3. Waste management and nutrient flows in the city of Turku

A detailed N and P flow study to estimate the capacity of biowaste sorting to contribute to nutrient recycling

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3.1 BIOWASTE MANAGEMENT

3.1.1 The EU landfill directive and the Finnish Waste Act

The landfill decision, given by the Finnish Council of State to execute the EU landfill directive, prohibits, from the beginning of the year 2005, the disposal of crude waste at a landfill. In practice, the decision in question forbids the placing of biodegradable waste (food, garden, paper, and cardboard waste) at a landfill and requires it to be recovered separately from other waste and to be processed properly. Depending on the period of validity of the existing landfills' environmental permits, the above-mentioned obligations may already enter into force before 2005. For example, the environmental permit of the Turku Topinoja landfill prohibits biowaste delivery to the landfill already from the year 2001.

Pushed by the decision, more and more municipalities have passed a regulation on the sorting of biowaste and started its separate collection. In practice, pre-treatment of biowastes mentioned in the landfill decision means that they are utilised either by composting or digesting (decomposition). According to the Waste Act, utilisation of biowaste for energy production by incineration can be established only as a secondary solution, after the utilisation methods mentioned above.

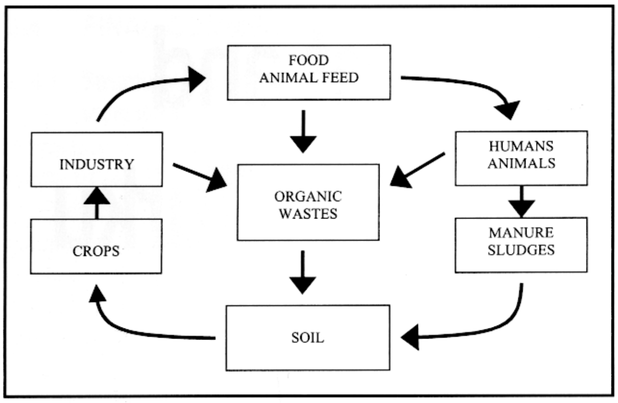

Figure 3.1 Nutrient cycle between food production and the use of food.

Until now, separate treatment of biowaste has been examined and assessed mainly from the technical-economic points of view. In addition, research has strongly focused on the development of the actual processing methods and on improving their ability to function. The importance of the separate treatment of biowaste within a larger entity, for example in terms of the nutrient cycle, has received less attention; this study aims to help fill this gap.

The aim of the study is to evaluate the significance of the separate treatment of biowaste from the point of view of recycling of the most important plant nutrients, i.e. nitrogen and phosphorus. By recycling we mean the returning of plant nutrients back to food production, to arable land, after food preparation and use (Figure 3.1). The study has investigated the nutrients' flow channels and estimated nutrient volumes flowing in each channel. The nutrient cycle has been examined in its present situation and a prediction for the year 2005 (a scenario) has been created. In addition, the potential nutrient cycle in the case where all biowaste is being treated separately has been estimated. The area under study is the City of Turku and nutrient flows have been estimated to correspond to the real situation as much as possible. The criteria of the estimates have been presented in a way that they can also serve as a basis for the estimating of nutrient flows in some other research area by modifying the initial data and emphasises.

3.1.2 The waste management system in use in Turku

The nutrient flows have been estimated from the area of the City of Turku, situated on the south-western coast of Finland. There are 171,000 inhabitants in the City of Turku and the land surface area is 243 km^2. The urban population amounts to 96%; the sparsely-populated areas are mainly located in the northern parts of the city and on the islands. There are a few large food production plants and many smaller food-processing enterprises in the city. There are rather few production animals in the city; however, the number of horses is comparatively high.

The waste management system of Turku is based on the incineration of combustible municipal waste (mainly household waste), the landfill treatment of other municipal waste, and separate sorting of recyclable material. Waste incineration is done as "mass incineration" at the only plant of Finland that incinerates only waste. The waste management regulations have obliged residential properties with more than four dwellings to collect mixed waste, paper, glass and metal in separate collection bins. In premises other than residential ones, separate collection of cardboard may also come into question. Those premises that do not have their own collection container for recyclable material have been obliged to deliver the recyclable material to local collection points. The obligation for separate collection of biowaste has not yet been put into force. However, voluntary separate collection of biowaste is being practised in some residential areas and business premises in Turku. In addition, some commercial enterprises have been given separate regulations about the sorting of biowaste. The separately collected biowaste is transported to the town of Forssa to be composted there in a composting plant. Permission for independent composting of biowaste (food waste) in compost bins is obtained by informing the Environmental Department of Turku.

Wastewater generated in Turku is mainly processed at the municipal wastewater treatment plant (central treatment plant). There are also houses – chiefly in sparsely-populated areas – that are not connected to the municipal sewer network. These houses are also required to deliver their septic tank and cesspool sludge to the central treatment plant of the city.

3.2 THE RESEARCH PROJECT – METHODS AND MATERIALS

3.2.1 Research material

In the study, the transportation of nutrients (nitrogen and phosphorus) was estimated from the starting points that had importance in terms of recycling of nutrients and, in particular, of the utilisation of biowaste. In order to illustrate entities, the study has been extended up to those end channels where the recovery of nutrients is no longer possible in practice.

The first step of the study was to clarify the primary flow channels and the amounts of nutrients that flow in them. Research data was available only on the nutrient contents that enter the wastewater treatment plant and exit it. For the other flow channels, the amounts of nutrients were calculated on the basis of the material flows and the nutrient contents these flows contain. Secondary flows separating, after the treatment processes, from each primary flow channel were then determined based on the process operation information that was available on the process in question or a similar process (e.g. data on environmental impact). The proportions of households, business or production activities were not estimated separately in the study, because compiling these estimates would have been very imprecise in practice, and would not add much value to the study.

Most of the research data has been gathered, in addition to local data, from other Finnish studies and from Swedish studies. In addition to written research material or when it has been lacking, material has been assembled by interviewing experts. However, no empirical samples have been collected for this study.

The values presented in the study describe (unless otherwise specified), the situation in the year 1998. The year in question was selected, because statistics available from 1999 were still scarce during research work. In all flow channels, nutrient volumes have been given as total nitrogen and total phosphorus. For the sake of clarity, the examination unit was chosen to be kilograms per day and the values were given as integers. For both nutrients, the examination limit was regarded to be 0.5 kg/d; the nutrient flows under this were not determined precisely and were represented with the value 0 kg/d.

While reading this study, it is important to note that the nutrient flow volumes presented must be observed as relative values rather than absolute values. The majority of these readings is based on theoretical estimates, and the margin of error with respect to the real-life situation cannot be precisely determined.

3.2.2 Estimate of the amount and nutrient content of biowaste

The estimate of the amount of biowaste and its nutrient content holds an important role when the total volumes of nutrient flows are being compiled. Many studies have presented estimates of the proportion of biowaste (i.e. waste consisting of organic substances) of municipal waste. The varied ways of classifying of different waste components, however, makes the generalisation of the studies more difficult. The most exact information on the division of waste into different fractions can be obtained by making labourious sampling analyses from the collected waste.

In the estimating of biowaste volume, composition information from the region of Helsinki Metropolitan Area Council (YTV) as well as from the Waste Management Area of Päijät-Häme have been used as initial data (YTV, 1991; Rahkonen ja Salonen, 1997; Tanskanen, 1997:7). On the basis of these studies, the proportion of the organic substance (biowaste) contained in municipal waste generated in an urban area was estimated to be 27% of weight.

The volume of biowaste generated in Turku has been estimated as follows: the total amount of municipal waste in Turku is 99 360 t/a (City of Turku, 1999a), of which 27% or 26 827 t/a is biowaste. The total volume includes the separately collected biowaste 1670 t/a and the estimated proportion of independent composting 700 t/a. The total amount of biowaste to be transported for treatment at the incineration plant and landfill is, based on the above, 24 457 t/a. The amount of municipal waste transported to the incineration plant and landfill is 73 270 t/a; consequently, the proportion of biowaste of this amount is 33.4%.

To determine the nutrient content of biowaste, several studies on the quality of biowaste collected separately mainly in Sweden and Finland were examined. (e.g. Widén, 1993:41; Eklind, 1998:168; Kirchmann, 1996; Brink, 1993a, 1993b, 1994; YTV, 1995a). From the point of view of comparability, the makeup of biowaste is essential, especially the amount of garden waste in proportion to kitchen waste. Generally, the proportion of garden waste in biowaste in Finland is clearly smaller than, for example, in Central Europe. In the studies examined, the biowaste nitrogen content ranged from 16.5–23.0 g and the phosphorus content from 2.6–5.4 g/kg of dry solid matter. The most typical nutrient contents were of an order of magnitude of nitrogen 20.0 g/kg and phosphorus 3.0 g/kg of dry matter. The dry matter contents varied in the range of 29–45% of the fresh weight.

