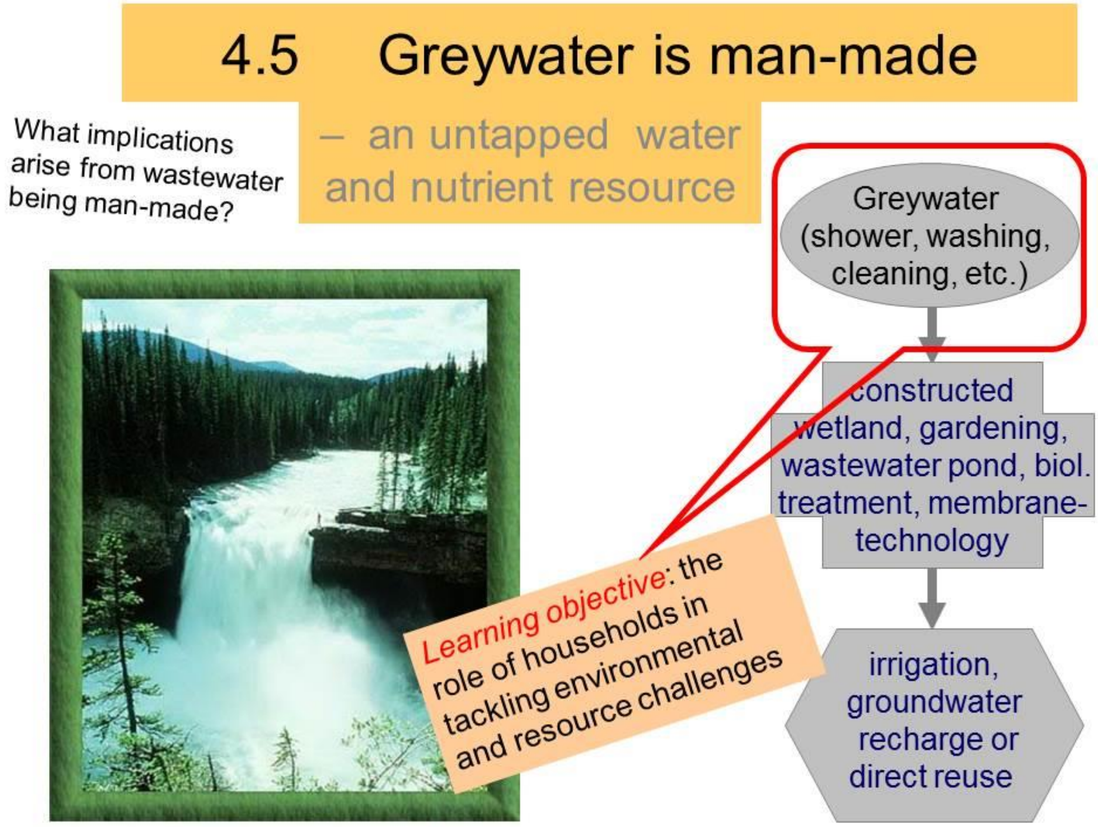


We are undergoing a radical shift in our understanding of water pollution. Up to a few decades ago we were mainly concerned with microbial risks to humans from polluted drinking water. These risks have been extensively studied and they can be controlled rather well by improving sanitary practices and protecting water sources, be they wells or containers in the home. Now, the eutrophication problem is largely understood and heavy investments in P and N reduction in wastewater treatment plants have reduced the problem.

The current threats come largely from chemical pollutants in wastewater originating from production and consumption of goods in our ‘chemical society’. These pollutants affect both the environment and human health. Chemical health threats are more complicated to analyse than those of microorganisms since chemical compounds are ingested in very small amounts and may persist and accumulate in our bodies. Dose-response studies therefore require long time periods and are expensive. Also, the number of artificial substances is very high – about 150,000 registered compounds – but these are known at least by the manufacturers. This is very different from microorganisms which emerge as part of the evolution and are gradually detected, with some new strains causing diseases within days.

During the last century, the industrial sector was blamed for causing environmental problems. Industry earned its bad reputation through many bad practices. However, legal action and greater awareness have improved the situation and today many industries are treating their used water on site. They can often recover some of the chemical substances in the wastewater and use these again in their production and also recycle the partially treated wastewater back to the production line.

Today, releases of environmentally hazardous substances are increasingly linked to diffuse consumption-related sources (e.g. individual households) rather than production-related large point sources. Discharges from households may even be more polluted than those from industry and offices. This is because households buy more and more chemical products such as personal care products, textiles, medicines, plastics, etc. Substances related to these products include plasticizers, brominated flame retardants, endocrine disrupting substances and many others that should not be released into the environment. A generation ago most of these products were not available at all, while the corresponding products were mainly biodegradable and we did not have to worry about them. Today, we have wastewater treatment plants, but they are not built to take care of the tens of thousands chemical compounds in the wastewater we discharge. It is true to say that householders are responsible for their purchase, use and discharge. However, the task of informing millions of inhabitants about the effects of these products, and making sure they take appropriate precautions is daunting.

A major problem to overcome is the perception that transparent water is always clean water. Staff at wastewater treatment plants may proudly show a bottle of clear water after the treatment of dirty water, but the disturbing fact is that this water still contains disease-causing microorganisms, hormones, heavy metals, etc. No WWTP in the world monitors more than a handful of the tens of thousands of compounds in the effluent and sludge. All stakeholders need to be involved in order to improve the quality of used water by not discharging harmful substances.

Population centres are becoming hot spots for pollution. Dealing with diffuse sources raises new challenges since legislation and other available tools are traditionally directed towards point sources. Therefore, there is a need to develop new methods to deal with these diffuse sources. Such methods include source control through, for example, legislation on hazardous compounds, information, green procurement, cooperation with stakeholders and new approaches to supervision.

This Module focuses on how households can manage their water use so that the used water becomes less polluted and useable again after some treatment, and thus more sustainable. We discuss what potential pollutants can be avoided (source control) and what valuable resources can be recovered and used for crop and energy production. Also, if water and greywater are properly managed, there will be no water shortage in cities, since the water can be used over and over again with little treatment!

There is recommended hierarchy of solid waste management measures:

1. ***Minimise waste*** volumes by reducing the amount of products and the quantities of toxic components in them to avoid unnecessary problems,
2. ***Reuse*** particular products several times,
3. ***Recycle*** products by processing waste materials to a new product,
4. ***Incinerate or digest (biogas)*** what cannot be recovered in order to take out the energy content
5. ***Safe landfill*** of toxic and other non-recovered material from the other options.

There is a similar hierarchy for the management of greywater. The first step is source control to minimise the volume and pollutant content of greywater. This involves residents as well as manufacturers of household products, often with the support of government agencies. The second step is to install arrangements that enable the sorting waste streams and may include not mixing flows from stormwater, industrial wastewater, black water, urine and faecal matter. The second and third steps are to reuse and recycle the components of the treated flows.

We discuss greywater from households, that is, all used water except toilet water but most conclusions also apply to mixed wastewater. Four aspects of greywater management are presented: consumption and use patterns, source control and content of greywater, treatment processes and arrangements, and recycling of water and nutrients.

Challenges and possibilities

4.5- 2

Greywater represents environmental challenges:

- Unpleasant odours
- Health hazard (pathogens and toxic compounds)
- Soil erosion
- Pollution of surface water and groundwater
- Mosquito breeding

Benefits of using treated greywater and sludge:

+ Reduces water shortage
+ Reduces environmental degradation, eutrophication and health hazards
+ Reclaims otherwise wasted nutrients
+ Alleviates food shortages and poverty
+ Protects the quality of groundwater

Courtesy of Nicola Rodda University of KwaZulu Natal, Durban

Some of the most common challenges and benefits related to greywater are given in the list above. After just a few hours, stored greywater releases an unpleasant odour. It may contain pathogens and chemical compounds detrimental to human and animal health, and if the effluent is released in an uncontrolled manner it may cause soil erosion. Depending on how well the effluent is treated, it can pollute soils and the waterways into which it is discharged. Some species of mosquitoes thrive in standing wastewater and can spread diseases.

The effluent coming out of a treatment process should be put to good use. Examples are irrigation, recharge of groundwater, recycling as toilet flush water or other non-potable uses. Treated greywater can reduce water shortages in households and industries, and larger volumes from towns can be used to irrigate farmland. Equally important is using the nutrients in greywater and sludge for fertilising crops. Increased yields may in turn help alleviate food shortages and help attain food security. An instant benefit is that environmental degradation such as eutrophication and groundwater pollution is reduced or prevented.

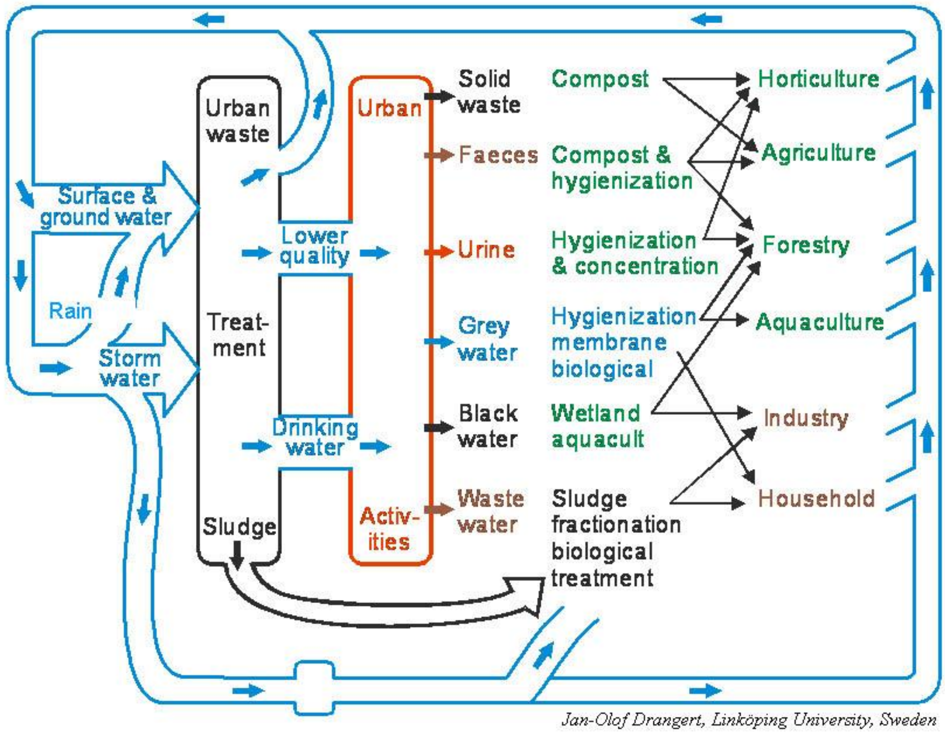
In Singapore, wastewater is treated to a high degree and used for drinking water. Several states in the US and in India allow urban reuse of treated greywater. Applications range from permitting households to use it for irrigation to allowing commercial buildings and housing complexes to use it for toilet flushing (see 2.1–18). It seems as if the growing scarcity of virgin sources of water tends to make legislators more open to allowing the reuse of wastewater. In future, increased scarcity of nutrient sources may also encourage the recycling of wastewater by-products.

