EFFICIENT MANAGEMENT OF WASTEWATER, ITS TREATMENT AND REUSE IN THE MEDITERRANEAN COUNTRIES

- Summary -

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Based on a works of:

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1. Introduction

The increasing scarcity of water in the world along with rapid population increase in urban areas gives adequate reason for efficient management of wastewater, its treatment and reuse based on modern technologies and especially conceptions. Unfortunately only little investment has been made in the past in Mediterranean countries on sewage treatment and reuse facilities. Water supply and treatment often received more priority than wastewater collection, treatment. However, due to the increasing need wastewater treatment deserves greater emphasis. Currently there is a growing awareness of the impact of sewage contamination on rivers and lakes. The reuse of water itself is possible within the recovery of nutrient and water resources and correspondents with the reduce of the user-demand for water. In order to achieve ecological wastewater treatment, a closed-loop treatment system is desirable. Therefore the traditional linear treatment systems with end-of-pipe technologies must be transformed into the cyclical and integrated treatment to promote the conservation of water and nutrient resources. All these aspects are integrated in the so called sustainable wastewater treatment. The major criteria for sustainability in the treatment of wastewater are economical efficiency and affordability, ecological soundness and socially acceptability.

2. Characteristic, Analytic and Sampling of Wastewater (A1)

Basis for all conceptions and treatments systems is the detailed knowledge about the existing wastewater characteristic, which is one of the main aspects for the problem solution.

2.1 Domestic wastewater sources

Wastewater is the term for discarded or previously used water from a municipality or industry. The wastewater that is produced due to human activities in households is called domestic wastewater i.e. wastewater from the kitchen, shower, wash basin, toilet and laundry (see figure 1).

Figure 1: Sources of domestic wastewater (Samwel 2005)

The strength and composition of the domestic wastewater changes on hourly, daily and seasonal basis, with the average strength dependent on per capita water usage, habits, diet, living standard and life style. The main reason is variation in water usage in households. Households in developed countries use typically more water than those in developing countries. Wastewater components can be divided into different main groups as shown in table 1. They can adversely affect the aquatic life if discharge them into environmental.

Physically, domestic wastewater is usually characterized by a grey colour, musty odour and has a solids content of about 0.1%. The solid material is a mixture of faeces, food particles, toilet paper, grease, oil, soap, salts, metals, detergents, sand and grit. The solids can be suspended (about 30%) as well as dissolved (about 70%). Dissolved solids can be precipitated by chemical and biological processes. From a physical point of view, the suspended solids can lead to the development of sludge deposits and anaerobic conditions when discharged into the receiving environment.

Chemically, wastewater is composed of organic (70%) and inorganic (30%) compounds as well as various gases. Organic compounds consist primarily of carbohydrates (25 %), proteins (65 %) and fats (10 %), which reflects the diet of the people. Inorganic components may consist of heavy metals, nitrogen, phosphorus, pH, sulphur, chlorides, alkalinity, toxic compounds, etc.. Gases commonly dissolved in wastewater are hydrogen sulphide, methane, ammonia, oxygen, carbon dioxide and nitrogen. The first three gases result from the decomposition of organic matter present in the wastewater.

Table 1: Components present in domestic wastewater

Component	Of special interest	Environmental effect
microorganisms	pathogenic bacteria, virus and worms eggs	risk when bathing and eating shellfish
biodegradable organic materials	oxygen depletion in rivers and lakes	fish death, odours
other organic materials	detergents, pesticides, fat, oil and grease, colouring, solvents, phenols, cyanide	toxic effect, aesthetic inconveniences, bioaccumulation in the food chain
nutrients	nitrogen, phosphorus, ammonium	eutrophication, oxygen depletion, toxic effect
metals	Hg, Pb, Cd, Cr, Cu, Ni	toxic effect, bioaccumulation
other inorganic materials	acids, for example hydrogen sulphide, bases	corrosion, toxic effect
thermal effects	hot water	changing living conditions for flora and fauna
odour (and taste)	hydrogen sulphide	aesthetic inconveniences, toxic effect
radioactivity		toxic effect, accumulation

Biologically, wastewater contains various microorganisms but the ones that are of concern are those classified as protista, plants, and animals. The category of protista includes bacteria, fungi, protozoa, and algae. Plants include ferns, mosses, seed plants and liverworts. Also, wastewater contains many pathogenic organisms which generally originate from humans who are infected with disease or who are carriers of a particular disease. Typically, the concentration of faecal coliforms found in raw wastewater is about several hundred thousand to tens of million per 100 ml of sample. The composition of typical domestic wastewater is shown in table 2.

Table 2. Different parameters in domestic wastewater (Henze and Ledin, 2001)

Analysis parameters		**Wastewater type**			
	Unit	**Concentrated**	**Moderate**	**Diluted**	**Very diluted**
BOD_5	mg O_2/l	350	250	150	100
COD	mg O_2/l	740	530	320	210
TOC	g C/m^3	250	180	110	70
SS	g SS/ m^3	450	300	190	120
VSS	g VSS/ m^3	320	210	140	80
Alkalinity	eqv/ m^3 *	37	37	37	37
Conductivity	mS/m **	120	100	80	70
Total Nitrogen	g N/ m^3	80	50	30	20
Total Phosphorous	g P/ m^3	23	16	10	6
Fats, oil and grease	g/ m^3	100	70	40	30

* 1 eqv/ m^3 = 1 m eqv/l = 50 mg $CaCO_3$/l
** mS/m = 10 µS/cm = 1 m mho/m

2.2 Wastewater parameters

Wastewater usually is characterized through several parameters, which can be categorized as follows:

- **Physical parameters** (Solids,Turbidity, Colour, Temperature, Odour)
- **Chemical and biochemical Parameters** (Alkalinity, pH, Dissolved (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), *Chlorides, Nitrogen, Phosphorus*, *Oil and Grease*, *Gases, Sulphur, Adsorbable organic halides (AOX, Metals*

The world of chemical analyses - even that of environmental or more restricted that of wastewater analyses - is hardly to survey. For many analyses, there exist several analytical methods, and additionally wastewaters contain innumerable different kinds of constituents. But these are really the minority of possible parameters. Based on specific water- and regional conditions the application other parameters can be reasonable. In additions microbiological parameters of wastewaters are extremely important for judging their pathogenic potential.

3. Hygiene and Risk Management (A2)

Hygiene is the science of preventing and protecting the health of people through control of the environment i.e. the physical surroundings: air, water; and land, biological ecosystems: animals and plants, and social structures. There are several environmental influences (see figure 2), which can overcome human's adaptation and defence capacity and cause diseases, which can be described in two types: infectious and non-infectious. An infectious disease is one which can be transmitted from one person to another or, sometimes, to or from animals. Other health problems related to environmental pollution are considered to be the result of contamination of water, food, and air with toxic chemicals. The resulting diseases are non-infectious.

Health is defined in the WHO (World Health Organization) constitution of 1948 as: a state of complete physical, social and mental well-being, and not merely the absence of disease or infirmity and Hygiene is the science of preventing and protecting the health of people through control of the environment. The Hygiene comprises the areas: Environmental hygiene, Social hygiene, Individual hygiene, Food hygiene an Occupational and domestic hygiene.

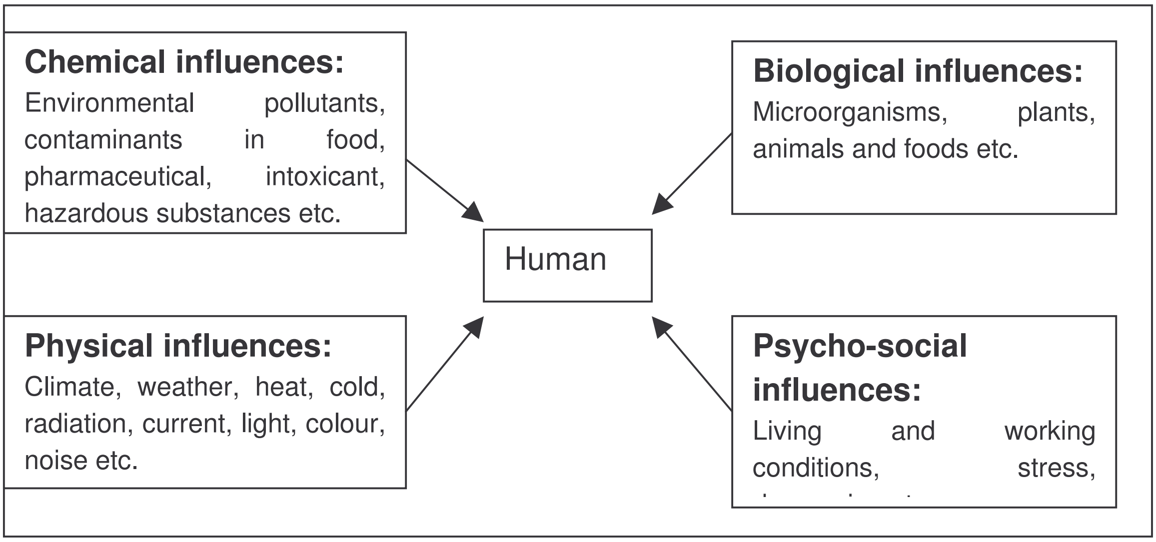


Figure 2: Environmental influences on human

3.1. Wastewater management and associated hygienic risk

3.1.1 Conventional sanitation

Due to disease risks caused by faecal wastewater, in large European cities sewers were constructed to drain the wastewater away from the people's surroundings to the nearby water courses, and ultimately into the sea. Later it was found that discharging raw wastewater had deteriorated aquatic environment of the receiving water body, and at the same time it caused diseases to the people, who received their drinking water from the same river downstream. To protect these rivers from the pollution as well as the public health from water borne diseases, the wastewater is treated at the end of the sewer before discharging it into the river. This tradition has been widely established as a standard way of managing wastewater world wide. However, most of the wastewater is discharged without any treatment mostly in developing countries.

Centralised wastewater management systems have been built and operated for more than hundred years. In the mean time, because of advanced technological development, the wastewater management has reached a high standard in many industrialised countries. However, in developing countries the present situation is still similar to that of the currently industrialised countries in the 19th century in many respects. About 95 % of wastewater in developing countries is still discharged without any treatment into the aquatic environment. This contributes largely about 1.2 billion people without access to clean drinking water. Almost 80 % of diseases throughout the world are water-related. Water-borne diseases account for more than 4 million infant and child deaths per year in developing countries.

In conventional sanitation systems, a huge amount of fresh water is used as a transport medium and a sink to dispose of wastes (see figure 3). In this process a small amount of human faeces is diluted with a huge amount of water. Therefore, it is hardly possible to prevent contaminants from emitting into surface and ground water bodies. As a result a huge amount of fresh water is contaminated and deemed unfit for other purposes. Moreover, due to the pollution and hygienic problems in receiving waters, surface water can no longer be used as a source for drinking water supply. Huge investments have to be made to improve the surface water quality in order to use it as drinking water.

Conventional sanitation systems show clear deficiencies in recovery of nutrients and organic matter, which are valuable fertiliser and soil conditioner respectively.

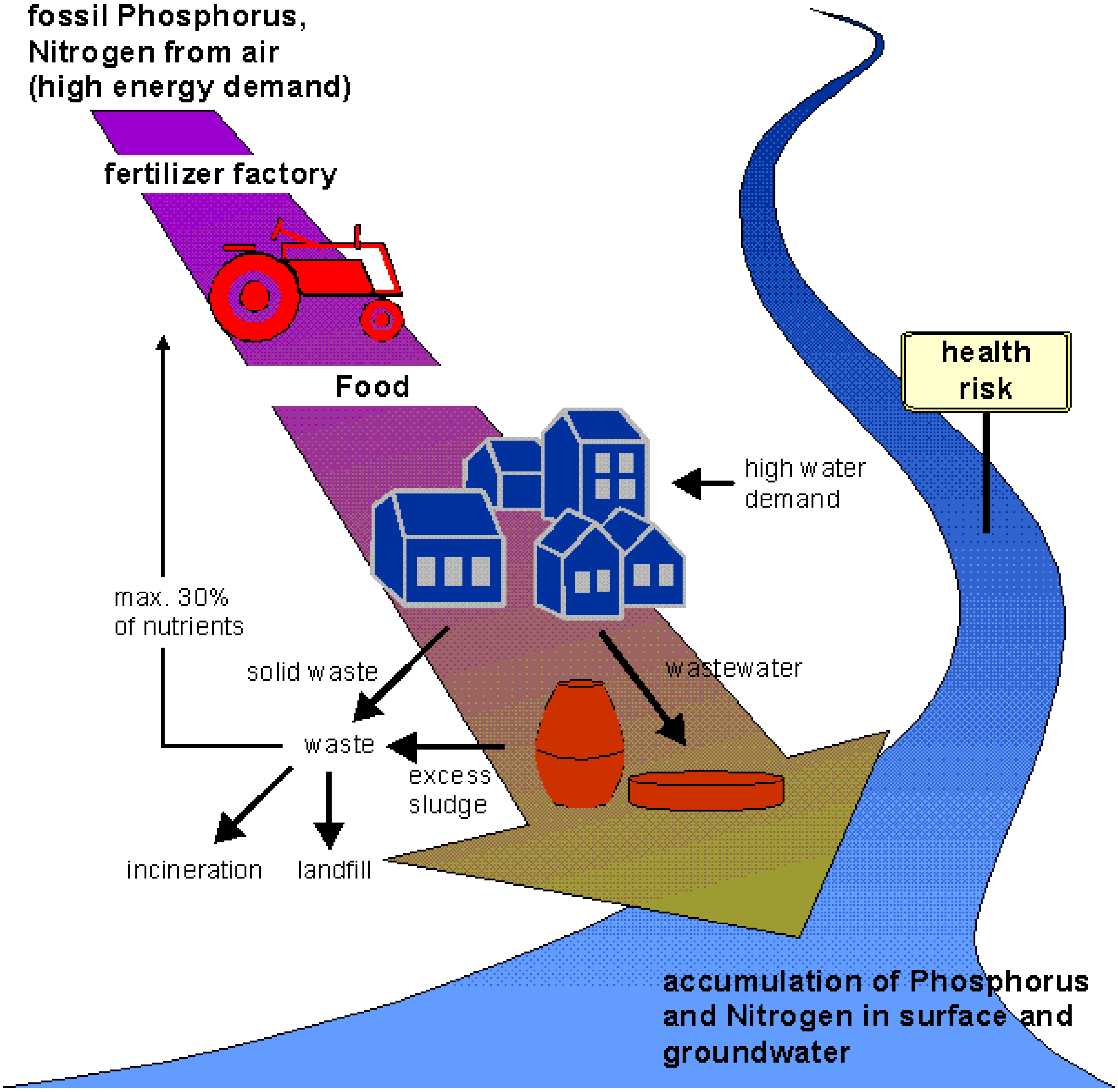


Figure 3: Conventional Sanitation System (source Otterwasser GmbH)

Also decentralised sanitation systems, such as pit toilets, septic tanks, etc. cause pollution i.e. nutrients and pathogens seeping from these systems contaminate the groundwater and nearby surface water - they cannot destroy pathogens.

3.1.2 Ecological sanitation

Human faeces contain most of the pathogens with a potential of causing diseases. Therefore, source control of faeces from household wastewater prevents these disease-causing pathogens gaining access to water bodies where they survive longer than on land and pose a long-term threat to human health. The most beneficial is when it is kept separated at source which avoids dilution of faeces. The separated solid fractions, which are easily biodegradable, can be treated biologically. When organic matter is decomposed under aerobic conditions, heat is produced due to self heating capacity. This self produced heat kills pathogens and creates self-hygienization of the matter (composting).