It was decided that in this study, the average nutrient contents both of biowaste contained in municipal (mixed) waste and of separately collected biowaste would be as follows: nitrogen 16.5% g/kg of dry solid matter and phosphorus 16.5 g/kg of dry solid matter. The dry solid matter content would be 45%. The initial data has been primarily deduced from the quality examinations of biowaste collected in the area of Helsinki Metropolitan Area Council (YTV) (Hänninen & Mäkelä-Kurtto 1995; YTV 1995) because the representativeness of the study in question in relation to the situation of Turku was the best of all the studies examined. However, the problem with the YTV study was that the phosphorus contents had not been analysed before the composting of waste. The earliest phosphorus analyses had not been made until two months after composting, when small changes had possibly already taken place in the contents. By comparing the phosphorus contents analysed during composting to the data of other studies, it was decided that the biowaste phosphorus content would be 3.0 g/kg of dry solid matter. Generally, the analytical results obtained in the YTV study differed from the other studies examined by their slightly lower nitrogen content and slightly higher dry matter content compared to the other data. This factor decreases the difference in the total nutrient content calculated for a certain substance as estimated on the basis of the YTV study results or other study results examined.

3.2.3 Sources of error

Some possibilities of error are connected to the study, and it is impossible to determine precisely their relative impact on the outcome. Specific possibilities of error, as well as the assumptions made, have all been listed separately for each flow channel. On the more general level, the possibilities of error include the following:

Representativeness of sampling. The representativeness of sampling has a significant effect in the determination of the nutrient content of substances. It is difficult to obtain a representative sample especially from solid, non-homogenic materials, such as waste, without large sampling and equalising (pre-treatment) of the material, for example, by crushing.

Congruence and precision of the analytical practice of amounts of nutrients. The comparability of nutrient determinations made from solid environmental samples is hindered by the fact that there is no established practice of their analytical methods. Different laboratories make determinations with different methods and there is variation both in Finland and internationally. In the future the issue will, however, be remedied by European standardisation of the analytical methods of waste samples. In addition, a margin of error included in the methods themselves is related to the determination of nutrient contents. For example, the margin of error of the soil samples' typical nitrogen and phosphorus determinations (often used also for waste samples) is 10 % (Koivunen, 2000, oral communication).

The multifaceted character of nutrient transportation and lack of researched information. There are several

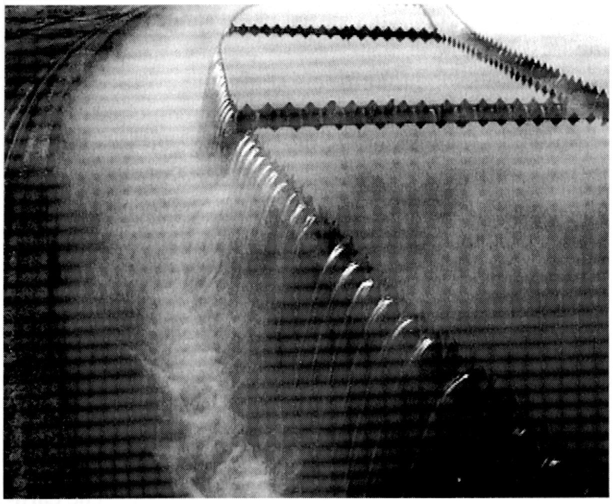

Figure 3.1 Wastewater treatment. Photo: Uldis Cekulis (video).

physical-chemical factors that influence the nutrient transportation and changes in nutrient volume in different flow channels. One important factor is the micro-level conditions that prevail each time. It is difficult to theoretically simulate processes that occur in nature; this also applies to the behaviour of nutrients. As to this study, there was very little information available especially about the nutrient flows in waste incineration and compostion in a composting plant. For this study, it was not possible to carry out any nutrient determination by field surveys. Use of general (mean) loading values presented in the literature always includes a margin of error that is difficult to estimate with respect to the real situation.

3.3 ESTIMATION OF TURKU BIOWASTE FLOWS

3.3.1 Municipal sewerage

84% of the inhabitants of Turku have joined the municipal sewer network (Lehtonen, 2000, oral communication). In addition, the sewer network is fed by different production facilities and special operations (incl. the waste incineration plant and the Topinoja landfill). Part of the sewer network (20%) has been implemented as "combined sewers" that collect also surface waters (Turku Waterworks, 1999).

The majority (26.2 million m^3) of the wastewater of the Turku sewer network is conducted for processing at the City of Turku central treatment plant in the Iso-Heikkilä area of the city. A small part of the wastewater (1.37 million m^3) is directed to the treatment plant of Kaarina, a neighbouring town. On the other hand, the Turku treatment plant also receives wastewater from the neighbouring Rusko, Raisio and Kaarina (altogether 0.25 million m^3). Therefore, to get the whole picture, it has to be taken into account that the amount of wastewater to be treated at the Turku central treatment plant is about 4% smaller than the real amount of wastewater of Turku. On the other hand, septic tank and cesspool sludges of other municipalities are also treated at the treatment plant. To simplify the thing and to maximise the reliability, only wastewater that in reality arrives at the Turku treatment plant and is processed there has been examined.

The nutrient amount data has been gathered mainly from the the treatment plant's weekly required control analyses and the nutrient examination of sludges, both made at the Water Protection Association of South-West Finland (Water Protection Association of South-West Finland, 1999b). Of the initial data used, the most reliable data is from the influent load and water body load readings. The highest degree of imprecision is related to the nutrient content of sludge (Saarinen, 2000, oral communication).

The total load of wastewater flowing into the treatment plant is: N = 2109 kg/d and P = 390 kg/d. See Figure 2.2.

3.3.2 Private sewerage

16% of Turku inhabitants, that is 27 000 residents, have not joined the municipal sewer network. Premises that are not connected to the sewer network are located in particular on the islands of Turku and in the sparsely populated area of Paattinen. Of the premises concerned, 89% conduct their wastewater through septic tanks to a ditch, 5% use soil filtration and 6% conduct their wastewater into a cesspool (Agenda 21 of South-West Finland, 1998). The average nutrient absorption proportions (purification efficiencies) are, for nitrogen, 15%, 30% and 100% and for phosphorus, 15%, 50% and 100% (Santala, 1990, 16-17).

According to the general waste management regulations for the City of Turku, the septic tank and cesspool sludge must be transported to the City central treatment plant (City of Turku, 1996: 9, 11). In practice, it is possible to spread a small amount of the sludge in question onto the fields near its place of origin.

The total load has been calculated on the basis of the number of people who do not belong to the municipal sewer network and the general pollution load value generated by one person. (totalN = 12 g/inh.d and totalP = 2.5 g/inh.d) (Santala, 1990: 12): N = 324 kg/d and P = 68 kg/d. See Figure 3.3.

3.3.3 Waste incineration plant

At the Turku waste incineration plant, mainly municipal waste is incinerated in two parallel-bed boilers. The boilers have been replaced in 1994 to 1995, at the same time when the purification of flue gases of the plant was being significantly improved by adding a semi-dry scrubber to the process.

In the incineration process, waste is fed from the reception silos to the boiler where waste is forced into a rising and rotating motion to accelerate the combustion. The flue gases generated in combustion are purified with electrical filters and with a semi-dry lime wash scrubber and a hose filter before they are released to the atmosphere via a smokestack.

As its wastes, the combustion process yields slag, ESP dust and, from the semi-dry scrubber, filter cakes. ESP dust and filter cakes are stabilised by adding cement and water to the mixture. The end product that has been solidified in this way is then transported, together with slag, to the Topinoja landfill. Before 1999, all the wastewater produced in the slag extinguishing process were transported to the wastewater treatment plant, but today part of the water is used to moisten the end product that is to be stabilised.

