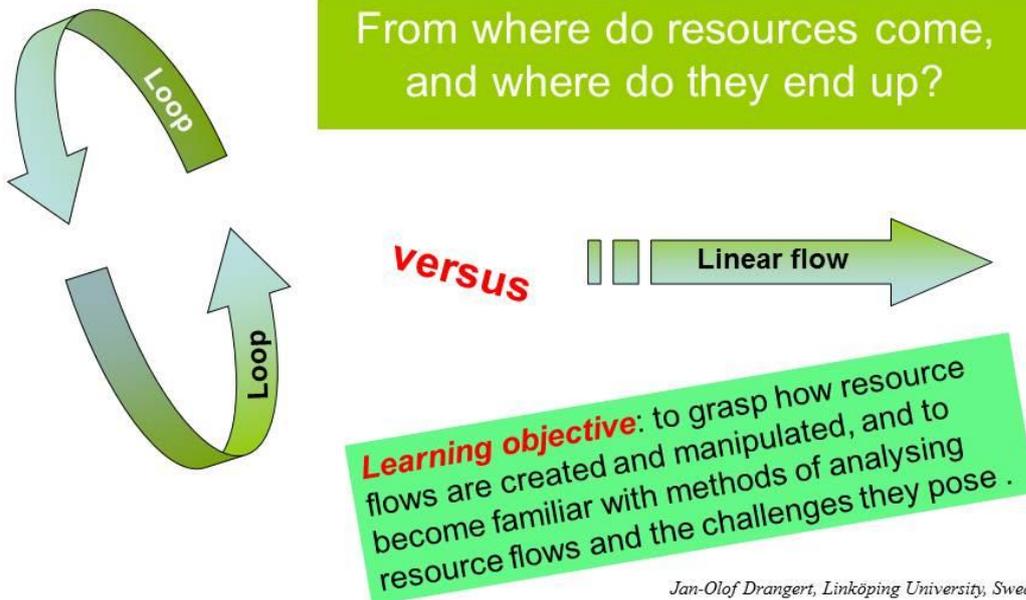


## 1.3 Resource Flows



In this module we focus on physical resources and their **flow** through urban areas. A method to study and understand the interlinkages is presented (Material Flow Analysis, MFA for short). The aim is to understand a local situation well enough to be able to formulate improvements and solutions to problem situations. The MFA fosters a holistic approach and gives decision-makers a tool to correctly identify the problem and from there try to employ effective measures.

Flows require gravity or other energy to get going. The shorter the distance less energy is used. For instance, it has been estimated that 20% of the total energy used in California (USA) is for pumping water and for treating water and wastewater (California Energy Commission, 2004). This shows the magnitude of energy that linear flows may deal with, and also points to the potential savings that can be achieved through far-sighted development of systems with short loops.

A city-wide loop for water exists in water-stressed Singapore. Wastewater is treated to drinking water standard and supplied to mainly industries. Ninety per cent of Singaporeans do not object to drinking this water given that it has been mixed with rainwater in reservoirs (which collect more than half of the rainwater on the island). This is an example of a high-tech city-wide loop which is very costly in energy and investment.

Here is a hypothetical example of extreme water reuse design. It is based on the understanding that a household or a community only pollutes water marginally while using it, and it can easily be treated and used again. This example is more realistic if one thinks in terms of non-potable water reuse and one assumes that each person has access to two litres of safe bottled water per day. The water recovered from yesterday's usage is treated and put to use again by the households. In this way, water from shower, sink and wash basin is used over and over again after simple treatment. The daily need for fresh water is covered by the two litres of bottled water per person! Such a short loop of water is conceivable, since most of today's drinking water is already bought in shops in the form of bottled water, soda, beer, and milk.

We do not need to be hamstrung by the scarcity of water sources – there are ways to create alternative sources in a community, mainly to recycle water and harvest rainwater.

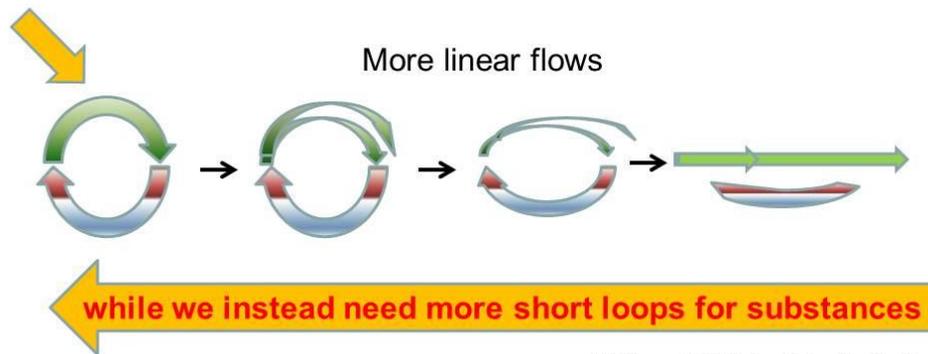
The discourse in the water sector is being partly redefined by the concept of “virtual water” embedded in food stuff and consumer products (slide 1.2-5). Trade in food from water-rich regions to water-scarce ones could be an alternative water “source”. Such trade can reduce pressure on water resources in the water-scarce regions – making it possible to divert water used in agriculture to domestic use. The economist David Ricardo (1772-1823) showed that such exchange could benefit both trading countries. It explains why nations such as the US, Argentina and Brazil ‘export’ billions of litres of virtual water in food each year, while others like Japan, Egypt and Italy ‘import’ billions. The virtual water concept has opened the door to more productive water use. National, regional and global water and food security can be enhanced when water-intensive commodities are traded from places where their production is ecologically viable to places where they are not. However, as mentioned earlier, trade and transport is an energy-consuming activity and has to be part of the cost-benefit analysis.

The sanitation sector can get inspiration from the energy sector when it comes to policies and strategies which call for major changes in people’s lifestyles. The Swedish EPA commissioned a study of what is required to contain the increase in temperature to less than two degrees by 2050, which indicated that an 85% reduction of the Swedish emissions would be required. One of the explored scenarios involved relying exclusively on technical improvements such as energy-saving vehicles, energy-efficient houses, changes to how goods are manufactured, and a switch to renewable energy. The study showed that these measures will not be enough if today’s trends of increased air travel; consumption and long-distance transport of goods continue ([SEPA, 2008](#)). The emissions are still 190% above the set goal. The report found that there should be no more major investments in new roads, that towns must plan for bicycles and public transport and that wind power is also an important ingredient in achieving the emission goal. This scenario involves a paradigm shift in which the cumulative results of individual activities bring about change on a global scale ([SEPA, 2008](#)). This gives the inspiration to think globally and act locally also for energy usage in the sanitation sector.

## Features of present policies and practices – and an anticipated paradigm shift

1.3 - 2

- Prime fertile soils converted to town areas
- Reduced recycling of organic material
- Less urban agriculture, etc.



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Since the Industrial Revolution a growing proportion of nutrients and a host of consumer products have stopped being recovered in short loops in favour of linear flows (see slide) – to the detriment of sustainability. Previously, households consumed only organic products and these were returned to agricultural soils together with composted excreta. Buildings were made of wood or clay bricks which are degradable. There were hardly any metal, glass or chemical products in the households, and almost no need for landfills.

The advent of manufacturing in the first half of the 19th century resulted in a dramatic increase in disposal of non-biodegradable products in landfills on the urban fringe. These flows accelerated in the mid 20-century, when advances in chemistry knowledge made way for a host of new products containing non-degradable components which made them unfeasible to be returned to agriculture. Much of these products were flushed down the sink and toilet after use.

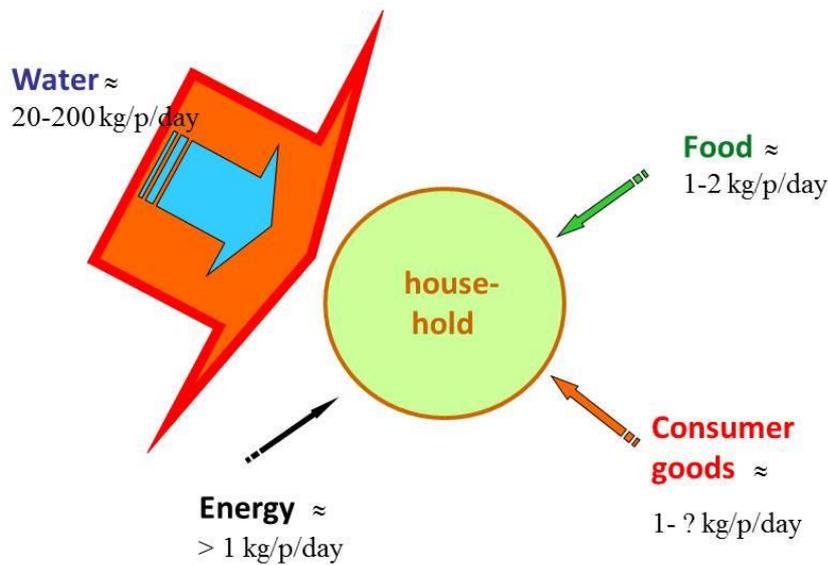
Although industrial revolution came later in many countries, they imported goods from the industrialised countries and had soon similar composition of discharged items.

There is a growing awareness that this development cannot continue due not only to planetary boundaries (slide 1.1- 15) but also simply due to difficulties to find dumping sites for non-biodegradable solid waste as well as sludge from wastewater treatment plants. Utilities now put a lot of efforts in building incinerators to reduce the waste volume. But this is not a solution to reach the goal to have a sustainable society.

A more encouraging development is when some manufacturers start to take on responsibility and try to reverse the linear flow into recovery, reuse and recycling of the used products. For instance, the automaker Toyota changes the way to assembling cars with the goal to make it easy to dismantle when scrapped. In this way the company estimates to recover 95% of the content of the car. This is a new way of thinking in addition to the earlier focus on designing the parts so that it took as short time as possible to assemble the car. The same goes for pharmaceutical industries trying to compose their pills with more degradable components (Module 4.5). We can sense awareness among manufacturers but the change is likely to be a prolonged one unless governments and agencies improve legal incentives to abandon present wasteful linear flows.

## What comes in .....

1.3 - 3



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Starting from the small unit of a household, we can estimate the volumes or quantities of incoming resources and materials. The amount of water is by far the largest input (picture). The quantities of other products are on average around one kilogram per person per day. The energy is counted here as firewood equivalents (e.g. an input of 1 kg is equivalent to the amount of energy that 1 kg of firewood would produce).