Poor waste management in dense informal settlements often has serious impacts, both on health and the environment. Yet, greywater and stormwater management is generally not a priority in these settlements. In many cases it may be that the social cohesion is too limited for collective action (Module 1.4). It appears that whatever management strategies are adopted, their success depends on communities' attitudes and understanding of the issues, as well as a commitment of the authorities.

Legislation and by-laws which allow treatment and reuse of greywater will stimulate innovation in the sector. WHO Guidelines (2006) provide scientific support and advice. Ways to address the above challenges and realise the mentioned benefits will be described below.

Urban *horizontal* water and nutrient flows

4.5- 3



The first step is to acknowledge that wastewater is part of the water cycle. The picture shows the *horizontal* flows of water (and partially nutrients) from nature to urban use and back to nature.

Water is always on the move (see Module 1.2- 4) not only in nature, but also in communities. Surface water and groundwater, and sometimes rain and storm water is collected, treated and used for urban activities in households, offices, and industry, and for street cleaning, firefighting, etc. A dual delivery system is possible, where lower-quality water is used for washing, and high-quality water is used for drinking, cooking and bathing. Bottled water is another way of distributing high-quality water for drinking.

Residents add artificial compounds to the water (red box) while using it, such as soap for washing hands, detergents for washing dishes and clothes, shampoo for washing hair, and excreta are transported in the wastewater pipes. These activities take away dirt and improve hygiene standards but at the same time they pollute the used water. The extent to which the various waste flows are mixed varies between communities as well as between types of infrastructure. A general rule is, however, that less mixing makes it easier to treat the water and to recover usable resources. The industrial sector is leading the way in the profitable recycling of treated water and of other useful products.

The household sector lags behind and only a few countries have started to treat and use the wastewater from households in a controlled way.

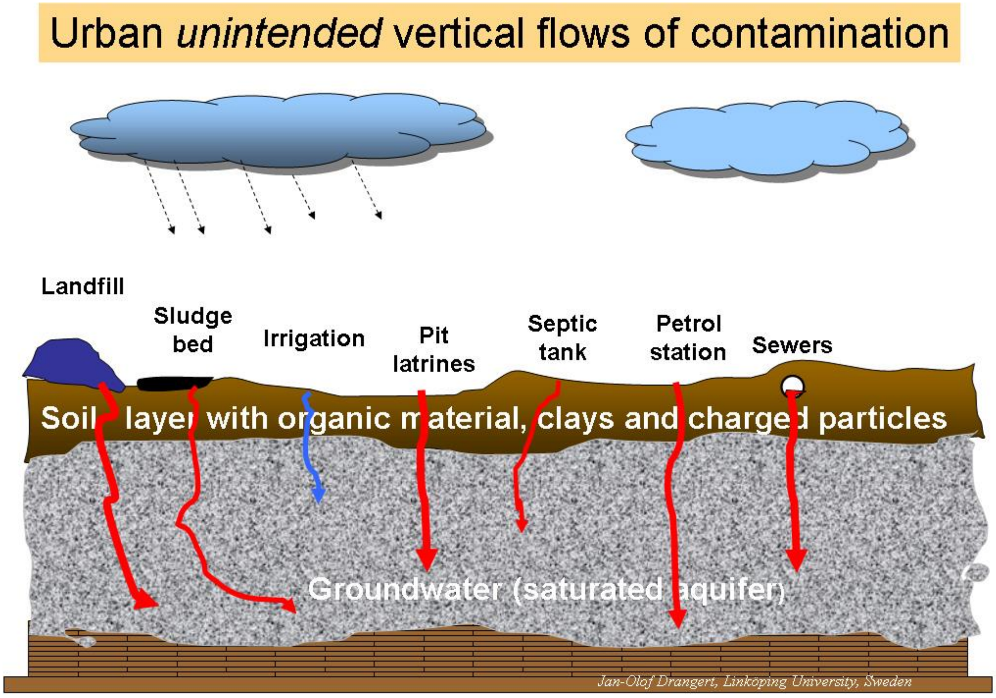
Various treatment methods and recycling options are indicated in the above picture (details in Modules 4.6 and 4.7). Potential reusable materials are the treated water itself and – perhaps equally important – the recovered plant nutrients. We do not deal with industrial effluent in this sourcebook, but it may be profitable to recover special components from such wastewater. If more sophisticated treatment methods are introduced (such as nanofiltration and reverse osmosis) the treated greywater may be directly circulated back to household use, as is being done in Singapore and some other water-scarce cities (www.waterhub.org). Sludge generated during treatment of wastewater remains a major management challenge.

Keeping valuable components separate is often easier than combining them and then separating them in WWTPs (source control). Collected urine from a single household can be used straight away to fertilise plants. In apartment areas, however, it is hygienically safer to collect and store the urine before application on farmland. The same goes for hygienized excreta (Module 4.2). In cases where the blackwater from flush toilets is collected separately, it can be treated in various ways, for example to produce biogas (see Module 4.4), and the treated slurry may be circulated back to farms via a wetland.

Fresh water is becoming increasingly scarce due to higher demand caused by population growth, urbanisation and economic progress. The amount of wastewater will also increase if we do not replace our 'business as usual' approach. In addition, there is an energy aspect attached to each water system. For instance, California uses 19 % of its electricity, 30 % of its natural gas, and 88 billion gallons of diesel fuel annually to pump and treat its water and wastewater! (California Energy Commission, 2004).

The main easily accessible water and nutrient resources are those involving recycling such as using wastewater for irrigation. There are obvious benefits from recycling such as better food security for many households and, in turn, improves nutritional status and lessens vulnerability to diseases. On the other hand, poorly managed greywater and sludge are associated with negative impacts on human health. Such health risks can be minimized when good management practices are adhered to. The WHO Guidelines (2006) for the safe use of wastewater, excreta and greywater provide practical guidance on what to do and what not to do from a health-risk assessment point of view.

4.5 - 4

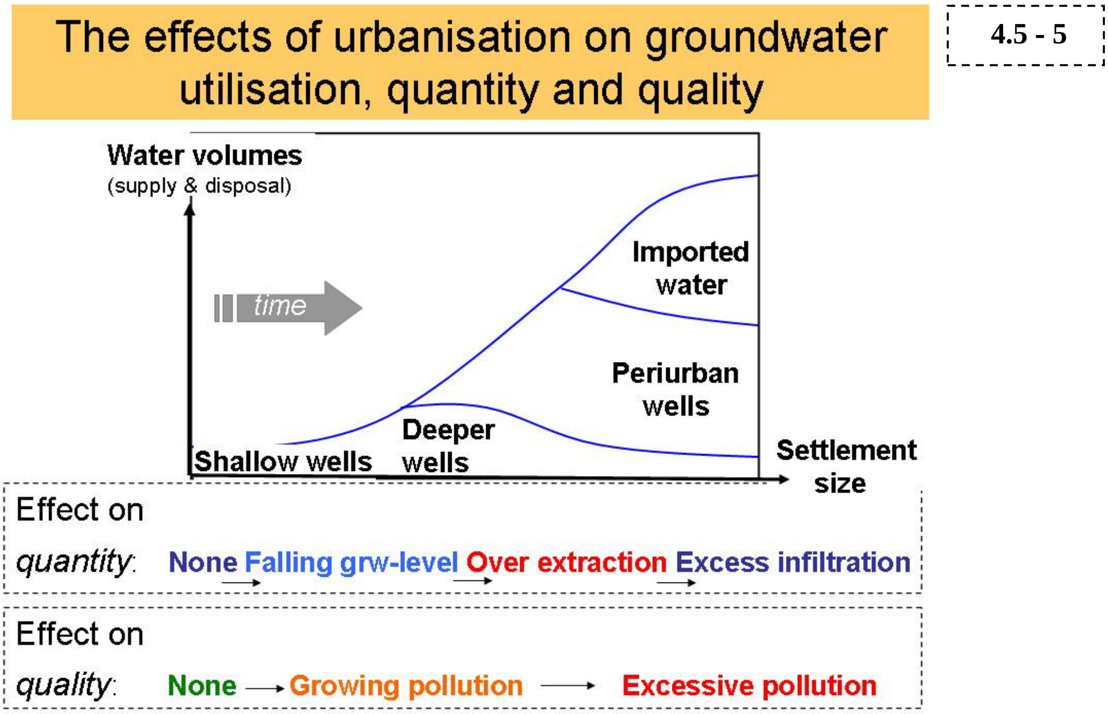


A water-based system also has a vertical part! The picture shows the mostly unintended vertical flows of water and whatever is mixed into it, which move microbial as well as chemical pollutants from the surface down to the groundwater. Groundwater is a valuable resource which can be polluted via various pathways from sludge, pit latrines, leaking sewers and landfills. Pollution may be made worse by occasional rain that washes various wastes into water bodies or helps infiltrate them into the soil, from where it may reach the groundwater. Simultaneously, valuable nutrients and water are lost.

There is a complex interaction between water, soil, and human activities (BGS, 2001). Most soils are vulnerable to being polluted by water from urban infrastructure and human activities. All pipes, septic tanks and pit latrines leak. Therefore, all groundwater under cities is polluted by pathogens and/or chemical compounds which may make the groundwater unfit for human use. This is particularly serious in areas where groundwater is the only water source, and is drawn from wells and used by households – often untreated. The only secure water supply is thus made into a health hazard for the users, and water utilities are not likely to provide any other water supply. The remedy is to ensure that waste handling is done properly to protect groundwater from all waste flows.

Waste should be treated above ground rather than in the ground where it becomes invisible and very difficult to monitor. The soil contains most of the microorganisms (see Module 4.6- 24) and animals that can help to decompose waste material in its upper layer.

There is also on upward vertical flow of greenhouse gases from landfills, sludge drying beds, septic tanks, and wastewater treatment plants. This will be discussed in connection with the various treatment systems presented in this chapter.



