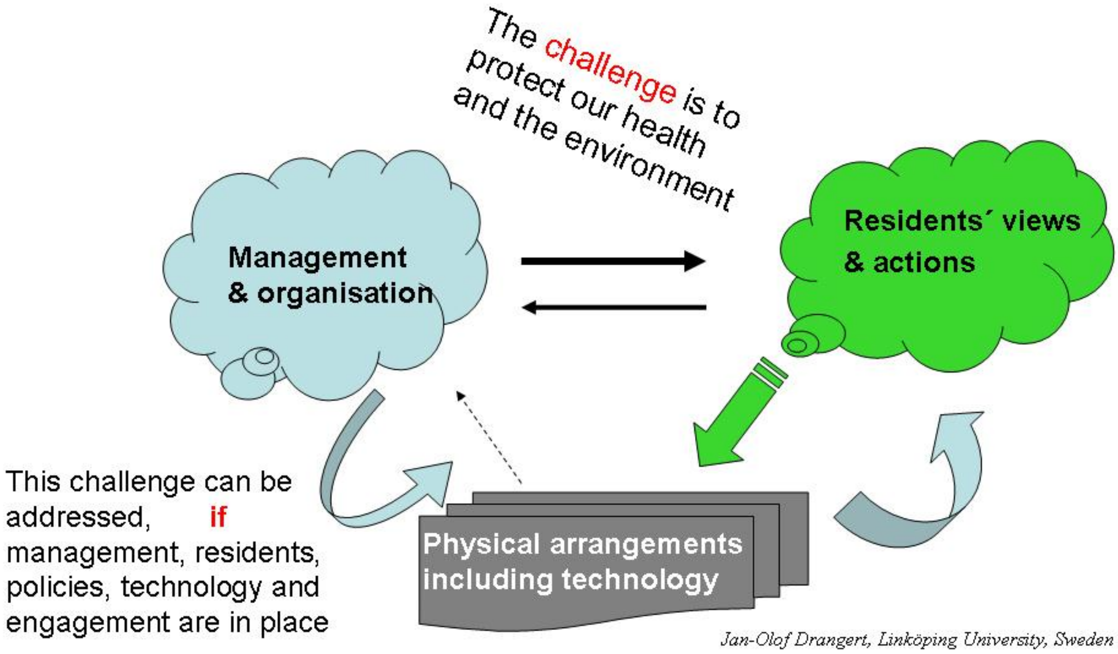
Ch 1. Sustainable sanitation - a review



Sanitation is about ensuring safe conditions for human beings and their communities. The aim is to protect our health and the environment. People themselves play a crucial role in improving sanitation conditions, while health professionals and environmentalists can give guidance about what to do. However, are health professionals yet up to the task? Dr. Jamie Bartram at WHO wrote recently:

> "In developing countries, some 2.6 billion people invest a significant proportion of their household time or money in simply securing drinking-water or somewhere private to defecate. In the European Union, planners are preoccupied with the cost of serving the public´s preference for bathing in sewage-free seas – as enshrined in the Bathing Water Directive, its most popular legislation.
>
> Intervention studies report reductions in diarrhoeal disease incidence averaging 25-37 %, and – using the criteria of the Commission on Macroeconomics and Health – these interventions are cost effective or very cost effective in developing countries. Even the findings value only health outcomes – analysing all impacts indicates a benefit that can be valued at 3 to 34 dollars per dollar invested.
>
> … Yet water is fundamental to both unfinished business; diarrhoea, re-emerging cholera, malaria control, Guinea worm eradication and drowning prevention - and to the new health agenda. This agenda includes non-communicable conditions such as fluorosis, arsenicosis, hydration-related effects and exposure to modern pollutants. …
> A public health perspective in water management provides opportunities to both improved population health and reduced costs.
>
> … The slow progress in extending basic services leaves a billion people waiting in line for services to reach them. But empowering households to take charge of water quality can dramatically reduce diarrhoeal disease. Since the establishment of the WHO network for safe household water in 2003 there has been a tangible shift from seeing this empowerment as a dangerous competing approach to a complementary response.

Is the health system adequately prepared to exploit these opportunities? Often not. The need for surveillance of water-related disease is recognized … but surveillance systems are often ineffective. … Similarly, health impact assessment - which considers health impact in local decision-making - is rarely required. Tools to address costs and impacts of policy and technical alternatives are only now in development.

Water is critically important for health. Yet it is typically low on the health agenda and the health system is often ill-equipped to engage effectively. It is time to re-engage. " (Bartram, 2008)

Sanitation is implicit in the above account. But, sanitation is too important to be appended only to water, and it deserves attention in its own right. Careful reading of the Millennium Development Goals shows that improved sanitation is promoted, but mostly indirectly as a by-product of other measures. In this chapter we give an overview of sanitary conditions in the world and the role sanitation can play for human wellbeing and for the environment.

In Chapter 3 we provide a full account of hygiene issues with a focus on microorganisms and risk management.

In the quote from Bartram above, he only hints at the emerging chemical society when writing "… exposure to modern pollutants." These pollutants are discussed in this chapter but more fully in Module 4.5 – 4.7 in connection with treatment of wastewater containing medicinal residues, persistent organic compounds, heavy metals, antibiotics and other pollutants.

Chapter 1 provides updated information on sustainable sanitation as evidenced today:

Module 1.1 deals with 'Sanitary conditions in the world'

Module 1.2 deals with 'Resources-from waste to reuse and sustainability'

Module 1.3 deals with 'Physical resource flows'

Module 1.4 deals with 'Demographic change'

1.1 Sanitary Conditions in the world

How do we perceive sanitary conditions?
What functions must a sustainable system fulfil?

***Learning objective*:**

To become familiar with various sanitary conditions in the world, functions of sanitation, and to foster a critical understanding of statistics and other data.

Jan-Olof Drangert, Linköping University, Sweden

Sanitary conditions vary over time and between places. For a long period of time, sanitation was about protecting humans from disease and death. This was a time when a hundred or two hundred infants out of a thousand live born died before the age of one. In the last half century infant mortality figures have dropped dramatically and are now mostly in the range of a handful to 60 deaths out of 1000 live born (UNICEF, 2008). Many different improvements have contributed to this positive development, not least improved sanitation behaviours.

Sustainable sanitation has gained importance in the last half-century, inspired by the fall in infant mortality and morbidity. Another reason is that population growth and growth of consumption per capita put pressure on natural resources to produce the products as well as on a degrading environment by poor disposal of the used goods. A study of human footprints on nature showed that the 29 largest cities of the European part of the Baltic Sea watershed appropriate - for their resource consumption and waste assimilation - an area of forest, agricultural, marine, and wetland ecosystems that is at least 565 – 1130 times larger than the area of the cities themselves (Folke et al., 1997). The largest area was required for waste assimilation. Can the situation be improved with recycling and reuse of used resources?

When silk and porcelain was transported on the Silk Road from China to Rome in return for glass two thousand years ago, the environmental impact was negligible. The amounts were small and the means of transport required only human and animal energy which would have been used anyway. When China today is the manufacturing powerhouse of the world and providing lots of goods to billions of people the impact is sizeable. Emissions from transports alone contribute substantially to global warming. This is one reason why today information appears about the environmental impact of several products. This is an important information tool to make individuals conscious of their own impact on the global environment.

Sanitation must not be reduced to an issue of toilets. In this introductory chapter on sustainable sanitation we present the width of sanitation issues, comprising clean environment incl. water and wastewater treatment, solid waste management, grey water and excreta/sludge disposal, storm water handling, and personal and household hygiene. Some pictures will illustrate these points.

1.1 - 3

Data on sanitation conditions in the world are indicative rather than exact, since countries define adequate sanitation slightly differently and data is not updated regularly. WHO and UNICEF (2010) recommend some definitions, but each country can adopt their own standards. Their Joint Monitoring Programme estimates that 2.5 billion people lack adequate sanitation by 2015.

The global statistics tell that about 2 of every 10 people in the developing world were without access to safe water in year 2000; 5 of 10 lived without adequate sanitation; and 9 of 10 lived without their wastewater being treated in any way (IMF and World Bank, 2003). The combined effects of unsafe water and poor personal and environmental sanitation are considered to be the most important risk factor for diseases and death (Murray and Lopez, 1996). Yet, more human and financial resources are directed towards other sectors than to sanitation. This is why sanitation is viewed as “the silent crises”.

Municipal and city councils as well as international organisations focus on installation of piped water supplies and to a lesser extent on sewers and wastewater treatment plants. The reported data to the Millennium Development Goals (MDG) global statistics on water and sanitation take for granted that if piped systems are in place, the community has solved the silent sanitation crises. Yet, it is well known that technical systems can fail for shorter or longer periods of time. Therefore, we endorse function-based definitions in this material. For instance, a function-based definition of water quality is that it is safe to drink all the time, instead of taking for granted that a piped water supply always provides safe drinking water. Safe water may contain microorganisms, even pathogens, but not in quantities that cause illness with a certain probability.

Malnutrition lowers the body´s self-defence towards all kind of diseases. Since sanitation deals with organic material, good fertilisers can be produced to increase food production. Thus, sustainable sanitation can reduce malnutrition. A proper sanitation policy can play a strategic role to improve health as indicated by Bartram (slide 1.1-1).

In the following slides some data are given about technical infrastructure and backlogs that the MDG tries to address.

1.1 - 4

Proportion of households in major cities connected to piped water and sewers

	House or yard connection for water (%)	Connected to a sewer (%)
Africa	43	18
Asia	77	45
Latin America & Caribbean	77	35
Oceania	73	15
Europe	96	82
North America	100	96

Source: *Stockholm Water Front*, No. 4 December 2007

The coverage of piped water in major cities in 2007 was fairly high, while coverage of sewerage was much lower, except for North America and Europe. In smaller towns the difference is likely to be even greater. The data reflects the emphasis on water supply over the previous decades, and the modest interest in sewerage. This is particularly evident from data on wastewater treatment plants as shown in the next slide.

There is a general view among experts that proper sanitation poses special challenges to achieve in urban areas, as described by Barbara Evans, Leeds University:

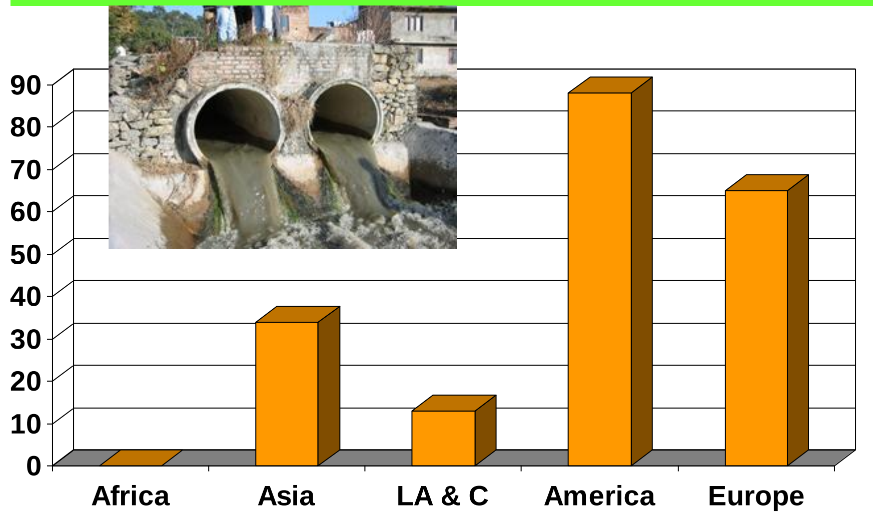
> Providing urban sanitation services, as compared to rural sanitation or other urban services poses special challenges. One central challenge is that services to the household have to be embedded within a workable, sustainable and effective urban system, which in many areas does not exist. A city's infrastructure or lack thereof, impacts its ability to install functional sanitation systems, especially in slums. This connection goes both ways, as wastes generated in the slums – such as excreta, greywater, stormwater runoff. – negatively impact the city as a whole. Regrettably, cities generally have a poor track record of positive engagement with underserved and marginalised communities. Self-help in communities that lack adequate sanitation only works over long periods of time if integrated with the holistic planning and functions of the city. (Stockholm Water Front, No 4. December 2007)

This is true when thinking along conventional municipal-wide solutions, since the rapidly growing towns are next to unmanageable (See Module 1.4). The prospect of improved sanitary conditions, in particularly in informal areas, is brighter if the authorities accept a wider range of solutions that communities and households can organise and implement. In Module 2.1 five inspiring local examples are presented.

Countries and cities with a low percentage figure for sewers have an advantage from the point of view that they can select an appropriate treatment method without inflicting sunk cost for previous investments. Examples are to take care of wastewater on individual plots or to lay low-cost condominium sewers as in Brazil (Melo, 2005). 18% coverage for sewers in Africa means that 82% can install sustainable on-site solutions at a much lower investment and running costs than centralised piped systems.

1.1 - 5

Wastewater - collected and treated by effective treatment plants (median percentage)



Source: UNDP & UNICEF 2003 (Fig. 3.13)

Equally important as provision of infrastructure, is the issue of where the sewer pipes end up. The diagram shows that only a small fraction of the urban wastewater is being effectively treated, again with the exception of North America and to some extent Europe. However, more detailed information would be necessary in order to let the statistics guide strategies. In the end, it is only possible to draw up a strategic plan for a known community. For instance, greywater (no toilet water) from a single household that uses few chemicals needs very little treatment and can safely be poured on the ground. Source-control can thus give a better result than sophisticated treatment of wastewater loaded with chemicals from households and industries. A common experience of effective treatment plants with too small capacity to treat all water, in particular during heavy rainfall, shows that they may discharge substantial volumes of organic matter and other substances directly to the receiving water (slide 1.3-17). For instance, the sewers in London overflow into the Thames about 60 times per year, and pollute the river. Half of London's water mains are thought to be more than 100 years old and a third could be over 150 years old – and leaking to the groundwater (Deloitte, 2011). These issues are addressed in the Modules 4.5 – 4.7 dealing with greywater.

As in the case of sewers, countries with a low coverage of plants to treat wastewater can have an advantage in that they can select an effective and efficient system without inflicting sunk costs of previous investments. They still have the option of treating at the source or at the end of pipe. They may also plan for treating not only today's wastewater but also the anticipated future constituents of wastewater.

Treatment plants produce sludge and the more effective the treatment is, the more contaminated sludge is produced! If sludge did not contain contaminants from a mix of industrial and household chemicals, it could be turned into a good fertiliser. However, most sludge from treatment plants has to be treated before use or contained. In the following chapters we will discuss affordable methods to treat wastewater to a quality level which makes it possible to use sludge with little risk of accumulation of contaminants in the soil. A decent treatment before use would cost only 0.3-0.5 USD per cubic meter (IMF and World Bank, 2003).

1.1 - 6

Stormwater, solid and organic waste

Stormwater drainage as a conduit for solid waste

Animals scavenging organic material and clogged storm water drains

Jan-Olof Drangert, Linköping University, Sweden

Storm water drainage is an important part of sanitation, and how it functions can often serve as a litmus test for other components of a city´s sanitation system. Poor solid waste collection compels residents to use drains to get rid of waste, which may result in clogged drains and inundation of low-lying settlements (pictures above). Also cities with functioning waste collection and sewerage frequently face problems caused by occasional large downpour of rain. This is particularly common where there are combined sewers. Large enough combined sewers are too costly, however. It is next to impossible to divert all rainwater and a partial solution is to collect and use or recharge rainwater on site. New housing complexes in Berlin are required to make on-site arrangements to infiltrate the rainwater. However, it is more common that cities remove existing pond and tank systems to build roads and buildings and thereby block natural routes for stormwater. The result is recurrent flooding of parts of the city.

Another common cause of flooding, which is beyond the city's jurisdiction, is found upstream where water-containing forests have been cleared and the river straightened out and even walled (Mississippi, the Rhine, Ganges and other rivers). Storm water can flush whole cities and where there are sewers, these are washed out and the content may spread disease. Even wastewater treatment plants can be flushed out, and wastewater and sludge end up in rivers and lakes. Such disasters are often called natural, but they are actually made possible by human activity. Another way of obscuring the cause-effect is to say that such events only occur with long intervals, and the longer this period is it seems that the likelihood of remediation goes down.

The amount of solid waste is steadily increasing with improved living standard. The only solution to growing mountains of disposed solid waste is to sorting in fractions what can be recycled, reused or incinerated while hazardous waste is stored. The solid waste aspect is only dealt with in connection with organic matter in this sourcebook. Suffice it to mention that there is an established waste handling hierarchy (EU Waste Directive) that is not very different from what applies to wastewater as we interpret it in slide 1.3 - 8:

1. Reduce waste volume and harmful content in products,
2. Recycle items that are possible to use again,
3. Treat and use the material to make new products,
4. Incinerate what is left in order to generate energy, and
5. Hazardous products are stored or put safely on a landfill.

1.1 - 7

Pathogens thrive in specific environments and, for example, bacteria thrive where there is substrate to feed on. Improved sanitation is about creating barriers and harsh conditions for the pathogens. For instance, the pictures above show a narrow alley that was paved with cement. The man hole indicates that a sewer line is collecting the wastewater from the adjacent houses. The alley became easy to sweep and mosquitoes have no wet debris where to breed. Stormwater runs off easily to irrigate fields which also become infiltration sites. Greywater is no longer disposed in the alley.

The exercise is to discuss the reductions of pathogen exposure to human beings. For example, if used water is just disposed outside the housing area, mosquitoes will still breed and enter nearby houses. Kids are likely to play there and they may attract helminths and disease-causing vectors. Half-measures may therefore not improve people´s health as expected.

The second part of the exercise is to suggest further improvements of the sanitation conditions in this alley and beyond. Just like members of the community need to think through the entire flow system and pay attention to how the flow ends. One way is to think in terms of a waste handling hierarchy (see previous slide) for getting rid of disease-causing matter in a safe manner.

There are a lot of technical solutions available. A challenge lies with organising the process to upgrade the urban environment (Module 2.3) and to select a sustainable arrangement (Module 2.5).

The kids in the pictures are exposed to very different levels of health risks. One important aspect of sanitation is about keeping humans and pathogens apart as far as possible.

There are numerous options for defecation arrangements. The choice may be guided by local tradition, religion, economic conditions, taste, modernity or self-image or a combination. A commonplace communal pour-flush toilet (top-left) often functions poorly and the content may be emptied in a nearby drain. This is not very different from open defecation and resembles ”delayed open defecation”. Better is, for instance, to bury the excreta in the soil or in a shallow pit such as an arbor loo (see Module 5.4). The challenges facing public toilets are discussed in detail in Module 5.2. Common sense tells that the chance to keep the toilet clean and functional increases if it is a private one in the home. In addition, toilets that keep urine and faecal matter separate (top-right) are hygienic – and productive if urine and treated faecal matter is used to fertilise a garden.

Chapter 3 presents a wide range of measures that reduce health-risks, not the least for the most vulnerable groups in society. One important function of any defecation arrangement is to keep excreta away from the water cycle, and divert products to soil as rapidly as possible. As can be seen from the two lower pictures, nutrients from faeces do NOT belong to water but to soil, food production, and to make our environment green.

The cost issue is important for any aspiring household. In many cities there is no choice but the existing flush toilet, and the household cannot influence what happens to the black water after flushing. On plots with no existing building, on the other hand, any arrangement can be considered. The selection process should build on what functions are to be fulfilled (see table below). A selection procedure is presented in slide 2.5-11.

One way to receive relevant information about costs could be to check on a typical existing arrangement (slide 2.1- 3). The case of a private house in Kathmandu, Nepal, shows that the extra investment for in situ water and toilet arrangements was repaid in six years by not being obliged to pay water bills. In two centuries the value of the whole house would be earned from paying no bills. In addition, the household is ensured 24 hour water supply and does not contribute to the city’s stormwater or wastewater problems.

Table: Sanitation Cost Ladder for Conventional and ecological Sanitation Methods

Conventional Sanitation (sourced from UN Millennium Project, 2005; original source UNEP 2004:9			**Sustainable Sanitation** (various sources)	
	Method	Estimated cost per person (USD) incl. operation and maintenance		Method
Mainly urban	Tertiary wastewater treatment	800	340 (1190 per household (hh)) China Dong Sheng EdoSanRes Programme	Urine-diverting high standard porcelain dry toilet (indoors); piped urine system, dry faecal collection and composting, decentralised piped grey water treated using septic tank, and aeration treatment local collection and transportation costs included
	Sewer connection and secondary treatment	450	330 (1500 per hh) Sarawak (Mamit et al, 2005)	Conventional indoor toilet with sealed conservancy tank, black water collection by truck; local biogas digester; decentralised piped greywater treated using septic tank and vertical biofilm filter technique
	Connection to conventional sewer (without treatment)	300	150 (675 per hh)	Indoor dry single-vault urine-diverting pedestal toilet; decentralised piped greywater treatment using constructed wetland: local transportation included
Mainly peri-urban	Sewer connection with local labour (without treatment)	175	88 (400 per hh) South Africa 25 (110 per hh) Mexico, El Salvador, India, South Africa, Zimbabwe (Morgan 2005)	Dry single or double-vault urine-diverting squatting pan or pedestal toilet with permanent upper housing structure: greywater treatment and disposal on site: local recycling
	Septic tank latrine	160	12 (55 per hh) Nanning, China 8 (35 per hh) West Africa Klutse &Ahlgren 2005	Dry single or double-vault urine-diverting squatting pan or pedestal toilet with permanent upper housing structure: greywater treatment using on site infiltration pit; transportation assumes as local labour
Mainly rural	Pour-flush latrine	70		
	Ventilated improved pit latrine	65	8 (40 per hh) Zimbabwe, Mozambique. (Morgan 2005)	Soil composting pit with cement slag and simple upper housing structure (Aborloo or Fossa Alterna); greywater treatment and disposal onsite; local recycling
	Simple pit latrine	45		
	Improve traditional practice	10	3 (10 per hh) (estimated)	Soil composting shallow open pit; soil added after each use

Source: (SEI, 2005)

1.1 - 9

Diseases related to excreta and wastewater

Disease:	Mortality (death/year)	Burden of disease*	Comments
Diarrhoea	1 800 000	62 000 000	99.8% of deaths occur in dev. countries; 90% are children
Typhoid	600 000	no data	Estimate: 16 million cases/year
Ascariasis	3 000	1 800 000	Estimate: 1.45 billion infections, of which 350 million suffer adverse health effects
Hookworm disease	3 000	60 000	Estimate: 1.3 billion infections of which 150 million suffer adverse health effects
Schisto-somiasis	15 000	1 700 000	Found in 74 countries, 200 million estimated infected, 20 mi with severe consequences
Hepatitis A	no data	no data	Estimate: 1.4 million cases/yr. Source: WHO, 2006

* DALYs/year estimates the time lost due to disability or death from a disease compared with long life free of that disease (See Ch 3).

Excreta and wastewater contain high concentrations of pathogens, and excreta-related infections are common in many countries. The failure to properly treat and manage wastewater and excreta worldwide is directly responsible for adverse health and environmental effects. Human excreta have been implicated in the transmission of many infectious diseases, including cholera, typhoid, viral hepatitis, polio, schistosomiasis and a variety of helminth infections. Most of these excreta-related illnesses occur in children living in poor environments. Overall, WHO estimates that diarrhoea alone is responsible for 3.2 % of all deaths and 4.2 % of DALYs worldwide (Module 3.1). In addition, 16 million people contract typhoid and over *one* billion people suffer from intestinal helminth infections (Table).

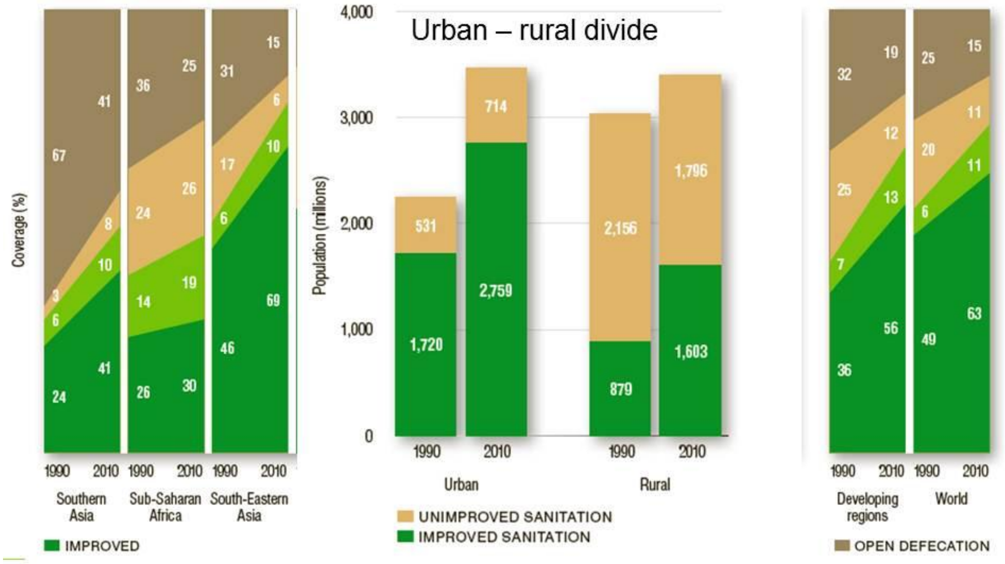
Diarrhoea or gastrointestinal diseases are often used as a proxy for all excreta-related infections. The average person in the USA suffers from 0.79 episodes of acute gastroenteritis (diarrhoea, vomiting or both) per year. Worldwide, adults suffer the same magnitude of gastroenteritis. However, children especially those living in high-risk situations generally have a much higher rate and one study found the rate to be 3.2 episodes per child per year (WHO, 2006).

Generally a well-nourished child stands a much better chance to have a mild effect of an infection compared to a mal-nourished child. Several studies show that children who are living in poor sanitary conditions are infected with one infection after the other. They hardly recover from one before they attract the next, and in severe cases this may lead to stunning (Mata, 1978).

The table above compiled by WHO (2006) gives some rough data on the magnitude of some common diseases. The diseases affect billions of people and causes death for millions.

Sanitation coverage trends by developing region, and urban-rural divide 1990-2010

1.1 - 10



Source: UNICEF and World Health Organization, 2012

The diagram shows the improvements in sanitation arrangements in the world between 1990 and 2010. The proportion of people with so called improved arrangements have increased by one-third, while the number of people without improved toilets also has gone up. The definition of improved and unimproved sanitation used for the data is as follows (Unicef & WHO, 2012):

Improved sanitation:	Unimproved sanitation:
Flush or pour-flush to: - Piped sewer system - Septic tank - Pit latrine	Flush- or pour flush to elsewhere (htat is not to piped sewer system, septic tank or pit latrine)
Ventilated improved pit (VIP) latrine	Shared or public facility of any type
Pit latrine with slab	Pit latrine without slab, or open pit
Composting toilet	Bucket toilet
	Hanging toilet or hanging latrine
	No facilities, bush or fields (open defecation)

The above definition seems to take into account accessibility to some degree and health issues (in toilet rooms as well as in the environment). The improved arrangements are fairly safe (e.g. a slab is easy to keep clean) and the excreta is contained or treated to some extent before release to the environment. The potential contamination of groundwater through seepage from pits is viewed as acceptable. The unimproved arrangements include those that pose a threat to the environment, or where excreta are not contained, or those that are difficult to keep clean (e.g. being used by more than one household, toilets may not be hygienic and fully separate human waste from contact with users, and may not be available at night, or used by children).

The definition does not consider nutrient reuse aspects (Module 5.1), and only indirectly the aspect of easy access to hand-washing (slide 5.3-4).

The fact that rural population remains almost stagnant at about 3 billion people is reflected in the table as increased coverage of improved facilities, most clearly for water, but also for sanitation. Regions with low sanitation coverage today will need to make a substantial effort to reach the MDGoals, such as rural Southern Asia, Sub-Saharan Africa and East Asia.

The slide shows that 15 per cent of the world population still practise open defecation, defined as defecation in fields, forests, bushes, bodies of water or other open spaces. This represents 1.1 billion people of which 626 million live in India. Though the proportion of people practising open defecation is decreasing, the absolute number has remained at over one billion for several years, due to population growth.

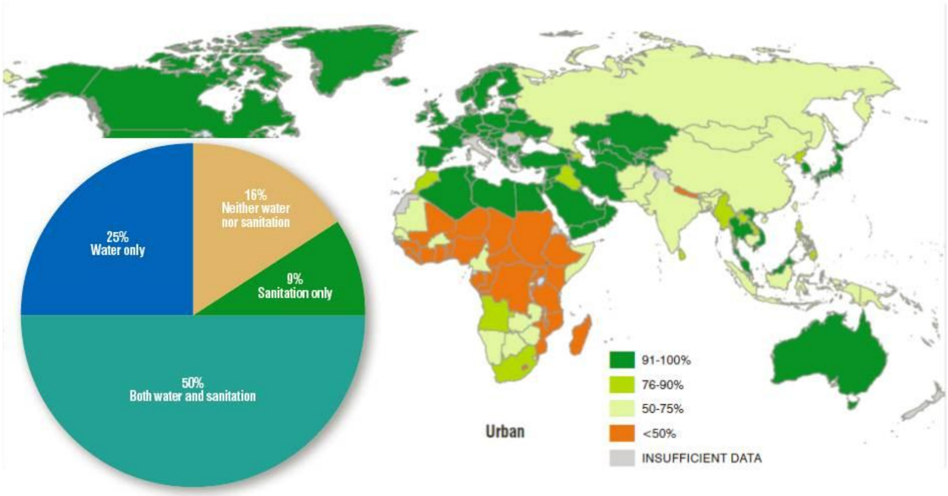
The figures on open defecation need to be commented on. Open defecation is a disputed issue about which local and professional views often differ. If 'open defecation' is instead defined as defecating in the open and leaving the excreta exposed like dogs do, but different from cat behaviour, a range of defecation practices do not qualify as open defecation (Drangert & Bahadar, 2011). Women going out in the dark to a designated place are not seen defecating, and they do cover the faecal matter. A man defecating behind his robe is not seen defecating, although any passer-by understands what is taking place. If he covers the faecal matter it is not counted as open defecation. The next level of being seen is when someone defecates behind a straw or mud wall; no one can see what is going on but anyone understands that the person goes to that place for urination or defecation. If there is only a cat hole in there, then this situation is little different from attending an ordinary toilet room. If there is a pour-flush toilet in there, the discharge goes to a pit or to a sewer or an open drain or to the street. The latter two cases represent a kind of delayed open defecation where the sewage is left in the open.