Energy use and purchase of consumer goods vary greatly between individuals as well as between societies. The quantity of food consumed by different households is more equitable than the quantity of water.

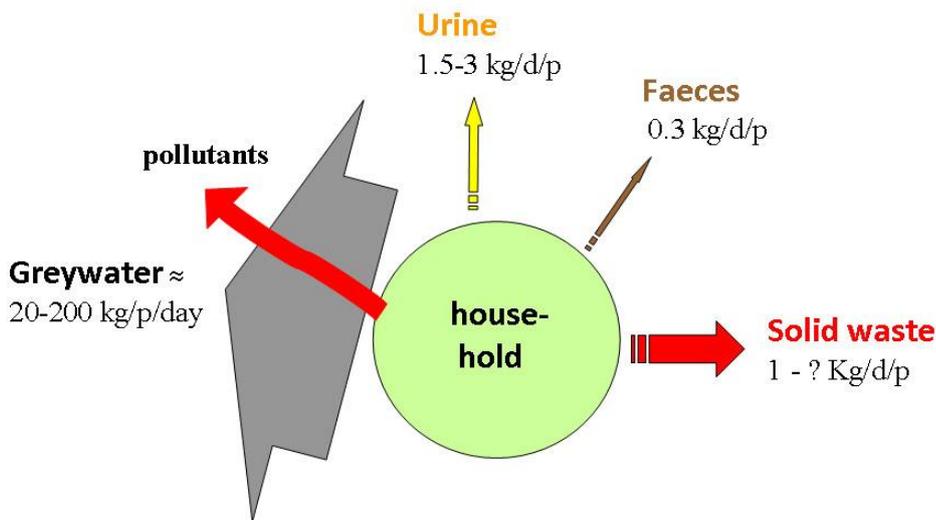
Water use may range between ten litres per person per day in severely water-scarce areas to several hundred litres per day in water-rich areas. Also, the amount of virtual water, i.e. the water which is used to produce food and other items that an average person consumes, is some 4,000 litres per day. Fortunately, we only need to carry a few kilograms of the final food home!

There is a culturally defined lower limit for water use, regarded as necessary for maintaining sufficient standards of cleanliness and comfort. Households do not *consume* water, products and energy; rather, they *use* them to achieve their desired lifestyle. Variations in water-use routines seem to be largely socio-culturally defined. For example, there is a recently acquired norm in urban society that shirts and blouses should not be worn more than one day before being washed. Frequent washing of clothes is necessary to meet these expectations and therefore, most people would not consider wearing clothes for a few days to be an acceptable option, even if it saved water and prevented a deterioration of wastewater quality. Using a biodegradable soap or detergent would be a technical solution, but residents tend to think that soap does not make clothes clean enough and prefer to continue to use chemical detergents.

Sooner or later, the used water is discharged.

## ... must go out

1.3 - 4



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Households do not *consume* water, products and energy; rather, they *use* them and the so-called waste will sooner or later leave the house. By volume, water is both the largest input and the largest output, now in the form of greywater (picture). Greywater contains pollutants from products that are used by household members such as the chemicals which some clothes are impregnated with, body-care products and pharmaceuticals (red arrow). The greywater is either thrown in the yard to infiltrate in the soil, or – more often – collected in pipes and discharged in water bodies.

The volumes of urine, faeces, and solid waste are relatively small. A person excretes about 0.3 kg of faecal matter and 1.5–3 litres of urine daily. Urine is often allowed to infiltrate the soil via pit latrines or cess pits. Faeces are usually just stored in the soil (pit latrines), except in sewered areas where all flows come together and are discharged downstream. The growing amount of solid waste is becoming a more serious problem as it includes more and more products containing complex chemicals.

Sanitation management is about how to develop appropriate arrangements and to operate and maintain these in a sustainable way (see Module 2.5). Innovative urban infrastructure is required to recover nutrients from household sanitation systems and organic waste directly at the source and new technologies have to be developed to treat sludge. Urine-diverting toilets that keep urine and composted faecal matter separate help simplify treatment and enable safe use in agriculture (WHO, 2006). This solves the problem provided there is a little storage space! Technical, socio-economic and cultural aspects need to be addressed in order to determine the feasibility and sustainability of recycling options.

Each one of us can contribute to a more sustainable city by incorporating environmentally friendly routines when purchasing products, using them in our homes, and eventually discharging what is left. We will see throughout this sourcebook that all improvements involve the household level. In Module 2.1 we will give examples of single urban households or groups of households that are self-sufficient in water and discharge waste in a sustainable manner.

## The trick is to bend today's many linear resource flows

1.3 - 5

- **Solid waste** is the most visible output. It may be discarded or sorted and recycled. Scavengers perform an important service
- **Faecal matter** is very small in volume, but is a major health threat unless treated and used wisely
- **Urine** (urine) volumes are small. Bad odour may be a problem unless urine is returned to the soil
- **Greywater** is voluminous and a major challenge in dense areas but can be a useful product if handled well
- **Stormwater** may be a serious problem but harvesting it can augment household and irrigation water supplies
- **Energy** is invisible but heat may be recovered

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The main output flows from houses and communities consist of solid waste, stormwater, greywater, urine, and faecal matter. Each society can choose to treat outputs as problem-creating waste or as potential resources. A priority in a sustainable community is to minimise resource use and not just accept prevailing values (slide 1.2-12), and to make sure that used products are returned as inputs in new processes. “*The trick is to bend today's many linear resource flows*”.

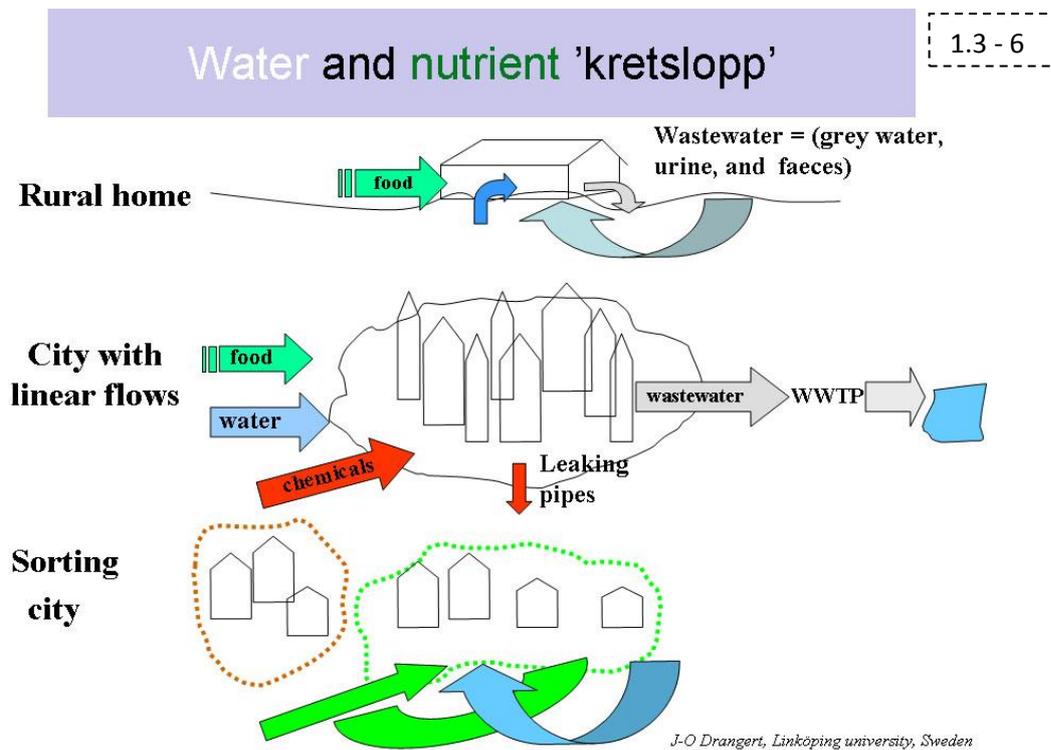
We tend to be more aware of discharges that are easily seen or felt. In a study of environmental awareness it was found that the more visible a certain waste is, the more people are prepared to contribute to take care of it ([Krantz and Drangert, 2006](#)). For instance, solid waste is the most visible and residents sort it and each fraction is collected and returned to industry as an input in new production. New bottles are made from plastic waste, new newspapers are printed on recycled paper, insulation material is made from collected glass, etc. In many cities around the world collection is done, not in the households, but by scavengers. They have grasped a business opportunity and they provide an essential environmental service.

Latrine buckets and faecal matter are considered disgusting and are hidden, but are easily observed when they are emptied. In this case people are less willing to take care of the fresh content but are willing to pay someone else to move it out of sight and out of smelling distance. Council staff or someone else is expected to do this work. The same goes for emptying dug latrines. This task is done by special entrepreneurs. The same is not true for composted faecal matter, which looks and smells more like soil. This treated material is often considered acceptable to mix into the soil in a home garden.

Urine is seen for a while, and may be touched accidentally with little harm done. If it infiltrates in the soil we do not look upon the soil as very polluted. But residents want to get rid of urine as fast as possible since it soon starts to smell bad. Awareness of its fertiliser value may make residents willing to apply their urine in the home garden.

Wastewater, on the other hand, is hardly seen before it disappears in the sink or down the toilet. We have no objections to dipping our hands in water used for washing dishes or clothes, but we may find standing wastewater in puddles repulsive due to its bad smell or greasy appearance. Residents connected to sewers tend not to bother about their wastewater quality because they see it only momentarily. Therefore, it will take an attitude based on environmental awareness and concern not to pollute wastewater unnecessarily.

Lastly, electric energy is invisible and awareness among users about pollution at the site where it is generated (coal-driven generators or nuclear plants) is rarely a concern of theirs unless they live in the affected area. Energy is made visible by the tariff.



The amount of household chemicals used nowadays makes treatment and reuse more complex. Whereas previous generations focused on the provision of water and other resources, today the greatest urban challenge is the handling of wastes. Therefore, old town-planning solutions need to be revised to take account of new sustainability requirements. The picture clusters households into communities and indicates how these can be planned in order to become more sustainable.

In rural homes, material flows are bent so that the outputs of water and organic waste are productively used in irrigation and as fertiliser (top picture). However, this is not the case in today's urban areas where residents have become divorced from the tacit knowledge of the origins, as well as fates, of various goods and products, be it milk, iron, or pills. Consequently, flows tend to be linear (middle picture), BUT they do not have to be. Bending linear flows in urban areas could be done by selecting feasible sanitation arrangements that fit the specific conditions of different parts of a city. Contrary to common understanding, we maintain that there is no intrinsic value in installing a uniform solution to an entire city. In fact, no one technology is a feasible solution for all situations. Already, cities have complementary systems such as piped water and sewerage in some areas and wells and pits in poor periurban areas.