Courtesy of G. Jacks, Royal Institute of Technology, Stockholm

It is useful to observe how water systems change over time. For example, the quality and availability of groundwater can change dramatically when settlements grow into cities. Small settlements may find enough water from local wells, and the groundwater is likely to be of good quality (left-hand side of picture). However, on-site sanitation may threaten groundwater quality. The groundwater level may fall as the settlement grows, and deeper wells are drilled to reach deeper aquifers. The groundwater quality in the upper aquifers deteriorates due to increasing pollution. Unless the geology is particularly favourable, with a clay cover large and thick enough to protect the aquifer, pollution will occur from bacteria, virus, nitrate etc. Even salinity may become excessive. In periurban Dhaka, the geological conditions are very favourable with a 10–15 metre clay layer above a sand aquifer, and no bacterial or nitrate pollution has been detected so far. However, further population growth will result in over-abstraction of groundwater and its level will subside further. In that phase even houses may be destabilised and crack when the soil dries out (e.g. Mexico City 2.2-7).

The so-called water scarcity in cities is addressed by conveying additional water from distant rivers, lakes and well fields. When this happens, the water situation is reversed and the groundwater level rises, since the amount of discharged used water is so huge that infiltration becomes excessive and the quality of groundwater deteriorates because of the infiltration of polluted water. In this phase basements of houses built during the dry period may be inundated by groundwater. In central London during the first half of the 20th century, the groundwater also rose because water-consuming industries were forced to move out from the central city, and today groundwater is constantly being pumped out to secure dry basements in all houses. (Drangert and Cronin, 2004). Many cities in the world face similar problems caused by leaking water and sewage pipes which raise the groundwater level to the extent that drainage is needed.

As cities grow, avoiding pollution and waste of water resources becomes more important. In eastern Botswana, thousands of inhabitants used wells in the villages in combination with pit latrines. Unlike in Dhaka in Bangladesh, the soils in Botswana are permeable and excessive bacterial pollution and nitrate levels were detected. Today these so-called “villages” have tens of thousands of inhabitants and their water is now pumped in pipes from new well fields kilometres away.

All groundwater under cities is polluted

4.5 - 6

As shown in the above example of the city of Nottingham, UK, groundwater is vulnerable to polluting land uses and leaking water infrastructures. Nottingham is sited on a sandstone formation which contains an open aquifer of between 65 and 150 metres. Dramatic changes in land use have occurred over time, from farming activities to city infrastructure. The first steam-powered public supply well was installed in 1858. Rapid urban growth commenced in the 1870s. Over-abstraction took place in the early expansion of Nottingham, causing the water table to fall (by 10 m) and some areas to subside. The water supply infrastructure had to be continually refurbished. In the later stages of city development, increased recharge was more common due to reduced abstraction and increased leakages. This may cause flooding of basements and tunnels, infiltration of pollutants into the unsaturated zone and damage to the foundations of buildings.

A research team undertook a study of the history of Nottingham's groundwater recharge, use and quality for the period 1850–1995 (Yang et al., 1999). They developed a groundwater flow model, supplemented by calibrated solute balances (Cl^-, SO_4^{2-} and total N), to identify the origins of recharge fractions from precipitation, water mains and sewers. The validity of their results was checked by a sensitivity analysis to mitigate for the limited availability of early data (Cronin et al., 2003). The studies show (when average flow is expressed in the same units as precipitation) that:

- In the 1850s rainfall (which averaged 700 mm a year) recharge of the groundwater was about 230 mm per year
- Today the city's use of water from external sources is equivalent to 700 mm per year.
- Recharge from water mains leakage has grown significantly and is now the major contributor to recharge with an estimated 93–162 mm/year over various parts of the city.
- Total recharge has varied little over the period (-8%) because increases in leaks from the water supply pipes have compensated for the effects of the increase in the area covered by impermeable surfaces in urban areas.
- Recharge from sewer leakage is estimated to be 6–13 mm/year (+/- 100%) and has changed very little, perhaps reflecting widespread use of foul soakaways in the nineteenth century.

- Sewage-derived bacteria and viruses were detected to depths of 60 m (Cronin et al., 2003)

These results refine our understanding of recharge, abstraction and land use. Groundwater tends to be polluted by wastewater, but generalisations about the overall effect of urbanisation are not possible across all cities due to the variable geologies, climates and infrastructures.

The research team sampled data on microorganisms and inorganic matter from three depth-specific multilevel piezometers installed into purposely drilled open boreholes (Taylor et al. 2000). Data from one of the boreholes is presented in the table about the distribution of faecal streptococci. Note that the seven sampling periods have varying scales. The depth profile is from 0 to 50 mbgl (metres below ground level) and heterogeneities in the soil profile (symbols: fissure ⟶, mudstone band ▬▬, and coarse horizon). The level of the water table (in November 2000) is indicated by the dashed line at 6.5 mbgl. The table shows that anthropogenic loading of chlorides, nitrates, and sulphates were rather stable over the year and decreased with depth (Cronin et al., 2003).

The depth-specific monitoring of microorganisms (thermotolerant coliforms, faecal streptococci and sulphite-reducing clostridia, and enteroviruses, Norwalk-like viruses, and coliphage) showed they were regularly detected to depths of 50 mbgl.

The team found strong temporal variations in the presence and levels of sewage-derived bacteria and viruses. Enteric viruses were detected during periods of the year when their prevalence in the population was high (Powell et al., 2003). The rapid penetration of microbial contaminants into sandstone aquifers, presumably through fissures and mudstone bands, not reported in previous studies, highlights the vulnerability to leaking sewers. The results invalidate the assumption that faecal bacteria and viruses are effectively attenuated within the subsurface through filtration, adsorption and inactivation.

4.5 - 7

Environmental and Human health hazards

	Pathogenic microorganisms	Chemical compounds
Num-bers	A few hundreds: handful unknown detected each year	150,000 man-made; Hundreds new man-made added each year
Expo-sure	In food, by skin penetration, insect bites, in aerosols. -	In food, by skin penetration, on skin, in aerosols. Water bodies, soil accumulation
Dose-response	One up to millions; a few to millions needed for infection	Nano- to microgrammes; small amounts that may accumulate.
Vulne-rable	Humans but not environment. Mostly children & elderly	Both humans and environment. All, but particularly babies
Barriers	Wash hands & veggies, no finger in mouth, heat food, etc	Only biodegradable, caution with medicines, effluents to soil

Jan-Olof Drangert, Linköping university, Sweden

The picture summarises and compares the hazards that pathogens and chemical compounds pose to human health and the environment. It follows WHO's risk-assessment approach based on numbers or concentrations of each hazardous item, exposure, dose-response relationship, vulnerability, and barriers (WHO, 2006).

The health hazards caused by pathogenic organisms (viruses, bacteria, helminths and protozoa) and chemical compounds (heavy metals, persistent organic compounds, nutrients etc.) have different features. Microorganisms are present in nature and perhaps a handful of new strains or species are detected every year. Many chemicals are present in nature, but almost all compounds that humans are exposed to are man-made. Altogether there are some 150,000 compounds in our chemical society, out of which 30,000 are used by households (slide 4.5- 12). Industries add hundreds of new compounds to products every year. These new ones are known by industry, but their harmful effects are not necessarily known.

Human exposure to pathogens is mainly through ingested food and water, skin penetration (snails), bites (mosquitoes), and inhalation of aerosols. However, since pathogens inhabit nature they do not represent an additional burden on nature. The exposure varies widely from hundreds of viruses or helminths to hundreds of millions of bacteria. The infectious dose, however, varies from a few Ascari eggs to millions of enteric coliform bacteria and the effect is seen within a short period of time. Not all pathogens can multiply, and they may be preyed or die off (see Chapter 3).

Humans are exposed to chemical compounds in the same way, and also through the skin (from chemicals in clothes, etc.). Chemical compounds are usually available in small doses, but some of them may accumulate in the human body through the food chain or in the environment and eventually reach hazardous concentrations. The effects are only seen after long exposure. Some heavy metals (cadmium, lead etc.) affect the human body functions and so can persistent organic matter such as PCBs and some pesticides. The symptoms can be difficult to diagnose, however.

Pathogens cause disease and death among humans and other animals, but have little direct impact on the environment. Children, the elderly and the undernourished are the most vulnerable people. Chemical compounds, on the other hand, can have a negative impact on both animals and the environment. Babies are most vulnerable to acute or short-term toxic exposures (e.g. blue baby syndrome from excess nitrate) while carcinogenic and other disease-causing chemicals affect all age groups. Water bodies are sensitive in the short-term and the atmosphere and soils are affected over longer periods.

Protection against health hazards can be described as barriers, and they include washing hands and vegetables before eating, boiling food and water if necessary, heating left-over food before eating, no fingers in the nose or mouth, and using ORT to cure diarrhoea. Barriers against chemical hazards include being restrictive with medicines, avoiding breathing polluted air, washing new clothes before wearing them etc. However, most barriers against chemicals are long-term remedies which involve protecting the environment, such as only using biodegradable body care products and detergents, collecting and destroying expired medicine and left-over hazardous chemicals, and disposing of wastewater on soil rather than in water bodies.

A stark difference between pathogens and chemicals emerges from this. The barriers for pathogens are controlled by the individual and the barriers do not require consumers to stop buying any products. Barriers to chemical compounds, on the other hand, require collective action to ban certain compounds and replace them with safe products to protect both our health and the environment. At the same time, all of us also have an individual responsibility to change our consumption patterns for chemical products. This involves decreasing our general consumption of status symbols, and restricting the purchase of products containing substances with unknown or negative health and environmental impacts.

There are thus contrasting features of effective simple rules of thumb to avoid pathogen risks while chemical hazards call for radically different approaches to remedy the threats they pose. In 2011, the EU commission commented as follows on the deep problems with existing registration, evaluation, authorisation and restriction of chemicals:

> "There are some 3 000 new substances (since 1999). Directive 67/548 requires **new** substances to be tested and assessed for possible risks to human health and the environment before they are marketed in volumes starting at 10 kg. For higher volumes more in-depth testing, focusing on long-term and chronic effects, has to be provided.
>
> In contrast, **existing** substances amount to more than 99% of the total volume of all substances on the market, and **are not** subject to the same testing requirements. The number of existing substances registered in 1981 was 100,106, the current number of existing substances marketed in volumes starting at 1 tonne is estimated at 30 000. Some 140 of these substances have been identified as priority substances and are subject to comprehensive risk assessment carried out by Member State authorities under Regulation 793/93.
>
> There is a general lack of publicly available knowledge about the properties and uses of existing substances. The risk **assessment process is slow and resource-intensive** and does not allow the system to work efficiently and effectively. The allocation of responsibilities is inappropriate because the public authorities are responsible for the assessment instead of the enterprises that produce, import or use the substances. Furthermore, current legislation requires only the manufacturers and importers of substances to provide information, but does not impose similar obligations on downstream users (industrial users and formulators). Thus, information on uses of substances is difficult to obtain and information about the exposure arising from downstream uses is generally scarce. **Decisions on further testing of substances can only be taken via a lengthy committee procedure and can only be requested from industry after authorities have proven that a substance may present a serious risk**. Without test results, however, it is almost impossible to provide such proof. Final risk assessments have therefore only been completed for a small number of substances."
>
> (*14 March 2011 from EU website on Regulation of the European parliament and of the Council*)

This is not a European problem only, but applies to all countries and has to be addressed on a global level.