The secondly applied method for the sanitization of separated faecal waste is dehydration. Treatment methods based on dehydration can reduce pathogens effectively, because there is a rapid pathogen destruction at moisture content below 25 %.

The hygiene risk associated with urine is quite small compared to that with faeces. The fate of the pathogens entering the urine collection tank due to faecal contamination in urine diversion toilets is of vital importance for the hygiene risks related to the handling and reuse of the urine. In practice, complete elimination of pathogens may not be possible in any kind of sanitation. Therefore, secondary barriers such as personal, food and domestic hygiene must be included to destroy the pathogens completely. Consequently, hygienic awareness and proper education are crucial isssues.

3.1.3 Sustainable Sanitation

Although the terms are not very clearly defined and diversely understood, here it is tried to specify the term sustainable sanitation.
Sustainable sanitation includes some further aspects as (see also figure 4):

- Closing and separating the cycles of water and nutrients; avoidance of hygienic problems due to the separation of faeces from the water cycle
- Reclamation of nutrients (phosphorus and nitrogen) for agricultural use and hence saving of resources and energy (for the production of artificial fertilizer)
- Considerable savings of freshwater through the use of water saving toilet systems (vacuum, separating or dry toilets)
- Energy production (biogas) instead of energy consumption (for carbon degradation in sewage plants)
- Savings of construction, operation and maintenance costs compared to the conventional central sewerage systems
- Sophisticated modular system, which can be adapted perfectly to local social, economical and environmental conditions
- Easier operation and maintenance compared to centralized technology; local job creation

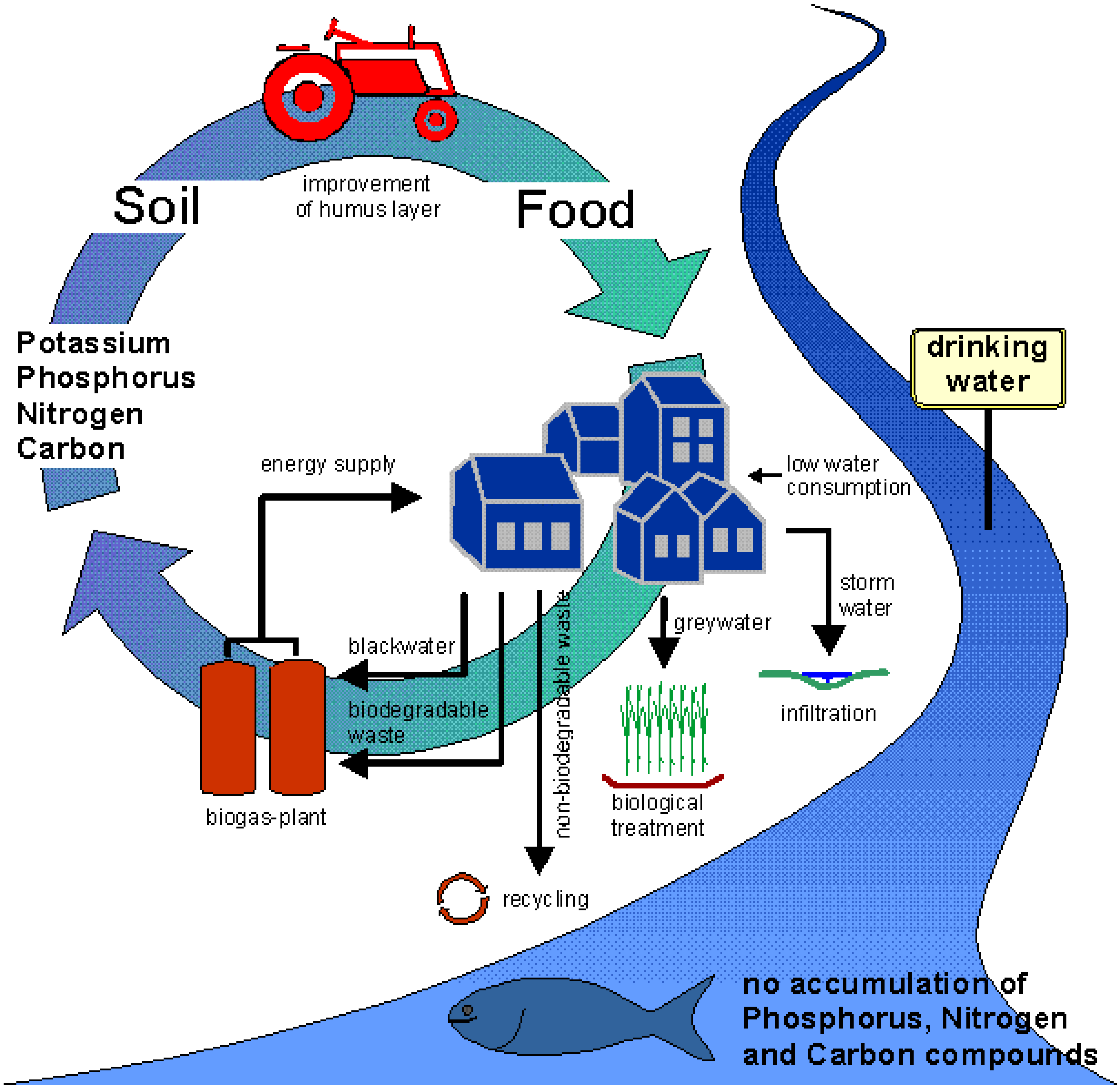


Figure 4: Sustainable Sanitation System (source Otterwasser GmbH)

3.4 Risk management through guidelines

Guidelines and recommendations for the handling and reuse of wastewater can work as a tool to minimise risks. Currently, it is recommended that the sanitised faecal matter is covered after application and not used as fertiliser to vegetables, fruits or root crops that are consumed raw, excluding fruit trees. Urine etc. Definite guidelines in ecological sanitation for safe handling and reuse of urine and faeces are currently developed by the World Health Organisation (WHO) and will be released in 2006. The already existing guidelines for reuse of wastewater in agriculture by WHO, where faecal coliforms and intestinal nematode eggs are used as pathogen indicators and are also indicator or limiting parameter for restricted irrigation, are now under revision.

4. Resource management sanitation (B1)

Human excreta contain valuable plant nutrients as well as organic matter and can be converted into fertiliser and soil conditioner for agriculture. Thus, reuse of human excreta reduces the production of chemical fertiliser which is energy intensive, causes environmental problems and draws on very limited fossil resources. Additionally, the surface water is preserved which is otherwise polluted by discharging human excreta into it. Due to high dilution, it is hardly possible to recover good amount of nutrients in conventional sanitation systems. Even modern wastewater treatment plants that are hardly affordable for developing countries emit nutrients into water bodies where they cause eutrophication. Also, pathogens contained in faeces can spread to the aquatic environment causing disease to people.

A high amount of nutrient recovery is possible with source control in households. With the application of Resource Management sanitation it is possible to keep human excreta in non-diluted or little diluted form which provides good condition for high levels of nutrient recovery as well as for effective sanitisation. The systems that are applied in Resource Management sanitation for the source control are composting/dehydration toilets, sorting or no-mix toilets as well as vacuum toilets.

4.1. Material flows in domestic wastewater

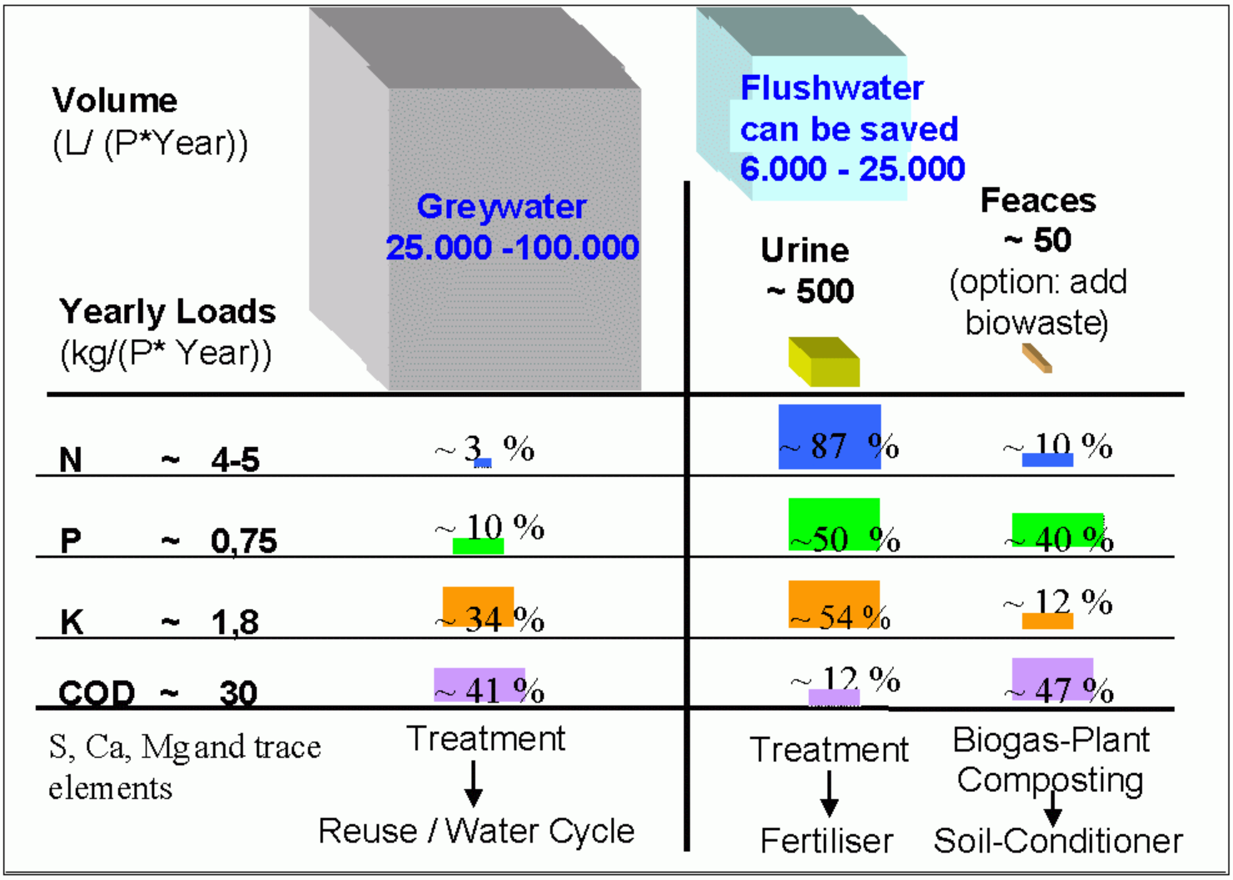
Different particular wastewater streams are forming the domestic wastewater (see figure 1). The wastewater originating from toilets is called black water and can be further divided into yellow water (urine with or without flush water) and brown water (toilet wastewater without urine). Additionally, grey water is that part of domestic wastewater which originates from kitchen, shower, wash basin and laundry.

The typical characteristics of the streams of domestic wastewater, shown in table 3 clearly characterize that yellow and brown water contain most of the nutrients discharged to sewers in the conventional sanitation. This means that they are generally wasted instead of being used as fertilizers (except the small portion of nutrients being contained in sludge which is used sometimes as fertilizer after sanitisation).

Due to pathogens, brown water poses high health risk, but it represents a very small volume flow in domestic wastewaters (only 50 litres are excreted per person per year).

In conventional systems, this small volume is mixed with other streams of domestic wastewater with higher volume flows: yellow water (tenfold volume flow compared to faeces) and grey water. Grey water volume flows depend on habits. That is why a wide range is given for grey water volume flow: 25,000 to 100,000 litres per person per year.

Table 3: The typical characteristics of the streams of domestic wastewater
(Compiled from: Geigy, Wissenschaftliche Tabellen, Basel 1981, Vol.1, Larsen and Gujer, 1996 and Fittschen and Hahn, 1998)



4.2 Yellow water as fertilizer

Separate collection of yellow water is possible with sorting toilet. Among the flows of wastewater, yellow water contains most of the nutrients (table 3). These nutrients in general are in a form which are ideal for uptake by plants and can be used in fertilizers. Beneficially, urine contains very low levels of heavy metals and pathogens. These heavy metal concentrations are much lower than those of most chemical fertiliser. In the conventional wastewater treatment systems, instead of utilising the yellow water for plant nutrition, it is wasted. In modern municipal wastewater treatment plants, nitrogen compounds (most of them originating from yellow water) is removed with the costly nitrification and denitrification process.

4.3 Brown water as soil conditioner

Soil degradation caused by human activities is alarming worldwide. The main causes of soil degradation are: erosion, fertility decline, overcropping and use of synthetic fertiliser. Since synthetic fertiliser does not contain organic matter which prevents soil erosion, reuse of brown water as soil conditioner plays important role to reduce the soil degradation as brown water contains most of the organic solids in domestic wastewater. Like yellow water, separate collection of brown water is possible with sorting.

4.4 Conventional decentralised sanitation systems

In decentralised systems, wastewater from individual houses is collected, treated and disposed / reused at or near the point of its origin. The most important benefits of this system compared to the centralised system are:

- there is no need of laying sewers for the transportation of sewage as in the centralised treatment plant, which is normally located far from the point of the origin of the sewage; construction, maintenance and operation of sewers are very costly parts of sanitation systems;
- there is far lower dilution of sewage than in the centralised system, which creates possibilities to reuse treated wastewater and nutrients.

There are many existing decentralised wastewater treatment systems which have been widely used worldwide. However, all of them cause pollution i.e. nutrients and pathogens seeping from these systems contaminate the groundwater and nearby surface water, they cannot destroy pathogens and deprive agriculture of valuable nutrients and soil conditioner from human excreta.

4.5 Resource Management Sanitation

All conventional wastewater treatment systems usually deprive agriculture, and hence food production, of the valuable nutrients contained in human excreta, since the design of these systems is based on the aspect of disposal. The future sanitation designs must aim for the production of fertiliser and soil conditioner for agriculture rather than waste for disposal (Otterpohl, 1999). Nutrients and organic matter in human excreta are considered resources, food for a healthy ecology of beneficial soil organisms that eventually produce food or other benefits for people. One person can produce as much fertiliser as necessary for the food needed for one person (Niemcynowicz, 1997). Therefore, the new approach should be designed in such a way that it could reconvert the waste we produce into resources free of pathogens in reasonable costs without polluting aquatic environment.

Figure 4 illustrates a possible scenario for closing the nutrients cycles and simultaneously preserving fresh water from pollution. This scenario can be achieved with the application of resource management sanitation, base on ecological principal. There are numerous advantages of resource management sanitation compared to conventional sanitation (Werner et al., 2002; Otterpohl, 2001; Esrey et al., 1998). The major advantages of them are :

- reuse of human excreta as fertiliser and soil conditioner; water and energy;
- preservation of fresh water from pollution as well as low water consumption;
- preference for modular, decentralised partial-flow systems;
- design according to the place, environment and economical condition of the people;
- hygienically safe;
- preservation of soil fertility;
- food security;
- low cost (ecological, economical and health cost);
- reliable.

Sorting toilet is a suitable technology to separate the urine and faeces at source (see figure 5). Usually, the toilet has two bowls, the front one for urine and the rear one for faeces. Each bowl has its own outlet from where the respective flow is piped out. The flush for the urine bowl needs little water (0.2 l per flush) or no water at all, a mechanical device closes the urine pipe when users stand up whereas flushing water for faeces bowl can be adjusted to the required amount (about 4 to 6 l per flush). However, in the present system separate collection is efficient only when men sit down while urination.

