, sum of incinerated sludge from industrial and communal waste water treatment plants (from CBS data)
P12	F38	Exp_waste	P27,ExpWaste			2.7	Calculated as the sum of F60 and F61
P12	F35	To SurfaceW	P25,ToSurfWater	P13,SurfaceWater		3.5	Calculated as F52 + F51
P12	F67	Wastetofeed	P21,SludgeIND	P8,Feed_Ind	0.2	0.2	Sludge CBS data 2005
P12	F71	CemtoLost	Process 29,CementInd	P16,LOST P		3.9	Calculated, input to cement industry is lost for

Process	Flow	Flow name	Source process	Destination Process	Mass flow	Mass flow (calculated)	Data Source
							recycling (F69+F70)
P12	F74	To Landfil2	P29,ToLandfill	P16,LOST P		7.1	Calculated as the sum of F55, F73 and F72
Process name: WWTP							
Input							
P20	F46	HHtoWWTP	P24,HHwaste	P20,WWTP	12.4	12.4	Influent of wastewater treatment, assuming an efficiency of 82%
P20	F75	IndToWWTP	P17,Organic Waste from Industry	P20,WWTP	2.0	2.0	W. Schipper (Thermphos) pers. comm..
Output							
P20	F42	WWTPtoSLU	P20,WWTP	P23,SludgeHH	11.8	11.8	CBS data communal sludge
P20	F52	WWTPtoSURF	P20,WWTP	P25,ToSurfWater	2.7	2.7	P in effluent of WWTP assuming an efficiency of the plant of 82%