Wastewater = clean water + what has been added

4.5 - 8

Component	Content in different fractions			*Impact (potential)*	*Means of control*
	Faeces	Urine	Greywater		
Water lit/person/day flush included	4-10 (WC) 0 (no flush)	20-40 (WC) 0 (no flush)	80-200	- water scarcity - heat loss - investment - water logging	- behaviour - fee structure - water saving equipment
Pathogens (bacteria, viruses, helminths)	high	very low	low	- infections	- 'no' faeces in water - hygienic handling - aerobic treatment - minimize exposure
Organic matter BOD kg/p/year	5.5	2	10	-deplete oxygen -bacteria growth	Physical, aerobic, anaerobic treatment
	Excreta 7.5				
Phosphorus kg/person/year	0.2	0.4	0.05-0.3	-eutrophication	urine separation, precipitation, etc
Nitrogen kg/person/year	0.5	4	0.5	-eutrophication -consume oxygen	urine separation, aerobic/anaerobic
	Mean value 5.0				
Heavy metals	present	negligible	present	-toxic to humans	use other products
Organic toxic compounds	negligible	negligible	present	-toxic to humans	Aerobic treatment
Pharmaceutical residue/hormone	present	negligible	negligible	-toxic for aquatic	Degrade in top soil

Courtesy of Peter Ridderstolpe, WRS, Uppsala, Sweden

Wastewater is the sum of clean water and the substances we add while using it. The table above summarizes some information that is useful when considering the contribution from an individual to the wastewater content. The degree of potential impacts of various components and how to avoid ensuing problems are indicated. Module 4.6 gives details of how various treatment methods work.

Today, monitoring of the discharge from wastewater treatment plants only pays attention to a small number of easily measured indicator substances and organisms. This limited scope is understandable since there are, say, 30,000 chemical compounds in household wastewater and hundreds of pathogen species. New strains of bacteria and viruses are found every year, and improved analytical methods allow us to identify chemical compounds at lower and lower concentrations. Yet, we do not take advantage of this and we still know too little about what substances there are in greywater (and wastewater more generally). In small-scale systems, householders may know more about what is in their greywater, simply by knowing what products they purchase and use in the home and whether they are discharged with the wastewater or not!

The health risks and chemical risks arising from effluents and sludge from wastewater treatment plants as well as from small household treatment units are addressed here and more in Chapter 3. The toxicity, volume or frequency, persistence or die-off, and bio-accumulation or exposure of each component or compound has to be considered, as well as how vulnerable humans and the environment are to the threats they pose. Such data is available for many pathogens, but only for a small portion of organic compounds and non-organic chemicals as discussed in WHO (2006).

Constituents in wastewater may cause other types of problems as well. Laundry, for instance, presents special challenges due to lint material from washed clothes. Non-biodegradable fibres of nylon, polyester and polyethylene are too small to be trapped in washing machine sieves, but too big to easily pass through a soil or sand filter. Even when lint and other insoluble materials pass through the treatment they may settle in distribution pipes and drip irrigation nozzles. In fact, wash water is responsible for many clogging failures of soil filters and subsurface flow wetlands. There are filters which can be fitted to washing machines to remove fibres. However, clogging may also occur due to other solids in the rinsing water such as solid insoluble grit from dirt and building materials.

The organic and mineral content of municipal wastewater (mainly domestic) and urban stormwater (mg/l) differs, but Jan Vymazal gives estimated ranges of some indicators as follows:

Indicator in mg/l	Raw waste-water	Pre-treated wastewater	Gram per capita/day	Urban stormwater
BOD_5	200-400	100-300	60	20
COD	300-800	200-500	120	75
TSS	300-700	100-200	55	150
TN	40-100	40-90	11	2.0
NH_4-N	20-50	20-50		0.6
TP	5-15	5-15	2.5	0.4

The indicators above concern mainly the impacts on nature, and not humans. Even in this case, setting limits for contaminants may be problematic. Only of late have authorities and researchers understood how eutrophication comes about and that knowledge has contributed to more stringent and effective regulations of N and P emissions.
As a comparison, the organic content in some industrial wastewater is presented below (mg/l). The high loads of organic materials underpin the no-mix principle for waste streams, in this case not to mix municipal and industrial wastewater flows:

	BOD_5	*COD*	*TSS*	*NH_4-N*	*TP*
Laundry	500	10,000	200	a	
Tannery	2,000	10,000	20,000	200	20
Meat processing	2,000	5,000	4,000	400	30
Pulp and paper	5,000	20,000	10,000	200	15
Sugar mill	5,000	6,000	350	a	
Yeast processing	10,000	15,000	1,000		
Winery	25,000	30,000	5,000	1	50
Dairy/cheese	25,000	45,000	12,000	80	250
Distillery	30,000	100,000	8,000		
Brewery	30,000	40,000	1,000	5[a]	100
Fish processing	40,000	50,000	5,000	500	180
Olive mill	70,000	250,000			

What do we put into the water?

4.5 - 9

What is in soap, detergents, shampoos, solvents, disinfectants, paints, medicines, pharmaceuticals, etc ?

Soap contains alkali salts with long-chained fatty acids:
- Hard soap usually contains sodium (Na) ☹
- Liquid soap usually contains potassium hydroxide (K) ☺

Detergents can contain (check list of contents on package)
- Phosphorous: ☹ in water, and ☺ on soil
- which can be replaced by potassium 😐 in water ☺ in soil
- Salts: sodium 😐 in water, and ☹ in soil
- Bleaches: chlorine ☹ in water and soil, while peroxide 😐
- Fluorescent whitening agents ☹ in water and soil
- Non-degradable substances:
  zeolites ☹ in water, ☺ in soil; and fillers ☹ in water ☺ soil

Courtesy of H. Jönsson, Swedish University of Agricultural Sciences, Sweden

The selection of consumer products in the shop and their use and misuse in the home decide what treatment is required for your wastewater. Wise choices of products will improve the sustainability of any sanitation system, be it in rural homes or inner-city flats.

The environmental impact of some common household products is indicated in the list above. A positive impact is represented by a smiling face. In the case of detergents the first face relates to the impact on surface water, while the second face relates to the impact on soil.

The long-chain fatty acids in soap can clean hands and clothes by breaking the bond between the surface of skin or cloth/fabrics and dirt particles and microbes. Particles are suspended in the wash water and become part of the wastewater. Hard soap is based on sodium that has a negative effect on vegetation. For instance, sodium can inhibit the transport of water and nutrients in some plants and it can cause hypertension in their cells. Potassium-based soaps, on the other hand, have the same bond-breaking capacity as sodium, but potassium itself is a plant nutrient.

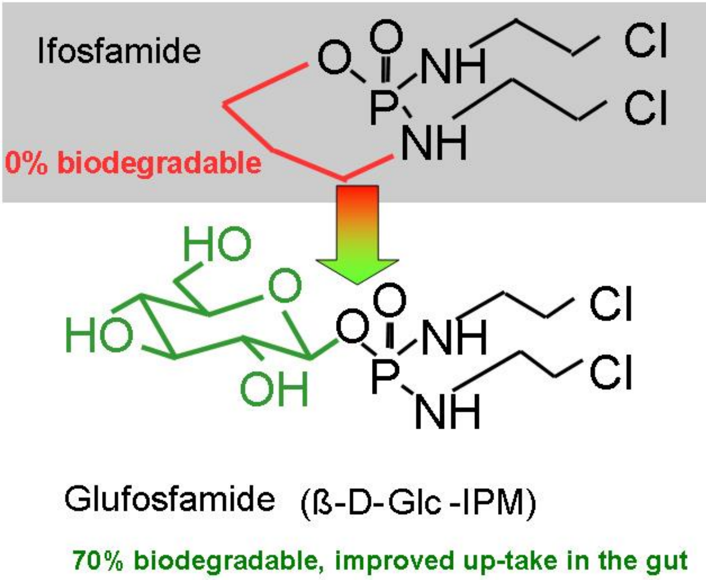
Recently, the European Union banned phosphorus in detergents because it contributes heavily to the eutrophication of water bodies. Instead, manufacturers now add zeolite in conjunction with other chemicals such as polycarboxylates which have the same positive washing effect as the phosphate compounds. Customers do not see the difference in washing results but surely do in eutrophication! Detergents contain not only phosphorus but other chemicals such as bleaches, corrosion inhibitors, fluorescent whitening agents, enzymes, anticoagulation agents, and bulking material. Some of these components are commented on in the picture.

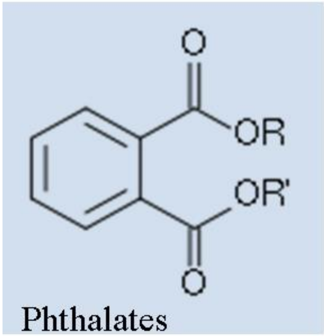
At present, big detergent manufacturers are trying to reduce or abandon altogether the bulking material in detergents, since it contains harmful salts that have no washing effect. Their problem is to convince households that a smaller dosage (since no bulking material has been added) gives the same washing result.

We could easily reduce the use of harmful products, and totally abandon the ones with a red face.

Toxic organic compounds

4.5 - 10





Source: Kümmerer, 2007

As mentioned before, in our daily lives we use numerous organic substances in household chemicals, cosmetics, and pharmaceuticals and also as additives in clothes, mobile phones, computers and other products. Even the food that we eat and drink may contain synthetic chemicals. One example is artificial sweeteners. For example, sucralose is produced from sugar but the saccharose molecule has been chlorinated to become more stable against degradation. This substance has been detected in small quantities in discharges from wastewater treatment plants in countries where this has been investigated. In 2008, an estimated 8 tonnes of this substance was released into surface water in Sweden alone. So far there is NO scientific knowledge of whether this has any effects on ecosystems or human health.

Small quantities of pharmaceuticals such as *psycopharmaca*, hormones and antibiotics are excreted by humans, and end up in greywater. Many of them are fairly resistant to degradation, and are only partially removed in wastewater treatment units. They represent some of the persistent and water soluble substances that are discharged to aquatic ecosystems. Some of these substances are known to have a negative impact, but for others we have very limited knowledge. The discharge of antibiotics to the environment may spur the development of resistant bacteria with long-term health impacts for human beings. It is also known that sex hormones such as testosterone and estradiol may have severe negative ecological impacts on processes such as fish reproduction. A source-control measure is to avoid flushing leftover medicines away in water, and return them to the pharmacy as hazardous waste.