Figure 5: Sorting toilet (Source: Roediger)

Figure 6: Vacuum toilet (Source: Roediger)

Vacuum toilets as shown in figure 6 has been used in aeroplanes and ships for many years and is increasingly used in trains and flats for water saving. It uses 1 l water per flush and is independent of gravity. The black water is transported by air and pressure differential (vacuum) instead of water and gravity to bio-gas plant. Water is used only for rinsing the bowl, not for transporting the faeces. Limited vertical lifts and long horizontal transportation of the black water are possible. Noise is a concern with vacuum toilets but modern units are not much louder than flushing toilets and give only a short noise.

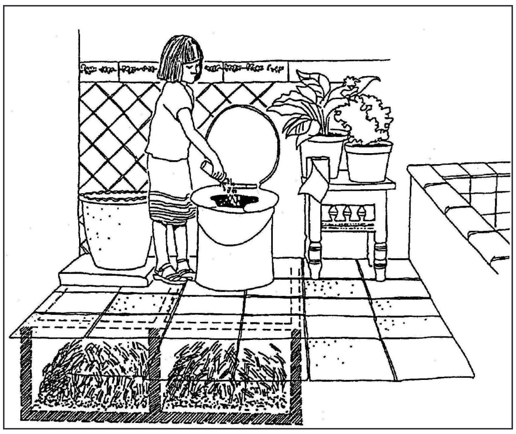


Figure 7: Double-vault toilet with urine diversion (Source: Esrey et al., 1998)

Composting / dehydrating toilet needs 0.2 l water per flush, only for cleaning the toilet seat. There are also urine diversion composting or dehydration toilets (figure 7). These low-flush and non-flush toilets save not only water, but also produce low diluted or dry faecal material that is easier to manage than highly diluted faecal wastewater as in conventional systems.

In February 2000, there has been an experts consultation arranged by the Water Supply and Sanitation Collaborative Council (WSSCC) which resulted in the formulation of the so-called ***"Bellagio Statement"*** ("Clean, healthy and productive living: a new approach to environmental sanitation"), which gives some insight into philosophy and basics of Resource management sanitation.

The mentioned aims can be achieved by source control in sanitation! Source separation of different streams of domestic wastewater helps to prevent pathogens from faecal matter to be spread in the environment, utilizing nutrients from yellow water, and preventing grey water from being further contaminated with nutrients, faecal pathogens, and contamination with hazardous substances from industrial wastewaters making it a suitable source for being reused - even for high quality demand like groundwater recharge. The issue of source control requires some special pre-requisites: separate pipes for yellow, brown and grey water, no-mix toilets for separate collection of yellow and brown water and low volumes for toilet flushing.

Generally, there are different options for source separation. A simple scheme would be the separation of grey water from black water, requiring two separate pipe systems in the home (one for grey water, one for black water). Low volumes of toilet flush water are helpful in further treatment of black water solids in order to sanitise them. For certain sanitation techniques (dehydration, composting), the black water solids have to be separated from the liquid phase. One possibility for sanitisation the entire black water is anaerobic digestion, which also offers the possibility of harvesting biogas.

The second option is to collect all three sources of domestic wastewater separately: grey water, yellow water, and brown water. This option requires three different types of pipes in the home (for grey water, yellow water, and brown water). In such a scheme, the excellent fertilizer “yellow water“ is collected very purely.

4.6 Treatment systems for brown and black water

There are two types of treatment systems, namely dry and wet systems for the treatment of brown and black water. Dry systems use no flush water whereas wet systems use flush water, but only very low amounts just to transport faecal matter to the treatment plant located close to the origin of faecal matter. The non-diluted or less diluted faecal matter has to be sanitised before reuse in agriculture. This can be done with composting, dehydration, vermicomposting and anaerobic fermentation/digestion. Based on this Processes following sanitation systems have been applied:

- Composting and dehydration systems
- Solid-liquid separation systems
- Rottebehaelter systems

4.7 Treatment systems for grey water

Biological treatment methods are required to remove organic contamination. The mostly used methods are constructed wetlands, Sequence Bach Reactors (SBR), membrane bioreactors and biological aerated filter. The biological process must be followed by a physical process in order to retain active biomass and to prevent the passage of solids into the effluent, if the effluent is for reuse purposes. Treatment with the membrane-bioreactors (MBR) will probably be the choice of the future, especially if reuse is intended.

Physical methods used for grey water treatment are sand filter, ultrafiltration, micro-filtration, reverse osmosis. Small scale experimental results have shown that grey water treated with combination of SBR and slow sand filter has achieved the quality required for groundwater recharge (Jiayi et al., 2001).

4.8 Treatment systems for yellow water

Urine is relatively sterile and can be reused without further treatment (Wolgast, 1993). However, due to faecal contamination, pathogens have been found in yellow water; but in low concentration, which will pose low hygienic risk of using yellow water as a fertiliser, if it is stored at least for 6 months before being used in agriculture land (Jönsson et al., 1999; Hellström and Johansson, 1999). Recently, many methods for treatment and volume reduction of collected yellow water have been studied.

5. Rainwater Harvesting (B2)

The management of rainwater runoff represents an important aspect of water and wastewater management. Different methods exist in order to prevent flooding and erosion as well as to restore the natural hydrological water cycle. In contrast to off-site methods where the rainwater is collected, conveyed and discharged into waterways, rainwater infiltration and the use of rainwater by means of rainwater harvesting allow to address these issues and thus improve the water supply.

5.1 General aspects

Stormwater management techniques have to be designed specifically for the types of effect that are wanted to be brought about. In general, following measures for management of rainwater are commonly used (Ferguson, 1998):

- Use of rainwater / rainwater harvesting
- Infiltration of rainwater
- Conveyance
- Detention

Rainfall usually varies significantly with respect to time and geographical location. A rainfall event is characterised by the duration and the intensity or total quantity of rainwater that is falling down. A design storm on which the design of a wastewater management facility is based is a particular combination of rainfall conditions for which runoff is estimated. When choosing the design storm for designing a stormwater facility one needs to balance the risks and the costs. The selection of a large, infrequent storm as design storm reduces the risk of failure of the facility but increases the costs for construction and, thus, can make the facility uneconomical.

The drainage area, or watershed, is the land area that drains to the point at which you estimate runoff. Any rainfall runoff model requires you to identify the drainage area and to specify its size, soil, and condition. A drainage area is identified by defining its boundaries on a map.

Runoff's travel time is one of the watershed characteristics that can strongly influence the rate of storm flow. If a given volume of runoff drains off a drainage area quickly, the peak rate of flow at the outlet is correspondingly high. Time of concentration is a special case of travel time. It is the maximum amount of time runoff from any point in a drainage area takes to flow to the outlet.

Before a rainwater management facility is designed, the storm runoff should be established, which refers to the volumes and rates of flow in individual rainfall events. The actual volume of runoff reaching a rainwater management facility depends on several factors. These include the design storm, the size of the catchment area, the degree of development in the basin (i.e., amount of impervious surface) as well as the

the soil surface. It is often called "direct runoff", because it results from surface flow and other immediate responses to precipitation. A runoff gauging station would provide a direct, factual way to observe flows from a site in its existing condition.

5.2 Water balance

A water balance, like a storm runoff estimation, establishes volumes and rates of flow. Storm runoff and water balance estimations supplement each other as tools for evaluation and design. Storm runoff estimation is needed to protect against, control and utilise runoff during individual storm events. Water balance estimations show the effects of land use and stormwater control on the local ecosystem. The underlying principle of the water balance is the change-of-volume concept. Any difference between inflow and outflow must be accounted for by a change in the amount of water stored. The inflow can include precipitation, stream flow or artificial irrigation. The outflow can include evapotranspiration, direct runoff, base flow and additional outflows such as withdrawals for water supply. Figure 8 illustrates these different flows and the water balance concept. The water balance is a way to evaluate the aggregate effect of the hydrologic regime.

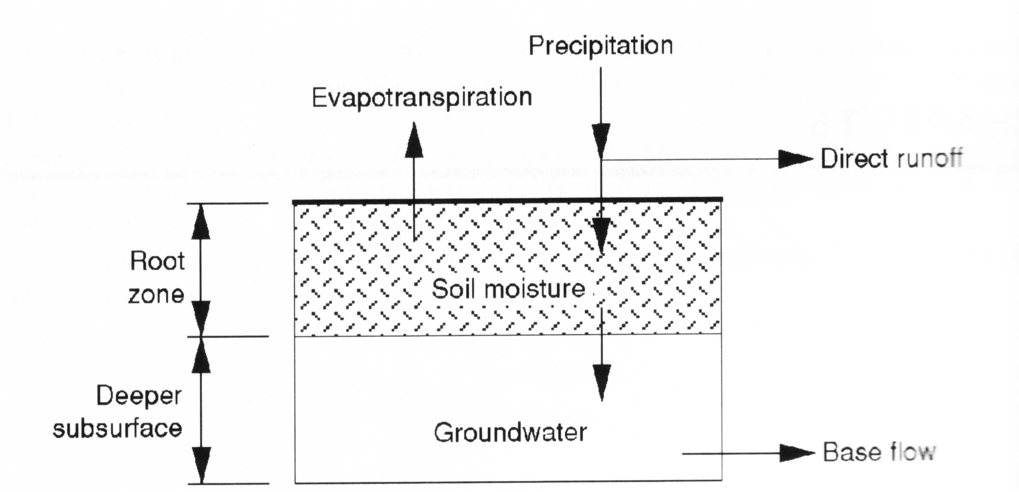


Figure 8: Water balance concept (Source: Ferguson, 1998)

5.3 Stormwater pollutants

Pollution of rainwater is caused by atmospheric pollution (such as emissions from industries and transport) as well as pollutants that are taken up during surface runoff. Among other things paper, oil, remainders of metals and rubbers, organic matter from vegetation and excrements can accumulate in the surface runoff. The main sources of anthropogenic pollution of rainwater is traffic and waste. The constituents vary in their nature and concentration according to local conditions.

Atmospheric rainwater is usually very pure and most contamination of the water occurs after contact with the catchment system. Rainwater from ground catchment systems is not recommended for drinking unless it is first boiled or treated. For the pretreatment of rainwater physical (such as sedimentation and filtration) and biological processes can be used. Biological treatment often occurs in biologically active soil filters or root zones. Please refer to the respective sections of this course for further information about physical and biological treatment processes.

5.4 Rainwater infiltration

The use of infiltration facilities represents an attractive opportunity to contribute to the recharge of groundwater and thus to minimise the interference of the natural water cycle. Stormwater infiltration returns surface flows to the subsurface and, thus, never aggravates flooding downstream. Additionally, a significant portion of the pollutant load of stormwater, which is normally directed to the receiving water, can be removed. If the soil through which water infiltrates contains any degree of clay or humus, the soil is a powerful filter that protects aquifers from contamination.

Some advantages of local rainwater infiltration are:

- recharge of groundwater
- preservation and/or enhancement of natural vegetation
- reduction of pollution transported to the receiving waters
- reduction of downstream flow peaks
- reduction of basement flooding in combined sewer systems
- reduction in the settlement of the surface in areas of groundwater depletion
- smaller storm sewers at a lesser cost

In some cases rainwater infiltration may have following negative impacts (Urbonas & Stahre, 1993):

- soils seal with time
- some infiltration facilities may not receive proper maintenance
- reliance on their operation may leave communities facing enormous capital costs in the future, if these systems begin to fail

- groundwater level may rise and cause basement flooding or damage to building foundations

There are a number of possibilities for decentralised or on-site infiltration systems and often combinations of the different systems are used:

- Infiltration beds
- Open ditches
- Percolation basins
- Pipe trench

The design of infiltration facilities should be in such a way that the facility will contain the design inflow without overflowing. Regular maintenance is needed to ensure proper operation of infiltration systems.

5.5 Water harvesting techniques

Generally the term “water harvesting” comprises many techniques that are used to supply rainwater collected from surfaces (roofs, ground surface, rock surface) for domestic or agricultural use. It can be defined as “... the process of concentrating rainfall as runoff from a larger catchment area to be used in a smaller target area” (Oweis et al.,1999, p.2). Water harvesting techniques represent methods to provide water for irrigation, watering domestic smallstock or domestic purposes from other sources than (permanent) streams, rivers and pumped groundwater. Usually a rainwater system consists of three main components: a catchment area, a storage reservoir and a delivery system. The target area can be the soil profile of the cultivated area or some kind of reservoir or tank. Water harvesting is particularly relevant to areas where rainfall is insufficient to balance evapotranspiration of crops and to sustain a good pasture growth.

Surface water harvesting requires runoff producing areas with sufficiently high runoff coefficients and runoff receiving areas, where the water is utilised. The differences between the different harvesting methods lie mainly in the size of the systems.

5.6 Water storage

Storage facilities allow the later use of runoff water as supplemental irrigation water. They can partly overcome the problem of the unreliability of rainfall. This also allows the prolongation of the cropping season or a second crop. The storage can be aboveground or underground. Surface tanks can be made of ferrocement, bricks, reinforced concrete, metal, plastic, fibreglass and wood. Sub-surface tanks are usually made of ferrocement, concrete, brick and traditional clay linings. Furthermore, water harvesting dams can be built of soil, rock or sand.

Storage tanks should be watertight with a solid, secure cover, a screened inlet, an overflow pipe and a covered manhole. The extraction system should be designed in such a way that the water quality is protected. The choice of a specific system depends on several factors such as for example:

- space availability
- option available locally
- local traditions for water storage
- cost - of purchasing new tank and of materials and labour for construction
- materials and skills available locally
- ground conditions
- patterns of usage

5.7 Traditional water harvesting techniques in southern Mediterranean region

Typical traditional harvesting techniques in the southern Mediterranean region are “Meskats”, “Mgouds”, “Jessours” and Cisterns.

The *meskat* system is a very ancient water harvesting technique that was already known and wide spread in the Roman era. The technique is an example for micro-catchment water harvesting techniques with relatively small catchment sizes. It is based on a catchment area or impluvium called “meskat” and a cropping zone (“mangaâ” or “mankaâ”) (see figure 9). The impluvium, generally about 500 m^2 in size, supplies additional water to a series of downstream plots, which are enclosed by small earth bunds (about 20 cm) and connected by spillways for discharging the excess water. In general the surface of the impluvium should be twice the cropping area, thus the catchment to cropping ratio (CCR) is 2:1 (Achouri, 1994). By breaking the runoff the *meskat* technique also contributes to the recharge of ground water as well as to the decrease of floods and water erosion.

Mgouds are a floodwater diversion technique which is very common in the plains adjacent to great wadis. It is a channel system based on the diversion of floodwater from its natural course in wadi beds to the nearby fields. The floodwater is diverted by solid dikes and lateral channels with minimal slope (“mgoud”) and then distributed by an extensive network of drainage channels to the irrigated area with fruit trees, cereals and vegetables. The crops are planted in parallel strips with a surface from 3 to 5 ha; each enclosed by small bunds and separated from the other strips by uncultivated land (Alaya et al., 1993).