It may appeal to voters to move the environmental problems away from the city to downstream areas, but a sustainable city must take responsibility for its own waste. Decisions must take into account environmental considerations and other issues. The challenge for professionals and decision-makers is to give up uniform systems thinking and make a non-biased evaluation of what could work in a particular town district. For instance, flush toilets in an area with an intermittent supply of water are inconvenient for the users.

A "sorting city" (bottom picture) may provide advantages such as reducing the distance that waste has to be transported for recycling, incl. local food production. In addition, energy for pumping water and wastewater can be saved if the topography of a city is taken into account. A decentralized infrastructure is more visible to residents than a centralized one and the hope is that they and utilities will install less linear discharges to groundwater and surface waters. Such shorter loops or "kretslopp" are often economically beneficial. Yet, it is vital in town planning to make estimates and evaluate different systems beforehand, and this can be done with tools such as material flow analysis or life-cycle analysis. Some examples of such studies are presented in the rest of this module, while Module 2.6 deals with selection criteria.

## Three examples of 'kretslopp' thinking

1.3 - 7

Fraction:	In Stockholm	In Kimberley	In Kampala
<b>Solid 'waste'</b>	Provides heating/energy	No sorting, collected and put on landfills	No sorting, burnt in situ, the rest to landfill
<b>Organic 'waste'</b>	Provides soil conditioner		Soil conditioner
<b>Faecal matter</b>		Soil conditioner	Soil conditioner
<b>Urine (urine)</b>	Liquid fertiliser	Liquid fertiliser	Liquid fertiliser
<b>Grey water</b>	Irrigation water and biogas	Grey water to pond after biological treatment, and rainwater to the same pond. Little rain.	Infiltrated in situ and to drains
<b>Storm water</b>	Groundwater recharge		In drains but flooding due to heavy rains

*Jan-Olof Drangert, Linköping university, Sweden*

The picture shows examples of material management in three “sorting” city districts. A new central area of Stockholm, Hammarby Sjöstad, has 20,000 inhabitants, while there are some 500 residents each in Hull St in Kimberley, South Africa, and in a project area in periurban Kampala, Uganda. Their sanitation arrangements vary in types and scale.

Arrangements in Hammarby Sjöstad rely on sophisticated technology (slide 1.3-11). The original idea to separate urine was abandoned in 1996 because the technology was not yet mature at that time. Wastewater is treated and used for gardening. Solid waste is sorted and recycled, and what cannot be reused is incinerated to provide district heating. The organics, including sludge, is co-composted and used for biogas production. Stormwater recharges groundwater or empties into a lake after simple treatment.

The Hull Street project in central Kimberley provides communal piped water and short sewers for greywater, dry urine-diverting toilets and local reuse (slides 2.1—9 - 11). There is no sorting of solid waste yet; only conventional collection and storage in a municipal landfill. Faecal matter is composted locally and used as a soil conditioner in the gardens, while urine may be collected by the household or discharged with the greywater. Some residents use the greywater, in particular from washing and even washing machines, to water their gardens.

In the capital of Uganda, Kampala, the council supports the introduction of dry urine-diverting toilets in non-serviced areas. The collected urine and dried faecal matter is used in household gardens or transported to farmers who use it on their farms. Greywater is infiltrated and/or flows to drains together with stormwater with no productive use, except during heavy rains when pushing garbage deposited in the drains to the outside of the community.

The three towns have adopted different strategies to improve their sustainability, and these can be developed further (see Chapter 2). After this exposure to some practical examples, we can now discuss ways and means to assess how effective various systems are.



Jan-Olof Drangert, Linköping University, Sweden

The overriding policy of sustainable cities (slide 1.1-14) puts some restrictions or requirements such as resource conservation and no depletion of natural resources. The two kinds of wastes, liquid and solid waste, face similar challenges. The so called Waste Hierarchy provides an order of different actions to address the challenges ([Arcadis, 2010](#)).

The primary action is to **reduce** the amount of manufactured goods and products, and harmful contents of all products. Actions may comprise e.g. only buy the amount of food that is eaten, use less packaging material, produce less non-degradable products, make detergents with no phosphorus. Still, there will be waste produced but will be easier to reuse and recycle since they contain less harmful components. The next two actions will incidentally also reduce waste generation by making new products from waste and thus saving on virgin resources.

**Reuse** of waste products involves using the waste product again for the same purpose, often after some treatment. Examples are when students sell their text books to the following batch of students, preparation of left-over food for a new meal, use of returned glass and plastic bottles, reuse scrap building materials, bringing nutrients in urine back to plants as a fertiliser, etc.

**Recycling** of wastes involves making new products out of converted waste. Used aluminium cans are melted down and turned into new cans (saves 95% of energy), scrap metal is similarly melted and used for new iron products, newspaper becomes cardboard, and glass becomes insulation material. Organic waste may be composted and release heat (hygienization) and the end-product is a perfect soil amendment. Good quality sludge can be recycled as a fertiliser.

**Incineration** can be used to remove some of the energy content in waste products that could not be reused or recycled. Equally important may be that incineration reduces the volume by about 90% and delays the search for new landfill sites. The process produces ashes and toxic gases that have to be taken care of. It is difficult to extract nutrients such as P and K despite that they do not burn. All nitrogen is lost in the incineration and cannot be recovered.

Storing waste in a **landfill** is the last and least desirable measure. The landfill has to be meticulously designed to avoid leakage of toxic compounds as well as methane and carbon dioxide from the anaerobic processes in the landfill have to be controlled.

If the water is not mixed with toilet content and not with oil and grease, this greywater will have very low concentration of nutrients and not be useful for fertilising the soil. It may also contain harmful levels of toxic compounds. If not, the sludge will be unfit as a fertiliser. If blackwater is kept separate, it contains valuable nutrients and pathogens can be easily removed.

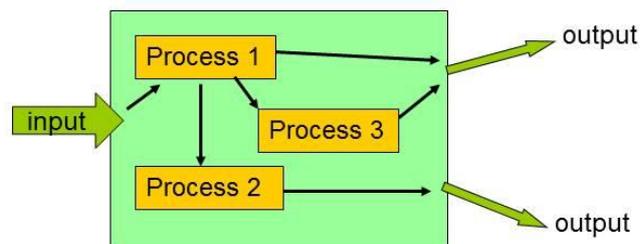
## Material Flow Analysis for human settlements

1.3 - 9

MFA uses the principle of mass balance:

$$\mathit{input} = \mathit{output} + \text{accumulated } \mathit{stock} \text{ in the system}$$

and provides a systematic description of the flow of goods, materials or substances through various processes and out of the system.



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The simple idea behind the material flow analysis is that input equals output plus what remains in the system (picture). If you receive 100 cents (input) and you spend 70 the next day (output), you remain with 30 in your pocket (stock). What MFA can assist in doing is to disentangle complicated interlinked flows by using mathematical analysis. Baccini and Bruner (e.g. [1991](#)) among others developed MFA and applied it to various material flows. Mathematical modelling is necessary in case the system is complicated and comprises several simultaneous processes.

MFA is discussed in some detail in this module and four examples are given to show the model's ability to forecast consequences and allow for a sensitivity analysis.

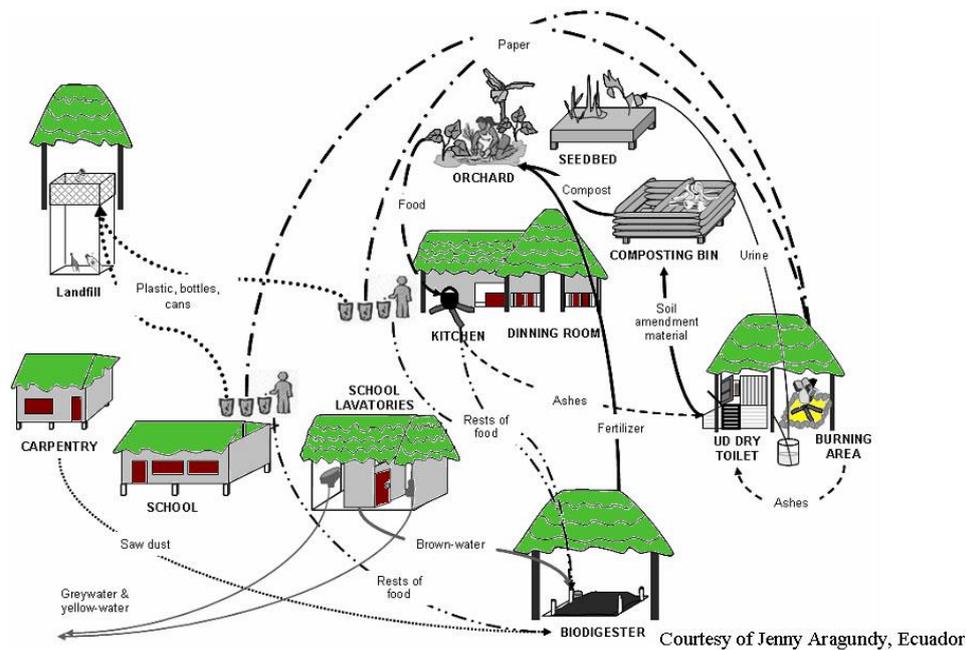
There are also other models such as Life Cycle Analysis (see Module 4.9) and each model has its own standard calculation program. All models comprise system equations with boundary conditions. Each system investigated here is described with all relevant processes. The outcomes of the calculations might bring interesting results that could not be envisaged without such an analysis. The MFA allows us to play around with any assumptions and it will show in numerical terms how the system will react. The numbers may inspire to different interpretations and new questions may be asked to the models.

It is important to acknowledge that models and inputs tell you what is likely to happen in a technical system, but, this does not replace the responsibility and active decision making by human beings. MFA is being used as a decision-making tool – restricted only by the availability of data. The results of an analysis are more reliable the better the quality of provided input data.