Recently, more research is indicating that toxic compounds may affect hormones in the human body. Should that be the case, it is worrying since a fetus receives the toxins via the mother's blood already from conception. The hormones programme the cell development, and if the drawing (hormone) is affected, the cell functions may be disturbed – and this will continue as the cells multiply. The toxic effect may thus start much earlier than previously thought.

Kümmerer (2007) provides an example of an unintended life-cycle improvement of a pharmaceutical product. The cytostatic agent Ifosfamide (top right) had undesirable side-effects.

By modifying the chemical structure to Glufosfamid (bottom right) the side-effects were reduced by improving the uptake in the bowel. At the same time, the new medicine proved to be biodegradable to 70% while the previous one was persistent. It is difficult to modify pharmaceutical products since the environment in the human gut is different to the environment in which the product ends up when it is discharged via urine.

The diversity and prevalence of bacteria and enzymes is different in the bowels and the outside-body environment for several reasons. The body temperature is high and stable (thermophilic microorganisms), and there is an abundance of nutrients to feed on. The bowels provide essentially anaerobic conditions (mostly anaerobic microbes) and the pH is well below 7 in the stomach, while it is above 7 in the wastewater. The resulting difference in redox conditions (slide 4.6-19) makes for different chemical reactions in the bowel and in the environment. Also, it is dark in the bowel while surface water and topsoil is affected by UV light. These aspects are discussed in Module 4.6.

Phthalates (left picture) belongs to a group of toxic organic substances that are added to plastic products to make them tender. They are commonly also found in roofing materials, flooring and wall coverings. This means that there is a stock of phthalates in buildings which is gradually released. It is not chemically bound to the plastic material and can easily be taken up by fats, oils and solvents used in the household. Phthalates are very toxic for aquatic organisms, but less so for human beings. Studies indicate that between 75 and 97 per cent are degraded in treatment plants or appear in the sludge. Thus, between 3 and 25 per cent remains in the effluent and is discharged to water bodies.

Often there are limits to the amounts of *phthalates* that are allowed in sludge to be used as fertiliser on farms, but no regulations apply to the discharges to water bodies! This is an example where legal approval does not only take human and animal health and nature into consideration as intended, but other aspects possibly claimed by strong lobbyists (slide 4.5 - 7).

4.5 - 11

Metals in wastewater and excreta

Element		Daily intake (mg)	Output in faeces (mg/kg P)	Found in sludge (mg/kg P)	Ratio (sludge/faeces)	Output in urine (mg/kg P)	Ratio (sludge/urine)
Copper	Cu		1,000	14,000	14	68	206
Chromium	Cr	300	214	1,300	6	0.65	2,000
Nickel	Ni	120	88	720	8.3	16	78
Zinc	Zn	11,000	7,200	25,000	3.5	424	69
Aluminium	Al	12,000	8,600	1.5 mil	174	67	22,400
Mercury	Hg	5	3,5	40	11	0.64	63
Lead	Pb	23	16	1,500	94	16	94
Cadmium	Cd	14	10	44	4	0.32	137
Silver	Ag	7	5	330	66	0.076	4,300
Manganese	Mn	4,500	3,200	9,300	3	3.8	2,400

Courtesy of G. Lindgren, Sweden

Human beings eat and excrete heavy metals and other inorganic micro-elements. Some of these are essential for our metabolism and survival, but excessive doses are hazardous. Studies of the origin of metals in municipal wastewater show that more than half comes from households and, for example, cobalt (Co) and nickel (Ni) are found in residual sediments in treatment plants. Human exposure to heavy metals must thus be controlled. Since this sourcebook recommends the recirculation of nutrients in excreta we need to show that it is beneficial not to mix them with other wastewater before treatment. The table shows how much of various metals an average person ingests daily and how much of these are found in the faeces, urine, and municipal sludge (in micrograms per kg of phosphorus to make a comparison with P in commercial fertiliser possible).

Regulators first became aware of the presence of heavy metals in sludge around 1970 when atomic adsorption spectrophotometry first made sensitive heavy metal analysis possible (Balmér, 2001). Excreta contain only background levels of heavy metals originating from the eaten food (columns 2 and 5). The values are expressed here in mgr per kg of P (phosphorus) to make it easy to calculate the application of heavy metals to soils in accordance with required P level.

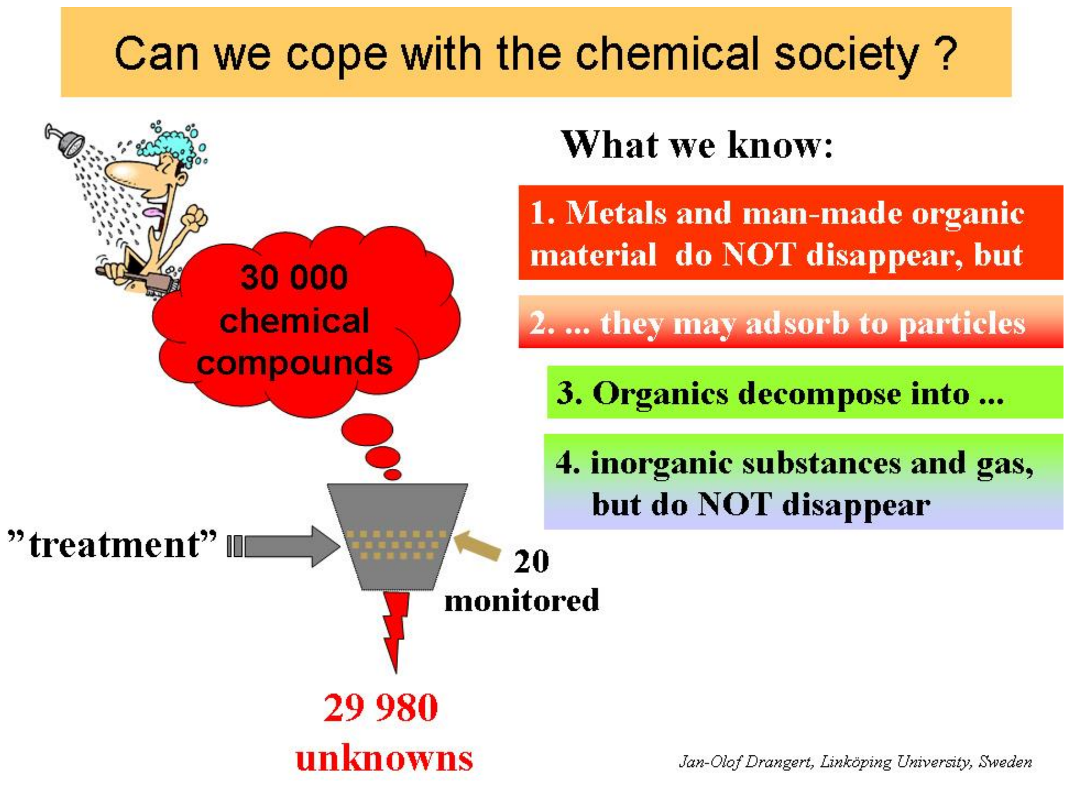
A direct comparison with the concentration of heavy metals in wastewater sludge (column 4 and 6) shows that urine and faeces contain only small fractions compared to sludge. For example, the cadmium concentration in sludge is 137 times greater than in urine, and sludge needs to be reduced by more than 2 log units to attain the same quality as urine.

In most countries the permissible concentrations of heavy metals in wastewater sludge are regulated. Since data on environmental and health risks are not available, country-based limits vary considerably. In some countries, it seems that regulations are based on what is believed to be achievable. In other countries, regulations are based or risk analysis and in some countries the approach is that the concentrations of heavy metals in agricultural soils should not increase when wastewater sludge is used as a fertiliser (Balmér, 2001). Over time, set limit values have become more strict, which shows that previous limits were inadequate. Yet, they were used to convince residents that it is safe to dispose of the sludge on farmland.

The accumulation of metals worries most authorities and the European Union has established a commission (ECHA) to oversee the production of chemicals and their use. In 2008, the commission established new regulations for industries and manufacturers, and this is viewed as a step towards enforcing source control of what goes into wastewater. The most toxic metals are mercury (Hg), lead (Pb) and cadmium (Ca) but these are ingested in very small quantities. However, the products causing contamination have only been on the market for some decades, and increased consumption of such products may, as time passes, reach alarming levels. Hamilton et al. (2005) classify potentially phytotoxic metals in wastewater into four groups based on their retention time in soils, translocation in plants, phytotoxicity and potential risk to the food chain. They place cadmium (Cd), cobalt (Co), Mo and Se in the group posing the greatest risk to human and animal health even though these elements may appear in wastewater irrigated crops at concentrations that are not generally phytotoxic.

Application of these metals on soils via wastewater irrigation is undesirable because, once accumulated, they are extremely difficult to remove. Qadir and Scott (2010) found that the time it takes varied substantially for wastewater-irrigated soils (with cation exchange capacity CEC 5-15 $cmol_c\ kg^{-1}$) to reach today's loading limits in calcareous, alluvial soils from three locations in Pakistan. For Cd the time taken was between 13 and 67 years; for copper it was between 48 and 69 years; for nickel it was between 13 and 120 years, and for lead it was between 96 and 1676 years. The amounts of metals removed by crops are small (< 10 per cent of the added metal) compared with the amounts applied to the soils. If excreta were not mixed with greywater, farmers could apply urine and hygienized faecal matter as fertilizer without the risk of heavy metals accumulating in the soil.