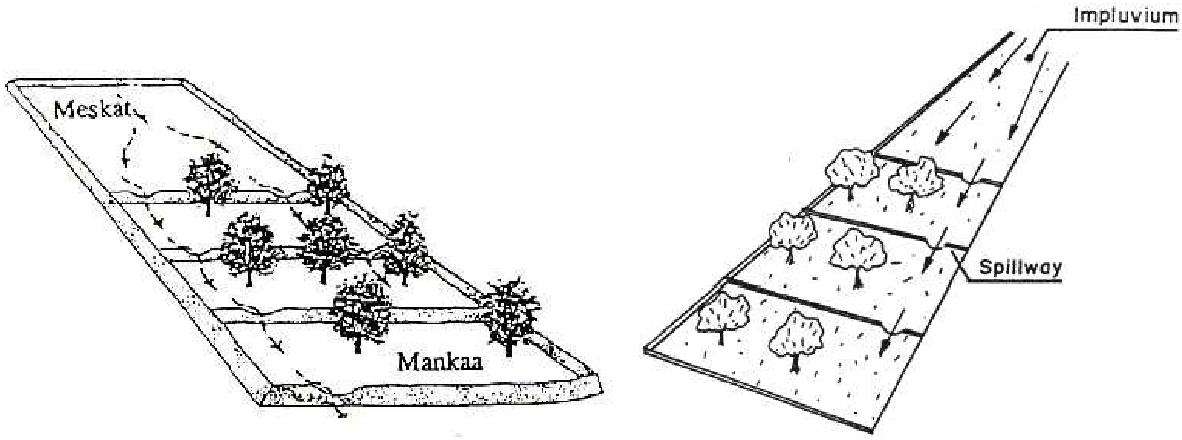


Figure 9: Meskat system (Source: Prinz, 1996 and Oueasser)

The technique of the J*essour (*singular: *Jesr)* is a typical system of the highlands in the southeastern regions of Tunisia and constitutes the foundation of the agricultural activities in this region. It is based on a retention dam made of earth or stone perpendicular to the runoff, behind which the crops, mainly fruit trees, are cultivated. The dam stops and stores the runoff and supplies in this way water to the crops. *Jessour* (singular: *jesr*) are generally used in mountainous areas, where they are often built into wadis, but they are also constructed on plains. The dams encourage the infiltration of the rainwater, which not only intensifies the agricultural production but also recharges the ground water. During extreme rainfalls a part of the disastrous runoff can be retained behind the dams which helps to reduce the damage that may be caused by floods.

The principal idea of cisterns or storage tanks is the collection of rainwater for storage and use as drinking water for domestic needs, animal watering or irrigation. A cistern is a man-made hole in the soil with a gypsum or cement coating to avoid vertical and lateral infiltration losses. Generally these underground reservoirs with capacities from 1 m^3 to 70000 m^3 occupy the outlet of a small catchment area (impluvium) that collects the rainwater. In a natural environment the impluvium is demarcated by one or more grooves or small stone bunds conveying the runoff water towards the opening of the storage tank. The water passes a decantation basin that retains plants, silt and other material that is carried by the runoff water. One or two openings in the covered top, which constitutes the protection against evaporation, allow the taking of water.

In Tunisia two different kinds of cisterns or storage tanks can be found: the "majel" and the "fesguia". Generally *fesguia* have a larger storage capacity, but their construction is accordingly more expensive. Further different types of cisterns are:

- Integrated into buildings
- Isolated, with sealed impluvium
- Natural impluvium

6. Anaerobic sewage treatment (B3)

Sewage treatment by conventional means, including secondary aerobic biological treatment, is efficient. But this efficiency is at the price of high capital and running cost and technology requirement. Alternatively, anaerobic treatment has been proven to be an admirable process and considered as the core of sustainable waste management.

6.1 Definition of anaerobic process

The fermentation process in which organic material is degraded and biogas (composed of mainly methane and carbon dioxide) is produced, is referred to as anaerobic digestion. Anaerobic digestion processes occur in many places where organic material is available and redox potential is low (zero oxygen). This is typically the case in stomachs of ruminants, in marshes, sediments of lakes and ditches, municipal land fills, or even municipal sewers.

The anaerobic ecosystem is the result of complex interactions among microorganisms of several different species. The major groupings of bacteria and reaction they mediate are:

- fermentative bacteria
- hydrogen-producing acetogenic bacteria
- hydrogen-consuming acetogenic bacteria
- carbon dioxide-reducing methanogens
- aceticlastic methanogens.

The reactions they mediate are presented in figure 10. The anaerobic degradation pathway of organic matter is a multi step process of series and parallel reactions. This process of organic matter degradation proceeds in four successive stages, namely Hydrolysis, Acidogenesis, Acetogenesis and Methanogenesis.

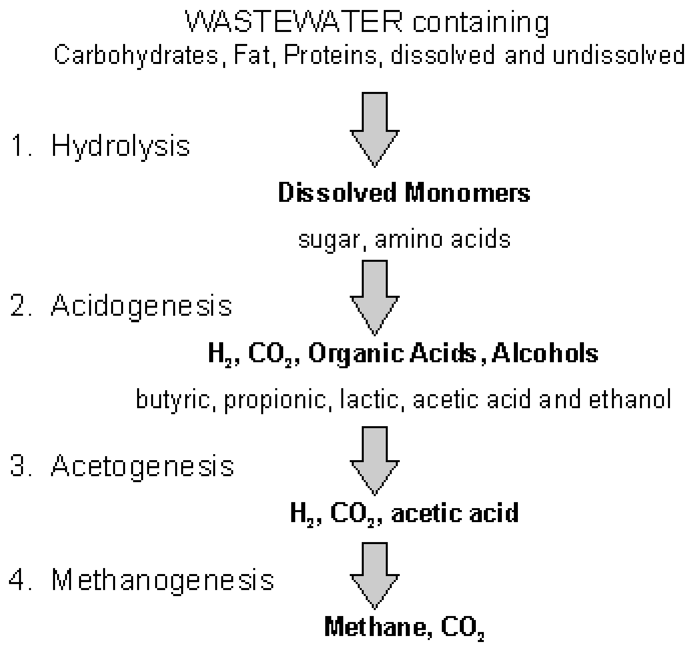


Figure 10: Anaerobic Microbiology

6.2 Anaerobic Treatment technology

One of the major successes in the development of anaerobic wastewater treatment was the introduction of high-rate reactors in which biomass retention and liquid retention are uncoupled. The anaerobic high–rate systems enables the application of a relatively high loading rate. The main advantages and drawbacks of the anaerobic high rate systems applied for sewage treatment are shown in table 4. In these systems, wastewater flows through the anaerobic sludge where purification takes place through complex bio - physical - chemical interrelated processes. Organic matter is converted into biogas and sludge.

Table 4: Advantages and drawbacks of anaerobic sewage treatment in anaerobic high rate systems

Advantages	**Drawbacks**
A substantial saving in operational costs as no energy is required for aeration; on the contrary energy is produced in the form of methane gas, which can be utilized for heating or electricity production. The process can handle high hydraulic and organic loading rates. Thus, the applied	Need for post treatment, depending on the requirements for effluent standards. No experience with full-scale application at low/moderate temperatures. Considerable amount of produced biogas, i.e. CH_4

technologies are compact. The technologies are simple in construction and operation; so they are low cost. The systems can be applied everywhere and at any scale as little if any energy is required, enabling a decentralized application. The excess sludge production is low, well stabilized and easily dewatered so does not require extensive costly post treatment. The valuable nutrients (N and P) are conserved which give high potential for crop irrigation.	and H_2S remains in the effluent especially for low strength wastewater (sewage). Produced CH_4 during anaerobic sewage treatment is often not utilised for energy production.

Different high–rate systems were developed over the last three decades including the anaerobic filter, the upflow anaerobic sludge blanket (UASB), the fluidised and expanded bed reactors and the baffled reactors.

6.2.1 Upflow anaerobic sludge blanket (UASB) reactor

The UASB reactor is the most widely and successfully used high rate anaerobic technology for treating several types of wastewater. The success of the UASB reactor can be attributed to its capability to retain a high concentration of sludge and efficient solids, liquid and water phase separation.

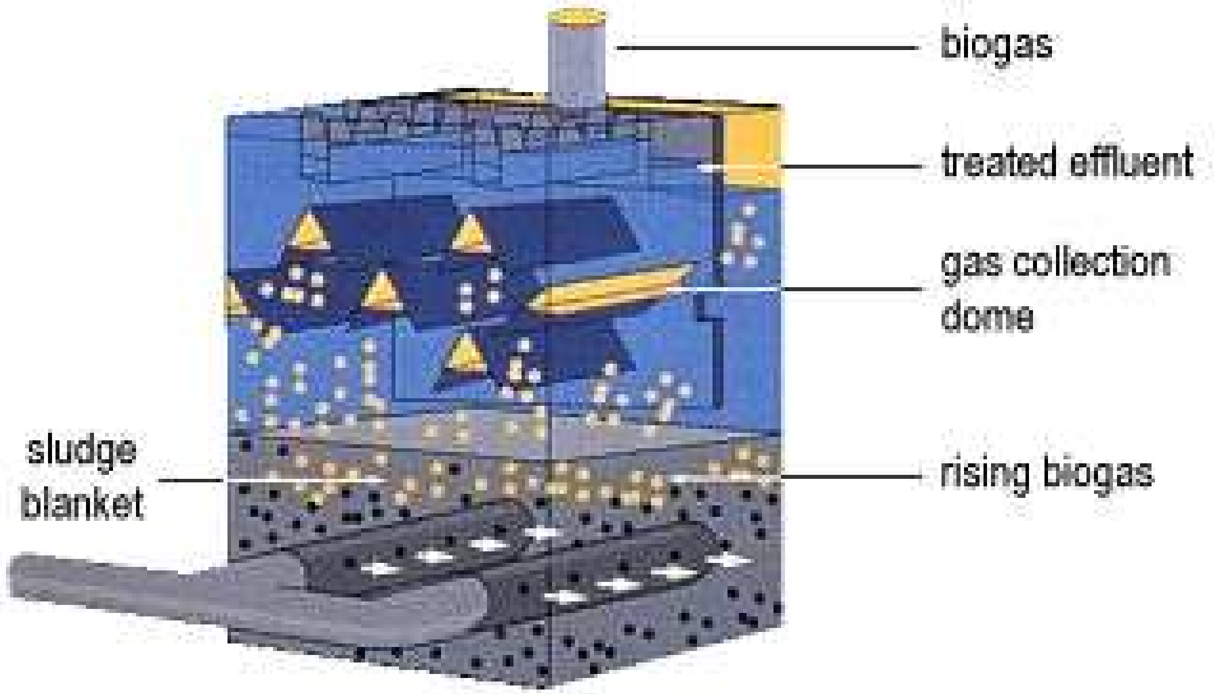


Figure 11: Schematic diagram of the UASB reactor

The UASB reactor consists of a circular or rectangular tank in which waste (water or sludge) flows in upward direction through an activated anaerobic sludge bed which occupies about half the volume of the reactor and consists of highly settleable granules or flocs. During the passage of this blanket the purification takes place by solids removal and then organic matter is converted into biogas and sludge. The produced biogas bubbles transfer to the top of the reactor, carrying water and solid particles (i.e. biological sludge and residual solids). These bubbles strike the degassing baffles at the upper part of the reactor, leading to an efficient gas-solid separation (GSS). The solid particles drop back to the top of sludge blanket, while the released gases are captured in an inverted cone located at the top of the reactor. Water passes through the apertures between the degassing baffles carrying some solid particle which settle there due to increase of the cross sectional area and return back to the sludge blanket, while water leaves the settlers over overflow weirs. A schematic diagram of the UASB reactor is shown in figure 11.

6.3 Comparison of anaerobic and aerobic treatment

In the wastewater engineering field organic pollution is measured by the weight of oxygen it takes to oxidize it chemically, referred to as the "chemical oxygen demand" (COD). COD is basically a measure of organic matter content or concentration. The best way to appreciate anaerobic wastewater treatment is to compare its COD balance with that of aerobic wastewater treatment, as shown in figure 12 below.

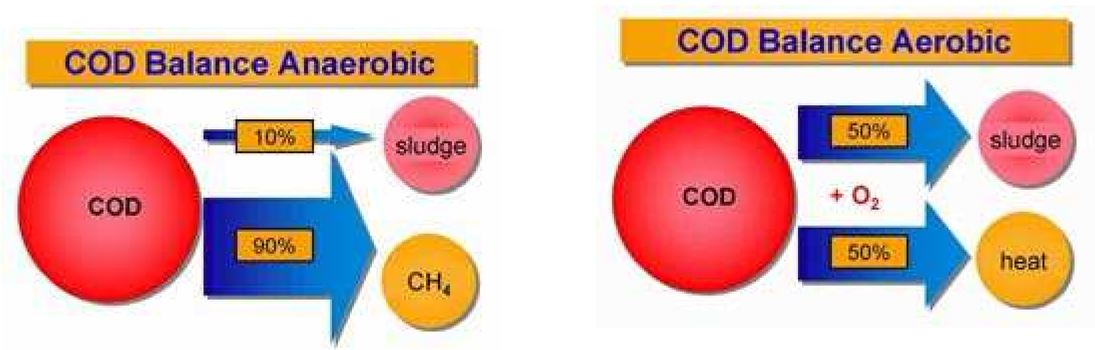


Figure 12. Comparison of the COD balance during anaerobic and aerobic treatment of wastewater containing organic pollution

The COD in wastewater during anaerobic treatment is highly converted to methane, which is a valuable fuel. Very little COD is converted to sludge. No major inputs are required to operate the system. Nevertheless it depends on stable preconditions as i.e. temperature to make the process stable.

The COD in wastewater during aerobic treatment is highly converted to sludge, a bulky waste product, which costs lots of money to get rid of in developed countries with less area, but can be of interest as low-cost fertilizer in developing countries if the sludge is not contaminated. Elemental oxygen has to be continuously supplied by aerating the wastewater.

7. Constructed Wetlands for Wastewater Treatment (B4)

Constructed wetlands are artificial wastewater treatment systems consisting of shallow ponds or channels which have been planted with aquatic plants and which rely upon natural microbial, biological, physical and chemical processes to treat wastewater. They have impervious clay or synthetic liners and engineered structures to control the flow direction, liquid detention time and water level. They are one of the most promising treatment options for municipal wastewater with respect to the decentralised settlements, especially in rural and suburban areas, because they are low in cost and maintenance requirements with a good performance. They need more land compared to technical intensive treatment but less space than pond systems.

Constructed wetlands can be installed as two different technological systems according to its hydraulic regime: the free water surface (FWS) and subsurface-flow (SF) constructed wetlands, in which the latter can be further categorized to horizontal (HSF) and vertical subsurface-flow (VSF). The FWS system in one sense is similar to a pond system incorporating with the emergent macrophytes. For SF system, the water is maintained below the surface of the wetland bodies, usually made up of gravel planted with the emergent macrophytes. In HSF, the flow is usually continuous thereby creating a saturated condition within the wetland body, whereas in VSF, the media is completely unsaturated due to intermittent feeding. (Crites, et. al., 2000)

It should be noted that FWS and SF constructed wetlands work differently because the latter system does not support any aquatic wildlife. Some biological and chemical interactions only occur in an open water column and thus these will happen only in a FWS system. Moreover, constructed wetlands should not be mixed with created or restored wetlands which are not designed for wastewater treatment but have the function of wildlife habitat.

Constructed wetlands are principally using the same natural degradation processes and nutrient uptake but they are acting as extensive systems. There is wide acceptance and interest because of the following advantages (SWAMP 2002):

- Simple in construction, operation and maintenance
- Low operation and maintenance costs (low energy demand)
- High ability to tolerate fluctuations in flow
- High process stability
- Aesthetic appearance

Constructed wetlands are used in various fields and at various treatment levels. Nevertheless, this lesson deals mainly with the conventional use of constructed wetlands, which are to treat the pre-treated municipal wastewater, or so-called primary effluent. The typical treatment cycle is shown in Figure 13.