Free software of a MFA, called STAN, can be downloaded from <http://iwr.tuwien.ac.at/ressourcen>

## A resource flow model for a hamlet

1.3 - 10



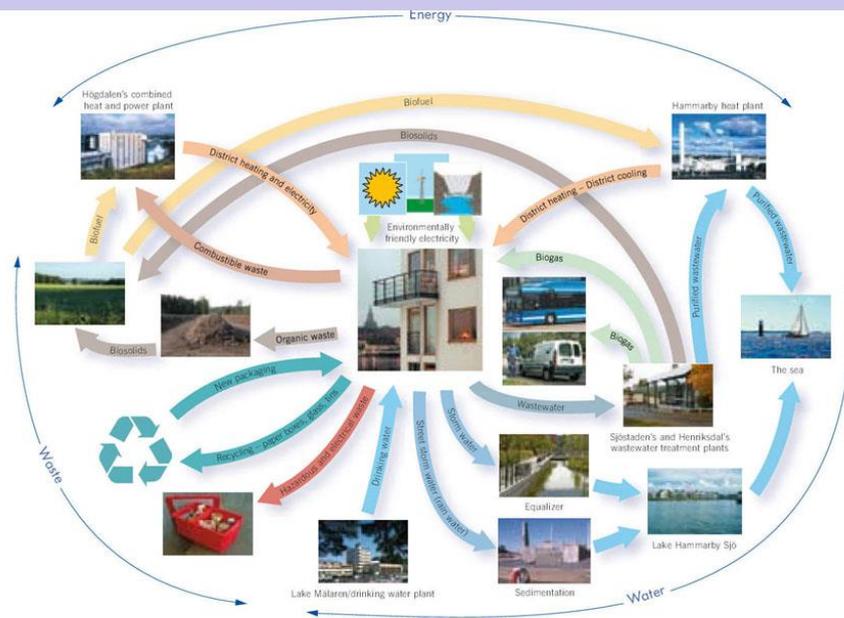
Jenny Aragundy from Ecuador produced the above picture in collaboration with villagers who wanted to improve the sanitary conditions in their village. All the so-called waste products are included, and the picture shows how they flow through the village. The villagers know where the unwanted material is produced and used, where it is stored or transported to, and where it ends up eventually. The flow diagram is displayed and discussed in village meetings, and helps to create a common understanding of who are responsible for what part of each environmental problem. The community can identify what can be done individually and jointly to reduce the problems they experience. Implementation is, as always, restricted by local social and power structures.

In a situation like the one above, it may not be necessary to talk about the exact volumes of all flows, and no mathematical analysis is needed to arrive at assessments that can guide sensible measures to ameliorate sanitation problems. It is enough to make visual qualitative assessments and community members can envisage what the outcome of any measure is likely to be if implemented.

As is the case in all MFA studies, the challenge is to get the stakeholders together and derive at a common understanding and to agree on a strategy to ameliorate the perceived problems. The MFA tool helps create a common understanding, which is crucial for success, but it does not make the decisions.

## The Stockholm model to improve sustainability

1.3 - 11



Courtesy of Stockholm Water Company

In the year 2000 the Stockholm city council launched a project to build an sustainable housing and office area where resource flows were geared towards closed loops. The municipal agencies in charge of water, wastewater, energy, and solid waste handling coordinated their planning activities so that each single flow was viewed in a holistic fashion irrespective of which utility had the formal responsibility. The goal of the city district was to become *'twice as good as one with conventional buildings'*. In practical terms this translated into the following aims: use half the water, half the energy, reduce eutrophication loads by half, and reduce personal transport by individual cars not by 50%, but by 80%

(<http://international.stockholm.se/Press-and-media/Stockholm-stories/Sustainable-City/>).

The buildings are well insulated, the streets have bicycle lanes and tram tracks, solids are sorted and primarily reused or recycled by manufacturers, and some are incinerated to produce heat. There is a lot of energy-saving equipment and water-saving installations in the homes, the warm wastewater generates heat and biogas is taken out of the sludge. The picture shows the intricate resource flows. Here are some of the early achievements:

- Household water use down 40%
- Hot water use (35% of total) not measured yet, but expected to decrease 15–25%
- Eutrophication agents to the receiving lake reduced by 50%
- 60% of phosphorus and nitrogen returned to agriculture
- Greenhouse gases, acidification, and use of non-renewable energy reduced by 30%

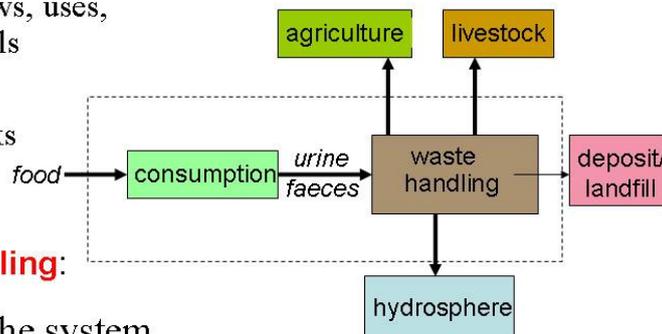
These improvements were made by resource-saving installations, rather than changes in individual resident behaviour. Technical improvements can be improved further, but more important and challenging will be the next step of involving residents in sustainable living.

Next step: residents become partners in sustainability by changing some of their behaviours.

## Modelling the situation (MFA)

1.3 - 12

- Select the material, product or chemical you are interested in
- Include all the flows, uses, losses and disposals
- Find estimates for all flows and stocks
- Decide the boundaries of your system (dashed line)



### 4 STEPS in modelling:

- (1) Description of the system
- (2) Formulation of model equations, (3) Calibration, and
- (4) Simulation incl. sensitivity and uncertainty analysis

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The MFA model is always specific to the situation under study. Once it has been decided which product(s) or chemical(s) to study, the next decision is at what point the product enters and leaves the system (system boundary). The case shown above is about nutrients in our food. The study unit could be a single household or a community. In this case food is eaten by residents (Process 1: consumption) and urine and faeces are produced and enter Process 2: “waste” handling. From the toilet the nutrients in excreta may flow to the hydrosphere, or to a deposit or landfill, or be used as fertiliser in agriculture or as feed for fish or pigs.

**Step 1: Description.** All flows, uses, losses and disposals should, as far as possible, be estimated in your system description. Had the above system also included what comes out of food preparation, a new process box would be added. For example, flows of banana and potato peels should be estimated and be part of the flows, some of which would end up in agriculture.

**Step 2: Model equations.** In the second step, equations are formulated which describe what happens in each process. For instance, are all excreta handled in the system or is some excreting done in other places? What proportions of nutrients flow to the hydrosphere, landfill, livestock, and agriculture respectively?

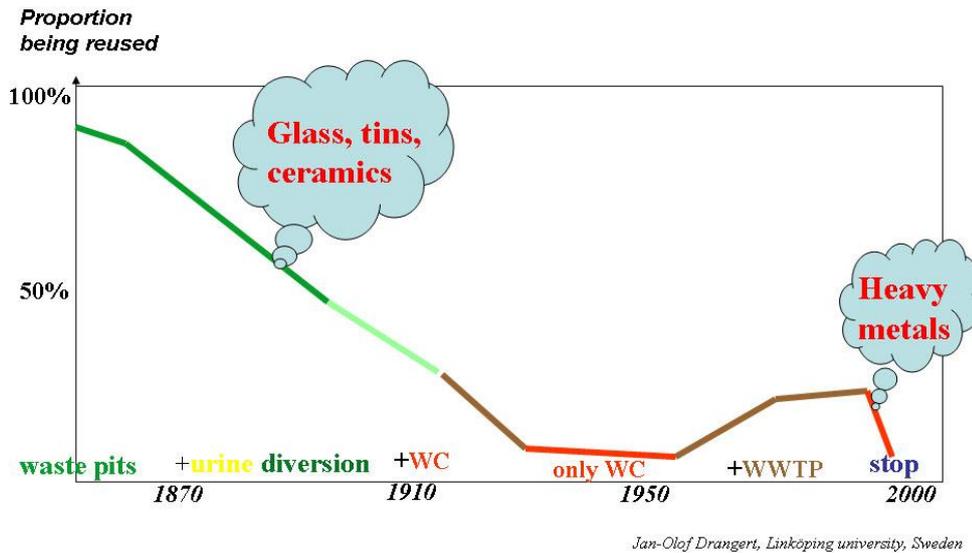
**Step 3: Calibration.** It is cumbersome but necessary to measure or estimate the sizes of all the flows. Often we need to modify model equations. An evaluation of model calculations using rough estimates can then be used to revise the estimate if necessary. This iterative calibration will provide improved estimates.

**Step 4: Simulation** can now be done by inserting scenario figures into the equations, and calculating the output amounts from the system. Since it is difficult to make some of the estimates, you can also give ranges of real values and conduct an uncertainty analysis to see to what extent the final flows are affected by different values in the range. An example of ranges is given in the next two slides.

We give four examples of how MFA can be used: the first is a historical study of nutrient recycling, the second describes how a eutrophication problem can be addressed, the third is a prospective study of changes in circulation due to choice of sanitation arrangements, and the last is about global phosphorus (P) flows in the past and in the future.

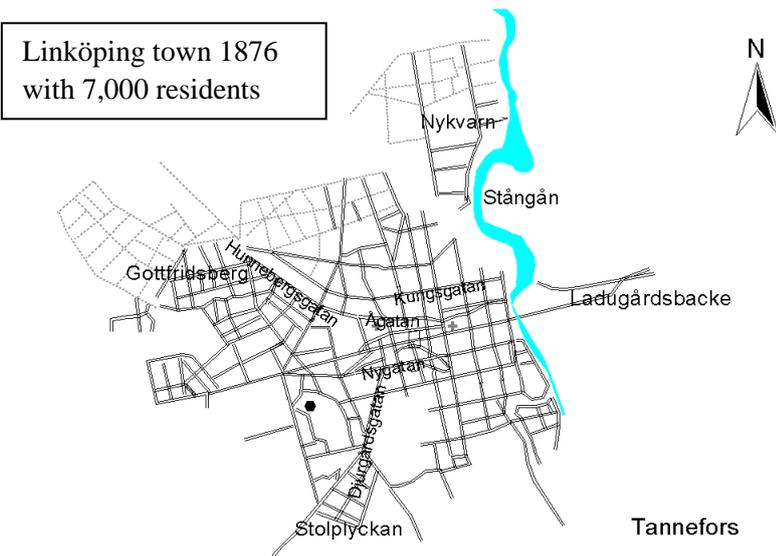
**Example 1: Actual reuse of nutrients from households in urban agriculture**

1.3 - 13



Sustainable sanitation and food security have been important issues in all human history – although they have been given different names at different times. Thomas Malthus wrestled with the interactions between food production, population increase and mortality in his *Essay on the Principle of Populations* (Malthus, 1798). He predicted recurrent famines would bring back a balance between population growth and food production (see Module 1.4).