4.5 - 12



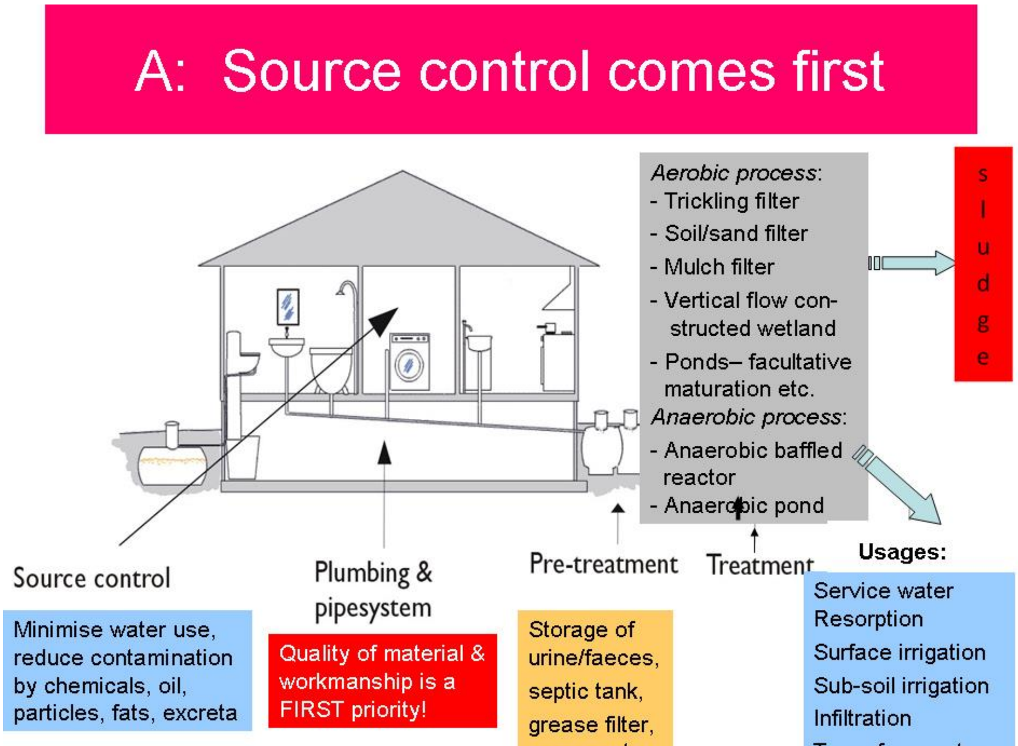
Artificial chemical products have inundated the whole globe via international trade. Most households use medicines, detergents, shampoos, synthetic clothes, etc. which contain various chemicals. Today many households use some 30 000 different chemical compounds in a year, many every day and others occasionally. Some of these compounds are toxic, others are not degradable and will remain for a long time though their possible impacts are not known. This is very different from fifty years ago when most household products were biodegradable and few contained artificial chemicals.

It is common knowledge that most organic chemicals can be decomposed but at very variable rates. They can adsorb to particles and become partly immobilised, thus prolonging the time of potential exposure. Some artificial organic compounds are also very persistent and do not disappear easily. During incineration, some organic compounds in waste may convert to very toxic gases. Other organic materials are rapidly decomposed by microbial activities and the resulting parts are used to build new cells and organisms. In the process, gases are produced e.g. CO_2 in a compost or methane in a biogas digester.

The result is that today's wastewater treatment units receive water mixed with difficult-to-degrade organic matter and inorganic chemicals that are difficult to "treat" i.e. to disentangle into non-hazardous recyclable compounds. Typically, the staff in treatment plants measure some indicators such as BOD and COD levels for organic matter, total phosphorus and nitrogen, and occasionally some specific chemical substances. This is to say that the focus (which is actually what most wastewater treatment plants have been designed for) is on organic matter and the nutrients that cause eutrophication, algal blooms and dead zones on lake bottoms. The other chemical residues are rarely measured and perhaps 29 980 substances are not accounted for. This is a mammoth challenge for our societies.

Our collective failure to address the challenges posed by the present chemical society is the starting point for this chapter on greywater management. The main remedy is to control the source of pollution i.e. by being careful with what we buy and use in the household.

4.5 -13



Courtesy of Peter Ridderstolpe, WRS, Uppsala, Sweden

This Module deals with water flows through homes and communities. A home may contain a number of water installations, and the purpose of the above picture is to illustrate various installations and conventional measures to deal with flows through the home.

The better the quality of workmanship and materials of sanitation systems, the easier they are to manage. Some examples: a leaking pipe requires regular mopping, that could have been avoided. A rough floor surface makes cleaning more difficult. A urine pipe leaning backward will cause crystallization and eventually a blockage. An overburdened treatment unit will stop working properly. Therefore, proper design and installation are crucial for easy operation and maintenance (see Module 2.7).

Source control of what is added to the water while using it is essential for attaining ecological sustainability and residents become indispensable partners in managing the flows. The basic recommendations made in this Module apply to ALL houses. Poor homes are more vulnerable to polluted surface and groundwater in their crowded areas, and they need to be protected against pollution. Rich districts may import virgin water from afar and dispose of it in sewers which make residents less aware of their polluting activities.

We buy and use washing agents, solvents, lotions, paints, antibiotics and other chemical products and mix them with water and discharge them in sinks, wash basins, toilets and drains. The discharged wastewater therefore contains everything we have put into the water while using it. Buying environmentally friendly products, and using less of them, will therefore enhance wastewater quality.

Pharmaceuticals and endocrine disrupters pose a challenge for conventional wastewater treatment methods, since these chemicals pass through all treatment steps together with the effluent. Since these chemicals remain in the water, they can have severe impacts on aquatic animals. The story of fishes changing their sex is a telling one. Research indicates that applying such effluent water on soils is less harmful than discharging in into waterways since soil microorganisms will in due time decompose most of these compounds. In this connection it may be said that the dung from cows, which are given antibiotics everyday to stay healthy (*sic*), is applied to farmland with no restriction. This is an example of an unresolved conflict between health and other considerations.

Households can contribute – NOW!

4.5 - 14

Use as little water as possible by mimicking the use of water in buckets (do not wash under running tap, take quick showers, mend leaking taps, put full loads in washing machines, ...)

Do NOT add solid matter to water (put food scraps from plates and utensils in the waste bin, do not flush tooth picks etc. down the toilet, do not put cigarette butts in urinal, ...)

Do NOT add chemicals and oils to the water while using it (put fat from frying pan in the solid waste bin, use biodegradable soap and detergent, do not flush paint, medicines or other chemicals down the toilet, ...)

Buy and use environmentally friendly products for your home

Then you can use greywater in your garden, and you avoid blockages

Jan-Olof Drangert, Linköping university, Sweden

There is no excuse for waiting – each one of us can contribute to a safer and more sustainable environment by modifying our routines in the kitchen and bathroom – and when shopping. If we all do so, the global pollution load can be substantially reduced (see 2.4-2).

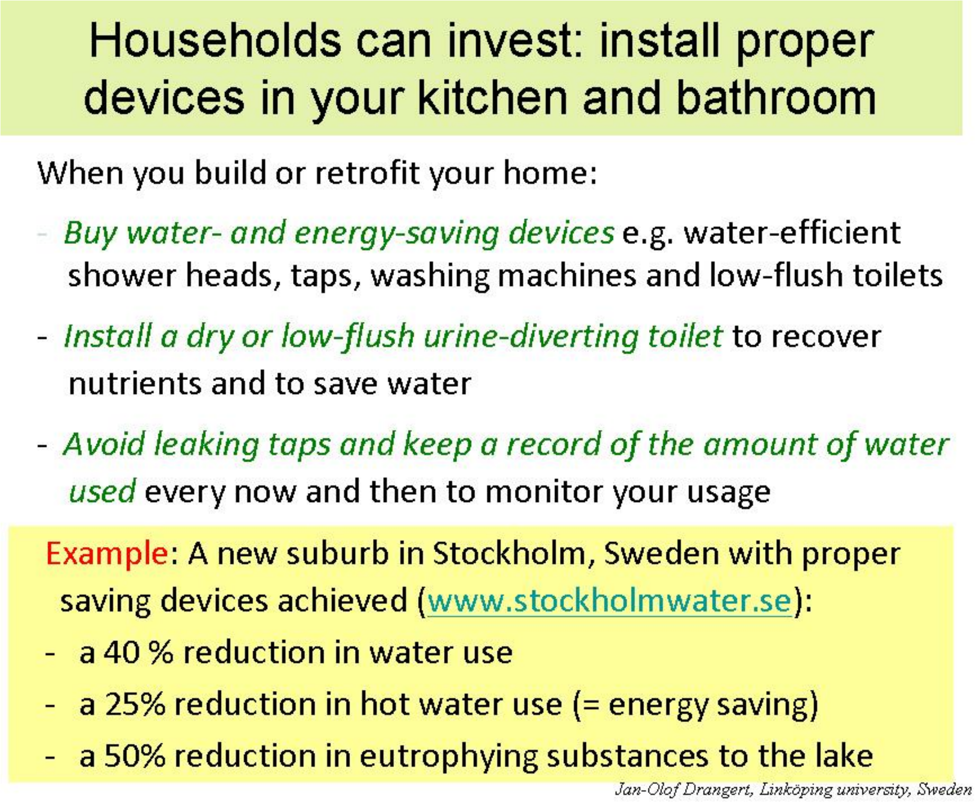
If we follow the above recommendations our greywater will have a much improved quality. Sewer pipes will not clog as easily and the smell from the water will be reduced. There will be less clogging of sand filters and other filters from oil, fat and food scraps. Filters need not to be cleaned or backwashed so often, and the amount of sludge will be less.

Water-saving installations will reduce the amount of discharged greywater and, at the same time increase the concentration of pollutants. This is no problem but rather an advantage from a treatment point of view. Water demand management has been quite successful in reducing the demand for water. Measures include progressive and high water tariffs, low-flush toilets, waterless urinals, dry toilets, etc. (see Module 2.1).

It is best to use toilet tissue that is made from wood or recycled paper. Turning a tree to paper requires more water than turning paper back into fibre. One eucalyptus tree can produce as many as 1,000 rolls of toilet paper and one person may use 20 rolls per year, or one tree per lifetime. Toxic chlorine-based bleaches are used for whitening toilet paper, but can be replaced by peroxide which is environmentally friendly and good for the soil. Ask for this next time you buy toilet paper.

If a household uses only biodegradable products for washing, its greywater can be used to water the garden without causing the accumulation of heavy metals, salts and other pollutants. From a society viewpoint, there is a need to develop strategies to support and promote sustainable household routines. Also, authorities can support users by regulating what chemical compounds that manufacturers are allowed to put in household products to be sold in shops. The European Union REACH programme is working towards this end and monitors the introduction of chemical compounds in products sold in shops, so that consumers do not have to be experts in selecting environmentally friendly products (http://echa.europa.eu/news/press_en.asp). The responsibility for the quality of the greywater lies with all parties in our society including the manufacturing industry.

4.5 - 15



The previous picture suggested changes in household *routines* that we adopt to sustain nature. There are also many installations that contribute to improved sustainability without changes to routines. Worldwide in the next 50 years, we will need to double the number of urban buildings. If we build and equip these houses with sustainable installations, they will require less resources than the present stock of houses. The cost is not higher for such buildings, and they need no retrofit after some years because we did think ahead! Here are a few examples:

Flush toilets: About 1/3 of the total household water is used to flush the toilet. A conventional WC uses 6–9 litres per flush. You can save a few litres per flush by placing a brick or two into the water cistern. So-called low-flush toilets only use some three litres per flush which cannot be reduced further without compromising the ability to flush away all excreta and paper. With less than three litres you may have to flush twice! A dual-flush toilet uses less than 0.5 litres of water to flush away urine while a waterless urinal uses none at all, and it does not smell and allows for easy use of the nutrients in the urine.

Dry toilets: A composting waterless toilet is easy to install when retrofitting. No flush water means no excreta in the wastewater. The dry toilet system does a better treatment job than septic tanks can do with black water, and it is often enough to treat the greywater in a sandfilter to reduce its solids.