Figure 13: Constructed wetlands in the treatment cycle

Constructed wetlands may need a post treatment particularly to completely remove nitrogen (nitrification and denitrification) and phosphorus, if the removal of both parameters is required in this region.

Table 5: Principle removal and transformation mechanisms in subsurface flow constructed wetlands for the concerned constituents in wastewater *(modified after Crites and Tchobanoglous, 1998)*

Constituent	Mechanisms
Biodegradable organics	Bioconversion by facultative and anaerobic bacteria on plant and debris surfaces
Suspended solids	Filtration, sedimentation
Nitrogen	Nitrification/denitrification, plant uptake, volatilization
Phosphorus	Filtration, sedimentation, plant uptake
Heavy metals	Adsorption of plant roots and debris surfaces, sedimentation
Trace organics	Adsorption, biodegradation
Pathogens	Natural decay, physical entrapment, filtration, predation, sedimentation, excretion of antibiotics from roots of plants

Treatment processes in wetland incorporate with several physical, chemical, and biological processes. The major physical process is the settling of suspended particulate matter which is a major cause of BOD reduction. The chemical processes involve adsorption, chelation, and precipitation, which are responsible for the major removal of phosphorus and heavy metals. In term of biological processes, the treatment is achieved by microorganisms (Gopal, 1999). Due to fixed film or free bacterial development, biological processes allow the degradation of organic matter, nitrification in aerobic zones and denitrification in anaerobic zones. The microbiological activity is the key parameter for their performance. The principle removal mechanisms in subsurface flow constructed wetlands for some constituents in wastewater are summarized in table 5. The detailed schematic of HSF constructed wetlands is shown in figure 14.

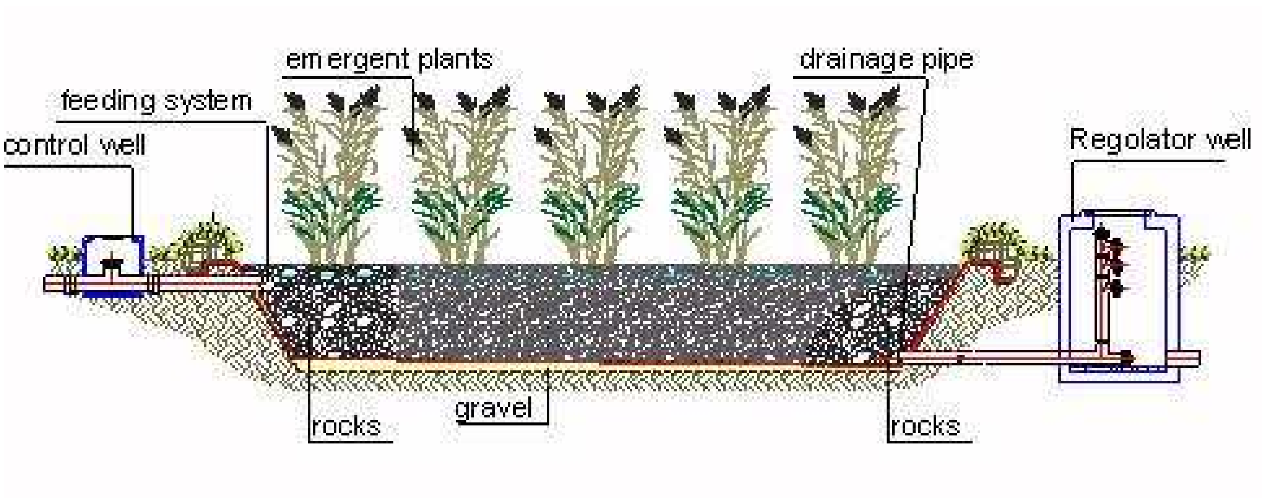


Figure 14: Detailed schematic of a horizontal flow system (HSF)

The VSF system illustrating more detail shown in figure 15 needs a well designed and constructed system to distribute the water equally over the whole area. The construction is therefore more expensive than for the horizontal flow systems. For VSF, filtration is also an important removal mechanism. The bed media must be carefully chosen according to the wastewater constitution.

The water level is always at the bottom. Its best performance can be achieved by intermittent feeding when aerobic and anoxic phases alternate. Due to the higher effort in designing and constructing the VF properly, the performance of these systems in term of COD and nitrification is much higher than in the other constructed wetland systems.

In general, wetland sites should be located outside of flood plains, or protection from flooding should be provided (Tchobanoglous and Burton 1991). A successful physical pre-treatment is necessary for a good performance of all constructed wetlands. The pre-treatment can be realised as primary sedimentation in tanks, for small scale plants typically septic tanks are used. Imhoff tank is a possibility which reduces sludge production. Ponds may be an option for pre-treatment, often used before a VSF system. (SWAMP 2002). Constructed wetlands must be sealed at the bottom and sidewalls to avoid any groundwater pollution.

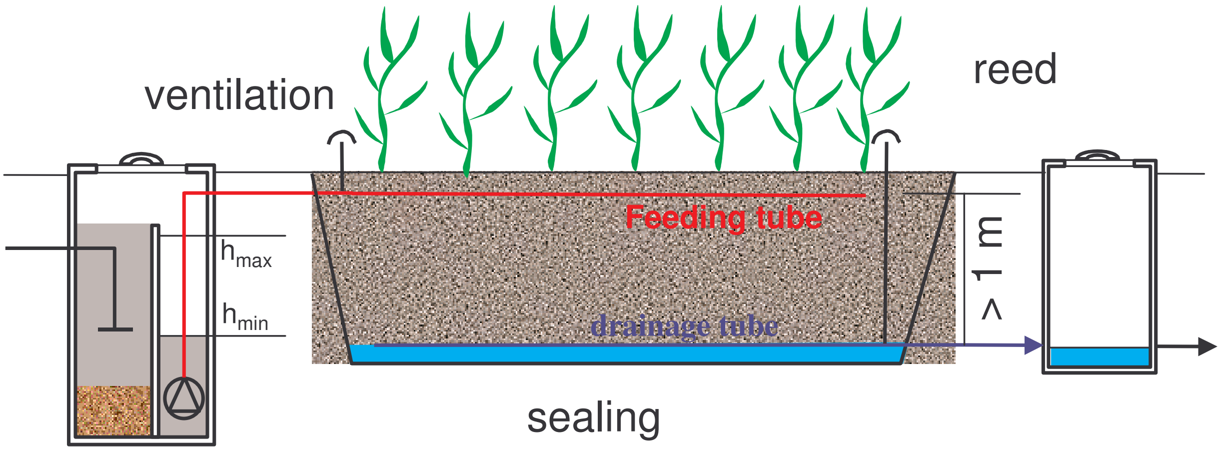


Figure 15: Detailed schematic of an unsaturated vertical flow system (VSF)

8. Sewage Sludge Treatment (B5)

Sludge originates from the process of treatment of wastewater and is separated from the treatment process by sedimentation or flotation. Sewage sludge consists of water and solids that can be divided into mineral and organic solids. The quantity and characteristics of sludge depend very much on the treatment processes. Most of the pollutants that enter the wastewater get adsorbed to the sewage sludge. Therefore, sewage sludge contains pathogens (and heavy metals, many organic pollutants pesticides, hydrocarbons etc. if the sewage contains industrial influence). Sludge is, however, rich in nutrients such as nitrogen and phosphorous and contains valuable organic matter that is useful if soils are depleted or subject to erosion.

Options for sludge treatment include stabilisation, thickening, dewatering, drying. Sewage sludge is stabilised to reduce pathogens, to eliminate offensive odours and to inhibit, reduce or eliminate the potential for putrefaction. Moreover, stabilisation is used for volume reduction, production of usable gas (methane), and improving the dewaterability of sludge. Thickening, dewatering, drying are used to remove water from sewage sludge. Several techniques are used in dewatering devices for removing moisture. A technique close to nature and very effective is dewatering in drying beds. The principal advantages of drying beds are low costs, infrequent attention required, and high solids content in the dried product, especially in arid climates. Disadvantages are the large space required, effects of climatic changes on drying characteristics, labour-intensive sludge removal, insects and potential odours.

The sources of solids in a wastewater treatment plant vary according to the type of plant and its method of operation. Usually there are two sources of sewage sludge within the treatment process:

- solids in the affluent to the treatment plant which consist of settable organic matter and mineral substances which are not trapped in the grit chamber.
- biomass that has grown on the organic load (BOD)

Sewage sludge is separated from the treatment process by sedimentation or flotation. In many cases there is a primary sedimentation (primary sludge) and secondary sedimentation (secondary sludge). Smaller treatment plants often have only one sedimentation tank in which the entire sludge is separated from the treated water.

8.1 Sludge stabilisation

Sewage sludge is stabilised to reduce pathogens, to eliminate offensive odours and to inhibit, reduce or eliminate the potential for putrefaction. The success in achieving these objectives is related to a reduction of the organic (volatile) fraction or the addition of chemicals to the sludge to render it unsuitable for the survival of microorganisms. In addition to the health an aesthetic reasons mentioned above, stabilisation is used for volume reduction, production of usable gas (methane), and improving the dewaterability of sludge. In some cases a sludge disinfection is required to meet the standard for agricultural reuse. Often applied methods of simultaneous aerobic stabilisation are:

- Simultaneous aerobic stabilisation
- Mesophilic anaerobic digestion
- Aerobic digestion
- Alkaline Stabilisation
- Thermophilic anaerobic digestion
- Pasteurization

8.2 Thickening/ dewatering of Sludge

Removal of water from liquid sewage sludge is divided into 3 different processes:

- thickening (up to approx. 9% TS)
- dewatering (up to approx. 35% TS)
- drying (up to approx. 100% TS)

At low TS contents the volume changes significantly with varying TS contents. If the TS goes up from 1 to 3%, the resulting volume is one third!

Gravity thickening is one of the most common methods in used and is accomplished in a tank similar in design to a conventional sedimentation tank. Normally, a circular tank is used, and dilute sludge is fed to a center feed well. The feed sludge is allowed to settle and compact and the thickened sludge is withdrawn from the bottom. Vertical pickets stir the sludge gently, thereby opening up channels for water to escape and promoting densification. The supernatant flow that results is drawn off and returned to either the primary settling tank, the influent of the treatment plant or a return-flow treatment process. Thickening can be achieved by mechanical devices, too. Examples are rotary-drums and gravity-belt thickeners. Solid contents up to 9% can be achieved. Centrifuges are suitable for both, thickening and dewatering.

8.3 Dewatering

Dewatered sludge is generally easier to handle than thickened or liquid sludge. For some options for disposal or further treatment dewatering is necessary: mechanical sludge drying, sludge composting, landfilling, trucking over longer distances.

Several techniques are used in dewatering devices for removing moisture. Some of these techniques rely on natural evaporation and percolation to dewater the solids. In mechanical dewatering devices, mechanically assisted physical means (filtration, squeezing, capillary action, centrifugal separation, compaction) are used to dewater the sludge more quickly. The most important mechanical devices are:

- solid-bowl centrifuge (25 – 30%TS)
- belt-filter press (25 – 30%TS)
- recessed-plate filter press (30 – 40%TS)

These techniques are not discussed here since they are economically and ecologically not feasible in small and rural waste water treatment plants.

A technique close to nature and very effective is dewatering in drying beds. The principal advantages of drying beds are low costs, infrequent attention required, and high solids content in the dried product, especially in arid climates. Disadvantages are the large space required, effects of climatic changes on drying characteristics, labour-intensive sludge removal, insects and potential odours.

An alternative to this simple sludge drying are sludge humification beds. As well as for water reuse applications, utilisation of sewage sludge can be a problem of acceptance in the society.

9. Operation and management of wastewater treatment plants (C1)

The purpose of the Operation and Maintenance (O&M) Manual is to provide wastewater treatment plant's (WWTP) operators with the proper understanding of recommended operating techniques and procedures, and the references necessary to efficiently operate and maintain their facilities.

The O&M manual shall contain all information necessary for the plant operator to properly operate and maintain the collection, treatment and disposal systems in accordance with all applicable laws and regulations. A copy of the approved O&M manual shall be maintained at the treatment plant at all times.

The O&M manual shall include:

a) Introduction
b) Permits and Standards
c) Description, Operation and Control of Wastewater Treatment Facilities
d) Description, Operation and Control of Sludge Handling Facilities
e) Personnel
f) Sampling and Laboratory Analysis
g) Records and Reporting
h) Maintenance
i) Emergency Operating and Response Program
j) Safety
k) Utilities

9.1 Wastewater treatment plant (WWTP)

Wastewater treatment or sewage treatment is the process that removes the majority of the contaminants from waste-water or sewage and produces both a liquid effluent suitable for disposal to the natural environment and a sludge. To be effective, sewage must be conveyed to a treatment plant by appropriate pipes and infrastructure and the process itself must be subject to regulation and controls. There are many and various forms of treatment processes. The site where the processes are conducted is called a wastewater treatment plant (WWTP). The flow scheme (see figure 16) of a conventional WWTP is generally the same in all countries and exists our of following physical-chemical elements:

- Mechanical treatment;
    - Influx (Influent)
    - Removal of large objects
    - Removal of sand
    - Pre-precipitation

- Biological treatment;
    - Oxidation bed (oxidizing bed) or Aerated systems
    - Post precipitation
    - Effluent

- Chemical treatment (this step is usually combined with settling and other processes to remove solids, such as filtration.