According to this definition, very little open defecation takes place among adults. However, children are seen defecating indiscriminately, and their faeces are likely to be collected only when found inside the compound. A widespread perception is that children's faeces are harmless. Therefore, they may not be considered to be in the wrong place if they are found in public places. Non-farming sections of communities have little experience-based reference to nutrient loops, so they may adopt more restrictive views on what is a right place and what is orderly. The fact is that child faeces contain equally or more pathogens than adult faeces which makes open defecation among children a serious health concern.

There is a marked difference in attitudes to the role of water: professionals say that adding excreta contaminates water, while farmers may claim that adding water to excreta will change the colour, smell and appearance of the excreta and thus make it less risky. This perception can be used to justify the use of wastewater for irrigation (and fertilisation) without upsetting social order. It is similar to the tradition of farmers encouraging defecation in their fields and to applying partly composted human excreta in agricultural fields. This practice is in line with the concept of waste being in the right place (reused) according to their tacit understanding of a nutrient loop. The same goes for the widely accepted practice of peeing near to fruit trees. Often, peeing on the ground is perceived as orderly since urine disappears almost immediately.

Improved urban sanitation coverage 2010

1.1 - 11



Proportion of the population in 59 developing countries using both improved drinking water sources and improved sanitation (per cent)

Source: UNICEF and World Health Organization, 2012

2.5 billion people were estimated to lack improved sanitation in 2010 (Unicef & WHO, 2012). Of these, 1.8 billion live in rural areas and 0.7 billion in urban areas (up 183 million since 1990). Already at this stage data has to be interpreted carefully since the definition of urban and rural differs between countries. Urban sprawl in the last decade has made 830 million people live in urban slums 2010, up from 770 million in 2000 (UN-Habitat 2008). This would mean that less than half of the slum dwellers had access to so called improved sanitation. Proportions of slum dwellers are declining, but numbers are growing. As we near 2015 the 'running target' of slum dwellers targeted for Millennium Development Goals (MDG) will increase considerably if the UN population estimate holds of more than 6 billion urban dwellers (up from 3 billion) by 2050.

Shared sanitation is defined as sanitation facilities of an otherwise acceptable type that are shared between two or more households, including public toilets. Globally, the number of people using shared sanitation is growing and the number of users has increased by 425 million since 1990 – an increase from 6 per cent to 11 per cent in 20 years. For instance, hundred thousand Sulabh community toilets have been built in India, but they are not counted as improved toilets in the JMP statistics. Shared sanitation is predominantly an urban phenomenon, and over 60 per cent of people using this type of facility live in urban areas. In many countries, particularly in crowded urban areas, shared sanitation is the only viable option for those wishing to avoid open defecation; in rural areas, families often keep costs down by sharing latrines between one or more households with family ties (Unicef & WHO, 2012).

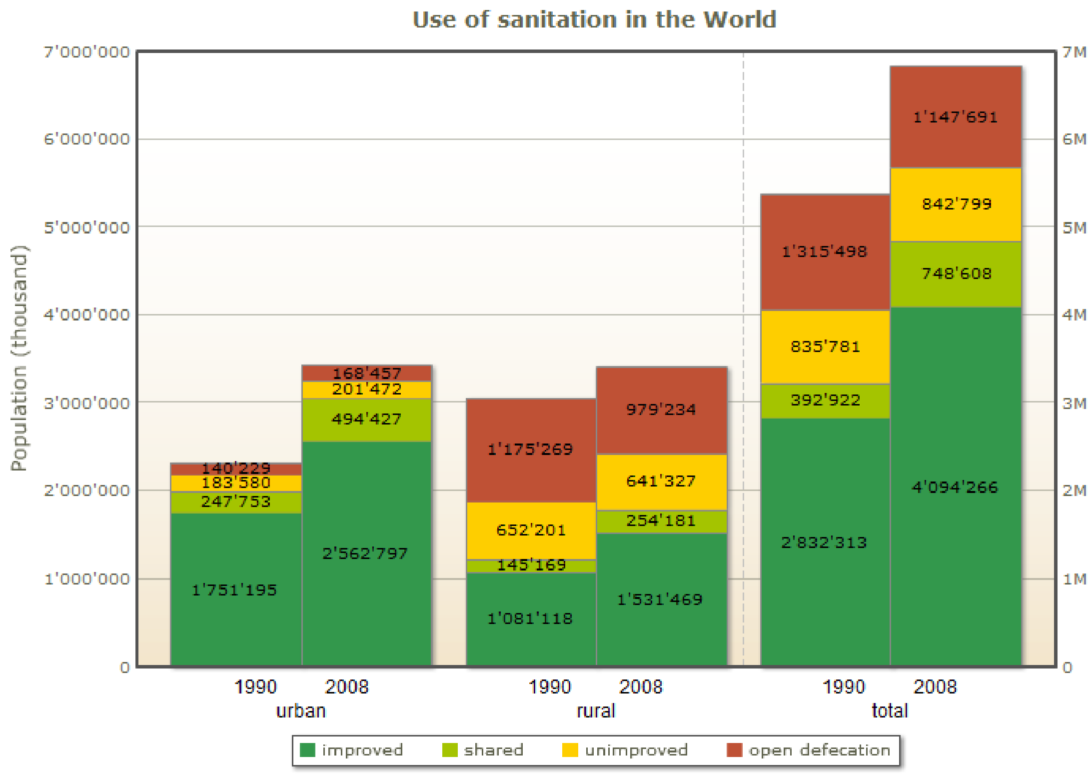
The capacity to attain the MDGs could be more favourable in urban areas than in rural areas, since the proportion of the population of working age is much higher. It may or may not be easier to construct infrastructure here than in rural areas, however, due to factors such as corruption, inefficiencies and simply lack of space for locally organised *own-key* arrangements (see Module 1.4). Several examples of decentralised urban arrangements are presented in Module 2.1.

The World Water Development Report (2006) stated that, while we are globally on track to meet the 2015 drinking-water target, we will miss the sanitation target by over half a billion people if current trends continue. WHO (2006) stated at the World Water Forum:

"*In sub-Saharan Africa, where coverage of both drinking water and sanitation is lowest in the world, there is a looming threat that both targets will be missed. And in South Asia, governments are challenged to provide access, to sanitation in particular, to the largest group of people in absolute numbers. The conclusions are clear: we need more and more effective action, so that efforts to achieve the targets can be intensified and trends effectively adjusted. At all levels, available resources need to be used more efficiently. This applies as much to the efficient use of human resources as to the use of water resources themselves*". Such strong statements are important, but words will not be enough.

The statement takes the stand that GOVERNMENTS are challenged to provide. This view is itself challenged by many stakeholders, for instance the comment made by Jamie Bartram about household inputs (slide 1.1). The reality is that water infrastructure in urban areas is paid by residents as connection fees and through water bills, while governments have taken the necessary loans for the investments. Governments are in charge of the framework for sector development, but not for providing all necessary financial and other resources. Unfortunately, utilities and financing institutions are almost exclusively planning new infrastructural developments as blue-prints of existing conventional centralised solutions. The time is ripe for rethinking how to make the urban water cycle sustainable by considering also decentralised systems (Module 2.1). This message is clearly challenging for professionals, and the issue will be discussed throughout this sourcebook.

The Joint Monitoring Programme (2010) provides data on the number of water and sanitation arrangements there are of various kinds. The table can be read as a list of backlogs of MDGs.



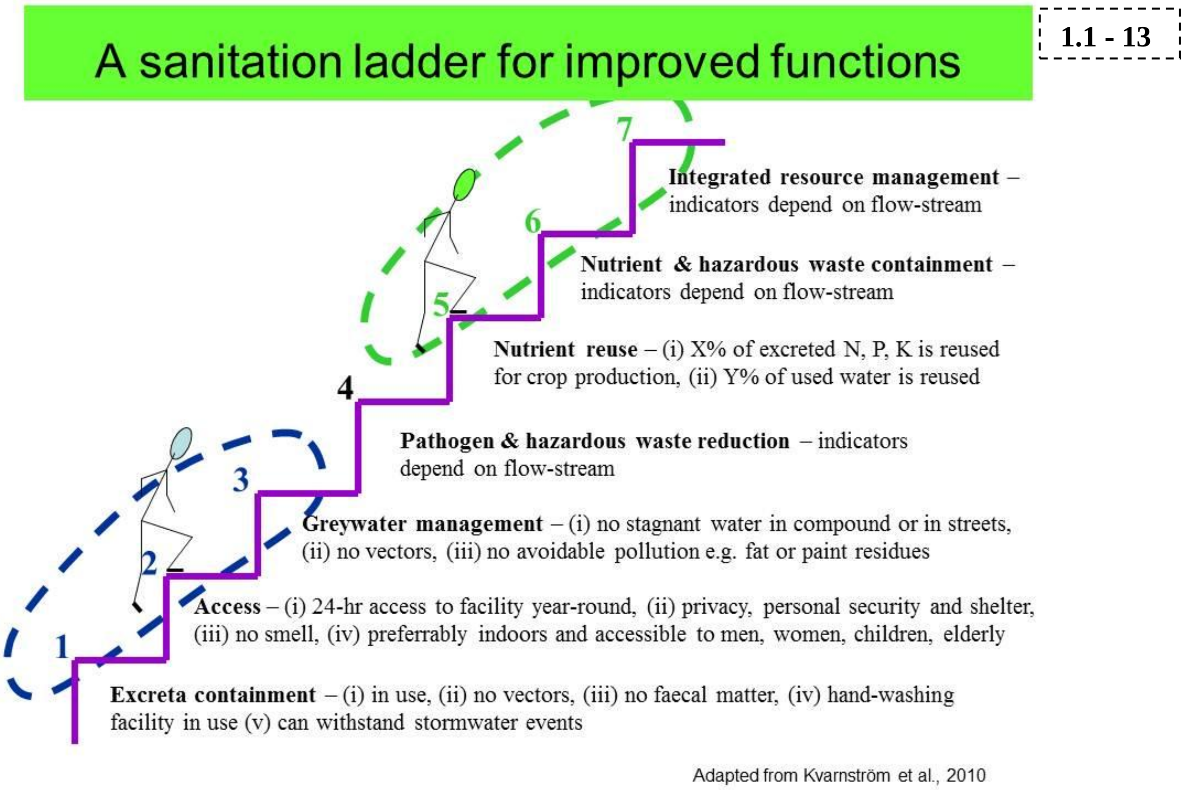
1.1 - 12

Sanitation measures include attaining clean water, managing solid waste, safely disposing grey water and excreta, handle stormwater, and practise personal and household hygiene. Some pictures of the above points are shown in the slides 1.1-6–8.

Two new requirements have been added; the arrangement must be acceptable to residents and represent an environmentally sustainable solution. In the next picture we will discuss what sustainable sanitation includes, but one point should be mentioned already here. Material flows through the sanitation system must contribute to sustainability. This demanding requirement joins sanitation to other sectors in society, foremost the agriculture sector. This is not a new situation, but has been forgotten for a century.

A fundamental change has taken place over the last century. Few consumer products were available before industrialisation and landfills were small. Most products were biodegradable, such as wooden equipment and building materials. Soap made of vegetable oils was used for all kind of cleaning. Household wastewater could thus be used for irrigation purpose without any treatment. Industrialisation brought in new non-degradable products which were discharged in the sink or toilet. The wastewater could be quite contaminated and as more chemical products entered the market since 1940s, the quality of the wastewater from households has degraded (Module 4.5). In order to meet these new challenges, authorities have to engage in activities such as source control to reduce waste volumes and hazardous content, reuse, recycling, incineration and proper landfill.

Today, major challenges are environmental in nature. The receiving water bodies cannot accumulate the loads of nutrients and pollutants, and finding space for new landfills is problematic. Solutions require revised policies, management and technical arrangements to be ’sustainable’. Fortunately, not only goods and air-borne pollution are transported between countries and continents, but also information and knowledge about ways to solve environmental problems.



We may define a sanitation ladder or hierarchy which orders improved functions related to human health and the environment (blue for health and green for environmental in picture). People can climb the ladder by moving to a new dwelling or by improving the one they inhabit.

Typically ladders are based on technology arrangements, but in this sourcebook the focus is on how arrangements function in real life and therefore a function-based ladder is advocated. It is certainly more demanding to assess functions than counting the numbers of various technical installations, but the information is vastly more useful. The following account is a slightly revised version of a ladder by Kvarnström et al. (2010) by adding aspects of hazardous waste. The ladder is intended to be universally applicable and technology neutral. Each step includes all functions of the previous step(s).

1. The first function is to **contain faecal matter** since it poses the greatest health risk: This function comprises well-known containment of excreta (e.g. no-open defecation, faeces out of reach for children, toiletwater out of reach for humans and groundwater) and barriers to pathogen spread (e.g. no flies or rodents, washing hands, no fingers in the mouth, covering food items). The containment must function also during heavy rains and regularly occurring flooding.

2. The second function comprises **easy access to the facility:** It should be available 24 hours a day, easy to reach from the house/flat preferably indoors and with no stairs to reach and with a hand washing basin nearby, and provide personal safety and privacy. If so, the facility is also user-friendly to less able persons. Users should also encounter a clean and odour-less toilet room in order to be encouraged to use it with care.

3. The third function concerns **greywater management** (the toiletwater is dealt with under the first step): Greywater should be disposed of so that no stagnant water is formed (mosquito breeding) and no pollution of groundwater or surface water occurs.

4. The fourth function is to **reduce pathogens and hazardous waste to levels which are safe:** Allow long enough storage time for urine and faecal matter to make them safe. Avoid using products containing hazardous waste and use biodegradable products whenever possible. Decrease levels of pathogens, organic matter and hazardous/toxic waste in sludge, toiletwater, and greywater below risk limits.

5. The fifth function concerns **reuse of nutrients:** Treated faecal matter, urine and/or safe sludge are to be used productively to increase food and energy production.

6. The sixth function deals with **containment of hazardous waste and nutrients:** Any treatment removes only partially nutrients and hazardous/toxic waste from the water, and they will be found in the sludge (or emitted as gases). Controlling that nutrient and hazardous waste levels released to the environment are below background levels in nature.

7. The seventh function is about **integrated resource management:** The resource flows to and from communities are managed in a coordinated manner in order to minimise waste volumes. The sanitation sector should be re-connected to the agricultural, manufacturing and energy sectors. The hierarchy for a sustainable end-of-flow is (Slide 1.3 – 8):

(a) Reduce waste volume and harmful content of products,

(b) Reuse items that are possible to use again,

(c) Treat and/or recycle the material to make new products,

(d) Generate energy of what is left through incineration or biogas production, and

(e) Hazardous products are destructed, stored or put safely on a landfill.

Thinking in terms of functions provides an incentive to include activities that each stakeholder can perform. Oftentimes a particular outcome can be achieved in more than one way.
Heavy metals can be removed from wastewater by filtering through a carbon filter, but it can also be achieved by a conscious choice of consumer products not containing these heavy metals. The integrated resource management embraces the chain from making products to use and further to treatment and disposal. The issue of selecting technical solutions should be raised only after the analysis of desired functions has been done.

1.1 - 14

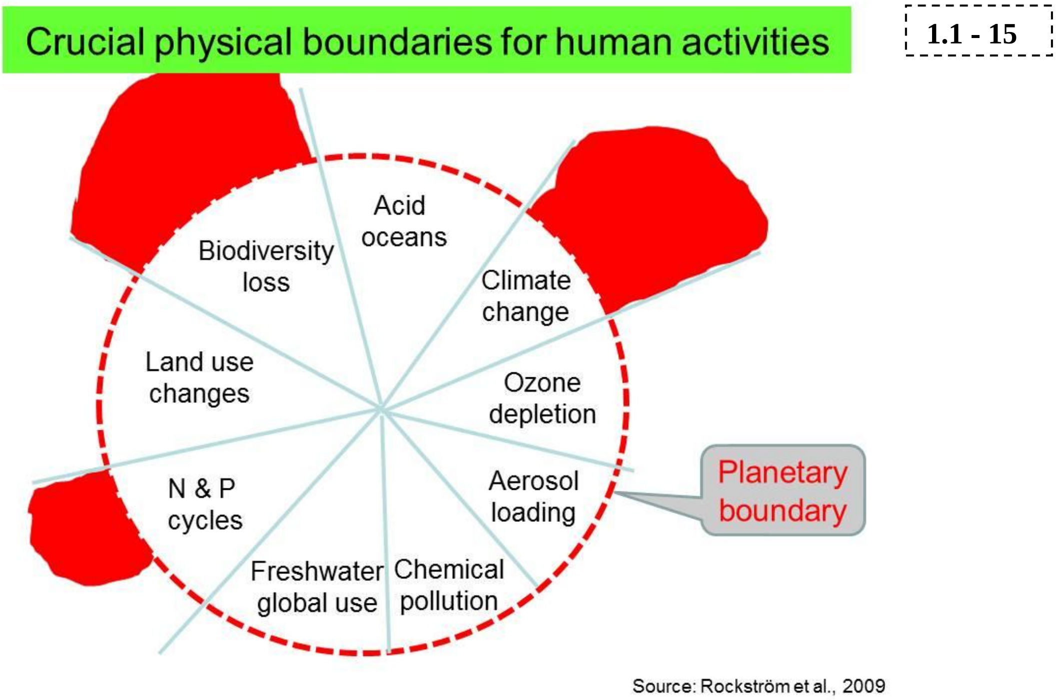
The Bruntland Commission's outline of sustainability set the stage for more detailed criteria of sustainability. There is general agreement about long time line and dealing with components such as ecology, economy, social, resource saving and, to a lesser extent, reuse. In the case of sanitation we include (picture) care about human health and the environment, and being appropriate in a wide sense. These criteria are analysed and used throughout the sourcebook.

Recirculation of plant nutrients from human waste to agriculture was very common in the period prior to late industrialisation in Europe and other countries. In connection with the dramatic growth of large conglomerates of workers and industries the nutrient flow changed direction and were flushed away through sewers (slide 1.3-13). This caused stress in agriculture since at that time there were hardly any alternative fertilisers.

Cities in those days comprised everything from pigsty, urban food production, and local use of human excreta to multi-storey buildings with piped water supply and sewerage. Worries that agriculture was being deprived of plant nutrients by introducing flush toilets is often represented by a quote from *Les Miserables* written by the French author Victor Hugo:

> Science, after having long groped about, now knows that the most fecundating and the most efficacious of fertilisers is human manure. The Chinese, let us confess it to our shame, knew it before us. Not a Chinese peasant -- it is Eckberg who says this -- goes to town without bringing back with him, at the two extremities of his bamboo pole, two full buckets of what we designate as filth. Thanks to human dung, the earth in China is still as young as in the days of Abraham. Chinese wheat yields a hundredfold of the seed. There is no guano comparable in fertility with the detritus of a capital. A great city is the mightiest of dung-makers. Certain success would attend the experiment of employing the city to manure the plain. If our gold is manure, our manure, on the other hand, is gold (Hugo, 1862).

Today, we anticipate a looming scarcity of nutrients, in particular phosphorus, potassium and sulphur, during this century which will affect our possibility to feed the growing world population (Module 5.1). Again, recycling of human excreta will be part of the solution that the sanitation sector can provide.



The concept of sustainability has now advanced beyond a vision into what is required to transform the world in the present era of change. The sanitation sector will play a strategic role in improving global sustainability as evidenced in this resource book.

Planetary boundaries are real (Rockström et al., 2009). They define the safe operating space for humanity with respect to the Earth system and are associated with the planet´s biophysical subsystems and processes. Today, most of the thresholds can be given by a value for one or more control variables, such as carbon dioxide concentration in the atmosphere (350 parts per million by volume). Two of the identified 9 boundaries have no threshold values yet (see slide). Three planetary boundaries have already been transgressed; the rate of biodiversity loss, climate change and the human interference with the nitrogen cycle. The variables and their boundary values are indicated below together with the present values and pre-industrial values.

Climate change (measured as CO_2 concentration < 350 ppm and radiative forcing < 1 watt per sq. m) is kept at bay if the temperature increase is below 2^{o}C above the pre-industrial level. Today, the CO_2 concentration is already 387 ppm, while the pre-industrial level was a mere 280 ppm. The radiative forcing is now 1.5 watts/m^2 and is estimated to have been zero around the year 1800.

Rate of biodiversity loss (as number of extinct species < 10 per million and year) has accelerated massively caused by e.g. land-use change. Current loss is estimated at >100 per year and fossil records indicate a pre-industrial loss rate of <1.

Nitrogen cycle change (as amount of N_2 removed from the atmosphere for human use < 35 million tons per year) is now at 120 million tonnes of reactive nitrogen mainly for production of fertilizers. Runoff of N and P from soils to water bodies cause pollution. The pre-industrial level of N_2 removal was zero.

Phosphorus cycle release to oceans (as millions of tonnes of P < 11 per year) is presently some 9 million tonnes, while the oceans released some P to soil and atmosphere before 1800.

Stratospheric ozone depletion (as concentration of ozone in the atmosphere < 276 Dobson units) is now 283 units, while it is estimated to have been 290 units in pre-industrial period.

Ocean acidification (as saturation level of aragonite in surface seawater < 2.75 units) has now reached 2.90 while the pre-industrial level was 3.44.

Global freshwater use (for human use < 4,000 km^2 per year) is now 2,600 km^2 per year and rapidly increasing while it was very small, 417 km^2, in pre-industrial period with almost only rain fed agriculture.

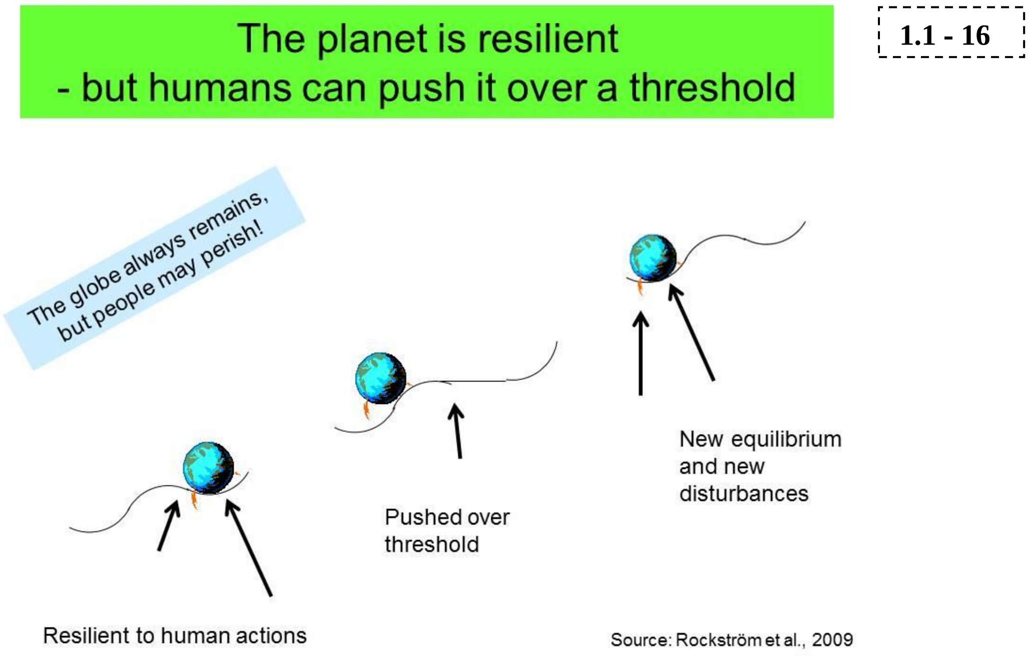
Changes in land use (as % of global land cover converted to cropland < 15 %) is now at 11.7%, while very small areas were converted to cropland before industrialization when the total world population was still below one billion people.

Atmospheric aerosol loading (variable and value to be determined) deals with the overall particulate concentration in the atmosphere such as dimming effects.

Chemical pollution (variables and values to be determined) deals with all more or less hazardous compounds that are being manufactured or unearthed for human use (persistent organic pollutants, endocrine disrupters, heavy metals and nuclear waste, etc.). The chemical society emerged after the Second World War and has accelerated since then.

An interesting and important observation is that the sanitation sector as defined in this source book will play a crucial role in preventing from coming close to most of the mentioned planetary boundaries. For instance, recycling nitrogen and phosphorus from the food chain back to agriculture would reduce the need for removing N_2 from the atmosphere and phosphate rock from the ground.

Although the planetary boundaries are described in terms of individual quantities and separate processes, the boundaries are tightly coupled. If one boundary is transgressed, then other boundaries are also under serious risk. For instance, significant land-use changes in the Amazon could influence water resources as far away as Tibet.



Recently (2011), a group of prominent researchers and Nobel Laureates discussed the leading themes of global sustainability under three headings; reconnecting people to ecosystems, from hunter-gatherer to planetary stewards, and tipping towards sustainability. The group recognizes the new situation at hand with unprecedented challenges of solving interrelated issues such as poverty, inequality, food security, and environmental degradation, and concludes on a rather optimistic note that the capacity and ingenuity to deal with these challenges exist – and **given that** we channel our creativity in a way that reconnects human development with the biosphere (the global ecological system) and continue to develop within planetary boundaries (Symposium on Global sustainability, 2011).

The first theme on **reconnecting people to ecosystems** outlined the gradual divorce between people and ecosystems from early Industrialization (1800). Five key messages are provided:

1a) In spite of immense technological development and progress, our economies and societies still fundamentally depend on ecosystems to provide us with a hospitable climate, clean water, food, fibres and numerous other goods and services;

1b) It is time to fully realise that our societies and economies are integral parts of the biosphere, and to start accounting for and governing natural capital. Poverty alleviation and future human development cannot take place without such a wider recognition of nature´s contribution to human livelihoods, health, security and culture;

1c) The issue at stake extends beyond climate changes to a whole spectrum of global environmental changes that interplay with interdependent and rapidly globalizing human societies. Science has a great responsibility in this respect to provide better understanding of the multiple challenges facing humanity and to explore solutions for sustainable development in an increasingly unpredictable world;

1d) Resilience thinking is an important part of the solution, as it strives at building flexibility and adaptive capacity rather than attempting to achieve stable optimal production and short-term economic gains;

1e) It is time for a new social contract for global sustainability rooted in a shift of perception - from people and nature seen as separate parts to interdependent social – ecological system. This provides exciting opportunities for societal development in collaboration with the biosphere; a global sustainability agenda for humanity.

The second theme concerns **the human-dominated planet** where our responsibility expands to cover all parts of our planet. Oceans are here viewed as a forgotten aspect of the functioning of the Earth as a whole. The key messages are:

2a) The human imprint of the planet´s environment is now so vast that the current geological period should be labelled the ’Anthropocen’ – the Age of Man;

2b) Human pressure has reached a scale where the possibility of abrupt or irreversible global change – challenging our own well-being – can no longer be excluded;

2c) The challenges of the 21st century – resource constrains, financial instability, inequalities, environmental degradation – are a clear signal ’business-as-usual’ cannot continue;

2d) We are the first generation with the knowledge of how our activities influence the Earth as a system, and thus the first generation with the power and the responsibility to change our relationship with the planet;

2e) Effective global stewardship can be built around the ’planetary boundaries’ concept, which aims to create a scientifically defined safe operating space within which humanity can continue to evolve and develop.