Washing machines: A normal washing machine requires 50 or more litres of water per wash, irrespective of the amount of clothes. If you only fill a 4 kg machine with 2 kg of clothes, you waste 25 litres of water. New machines adjust the amount of water to the weight of the clothes. Of late, washing machines without water are being developed in Japan.

Shower heads and water taps: You can reduce the amount of water per minute by half, without losing the feeling that the shower gushes enough, if you install a mesh in the shower head. Electronic faucets only use one-quarter of what an ordinary tap uses for the same purpose.

Leakages: If water drops every second from your tap it adds up to 15 litres per day, and if the drops come one after the other the wastage is 60 litres per day. With a water price of US$1 per m^3, you lose more than US$20 per year and you can buy a new tap every year if you replace the leaking one.

”Benign by design” - manufacturers need not make products with problematic content

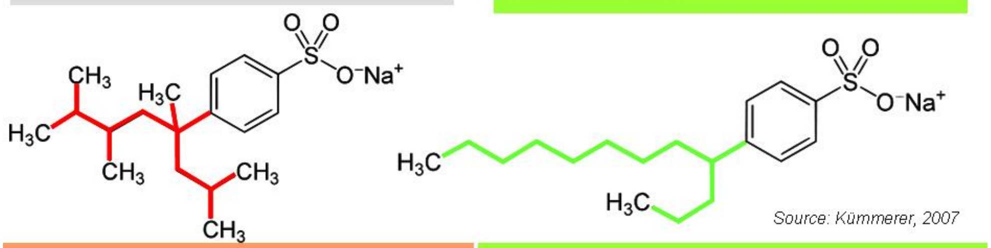
4.5 - 16

Classical view on functionality of chemical products:

- + stable (persistent)
- + effective
- + efficient
- + affordable

New view:

- + complete and fast degradation
- + no risk of harmful effects
- + effective
- + efficient
- + affordable



TPS non-biodegradable for washing powder | **LAS** readily biodegradable replacement of **TPS**

The last half-century can be characterised as the period in which the chemical society emerged. Almost all products in the shops today were not available fifty years ago. Scientific and technical development in combination with international trade is the basis for the saturation of every corner of the globe with consumer products that challenge sustainable sanitation. Manufacturers therefore play a central role in facilitating the task of treating greywater and wastewater through improved chemical design (picture).

In some cases manufacturers have changed their products more or less voluntarily. A good example was when manufacturers of toilet paper replaced chlorine with peroxide to bleach the paper. The biodegradable peroxide results in equally white paper and has no harmful side-effects, whereas chlorinated paper enters the wastewater and harms water bodies and living organisms.

On other occasions manufacturers refuse to swap hazardous compounds for biodegradable ones for commercial or other reasons. A continuous negotiation is going on between companies and government authorities on what should be allowed. Since it is costly and difficult to assess health and environmental impacts of chemical compounds, there is a serious lack of solid information to build decisions on (slide 4.5-7). Despite such problems, the EU Parliament adopted a policy in 2002 aiming for “… within a generation chemicals should be produced and applied that do not have any impact on the environment.” (EU Parliament, 2002).

Chemicals become problematic because some are persistent, and may accumulate in biological tissue and also be toxic. These risks are difficult to assess due to the long time-scale and large geographical areas involved which often makes evidence from lab trials inadequate. The EU REACH programme found that of 3000 tested chemicals, 30% are readily biodegradable and so are 27% of pharmaceuticals. The vast majority are more or less persistent. This was not a problem earlier when an important functionality criterion was that the compound should be stable. The new criterion is that products should be composed of chemicals that degrade rapidly and cause no harm to humans or the environment. This criterion can be fulfilled by clever chemical design.

New washing powders were introduced in the late 1950s, containing the persistent compound tetra-propylene sulfonate (TPS). It caused lots of foam and the manufacturers had to design a more friendly substitute. They choose LAS (linear alkylbenzenesulfonates), derived from naturally occurring lipids (bottom picture). Despite LAS being more toxic to aquatic organisms than TPS, it conquered the market due to its rapid biodegradability in the WWTP (Kümmerer, 2007). Recently, LAS molecules have been found in sludge in concentrations of 100–2000 mg per kg of dry matter. There is room for further chemical design engineering to improve washing powders (Yu et al., 2008).

In case insufficient evidence is available to assess whether a compound is harmful or not, the precautionary principle (slide 2.3-5) should apply. This means that a product cannot be introduced until more supporting data are available. However, this principle is likely to be under stress from strong economic interests prepared to introduce a product containing untested compounds.

One straightforward example is the introduction of diapers that small children could manage themselves. Procter and Gamble initiated a big promotion campaign in Sweden in 2008. Shortly afterwards, some WWTPs faced problems with thin plastic that choked moving parts in the treatment processes. The utilities identified the plastic and traced its origin to the diapers. The company claimed that the diaper was biodegradable within twelve hours, but tests by the Stockholm Water utility showed much longer degradation times. They contacted the manufacturer which responded that their product could not possibly cause this problem. As the use of diapers spread, more WWTPs faced similar problems. Utility managers called a meeting with the company and threatened to go public if they did not change the product or withdraw it from the market. The company must have rated the potential loss of credibility as high, since they decided to withdraw the product and end the costly promotion campaign.

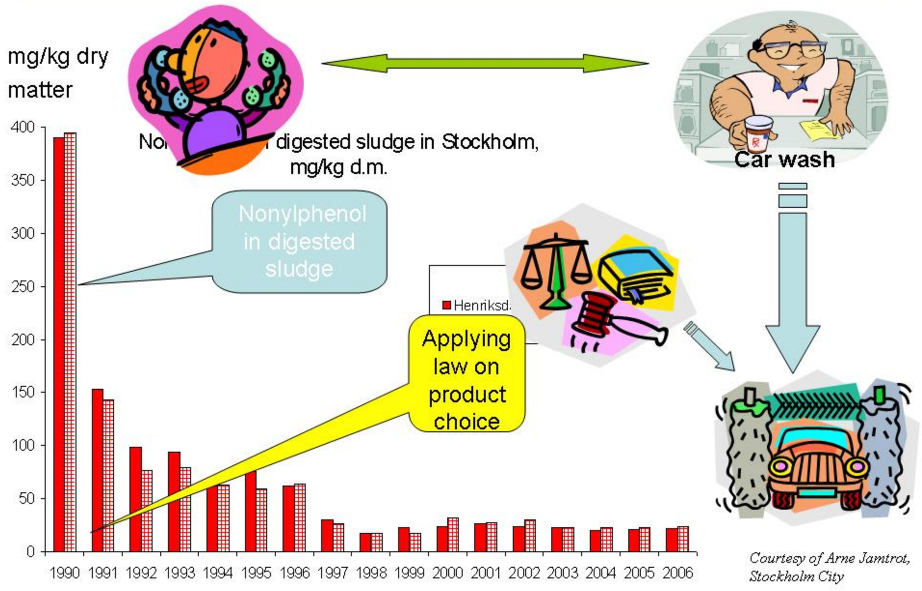
Another example is the use of sludge in agricultural production. One study (VMK, 2009) examined almost a thousand chemical compounds and found that octylphenol, nonylphenol and LAS were the only contaminants for which the PEC (Predicted Environmental Concentration in the water environment based on calculations or sample readings) exceeded the PNEC (Predicted no effect concentration). A PEC/PNEC ratio higher than one means a high risk of a biological impact on the aquatic environment. However, the authors argued that these compounds degrade rapidly ($t_{1/2}$ in soil = 8–10 days) and the highest concentrations were found immediately after the application of sewage sludge followed by a rapid decline. The report found octylphenol, nonylphenol and LAS 'to be of low concern' when taking into account the uncertainties related to the occurrence levels, and the rapid degradation in the soil. The precautionary principle was not applied; rather, the authors struggled to get around it.

The study also argued that only a few PAHs and PCBs were expected to accumulate with repeated applications of sewage sludge (every 10^{th} year) on fields in a 100-year period and still their model indicates that the concentrations of these substances will be well below the PNEC-value even at the end of the 100-year period.

The pressure to return contaminated sewage sludge to farmland is massive because the sludge volumes are huge and alternatives few. The only safe method to access the valuable nutrients P, K and N in the sludge is perhaps to apply a source control system on what goes into the wastewater.

4.5 - 17

Supervision: nonylphenol in car care products



With the active participation of various stakeholders, a wide range of improvements can be made to source control. Two previous slides (4.5-14 and 4.5-15) illustrate how individuals can contribute in the short term as well as with long-term investments in sustainable houses. Manufacturers carry a major responsibility because they choose what products enter the market. With some 30,000 compounds on the market, there is no silver bullet that will solve contamination problems, unless we want to return to the lifestyle of a few centuries ago. The task comprises a myriad of small contributions which together will make a difference globally. The City of Stockholm has several activities to reduce toxic materials in consumer products:

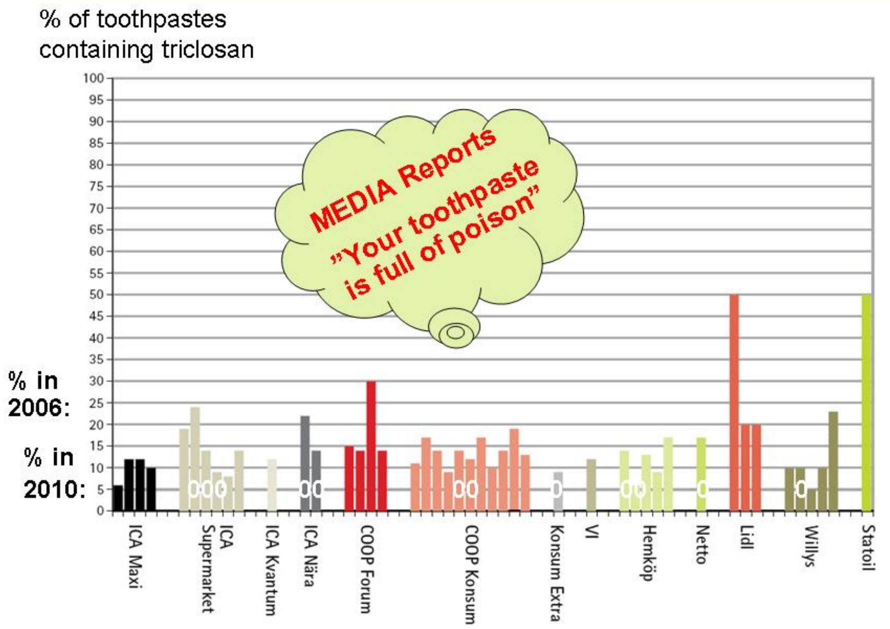
1. professional staff supervise various activities according to the environmental legislation
2. influencing the choice of construction materials
3. providing information about the content of products
4. having a green public procurement policy
5. engaging in dialogue with trade and customer organisations

The selection of substances is based on risk, prevalence and emissions, knowledge about sources, and prospect of effective actions (Bergbäck and Jonsson, 2008). The picture above shows an example of car wash facilities in Stockholm that used a common detergent containing the toxic compound nonylphenol which is harmful to the environment (4.5-16). The chemical was discharged into wastewater which went to a WWTP but they could not deal with it. Had the carwash facility not been connected to a sewer the nonylphenol may have damaged living organisms in a nearby stream or creek. Nonylphenol-free detergents were introduced on the market and the city´s Environmental and Health Administration launched a campaign in 1990 to inform all car wash facilities in the city that they were obliged by the product-selection act to switch to nonylphenol-free detergents. The owners gradually substituted these for the new alternative products and the diagram above shows decreasing amounts of nonylphenol in sludge. The concentration dropped from about 400 mg/kg dry sludge to 30 mg/kg over a seven-year period.