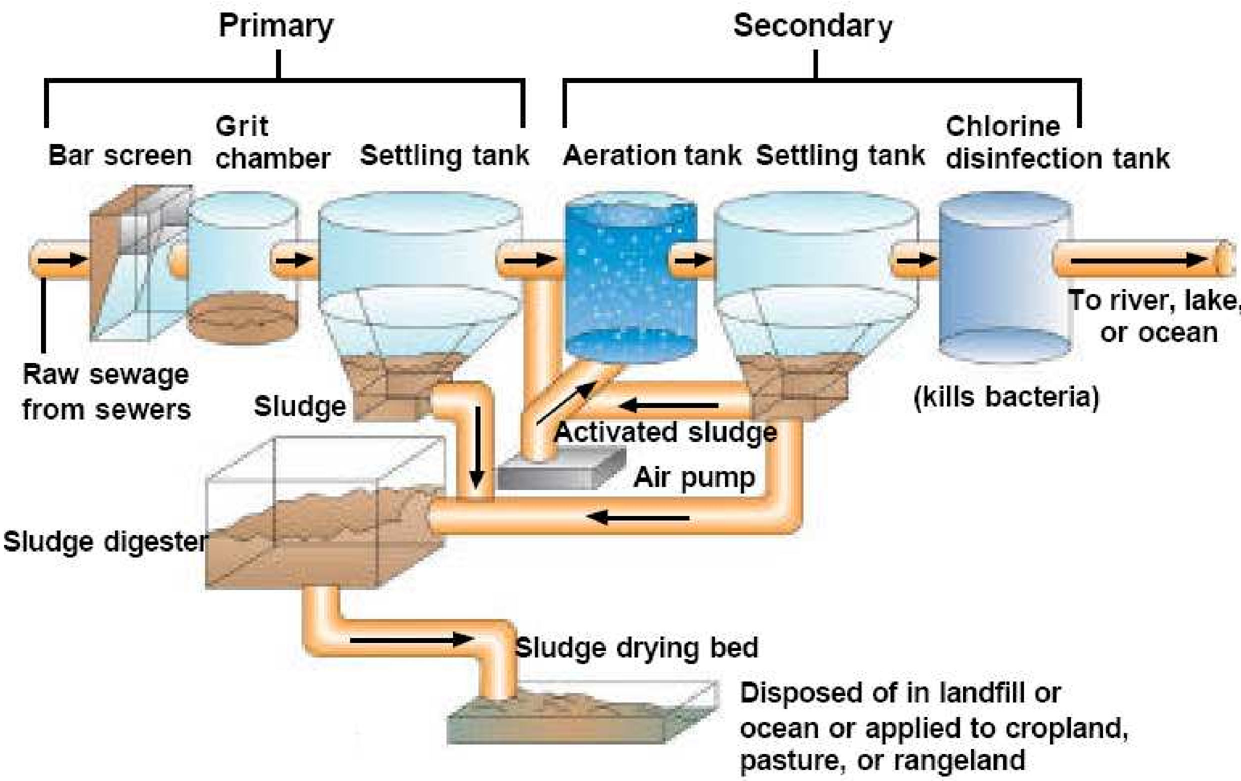


Figure 16: Wastewater treatment plant (Queens University 2004)

Besides the physical-chemical classification the technical classification is based on the steps, which are performed one by one other:

- **Primary treatment** (see figure 16): to reduce oils, grease, fats, sand, grit, and coarse (settle able) solids. This step is done entirely with machinery.
- **Secondary treatment** (see figure 16) is designed to substantially degrade the solved content of the sewage within a biological degradation system, such as activated sludge systems. These systems use the capability of microorganism to degrade solved components in water. The final step in the secondary treatment stage is to separate the used biological media from the cleared sewage water with a very low levels of organic material and suspended matter.
- **Tertiary treatment** or advanced treatment (not in figure 16) is yet not applied widely. It provides a final stage to raise the effluent quality to the standard required before it is discharged to the receiving environment. More than one tertiary treatment process may be used at any treatment plant. In most cases it is a further nitrogen or phosphate elimination and/or a disinfection. Additional steps like lagooning or constructed wetlands are also counted as tertiary step if they are used after secondary treatment.

9.1.1 Screening

Screening is a primary treatment in a wastewater treatment process. Screenings are the material retained on bar racks and screens. The smaller the screen opening, the greater will be the quantity of collected screenings.

The quantity of collected screenings varies depending on the type of the screen and, in particular, on the type of sewer system and wastewater characteristics. Their efficiency depend on the spacing between the screen bars and is named as follows:

- Fine screening: spacing < 10 mm
- Medium screening: spacing 10 - 40 mm
- Coarse screening: spacing > 40 mm

9.1.2 Grit removal

The goal of grit removal is to separate gravel and sand and other mineral materials down to a diameter between 0.2 and 0.1 mm. Grit chambers are provided to (a) protect downstream moving mechanical equipment from abrasion (b) reduce formation of heavy deposits in pipe line and (c) reduce the frequency of digester cleaning caused by excessive accumulation of grit.

There are three general types of grit chamber:

1. horizontal-flow – rectangular configuration
2. horizontal-flow – square configuration
3. aerated; (see figure 17)

The quantity of removed grit will vary depending on the type of sewer system, the characteristics of the drainage area, etc. The amount of removed gravel is different plant by plant.

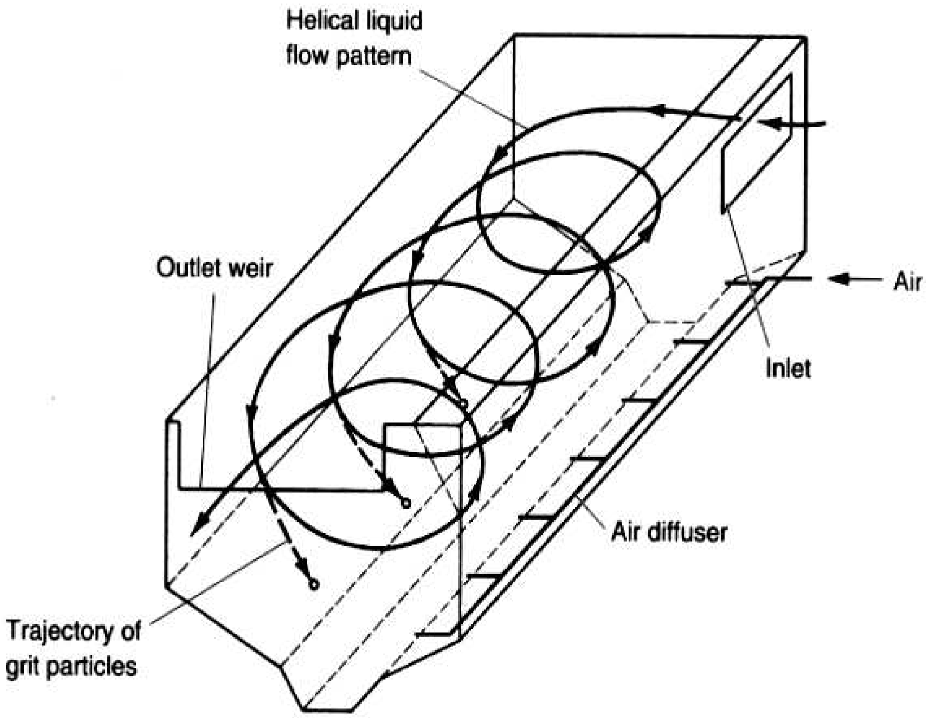


Figure 17: Aerated grit chamber (Crites and Tchobanoglous, 1998)

In aerated grit chambers, grit is removed by causing the wastewater to flow in a spiral pattern, as shown in figure 17. Air is introduced in the grit chamber along one side, causing a perpendicular spiral velocity pattern to flow through the tank. Heavier particles are accelerated and diverge from the streamlines, dropping to the bottom of the tank, while lighter organic particles are suspended and eventually carried out of the tank.

9.1.3 Sedimentation

The main goal of sedimentation is to remove readily settleable solids and floating materials (not removed in the upstream treatment phases) thus reducing the suspended solids content; so quiet conditions are set up in the sedimentation basin: collected solids are subsequently sent to the sludge treatment processes, and (in case of secondary sedimentation) partially recycled.

The sedimentation process takes place in a settling tank, which is a circular (see figure 18) or rectangular basins made of concrete or iron, having the bottom lightly sloped towards a zone where the sludge is conveyed by appropriate withdrawal devices.

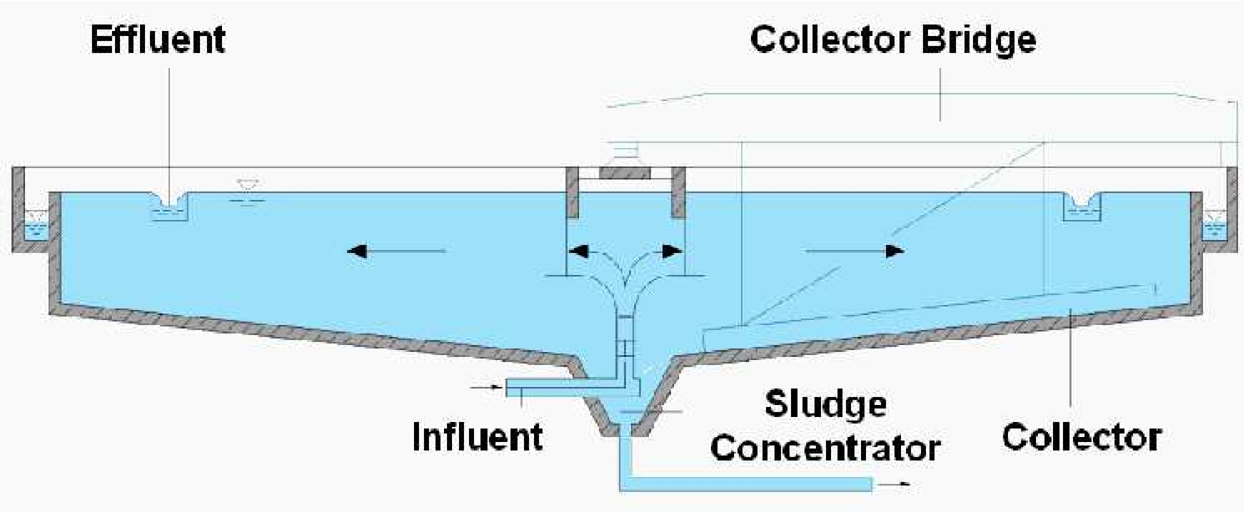


Figure 18: Example for a circular sedimentation tank (Source: Universität Stuttgart)

Sedimentation tanks are designed to operate continuously. Primary sedimentation tanks may provide the principal degree of wastewater treatment, or may be used as a preliminary step in further treatment of the wastewater. When used as the only means of treatment (not authorized in most developed countries), these tanks provide for removal of settle able solids and much of the floating material. When used as a preliminary step to biological treatment, their function is to reduce the load on the biological treatment units. Efficiently designed and operated primary sedimentation tanks should remove 50 to 65 percent of the suspended solids and 25 to 40 percent of the biochemical oxygen demand.

9.1.4 Activated Sludge

Activated sludge treatment step takes place into aeration tanks (activated sludge tanks), whose footprint shape has to be defined according to the aeration devices to be installed (see figure 16). The activated sludge process uses microorganisms to feed on organic contaminants in wastewater, producing a purified effluent. The basic principle behind all activated sludge processes is that as microorganisms grow within metabolizing soluted organic material. They form particles that clump together. These particles (flocks) in most cases are able to settle, so that they can separated with a simple settling process, which works according to the same principle as the pre-settling. Wastewater supply is mixed with return of activates sludge (see figure 16) containing a high proportion of organisms taken from the final sedimentation. This mixture is stirred and injected with large quantities of air, to provide the oxygen demand of microorganisms and keep solids in suspension. After a period of time, mixed liquor flows to a clarifier, which is in most cases a settling tank. In special cases also a flotation tank or membranes can be used to separate microorganisms. Partially cleaned water flows on for further treatment if needed. The resulting settled solids, the activated sludge, are returned to the first tank to begin the process again. Due to the fact, that during the process microorganisms grow, the excess sludge has to be removed out of the system to held the microorganisms concentration nearly constant.

Basic parameters that characterize the activated sludge process are:

- HRT, Hydraulic Retention Time into the aeration tank
- TSS into the mixed liquor
- Organic Load referred to the biomass
- Volumetric Organic Load
- SRT, Sludge Retention Time
- Recycle Ratio
- Type of flow into the tank (completely stirred, plug flow)
- Aeration System

9.1.5 Anaerobic Treatment

Activated sludge treatment step takes place into aeration tanks, whose footprint shape has to be defined according to the aeration devices to be installed. Wastewater load and temperature affect the feasibility of wastewater anaerobic treatment. Generally, COD concentration higher than 1550–2000 g m^{-3} and reactor temperature in the range of 25-35°C are needed. More details are already described in chapter 6.

9.1.6 Lagoons

Suspended growth lagoons are shallow earthen basins varying in depth from 1 to 6m. The aerated lagoons depth ranges usually between 1.8 and 6m, mixing and aeration is provided through the use of slow-speed surface aerators mounted on floats. Non aerated lagoons can be classified in aerobic, facultative and anaerobic lagoons, depending on the main environmental conditions: biological conversion is carried out in aerobic and/or anaerobic conditions. The aerobic lagoons depth usually ranges between 1 and 1.5m in order to guarantee sufficient oxygen concentration in the water. In facultative lagoons three different zones can be observed: superficial aerobic zone, anaerobic bottom zone (where settleable solids accumulate) and a facultative zone where biological processes are carried out by facultative bacteria. The anaerobic lagoon are deeper than the others and the main biological conversion is essentially anaerobic.

10. Operation Costs of wastewater Treatment Plants (C2)

The objective of the installation and operation of wastewater treatment systems is to assure an environmentally friendly effluent quality meeting the determined border values. The high costs for construction, maintenance and operation of conventional treatment systems exert economic (and social) pressure, even in developing countries. Therefore, all over the world engineers look for creative, cost-effective and environmentally sound ways to control water pollution. Operation costs can be differentiated as personnel costs, maintenance costs, energy costs, chemicals and material costs, disposal costs and miscellaneous costs for administration, insurance, discharge duty (if exists), external services etc.. The costs for personnel of wastewater treatment systems depend significantly on the size of the treatment plant, the selected technology and the level of automation. The costs for maintenance of wastewater treatment plants usually amount up to 15-25 % of the total operation costs. Thus, the organization and strategy of maintenance activities play an important role for the agency. Maintenance costs include: repairs on mechanical, electrical, electronic and civil parts and minor or major replacements like small or large parts for pumps, blowers or motors. They include internal personnel costs, material expenses and external services. Quantities of spare parts kept in stock and purchasing deals also influence the total maintenance costs. Energy consumption is further a major contributor to the operation cost of wastewater systems and therefore is an important parameter for choosing a treatment technology. The costs for energy usually amount up to 10–30 % of the total operation costs. Energy costs include the consumption (and internal production) of electricity, gas, oil and district heating. In sewer collection systems energy is used for transportation by pumping stations in case of a lack of sufficient hydraulic gradients. The costs for disposal consist of the disposal of sewage sludge, screenings, sand and municipal waste. The disposal costs can differ between 15 and 50 % of the total operation costs. Further costs for chemicals and materials usually range between 5 – 7 % of the total operation costs.

11. Guidelines and Standards for Wastewater Reuse (D1)

Reclaimed wastewater requires effective measures to protect public health and the environment. Strong wastewater reuse guidelines and regulations are developed for the purpose. It is difficult to establish wastewater guidelines and regulations that can suit all regions in the world. Among the broad reasons for this as limiting factors, are economics of countries relating chosen treatment technologies and additionally, the local context of a region must be taken into consideration in settings. Almost all wastewater reuse guidelines and regulations are bacteriological-based. Some of them consider biochemical parameters. Standards for such guidelines should be: realistic in relation to local conditions (epidemiological, socio-cultural and environmental factors), affordable, and enforceable.

In addition to standards regarding biological and chemical loads of wastewater, regulations can include best practices for wastewater treatment and irrigation techniques as well as regarding crops and areas to be irrigated.

11.1 International Experiences in Formulating Guidelines

A comparison of international standards might help to develop guidelines for the reference area within each particular project. In many countries only regional standards exist. A very limited number of European countries have guidelines or regulations on wastewater reclamation and reuse because first they usually do not need to reuse water and second their rivers have a sufficient dilution factor.

Many developing countries focus on use restrictions in their legislation. Often, for example, such regulations ban wastewater irrigation for vegetables that can be eaten raw, or for edible plant parts in general, and require a minimum time interval between irrigation and crop harvest.

The World Health Organization (WHO) has recognized both the potential and risk of untreated wastewater use and so has developed guidelines for policy makers attempting to legislate permission for the safe use of wastewater. In the 1989 guidelines, the WHO acknowledged that most previous standards were unnecessarily high for public health protection and do not reflect reality of wastewater use on the ground. The WHO is currently revising their guidelines on wastewater reuse.

In contrast to the WHO guidelines that focus mainly on the protection of human and public health, the FAO has developed a field guide for evaluating the suitability of water for irrigation. Guideline values given identify potential problem water based on possible restrictions in use related to 1) salinity, 2) rate of water infiltration into the soil, 3) specific ion toxicity, or 4) to some other miscellaneous effects. The guide is intended to provide guidance to farm and project managers, consultants and engineers in evaluating and identifying potential problems related to water quality.