The third theme of **tipping towards sustainability** regards the social-ecological innovations for planetary opportunities. The 5 key messages are:

3a) An immense number of sustainability initiatives are emerging (transition towns, clean energy, agroecological farming, ecosystem-based fisheries management, etc.) Such initiatives need to be upscaled through e.g. innovation funds, seed money, structural adjustment funds and other incentives in order to have a global impact. Social media and associated advances in information and communication technologies can play a role in this process;

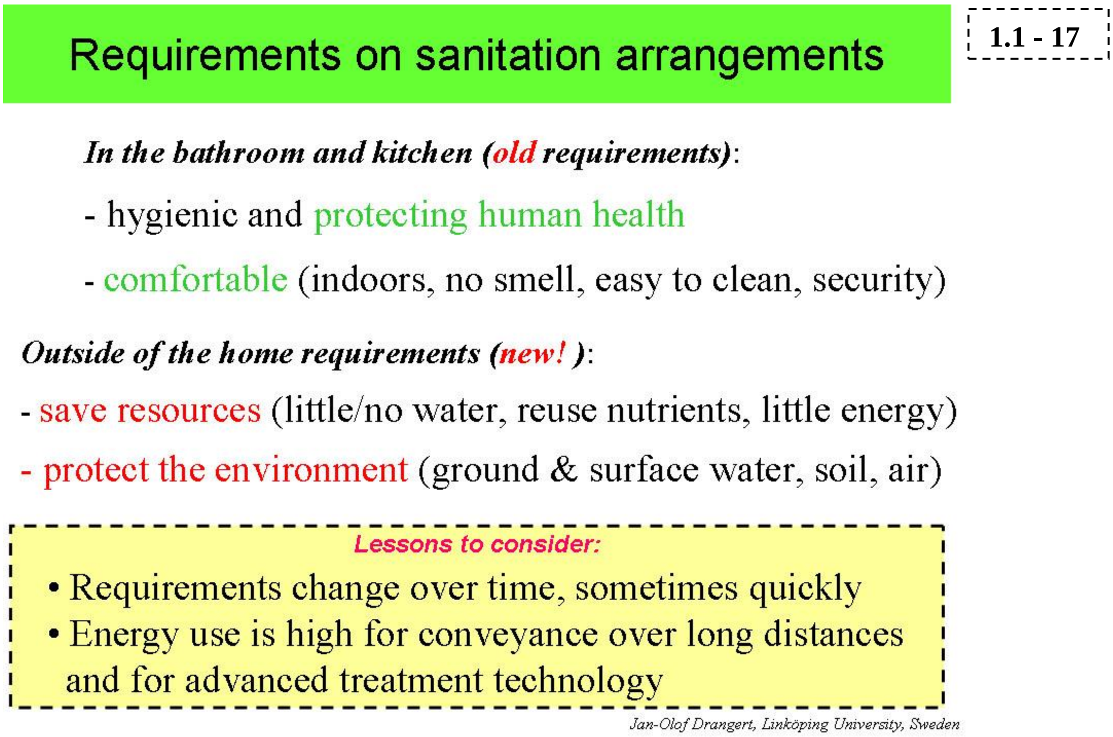
3b) On-going large-scale transformations in e.g. information technology, biotechnology and energy systems have the potential to significantly improve our lives in a sustainable way, but only if we incorporate knowledge of social-ecological systems and planetary boundaries in risk assessments and development strategies;

3c) Most current economic and technological solutions are ecologically illiterate and too linear and single problem-orientated. What is needed is financial and political support for safe-fail experiments in communities around the world, using diverse technologies, organisations and ideas, for instance in ’Policy Laboratories’ or ’Change Labs’;

3d) Policy makers around the world need to adopt a new system thinking that pays much more attention to the negative side-effects of quick fixes and recognizes the numerous possibilities in investing in sustainable use of ecosystems and their services;

3e) We need a new type of social-ecological innovations and technologies that work more directly for social justice, poverty alleviation, environmental sustainability and democracy, while including the creativity and ingenuity of users, workers, consumers, citizens, activists, farmers and small businesses alike (excerpt from Symposium on Global sustainability, 2011).

Ecosystem services and the resilience of the planet have served our activities rather well up to now, but we have reached a stage where we push the planet out of its present equilibrium. Next slide will discuss how that might happen, and here we end with a matter of fact: The planet will remain after such a shock, and it is the human community that will suffer – to the extent that it may perish.



Requirements on sanitation arrangements change over time, because of changes in lifestyle and material wealth. They may also change in response to changes in environmental impacts and awareness, as witnessed by the issue of climate change and planetary boundaries (1.1 – 14&15). Our perceptions about what is beneficial may also be influenced or manipulated by ads and business interests.

Urban residents tend to take good care of private bathrooms, and invest in affordable arrangements. But, they also tend to put a blind eye to environmental problems away from the home as long as these are perceived as having no solution.

Introducing an improved sanitation arrangement contributes to a healthier environment in the cities where they are installed, but often they do the opposite for those living downstream. The reason is that reduction of pathogenic organisms and chemicals is often insufficient. Conventional treatment plants were developed to remove large particles, biodegradable organic substances and nutrients in order to protect receiving waters from eutrophication. Only recently is the removal of the chemical content in wastewater in focus (Module 4.5). Today´s treatment plants are not designed to remove all pathogens and chemical compounds. For instance, residues of medical products are not trapped in the treatment. Therefore, even if functioning properly, the discharge from conventional wastewater treatment plants is still not safe, failing to meet the quality requirements of bathing water, if the dilution with cleaner lake water is not large enough.

Conventional sanitation systems often fail the new requirement of saving resources since reuse of compounds is minimal and energy use is high for conveyance over long distances and for sophisticated treatment of wastewater. In Sweden, for instance, many hamlets were connected to urban utilities and water had to be pumped tens of kilometres, and the wastewater was pumped back the same distance to a centralised wastewater treatment plant situated on the outskirt of towns. The energy cost for pumping is prohibitive today and cannot be expected to go down in the future. The calculations done when building these infrastructures in the 1960s and -70s did not take the energy use and cost seriously because cheap energy was available (slide 2.3-11).

1.1 - 18

Saving water at your home

Activity	Method practiced	Qty lit	Method to be adopted	Qty lit
Brushing	Running tap for 5 min	45	Tumbler or Glass	0.5
Hand washing	Running tap for 2 min	18	Half filled with wash basin	2.0
Shaving	Running tap for 2 min	18	Shaving mug	0.25
Shower	Letting shower run	90	Wet down, tap off, soap up, rinse off	20
Flushing toilet	Using old fashion cistern	>13	Dual system short flush	4.5
Watering plant	Running hose for 5 min	120	Water can	5
Washing Car	Running hose for 10 min	400	Bucket	18

Jan-Olof Drangert, Linköping University, Sweden

The sustainability requirement of saving resources is a practical and doable one. It helps to bring back responsibility to the users, who will become partners in sustainable development.

The slide shows some examples of the potential of saving or wasting water in the home. The figures are not precise, but depending on the rate of water flushing through the pipe. A drop per second will add up to half a litre in one hour, while a hose may provide 2.5 m^3 in one hour. Keeping this difference in mind, we can have a closer look at the figures in the diagram.

People commonly brush their teeth twice daily. If they are considerate with the rate of water flush they may use 3 litres per minute. Two 2-minute brushes a day require 12 litres as compared to the 90 litres used by wasteful person. It they instead use a cup or glass they will save 11- 89 litres every day. This will add up to 330 – 2,600 litres per month. With a real water cost of 3 USD per cubic meter the saving in cash is 1- 7.5 USD per person monthly.

The same kind of calculations can be done for the other water-using activities. The changes in use are facilitated further by installing a one-grip handle faucet which will keep the temperature when switching on and off. Also, inserting a mesh at the tip of the tap (will add air to the water) will retain the feeling of unchanged rate of flushing water, despite the fact that actual volume is reduced by half.

The demand management component (see slide 2.2-5) of having a progressive tariff to stimulate users to use less water could be quite effective, given that the users are well informed about the tariff system. It requires that each flat has a water meter, and the fee collection is done properly. The saving is always done at the last litre of total water use, and therefore the higher cost per litre is gained for each litre saved. The first litres used could have a very low cost level in order to assist poor users to afford a minimum of required water, while the following cost steps could be quite steep in order to send a monetary signal to normal earning citizens to stop wasting – or even better – start saving water.

Demand management is a tool to reduce wastage of water, not a way to reduce comfort and joy of the user.

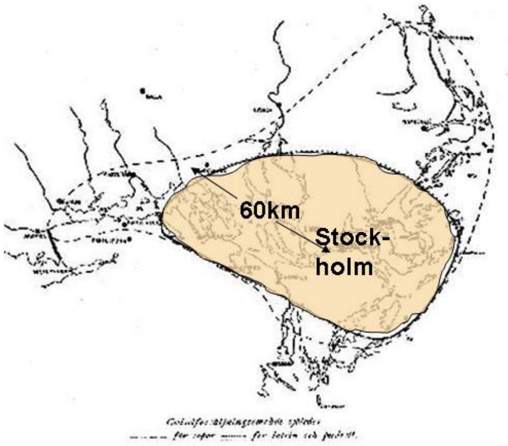
Reuse or disposal in the history of sanitation

1.1 - 19

The ”silent highway” man rowing on river Thames

Illustration: www.CartoonStock.com.

Land area making use of organic waste from the city of Stockholm 1910



Karl Tingsten, 1911

Countries adopted different policies in the sanitation sector. In mid-19th century, the UK went for disposing sewage into rivers. An editorial cartoonist in London lamented the rise in sewage carried into the river Thames – killing off fish, risking public health and causing the “Great Stink” that was so bad that it forced the House of Commons to abandon the parliament building for a period. The ‘silent highway’ man (left picture) rows his boat among rats and debris. Despite this disastrous consequence of this policy, it did not change. It took a century before most of the wastewater was partly treated before emptied in river Thames.

In other countries the policy was similar but protests were rampant. In Paris, the issue pertaining to the new flush toilets focussed on the loss of valuable nutrients (our manure is gold) to the rivers and lakes. In the second half of the 19th Century the debate was fierce between farmers and other citizens as shown by the quote from Victor Hugo in the slide 1.1-14.

In Stockholm, Sweden where industrialisation came later, flush toilets were introduced only gradually and human excreta were returned to agricultural use up to the 1920s. The map (right) shows the agricultural area that was fertilised with sanitised excreta (inner brown circle) and composted material from organic waste (dotted circle). The view of reuse in those days foreshadows the modern concepts such as ‘carrying capacity’ and ‘ecological foot prints’.

In the European Union, more than a century later, planners are still preoccupied with the cost of serving the public´s preference for bathing in sewage-free seas – as enshrined in the Bathing Water Directive. The Londoners were lucky in the sense that the ebb and flood reached up to London and made the river carrying the polluted water out into the English Channel once every day. At the same time this hydrological regime and accompanying perceptions have delayed sustainable sanitation solutions.

Many countries still suffer from the legacy of these British perceptions of sanitary solutions. Their experiences became a precursor of what happens in many big cities today. Poor handling of wastewater causes health risks both directly and indirectly through pollution of groundwater from leaking pipes. The groundwater under all towns is contaminated by leaking sewers and therefore well water drawn in poor areas often contains chemicals and pathogens which would require pre-treatment (slide 4.5-6).

Epidemics rather than endemics have shaped our views

1.1 - 20

Example 1

After John Snow discovered (1854) that cholera can be transmitted by contaminated well water, sanitary engineers focussed their interest on organic matter in water as an indicator of faecal contamination. Many rivers with high organic loads were wrongly labelled as hazardous since the origin of the organic matter was not from faeces but from humus! (Hamlin, 1990)

Example 2

Sanitary inspectors in Linköping (small town in Sweden) described the sanitary conditions in the workers´ living quarters as deplorable with stagnant storm water and awful smell, and causing ill health (1870s). However, infant mortality in such areas did not differ from that in richer areas with piped water and sewers. Lack of sanitary precaution by all classes was the reason, and not until the general hygiene improved did the death toll figures come down! (Nilsson 1994; Esrey, 1990)

Evidence-based experiences often guide our actions, be they tacit or scientifically derived. A look back in history can provide us with some useful insights of the relationship between our perceptions and scientific statements.

Chris Hamlin (1990) brought up interesting facets of what John Snow and others thought about the cholera spread around the Broad Street well in London in the 1850s (14,000 people were killed by cholera in the epidemic of 1849). It was during this period that the modern concept of disease specificity and the corresponding emphasis on a single exciting cause of each disease were coming to be applied to the kinds of diseases bad water was thought to cause. Hence, where Chadwick and the early sanitarians had assumed that each outbreak of disease was a version of a common filth disease and had felt little obligation to restrict the number of operating causes in any particular case, sanitarians in the 1860s and 1870s were beginning to look for single causes and tending to regard multi-factorial explanations as the lumping together of an important, exiting cause with a collection of less important predisposing causes. More significant than the change in ideas of how disease spread was the change in the concept of what a disease was. This was long before the German chemist Koch could identify microorganisms in 1893.

Hans Nilsson (1994) compared infant mortality data in a small town in Sweden for the period before the introduction of piped water and sewers in 1875 with data for the following years. He found that there was a reduction of some 25% in infant mortality! But are we certain that the improvement came about due to the new infrastructure? Nilsson also collected data for working-class suburbs with very poor sanitary conditions and no such services (and occupied only after 1875). He found that infant mortality here was as low (or high) as in the piped part of the town. The water in the pipe came from the same river where the workers draw their water. The explanation for this unexpected result with similar rates of infant mortality is that all classes practised the same poor hygiene in relation to babies.

This finding is supported by Steven Esrey´s study (1990) in which he compared results from various studies of the impact of provision of water on users´ health. He found that very few studies could prove a health benefit from improved water supply only and also that many of the studies had serious flaws. His conclusion was that improved sanitation conditions enhance public health more than improved drinking water quality.

Continued

1.1 - 21

Example 3

Water issues have been in focus to the detriment of appreciating good sanitation. Cairncross (1989) and others have reached the conclusion that water quantity is more important to good health than water quality for many diseases. Enough water to clean the hands and body, wash clothes, clean the house, etc. is more important than improved drinking water quality at the margin.

Lesson to consider:

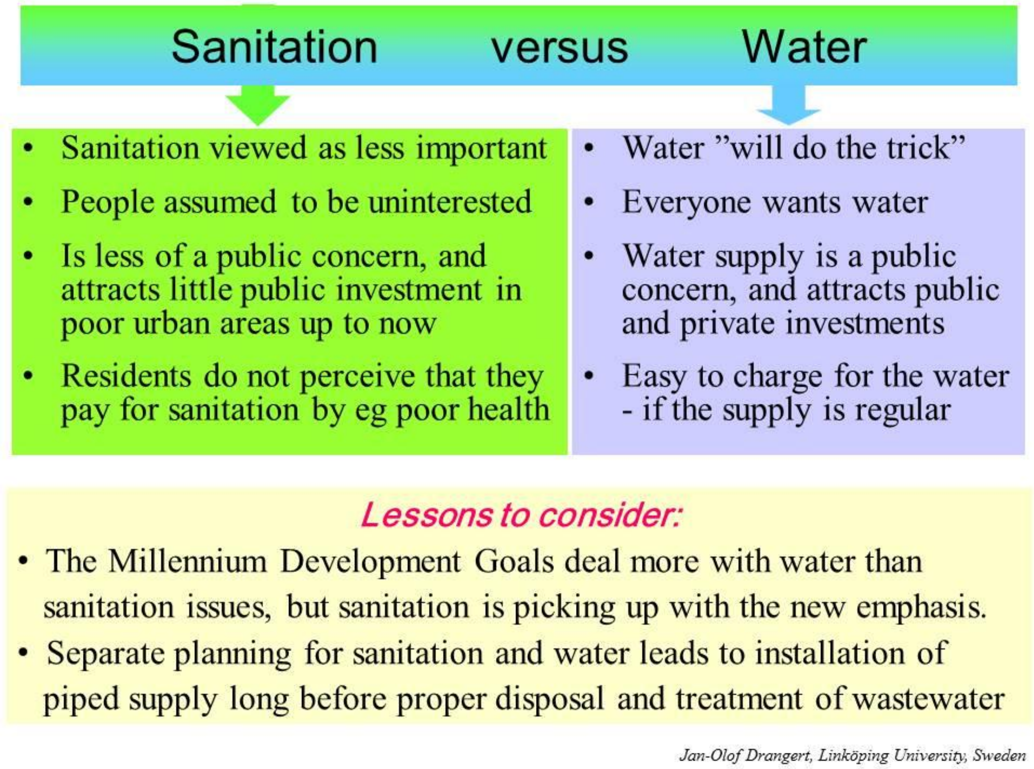
We need to measure the right parameters to be able to draw useful conclusions.

Jan-Olof Drangert, Linköping University, Sweden

Chadwick preached organising public service to achieve complete urban drainage and plenty of water to flush all wastes from cities to sewage farms. In his sanitary report of 1842 the final word on water was that “the formation of all habits of cleanliness is obstructed by defective supplies of water” (Hamlin, 1990). Hamlin also interprets this formative period for understanding the relationship between water, sanitation and causes of disease as much as a means to improve water quality and human health as a struggle between proponents of public and private ownership of the systems. There is also a competition between proponents of chemical and biological causes of disease.

These three examples show that data can give valuable information about sanitation conditions. However, there is a need to interpret the data carefully in order to let them guide our strategies and policies. In short, we need to measure the right parameters to be able to draw useful conclusions in order to make relevant policy decisions. This challenge will be discussed more in detail in Module 2.4 where we deal with selection of sanitation arrangements and in Module 3.1 where hygiene aspects are scrutinized.

1.1 - 22



Sanitation and water issues are partly similar, partly radically different.

Viruses survive much longer in cold water than in warmer water. Bacteria in water die off due to lack of feed and due to cannibalism. In contrast, bacteria multiply rapidly on substrates like left-over food. This is one of the reasons why ingestion of infectious doses is more likely to come from food than from water. But, not all pathogens need high numbers to cause disease.

Authorities and donors have put much more resources into water supply than sanitation as a response to assumed difference in popular demand. Water supply is a public concern and conforms nicely to making political promises. Yet, much of the water supplied in periurban areas is actually provided by individual well owners or private entrepreneurs. Residents are prepared to pay for water if it is supplied on a regular basis.

Sanitation options other than sewerage and flush toilets tend to be viewed a private concern rather than a public one. Sanitation seems less rewarding for politicians, and comparatively small efforts were made previously. But the situation is improving with the implementation of MDGs. The mental separation of water supply and wastewater handling has resulted in that residents do not perceive that they pay for disposed wastewater or management of stormwater.

Rarely do decision-makers take into account that ‘more water in’ results in ‘more water out’ from households. A possible reason is the high cost of sewerage and contradictory perception that it is free of charge. Professionals and consultants seem to support this non-coordinated approach of water first, leading to higher total investment costs. They know that ensuing wastewater problems will feature high on the development agenda and will have to be dealt with sooner or later. They are certain to secure contracts for sewerage in due time. The problematic result of this piecemeal approach is that no sustainable intermediate solution is looked for. Instead haphazard arrangements evolve which tend to cause environmental problems for single households as well as causing groundwater pollution, drainage problems and pollution of rivers and lakes.

The piecemeal approach excludes a holistic integrated view of the water flow through society, and will not encourage a recovery strategy. Rethinking in this respect is evolving slowly, and is focussing on local small scale arrangements that are sustainable. Hopefully, these may be allowed to gradually replace the conventional city wide sewerage.

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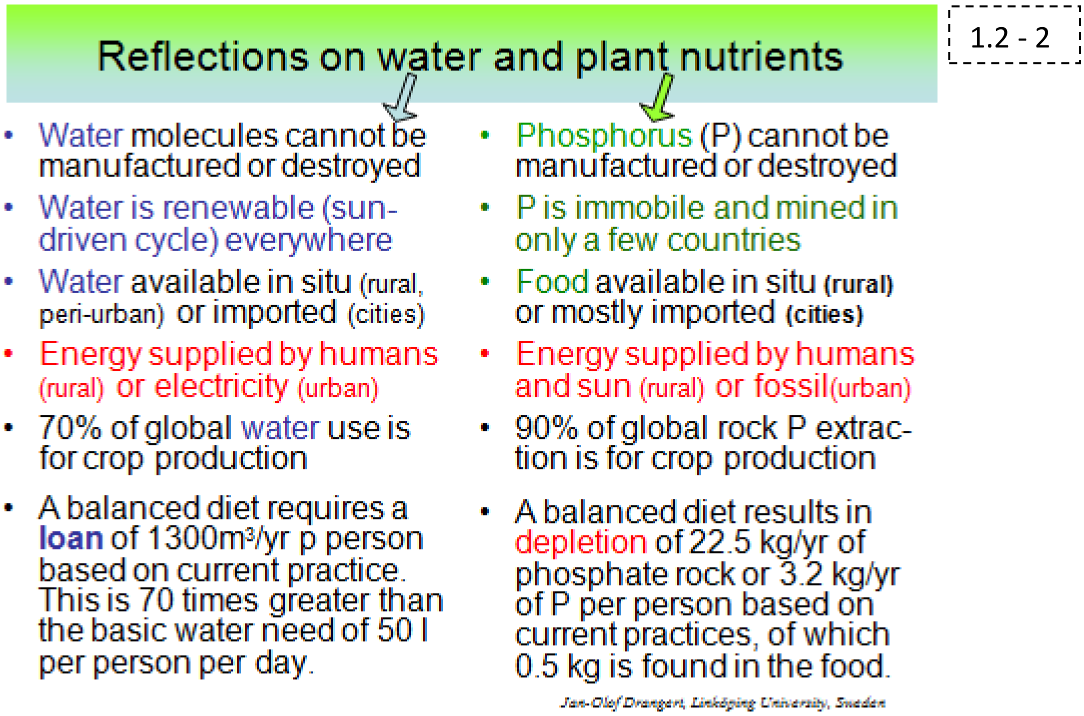
In this module we deal with management of the four resources: nutrients, water, energy and human resources to manage the natural resources.

For long, people have been mostly busy raising incomes and consumption levels, rather than worrying about depletion of natural resources. However, with more people on earth who are increasingly living in dense areas, more focus is on materials flowing through our communities. Looming serious challenges concern how the once used products (water, nutrients, chemicals, etc.) may be used again without too costly treatment measures and transports. The intended use of the output from our societies, be it agriculture, industry or nature, defines what quality criteria should be aimed for.

Present sanitation arrangements produce polluted water and mixed solid ‘wastes’ and also energy dependency. It has been calculated that 20 per cent of the energy used in the state of California is used for supplying and treating water. By mixing fewer flows of materials, ideally no mixing, the content of each flow becomes easier to treat and to recover for renewed use in production. This is a leading principle for achieving improved sustainability in the sanitation sector (slide 1.3-24).

Of particular interest are plant nutrients, here represented by phosphorus (P), since they cannot be manufactured nor replaced by substitutes in plant production. The mining of phosphate rock and converting it to plant–available phosphorus is in itself a polluting and energy-consuming activity. Moreover, P is being mined in only few countries in the world and requires long transport. This oligopoly market may become a weapon on the geopolitical scene. P is also a serious polluter of our water bodies. This account shows that phosphorus belongs to soil, not water. Means to re-circulate nutrients from the food chain back to the soil and food production is thus imperative for a sustainable future.

The module deals with understanding the potential in combining sanitary improvements with resource recovery in securing food for future generations.



Both water and phosphorus are sturdy molecules that are extremely costly to manufacture. They are significantly different, however, in that water is renewable through the water cycle whereas phosphorus is immobile.

Household water is mostly drawn from available groundwater and/or rainwater in rural areas, while it is mostly imported to urban settlements from distant rivers and conveyed by pumps. Food is produced in situ in rural areas and requires farm work, while food is mostly imported to towns from rural areas and requires transport work.
The energy needed to supply water and food is provided by humans in rural areas, while for city dwellers, water is pumped by electric pumps and food is transported on diesel-driven vehicles.

The world´s exploited water and nutrient (nitrogen, phosphorus, sulphur and potash) sources are mainly used for crop production, especially phosphorus.

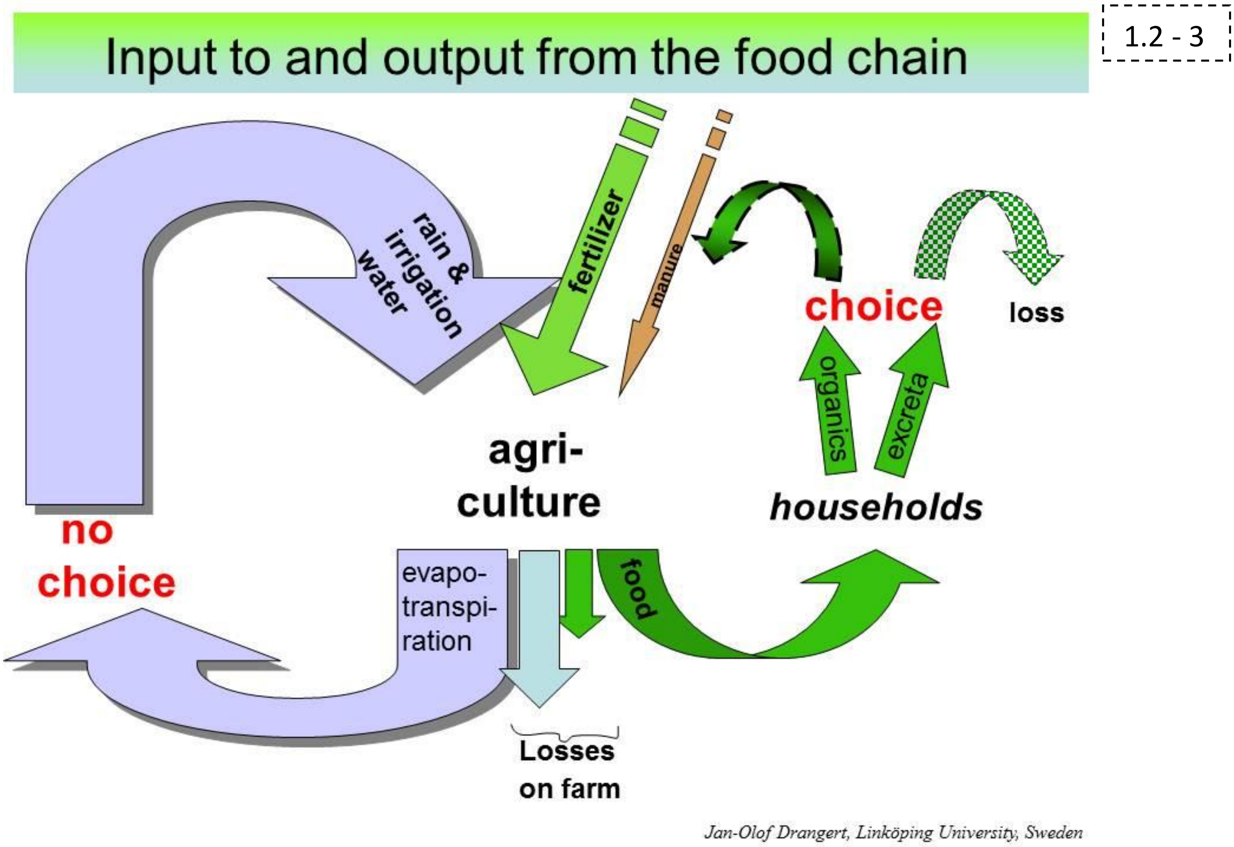
Each person uses an average of 1,300 m^3/yr of water to produce her food, called virtual water, and little is directly used in the household. She also uses 3.2 kg of mined phosphate rock to fertilize her crops, while only 0.5 kg of phosphorus reaches the food she eats. The important difference is that used water always returns to the water cycle (**renewable**) whereas phosphorus is usually immobilised in the sediments of rivers and lakes or in landfills.

These fundamental differences between water and phosphorus molecules call for different strategies for sustainable use of the two. The following commonly found perceptions about water, nutrients and sanitation face serious challenges today:

H_2O supply perception: Conveyer pipes from lakes and rivers, and/or wells will do the trick to supply water to urban areas. Challenge: Lack of virgin water bodies, sinking groundwater levels and degraded water quality makes this approach unsustainable, as does the related huge energy requirements for conveyance and treatment.

Nutrient perception: The Green Revolution will continue to do the trick in combination with subsidies for chemical fertilisers. Challenge: Looming scarcity of easy to reach sources of phosphate, potash and land suitable for irrigation.

Sanitation perception: Flush toilets will do the trick in combination with sludge application on farmland. Challenge: Poor recovery of nutrients and the quality of sludge is deteriorating as more chemicals are entering the market place. Sludge is often unfit for land application.

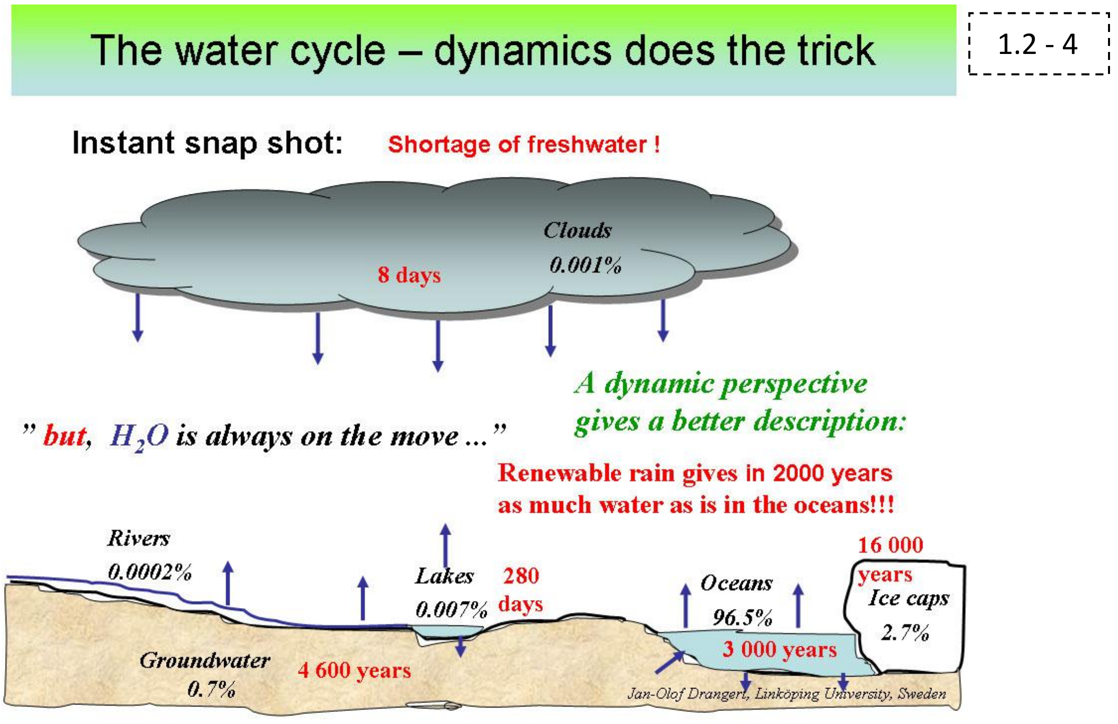


Plants require water, nutrients and solar energy to grow. The two large-scale nutrient and water flows in the picture are centred on agriculture and food production. Part of the water flow, evapotranspiration, is **outside of human control** and a necessary process of plant growth and is not considered a loss. Nutrient inputs, on the other hand, are controlled by man, and we do **have a choice** what to do with them after they leave the household.