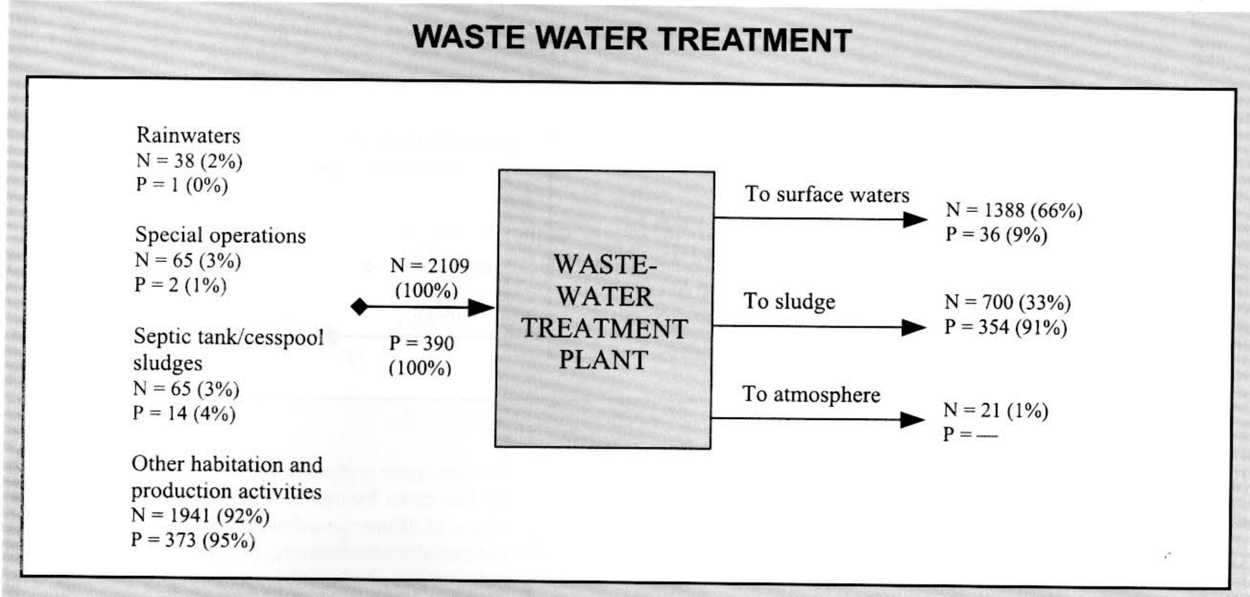

Figure 3.2 Nutrient flows through the Turku central treatment plant. Readings in kilos per day and, by flow channels, the proportions of influent and effluent flows.

INPUT

The total load of wastewater flowing into the treatment plant: N = 2109 kg/d and P = 390 kg/d.

From the total load, the following can be distinguished:

a) load received with the surface runoff (rainwater): N = 38 kg/d and P = 1 kg/d. The amount of nitrogen has been estimated on the basis of the following data: the (wet) fallout falling in the area of Turku through rain (nitrate content 0.5 mg/l, ammonia content 0.5 mg/l, in other words the nitrogen content in rainwater altogether 1 mg/l), of the wastewater amount conducted to the central treatment plant (26.2 million m^3) of rainwater 52.5 % or 13.755 million m^3 (Bernes, 1993: 41; Turku Waterworks 1999). The phosphorus load is nearly totally composed of dry fallout whose magnitude has been presented in the literature as 0.12-0.97 kg/ha/a (Morse et al., 1993: 5). The major part of the dry fallout accumulates in areas where vegetation is dominant and where there is no sewerage of surface waters. Therefore, the amount of phosphorus ending up in the sewerage is very small.

b) load resulting from special operations (landfill and waste incineration plant): N = 65 kg/d and P = 2 kg/d.

c) load resulting from septic tank and cesspool sludges: N = 65 kg/d and P = 14 kg/d (see section 4.2.3.).

d) load resulting from habitation and industrial activities as a difference of the above: N = 1941 kg/d and P = 373 kg/d.

OUTPUT

a) conducted to the surface water in full: N = 1388 kg/d and P = 36 kg/d. The proportion of by-pass discharge in nitrogen discharges is 4% and in phosphorus discharges 17%.

b) binds itself to the treatment plant sludge: N = 700 kg/d and P = 354 kg/d. The amount of nutrients has been estimated as follows: on the basis of the sludge volume recorded in the statistics and the nutrient proportions determined from the samples, the nutrient volume obtained is N = 855 kg/d and P = 373 kg/d (City of Turku, 1999b). However, by calculating the difference between the influent load of the treatment plant and the water bodies load, the outcome is N= 721 kg/d and P= 354 kg/d, which consists of nutrients that have adhered to the sludge and, for the part of nitrogen, also evaporated (see passage c). The difference in the above calculations can probably be explained by the large error margin in the determination of the sludge nutrient content (primarily the small number of samples has an effect). The above difference from which the volume of nitrogen evaporating in the purification process has been subtracted has been used as the nutrient content adhered to sludge.

c) evaporates into air in the purification process: N = 21 kg/d. The Turku wastewater treatment plant is a biological-chemical simultaneous precipitation plant where the actual biological nitrogen denitrification is not performed. It is however likely that part of the nitrogen contained in the wastewater changes to a gaseous form during the process and evaporates into air. The amount of nitrogen that evaporates into air has not been examined in Turku nor at other similar plants, but on the basis of the nutrient ratios presented, it could be 0-200 kg/d (Saarinen, 2000, oral communication). Most probably, the amount of nitrogen that volatilises into air is rather small, and therefore the amount in question in this study was estimated to be 1% of the total amount of nitrogen treated at the plant.

PRIVATE SEWERAGE

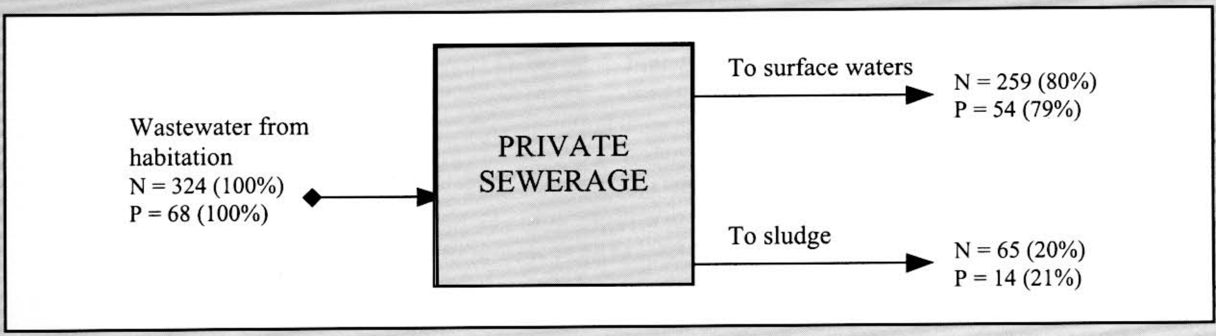

Figure 3.3 Nutrient flows through private sewers. Readings in kilos per day and, by flow channels, proportions of influent and effluent flows.

INPUT

The total load has been calculated on the basis of the number of people who do not belong to the municipal sewer network and the general pollution load value generated by one person. (totalN = 12 g/inh.d and totalP = 2.5 g/inh.d) (Santala, 1990: 12): N = 324 kg/d and P = 68 kg/d.

OUTPUT

a) leaches into water bodies: N = 259 kg/d and P = 54 kg/d. The estimate has been formed on the basis of the following data: proportions of different wastewater treatment systems in Turku and the purification efficiency obtainable with each system. As regards the use of different systems, the obtained mean weighted purification efficiency on nitrogen was 21% and on phosphorus 22%. Taking into account the precision, the purification efficiency used in this study is 20% for both nutrients.

b) sludge transported from septic tanks and cesspools to the wastewater treatment plant: N = 65 kg/d and P = 14 kg/d.

WASTE INCINERATION PLANT

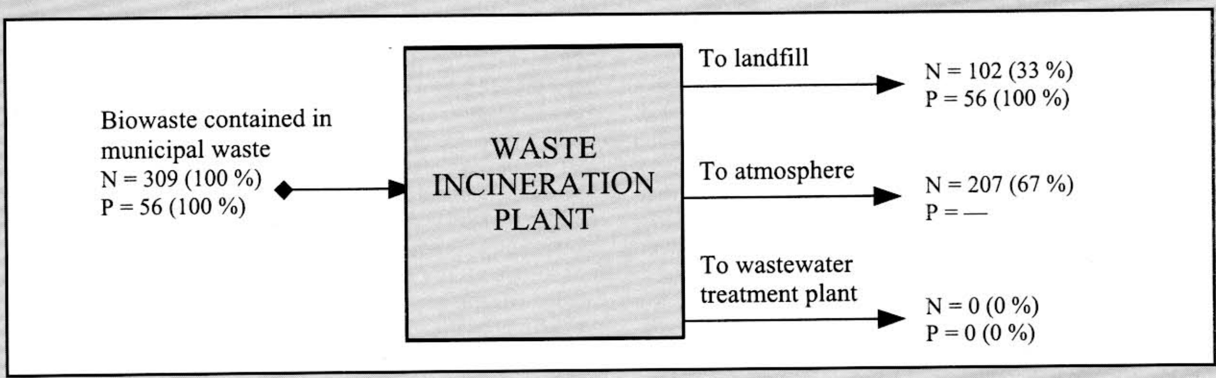

Figure 3.4 Nutrient flows through the Turku waste incineration plant. Readings in kilos per day and, by flow channels, proportions of influent and effluent flows.