An example of the evolution of sanitation arrangements and recycling of nutrients in the Swedish town of Linköping is presented for the period 1870 to 2000. This example provides some lessons of more recent developments (Schmid-Neset et al., 2010). The flow of nutrients from food consumption is estimated for each period and the output is divided into gainful use in (urban) agriculture and energy production and losses to the hydrosphere and landfills. The diagram above shows dramatic changes in losses and reuse due to changes in sanitation arrangements, food intake and content of waste products. Understanding how nutrient flows may contribute to plant growth and food security is essential in order to develop informed strategies for selecting sanitation arrangements in today’s world with looming depletion of phosphate rock (Module 5.1) and other plant resources such as potassium and sulphur.



In the mid-19th century almost all excreta and organic material were returned to crop production in urban areas and the urban fringes. Around 1875 central parts of most Swedish towns were piped and later sewerred. However, no flush toilets were installed since the small dimension of the existing indoor piping did not allow discharges of anything other than liquids. However, outdoor toilets (bucket or pit) were gradually replaced by indoor waterless urine-diverting toilets and the urine went into the sewer pipes, while the semi-dry faeces were collected in buckets and transported to farms. Thus, more and more of the nutrients in the urine was lost to the hydrosphere (see diagram above).

The Industrial Revolution (second half of the 19<sup>th</sup> century) brought new consumer goods to the market, such as glass, porcelain and tins. When used or broken these were thrown in the toilet bucket which made the waste unfit to spread on farms. The bucket system could not prevail despite rescue measures. In the first decades of the 20<sup>th</sup> century, WCs were gradually installed and large-diameter pipes in new houses made it possible to flush faeces and paper as well as urine (slide 2.2-4). As a consequence, the numbers of dry bucket and urine-diverting toilets were reduced and the demise of a recycling era was symbolised by the closure in the 1930s of the municipal pig farm which had reused excreta. Open spaces previously used for urban agriculture gradually gave way to new houses, streets and parks. During this period almost no nutrients from the households were used productively. All sewage went untreated straight to the river and lake.

By 1950, almost all inhabitants in Linköping had access to a WC connected to a sewer. However, the household wastewater was only treated mechanically before being discharged to river Stångån. Drainage pipes emptied untreated wastewater and stormwater in the river at several points. Only in the late 1950s was most sewage collected and treated in a chemical process, and in the 1970s the biological removal of phosphorus was introduced. The effluent was discharged into the river mouth at Lake Roxen, while the sludge was brought to farmland. Since the 1970s the use of human-derived nutrients has picked up with the introduction of a phosphorus removal unit at the wastewater treatment plant and use of the nutrient-rich sludge in agriculture.

Farmers eventually became concerned about the accumulation of heavy metals in their fields from sludge made from mixed industrial and household wastewater. In 1998, the Swedish Farmers Union advised its members to end the use of sludge as fertiliser. They were afraid that the pollution of the soils would eventually make it impossible to sell their produce to consumers. However, not all farmers followed this recommendation, and in 2000, an average of 20% of the sludge from the treatment plant was used to fertilise mainly energy wood lots – not cereal crops.

An important lesson from this study is that changes in the levels of nutrient reuse are caused by changed consumption patterns. When industrialisation took off in Sweden in the 1870s new products made of porcelain, glass, metal etc. replaced previous (biodegradable) wooden products. When porcelain plates or metal forks were broken, they were disposed of in the latrine bucket. This content was not appropriate for feeding pigs anymore, and farmers did not want to spread broken glass on their fields. Therefore, farmers did not resist the introduction of flush toilets. Similarly, when the chemical society emerged after 1960s, washing was not done with biodegradable soap anymore, but with chemical detergents. Medicines, paint residues and other products containing chemical compounds were flushed down the toilet. Wastewater treatment plants could not cope with such substances and the sludge became too contaminated to be used as a fertiliser.

## Ex. 1 cont.: Examples of ranges for parameters

1.3 - 14

Table 1: Data for the primary and secondary waste treatment for Linköping, 1870-2000

Year	No of inhabitants	Primary waste treatment/toilet system	Comments	Secondary waste treatment or storage	Comments
1870	7 300	0% WC 10% water-tight buckets 90% dug pit/outhouse	Level 3 based on (1)	70-90% to soil 10-30% to animal fodder	
1885	10 700	2% WC 5% urine separation 30% water-tight buckets 63% dug pit or equiv.	Level 3 based on (1)	80-100% to soil 0-20% to animal fodder	
1900	14 500	8% WC 16% urine separation 76% water-tight buckets 0% pit latrine or equiv.	Level 3 based on (1)	80-100% to soil 0-20% to animal fodder	
1920	26 900	20% WC 10% urine separation 70% water-tight buckets	Level 3 based on (2)	95-100% to soil 0-5% to animal fodder	
1940	38 650	50% WC 0% urine separation 50% water-tight buckets	Level 2 (3)	40-60% to soil 40-60 % to landfill	
1950	54 500	90% WC 10% water-tight buckets	Level 2 (4)	wastewater treatment plant (WWTP), no P reduction unit	60% of WC connected to WWTP
1975	78 000	100% WC	(6), (7)	WWTP with 90% of P to sludge; 0-20% to plant/soil	All WC connected to WWTP
1990	82 600	100% WC	(5), (6), (9)	WWTP with 95% of P to sludge; 20-30 % reused (of which 2/3 to energy forest and 1/3 to farmers) 70-80% to landfill	same assumptions as for the year 2000
2000	94 000	100% WC	(5), (8), (9)	WWTP with 97% of P to sludge; 21% reused (10-40%) (of which 2/3 to energy forest and 1/3 to farmers) 79% to landfill	

Sources: Neset and Drangert, 2010

The number of inhabitants in Linköping grew from some 7 000 in 1870 to about 94 000 (city centre) in the year 2000. The town is situated on a gentle slope towards the river Stångån and Lake Roxen (see previous map). The water intake for the first town supply was constructed in 1875 upstream of the town. The drainage pipes (double lines) for untreated greywater (which contained no excreta) and stormwater emptied into the river at several points.

In the above table the column for “Primary waste treatment/toilet system” gives the estimated distribution of various toilet arrangements for single years. The dug toilet pit was initially replaced with a bucket system. The urine-diverting toilet became popular around 1900, not least in the upcoming multi-storey apartment buildings. However, soon the flush toilet (WC) became popular despite technical shortcomings, and by 1950 almost all had a WC connected to a sewer.

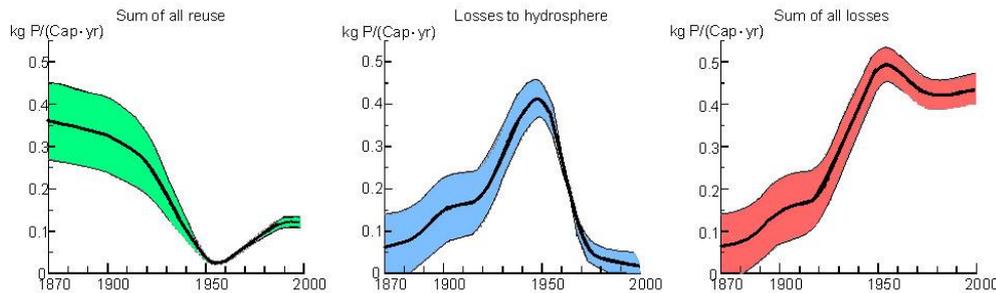
Lack of detailed historical data for toilet systems, and more so for secondary waste treatment or storage, is compensated for by informed guesses building on information from various archives in the city. Generally, data becomes more uncertain as we go further back in time. The column in red gives estimates for the proportion of phosphorus recovered from the various toilets arrangements. This phosphorus was gainfully brought to gardens and fields as fertilisers (Schmid-Neset et al., 2010).

Only by the 1950s was most sewage collected and treated in a mechanical process, which was extended in the 1970s to remove phosphorus and nitrogen before discharge at the river mouth on Lake Roxen. The proportion of sludge being fetched by farmers is reduced from 30% to 20% and the latter almost exclusively applied to energy wood lots.

## Ex. 1 con't Sensitivity analysis

1.3 - 15

## Phosphorus reuse and phosphorus losses 1870-2000



The filled curves represent calculated averages, while coloured areas between the dotted curves indicate uncertainty ranges due to estimated input data (in kg phosphorus per capita per year)

Source: Neset and Drangert, 2010

It is possible to manually calculate single points on the reuse graph for single years, when using the average for each given range. The resulting graph would give a first approximation of the development as seen in slide [1.3-13](#). However, by using a computerised MFA model we can take into account all uncertainties in data, and after crunching the numbers for 24 hours the computer comes out with nice coloured band-curves which are encapsulated between the extreme values (low and high) that occur from all combined uncertainties. The curves in the middle of the band-curves represent calculated averages. The three graphs are presented in the above picture.

If ALL nutrients in the excreta were used in plant and energy production, each person would provide an average of 0.5 kg of phosphorus per year. A calibration was carried out in order to assess the variability of the estimated flows due to uncertainties in parameter values. The assumed uncertainty ranges for various parameters (given in the previous table) were tested, and those with a significant effect on the results were singled out for further refinements from archival data. The uncertainty of food inputs does not affect the proportions of productive use and losses, only their magnitude. The assessment of the variability of the flows due to uncertainties in input data on secondary treatment and sludge handling showed some variation for the selected variables, however, they do not alter the general finding.

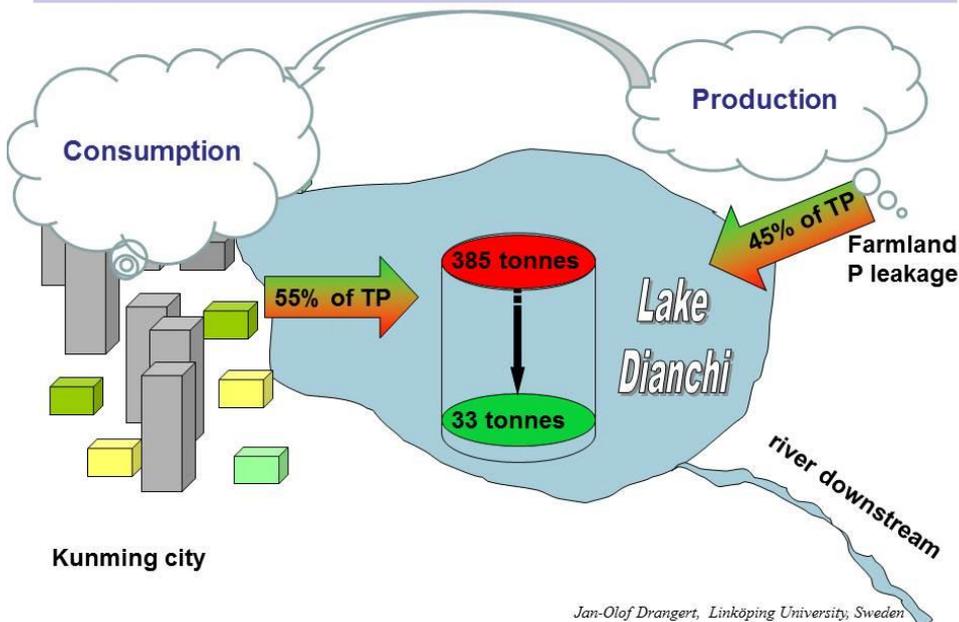
The range of uncertainty during the period 1870–1920 (the span between the extreme curves) seems to be due to uncertainties about the losses to the hydrosphere (middle graph), since its magnitude is the same as for the total losses (right hand figure).