In Mexico, microbiological and chemical standards for wastewater reuse in agriculture have developed considerably over the last 15 years. Existing guidelines were reviewed in 1991, 1993, and again in 1996. Particular attention was paid to (1) the cultivation of vegetables and other crops eaten raw, (2) the importance of wastewater reuse in agriculture as a form of wastewater treatment and disposal, and (3) the diversity of treatment processes available to achieve the guidelines.

11.2 Regional Experiences in Formulating Guidelines

In most of the countries of the Mediterranean region, wastewater is widely reused at different extents within planned or unplanned systems. However, only few Mediterranean countries (such as Cyprus, Jordan, and Tunisia) have included water reuse in their water resources planning and have official policies calling for water reuse. Regarding the EM-Water countries, legal standards for wastewater reuse have only been adopted in Jordan and Turkey. The Palestinian Water Authority has developed guidelines for wastewater reuse, but these have not yet been enforced. In Lebanon, no specific guidelines for the reuse of wastewater have yet been developed, but are envisaged for the future. This delay can be explained by the fact that Lebanon is not as much suffering from water shortage as are other MEDA countries.

Irrigation with recycled wastewater is well established in Tunisia. The Tunisian government is pursuing wastewater reuse in agriculture as a strategic objective and is translating the objective into systematic practice. A wastewater reuse policy was launched at the beginning of the eighties.

In Turkey water reuse was officially legitimized in 1991 through the regulation for irrigational wastewater reuse issued in by the Ministry of Environment. According to the "Water Pollution Control Regulations", in order to use treated wastewater in irrigation, a written permission from concerned government organisations must be obtained. A commission organized by the State Water Organisation, İller Bank and Agriculture Ministry and Environmental and Forest Ministry will decide whether the effluent can be used in irrigation or not. The effluent quality criteria for irrigation according to the Turkish Water Pollution Control Regulations are in general, the WHO standards, which have been adopted except the limits for the intestinal nematodes and the residual chlorine.

The key policy objectives of the Jordan water reuse management plan are to use reclaimed water, where practical, in exchange for present and future use of freshwater and to maximize the returns from reclaimed water resources. Therefore, the Government of Jordan has imposed that all new wastewater treatment projects must include feasibility aspects for wastewater reuse and has set standards for treated domestic wastewater effluent (Jordanian Standards JS 893/1995 revised in 2002). The Jordanian standards for wastewater reuse are based on reuse categories depending on crops/ areas to be irrigated. The standard prohibits using reclaimed water for irrigating vegetables that are eaten uncooked (raw). Further, it is prohibited to use sprinkler irrigation except for irrigating golf courses.

Although reclaimed wastewater reuse for agriculture is increasingly being recognized as an essential component in the management strategy for water shortage in the neighboring countries, such practice is still not officially followed for agriculture in Gaza Strip. There is now a master plan introduced by donor countries to construct three new WWTPs in Gaza Strip to replace the existing ones by the year 2020. Most of the reclaimed wastewater produced from these plants would be suitably managed for use in irrigation. Environmental Limit Values for reuse of wastewater have been prepared by the Palestinian Standards Institute and the Palestinian Water Authority. However, these limit values have not been enforced so far.

Common guidelines on water reuse in all Mediterranean countries have been proposed by Bahri and Brissaud (see Kamizoulis 2003). These guidelines have been developed under a project funded by UNEP/WHO and have been presented in various meetings. These are based on the consideration that: (a) an agricultural Mediterranean market is developing with large amounts of agricultural products (vegetables, fruits, etc) imported and exported among Europe and other Mediterranean countries; (b) tourism is an essential part of the economic activity of the region; its development might be jeopardized in the long term by disease outbreaks linked to wastewater mismanagement; (c) there is a growing concern of consumers about the food quality and health hazards; (d) unfair competition among farmers should be avoided. These guidelines have been prepared making a large use of the results of the recent assessment of the WHO guidelines by Blumenthal et al., (2000). The proposed Mediterranean guidelines are minimum requirements which should constitute the basis of water reuse regulations in every country of the region. Wealthy countries might wish higher protection. Due to late development of wastewater treatment in several countries, all of them cannot be expected to comply with the guidelines within the same delay. However, every country could commit itself to reach the guidelines within a delay depending on its current equipment and financial capacities.

12. Wastewater Reuse technologies (D2)

Wastewater reuse always comes along with public acceptance, environmental issues and investment costs. One should ensure that these basic requirements are fulfilled. Good understanding and clear definition of the whole procedure must be performed; it is necessary to do a preliminary study. This study must assess the effluent quality (water treatment and disposal needs), identify a potential reclaimed water market and set up an estimation of investment costs of the reclaiming procedure. The study must also provide insight into the viability of wastewater reuse and starting point for detailed planning. Table 6 summarises the major elements which need to be considered.

Table 6: Summary of major elements of wastewater reuse planning (Asano, 1998)

Planning phase	Objective of planning
Assess wastewater treatment and disposal needs	Evaluate quantity of wastewater available for reuse and disposal options
Assess water supply and demand	Evaluate dominant water use patterns
Analyse market for reclaimed water	Identify potential users of reclaimed water and associated water quantity and quality requirements
Conduct engineering and economic analyses	Determine treatment and distribution system requirements for potential users of reclaimed water
Develop implementation plan with financial analysis	Develop strategies, schedules and financial options for implementation of project

12.1 Overview of basic treatment technologies

The first step in wastewater treatment is usually a physical pre-treatment. The following biological treatment is the main efficient technology to degrade the majority of organic compounds, parts of the nutrients and to decrease the level of microbiological pollution. The most developed techniques at the level of urban treatment plants are intensive biological processes (removal of organics and nitrogen). Their principle is to enforce and concentrate the natural phenomena of organic and nutrient removal in a small space. They are especially appropriate and effective for high concentrated domestic wastewater and blackwater.

The following technologies are some examples of those used for an intensive treatment: Activated sludge plant / Sequencing batch reactor (SBR), Trickling filter, Rotating biological contactors, Anaerobic treatment systems. On the other hand there are extensive treatment techniques available which are less intensive processes close to nature, use very little energy and often much more space: Constructed wetlands (soil filter), Natural lagoon, stabilisation pond, Slow sand filtration (see also chapter 9). Wastewater technologies and their characteristics are listed in table 7.

Table 7: Wastewater technologies and their characteristics (Wendland, 2003)

Technology	Climate	Ground space demand	Energy costs	Capital and operation costs	Technical knowledge for operation and maintenance	Hygienic Quality in the effluent
Activate sludge plant (SBR)	Good biological activity in warm climate, evaporation in warm and dry climate	low	high	High capital costs, lower operation and maintenance costs	high	Elimination by factor 10-100
Trickling filter, rotation disc contactor	Independent, usually built in house	low	medium	High capital, operation and maintenance costs	medium	Elimination by factor 10-100
Anaerobic reactor	No evaporation problems, the warmer, the better the biological activity	medium	Energy recovery	High capital costs but energy recovery of biogas	high	Elimination by factor 10-100
Constructed Wetland	Transpiration depends on the type of plants	high	low	Low capital, operation and maintenance costs	medium	1 log elimination
Lagoons (aerated or natural)	High evaporation rate in dry climate	high	Low for natural, medium for aeration	Low capital, operation and maintenance costs	low	> 3 log elimination for long residence time
Membrane reactor	Evaporation in warm and dry climate	very low	very high	High capital, operation and maintenance costs	high	Hygienically safe (UF)
Slow sand filtration	Evaporation in warm and dry climate	medium	medium	Low capital, operation and maintenance costs	medium	Hygienically almost safe
UV, Chlorine Ozone	Needs building	low	high	Low capital, high operation and maintenance costs	high	Hygienically safe

12.2 Disinfection technologies

The regulation in many countries requires the disinfection of the treated water in order to protect farmers and consumers. The goal of disinfection is the removal, killing or inactivation of pathogens so that there is no danger for health any more. This means at least a reduction of 4-5 logs in municipal wastewater.

The conventional wastewater treatment with physical and biological technologies is not able to disinfect the wastewater efficiently. Since organic load and suspended solids have an negative impact on the disinfection rate, it is recommended to treat the wastewater biologically before disinfection.

Disinfection methods can generally be grouped in two types: physical and chemical methods. An overview is given in table 8.

Table 8: Disinfection efficiency of several technologies *(Jacangelo & Trussell, 2001)*

Disinfection Technology	**Bacteria**	**Viruses**	**Protozoa**	**Total**
Chlorine gas	+++	+++	+/-	++
Chloramine	+	-	--	-
Chlorine dioxide	++/+++	++/+++	+	++
Ozone	+++	+++	++/+++	++/+++
UV	++/+++	+	++	++
Ultrafiltration (<0.01 µm)	+++	+++	+++	+++

+++ very good, ++ good, -bad, --very bad

13. Economic instruments in wastewater management (D3)

Economic instruments, such as water tariffs or pollution charges, are an important complement to technical, regulatory, and institutional tools to achieve a sustainable and efficient management of wastewater. Economic instruments use market-based, mostly monetary, measures with the objective to raise revenue to help finance wastewater services, to provide incentives to use water efficiently and carefully, to provide disincentives for the anti-social release of polluted wastewater, to make the polluter pay for the environmental damage done, and to raise awareness on the environmental and societal costs of water use and wastewater discharge. The most common economic instruments used in wastewater management are the pricing of wastewater services and levying of charges for wastewater discharge into the environment. In this lesson, different economic instruments used in wastewater management will be presented. Special emphasis will be given to the various tariff structures that are used to levy wastewater service fees. Tariffs determine the level of revenues that service providers receive from users. They are designed for different purposes, and often contain some elements to address poverty.

The most obvious reason for using economic instruments, such as wastewater service fees or effluent charges, in wastewater management is the aim to raise revenue for financing service infrastructure or remedial actions for environmental damage. For recovery of costs of sanitation services, the polluter pays principle requires that not only the investment and operational costs of a treatment plant have to be covered, but also the costs that arise from the environmental damage linked with discharge of (treated) wastewater into surface waters.

Various economic instruments are being applied in wastewater management with the aim to pursue the above mentioned objectives, for example:

- Pollution charges
- Fees for wastewater services / user charges
- Indirect local taxes
- Discharge permits

In order to balance the varied objectives of wastewater charges, different tariff systems have been developed. A tariff is a system of procedures and elements which determines the customer’s total water/ wastewater bill. Any part of that bill can be called a charge, measured in money per time (e.g. per month) or money per volume or money per unit pollution load.

Most tariffs are a combination of elements dependent on consumption or other factors. Usually a connection charge is further put on a customer who joins the public water supply and/ or sanitation systems.

13.1 Examples of Water Pricing in the MEDA Region

The regional water authorities in Lebanon are empowered to set and collect water tariffs for domestic and agricultural use. Subscription fees for domestic water supply vary among the water boards. During the year 2001, tariffs ranged from US$ 44 per year to US$ 153 per year for a 1 m^3/day gauge subscription. Differences are partly due to water availability and distribution costs as gravity distribution is cheapest, while distribution by pumping is far more expensive. In Beirut and the Mediterranean area, where water tariffs are highest, water is conveyed long distances and/or pumped from deep wells. In Bsharre and Dinniyeh, where water tariffs are lowest, water is available from springs and delivered by gravity.

The Municipalities in Palestine and regional water authorities set and collect water tariffs for domestic use. Water fees for domestic water supply vary considerably among different localities. Tariffs ranged from US$ 0.15-0.2 to US$ 1.0-1.2. Differences are partly due to the level of services, water availability and distribution costs. In Dura and Ramallah area for example where water tariffs are highest, water is conveyed long distances and/or pumped from deep wells. In Qalqiliya and Jericho, where water tariffs are lowest, water is available in shallow wells (Qalqiliya) and/or springs (Jericho) at low pumping cost.

Water pricing activities of Irrigation Districts in Turkey are parallel to that of other organizations. The specific aspects for water pricing in Irrigation Districts can be gathered under the following topics:

1. The expenditures of that year to be determined by an estimated budget before the irrigation season.
2. The application of the tariff according to defined conditions to be based on qualifications of the scheme (under the responsibility of each organization) and region.
3. Making the collection in the same year and deterrence of applied penalties to recover charges, which can not be collected.

Water user organizations have to work with a balanced budget from the standpoint of revenues and expenditures. Therefore they have to determine expenditures of that year for the scheme under their responsibility and form a budget to recover these expenditures. Each association determines its own expenditure budget. These methods can be cited as follows: Area based: Crop based (TL/da) (TL is Turkish Lira), Fixed charge (TL/da), Crop based depending on irrigation times (TL/da), Fixed charge depending on irrigation times (TL/da) or Volumetric: Based on water amount consumed (TL/m3), Based on water consumed hourly (TL/m3).

The Water tariffs methodology in Cyprus used in calculating the required water tariffs for the agricultural and households sectors is described in the Loan Agreements with the World Bank (IBRD) (Government Printing Office 1988) and the Kuwait Fund (KFAED) for the financing of the Southern Conveyor Project, the largest water resources project in Cyprus. The water tariff for agriculture is calculated using the “Present Worth Value” method while for the households sector the “Balanced Budget” method is used.

It has to be mentioned, that not every effective solution in one region can be transferred or copied to another region without adapting it to the specific regional situation!

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EFFICIENT MANAGEMENT OF WASTEWATER

Lesson A 1

CHARACTERISTIC, ANALYTIC AND SAMPLING OF WASTEWATER

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Domestic wastewater characteristics, analytic parameters, sampling and determination technique

Table of content

Overview and summary of this lesson

Wastewater is the term for discarded or previously used water from a municipality or industry. The wastewater that is produced due to human activities in households is called domestic wastewater i.e. wastewater from the kitchen, bathroom, toilet and laundry. Such water usually contains dissolved as well as suspended matter and must be treated prior to its discharge into natural water. To examine the quality of wastewater to be discharged into aquatic environment or to be treated and reused, the characteristics of wastewater in question must be defined precisely. Quantitative assessments of the quality of wastewater are made by considering many criteria, including temperature, dissolved oxygen level and concentration of organic as well as inorganic compounds. The most frequently used parameters are: Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), Alkalinity, Chlorides, Nitrogen, Oil and Grease, Dissolved Oxygen, pH, Phosphorus, Gases, Sulphur, Solids, Temperature, Metals as well as Micro-organisms. In this lesson, these parameters are defined and methods for analysing them are discussed briefly. In addition sampling and determination techniques are discussed.

1. Domestic wastewater sources and its characteristic

Wastewater is the water which is disposed from homes, offices and industry. It comes from toilets, sinks, showers, washing machines and industrial processes and was historically called sewage.

*Fehler! Keine Indexeinträge gefunden.****ure 1: Sources of domestic wastewater (Samwel 2005)***

Wastewater produced due to human activities in households is called domestic wastewater i.e. wastewater from the kitchen, shower, wash basin, toilet and laundry (see figure 1)**.** It is defined as follows:

- **yellow water:** human urine
- **brown water:** human faeces with flushed water (can include paper if used)
- **black water:** human faeces (brown water) mixed with urine (yellow water), in general: wastewater from toilets. It contains human waste and can be a public health risk if not treated properly.
  (Sometimes, water used in kitchen is also classified as black water)
- **grey water:** water used in the kitchen, bathroom including sinks, baths, showers and laundry, etc. or any water that has been used at home, except water from toilets

The strength and composition of the domestic wastewater changes on hourly, daily and seasonal basis, with the average strength dependent on per capita water usage, habits, diet, living standard and life style. The main reason is variation in water usage in households. Households in developed countries use more water than those in developing countries.