Today, poor management of irrigation water and over-application of plant nutrients result in large losses on the farm (picture). Sustainable food production requires that such inputs and production losses are kept at a minimum. A report from Stockholm Environment Institute (SEI, 2005) estimates the present water use to 4,500 km^3/year (2005) and that another 2,200 km^3/year will be needed in 2015 to meet the hunger Goal target, everything else unchanged. The good news is that the agricultural sector can save 350 km^3/year through ”*more crop per drop*” and another 1,000 km^3/year can be captured from local rain on current land. A different kind of water saving measure is to select crops with low water demand, and to compose water-saving diets.

Soil naturally contains plant nutrients to varying degrees, for instance much of the soils in Africa are deficient in phosphorus. When crops are harvested and taken off a field, also nutrients are taken away and have to be replaced if soil fertility is to remain adequate. Farmers, households, and communities could return most of the nutrients to the soil for plant production. However, today most of the nutrients from urban settlements are going to landfills, incineration or are flushed with water into rivers and lakes. There they cause eutrophication and other environmental damage, and are not available for food production. This is different from much of the animal dung and droppings which are returned to soil and made available for plants.

There are options to secure food provision but it requires new strategies using comprehensive and coordinated approaches for the agricultural, water, and sanitation sectors.



People often complain that water is in the wrong place (ice caps, deep groundwater), or is supplied during the wrong time of the year (seasonality), or is of wrong quality (saline). With such a **static view** of the global water sources as stocks, the situation looks grim.

It is true that only a small portion of the water on the globe is freshwater. The reason is that over billions of years rainwater has eroded rocks and brought salts along to the oceans where 96.5% of the water is found (Gleick, 1993). The second largest stock of water is in the ice caps (2.7%), while the rest is found as groundwater (0.7%) and small fractions in clouds (0.001%), lakes (0.007%) and rivers (0.0002%).

The reason we survive is that the water cycle is **dynamic** and water is renewed all the time (picture). Although only 0.001% is found in the atmosphere, the retention time there is only 8 days. A water molecule in the ocean, on the other hand, stays on for 3,000 years on average. The vast ocean area evaporates large quantities of water to the clouds. In ice caps retention time is 16,000 years, and in groundwater some 4,600 years. This means that water in the oceans and ice caps is almost immobile for practical purposes.

During 2000 years the total volume of rain water (renewed fresh water) is the same as all water on earth at any given moment! [0.001% times 50 weeks times 2,000 years which equals 100 %]. The sun runs the water cycle to our advantage by providing a lot of rainwater over vast areas. It provides water for rain-fed agriculture, and replenishes groundwater, rivers and lakes from where industries and households draw their water.

The other important role of the water cycle is that when evaporation and evapotranspiration takes place, most of the dissolved salts in the ocean water remains in the ocean and the cloud water is freshwater that mankind can collect and use without desalination.

Our task is to manage this resource wisely.

Annual renewal and use of fresh water

1.2 - 5

Country	H_2O m^3 /person/ year	km^3/yr total in country	Rivers from/to countries	Portion being used	Total use per year per person	- by house-holds	- by indu-stry	- by agri-culture
Sweden	21 110	176	+4	2 %	479 m^3	36%	55%	9%
Holland	680	10	+80	16 %	1 023 m^3	5%	61%	34%
Saudi Ara	160	2	0	164 %	255 m^3	45%	8%	47%
Lebanon	1 620	5	-1	16 %	271 m^3	11%	4%	85%
India	2 170	1 850	+235	18 %	612 m^3	3%	4%	93%
Tanzania	2 780	76	0	1 %	36 m^3	21%	5%	74%
Kenya	590	15	0	7 %	48 m^3	27%	11%	62%
Egypt	30	2	+56	97 %	1 202 m^3	7%	5%	88%
USA	9 940	2 478	0	19 %	2 162 m^3	12%	46%	42%
Chile	35 530	468	0	4 %	1 625 m^3	6%	5%	89%
China	2 470	2 800	0	16 %	462 m^3	6%	7%	87%

Source: P. Gleick, 1993

Countries differ in access to water and in amounts actually used. But, it is not sufficient to show one set of figures, because there is not only one reality. If all renewable water (essentially rainwater) is divided with the number of inhabitants (blue column), the variation is enormous. Egypt with 30 m^3 would never survive without the additional water from the river Nile. The benefit to have water in a river is obvious; it is easy to draw the water from it. This is very different from Sweden, where most of the rain falls over vast areas, and only a small portion can be collected from rivers. The 4th (yellow) column reflects this and other factors. Swedes only use 2 % for man-made activities, while other countries may use ten times larger a portion. An extreme case is Saudi Arabia using 164 % of the renewable water source. This is achieved by pumping up fossil groundwater that will not be replenished in thousands of years.

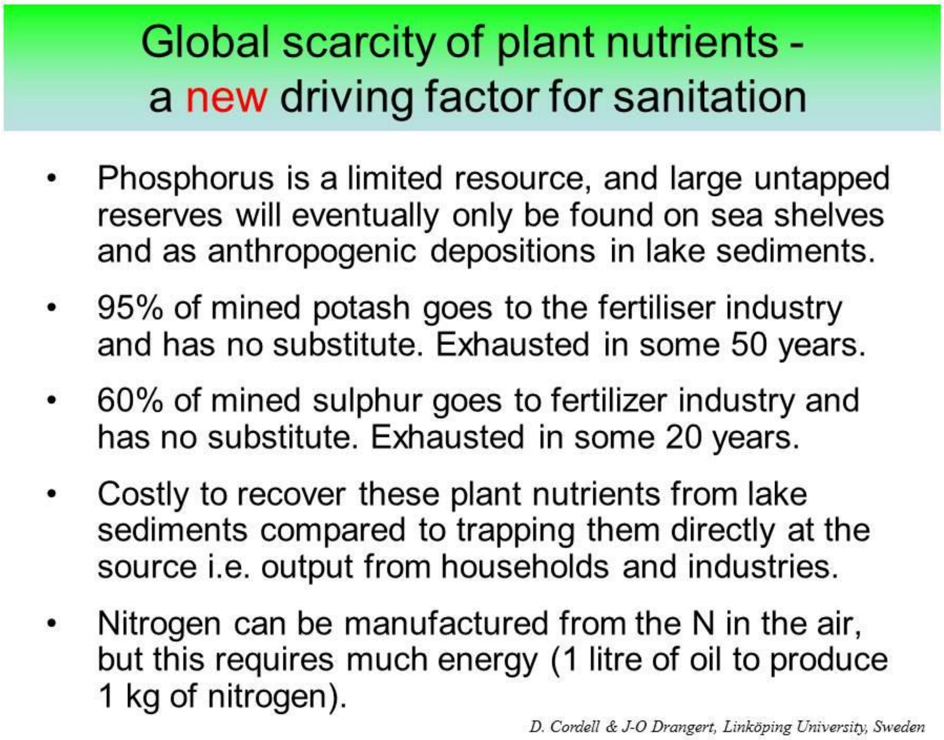
The 5th column shows the variation in actual use per person. In the USA each person uses more than 2,000 m^3 on average, while Tanzanians use 36 m^3. By combining column 5 and 6, we can calculate that Americans use 250 m^3 per person and year, and Tanzanians some 7m^3.

The last green column shows the large proportion for agriculture uses. Major water savings is therefore most likely to happen in the agricultural sector. Huge volumes of water are transformed into vapour during the plant production process. Between 500 and 3,000 litres of water are required to produce one kilogram of grain. Thus, the choice of food becomes crucial.

In 1993, Professor John A. Allan at the School of Oriental and African Studies in London, introduced the “virtual water” concept, which measures how water is embedded in the production and trade of food and consumer products. Behind that morning cup of coffee are 140 litres of water used to grow, produce, package and ship the beans. That is roughly the same amount of water used by an average person daily in England for drinking and all household needs. The ubiquitous hamburger requires an estimated 2,400 litres of virtual water. Per capita, Americans use around 6 800 litres of virtual water every day, over triple that of a Chinese person. A growing number of countries are also facing water stress (Hoekstra et al., 2010).

The water stress is therefore most prominent in agriculture, but is also affecting large cities with a geographically concentrated demand for water (Falkenmark, 2007). This has far reaching social and ecological consequences. Fill in the table with figures from your own country or region, and carry out some analysis of your water situation. You may find the figures in *Water in Crises* (Gleick, 1993) or annual reports from the World Bank.

1.2 - 6



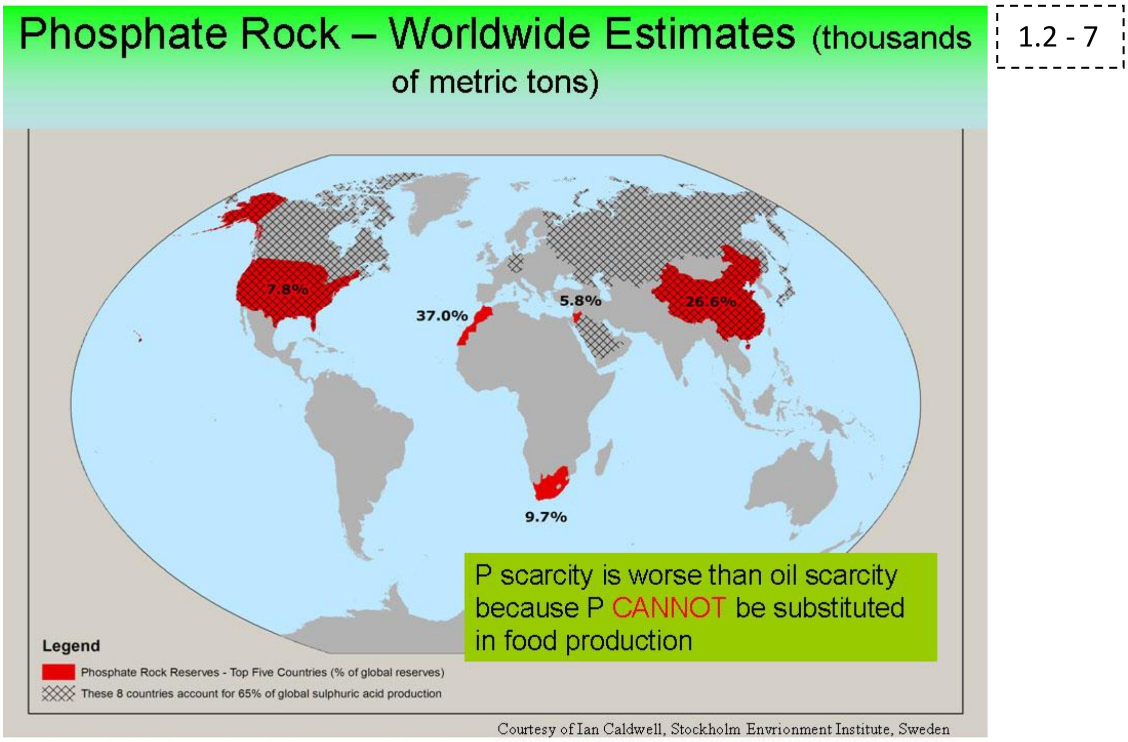
If farmers do not apply fertilisers, yields will decrease over time as the naturally available nutrients in the soil are exhausted. A rule of thumb is to return as much nutrients as was taken off the land during harvest. Today, the required ingredients in fertilisers are mined, treated, mixed and transported over long distances to the fields. Farmers reduce the need for purchased fertilisers by returning as much as possible of the non-edible part of the plants to the soil.

Nutrients in the soil are more or less immobile, but a substantial part can be eroded together with soil particles. Nitrogen is the exception and can easily dissolve in water and percolate or convert to gas and dissipate into the atmosphere. There is a cost to each effort to recover used nutrients, both in money and energy. One kilogram of nitrogen requires one litre of oil to be transformed from a gas in the air to plant available nitrate. There are also nitrogen-fixating plants which use the energy from the sun to do the same work.

The volume of the human-converted nitrogen to reactive forms is larger than the combined effects from all Earth´s terrestrial processes. Much of this reactive nitrogen ends up in the environment, polluting waterways and the coastal zone, accumulating in land systems and adding a number of gases to the atmosphere. Nitrous oxide, for example, is one of the most important non-CO_2 greenhouse gases and thus directly increases radiative forcing (Rockström et al., 2009).

The typical selection of sanitation systems in growing towns and cities is to discharge plant nutrients in food so that they end up in rivers and lakes. When nutrient resources become too expensive to mine, the alternative will be to recover them from lake sediments – at a high cost. Rethinking the system and building short circular flows would facilitate the recovery of the once used plant nutrients at or near the source of use. We will return to this strategic thinking in the following chapters.

In the beginning of the 21st century food prices increased due to changing diets, general population growth but also due to rapidly rising prices on nutrients such as phosphorus. This has triggered a serious mass media interest in world resources and resource use. This may become a springboard for sanitation to be discussed from a resource point of view, not to remain an isolated issue for the sanitation sector alone.



The skewed distribution of phosphate rock should worry countries that rely on imports of chemical fertilisers. There is no substitute for plant nutrients such as phosphorus, potash, and sulphur, unlike most other resources we need. For instance, energy from oil can often be replaced by energy from hydropower, biogas, nuclear power, wind power, bio fuels, etc. Yet, the oil industry and political awareness about future price-hikes for oil has resulted in a massive restructuring of investments to reduce oil-dependency. What about phosphorus?

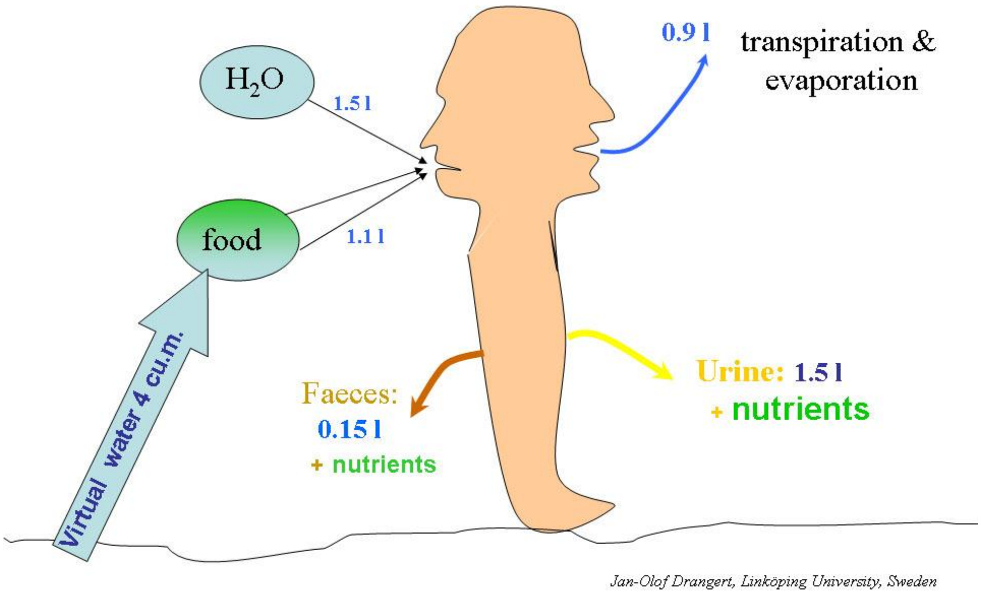
The economically extractable resources of rock phosphate will run out relatively soon, in about a century. Unfortunately, reserves of all other non-renewable resources for food production are also limited. Based on known reserves and world consumption, the static reserve life of sulphur is 27 years, phosphorus 107 years, and oil 40 years (USGS, 1999). We can anticipate a raised awareness of the looming scarcity of plant nutrients in the near future, perhaps initiated by rapid increases in commodity prices. The solution to the scarcity of plant nutrient is improved efficiency in its use and recycling of organic waste, in particular through an improved sanitation system. It may also require that we eat less animal products and more vegetable food (Module 5.1).

Not returning nutrients to the soil has led to a situation where there is an increasing demand for chemical fertilisers in response to the problem of decreasing soil fertility. The relatively inexpensive phosphorus used today will almost certainly cease to exist in the next 50 years; in fact the price tripled between 2008 and 2010. Farmers around the world require an estimated 135 Million tons of fertiliser for their crop annually, while at the same time conventional sanitation systems dump 50 Million tons of fertiliser equivalents into our water bodies - nutrients with a market value of around 15 billion US dollars (Werner, 2004).

If the world does not start recycle plant nutrients back to soil the future food supply will dwindle. However, the present and future scarcity is man-made and man can reverse the trend. In a recent article (Cordell et al., 2009) it is shown that if the looming scarcity is taken seriously, we can manage to return the needed plant nutrients to soil, combining a number of measures: plough back plant remains in the field, collect and compost organic waste as soil conditioner, remain vegetarian or become one, stop over-fertilisation, not buying or preparing more food than will be eaten, return urine and faecal matter to soil after hygienization (Module 5.1)

Food, water and nutrient flows

1.2 - 8



The Millennium Development Goals, agreed upon by the Millennium Assembly of the United Nations in 2000, seek to halve the number of undernourished people in the world by 2015. This, in itself, is a gigantic task for farmers and the international community. Moreover, this target is to be attained within an environmentally sustainable and socially acceptable framework.

Laudable efforts and accomplishments in global food production have led to a steady increase in the per capita consumption of food, from 145 kilograms of cereals in the year 1961 to 175 kg in 2000. Average global calorie intakes per capita have improved from 2,250 kcal in 1961 to 2,800 kcal in 2000. However, one billion people remain undernourished (2010). At the same time it is estimated that another billion suffer from overweight.

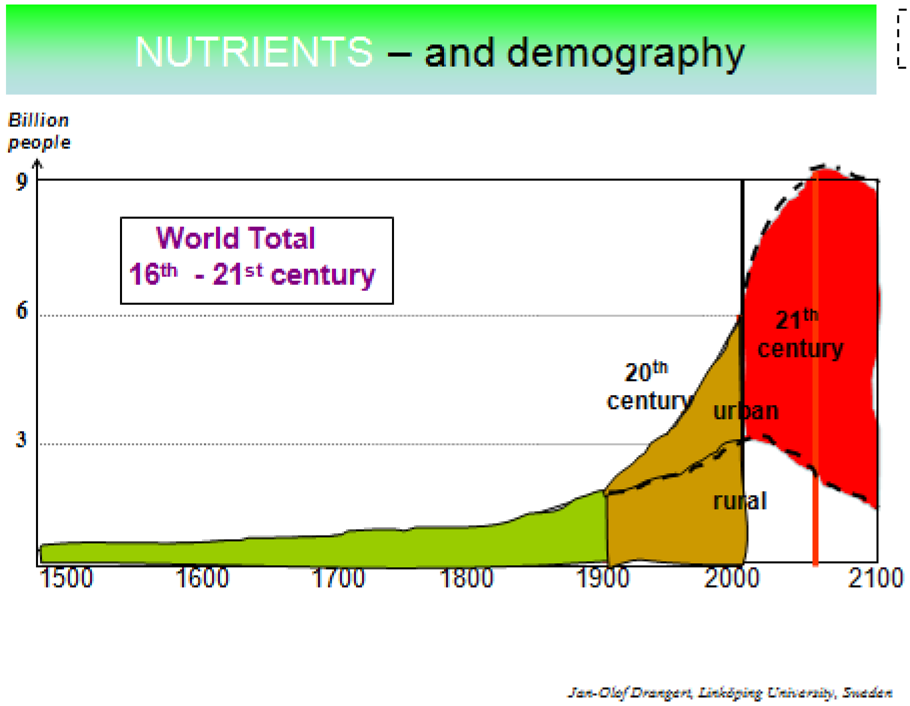
When we move from the 'Big Picture' of resources to resources for a human body (picture), we can conclude that the body's demand for water and nutrient is insignificant compared to the demand from growing the person's food requirement (virtual water and nutrients).

Adults drink 1.5 litres or more liquid every day in the form of ordinary water, soft drinks, tea or coffee, beer, etc. In addition to this amount we also ingest water that is in the solid food, which amounts to more than a litre per day. The fluid is processed in the body and almost a litre leaves when we transpire and breath. All this water ends up in the air and will return as rain. Most of the fluid passes our kidneys and the discharged urine contains both water and nutrients. Most nutrients from the food are in the urine, and the rest are found in the faeces together with some water (0.15 litres per day).

The digested food primarily provides the energy we need, and the body uses only a negligible amount of the eaten food to build cells (slide 4.1-3). Therefore, our excreta comprise the same plant nutrients that are in the food we eat. In rural areas most of the excreta is returned to soil and to plant production. As urban centres grow bigger, excreta are either left in the environment in a pit latrine, or are flushed into rivers and lakes – often without prior treatment. The wasted nutrients create environmental problems. So, the private activity of excreting turns into a public environmental concern.

Human excreta contain high-quality fertiliser with only background-levels of heavy metals and trace elements (Module 4.1). Chemical fertilisers, on the other hand, tend to contain in addition to a few essential nutrients, often too much heavy metals and other impurities.

1.2 - 9



The population in the world grows ever faster. It took about 50 000 years for humans to reach 1 billion by the year 1800, while only 10 years to go from 6 to 7 billion. Today, we are over 7 billion. In less than a generation we are estimated to be some 9.4 billion (slide). The present rapid increase in the world pushes the case of finding ways to manage short and energy-efficient loops of nutrients from food via the dining table back to plant production.

We may read the diagram of world population in the following way to understand the tremendous impact growth has on the total use of resources:

The vertical distance from the x-axis to the curve could for example represent the amount of urine produced in the world in a single year. The graph tells us that human beings produced three times as much urine in the year 2000 as in 1900, and six times as much as in 1800. In 2050 we will produce 50% more than today (2010).

We may also see how much urine has been produced over a century by measuring the area under the curve. For instance, the total amount of urine produced during the 20th century (brown area) equals the amount for the previous 4 centuries (green area)! In the coming 50 years we will produce almost as much as during the last 100 years. And, more excreta are just a reflection of more food being produced and eaten. This is only possible if we start recycling human-derived plant nutrients back to the fields.

Reuse of urine and faecal matter is often organised differently in urban and rural areas. Most plant nutrients from consumed food in rural areas are returned to productive soil. Where open defecation is practised, excreta are returned to soil, but usually not where it could be taken up directly by food plants. A very short nutrient loop from agriculture back to agriculture takes place where buckets are used and the content is returned to paddy field etc.

The situation is partly very different in urban areas. In poor informal settlements much of the nutrients are sunk into pits in the ground with little value for food production, even if a tree is planted on the abandoned pit. In urban areas served by sewerage the plant nutrients are transported to water bodies, sometimes with some treatment along the route. The nutrient-rich sludge produced when treating wastewater is often returned to agriculture. However, there are many examples where it is not. Untreated wastewater is more and more used for irrigation.

In the 1960s the sludge from Stockholm was loaded on barges and dumped in the Baltic Sea. After ten years of dumping there were signs of ‘dead zones’ with no life on the sea bottom since the oxygen-demanding decomposition of sludge deprived organisms and sea plants of life-sustaining oxygen. The practice was stopped in order to save the fishing industry and out of environmental concerns. Today, the sludge is transported 1,000 km and dumped in an abandoned mine in northern Sweden. In short, there is no meaningful recycling despite a substantial input of energy for the transport.

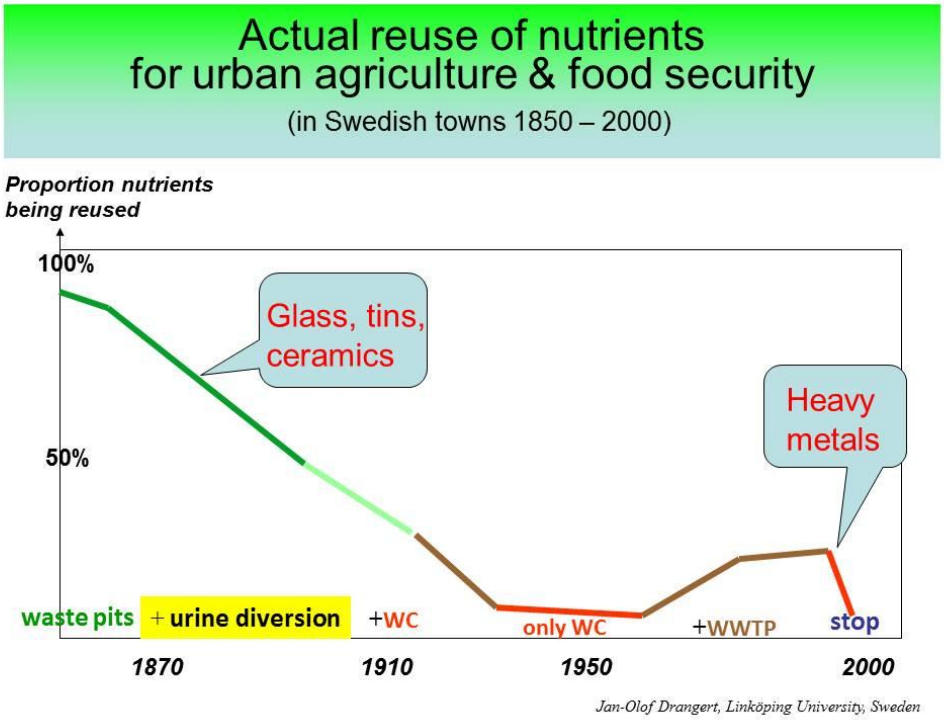
The new wastewater treatment plant in Buffalo City in South Africa treats the wastewater to a high degree, and discharges the effluent in a pipe reaching a kilometre into the Indian Ocean. The sludge is transported to the beach, loaded on a barge and dumped in the ocean. Again, this represents a costly effort to treat the wastewater without any recycling of its plant nutrients.

Most plant nutrients originating from urban settlements are not being recycled in a meaningful way. In 2008, the area of ‘dead zones’ in the Baltic had increased to the size of Denmark due to large discharges of sewage from a number of countries! This shows the amount of lost nutrients and their negative environmental impact.

We return to the graph to find out the global consequences of not recycling human waste from urban areas. The graph shows the proportion of urban and rural dwellers in the world. It may also be interpreted as volumes of excreta being produced in a specific year or as total amount produced over a certain time period. The red area represents the expected amount to be produced in urban areas during the current century. This amount is much greater than what is being produced in rural areas over the same period. Also, the volume is some 8 times larger than what was produced in urban areas in the 20th century.

We have up to now only seen the tip of an ”excretaberg” of human waste arising when no recycling of plant nutrients is implemented.

1.2 - 10



The diagram shows the level of use of excreta-derived nutrients in a Swedish urban community over 150 years (Schmid-Neset et al., 2010). The diagram shows the evolution from a short-loop recycling of nutrients towards a linear flow through gradual construction of sewers and water closets.

In the early period most human excreta were returned to agriculture by bringing buckets and waste pit (very shallow) content for use in gardens or nearby fields. No flush toilets were around. In 1875 a rudimentary sewer system was built. Towards the end of the century, urine-diverting dry toilets were gradually introduced in towns and the urine was discharged in sewers, while faecal matter was still collected and the content used in gardens. Therefore, an increasing proportion of nutrients in the urine were lost to water bodies. In the mid-world war period (1918-1939), flush toilets were gradually installed and eventually almost all human excreta were discharged in sewers with outlets in rivers and lakes without prior treatment, resulting in a complete loss of nutrients.

The degradation of lakes and rivers forced authorities to build wastewater treatment plants on a large scale in the 1960s and 70s. A substantial part of the sludge (= nutrients + other unwanted components) was returned to agriculture - again. The use of sludge increased up to the year 1999 when the farmers' union decided to stop using sludge for fear of heavy metals in soils.

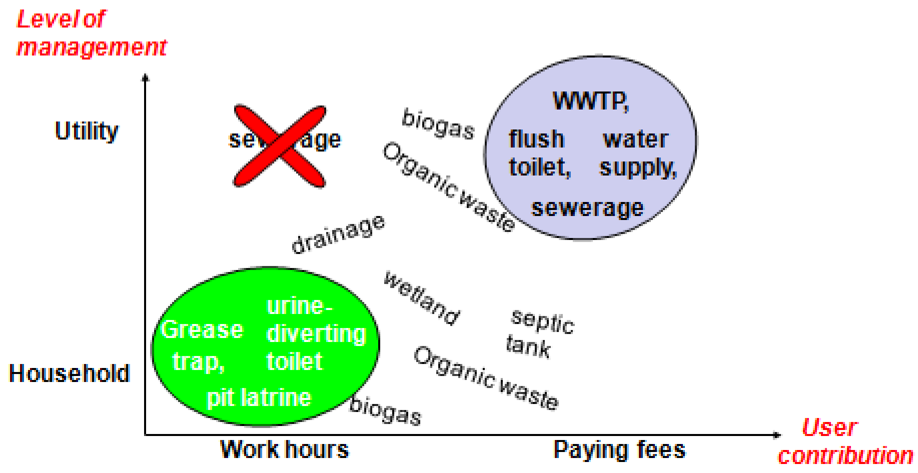
Changes in consumption patterns, primarily an increase in meat products, have caused an increase of about 30% in the phosphorus output per capita. Multiplied by population increase over the last 130 years, phosphorus increases about 16-fold in the Swedish city of Linköping.