INPUT

The incineration plant receives 45 470 t/a of municipal waste of which 15 187 t/a is biowaste (33.4%) Nutrient volumes are as follows: N = 309 kg/d and P = 56 kg/d (dry matter content 6834 t/a (45%), where the amount of nitrogen is 16.5 g/kg and the amount of phosphorus is 3.0 g/kg).

OUTPUT

a) with slag from the incinerators and the filter cakes from flue gas purification, the following are transported to the Topinoja landfill: N = 102 kg/d and P = 56 kg/d. Adhered to the slag, there are poorly soluble and insoluble nitrogen compounds and very small amounts (estimated at 5% of the total amount) of phosphorus compounds. The flue gas purification equipment is able to bind only a fractional part of the nitrogen compounds (estimated at 1%) whereas nearly 100% of phosphorus is being recovered.

b) emissions into air with flue gases: N = 207 kg/d. Nitrogen is carried in flue gases mainly as oxides of nitrogen and as N_2. The oxide contents of nitrogen are determined by yearly required controls and the amount of nitrogen that is released into the air from the incineration plant is altogether 76 kg/d (amount of NO_x 252 kg/d, of which the amount of nitrogen calculated from the reaction sequence 2 NO_2 (N_2 + 2 O_2 on the basis of molecular masses) (Imatran Voima Oy, 1998; Paananen, 2000, oral communication). However, one has to keep in mind that the above reading also contains nitrogen compounds that have become oxidised in the incineration of wastes other than biowastes. Substances that contain particularly much nitrogen include, among others, polyurethanes, nylons (synthetic textiles) and certain glues (e.g. those used in the fabrication of chipboard). As construction waste is mostly directed to a landfill, it is probable that the synthetic textiles are the next most important source of nitrogen after biowastes. In the emission calculation, it has been presumed that 75% of the oxides of nitrogen originate from biowastes. Normally, nitrogen originating from the atmosphere does not form oxides of nitrogen in the combustion processes of the plant, because such thermal NO_x is developed only at temperatures exceeding 1400°C, and usually the temperature of boilers is 1000 to 1100°C.

The N_2 concentrations of flue gases have been estimated based on the ratios of the incineration plant nutrient flow scheme. N_2 emissions have been estimated to be the biggest individual means of exit for nitrogen.

c) water conducted from the slag extinguishing basins to the wastewater treatment plant: N and P volumes under 0.5 kg/d. The nutrient volumes have been calculated based on the estimated amounts of water conducted to sewers and the nutrient analyses taken from the extinguishing water of the slag basin (City of Turku, 1997a).

PRIVATE SEWERAGE

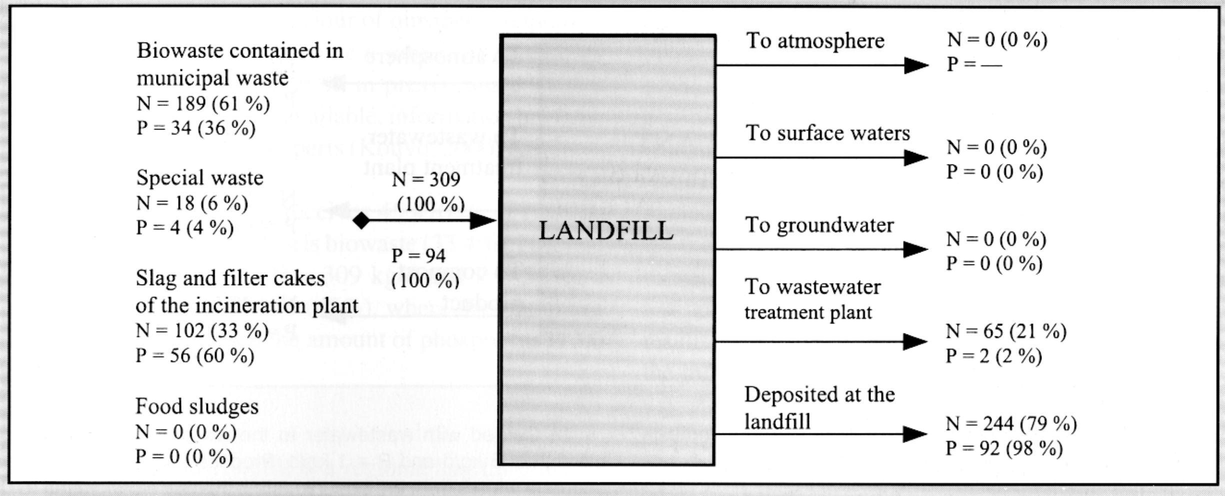

Figure 3.5 Nutrient flows via the Turku Topinoja landfill. Readings in kilos per day and, by flow channels, proportions of the influent and effluent flows.

INPUT

The waste volume data has been gathered from the data of the landfill (Turku Municipal Waste Management Centre, 1999).

a) Municipal (mixed) waste 27 800 t/a of which biowaste 9285 t/a (33.4%, see passage 3.2.). Nutrient volumes: N = 189 kg/d and P = 34 kg/d (dry matter content 4178 t/a (45 %) where nitrogen 16.5 g/kg and phosphorus 3.0 g/kg).

b) Special waste: lavatory faeces 63 t/a (N = 0.3 kg/d, P = 0.7 kg/d), slaughterhouse waste 0.32 t/a (N and P under 0.1 kg/d) and spoiled food 867 t/a (N = 18 kg/d and P = 3.5 kg/d). Nutrient volume altogether: N = 18 kg/d and P = 4 kg/d. Nutrient contents by waste types have been estimated on the basis of the following initial data: in solid faeces, there is nitrogen approx. 2 g/kg and phosphorus approx. 4 g/kg (Malkki, 1995:27); in food, there is nitrogen approx. 19 g/kg, and phosphorus 3.7 g/kg of dry matter, and the dry matter content is 40 % (Eklind, 1998:168). Nutrient contents of slaughterhouse waste were not estimated precisely, because due to the small amount of the waste, it could be presumed that the nutrient contents would be below the examination level.

c) Flue gas filter cakes and slag from the incineration plant: 12 946 t/a including the following nutrient amount: N = 102 kg/d and P = 56 kg/d.

d) Of the other waste types carried to the landfill, mainly only food wastes contained organic matter. Food wastes consist principally of grease separation basin waste. (Hämäläinen, 2000, oral communication). The accrued food sludges amount to 1547 t/a, but the nutrient content they include is without significance. Nutrient contents in food fats are very low and the nutrients of the grease separation tank waste have mainly been washed out to sewers (Kantti, 2000, oral communication; Loperi, 2000, oral communication).

OUTPUT

a) Evaporates into the air: N = under 0.5 kg/d (below examination level). The amount of nitrification that occurs at the landfill is marginal, and no such study where the amount would have been analysed precisely is known (Ettala, 2000, oral communication).

b) As surface runoff or seepage water to the surrounding surface waters: N and P amounts are below the examination level. On the basis of control studies conducted on ditchwaters, the landfill's impact on the quality of surrounding ditchwaters cannot be reliably indicated. (Lehtonen, 1991; Water Protection Association of South-West Finland, 1999c). The quality of ditchwater has also been compared to slightly contaminated natural water that can also result from diffuse pollution.

c) As seepage water and leachates to the groundwater: N and P amounts are below the examination level. Because of the structural factors of the landfill area soil, it has been regarded unlikely that the landfill would have (extensive) impact on the groundwater quality. (Ettala, 2000, oral communication). According to some estimates, however, the discharge routes have not been sufficiently studied (Lehtonen, 1993, cit. Ettala & Rossi, 1992; City of Turku, 1997b); the nutrient volume that is being infiltrated from the landfill to groundwater *may* be higher.

d) Seepage waters and leachate that are conveyed to the wastewater treatment plant through sewerage: N = 65 kg/d and P = 2 kg/d. No analyses have been made from the water flowing from the landfill to the treatment plant, because there is no suitable place for sampling in the sewer. (Vainio, 2000, oral communication). Consequently, the nutrient amounts have been estimated on the basis of the data obtained from the Kaarina landfill (Water Protection Association of South-West Finland, 1999a). When making the estimate, it was presumed that the nutrient contents in seepage waters are in proportion to the waste volumes disposed at the landfill. In addition, it was assumed that the nutrients residing in seepage waters originate from the waste listed in the above "Input" section. In practice it is possible that nutrients are also dissolved from other wastes, although their volumes are probably be very small.