The general impression of the left-hand figure ‘Sum of all reuse’ fits well with the manually-calculated one in the slide [1.3-13](#). The rate of reuse varies dramatically from high levels up to 1900, and then drops to almost zero around 1950. Reuse improves from the 1970s onwards with the building of a phosphorus and nitrogen removal unit at the wastewater treatment plant and the use of sludge in agriculture. Towards the end of the century the level is close to zero again after the farmers’ boycott.

In brief, the existing sanitation system is challenged by the changing composition of wastes they receive. Sometimes the result is a gradual change of the whole sanitation system, and sometimes an abrupt one.

## Example 2: Eutrophication of Lake Dianchi, China

1.3 - 16



Kunming city with its 2.4 million (2005) residents is on Lake Dianchi, one of China's largest lakes (300 km<sup>2</sup>) (<http://maps.google.com>; search key words: Kunming, China). It is a famous green lake resort but the lake is now heavily eutrophied. The shallow lake (average depth 4.4 m) is classified as having the lowest quality of lake water according to Chinese standards. This is not only a problem due to loss of tourists, but also since the lake serves as a fresh water reservoir.

The city is growing rapidly and the stress on the lake is intolerable. Nutrients are washed into the lake from surrounding agriculture (45% of TP) and effluents from the city (55% of TP). It is estimated that the lake can accommodate an annual influx of 60 tonnes of P without deteriorating. Presently (2007) the total load of phosphorus, some 700 tons, is 12 times larger than what the lake can accommodate ([Huang et al., 2007](#)).

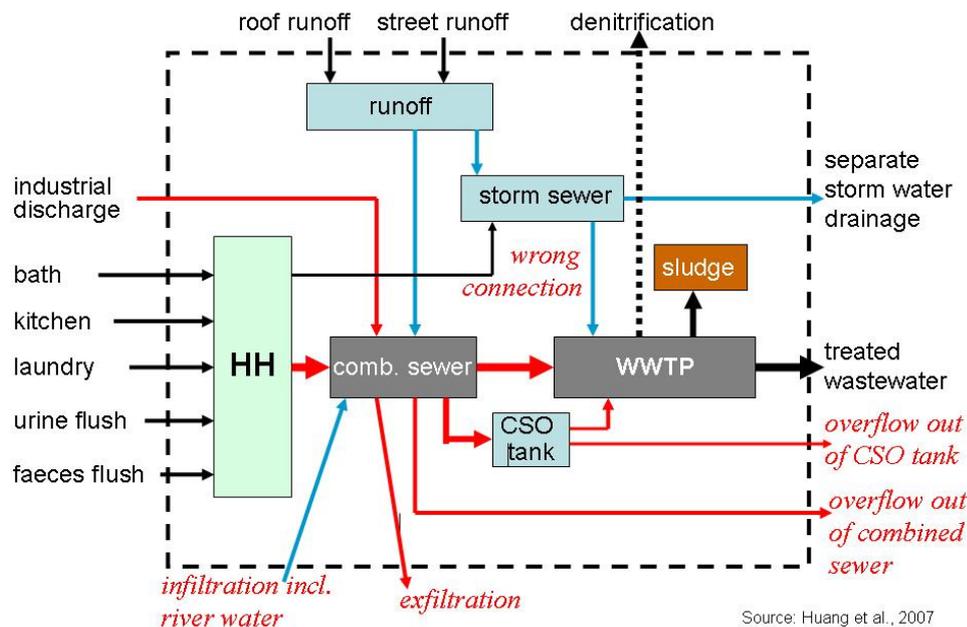
The city's environmental goal is to return the lake to the water quality it had in the 1960s, and it has invested heavily in wastewater treatment plants with high nutrient removal capability (US\$ 300 millions by 2000). However, less than 30% of the wastewater is being treated and most of the rest ends up in the lake. The authorities intend to continue to invest in improved wastewater treatment plants of modern design with the hope that the eutrophication problems will be solved. This is in line with the national law on Prevention and Control of Water Pollution. However, there is also an active interest in source control by reducing the main contributions of P and N from excreta by introducing urine-diverting toilets ([Medilanski, 2007](#)).

The city cannot influence agricultural practices which contribute half the eutrophication problem. It is possible to reduce major P leakage by preventing erosion through measures such as contour ploughing, vegetated strips along water courses, and adjusted fertiliser application rates. But the city can reduce its own annual TP of 335 tonnes. The goal is to come down to 33 tonnes (55% of 60 tonnes) through various measures. The fundamental question is whether the eutrophication problem can be solved with the proposed ever-better technical equipment.

A MFA study was conducted to get a better insight into the current situation and to analyse scenarios of the impact of potential actions ([Huang et al., 2007](#)).

## Ex. 2 Cont Urban P flow to Dianchi Lake, China

1.3 - 17



The flow chart in the picture describes the system, its boundary and relevant inputs and outputs. Most of these are obvious but some are unexpected (in red italic text). Firstly, the number of wrong connections to the stormwater sewer/drainage is high (1/3), and they alone contribute more than twice the total phosphorus (TP) tolerance load of the lake. Secondly, the combined sewers (wastewater and stormwater) are old and they leak, and only 20% of the built-up area is connected to separate storm drainage. This is serious since the water table in the area varies from 0.4 to 2.5 meters, while sewer pipes are found at depths between 1 m and 8 m. Thus, large sections of the sewers are actually in the saturated zone and this allows for heavy infiltration of groundwater and river water as well as some exfiltration of sewage. Already under dry weather conditions the incoming water to the WWTP comprises 50% ± 15% of relatively unpolluted infiltration water, but this figure can reach almost 100%. It is no surprise, then, that the average concentration of total nitrogen (TN) in wastewater is as low as 20–28 mg/l and TP 3.6–4.8 mg/l for dry weather conditions, due to high dilution levels. The present reduction rate in the WWTP is only 70% of TP. Thirdly, no CSO tank (Combined Sewer Overflow for temporary storage of rainwater) is in place, but included in one of the scenarios. It is likely to overflow a few times per year and untreated wastewater flushes directly to the lake.

All input and output flows were estimated, and the equations for each flow in the model were worked out. An uncertainty analysis ensured that the main conclusions were not affected by the shortage of data, which had been compensated for with data from the literature and informed guesses. The ensuing sensitivity analysis showed that the most sensitive parameters with respect to total emission to the lake are: population size, the specific emission per person from urine and faeces, infiltration of groundwater and rainwater into sewers, and WWTP capacity and treatment efficiency. Whether the sludge goes to incineration, landfill, agricultural reuse or any other disposal was not considered in the study.

Simulation of various scenarios points out that only a combination of measures can solve the eutrophication problem. The contribution from human excreta is huge as shown by the fact that a return to the practice of collecting and applying it on farmland would reduce the TP load from 1900t/year to about 400 t/year (Huang et al., 2007). The remaining 450 tonnes from kitchen, bath and laundry requires other source-control measures (see Module 4.5).

## Ex 2 Cont.: Outcome to guide a new strategy

1.3 - 18

1. A major problem is that during heavy rains the wastewater bypasses the WWTP and washes all wastewater straight into the lake. ➡ **Do not mix waste streams**
2. Groundwater and stormwater enter the poor-quality sewers and make up a large portion of the water coming to the WWTP ➡ **Infiltrate rainwater locally**
3. Even with the best available treatment technology (BAT with 98% P removal etc.) the discharge would still be twice what the lake can accommodate. ➡ **Source separate urine**
4. Source-control measures such as urine-diversion toilets and P-free detergents and body care products are required to avoid discharging untreated wastewater downstream the lake and, thus, just moving the environmental problems.

Source: adjusted from Huang et al., 2007

The MFA provides four scenarios for the impact of various measures on total phosphorus (TP).

**Scenario (1):** Assuming unaltered population size and best available technology (BAT) with 98% reduction of TP (instead of 70% today), no wrong connections, and only 30% infiltration in sewers, the annual load will still be **57 tons** of which 39 tons come with the WWTP effluent, 11 tons from CSO tank overflow, 5 tons from the separate stormwater drainage (because only 20% of area connected to separate storm drainage), and 2 tons from combined sewer discharge.

**Scenario (2):** As (1) but an urban population of 4.5 millions gives an annual load of **106 tons**.

**Scenario (3):** Based on scenario 2 but with 40% of the urine being collected separately. The annual load would be **87 tons**.

**Scenario (4):** Based on scenario 3, but with 60% of drainage water diverted to rivers downstream of Dianchi Lake. The annual load would be **35 tons** entering Lake Dianchi.