It is interesting to learn that major changes in the sanitation flow system are guided by changes in the kind of consumer goods available on the market. Accumulation of heavy metals in the sludge led to a stop in using sludge in agriculture. The heavy metals entered the market after the second World when new consumer products gradually conquered the market.

A hundred years earlier, new consumer products such as porcelain plates and metal cutlery, glass, tins replaced wooden plates etc. When broken, these items were thrown in the bucket for faecal matter. Farmers were not prepared to sort it out or to apply the mixed organic waste on their fields or give it to pigs. The municipal authorities failed to commit households to dispose of broken glass and porcelain in the solid waste collection. Again, this time the manufactured goods made the sanitation system unsustainable.

Human resources: capacity to manage sanitation arrangements

1.2 - 11



Jan-Olof Drangert, Linköping University, Sweden

Human capacity to manage sanitation systems can be extended by letting households either spend their own time to carry out sanitation-related tasks, or let them pay fees to finance someone else to do the tasks. In both cases the doer has to be knowledgeable about how to go about the task.

The picture shows how user contributions (work hours or paying fees) and management levels (utility and household) relate to various technologies. A number of sanitation arrangements can be purchased and installed by households or local masons. Other arrangements require specialised knowledge and skills of professionals to install operate and maintain. The picture is intended to encourage discussions about what combinations are feasible in a given local context.

The large sewerage system (pipes, treatment etc.) falls squarely in the upper right corner since only a utility (private or communal) has the capacity to manage the system and the users pay a fee for the service. It is hard to think of household work in this case, except for the very important task to not disposing of chemicals in the sewer. In the opposite corner falls pit latrines, urine-diverting toilets, grease trap for grey water etc. since households can install and operate these and allocate working time to such tasks as emptying pits and buckets. There is a host of arrangements which can be run by either a utility or households, or intermediate organisations. Module 2.1 presents a number of innovative management and technical options.

The choice of technical sophistication should, among other factors, be guided by availability of local management capacity to run the arrangement. Selection criteria for sanitation arrangements are explored in detail in Module 2.5. The crucial need of available funds and administrative capacity to collect user fees and to use them for the operation and maintenance of the system is often underestimated or overlooked (ADB, 2010).

One aspect to consider is that a large complicated system affects many households negatively when it is not operating satisfactorily. If a household-centred arrangement works poorly, the residents in the house are those who suffer.

Good management of a sanitation system has a positive impact on public health, the environment and on conservation of physical resources. Under such good regime there is no scarcity of safe water and nutrients for urban food production. This encouraging point runs through the entire sourcebook.

”Manpower blindness”: driver of new responsibility sharing

1.2 - 12

Our pre-conceived views play a role

- We tend to account only for what is done by governments and projects in water and sanitation
- What is done by residents and small entrepreneurs is rarely appreciated, if at all recognized (blindness)
- Yet, many urbanites survive thanks to such local initiatives
- Here, we pledge that both kinds of activities are needed to solve current sanitation problems

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Discussions during the last few decades have put more verbal emphasis on ”bottom-up”-approaches than on ”top-down”. The focus is to involve users (so called beneficiaries) in planning and implementation, be it a toilet or a well fitted with a hand pump. This could be a reaction to the previously strong tendency to only account for what is done by governments and projects in the water and sanitation sector. Rarely is the kind of activities that residents carry out (often in violation of local by-laws) seen as valid solutions, if at all seen or recognized (blindness). The fact remains that many urbanites survive thanks to local initiatives in the water and sanitation field.

This kind of blindness to local activities could be overcome. More emphasis is required to analyse local solutions from a functional perspective (slide 1.1-12). What driving forces and barriers are the actors facing? An open-ended inquiry would ask questions such as the following. Are existing bye-laws impractical or not allowing for alternatives? How are residents solving the problems today? A test case could be to investigate the sizeable proportion of solid (inorganic) waste management that is operated by the informal sector. What would be required of the sanitation sector for the organic waste to be run by households and the informal sector?

Before routinely considering engaging staff and professionals for an identified task, the first thing to do is to find out what human resources are available in the local community. For instance, how many jobless young men are there who could carry out tasks for a small fee? Are there women groups who can make business by improving their environmental conditions by engaging in sanitation-related activities or recycling plant nutrients to food production?

There are several measures needed to achieve universal sanitation. At the root is *’to make sanitation everybody’s business*’ by introducing societal norms that make citizens responsible and not someone else. Politicians, religious and other leaders can contribute to creating such new societal norm.

The sanitation sector may also learn from the energy sector when it comes to policies and strategies related to conventional water supply and sewerage. When the power supply company in South Africa, ESKOM, failed to supply industries with regular energy the company reduced its supply to households and provided electricity for part of the day only.

This was a wakeup call for awareness that the system is dependent on its parts. Everybody was used to a continuous supply of electricity and took for granted that the company would buy more coal to run the generators to solve the supply problem. However, ESKOM insisted that huge investments would be required to secure future supplies and asked the authorities for a doubling of the tariffs. They also requested households to lower their use by 10% which meant switching off geysers, bulbs, and other appliances when not at home. In a country with many sunny days per year part of the anticipated solution would be to install solar panels.

The demand-management directives from ESKOM met with little resistance, although some newspapers held the view that if households save 10% then ESKOM revenues would decrease by 10% and therefore they would raise the tariffs by another 10%! Interestingly enough, there were few poverty arguments against the propositions claiming that the system would be too costly for the poor.

The water and sanitation sector is different in this respect. Here the prevailing perception is that water is a human right. So, any increase in tariffs or household responsibility will be opposed by strong groups using the argument that the poor will suffer. In South Africa the legislation counteracts this argument by providing each household with a minimum of 200 litres of free water per day.

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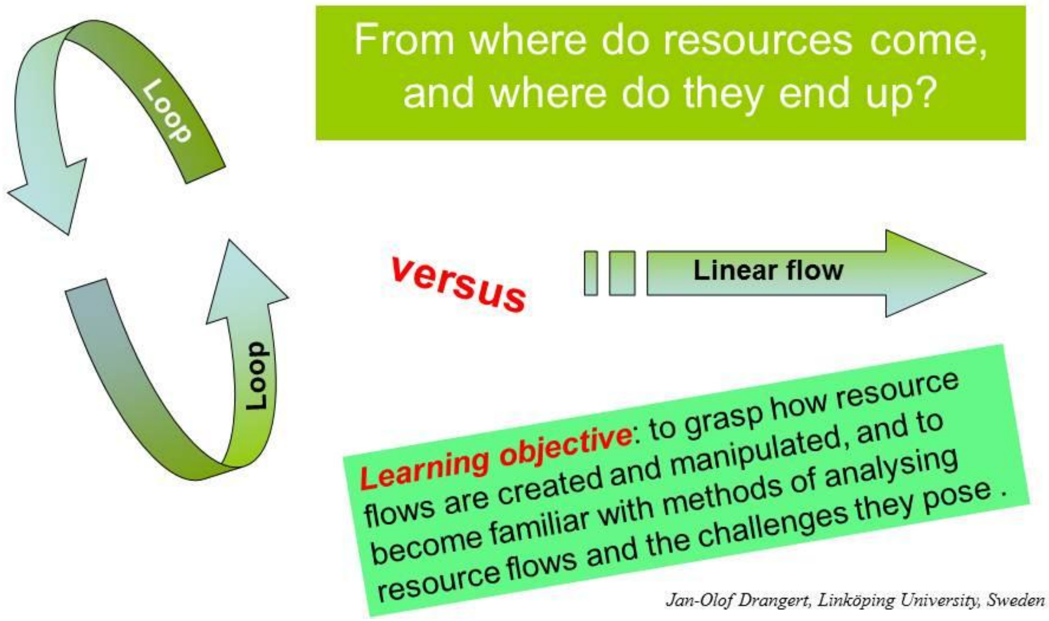
1.3 Resource Flows



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.

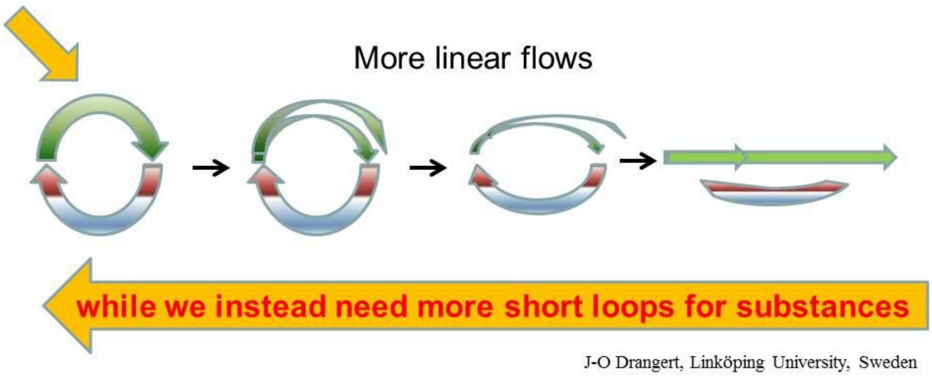
The discourse in the water sector is being partly redefined by the concept of “virtual water” embedded in food stuff and consumer products (slide 1.2-5). Trade in food from water-rich regions to water-scarce ones could be an alternative water “source”. Such trade can reduce pressure on water resources 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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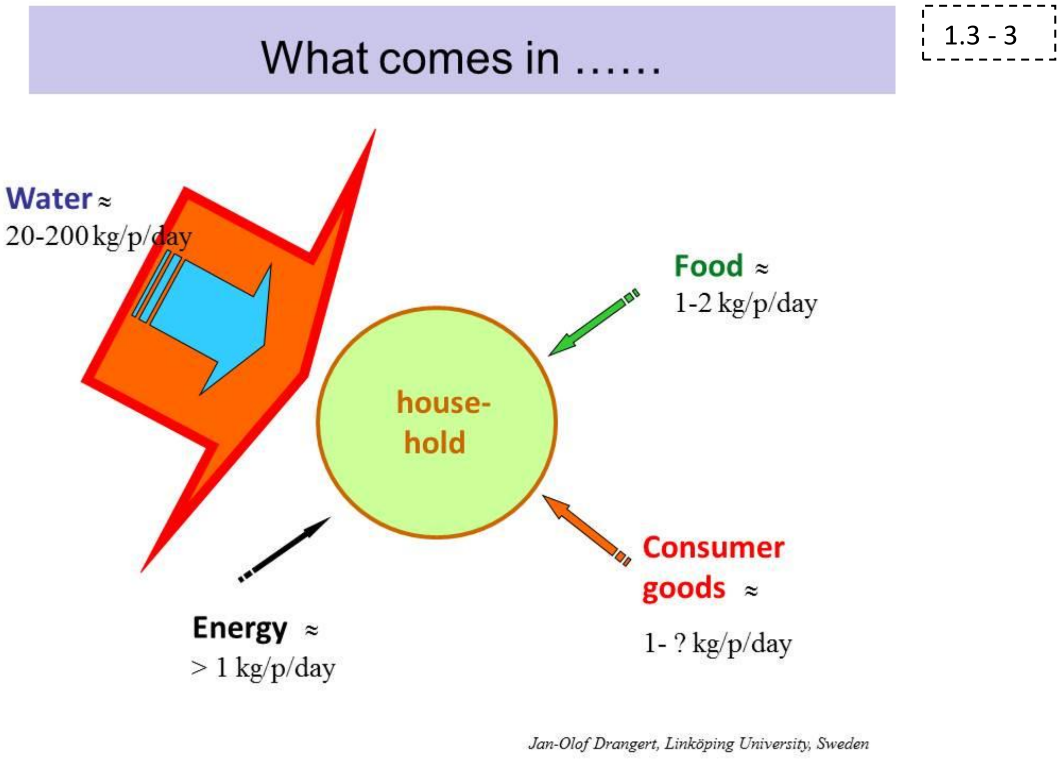
Since the Industrial Revolution a growing proportion of nutrients and a host of consumer products have stopped being recovered in short loops in favour of linear flows (see slide) – to the detriment of sustainability. Previously, households consumed only organic products and these were returned to agricultural 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.



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.

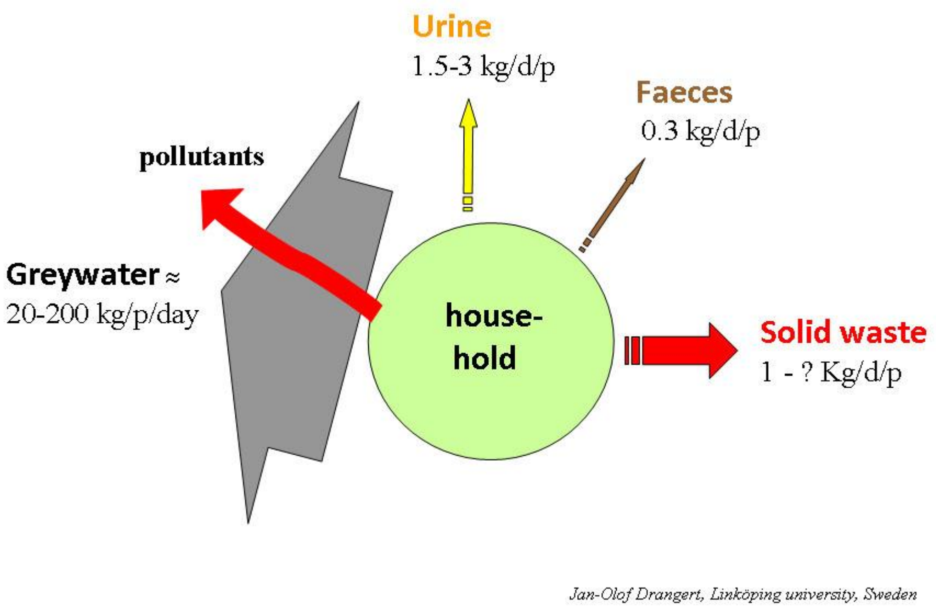
Water use may range between ten litres per person per day in severely water-scarce areas to several hundred litres per day in water-rich areas. Also, the amount of virtual water, i.e. the water which is used to produce food and other items that an average person consumes, is some 4,000 litres per day.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



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*".

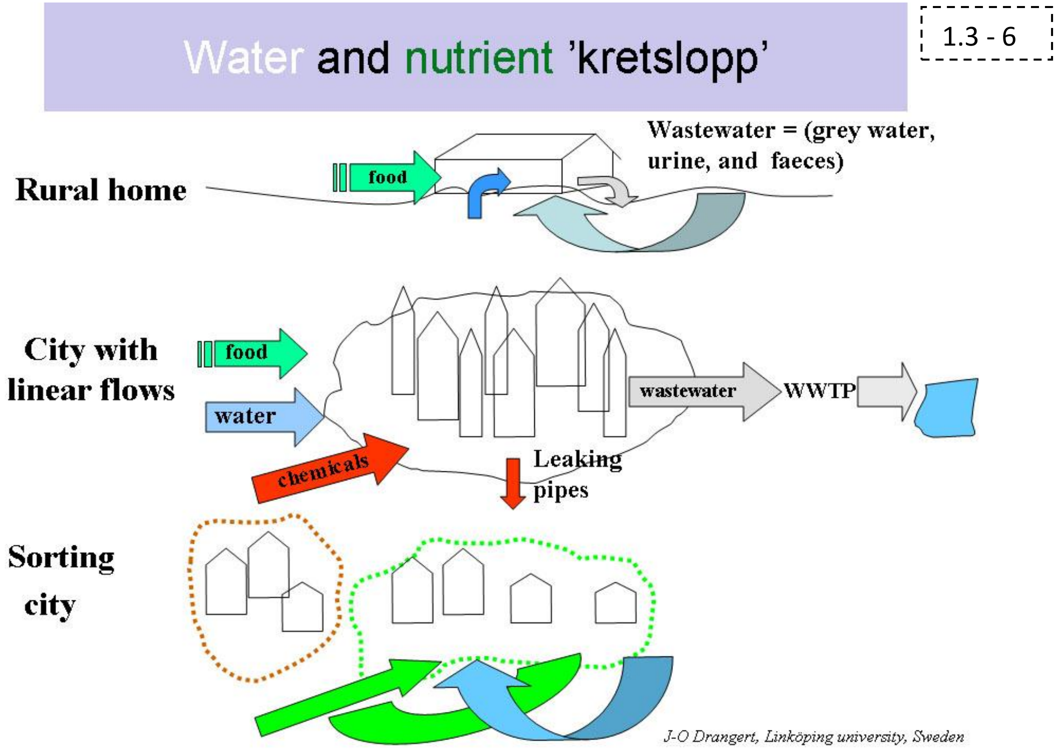
We tend to be more aware of discharges that are easily seen or felt. In a study of environmental awareness it was found that the more visible a certain waste is, the more people are prepared to contribute to take care of it (Krantz and Drangert, 2006). For instance, solid waste is the most visible and 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.

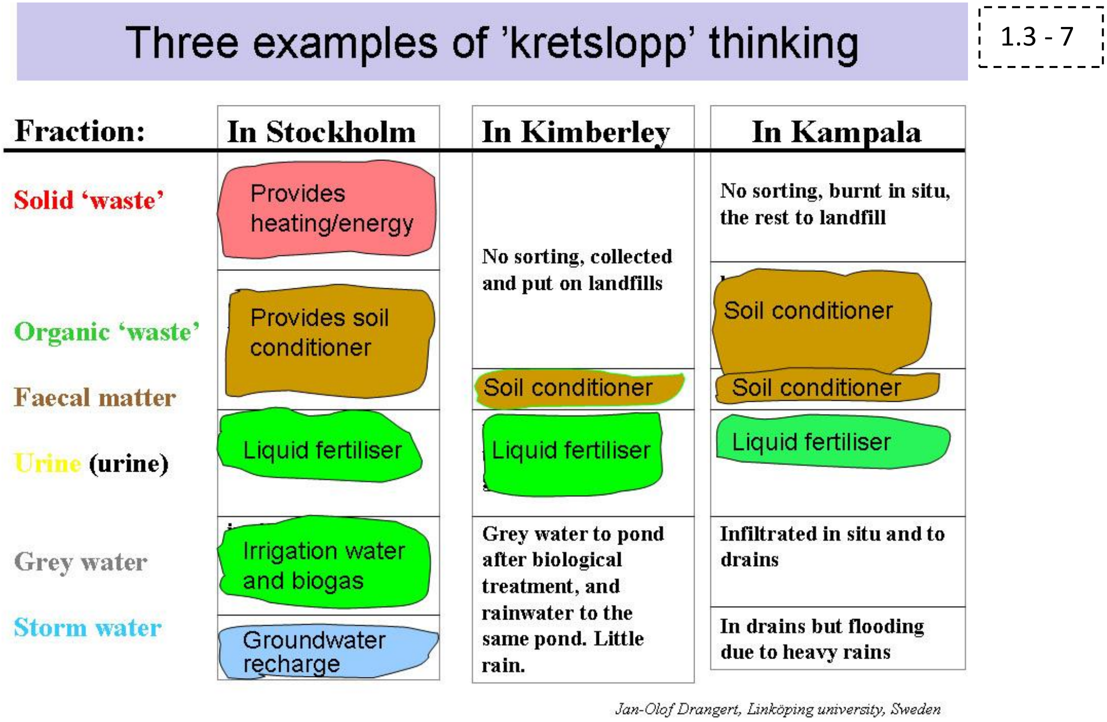


The amount of household chemicals used nowadays makes treatment and reuse more complex. Whereas previous generations focused on the provision of water and other resources, today the greatest urban challenge is the handling of wastes. Therefore, old town-planning solutions need to be revised to take account 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 down-stream 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.



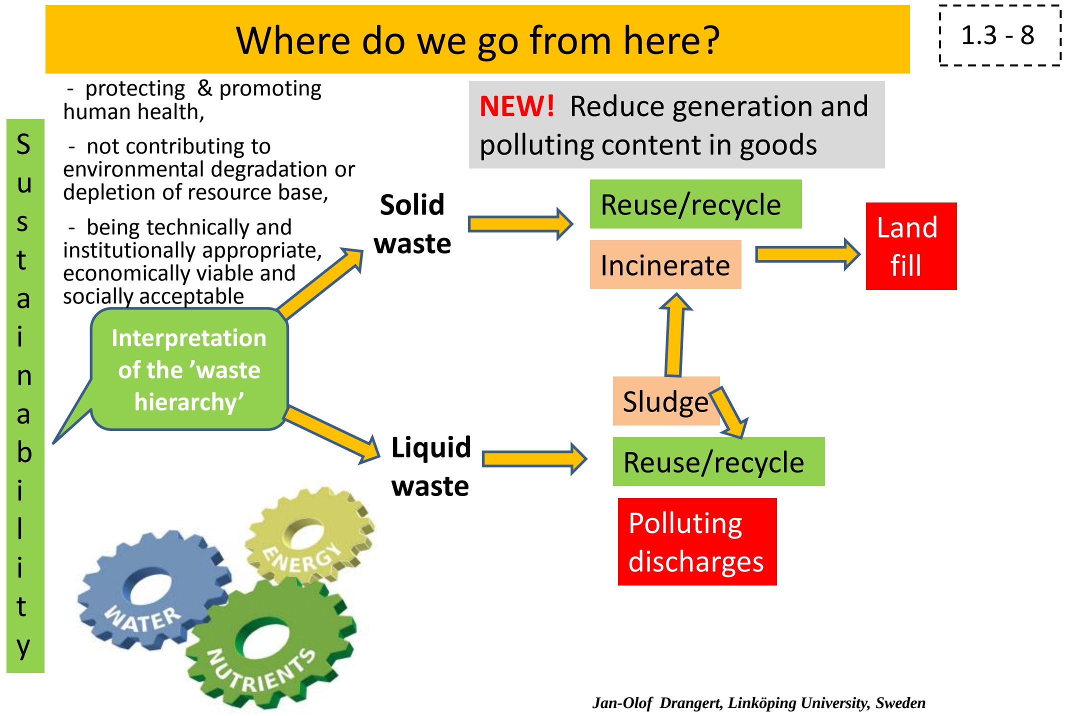
The picture shows examples of material management in three "sorting" city districts. A new central area of Stockholm, Hammarby Sjöstad, has 20,000 inhabitants, while there are some 500 residents each in Hull St in Kimberley, South Africa, and in a project area in periurban Kampala, Uganda. Their sanitation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



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.

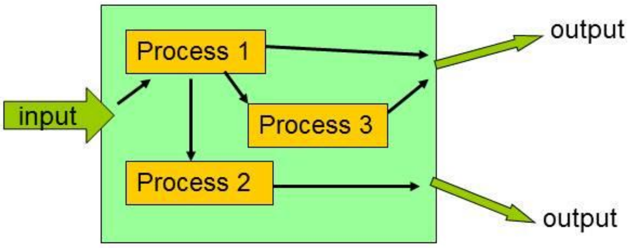
Material Flow Analysis for human settlements

1.3 - 9

MFA uses the principle of mass balance:

input = ***output*** + accumulated ***stock*** 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.

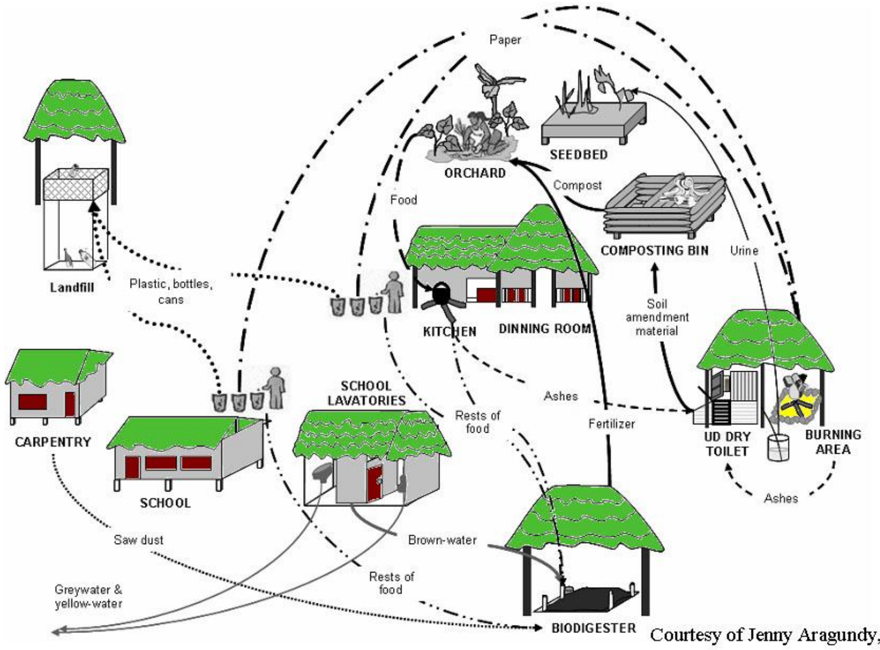
There are also other models such as Life Cycle Analysis (see Module 4.9) and each model has its own standard calculation program. All models comprise system equations with boundary conditions. Each system investigated here is described with all relevant processes. The outcomes of the calculations might 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



Courtesy of Jenny Aragundy, Ecuador

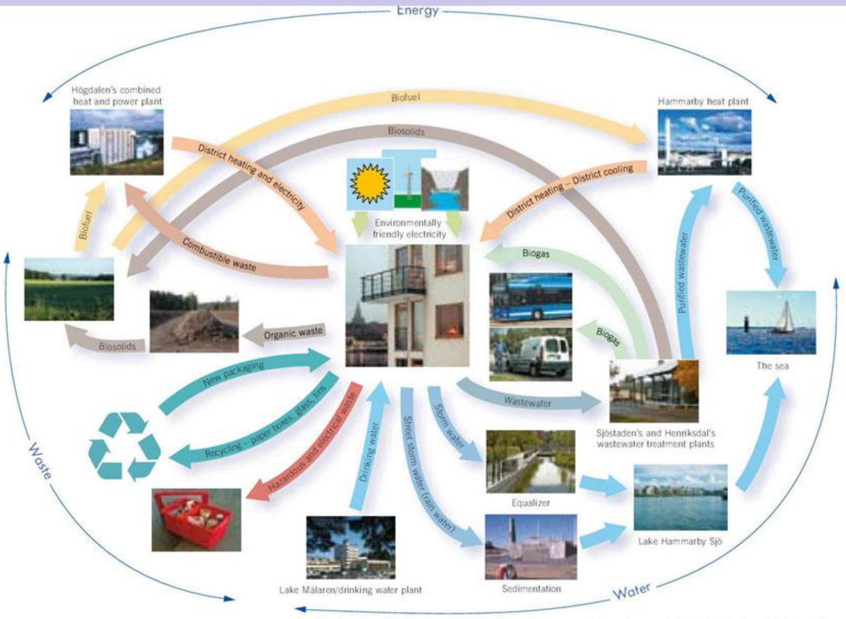
Jenny Aragundy from Ecuador produced the above picture in collaboration with villagers who wanted to improve the sanitary conditions in their village. All the so-called waste products are included, and the picture shows how they flow through the village. The villagers know where the unwanted material 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

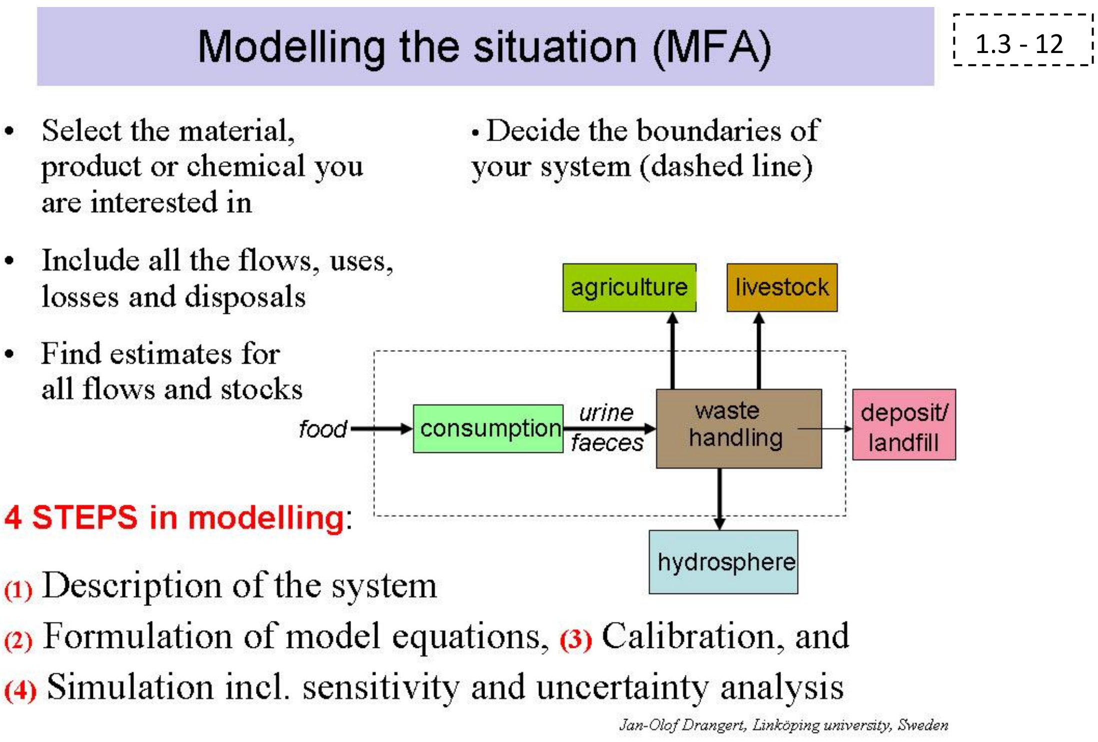
In the year 2000 the Stockholm city council launched a project to build an sustainable housing and office area where resource flows were geared towards closed loops. The municipal agencies in charge of water, wastewater, energy, and solid waste handling coordinated their planning activities so that each 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.