In the 1990s, the amount of municipal waste disposed at the Kaarina landfill was 8000-9000 t/a (the landfill was opened in 1972 and closed in 1998) (Saario, 2000, oral communication). That is approx. 30% of the amount of municipal waste delivered to the Turku landfill. At the Kaarina landfill, only a fractional part (on average under 10%) of wastewater sludge has been composted and heaped compared to the amounts treated at Topinoja. It is possible that at the landfills to which wastewater sludge has been delivered, the seepage water phosphorus contents are still, after several years, tenfold or even hundredfold higher than at those landfills where sludge has not been heaped. (Holm, 1997). At Topinoja, heaping of sludge from the treatment plant was stopped in 1996 and in Kaarina a few years earlier (City of Turku, 1999b; Saario, 2000, oral communication). The nutrient load conveyed from the Kaarina landfill to the wastewater treatment plant has been, with a few exceptions, for nitrogen 11-19 kg/d and for phosphorus 0.037-0.28 kg/d. The Topinoja landfill nitrogen releases have been estimated to be approximately fourfold and the phosphorus releases twentyfold compared to the nutrient releases from the Kaarina landfill. Uncertainties about the flow routes of the seepage waters of the landfill (see above, passage c) decrease the precision of the estimate. It is possible that part of the load that is estimated to be flowing from the landfill to the wastewater treatment plant is actually infiltrated to groundwater.

e) Deposited at the landfill: N = 244 kg/d and P = 92 kg/d.

PLANT COMPOSTING

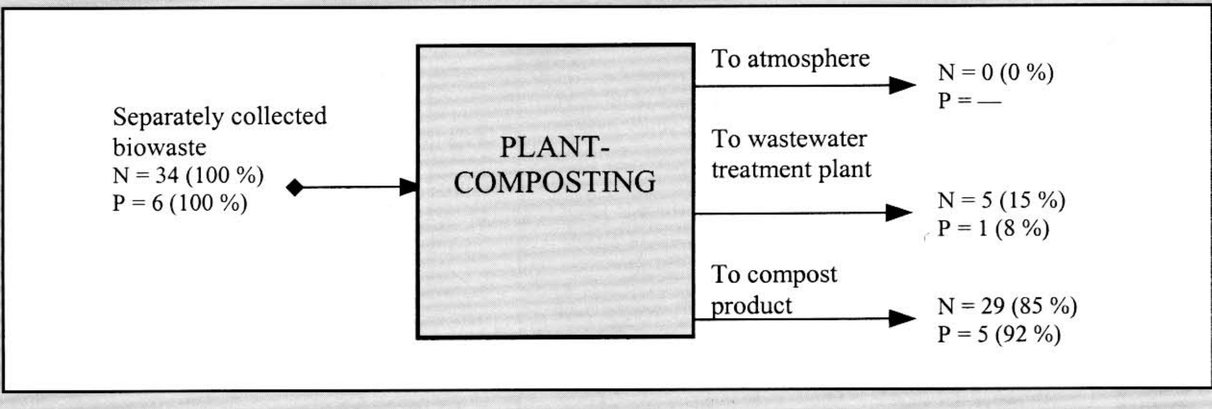

Figure 3.6 Nutrient volume included in the separately collected biowaste: N = 34 kg/d and P = 6 kg/d.

INPUT

The volume has been formed from the following starting data: volume of separately collected biowaste 1670 t/a of which dry material 752 t/a (45%), in dry material there is nitrogen 16.5 g/kg and phosphorus 3.0 g/kg.

OUTPUT

a) Evaporates into air: N and P volumes below the examination level. At most composting plants, purification equipment of different types are used for the purification of exhaust gases of the process. It has been found that the purification equipment effectively bind ammonia that is contained in exhaust gases. At those composting plants for which measurable results were available, nitrogen contents of exhaust gases after the purification equipment were at the ppm level.

b) Carried with wastewater to the wastewater treatment plant: N = 5 kg/d and P = 1 kg/d. Process waters as well as seepage waters from the post-digestion stack are conducted to the wastewater treatment plant. The solution of nutrients taking place in the post-digestion phase is significantly smaller than that in the "hot phase" of composting. Modern composting plants try to recycle as much as possible the leachate that is generated in the process, for example by directing them to moistening of the mass to be composted.

In the wastewater of the plants, nitrogen contents have been about tenfold compared to phosphorus contents. On the other hand, the nitrogen content of the initial product to be composted is, on average, over fivefold compared to the phosphorus content. It has been estimated that the nutrient volume carried from a composting plant to wastewaters is for nitrogen 15% and for phosphorus 8% of the nutrient amount flowing into the plant.

COMPOST BINS

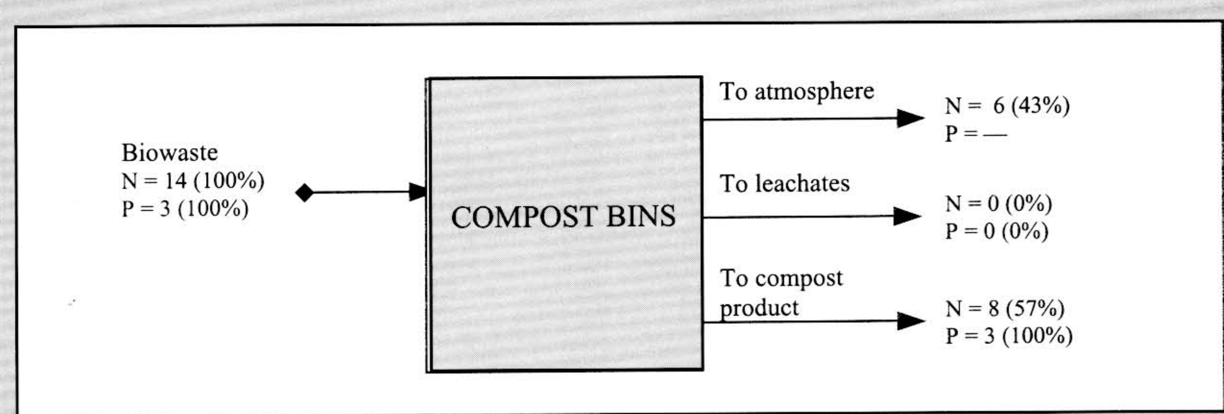

Figure 3.7 Nutrient flows through compost bins located in Turku. Readings in kilos per day and by flow channels, the proportions of influent and effluent flows.

INPUT

Household biowaste is composted privately approx. 700 t/a that contains the following amount of nutrients: N = 14 kg/d and P = 3 kg/d. It is assumed that the dry matter content is 45 %, and there is nitrogen 165 g/kg of dry solid matter and phosphorus 3,0 g/kg of dry solid matter.

OUTPUT

a) Evaporates into air: N = 6 kg/d. The amount of nitrogen evaporating into air as gases (mainly as ammonia) has been estimated to be over 40% of the total nitrogen volume to be composted. In literature, the nitrogen loss of household biowaste composting has been presented as 35-50% of the total nitrogen volume. (Malm, 1990; Brink, 1993a; Widén, 1993; Eklind, 1998). In kitchen waste composting, nitrogen losses are clearly smaller than in composting of material that contains substantially more nitrogen, such as sludges. In fact, the nitrogen losses of sludges may be as much as 60% of their total volume.

b) Carried away with leachates: N and P volumes fall below the examination level. In composters equipped with a lid, generation of leachates is low, especially when adding of dry material is taken care of.

c) Binds itself to the compost product: N = 8 kg/d and P = 3 kg/d.

As a whole, there are very few studies about how the nutrients contained in waste behave in the combustion process. Especially the behaviour of nitrogen compounds in waste incineration has become a subject of study only recently (e.g. Zevenhoven et al, in press). Since written research information is not available, information has been gathered by interviewing experts (Kouvo, 2000; Kilpinen, 2000; Paananen, 2000).

The incineration plant receives 45 470 t/a of municipal waste of which 15 187 t/a is biowaste (33.4%). Nutrient volumes are as follows: N = 309 kg/d and P = 56 kg/d (dry matter content 6834 t/a (45%), where the amount of nitrogen is 16.5 g/kg and the amount of phosphorus is 3.0 g/kg). See Figure 3.4.

3.3.4 Landfill

The Turku Topinoja landfill is a regional landfill that was taken into use in 1971. Such waste that cannot be incinerated but is suitable for disposal in a landfill is primarily directed there. During the summer shut-down (approx. 1 month/year) of the city waste incineration plant, also waste that is usually directed for incineration is treated at the landfill. In addition, for example slag and flue gas filter cakes from the incineration plant have been disposed at the landfill, as well as sludge generated at the city wastewater treatment plant.