It is likely that the manufacturers of detergents containing nonylphenol have adjusted the chemical formula in order to stay in the market. The city took this precautionary step despite the then ongoing discussion about how toxic nonylphenol is.

Media attention: Triclosan in toothpaste

4.5 - 18



Courtesy of Arne Jamtrot, Stockholm City

Toxic organic substances are rather common in household products. For instance, the bactericide triclosan is a common ingredient in toothpastes, deodorants and sports garments. Triclosan is classified as highly toxic to water-living organisms and can cause long-term harm in water environments. It is not considered acutely toxic for mammals, but *in vitro* studies on rats and humans indicate that it can disturb biological systems by affecting metabolism and the hormone balance. There has been no health risk assessment of long-term exposure of humans (Bergbäck & Jonsson, 2008). It is known that incineration of sludge can create, unintentionally, chlorinated dioxins from the burnt triclosan. So, if not caught as sludge it will be toxic to fish, and if caught and incinerated the resulting dioxin will be toxic to humans.

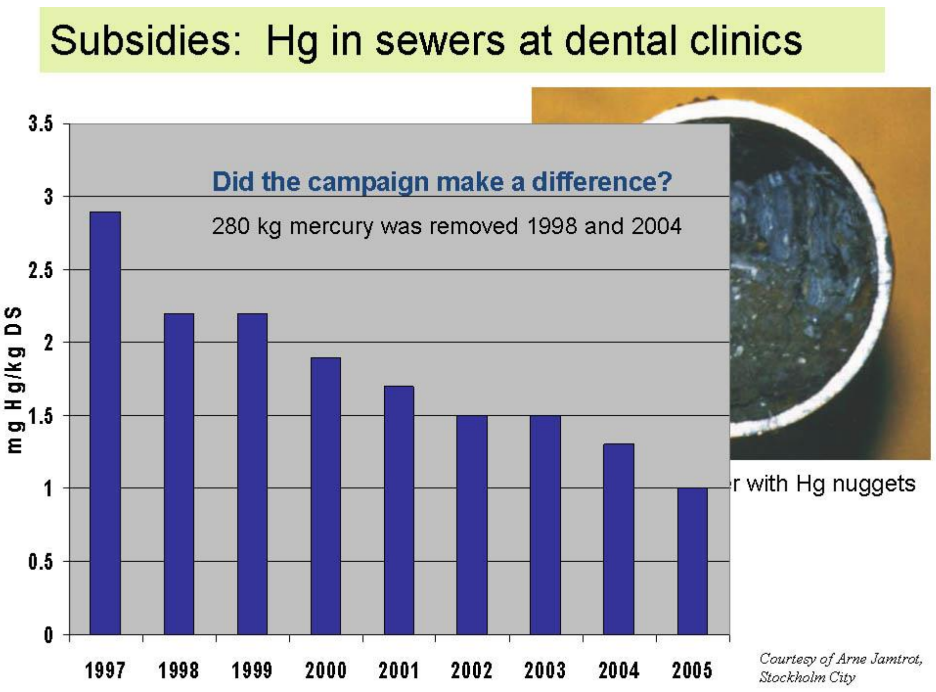
The City of Stockholm wanted to remove triclosan from the market because it was found in the treated wastewater (330 ng/l) and in fish (0.56 µg/kg fat weight). The first step to solving the problem was to identify the sources of triclosan. A survey showed that a total of about 4 tonnes of triclosan was used annually in Sweden, half of which was in toothpastes. The purpose is to kill bacteria in the mouth. However, the Swedish Dental Association has not found any odonatological justification for the widespread use of triclosan in toothpaste.

In 2006, a Swedish NGO named Nature Protection Association surveyed forty-five retail outlets from supermarkets to small shops to find out the proportion of toothpaste brands that contained triclosan (diagram above). Newspapers and TV reported several times about the environmental problems with triclosan using headlines such as “Your toothpaste is full of poison”. The “dialogue” with manufacturers was fruitless and they refused to change this component in the toothpaste with the argument that current labelling on triclosan toothpaste informs the consumer that a dentist should be consulted before use. Staff from the city´s Environmental and Health department visited the outlets and informed the purchase managers about the unnecessary use of triclosan in toothpaste. A survey in 2010 found that major retailers had withdrawn triclosan-containing brands from their shelves as indicated by a “0” in the diagram. This is rated as a success story for reducing triclosan.

For other toxic components in consumer products the City of Stockholm applies a Green Procurement Policy when they sign large contracts for school and office products. Suppliers who cannot, or do not wish to, comply are not considered. Since the city purchases goods and services worth billions of dollars every year the policy has an effect on what the market supplies.

At the same time it is a challenge for the city council to identify products which contain a certain harmful toxic compound. In this, the central government agency for chemicals and the environmental protection agency have important roles to play.

4.5 - 19



For generations, mercury has been known for its toxicity. Today, mercury has a very restricted use and the leakage of mercury to the environment essentially comes from forest soils and old sediments. In 1988 the city council of Stockholm decided to launch a campaign to reduce the sources of mercury pollution. The first step was to locate the known sites for leaking Hg – dentist clinics and hospitals, since mercury has for a long time been used for filling teeth. Investigations were launched to locate u-bends in sewers (right picture) which are likely to trap and contain Hg due to its high density. Owners, landlords, enterprises and institutions were contacted and offered a 60% subsidy towards the cost of removing the Hg-containing sediments in the pipes and install a trap to collect new mercury. The response was good and the government contributed € 1.3 million to the campaign and the property owners contributed almost as much.

Altogether 280 kg of mercury was removed from sewers in this campaign. The monitoring program at the wastewater treatment plant recorded a gradual decrease in Hg concentrations in its dry sludge (graph). The concentration of Hg in dry sludge went down from 3 mg per kg to 1 mg per kg during the eight-year project period and this is a permanent improvement since the source has been removed. Today all dentist clinics are equipped with traps for Hg to prevent further releases.

References:

Balmér, P. 2001. Possibilities to improve the quality of wastewater sludges. *Water Science and Technology*. Vol 44 No 10, pp 19-26. IWA Publishing.
Barrett MH, Hiscock KM, Pedley S, Lerner DN, Tellam JH, French MJ (1999) Marker species for identifying urban groundwater recharge sources—a review and case study in Nottingham, UK. Water Res 33(14):3083–3097
Bergbäck, B. and A. Jonsson (eds.), 2008. Stockholm – Towards a non-toxic environment. Stockholm City Environmental dept and Stockholm Water Company. At: www.stockholm.se
BGS 2001. Guidelines for assessing the risk to groundwater from on-site sanitation. British Geological Survey. Commissioned Rep CR/01/142:97.
California Energy Commission, 2004. In Steinfeld, C. and Del Proto, D. 2008. Reusing the resource: Adventures in ecological wastewater recycling. Ecowaters Books. USA.
Cronin A.A, Taylor, RG, Powell KL, Barrett MH, Trowsdale SA, Lerner DN 2003. Temporal variations in the depth-specific hydrochemistry and sewage-related microbiology of an urban sandstone aquifer – Nottingham, UK. *Hydrogeol. J* 11(2):205-216.
Drangert, J-O. and A. Cronin. 2004. Use and abuse of the urban groundwater resource: implications for a new management strategy. *Hydrogeology Journal*, 12:94-102.
Hamilton, A,J., Boland, A.M, Stevens, D., Kelly, J., Radcliffe, J., Ziehrl, A., Dillon, P.J. and Pailon, R. 2005. Position of the Australian horticultural industry with respect to the use of reclaimed water. *Agricultural Water Management*, vol 71, pp. 181-209.
Jönsson, H., Richert Stintzing, A., Vinnerås, B., and Salomon, E., (2004). Guidelines on use of urine and faeces in crop production. Report 2004-2, Ecosanres, Stockholm Environment Institute. Stockholm, Sweden. Available at: www.ecosanres.org.
Kümmerer, K. 2007. Sustainable from the very beginning: rational design of molecules by life-cycle engineering as an important approach for green pharmacy and green chemistry. *Green Chem*., 2007, 9, 899-907.
Powell KL, Taylor RG, Cronin AA, Barrett MH, Pedley S, Sellwood J, Trowsdale S, Lerner DN 2003. Microbial contamination of two urban sandstone aquifers in the UK. *Water Res* 37(2):339–352
Qadir, M., and Scott, C.A. 2010. Non-pathogenic trade-offs of wastewater irrigation. In Drechsel, P. et al. (eds). *Wastewater irrigation and health. Assessing and mitigating risk in low-income countries*. Earthscan. Lndon.
Taylor, R.G., Barrett, M.H., Baines, O.P., Trowsdale, S.A., Lerner, D.N., and Thornton, S.F. 2000. Depth variations in aquifer hydrochemistry using a low.cost multilevel piezometer. In Sililo, O. et al. (eds.) *Groundwater : past achievements and future challenges*. AA Balkema, Rotterdam, pp561-654
VMK 2009. Risk assessment of contaminants in sewage sludge applied on Norwegian soils. Norwegian Scientific Committee for Food Safety. 2009.
Yang, Y., Lerner, D., Barrett, M. and Tellam, J. 1999. Quantification of groundwater recharge in the city of Nottingham, UK. *Environmental Geology* 38(3): 183-198.
Yu, Y., Zhao, J., and A.E., Bayly. 2008. Development of surfactants and builders in detergent formulation. Chinese Journal of Chemical Engineering. 16(4) 517-527.
WHO (2006) *Guidelines for the safe use of wastewater, excreta and greywater*. Volume IV. Excreta and greywater use in agriculture. Geneva, 2006. http://www.who.int/water_sanitation_health/wastewater/gsuww/en/index.html