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?

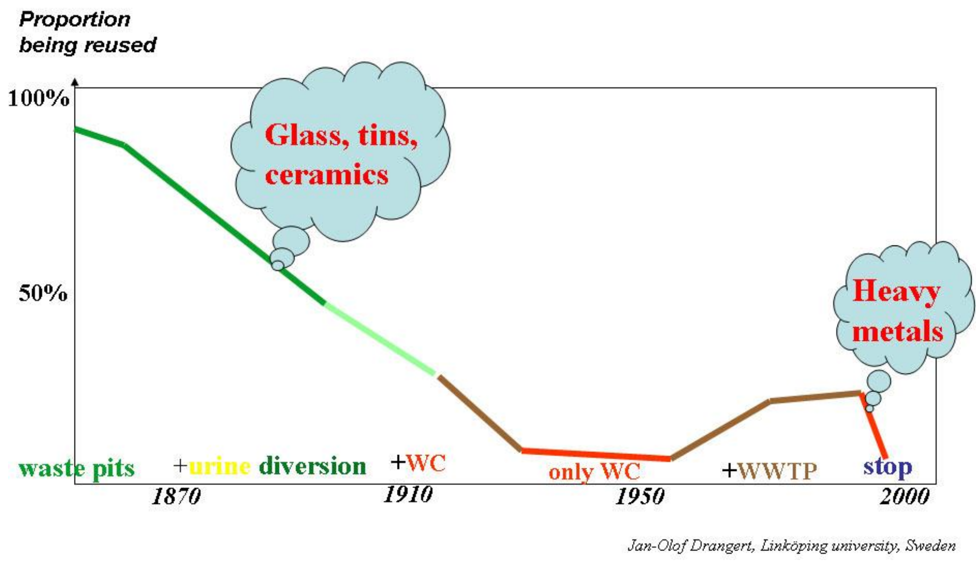
Step 3: **Calibration**. It is cumbersome but necessary to measure or estimate the sizes of all the flows. Often we need to modify model equations. An evaluation of model calculations using rough estimates can then be used to revise the estimate if necessary. This iterative calibration will provide improved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

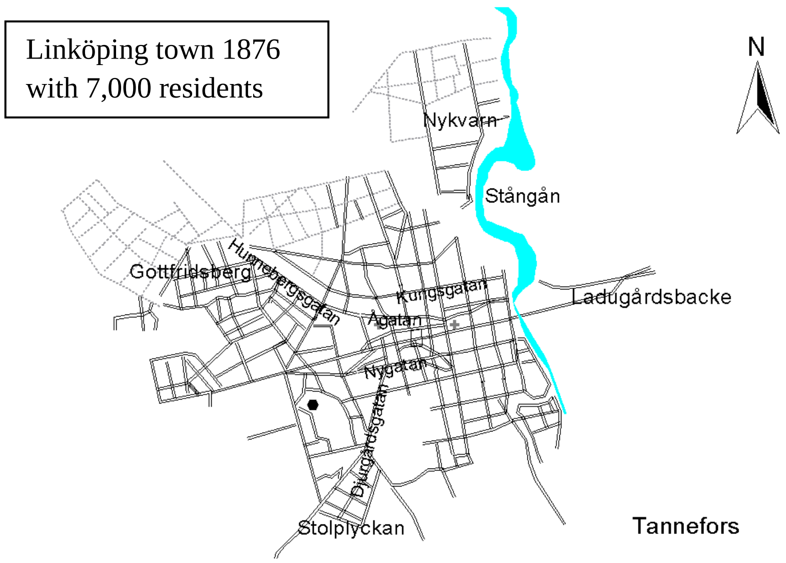
Example 1: Actual reuse of nutrients from households in urban agriculture

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 sewered. 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 19th 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 20th 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 bases 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.

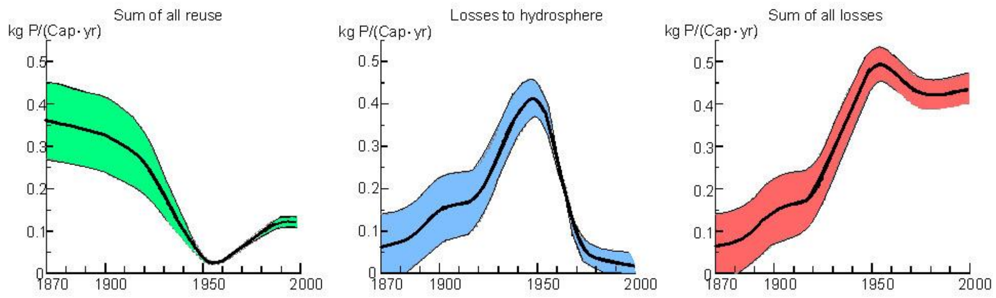
Lack of detailed historical data for toilet systems, and more so for secondary waste treatment or storage, is compensated for by informed guesses building on information from various archives in the city. Generally, data becomes more uncertain as we go further back in time. The column in red gives estimates 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.

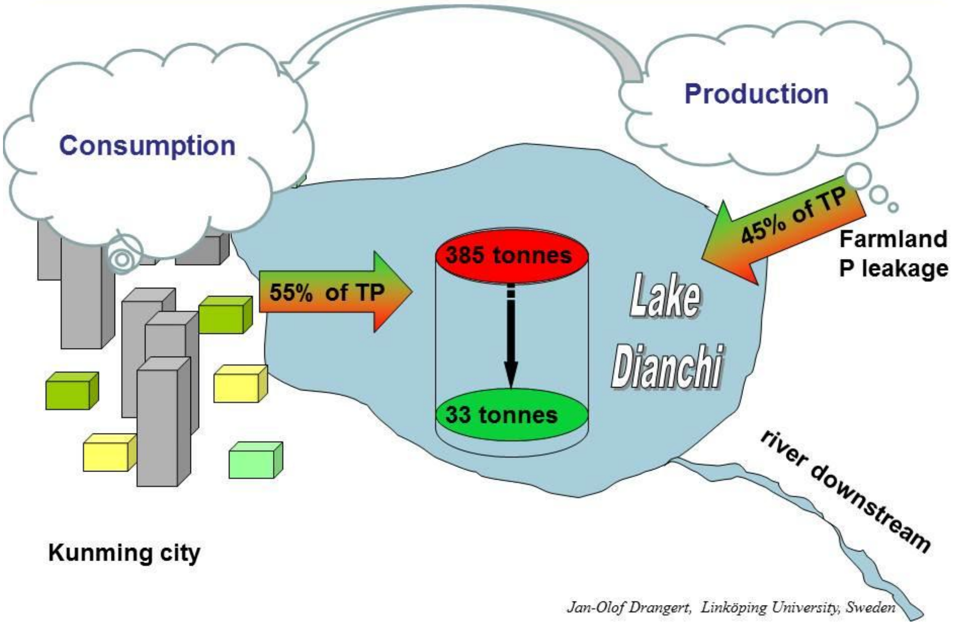
The range of uncertainty during the period 1870–1920 (the span between the extreme curves) seems to be due to uncertainties about the losses to the hydrosphere (middle graph), since its magnitude is the same as for the total losses (right hand figure).

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



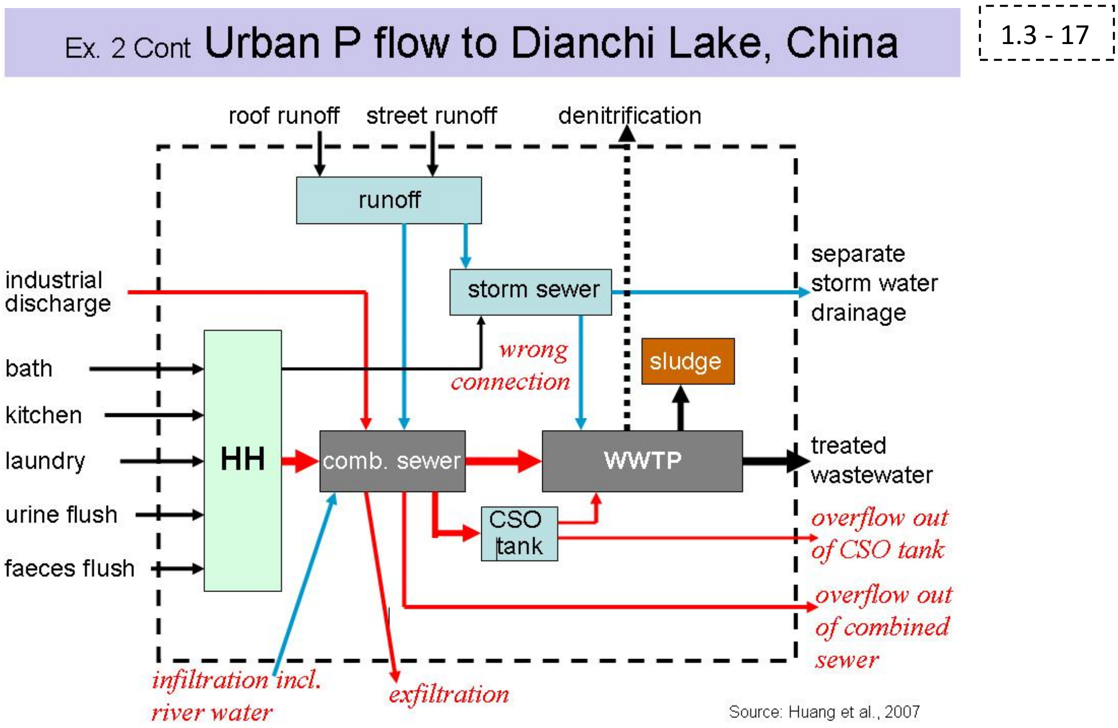
Kunming city with its 2.4 million (2005) residents is on Lake Dianchi, one of China´s largest lakes (300 km^2) (http://maps.google.com ; search key words: Kunming, China). It is a famous green lake resort but the lake is now heavily eutrophied. The shallow lake (average depth 4.4 m) is classified as 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).



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 almost100%. 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 overflows 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

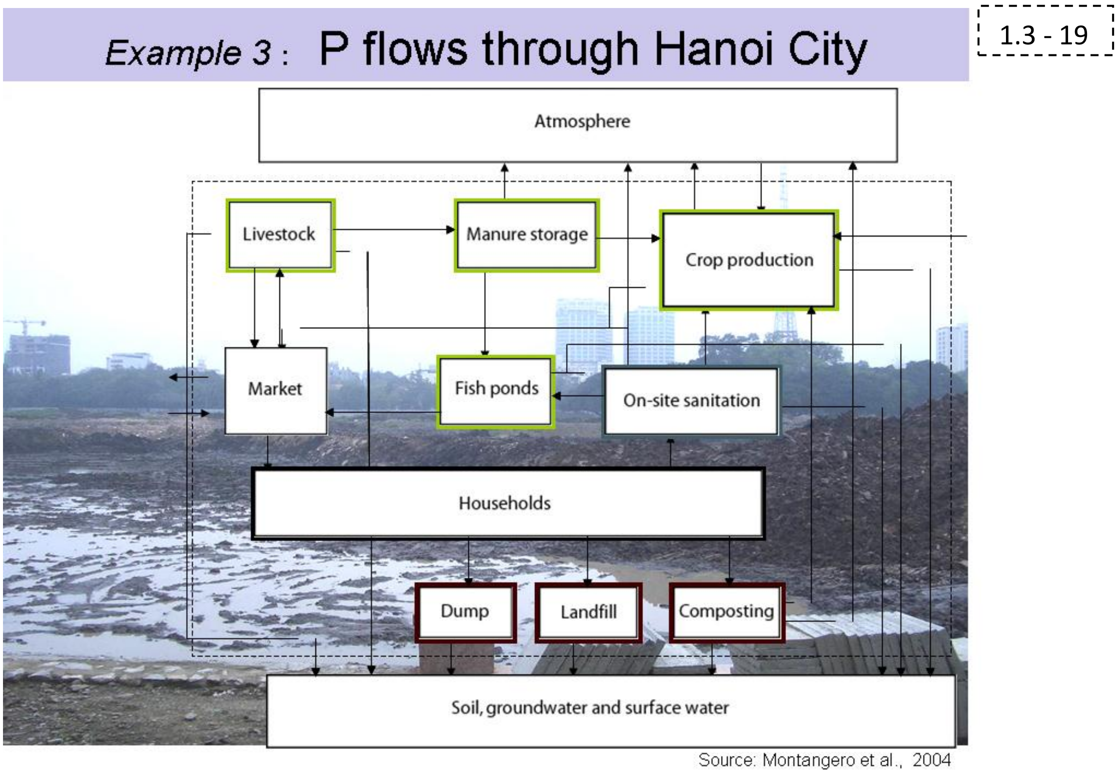
The MFA provides four scenarios for the impact of various measures on total phosphorus (TP).

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.



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).

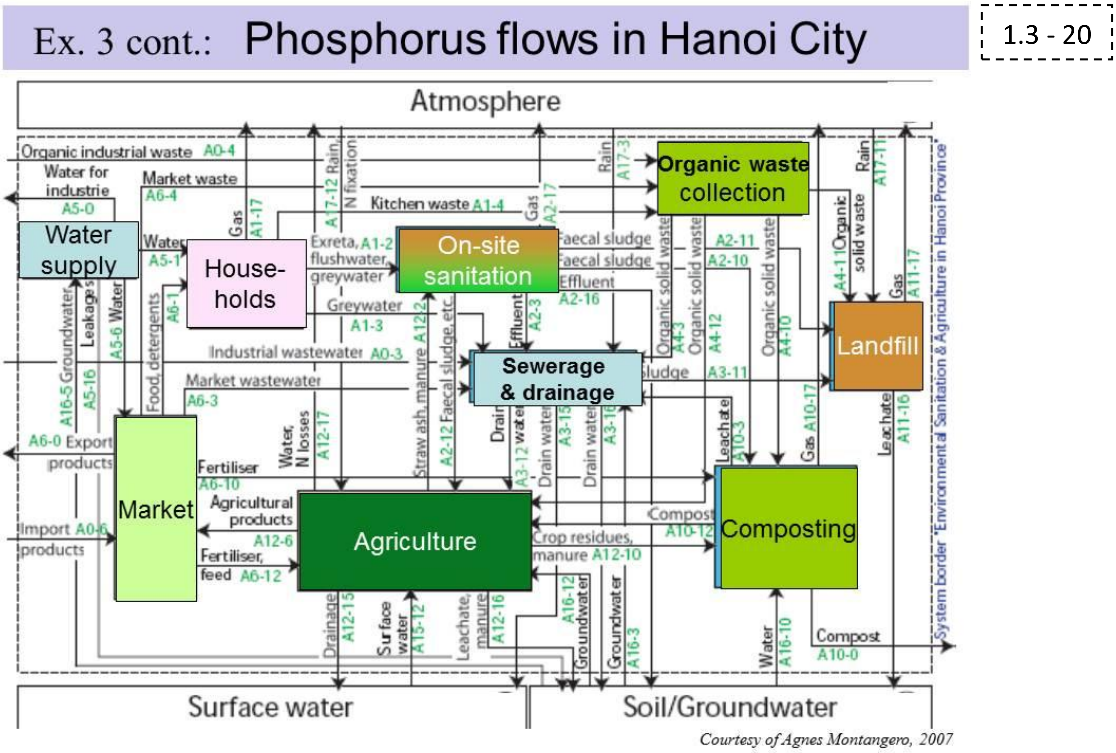
Presently, valuable agricultural land is being converted to compounds for residents, shopping areas, industrial sites and roads (picture). Due to incorporation of neighbouring municipalities with large agricultural areas, the reduction of urban agriculture is hidden in the statistics.

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^3 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^3.

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**.



Courtesy of Agnes Montangero, 2007

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.

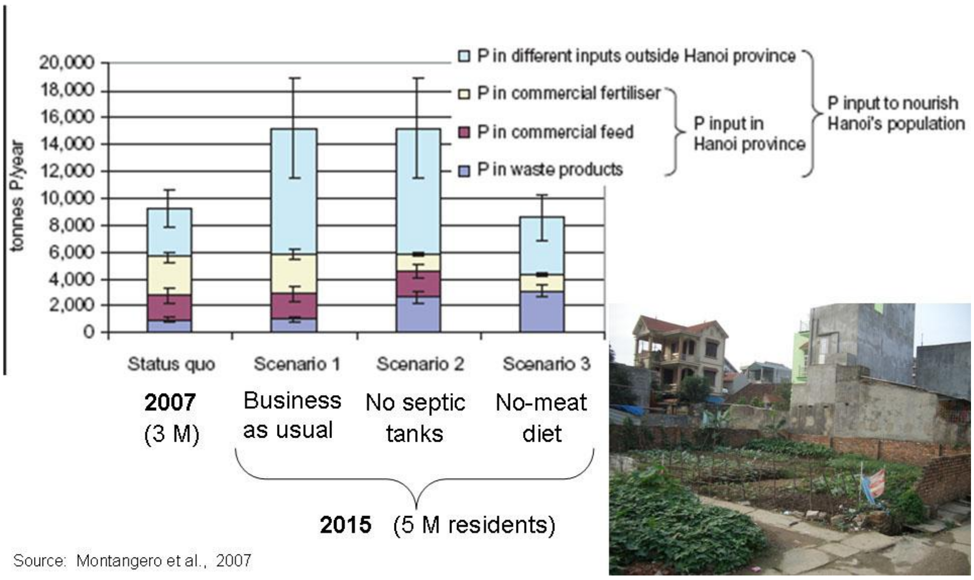
Currently, only 23 % of the P in waste products in Hanoi are recovered and used as organic fertiliser, in irrigation water, and in livestock or fish feed. This amount corresponds to 18% of the total P actually used for food production in Hanoi province. The bulk of P demand (82%) is met by artificial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

1.3 - 21

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



Source: Montangero et al., 2007

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.

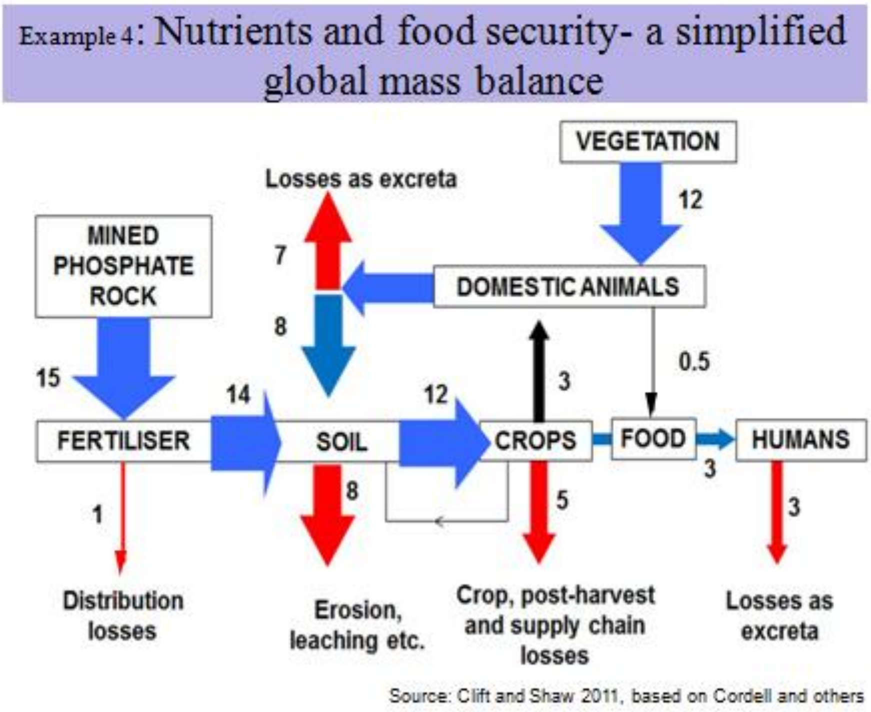
The bars indicate the required tonnes of P per year to feed the population (error bars indicate the standard deviation). The upper light-blue section of the bars represents P input in food produced outside the province, but consumed in Hanoi. Almost all food for the additional 2 million population will 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.

1.3 - 22



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).

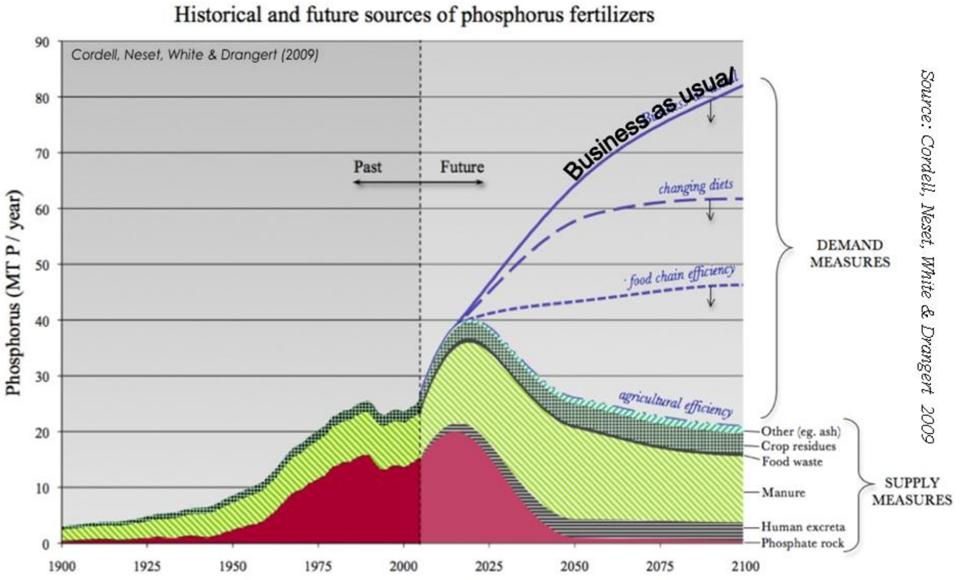
Today, food production relies heavily on chemical NPK fertilisers, and plants and animals need the P for survival. P is available in soils, but needs to be added to poor soils and to compensate for the P in biomass that is taken off the field.

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 future is not all dark!

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).

1.3 - 24

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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1.4 Demographic Change

Is urbanisation a solution or a problem for improving sanitation?

Learning objectives:
to gain insights about the role of demography in sanitation planning and implementation

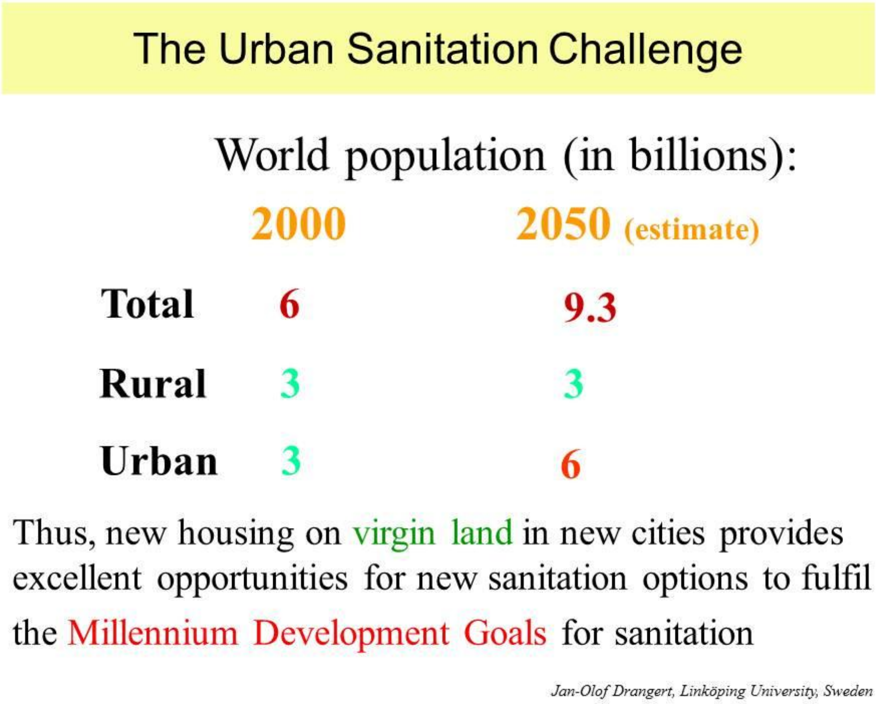
Jan-Olof Drangert, Linköping University, Sweden

Thomas Malthus wrestled with the dynamics of food production and population increase, and in his first *Essay on the Principle of Population* (1798) he stated two principles: population rises geometrically, and food production can only be increased in an arithmetic (linear) fashion. Thus, Malthus believed, recurring famine and death were inevitable to restore the balance between population and food supply. In his time, there were also devastating wars in Europe and a struggle for new agricultural land, and an emerging exodus to colonise so-called virgin lands in other parts of the world. Later, Marx and other social scientists refuted Malthus's principles. It was not until the 1960s, however, that the Danish agricultural economist Ester Boserup revised the principle about the linear growth of food supply. Her studies on agricultural change showed that the frequency of cropping a piece of land had been left out of the analysis, and the spotlight had been on the acreage under regular cultivation (Boserup, 1965). Boserup argued that the increase in population density was a major driving force in developing agricultural technologies rather than trade and applying these new technologies. Boserup made population **density** the independent variable impacting on methods of food production. It is ironic that, in an era when world population grew geometrically in accordance with Malthus's first principle, his second principle of linear increase in food production was shown to be wrong.

Nobel laureate Amartya Sen (1994) formulated three fundamental questions that are pertinent in the present phase of world population growth. The first one is "How close are we to the limit?" As mentioned above, food production has so far matched the number of people. As for the UN population predictions, the world's population will reach its peak of 10 billion in the year 2050 (World Population Projection, 2009). The worry today seems not to be the provision of food, but rather the scarcity of other physical resources and energy. This relates to Sen's second question, "Is food the main issue?" His third question is whether a rational social policy can be voluntary. The one-child policy which China implemented to limit its population growth has not been voluntary. However, the policy was rational in the sense that it has avoided an additional population growth in 30 years of some 400 million people!

In this module we examine the effects of rapid urbanisation on urban sanitation arrangements. To gain insights into what can happen and how, we look at some examples of city development over a century or two. A model for thinking about how to select feasible arrangements evolves from the examples. Publicly run infrastructure or local community solutions are not the panacea that their advocates frequently assume them to be.

1.4 - 2



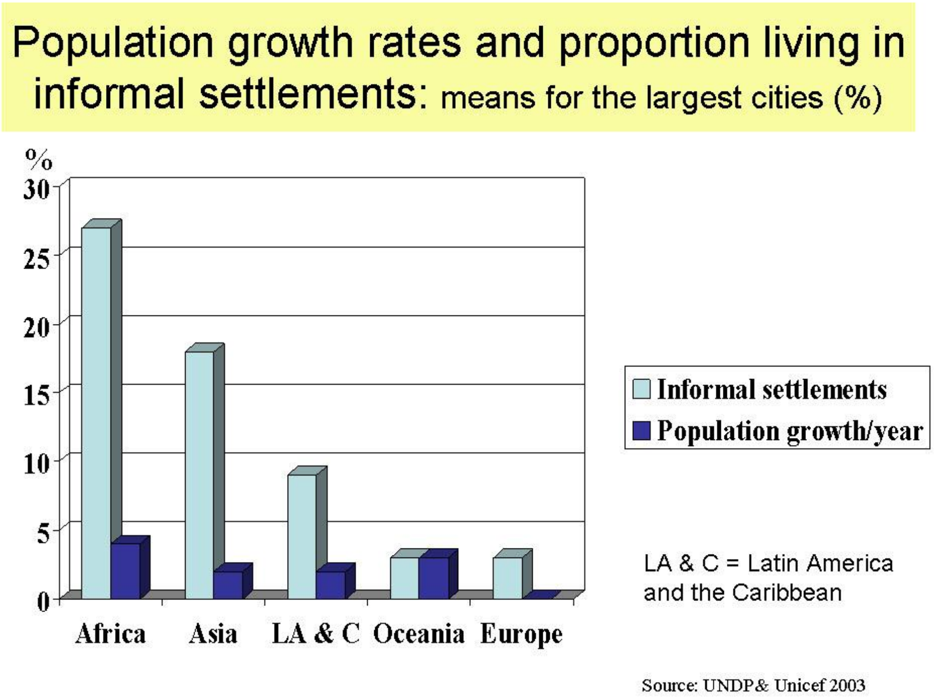
The world population is becoming more urbanised and today every second person is estimated to live in an urban area. The fact that the urban population will double from 3 to 6 billion in less than 50 years (UN, 2007) means that there is a need to build as many houses in the next 50 years as the present number of houses in all urban areas of today! This huge task will convert large stretches of what is presently agricultural land into housing areas.