The Topinoja landfill is situated in a clay-covered terrain depression that is bounded by rocky hills. Groundwater is formed only on the rocky slopes lining the terrain depression. The majority of the catchment area of the landfill is clay soil that is insignificant in the formation of groundwater. Where necessary, the landfill has been insulated in part from outside leachates with surrounding ditches. The seepage water are collected mainly with the help of sewers and subsurface drains leading to the wastewater treatment plant. Wastes are levelled with a landfill roller and are daily covered with ashes and excess soil. (Lehtonen, 1993; South-West Finland Regional Environment Centre, 1998).

The waste volume data by waste types has been gathered from the invoicing data of the landfill (Turku Municipal Waste Management Centre, 1999). See Figure 3.5.

3.3.5 Composting of separately collected biowaste

In Turku, about 15 000 inhabitants and several businesses and restaurants are participating in voluntary separate collection of biowaste. Since March 1999, the separately collected biowaste has been delivered to be composted in Forssa by Etelä-Suomen Multaravinne Oy. There composting is carried out by using an aerated drum composter.

Separately collected biowaste is picked up from the producers by waste collecting vehicles that compress the waste and deliver it to containers located at the Topinoja landfill. The containers are then transported by combination vehicles to Forssa. All biowaste produced in Turku and transported outside the city for composting, is transported in the above-mentioned way (Laine, 2000, oral communication).

The amount of separately collected biowaste used in the study is from 1998, when it was still processed at the Topinoja landfill. It can be presumed that the volume of biowaste that is nowadays taken to Forssa is of equal quantity.

The Forssa composting plant was not able to provide data that could have served as a basis for the exact estimate of nutrient outflowing flows from the composting process. On the other hand, it was desired that the study would be expanded to concern the composting plants' nutrient flows at a general level, irrespective of the equipment used at the plant. Data on nutrient flows was requested from three equipment manufacturers: Biofacta Oy (drum composters), Rumen Oy (drum/tunnel composters) and Vapo Biotech Oy (tunnel composters). In addition, the corresponding information was requested from ASJ Stormossen Oy which operates the only digestion plant of Finland treating municipal biowaste. None of the above-mentioned composting plants has studied nutrient flows in such a way that precise research results could have been presented on the mutual relations of the influent and effluent nutrient flows, in other words, of the rate of efficiency as far as nitrogen and phosphorus are concerned. (oral communications: Heino, 2000; Laine, 2000; Lehto, 2000; Olkkonen, 2000; Åkers, 2000). Some of the interviewed representatives of plant manufacturers thought that the publication of the information concerned, if such information already existed, might be questionable because of competitive factors.

The estimate of the nutrient flows (presented further) of a composting plant has been compiled on the basis of scattered information and views obtained from plant manufacturers and users. The most difficult flow to determine was the nutrient flow flowing out from plants with process waters proportioned to the nutrient volume that has been fed into the process. The determination is made significantly more difficult by the substantial decrease in mass during the composting, which correspondingly causes the relative increase of those substances that do not decrease. Nutrients belong to these substances. In addition, the nitrogen that is in the atmosphere may bind itself to the compost because of microbial activity (Paatero et al., 1984: 202; Widén, 1993), which also makes the estimate of nutrient ratios more difficult. Binding of nitrogen found in atmosphere can be assumed to occur to a significant extent on just those substances whose carbon/nitrogen ratio is high, such as separately sorted biowaste.

The estimates introduced do not describe only the Forssa composting plant nutrient flows, but they can be generalised to concern all composting plants and, with a moderate margin of error, also to digestion plants. The ratios composed describe a situation where the working of the processes has been optimised.

Nutrient volume included in the separately collected biowaste: N = 34 kg/d and P = 6 kg/d. The volume has been formed from the following starting data: volume of separately collected biowaste 1670 t/a of which dry material 752 t/a (45%), in dry material there is nitrogen 16.5 g/kg and phosphorus 3.0 g/kg. See Figure 3.6.

Figure 3.2 Children learning composting at school. Photo:Lars Rydén.

3.3.6 Private composting

Private composting means here composting that is taken care of by individual households or residential premises using compost bins to compost organic household wastes. When composting wastes all year round, the composter should, according to the city waste management regulations, be thermally insulated (City of Turku, 1996:10).

It has been estimated that individual composting is practised by about 8% of the inhabitants of Turku (14 000 inh.) and that the amount of biowaste accumulated per resident is about 50 kg/a, in other words, altogether 700 t/a is being composted (City of Turku, 1998, 1999a).

Because of the diversity of the structures of compost bins and the ways of using them, it is difficult to determine exactly the effects that the biological processes occurring in composters have on the amounts of nutrient fed into them and on the division of nutrients into different flow channels. Besides, the determination is made more difficult by the same factors that have been mentioned above for composting at a plant and that are due to the composting process: decrease of mass and binding of the nitrogen from the atmosphere to the compost.

Household biowaste is composted privately approx. 700 t/a that contains the following amount of nutrients: N = 14 kg/d and P = 3 kg/d. It is assumed that the dry matter content is 45%, and there is nitrogen 165 g/kg of dry solid matter and phosphorus 3,0 g/kg of dry solid matter. See Figure 3.7.

3.3.7 Utilisation of food fat

Fat waste is generated in restaurants, shops and other operations where food is prepared in grills and fat cookers. With regard to the functioning of grease separation basins and sewerage, it has been recommended that frying fats should be delivered for some utility purpose. Nowadays nearly all food fats that have been delivered to be utilised are then utilised as technical greases. (Allag Oy/ Anon., 2000, oral communication; Loperi, 2000, oral communication).

The fat waste delivered from Turku for utility purposes is mainly channeled to two nationally operating companies: Allag Oy in Helsinki and Rasmix Oy in Riihimäki. The amount of fat waste that is delivered from Turku for further utilisation has been estimated to be 60 t/a.

Because fat waste is utilised as technical greases, nutrient contents have not been determined. Nutrient volumes have been estimated on the basis of nutrient contents contained in pure food fat. In Finland, palm oil is usually used. (The estimates have been gathered from the following sources: Kantti, 2000, oral communication; Niemelä, 2000, oral communication; National Public Health Institute, 2000.)

Nutrient contents of pure food fat are very low (at the level of 4-220 ppm). Nutrients may, however, dissolve in fat waste from the foodstuff that is prepared in it. As a whole, it is estimated that the nutrient volumes found in food fat delivered for utility purposes from Turku are below the examination level (N and P = under 0,5 kg/d).

3.3.8 Sludge of domestic animals

The nutrient volumes of wastes of faecal origin produced by production animals and pets in Turku have been estimated according to the nutrient production volumes by animal species on the basis of numbers of animals. The nutrient output volumes of animal species have been obtained from a Swedish study (Kirchmann, 1996) and the nutrient output volumes of pets have been estimated. The numbers of animals have been gathered from the production animal statistics (Mäki-Mattila, 2000) and partly compiled on the basis of presented estimates (Janatuinen, 2000, oral communication; City of Turku/Anon., 2000, oral communication). The highest error possibilities lie in the numbers of dogs, cats and horses, as the proportion of the nutrients produced by these animals is the most significant one of the whole.

The amount of nutrients produced by domestic animals in Turku: N = 207 kg/d and P= 38 kg/d.

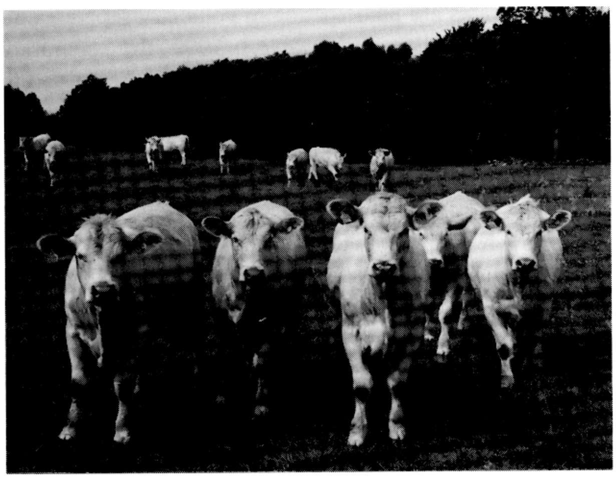

Figure 3.3 The nutrient volumes in waste produced by domestic animals in Turku was N 207 kg/day and P 38 kg/day. Photo: Lars Rydén.

3.4 NUTRIENT FLOWS IN TURKU

3.4.1 Present situation

The most significant nutrient flows, 75% of the total nutrient discharge, are conveyed in the sewage water (Figure 3.8). The amount of nutrients carried off in biowaste is less than one fifth of the total nutrient volume.