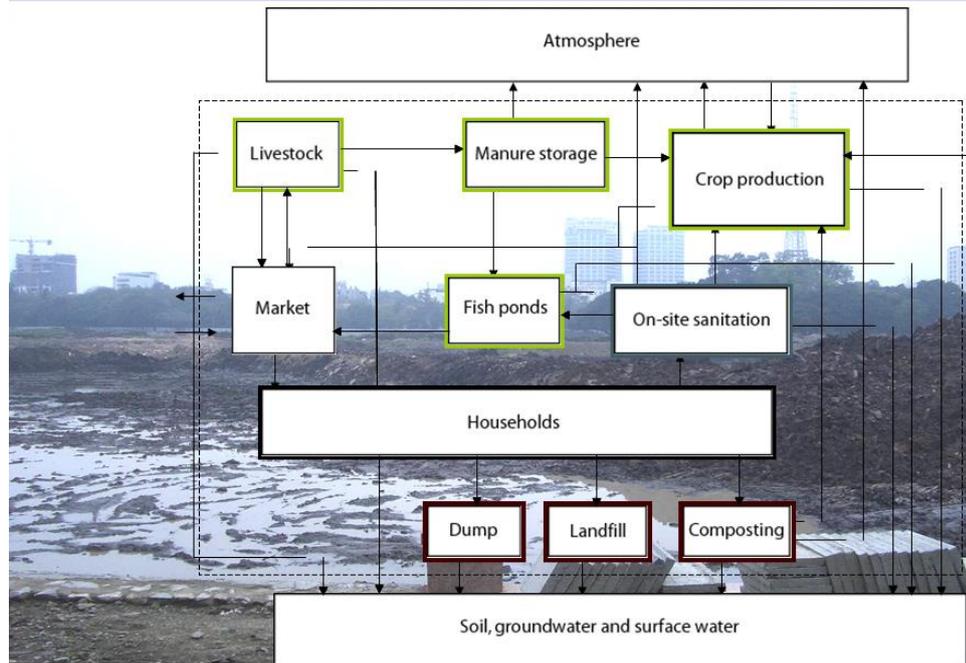
#### The main results are:

All the investment in BAT will lower the excess eutrophication from 12 times the permissible limit to less than two times. Separation of stormwater drainage and sewers will reduce incidents of combined sewer overflow and also require a smaller size of the WWTP and of pipes. Water saving in households (present use is 185 litres per person per day) would result in increased efficiency of TP removal. Urine separation toilets in only 40% of toilets will decrease TP by 20 tons per year and 100% coverage would mean a 50 ton reduction! Also, such toilets will reduce the required size of WWTP due to less nitrogen having to be removed. In Scenario 4, when 60% of urban drainage is diverted and discharge is downstream, the lake water level will be affected in an unpredictable way. Moreover, this only moves the problem to downstream towns.

The MFA demonstrates that the goal of returning to the water quality of the 1960s will never be reached with the proposed conventional approach of improved WWTPs, assuming that the allowed TP is only **33 tons** per year (55%). A combination of measures such as in Scenario 3 and revised agricultural practices reduces the eutrophication problem of the Lake Dianchi. Additional source control measures are necessary in order to avoid diverting 60% of the urban drainage discharge to downstream water bodies. This kind of presentation conveys the results in a pedagogical and convincing way. Decision makers and planners need this type of comparing outcomes to avoid ineffective measures and to help them make better planning decisions.

### Example 3 : P flows through Hanoi City

1.3 - 19



Source: Montangero et al., 2004

Hanoi City in Vietnam has a population of about 3 million (2005) and is expected to grow to 5 million by 2015. Already in 2007 the groundwater abstraction was at its limit, urban agriculture is encroached upon, and solid waste remains a problem. All these challenges need urgent attention and the council supported a MFA study to assist in formulating an effective strategy to address the looming water scarcity and to improve food availability (Montangero et al., 2007).

Presently, valuable agricultural land is being converted to compounds for residents, shopping areas, industrial sites and roads (picture). Due to incorporation of neighbouring municipalities with large agricultural areas, the reduction of urban agriculture is hidden in the statistics.

Industrialisation and economic growth are expected to continue and will speed up degradation of the environment even further by 2015. Most households have a septic tank and the effluent is discharged in sewers and drains that empty untreated into the Nhue and Red Rivers. Sludge from septic tanks is partially collected and put on landfills, while the content of latrine pits and buckets are collected and used as a plant fertiliser, often after on-farm composting with other organic waste. The uncollected waste (30%) is brought to open dumps or dumped in drainage canals, burnt in the open or recycled. Downstream of Hanoi, farmers use urban and industrial effluents as fertiliser and as fish feed.

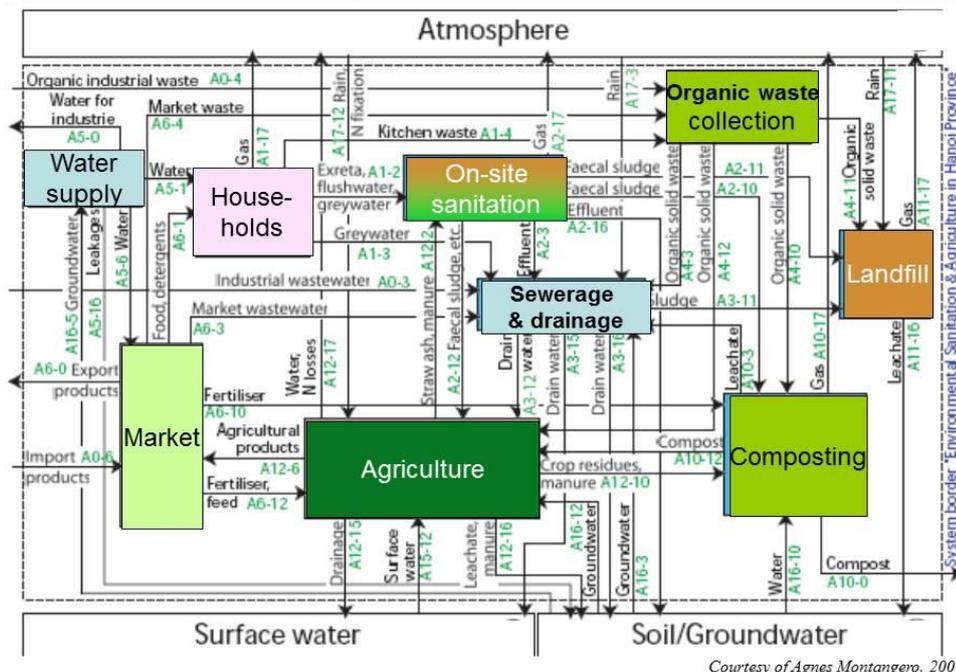
Our focus is on the P flow, but first we look at a brief summary of scenarios for water. Today's abstraction of groundwater in Hanoi province totals 620,000 +/- 90,000m<sup>3</sup> per day, of which 60% is used for domestic purposes, 25% is lost through leakages, 8% is for industry and 7% for markets. Present groundwater recharge is of the same magnitude of some 700,000 m<sup>3</sup>.

The **first scenario for 2015** assumes that the population grows to 5 million, per capita water use rises from 120 to 140 litres per day, the market area use increases 10% and the industrial use doubles. The total water demand will double and exceed existing recharge **by a factor 2**. The groundwater cannot supply all needs, and other strategies must be introduced. But, conveyance of large amounts from distant rivers is costly and will create critical local resource competition.

The **second scenario** adds on the effect of three demand-management measures: toilets are flushed with recycled water (water use drops from 140 to 113 litres per day or -16% of total abstraction), leakage is reduced from 25 to 10 % (-17%), and a 30% reduction of industrial water use (- 4%). This brings down **demand to almost the same level as groundwater recharge**.

## Ex. 3 cont.: Phosphorus flows in Hanoi City

1.3 - 20



Agnes Montangero (2007) built a probabilistic model in order to simulate the impacts of various measures on groundwater abstraction and nutrient recovery in Hanoi (picture). The model focuses on households, while industry is not included except for the overall water use and its wastewater and solid waste flows to the environment. The system boundary is shown in the flow chart (picture).

The detailed system with all phosphorus flows and stocks, and inputs and outputs is shown in the flow chart. The amount of phosphorus contained in waste products such as greywater, faecal sludge and liquid effluents from on-site sanitation installations, industrial wastewater, organic solid waste (from households, markets and industries), animal manure, and crop residues is estimated to 4,400 +/- 790 tonnes annually. Of this 44% is found in agriculture (38% in manure and 6% in crop residues), 25% in on-site sanitation effluent, 11% in greywater, 5% in organic household waste, 4% in faecal sludge, 3% in dehydrated faecal matter, and 2% in stored urine. Another 2% is in organic industrial waste. An interesting finding is that out of the P in urine and faeces which enters a septic tank, 73–89 % leaves the tank with the liquid effluent.

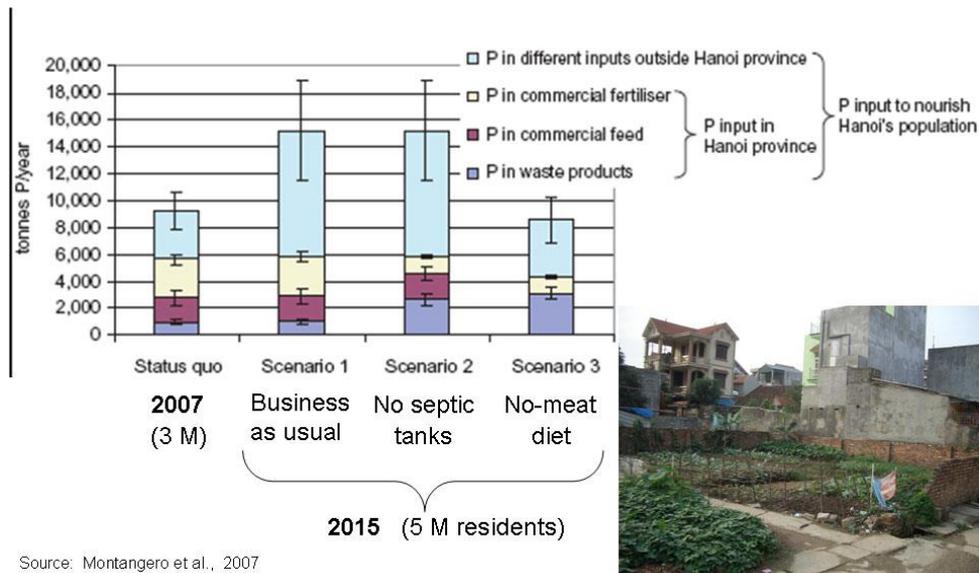
Currently, only 23 % of the P in waste products in Hanoi are recovered and used as organic fertiliser, in irrigation water, and in livestock or fish feed. This amount corresponds to 18% of the total P actually used for food production in Hanoi province. The bulk of P demand (82%) is met by artificial fertilisers and commercial livestock feed.

A significant portion of the food supply (44%) is produced within the urban and periurban areas of the province. This means that only 11% of the required amount of P is currently met by recycled waste products from the province. This may be compared with Linköping town (slide 1.3-13) which had a productive use of excreta-derived nutrients and other organics ranging from 90% in 1850 to 10% in 2000.

The expected population in Hanoi by 2030 is some 10 million. Already in 2009 the Hanoi city council decided on a future plan for 2030 which proposes to build five adjacent cities to offload the present city centre. This is necessary to help secure water supply, but there is not yet decided what kind of system requirements that will apply (Hanoi City Council, 2009).