Many researchers have argued that the world does not have enough resources to supply its present population. Wackenagel et al. (2006) coined the term ecological “footprint” to calculate the amounts of land and water needed to produce food and other essentials and to deal with waste from consumed products. An argument similar to Malthus’s second principle emerges: that there is not enough land and water. This is tantamount to saying that local pressure on resources from millions of urban residents in confined geographic areas can only be met by improved efficiency and recycling of materials and resources.

From a strategic point of view, the yet-to-be-built houses will allow us to invest in alternative sanitation arrangements without the normal constraints that apply to retrofitting. This opportunity to develop and install more sustainable sanitation arrangements should be explored for all new areas. An interesting development is going on, for instance, in Bangalore, India’s Silicon Valley, a city of seven million. In order to get building permits for big apartment complexes (several hundred flats) contractors must install mini-treatment plants in the basements. The treated water is used for flushing toilets and for gardening (slide 2.1-15).
In this way almost half the demand for water is met and the wastewater problem is ameliorated. The residents will with time realise that by not polluting the water too much while using it, they can make sure that the treated water does not smell when it returns to their bathrooms.

Living in a town seems to reduce people’s desire to have more than two children per family. Whether this choice is voluntary remains an open question. Economic conditions for urbanites seem to encourage the emergence of a societal norm of having few children. The effect is that global population will stabilise around 2050. The shift to small families means that a larger proportion of the population is of an economically active age for a few generations, and therefore can produce more goods and services (Rosling, 2010). The urban population will have the potential to invest more time and resources in the sanitation sector.

1.4 - 3



About two out of every 10 people in the developing world were without access to safe water in the year 2000; five out of 10 lived without adequate sanitation; and nine out of ten lived without their wastewater being treated in any way (IMF & World Bank, 2003). The focus here is on urban residents.

The diagram in the picture shows a likely link between the rate of population increase in major cities and the proportion of people living in informal settlements, with the exception of Oceania. The higher the population growth rate, the larger the proportion of residents live in informal settlements. In African cities, one in four residents lives in an informal settlement. In Asian cities, the figure is almost one in five. Services provided to residents in such areas are often rudimentary, and residents have to come up with their own solutions such as dug latrines and wells. The fact that residents find their own solutions to meet their needs is not intrinsically bad, and we should learn from it.

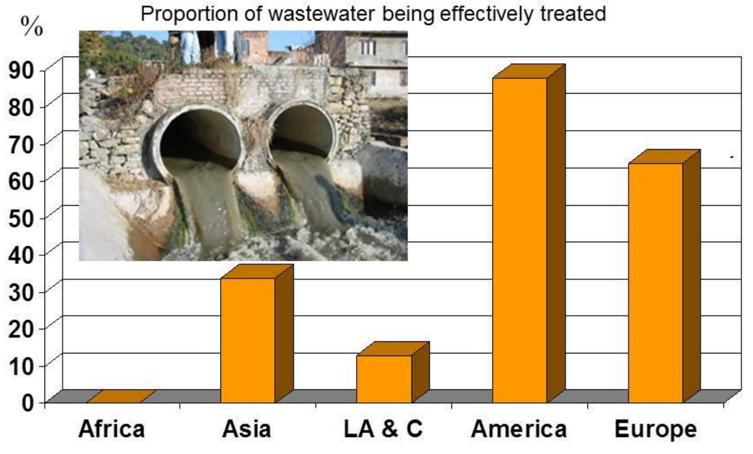
Informal settlements are not planned by authorities, and the authorities seem to lack the human resources, and sometimes the interest and proper organisation needed for such things as tax/fee collection to manage such settlements. Where a city's capacity to perform its duties is weak, private initiatives fill in the void. A myriad of individual, private and civil society activities make the city work anyway.

The diagram does show a static picture of what has happened during the urbanisation process up to the year 2000. It does not display the dynamics caused by the continuous upgrading of existing slum areas while new slums are added at the periphery of the expanding cities. Newcomers to town start from the bottom in their housing career as tenants or self-builders. It is likely that landlords and others who provide housing do not have information about non-conventional affordable sustainable sanitation and water options. The demand for housing is usually high and landlords do not have to compete by offering improved houses for the poor newcomers. Also, there is no cooperation between landlords and authorities, which is needed to improve district-wide sanitation arrangements. What is often missing is a market with products such as sustainable toilets and small-scale water treatment units, and masons, plumbers and other skilled workers who can install them (see Module 2.3).

We explore to what extent residents and authorities are able to cater for sanitation and water needs for a rapidly increasing urban population.

City council capacity to do its part

1.4 - 4



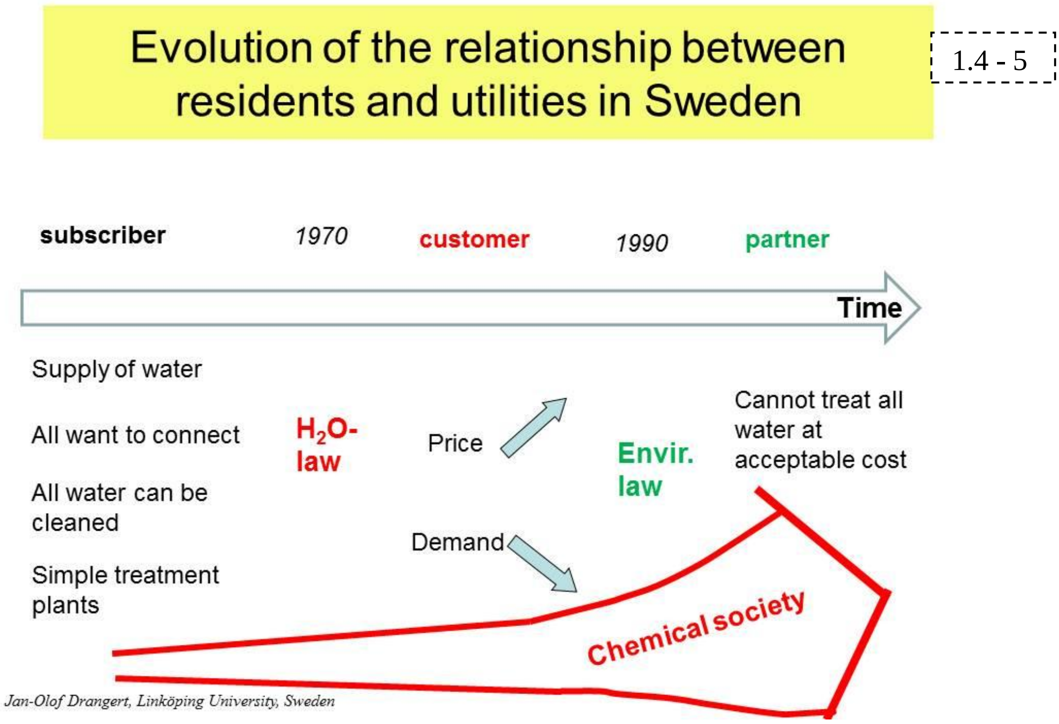
Source: UNDP & Unicef, 2003

The graph above shows the proportion of wastewater from urban areas that is being effectively treated (rural areas are not of concern here). In Asian cities 65% is not effectively treated; in Latin America the figure is 86%; and in Africa 100% of wastewater is not effectively treated. The data corroborate the impression from the previous picture about rapidly expanding large cities being likely to fail to achieve high service levels. Africa, with the highest rate of urbanisation, is the region with the lowest rate of effective treatment. Latin America, with the second-highest growth rate, is second, and Asia with third-highest growth rate is third.

There are at least two issues that should be brought up in connection with the data presented here. Urbanisation leads to high, urgent demands for safe water, and is accompanied by the disposal of correspondingly large volumes of wastewater. City councils' capacities to meet these demands fall short of expectations in most cities of the world. Often one can use the effectiveness of wastewater treatment as a litmus test for council capacity more generally, since if they fail in this sector, they are also likely to fail in many other sectors. A combination of factors led to the present conditions, and here the focus is on the contribution of rapid population growth.

It seems obvious that any treatment is better than no treatment. But we must not fall prey to the belief that all treatment has to be done in a wastewater treatment plant (WWTP) and forget that microbes also work in a situation where the wastewater is thrown on the ground. We need to keep in mind that even an efficient treatment plant without the capacity to treat all water during heavy rainfall may discharge substantial volumes of organic and other substances to the receiving water (slide 1.3- 17). More importantly, a wide range of consumer goods is disposed of via wastewater pipes. Unfortunately, modern WWTP are not designed to treat all of the 30,000 chemical compounds that households discharge in the wastewater. Usually, the plant monitors only 5–10 of these, while reduction rates of the rest are not monitored at all.
The label WWTP, therefore, does not adequately describe the performance of such plants and may be misleading.

In addition, all sewers leak and have over the years polluted the groundwater under every town. Cities with a low provision of WWTPs could even have an advantage from the point of view that they have a choice of selecting an appropriate treatment method without having already invested large amounts in a technology which may be inappropriate. This may also enable them to plan for the treatment, not only of today´s wastewater but also of the anticipated contaminants in future wastewater.



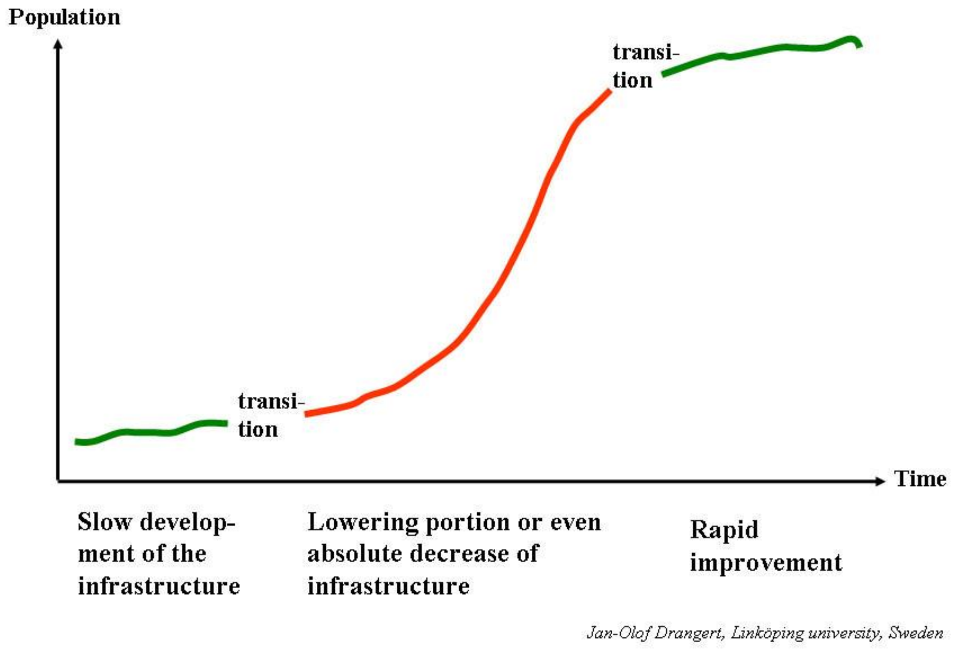
Urban dwellers in Sweden were gradually connected to water supply and sewers in the first half of the 20th century. Subsidies made it cheap to connect, and the understanding was that the wastewater was taken care of in a proper way. However, after having discharged untreated wastewater for a long time, nature reacted by algae blooming and eutrophication. The government responded by facilitating the building of wastewater treatment plants by generous subsidies (still tax money). In 1970 a new water law required all utilities to be self-sustained operating on a 'no profit and no loss' basis. Previous investments had to be repaid and therefore the utilities raised the water tariffs for households and industry. The immediate response from industry was to save water by conscious conservation. Soon households followed suit. The result was that the price hike did not bring higher incomes, so the utilities raised the tariffs even higher causing even lower demand. For the first time the utilities realised they were working on a market and had to adjust by employing economists to find a balance between costs and income. This took more than a decade to achieve by cost-reducing measures and treating the water users as *customers*. Previously they were treated as *subscribers* who were only expected to pay the bills they received.

As our chemical society slowly evolved, say after 1940s, a host of chemical compounds were introduced in household products. Improved economic standard allowed the growing population to buy ever more goods, so the challenge of collecting, sorting, treating and reusing them became evident. However, a common societal response was to only establish bigger landfills and longer wastewater pipes bringing the effluent further out in lakes and Oceans. A result is that residents are not aware of the limited utility capability and thus do not care what they dispose of. Similar developments were recorded in most countries and cities around the world.

In 1990 the central government enacted a new stricter environmental law forcing water utilities to improve the treatment of wastewater. This is not really possible because the content of the wastewater become increasingly complex with lots of new chemical compounds. The modern wastewater treatment plants are not designed to reduce all 30,000 chemical compounds found in normal household wastewater (Module 4.5). The utilities came to realise that they needed the cooperation from the customers for this endeavour. They initiated a dialogue to ask customers not to throw unwanted material in the toilet or flush down hazardous waste into the sink. This shift in the relationship between residents and utilities is taking place and residents are viewed as *partners* in improving the quality of household wastewater.

Demografic patterns are decisive: The growth-infrastructure hypotheses

1.4 - 6



Demographic characteristics, both density and growth rate, are of fundamental importance for water and sanitation management as indicated in the two previous slides. The graph above shows a hypothesised relationship between the rate of population increase in a town or expanding urban area and the capacity of authorities to organise access to water and disposal of human and household waste. The multi-dimensional causes of changes in population growth are not dealt with here, and times when these changes take place are only indicated as transition periods.

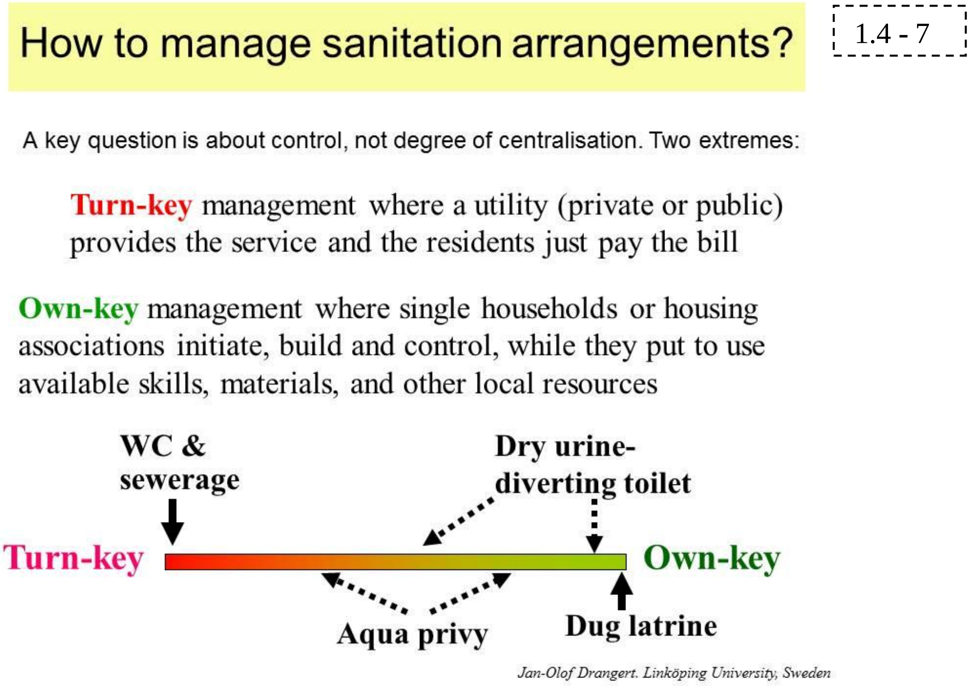
Hypotheses: When the population is ***small and stable or growing slowly*** (left *green* curve), strong social links among kin and other groups contribute to a cohesive community where societal norms reign fairly uncontested. A relatively large proportion of the residents belong to the economically active age group (Drangert, 1994) and therefore the human capacity to implement arrangements is good. The hypothesis is that at such times, community leaders are fairly reluctant to embark on major changes to the infrastructure. Although the financial capacity may be present, the leadership focuses on managing low-budget services to the residents, rather than acting as entrepreneurs involved in a rapid "modernisation" process funded by higher taxes. In the absence of external forces such as central government intervention, most community needs will be satisfied by arrangements that individuals and small groups initiate and control, using locally available skills, materials and other resources.

During periods of ***rapid population growth*** (middle *red* section of the curve), on the other hand, social cohesion tends to weaken and public sector management, including the collection of fees, is often less efficient. The hypothesis is that under such conditions the existing communal infrastructure operates poorly and that little, if any, expansion of the public infra-structure takes place – a decline is more likely. Even if personnel are trained and installations rehabilitated, such measures soon fall into disrepair due to the demographically induced structural stress. The task of authorities is simply **unmanageable**. Small and large informal areas develop. Residents, especially newcomers to town, are obliged to use their own initiative to solve, for instance, the provision of water and disposal of wastewater and human excreta. Their chosen solutions may fall short of what professionals consider to be desired.

Since the tax base and/or managerial set-up and other related council functions are not adequate in this phase, the option to invest in, for instance, conventional infrastructure is hardly present. The search for improvements needs to focus on solutions that do not require substantial inputs from the public sector. Such arrangements are commonplace and do take into account the existing sociocultural and economic constraints and yet, at times, they are sustainable. But they are rarely recognised or appreciated by the formal sector. However, authorities could assist with relevant information and advice on improvements, which would be possible within their limited capacity. The opposite is not uncommon, that staff and inspectors threaten to close down local arrangements with the argument that they are not up to standard. This boils down to harassment since the authorities do not have the capacity to provide municipal arrangements.

The rapid population increase will sooner or later ***slow down*** (right *green* section of the curve), however, and as a result the social cohesion and administrative capacity will improve. The whole city is again manageable. The hypothesis is that authorities will have the interest, capacity and financial strength to invest in and manage water and sanitation arrangements. The evolving water and sanitation system may still be a combination of municipal council installations and citizen’s arrangements.

Before proceeding with the analysis of links between population patterns and conditions of sanitation in urban areas, we need to introduce a vocabulary for this purpose. The next slide provides a useful outline of various management options.



Sanitation in today's cities is far from sustainable and new solutions are in demand in both rich and poor countries. We need to assess what human, financial and other resources are available and how to combine these for more efficient performance. In Module 1.2 the management of natural resources was discussed from the perspective of preservation and in Module 1.3 the role of the sanitation sector in recycling water and nutrients was in focus. Here the focus is on management from a human resources perspective.

A crucial management question is **who** is to take on the responsibility to manage various parts of a sanitation system. There are two extremes of management (not to be confused with centralised and decentralised arrangements).

Turn-key management. A utility (private or public) provides all services, while residents only pay. The term "turn-key" was initially used to describe a type of project that is constructed by a developer and sold or turned over to a buyer in a ready-to-use condition. This approach was thought to bypass many steps on the economic development ladder. *Turn-key* arrangements of piped water and sewerage, presently the most sought-after systems, can provide a household with one cubic metre of water "from the wall" and get rid of the same amount of wastewater "through the floor" each day without bothering anyone in the household. This is one of several attractive attributes of the piped system. A positive perception of this technology has been transferred successfully to almost all groups, including residents in developing countries with no such service. However, the system costs money and needs to be operated efficiently.

A typical water bill (in Sweden) covers about one-third of the total actual costs. The rest is paid for as part of the house rent to meet the costs of the initial connection fee and installations in the kitchen and bathroom. Previously, subsidised initial investments were paid for through taxes, while part of the cost of maintaining the pipes is pushed forward in time through neglected maintenance. The total cost for a family's daily water consumption of about 1 m^3 is some US$ 6–7 which is an ordinary income from half an hour's work. This, in turn, equals the average time spent every day by many rural women in Tanzania to fetch water for their families (Drangert, 1993). The difference is that the Tanzanian family only acquires perhaps 50–100 litres of water of lower quality.

Piped systems can provide good service, and their main limitations relate to the high investment cost, and lack of proper maintenance of pipes and good wastewater treatment in many countries. For instance, half of London's water mains are thought to be more than a hundred years old and a third could be over 150 years old (Deloitte, 2011). Even if the investment costs for sewerage were to be subsidised in poor periurban areas, there is often insufficient water for all additional WCs in the area.

Own-key management. Single households or housing associations initiate, build and control the arrangement. They put to use available skills, materials, and other local resources. The most common *own-key* solutions in urban areas are dug wells and pit latrines. However, there are many up-market technical arrangements as is shown in Module 2.1.

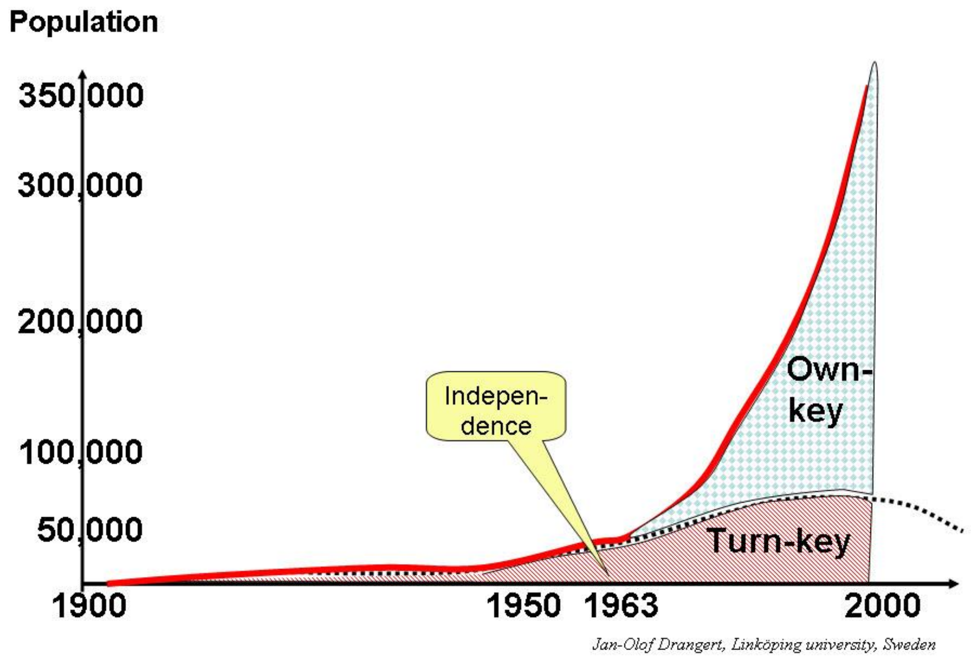
Own-key arrangements require some initial investments and usually time to operate them. However, they typically need a minimum of technical skill to operate and maintain. Time input may involve emptying urine in the garden, composting organic material, or putting grease on a hand-powered water pump. Part of the operation and maintenance work, such as collecting faecal matter, may be done by a contractor for a fee.

Pit latrines work rather well as low-cost, *own-key* installations. However, due to the number of users in dense periurban settlements latrines seem to be difficult to maintain. Unless the soil has a high capacity to drain the water used for anal cleansing and from the bathroom soakaway as well as entering rainwater, stagnant water may become a problem. Moreover, if the fluid in the pit percolates into the saturated zone, the groundwater will become contaminated and can transport micro-organisms to nearby wells (WHO, 2006). Ideally, a vertical safety distance of 1.5–2 metres should remain between the bottom of the pit and the highest groundwater level in all seasons.

The following two urban water and sanitation stories from a town in Kenya and another in Sweden illustrate how the above hypotheses (slide 1.4-6) can be tested in terms of own-key and turn-key management.

Example: Evolution of w&s in Kisumu town, Kenya

1.4 - 8



In 1900 there were very few towns in East Africa. Exceptions included Old Kampala in Uganda and the coastal towns of Bagamoyo, Zanzibar, Kilwa, and Lamu established by Arab traders and with water and sanitation solutions of Arabic design. A study of the development of sanitation and water arrangements in Kisumu town on Lake Victoria in Kenya during the 20th century provides some insight into the relationship between demographic change and water and sanitation infrastructure (Drangert et al., 2002).

Kisumu is situated on the eastern shore of Lake Victoria, the second-largest freshwater lake in the world. The town was founded in 1901 as a port town on the railway line from Nairobi to the lake region to serve agricultural exports from Uganda. Initially, the residents of Kisumu were largely people connected to the operations of the railway, shipping and related commercial services. Later on, fishing and large-scale farming in the hinterland dominated the town's economic activities, and after World War II urban industry and public administration expanded. The proportions of turn-key and own-key water and sanitation arrangements are indicated in the diagram above, together with population data.

Professor W. J. Simpson from the Ross Institute in London presented statistics of the number of annual deaths from plague that came to the notice of the medical authorities in the township. Deaths ranged from 4 to 71 a year during the period 1904–1913. Colonial Office records indicate that Kisumu had only 400 inhabitants by 1910, and population growth was slow. Initially, the small town was regarded as disease-ridden, and this made the authorities vigilant and proactive. Existing records show that the colonial administration developed the first piped water supply in the town in 1907 when lake water was pumped up to a tank above the township (Anyumba, 1995). However, the water supply for the European houses was derived from rainwater tanks attached to each house, possibly for fear of the plague. All refuse was removed twice daily, a drainage system was installed, and a sanitary inspector was employed. "*Rat destruction, street by street, ward by ward, house by house, and premises by premises*" (Simpson, 1914) was carried out. Professor Simpson rated the houses erected for the African employees as excellent and well lighted and also rat-proof. A bucket collection system for excreta was run by the authorities, and in 1916 incinerators for both night soil and rubbish were introduced. However, the bucket collection system was not used in the European part of the town, where there were flush toilets and septic tanks.

The town grew and sanitation and water arrangements were gradually upgraded with a high coverage of water supply and sewerage (picture). By restricting the influx of rural people Kisumu retained well-managed water and sanitation arrangements. Towards the end of the colonial period, two sewage disposal lagoons were completed to handle the growing amount of sewage. This situation compared favourably with the conditions in UK at the time.

After Kenya's independence in 1963, the population grew five-fold within two decades. A major reason for this unprecedented growth was that the independent government lifted earlier colonial restrictions on migration of the African population into towns. Also, incorporation of the densely populated periurban areas in 1972 contributed significantly to the population increase. Some of these newly incorporated suburbs were supplied with lake water from standpipes and water kiosks (Anyumba, 1995). Little has been added on since that time, with the exception of a World Bank project that put up a new suburb with 180 single-family houses fitted with water and sewerage, and well-drained tarmac streets. The Japanese aid agency (JICA, 1998) estimated that about 60% of the residents were served with at least some piped water. However, only 8% of those served had a continuous supply, 34% had a limited supply, and 58% were supplied from water kiosks.

The 40% with no access to taps, and a very large number of households with intermittent piped water, had to buy water from vendors or private wells when the municipal council was unable to deliver. Roof-catchment was only provided by some landlords and private homes.

The council phased out the bucket system for night soil in the 1970s without expanding the sewerage, and residents had to dig latrines in the suburbs. The latrine pits dotted the whole area, and jeopardised water quality in nearby wells. The sewage system served only the central part of the town and the effluent reached the lake untreated, except for the portion that entered the two treatment ponds. An advanced wastewater treatment plant was built in 1969 with donor funding and it was renovated in the mid-80s. Since 1999 this communal plant has not operated because of non-payment of electricity bills. The exhauster service for emptying pit latrines and cesspools has deteriorated sharply since the late 1980s. And much of the drainage is poorly maintained.

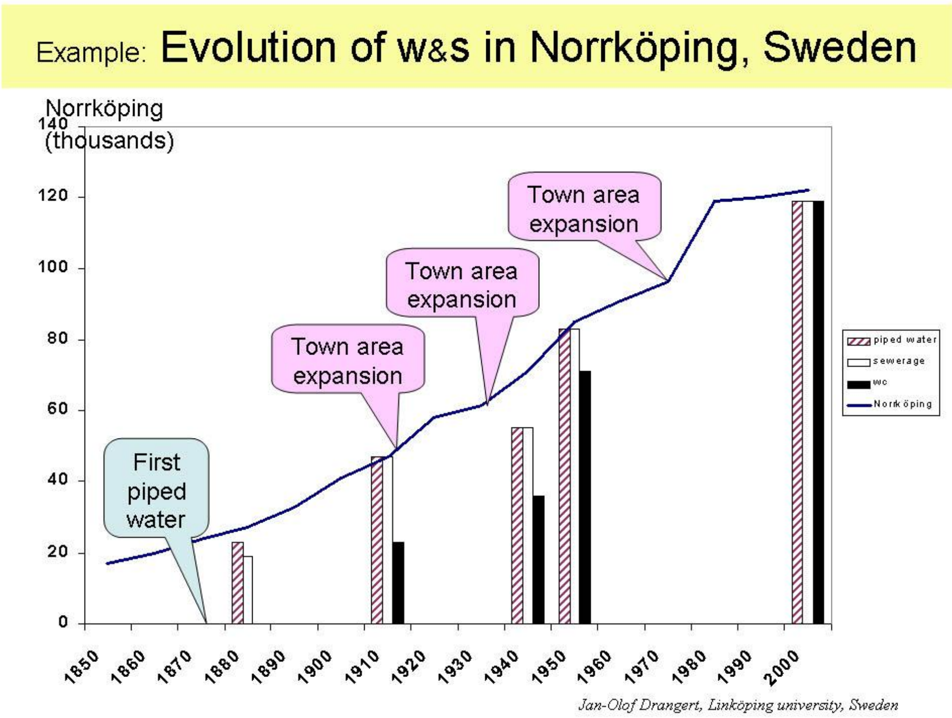
Water fees earn little since many of the individual water meters are out of order (JICA, 1998). Still, water and sewerage charges amounted to 100 million Ksh or 45% of the total revenue base for the council in 1995/96, while the actual expenditure for water and sewerage was 129 million. A serious problem arose later when a major water user, a beer manufacturer, moved away from Kisumu after it had been denied permission to develop its own water source. The result was that the council remained with its expenditure almost unaltered but it had lost half of its revenue. The non-payment of the electricity bills mentioned above is a result of this.