As one may conclude, the primary nutrient flow channel leads to the wastewater treatment plant (Figure 3.9). The nutrient flows to both the incineration plant and the landfill make up together only one fourth of the volume of nutrients flowing to the wastewater treatment plant. From the overall point of view, composting in plants and households is this far rather insignificant.

From the point of view of nutrient recycling it is more important to examine the end channels of the nutrient flows. In this study the end channels have been identified as ground water, surface water, landfill (deposit), atmosphere, sludge, compost product (biowaste) and other channels (animal sludge and utilisation of food fat and oil).

In the case of nitrogen, half of the total flow ends up in surface waters (Figure 3.10), and 23% in sludge. Less than 10% is deposited to landfill along with biodegradable waste. On the other hand, most of the phosphorus is bound in sludge (61%). The landfill is the second most important phosphorus sink, even though the volume of deposited phosphorus is only one fourth of the volume contained in sludge.

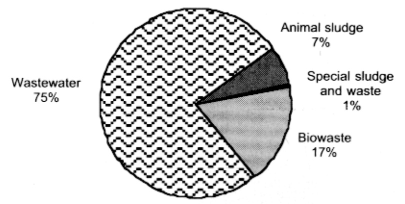

Figure 3.8 The amount of nitrogen and phosphorus contained in different waste fractions as proportions of the total nitrogen and phosphorus flow of the nutrient discharge of Turku. (Total N=3074 kg/d and P=583 kg/d.)

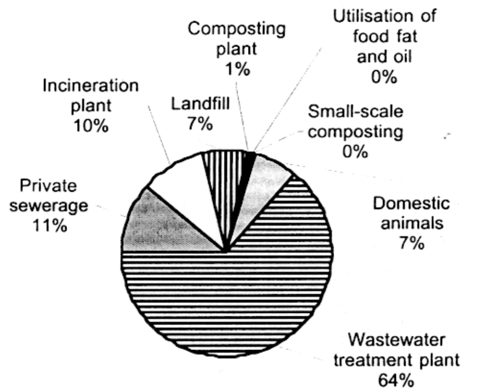

Figure 3.9 Primary nutrient flow channel for nitrogen and phosphorus in the present situation. Percentages represent proportions of the total nutrient flow of nitrogen and phosphorus.

3.4.2 Scenario for the year 2005

For the sake of comparison, a nutrient flow scenario was created for the year 2005. It was based on the assumption that separate collection of biowaste is well established. The initial level of nutrient volumes was assumed to be the same as at present. Differences to the present situation are caused by an increase in separate collection of biowaste, establishment of local composting (or digestion) plant, increase in the efficiency of denitrification at the wastewater treatment plant and improving purification performance of private sewer systems.

The accumulated amount of separately collected biowaste was estimated as 60 kg per inhabitant per year. The number was based on the experience of the City of Jyväskylä, where the separately collected biowaste has been 57-63 kg/inh/a (Hänninen et al., 1999). However, the volumes have been larger in Jyväskylä than, for example, in the Helsinki Metropolitan Area, where it has been 35 kg per inhabitant annually. The difference is probably due to the fact that in Jyväskylä the municipal waste management regulations requiring the separate collection of biowaste apply to all households, whereas in the Helsinki Metropolitan Area they apply only to residential properties comprising ten or more households.

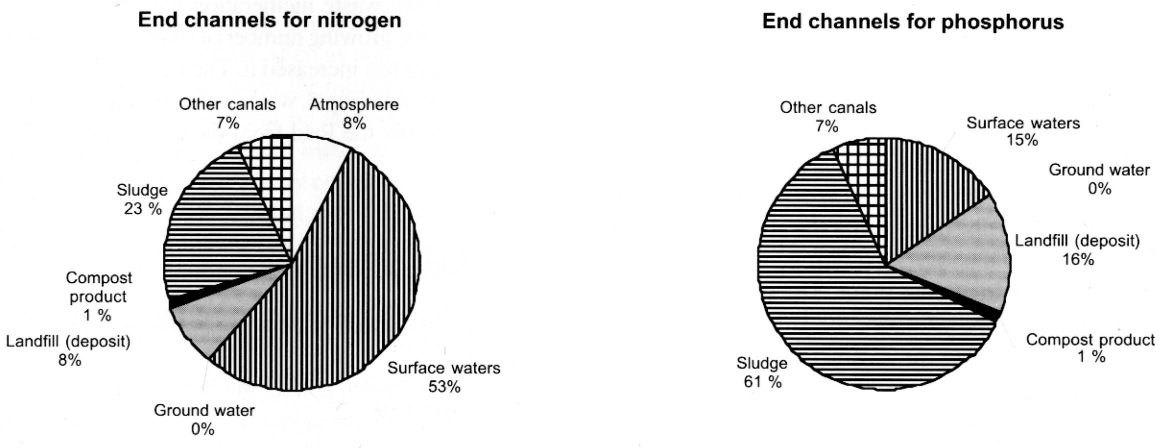

Figure 3.10 The end channels for the nutrient cycles of nitrogen and phosphorus, in the present situation. The figures represent proportions of the initial level of nutrient volumes (N and P).

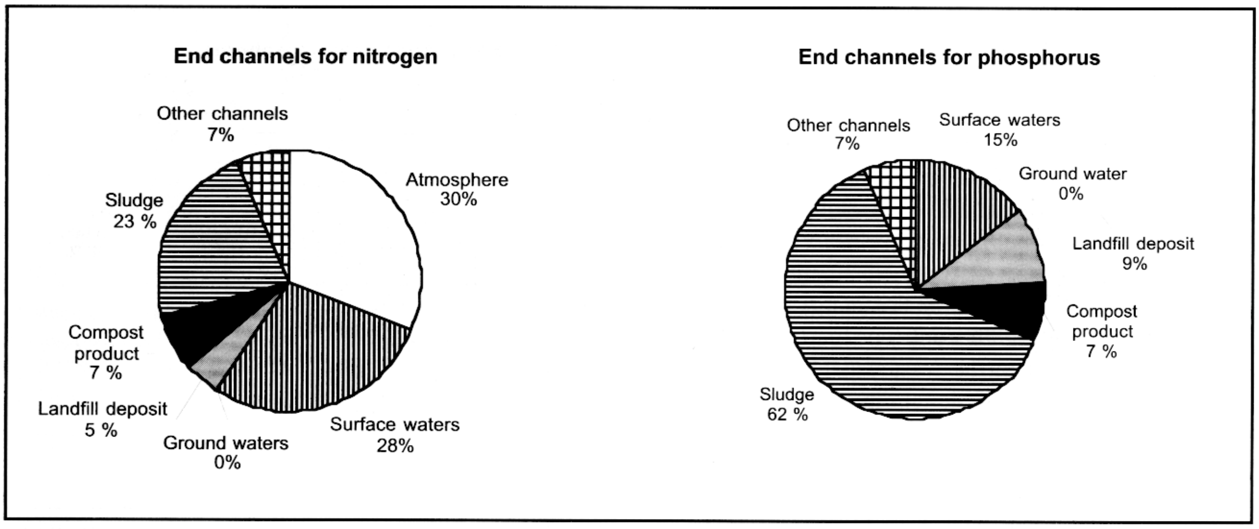

Figure 3.11 The end channels for nutrient cycles of nitrogen and phosphorus in the scenario for year 2005. The figures represent proportions of the initial level of nutrient volumes (N and P).

Small-scale composting was estimated to double compared to present activity. The volumes of biowaste ending up to the incineration plant and landfill were estimated to decrease by the same proportion (38%) in both waste flows. The decrease was calculated according to the simultaneous increase in small-scale composting and separate collection of biowaste.

In the year 2005, the nitrogen removal capacity of the wastewater treatment plant was assumed to be notably better than today. The capacity was set to be 70%, which level is already possible to achieve in plants using advanced technologies. In the case of phosphorus removal, improvements to the present day results are not likely to take place. Private sewer systems were estimated to improve their performance from 20% to 40% capacity for both nitrogen and phosphorus removal. This improvement was mainly due to the increasing number of private small-scale wastewater treatment plants.

In this scenario the most significant end channels of nitrogen are the atmosphere (30%) and surface water (28%) (Figure 3.11). Also sludge is an important end channel for nitrogen. The nitrogen content of compost products from plant and small-scale composting is slightly higher than the amount of nitrogen deposited in the landfills. For phosphorus the most important end channel is still wastewater sludge. The phosphorus content of the compost product is 7% of the total volume, a little less than what is deposited in landfill.