## Ex. 3 cont Feeding the people of Hanoi - a sensitivity analysis

1.3 - 21



The *three* phosphorus scenarios for the year 2015 include a population increase from 3 to 5 million residents, and in addition: 1) business as usual, 2) replacing septic tanks with urine-diverting toilets, and 3) as in 2) but also eliminating meat from the diet.

Each scenario may be compared with the status quo only if keeping in mind that this involves no population increase.

The bars indicate the required tonnes of P per year to feed the population (error bars indicate the standard deviation). The upper light-blue section of the bars represents P input in food produced outside the province, but consumed in Hanoi. Almost all food for the additional 2 million population will be imported from outside the province (scenarios 1 and 2). In scenario 2, when the septic tanks have been replaced by nutrient-collecting toilets, the recovery rate of P increases from 18 to 45%, and this can replace most of the P supplied by commercial fertilisers. At the same time, the polluting discharges from the septic tanks to the environment are reduced.

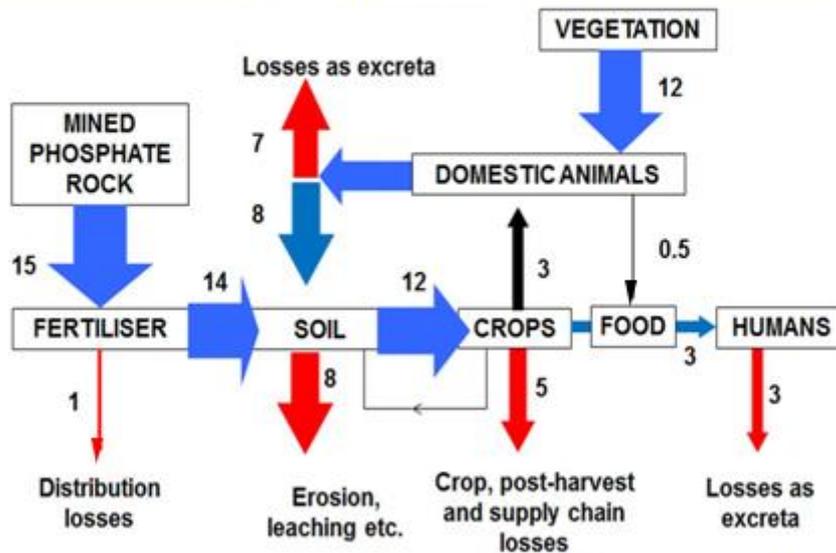
The amount of commercial feed remains the same in the status quo and in scenarios 1 and 2. This indicates that much of the meat products eaten by the newcomers to Hanoi will be imported from other provinces.

The greatest change occurs when meat is deleted from the diet (scenario 3) and the protein intake is compensated by a higher consumption of fish, beans, soybean, and nuts. Since meat production requires two times more nutrients per meal than vegetable diets, the total demand for P goes down to almost half compared to Scenario 1 and 2. The polluting discharges are reduced drastically and so is the demand for P rock. Animal manure is no longer generated so the total amount of P in waste products decreases sharply. The area under cultivation increases, but the amount of organic fertiliser remains about the same due to the slightly reduced application rates. P from recycled waste products rises from 45 to 82%. The P demand covered by waste products in peri-urban agriculture rises from 46 to 74% and from 18 to 36% for food production including imports from other regions,

The MFA as presented here has several benefits. It creates a system understanding very quickly, and can convey the magnitude of flows. MFA is a good communication platform between different sectors, and an entry point to integrate technical, social, economic and institutional aspects. But one should not underestimate the requirement of data and expertise to build the model and run the calibration and sensitivity analysis.

### Example 4: Nutrients and food security- a simplified global mass balance

1.3 - 22



Source: Clift and Shaw 2011, based on Cordell and others

When trying to predict what will happen with P at the global scale in the coming 50 years, we are really challenged by lack of data. Still, MFA may assist. A recent study of phosphorus futures estimated the phosphorus flow from rock mines via fertiliser and crop production to human and animal consumption (Cordell et al., 2009a) and an industrial ecology approach to the present use of phosphorus as in above slide (Clift and Shaw, 2011).

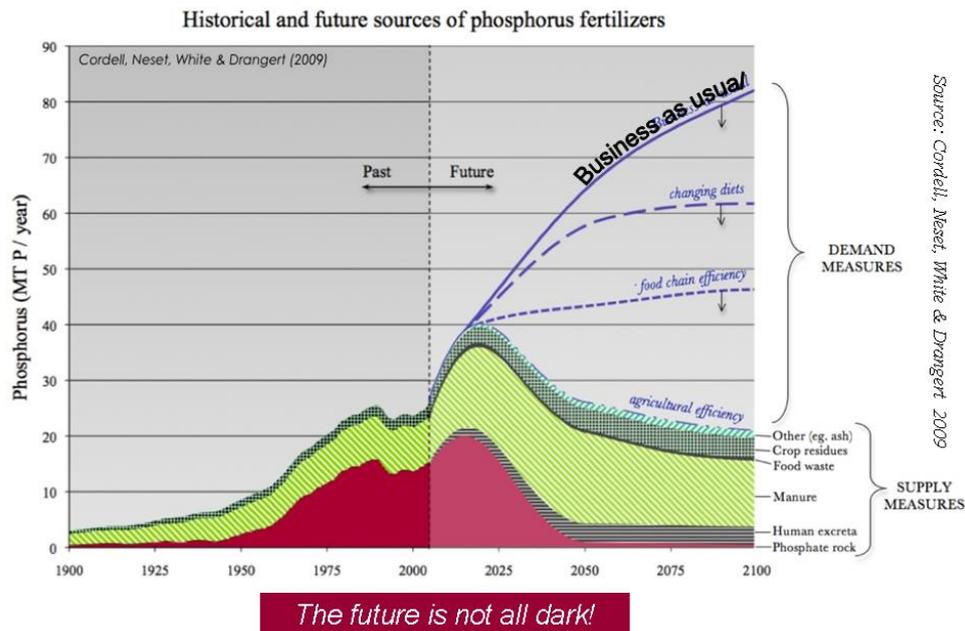
Today, food production relies heavily on chemical NPK fertilisers, and plants and animals need the P for survival. P is available in soils, but needs to be added to poor soils and to compensate for the P in biomass that is taken off the field.

Ninety per cent of the mined phosphorus is used in agriculture and the rest is found in detergents and other products. The diagram shows that 15 mega tonnes (MT) of mined P goes to manufacture P fertilisers and the P flow ends up with 3 MT in human excreta. The diagram also indicates where losses occur along the way. The main losses are from soil erosion, animal manure losses, crop residue losses, losses in the food chain, and the non-use of human excreta.

With today's rate of mining P and limited productive recycling of P in the various steps (losses), the economically viable reserves some researchers estimate that it will last about one hundred years and the peak production is estimated to occur around 2035. Others anticipate a much longer grace period. In this training material the view is that irrespective of the number of remaining years, there is a compelling reason to save on P resources and not waste them. A detailed discussion about what measures can be devised to close leakages in the system and save on P resources is found in Module 5.1.

Ex 4 cont. **Securing a sustainable phosphorus future**

1.3 - 23



The graph tells about past usage and about future projections for phosphorus in world food production. The diagram shows that the use of mined P (dark red area) increased rapidly in connection with the Green Revolution in the 1950s with irrigation, new varieties of rice and chemical fertilisers. By 1990 the use went down due to over-fertilisation in Europe and North America, and reduced demand from poor farmers and governments who could not afford the increase in price of P fertiliser. The P rock reserves will soon be producing less and have to be complemented by other sources of phosphorus. Animal manure (dashed yellow area) use remained about the same during the 20th century and cannot replace rock P in the future. Increases in returned biomass (black dotted area) left in the field after harvest is also not enough to replace rock P.

The huge gap between projected demand and supply of phosphorus towards the end of this century is shown in the diagram. The demand for P (blue line) – will grow rapidly if we continue ‘business as usual’ due to the growth of world population, changes in diets, etc. The demand from poor farmers will decrease due to price increases and reductions in their harvests due to exhausted soils. By 2050 the easily exploitable phosphate rock reserves will have been exhausted. This looks like a dark future for food production in the world and will cause havoc to agriculture as we know it. We will not be able to feed all people, and we are faced with the Malthusian threat of recurrent famines (slide 1.4-1).

The truth is, however, that the prospect of food security is good if we only improve the present poor management of the P resource! There is only scarcity of good management, not scarcity of the P resource – if we recycle what we have.

This good management includes measures that will affect every individual on the globe and that will require a lot of political and civil willpower. The sanitation and agricultural sectors have to abandon their present linear flows and develop recycling systems, and the present trend toward more meat-based diets must be reversed and we must become more vegetarian (see Module 5.1).

## Strategies for sanitation improvements

1.3 - 24

**Principle:** *mix as few flows as possible*

- Organic **≠** other solid waste
- Stormwater **≠** sewage
- Industrial **≠** household wastewater
- Black toilet water **≠** greywater
- Faeces **≠** urine

*Jan-Olof Drangert, Linköping University, Sweden*

Given that most environmental problems are caused by untreated waste and wastewater, our focus is on organising the sanitation arrangements so that treatment becomes easy. It is obvious that the fewer flows we mix, the easier it is to treat them since we know quite well what to reduce or take away. *The overriding principle is to mix as few flows as possible.*

Organic waste often makes up more than half of the total solid waste volume, and can be used productively as a soil conditioner after a composting process, possibly via a biogas production step. Most other solid waste can be sorted and reused or recycled into new products.

In most cases the mixing of stormwater and sewage is a bad idea. The volume to be treated increases and thus the treatment efficiency is reduced and during heavy rainfalls the treatment plants may overflow temporarily. Such events can reduce the treatment results significantly (as in Lake Dianchi, slide [1.3-18](#)).

Much of the industrial wastewater is already treated by the industry because it wants to recover compounds that can be used again in the production process. Many countries also require the industry to treat the wastewater before directing it to the municipal treatment plant.

If faeces are not mixed with any other matter its disease-causing pathogens are not to be found in the other flows, thus making them safer. According to the WHO Guidelines ([2006](#)) there are several affordable and safe methods to handle and treat faecal matter (see also Chapters 3 and 4). Nutrient-rich urine can be collected and used in agriculture with few restrictions.

If excreta are mixed with flush water, this so-called toiletwater may also be gainfully and safely used to produce biogas. The slurry can be treated and used for irrigation and as fertiliser.

The remaining fluid from a household, in the form of greywater (no toilet water) contains items such as detergents, shampoo, wasted medicines, paint residues etc. If the household only uses biodegradable products it is possible to treat the greywater and recycle it – as long as it is not mixed with industrial wastewater.

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