The low service standard of the municipal water and sewerage department can also be understood from the fact that only 102 out of a total of 326 positions were filled in 1997, and most of the vacancies appeared at senior levels. A government paper of 1999 recognised that such institutional weaknesses prevent the proper operation and maintenance of water supplies.

Conflicting interests between the council, the town clerk and other officers within the council were reported by the press, together with rumours that some influential decision-makers owned the vendor-business in the town and obstructed any rehabilitation of the system. The central government ended its support of the water services and donors were cautious about becoming involved. The Japanese government, for example, offered to support a large-scale water supply and sewerage project in Kisumu but the proposal was conditional on improvements to future water management (JICA, 1998). Few people believe that this large-scale turn-key arrangement will take off in the foreseeable future.

The picture illustrates the disastrous evolution of public turn-key provision of water and sewage by the municipal utility. When the city rapidly became big, the residents "went small" and they organised and installed own-key arrangements despite periodic council harassment.

1.4 - 9



The town of Norrköping was one of Sweden's leading industrial towns in the second half of the 19th century, dominated by textiles manufacturing. Swedish towns are small on an international scale, and so is Norrköping. There were some 17,000 inhabitants in 1850, 41,000 in 1900 and today the number is about 120,000 (see graph). Although there were some decades of peak in-migration to Norrköping in the 1880s and 1890s, its growth rates were still far below those of Kisumu town in the second half of the 20th century.

Piped water and sewers were installed in the 1870s only after a big donation from a wealthy manufacturer. The water intake was situated upstream of the town while the wastewater was discharged untreated at several points. The donor stipulated that the piped water must be free in order to benefit the many workers' households in town. It was cheaper to build and provide (by gravity) workers with good water than to treat all industrial wastewater from the many factories along the river. (It took another half a century and heavy fish deaths before the industries started to treat their effluent). It was estimated that 85 per cent of the households got water taps in the yard or indoors, while some 70 per cent were connected to a sewer. Initially, there were only a couple of flush toilets in town, and almost all excreta were collected in buckets and used together with cow dung as a fertiliser on nearby fields.

A generation later, in 1910, almost all households had a sewer connection, and piped water at least to the kitchen. Almost half of the houses had flush toilets (the highest urban coverage in the country at that time) while the rest relied on a bucket system (Drangert & Hallström, 2002). In the year 1900 the council started to charge the users for water despite the undertaking to the donor that the water would be free. When nearby areas were incorporated into the town in 1910 and 1935, little or no effort was made by the council to provide these areas with centralised water. Therefore the proportion of water coverage decreased during those years. The subsequent period of slow population growth made possible a rapid increase in coverage of water, decentralised sewers and WCs. The same was true for a big expansion of the city in 1972 (slide 2.3 - 11). Practically all houses and flats were connected to a communal decentralised system by the end of the 20th century.

These developments fit quite nicely to the hypotheses. The initial investment was enabled by a donation, without which it is likely that the piped system would have been delayed several decades (compare Kisumu town where the colonial government put up the initial funds). Since the 1950s the few *own-key* arrangements were restricted to distant homes which were too expensive to connect. They had indoor water pumped from a dug well in the garden and a septic tank and infiltration bed near the house. In some low-density areas neighbours organised their own small water association for supplying water.

The city council agreed to spend money on the operation of the water supply and sewerage and on some expansion of the system once it was established (thanks to the private donation). However, the council was reluctant to provide services to the newly incorporated informal areas despite the fact that many tax-paying workers from the city's manufacturing industry lived there.

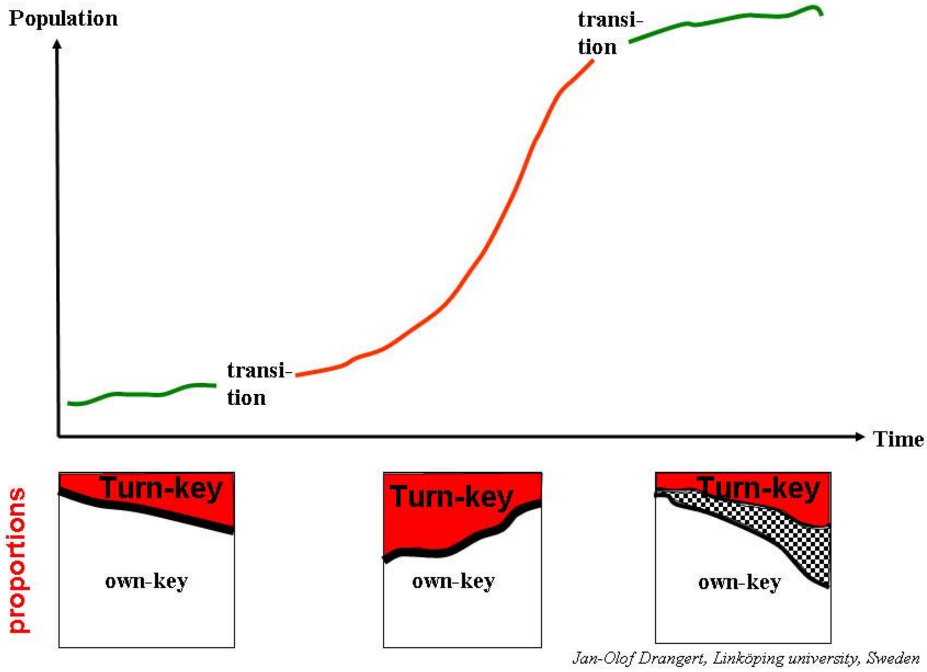
A different lesson is that by the time all residents were connected to the water and sewerage they had lost their option for an alternative system. The water by-laws prohibited alternatives in the utility's sewage catchment area. Households connected in the 1990s, for example, had already paid the connection fee of US$15,000 and additional costs for the pipes into the house. They were therefore reluctant to add a new investment for an individual household arrangement. The system has become inflexible with few avenues for trying out sustainable alternatives.

A reason for considering an own-key solution is the rising cost for the utility services. Energy prices have sky-rocketed since the first oil crisis in 1973 and the cost of pumping water to households and wastewater back to the centralised treatment plant has increased dramatically. Had the city network (slide 2.3 -11) been designed today, the energy cost would have been given more consideration than it was in the mid-20th century. The likelihood is that a more decentralised system would have been designed.

This account of the evolution of water supply and sewers would be incomplete if treatment of wastewater is left out. All household wastewater was discharged untreated to the river up to the 1960s. By that time, serious instances of fish death and emerging algae bloom in the nearby estuary were recorded. Outdoor bathing was a thing of the past. The city invested in a modern wastewater treatment plant in the late 1960s, and, as is common practice, the treated wastewater from households and industries was piped far out in the bay. New physical town plans forced industries along the river to close down or move to new industrial zones where they had to abide to the stricter environmental laws concerning discharges. Fifty years on the fish is returning but bathing is still not allowed.

Hypotheses on best management option

1.4 - 10



The previous two examples can be easily understood by using the concepts of *own-key* and *turn-key* arrangements and management. This terminology is useful for analytical purposes despite the experience that in real-life situations a system can be a mixture of the two. Anticipated service provision outcomes during the three demographic regimes are shown in the boxes. *Own-key* arrangements dominate in phase one, and the expansion of turn-key installations is slow. As the population starts growing faster, the proportion of *own-key* arrangements increases again, while the number of people served by turn-key arrangements may increase initially and later decrease due to inability of city councils to provide communal services. Urbanites apply their own resources to achieve local solutions; and in many areas they survive thanks to their own arrangements and efforts.

When the population stop growing fast both the proportion and number of urban residents having access to turn-key arrangements begin to increase. The checked area in the right-hand box between turn-key and *own-key* arrangements represents households which have a real choice between own-key and turn-key management. They may even use the turn-key services only part of the year e.g. during long dry seasons and relieve the utility the rest of the year. At the same time, the council may be reluctant to support or even allow *own-key* arrangements.

Kisumu and Norrköping towns developed the way the hypotheses predict. Both started as small towns with moderate population growth that did not require turn-key arrangements to start as early as they did. A private donation kick-started the building of a water supply and sewerage in Norrköping. The driving force seems to have been a combination of philanthropy and an awareness that it would be much more profitable to allow industries to continue to pollute the river while providing the workers free piped water of decent quality from an upstream intake. Kisumu, by contrast, was part of a colonial plan to expand export of the region's produce. There was a need to improve the public health situation and the British tradition of providing housing to railway and maritime workers resulted in an up-to-date water supply and sanitation system. However, it required a long-term government subsidy to survive.

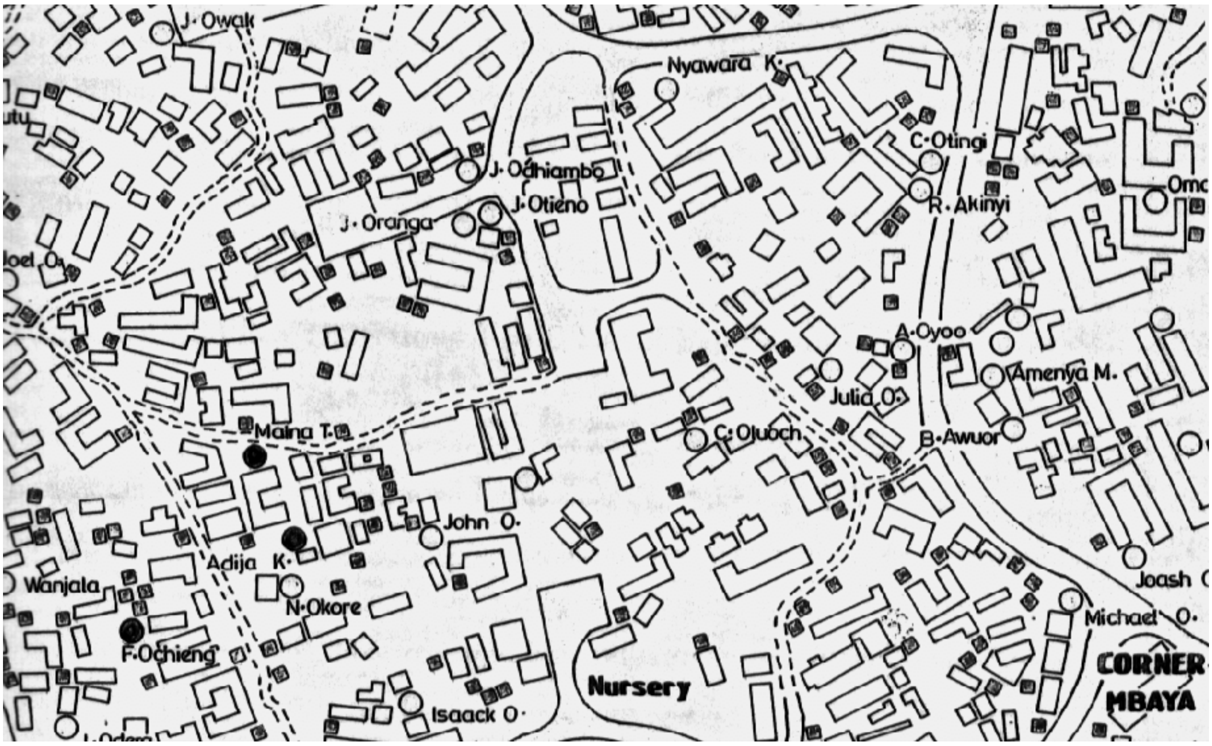
Norrköping continued to grow at a moderate rate all the way up to the year 2000, and never entered the rapid growth regime. The closest it got was when new areas were amalgamated and the utility failed to rapidly connect them to the decentralised system. The turn-key arrangements have been working well for the residents, but they also have to pay the full cost of the system.

Kisumu continued to grow at moderate controlled speed up to the end of the colonial period and the council ran a cost-effective water supply and sanitation system with bucket collection for a large part of the population and sewers for the office and commercial areas.

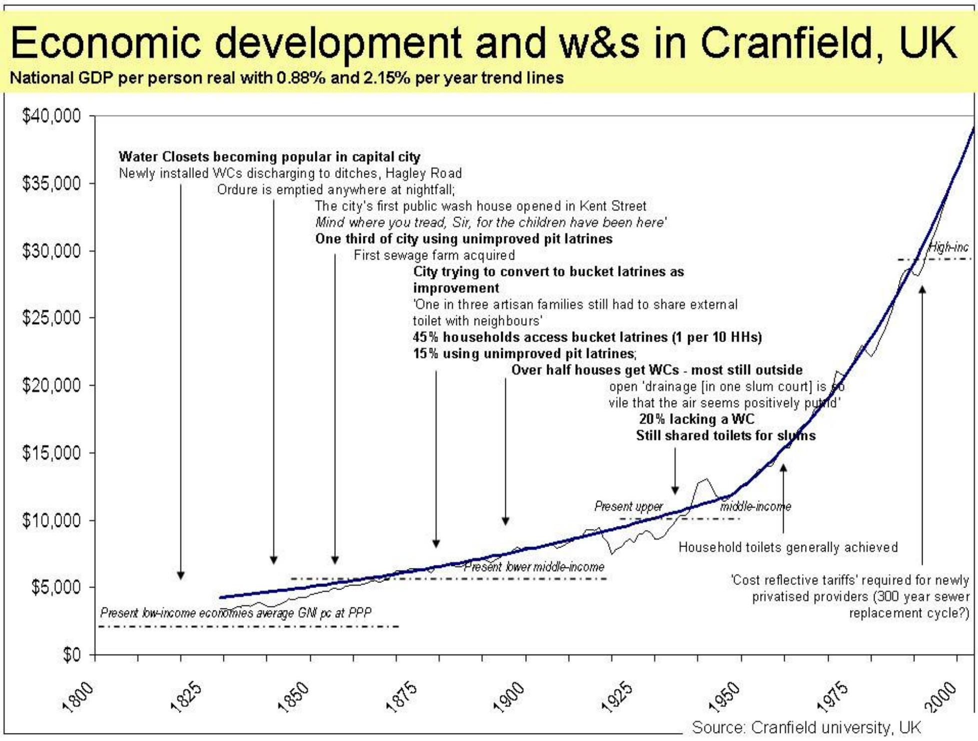
The post-colonial period after 1963 has been one with extremely rapid population growth that has put heavy stress on the municipal council, to the extent that it failed to provide water and sewage services to most of the new residents. The social cohesion in the community seems to have deteriorated progressively. The management of the council has become more and more politicised over the last few decades. The existing infrastructure deteriorated and provided only a small portion of the residents with reliable water and collection of wastewater. The bucket collection service and latrine-pit emptying has ceased altogether. Today, the majority of Kisumu residents live in periurban permanent or semi-permanent houses on small plots with dug latrines and possibly a well. Well water is sold to neighbours and water vendors supply wealthier households with water at high cost.

The hypothesis holds for Kisumu during the period of rapid population growth, during which service levels have deteriorated. The growth is ongoing, and few residents seem to believe that a turn-key arrangement will be in place in the foreseeable future.

Map fragment of the Manyatta Gonda area in Kisumu with wells and dug latrines



Source: Drangert et al., 2002. Ring = well, filled square = pit latrine



Source: Cranfield university, UK

1.4 - 11

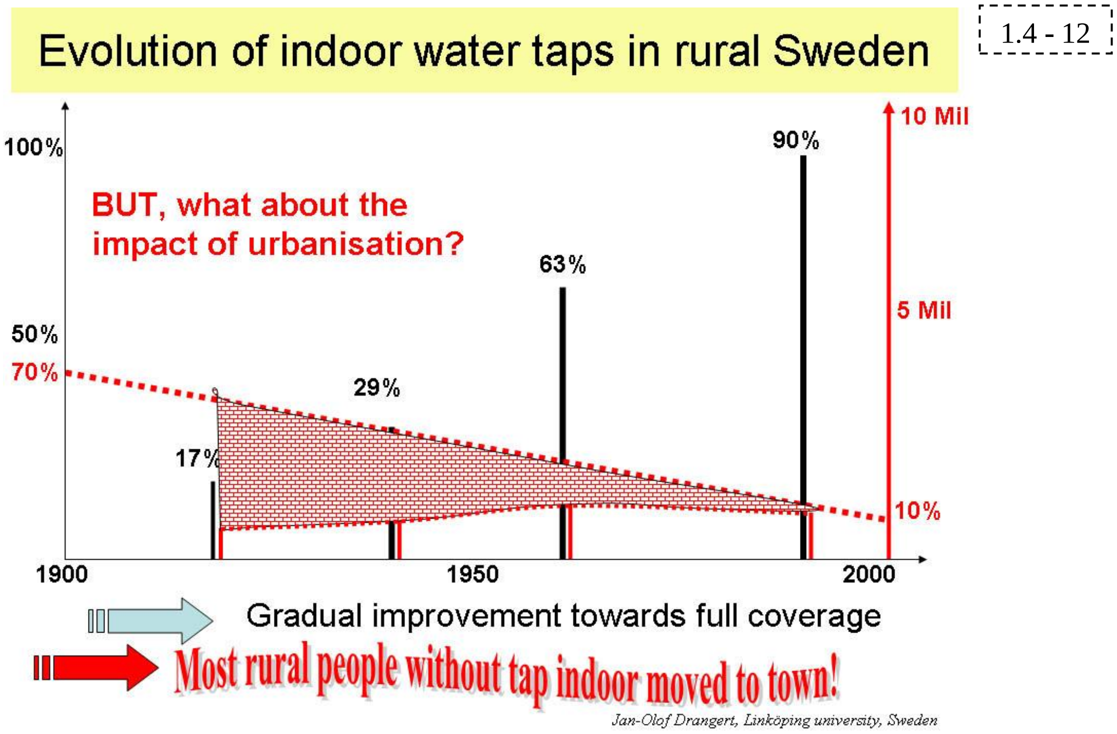
A different way of interpreting the evolution of water supply and sanitation is to relate existing arrangements to residents' average income, calculated as GDP per capita. The picture indicates the average income level on the vertical axis and the blue curve represents discounted increase in income over the period 1800 to 2000. The national GDP per person with 0.88% and 2.15% per year trend lines makes up for the lack of city-related data on economic status.

The picture shows the development of water and waste services in the medium-sized town of Cranfield in the UK. This time the evolution is not related to population growth but is described in terms of how rich the community (country) is. The picture provides a good visual description of the evolution in the city.

WCs were already getting popular in London in the 1820s, when the first WC was installed in Cranfield and evacuated into open ditches. The ordure was disposed of anywhere at nightfall. Half a century later the council opened its first sewage farm to take care of the wastewater. Open defecation was still common among children and there was a saying "*Mind where you tread, Sir, because the children have been here*." At this time, one-third of the residents still used unimproved pit latrines and the authorities tried to introduce a bucket system to improve the sanitary conditions. By 1880 approximately 45% of households had access to a bucket latrine, but it was shared with some ten other households.

By the year 1900, half of the households had a WC but oftentimes it was outside the house or flat. The likely reason was that they functioned poorly and emitted a foul smell. As late as the Second World War, 20% of households still lacked a WC. The evolution in Kisumu, Kenya, should be compared with this situation in the backyard of the colonial power.

Full WC coverage was achieved in the 1960s; almost a century and a half after the first flush toilet was installed in the city. In medium-sized towns such as Norrköping and Cranfield the evolution is likely to be similar. The pit latrines were abandoned and the council tried to improve its bucket collection system. Around 1880 about half of the households had access to bucket latrines, while 15% still used unimproved latrines.



Sanitary improvements in rural areas may or may not be related to demographic changes such as densification, rapid growth or the exodus of young people to towns. A common view aired in the international debate is that rural living conditions should be improved in order to make people stay on and thereby relieve cities from disastrous growth. Some interesting lessons on social dynamics can be gained from investigating the introduction of indoor water taps in rural homes.

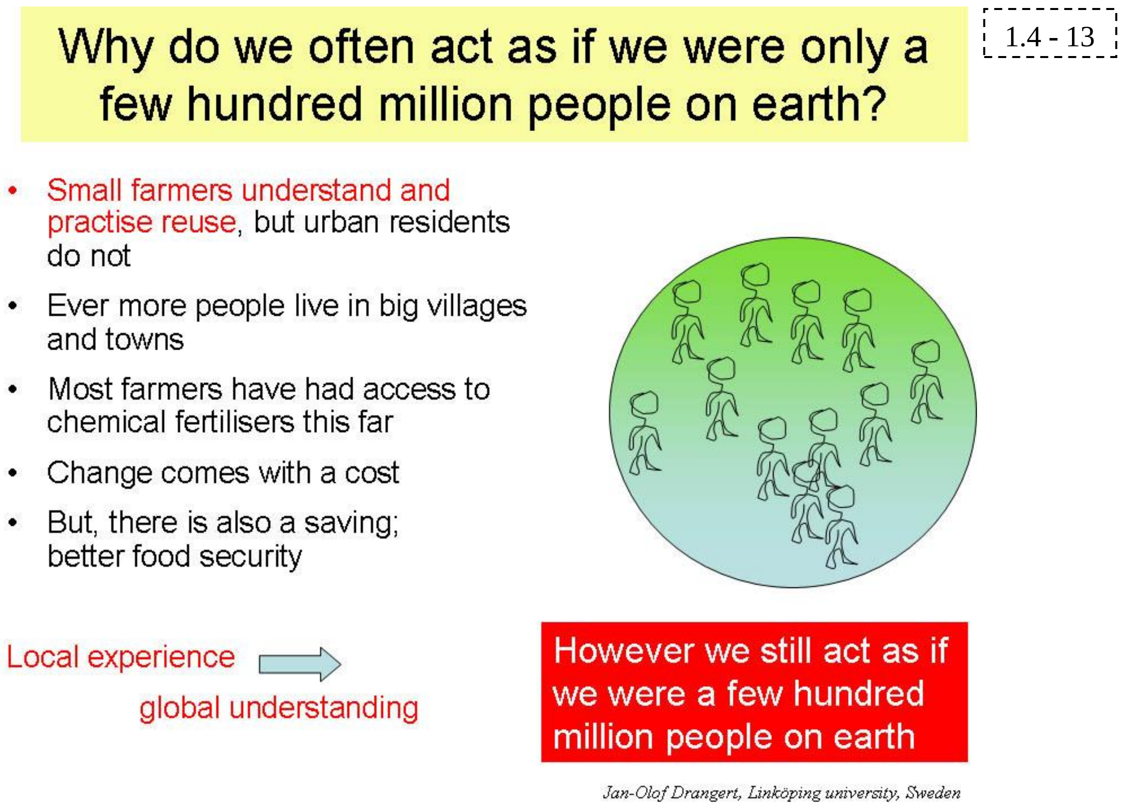
Rural households in Sweden usually had their own dug well from which they took water by the bucket to the house and to the stable or cow shed. In the second half of the 19th century, when cast iron made hand pumps affordable, it became popular to install them on the well. Only later did it become fashionable to install a small hand pump of cast iron in the kitchen. Later, when electricity reached the countryside the hand pumps were replaced by electric pumps. Data from 1918 tells that the proportion of rural households with a water tap indoors was 17 per cent, by 1941 the figure had risen to 29 per cent, and by the year 2000 to almost 90 per cent. This suggests that through gradual improvement, eventually all rural house-owners had installed tap water indoors (the water was pumped from the wells). However, it took a century to achieve.

This interpretation is challenged when taking migration from rural to urban areas into account. The rate of urbanisation was uniform over the whole century (picture). In 1900 some 70 per cent of Sweden's five million people lived in rural areas and towards the end of the century 10 per cent of 9 million did so. This means that about 3.5 million lived in rural areas in 1900 and 900,000 in the year 2000. Thus, the actual *number* of rural residents with tap water (red dotted curve) rose from roughly 600,000 (17% of some 3.5 million in 1918) to 900,000 (100% of 900,000 in 2000). The shaded area shows rural dwellers with no tap water indoors.
The conclusion is that rural homes with water indoors increased, while most rural residents with no indoor water tended to move to town instead of improving their rural homestead!

The latter interpretation provides a totally different understanding of how universal indoor tap water came about – not by gradual expansion but by migration to towns where an indoor water supply was available. We may add that the Swedish government did not run projects to support tap water, but during some periods they provided loans for improving rural housing.

The Water Decade strategy of (donor) governments to provide rural water had never been tried in the developed world. Therefore, when international bodies decided on slogans such as ‘Water for All’, they did something that had never been tried before. The prospect of success was slim, given that the rich countries experienced an easier situation with rural populations that were declining – rather than the situation in developing countries where numbers are stable or increasing and the rural populations are aging.

Ester Boserup introduced a new angle to the analysis of change in agricultural communities when she singled out population density as the autonomous factor making for a steady intensification of agricultural production (Boserup, 1965). She believed communities with a sustained population growth and increased density stood a better chance of achieving economic development than communities with stagnant or declining populations. This is similar to the situation with indoor tap water in rural Sweden. However, she made her thesis subject to a qualification: it may not be true of communities which have a *very high* rate of population growth and which are already densely populated, and are therefore unable to undertake the investment necessary for introducing still more intensive methods of agricultural cultivation. A similar approach to analysing the development of the sanitation and water sector in rapidly growing societies should be used in order to be useful for policy and strategy decisions.



It took more than 50,000 years to reach the first billion mark for Homo sapiens by the year 1800, and only ten years to add the latest billion people on the globe. We have difficulties to understand this pace. Collectively we still behave as if there were only some hundred million people on the globe. We focus on improving living standards for everyone without taking into account the available natural resources and the globe´s resilience. Of late, awareness about climate change may help us to understand the demands that 9 or 10 billion people will place on the world's resources (slide 1.1-15).

The closed loop was well understood and widely practised a century ago in the developed countries, and presumably also in developing countries. In the 1950s cheap fertilisers flooded the rich countries and gradually also former colonies. At the same time, urbanisation took off and fewer people had experience of farming. On the one hand, food production has grown faster than population due to improved management over the last century. For instance, production per hectare in Sweden has increased tenfold. At the same time, sanitation systems have become more centralised (sewerage) and involve less recycling as people move into more dense settlements, and thus the sanitation system has become invisible and less easy to understand. The concept of the closed loop simply faded away, and the flush system took over the sanitation sector (slides 1.3-2 and 2.2-2). Instead of bringing the human-derived nutrients back to soil where it belongs, sewage was simply emptied into water bodies. It is only in the last 50 years that wastewater has been treated to some extent before being released.

We started this module by asking whether urbanisation is a problem or a solution to sustainable futures. In a demographic sense the fundamental outcome of moving to town is that the number of children goes down. In most rural areas the decision to have two or four children is not restricted by economic reasons, since the two extra kids do not need an extra room for themselves, and their parents can produce the food by an increase in productivity (Boserup) or from an extra piece of farmland (Malthus). The decision is more likely to be guided by cultural influences. Parents in urban areas are also culturally guided, but this time to expect to extend the flat and to BUY clothes and other things that the extra kids need. Also, they have to BUY more food and the money for that can only be earned through work or spending less on other items.

The above exploration shows why one can expect higher numbers of children in rural communities than in urban areas.

The main challenge with high population growth – in both rural and urban areas - lies with providing public services for all newcomers. This is because the family is usually responsible for housing and feeding, while the public sector is responsible for health services and schooling. Such services require that parents pay higher taxes for their children’s schooling etc. Few of them see the connection between the family decision to have more children and the necessity to pay taxes or fees for public services, particularly if the education system is of poor quality. If no extra taxes are collected, the standard of schools will surely deteriorate.

The school sector can illustrate what happens if all families send four children instead of two to school. There must be twice as many teachers and classrooms available. Let us assume that the total population of a country is 23 million, that the growth rate is three per cent, the fertility rate is five per cent, and that each class has 35 pupils and one teacher. Over a period of seven years the cumulative requirement will be about 28,900 extra teachers and classrooms (slide 5.3-19). At least four new teacher training colleges would be needed per year to train the extra number of teachers, each with a capacity to train 1,000 teachers annually. Additional institutions to train trainers of teachers will also be needed. This is a daunting task that few countries can manage. Resourceful families in cities solve the problem by spending money on private schools for their children. The majority cannot do so, and there are not enough teachers available to fill all schools.

Governments cannot keep up with demands for services caused by rapid population growth and the situation becomes unmanageable, not because there is a lack of good planners, but because of the magnitude of the task. This applies to all public services that require financing through taxes or fees. This is confirmed by present development where most urban families can afford to build or rent houses, but authorities lag behind in organising acceptable water and sanitation arrangements in rapidly growing cities.

New ways to approach urban infrastructure are needed. The link between sanitation and food production has become less visible ever since the introduction of chemical fertilisers and sewerage. However, a likely scenario is that the understanding of closed loops will increase as the agricultural sector realise that they cannot afford to purchase chemical fertilisers (See Module 1.3). Decision-makers in cities may experience other push factors for closing the nutrient loops. One is that sewerage itself causes problems e.g. how to dispose of large quantities of contaminated sludge, and the increasing energy costs to pump effluent in pipes may also prove unaffordable. Change comes with a cost for urban residents, and one of those costs is the need to adopt new sanitation practices which involve some new routines.

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