The most essential change compared to the present situation, according to the scenario for 2005, is the notable increase of nitrogen discharged into the atmosphere. This is mainly caused by the increased nitrogen removal capacity of wastewater treatment plant. The increased capacity does not, however, influence the amount of nitrogen bound in sludge, because the advanced techniques of nitrogen removal release the nitrogen in gaseous form into the air. On the other hand, the amount of nitrogen released into the atmosphere by incinerating biowaste is halved, but its share of the total volume of nitrogen is only a few percent. The increase of separate collection of biowaste has decreased the amount of nitrogen deposited in landfills by one third, and phosphorus by almost half compared to earlier situation.

3.4.3 Potential nutrient flows

In this study it was also estimated how much it would be possible, in theory, to bind nutrients into compost product by the extensive sorting of biowaste. In this 'potential situation' it was assumed that all biowaste (excl. small-scale composting) is handled in composting plants. No biowaste would be incinerated nor taken to landfill. The volume of biowaste treated in small-scale composting was estimated to be the same as in the scenario 2005. Also the nutrient removal capacity of the wastewater treatment plant was according to the scenario. The efficiency of private sewer systems was assumed to reach the capacity of 50% removal of both nitrogen and phosphorus. The sludge from the private sewer systems would be collected without further treatment in the municipal wastewater treatment plant.

The most significant end channels for the nutrient flows are the same in the scenario 2005 and in this 'potential situation'. However, the amount of nutrients bound to the compost product is more than two-fold for nitrogen and phosphorus compared to the scenario. The nitrogen load released to the atmosphere from waste incineration has decreased, but at the same time the growing number of small-scale wastewater treatment plants has increased it. The nutrient load from the landfill to the municipal wastewater treatment plant has diminished, while the load from the composting plant has increased.

3.5 FINAL COMMENTS

3.5.1 The importance of biowaste in the recycling of nutrients

As it has been shown above, the largest nutrient flows in urban habitats are conveyed in wastewater. Generally it can be shown that the plant nutrient content of different waste fractions decreases in the following order: animal sludge > sewage water > organic household waste > organic waste from food industry (Kirchmann, 1996). This,

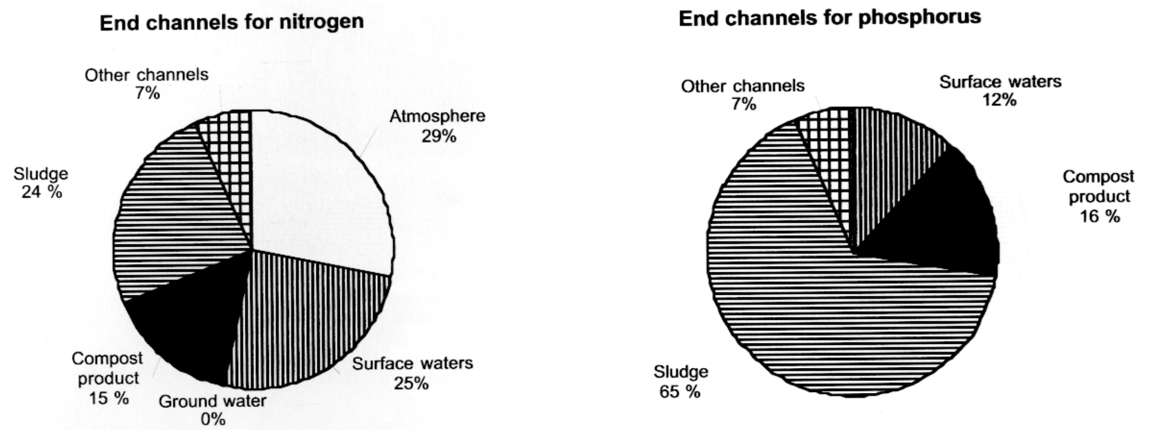

Figure 3.12 The end channels for the nutrient cycles of nitrogen and phosphorus - study of the potential. The figures represent proportions of the initial level of nutrient volumes (N and P).

however, does not mean that municipal biowaste would be insignificant in terms of their nutrient content. According to a Swedish research 10-30% of the phosphorus contained in food does not pass through the digestive system (i.e. is not eaten) and ends up mostly as waste (Wolgast, 1994). The rest of phosphorus contained in food passes through the digestive system and ends up in wastewater, except for a small part, which is absorbed into the system.

When returning nutrients from different types of waste back to plant production one should also consider a method, with which the nutrients can be returned to plants in a useful form. Usually this happens by composting waste. In some cases waste can also be treated by digestion (decomposition) or it can be both composted and digested before spreading to the field. Sludge can also be stabilised with lime and then spread to the fields. Incinerating biowaste should not be considered here, since in burning all usable nutrients would be lost.

When waste is treated by composting or digested, important nutrient losses also take place, especially in the case of nitrogen. The quantity of the losses depends on the methods of treatment and of the type of waste. Usually, the higher the nitrogen content in the original material, the higher the nitrogen losses are (Paatero et al., 1984). With nitrogen rich materials, such as manure of domestic animals and wastewater sludge, the nitrogen losses, mainly by evaporating ammonia, can be as high as 60% of the total nitrogen content, whereas materials with lower nitrogen content, such as separately collected biowaste, may have losses of only 40% (Eklind, 1998). This gives more importance to the nitrogen contained in biowaste compared to wastewater sludge, when thinking of utilisation of nutrients. However, nutrient losses can be better controlled in plant conditions and at some composting plants techniques have been developed to recirculate the reject waters of the process in order to reduce the nutrient losses. In practice, exact optimisation of the nutrient losses is difficult, and it is not simple to simultaneously manage cost efficiency, elimination of odour hazards, effective stabilisation and minimal nutrient losses of a composting plant. One may presume, however, that in the future advanced technologies and process know-how would also improve the rate of efficiency with regard to nutrients.

From the point of view of agricultural use, the quality of compost product made of biowaste is higher than one made of wastewater sludge. The heavy metal content of compost products made of biowaste have, almost without exception, been under the limits set for agricultural use in the Nordic Countries (Svensson, 1998). With regard to the plant nutrient content, in some cases the problem has been low nitrogen content of the compost, which has required added nitrogen for agricultural use (e.g. Mäkelä-Kurtto & Sippola, 1994). In the present situation, the most important factor is the maturity of the compost product. Maturity affects the utilisation value of the nutrients and decreases the quantity of harmful, phytotoxic substances in the compost material. Another important factor affecting the quality of compost product is the low level of impurities.

The use of wastewater sludge in agriculture has been hindered by its high phosphorus, and in some cases heavy metal, content. According to the EU requirements for receiving farming subsidies, the allowed volumes of phosphorus fertilizers are so low that using sludge in farming fields is not technically possible within these limits. On many occasions it has been emphasised that biowaste and sludge should be treated separately in order to better control the differences in their quality.

According to a Swedish research project, maximal recycling of biowaste would replace 1% of nitrogen and 9% of phosphorus of synthetic fertilizers used in Swedish farming fields (Widén, 1993:13). In practice one noteworthy obstacle to waste utilisation in agriculture is the attitude of people. Using livestock manure in fields is thought to be a more natural way of recycling nutrients than using human-originated waste. One ought to remember, however, that in addition to nutrient recycling, the utilisation of organic waste also has other advantages; it reduces the negative environmental impact of landfills and waste incineration.

Figure 3.13 Sludge in Turku is partly sent to landfills. Photo: Lars Rydén.

3.5.2 Summary

The importance of separate collection of biowaste, from the point of view of nutrient cycles (nitrogen and phosphorus), in the City of Turku, can be summarised as follows:

- The proportion of nutrients contained in biowaste is nearly one fifth of the total nutrient flow.
- Presently, nearly half of the nitrogen contained in biowaste is deposited in landfill, where some of it will in the long run dissolve into seepage water and mainly end up at the municipal wastewater treatment plant. Over one third of the nitrogen volume is released into the atmosphere by incineration. Only less than 10% is utilised in soil products. Similarly, 90% of phosphorus is deposited in landfill and less than one tenth is utilised.
- Once separate collection of biowaste is established (scenario 2005), approx. 40% of the nitrogen and phosphorus contained in this waste can be easily utilised in plant production.
- Recycling nutrients from waste to plant production always includes nutrient losses, which for nitrogen in some cases can be up to half of the nutrient content in original materials. In modern composting plants the nutrient losses can be controlled and it is estimated that they can reach a rate of efficiency of 85% for nitrogen and 90% for phosphorus. The aforementioned figures can also be potential levels for the rate of utilisation of the total nutrient flow contained in biowaste. Since the nutrient losses occurring in composting plants mainly end up at the wastewater treatment plant, higher rates of efficiency can be achieved by improving the performance of wastewater treatment and utilisation of sludge.
- At present, the nutrient volume utilised from biowaste is equal to one percent of the total nutrient flow. In the scenario for the year 2005 its proportion would be 7% and, with the maximal recycling of biowaste, 15-16% of the nutrients could be returned to plant production.

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