Wastewater components can be divided into different main groups as shown in Table 1. They can adversely affect the aquatic life if discharge them into environmental.

Table :1 Components present in domestic wastewater (Henze and Ledin; 2001)

Component	Of special interest	Environmental effect
Microorganisms	Pathogenic bacteria, virus and worms eggs	Risk when bathing and eating shellfish
Biodegradable organic materials	Oxygen depletion in rivers and lakes	Fish death, odours
Other organic materials	Detergents, pesticides, fat, oil and grease, colouring, solvents, phenols, cyanide	Toxic effect, aesthetic inconveniences, bioaccumulation in the food chain
Nutrients	Nitrogen, phosphorus, ammonium	Eutrophication, oxygen depletion, toxic effect
Metals	Hg, Pb, Cd, Cr, Cu, Ni	Toxic effect, bioaccumulation
Other inorganic materials	Acids, for example hydrogen sulphide, bases	Corrosion, toxic effect
Thermal effects	Hot water	Changing living conditions for flora and fauna
Odour (and taste)	Hydrogen sulphide	Aesthetic inconveniences, toxic effect
Radioactivity		Toxic effect, accumulation

Physically, domestic wastewater is usually characterised by a grey colour, musty odour and has a solids content of about 0.1%. The solid material is a mixture of faeces, food particles, toilet paper, grease, oil, soap, salts, metals, detergents, sand and grit. The solids can be suspended (about 30%) as well as dissolved (about 70%). Dissolved solids can be precipitated by chemical and biological processes. From a physical point of view, the suspended solids can lead to the development of sludge deposits and anaerobic conditions when discharged into the receiving environment.

Chemically, wastewater is composed of organic (70%) and inorganic (30%) compounds as well as various gases. Organic compounds consist primarily of carbohydrates (25 %), proteins (65 %) and fats (10 %), which reflects the diet of the people. Inorganic components may consist of heavy metals, nitrogen, phosphorus, pH, sulphur, chlorides, alkalinity, toxic compounds, etc. However, since wastewater contains a higher portion of dissolved solids than suspended, about 85 to 90% of the total inorganic component is dissolved and about 55 to 60% of the total organic component is dissolved. Gases commonly dissolved in wastewater are hydrogen sulphide, methane, ammonia, oxygen, carbon dioxide and nitrogen. The first three gases result from the decomposition of organic matter present in the wastewater.

Biologically, wastewater contains various microorganisms but the ones that are of concern are those classified as protista, plants, and animals. The category of protista includes bacteria, fungi, protozoa, and algae. Plants include ferns, mosses, seed plants and liverworts. Invertebrates and vertebrates are included in the animal category. In terms of wastewater treatment, the most important category are the protista, especially the bacteria, algae, and protozoa. Also, wastewater contains many pathogenic organisms which generally originate from humans who are infected with disease or who are carriers of a particular disease. Typically, the concentration of faecal coliforms found in raw wastewater is about several hundred thousand to tens of million per 100 ml of sample.

For samples of microscopically views on micro-organisms see the “Microbiological Garden”: **http://www.icbm.de/pmbio/mikrobiologischer-garten/eng/index.php3**

Or see the slide and video microscope under: **http://www.norweco.com/html/lab/Microscope.htm#**

The composition of typical domestic wastewater is shown in Table 2. Concentrated wastewater represents cases with low water consumption whereas dilute wastewater represents high water consumption.

Table 2. Different parameters in domestic wastewater (Henze and Ledin, 2001)

Analysis parameters		**Wastewater type**			
	Unit	**Concentrated**	**Moderate**	**Diluted**	**Very diluted**
5-days Biochemical Oxygen Demand (BOD_5)	mg O_2/l	350	250	150	100
Chemical Oxygen Demand (COD)	mg O_2/l	740	530	320	210
Total Organic Carbon (TOC)	g C/m^3	250	180	110	70
Suspended Solid (SS)	g SS/ m^3	450	300	190	120
Volatile Suspended Solid (VSS)	g VSS/ m^3	320	210	140	80
Alkalinity	eqv/ m^3 *	37	37	37	37
Conductivity	mS/m **	120	100	80	70
Total Nitrogen	g N/ m^3	80	50	30	20
Total Phosphorous	g P/ m^3	23	16	10	6
Fats, oil and grease	g/ m^3	100	70	40	30

* 1 eqv/ m^3 = 1 m eqv/l = 50 mg $CaCO_3$/l - ** mS/m = 10 µS/cm = 1 m mho/m

2. Definition and measurement of wastewater parameters

2.1 Physical parameters

2.1.1 Solids

Other than gases, all contaminants of water contribute to the solids content. Solids typically include inorganic matter such as silt, sand, gravel, and clay, and organic matter such as plant fibres and microorganisms from natural and man made sources. Classified by their size and state, chemical characteristics, and size distribution, solids can be dispersed in water in both suspended and dissolved forms. In regards to size, solids in wastewater can be classified as suspended, settleable, colloidal, or dissolved. They are also characterised as being volatile or non-volatile.

Photo 1: Separated solids *(source: Stadtentwässerung Göttingen)*

There are different analytical procedures (see figure 3) for analysing solids in wastewater such as settling, filtration, and evaporation; because of their different particle sizes (see figure 2).

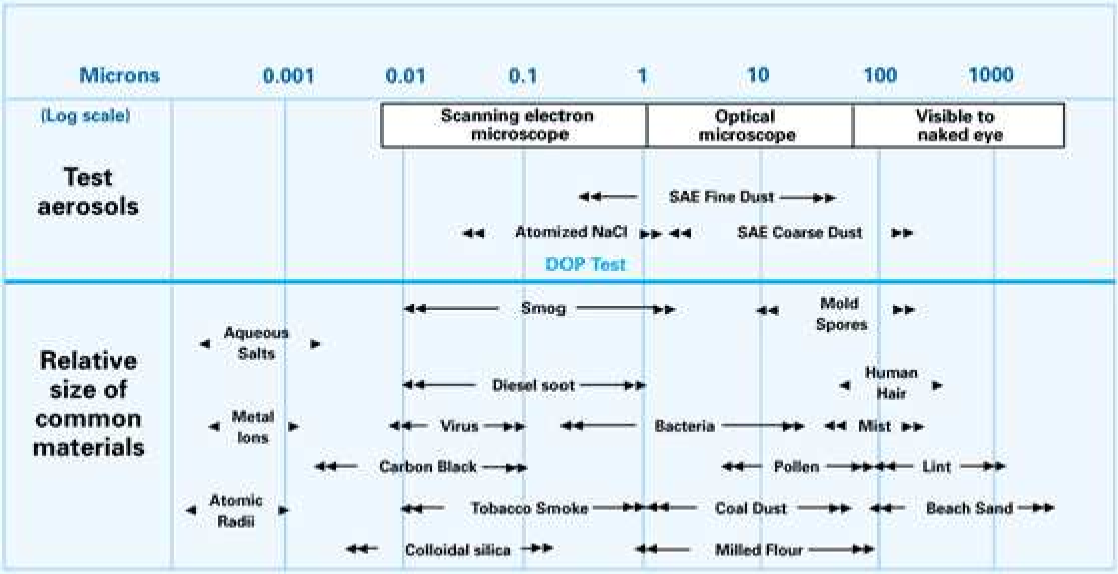


Figure 2: Particle sizes and their scanning method (Dunn, 2003)

Total solids (TS) in wastewater is the amount of all solids, which are determined by drying a known volume of the sample in a preweighed crucible dish at 105 ℃. After cooling in an exsiccator, the crucible dish is again weighed. TS is determined by using the following formula:

$$TS = (M_1 – M_2)/V$$

with
M_1 : mass of crucible dish after drying at 105 ℃ (mg)
M_2 : mass of initial crucible dish (mg)
V : Volume of sample (L))

Volatile solids (VS) are the amount of solid that volatilises when heated at 550 ℃. This is a useful estimation for organic matter present in wastewater and is determined by burning the total solid at 550℃ for about 2 hours in a muffle furnace. After cooling in an exsiccator to room temperature, it is weighed. VS is determined by using the following formula:

$$VS = (M_1 – M_3)/V$$

with
M_1 : mass of crucible dish after drying at 105 ℃ (mg)
M_3 : Mass of crucible dish after ignition at 550 ℃ (mg))
V : Volume of sample (L))

It can be divided in a suspended and a filterable fraction.

Fixed solids (FS) are the amount of solid that does not volatilise at 550 ℃. This measure is used to gauge the amount of mineral matter in wastewater. It is the difference between TS and VS. It can be divided in a suspended and a filterable fraction.

Suspended solids (SS) are the solids retaining in a filter and is usually determined by filtration using glass fibre filters. In all analytical procedures for determination of suspended solids, weighed filters are used for sample filtration, the filters are dried at about 105℃ after filtration, cooled in an exsiccat or to room temperature and the weight of the loaded filter is determined. SS is determined by using the following formula:

$$SS= (M_4–M_5)/V$$

with
M_4 : mass of filter after drying at 105 ℃ (mg)
M_5 : mass of initial filter (mg)
V : Volume of sample (L))

Volatile suspended solids (VSS) are, as indicated in figure 3, one portion of SS which are defined as that part of SS which can be removed by heating the solids at 550℃ in a muffle furnace. The suspended solids is burned at 550℃ for 2 hours in a muffle furnace and weighed after cooling in an exsiccator to room temperature. VSS is determined by using the following formula:

$$VSS=(M_4–M_6)/V$$

M_4 : mass of filter after drying at 105 ℃ (mg)
M_6 : mass of filter after ignition at 550 ℃ (mg)
V : Volume of sample (L))

Fixed suspended solids (FSS) are the solid that are unburnable at 550 ℃ and is determined by subtracting VSS from SS.

Dissolve solids (DS) or **filterable solids** can be determined by subtracting SS from TS. The solids passing through the filter consist of colloidal and dissolved solids.

Settable solids are those solids that will settle to the bottom of an Imhoff cone (a cone-shaped container) in one hour and determined by allowing a wastewater sample to stand for one hour in an Imhoff cone which enables to read the volume of the settled solids. It is expressed as mL/L and is important, because it is related to the efficiency of sedimentation tanks.

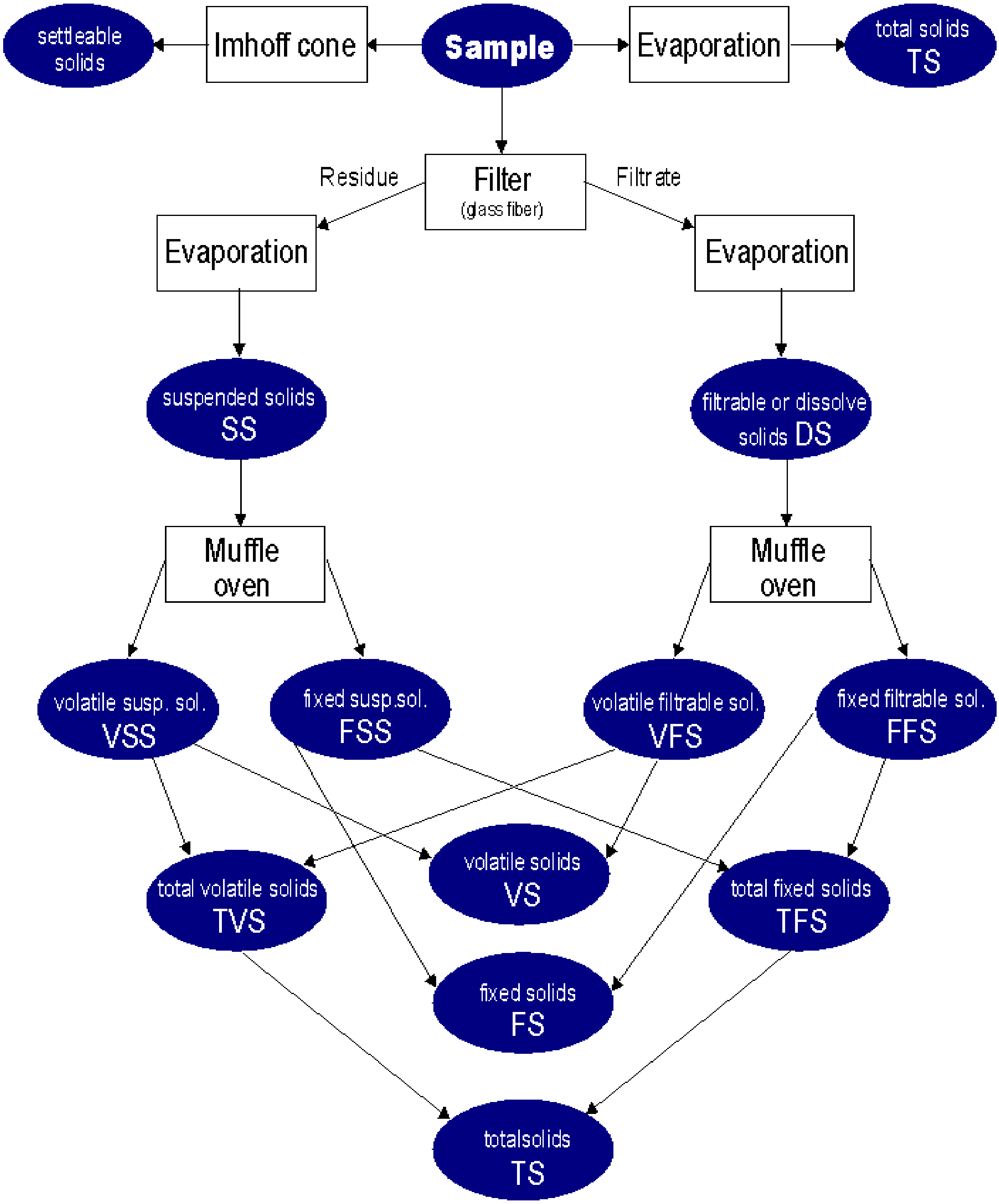


Figure 3: Interrelationships of solids found in water and wastewater

2.1.2 Turbidity

Clarity of water is usually measured by its turbidity. Turbidity is a measure of the extent to which light is either absorbed or scattered by suspended material in water, but it is not a direct quantitative measurement of suspended solids. Both the size and surface characteristics of the suspended material influence absorption and scattering.

Turbidity measurement is an important factor related to the quality of drinking water. It should be measured in treated wastewater effluent if it is reused. If ultraviolet radiation (UV) is used for disinfection of treated wastewater, turbidity measurement will be important because for UV to be effective in disinfecting wastewater effluent, UV light must be able to penetrate the stream flow.

Turbidity is measured by comparing the intensity of light scattered by the sample with the intensity of light scattered by a standard solution. The results are reported in NTU.

2.1.3 Colour

By colour the quality of water can be judged. Pure water is colourless. In wastewater treatment, colour is not necessarily a problem, but instead is a indicator of the condition of the wastewater. Condition refers to the age of the wastewater, which is determined qualitatively by its colour and odour. Fresh wastewater is a light brownish-grey colour.The colour of wastewater changes sequentially from grey to dark grey and ultimately to black as the travel time in collection system increases (flow becomes increasingly more septic) and more anaerobic conditions develop.

2.1.4 Temperature

Temperature is very important parameter because of its effect on chemical reactions on reaction rates, aquatic life, and the solubility of essential gases such as oxygen in water.The temperature of domestic wastewater is higher than that of the water supply, because of the addition of warm water from households. Depending on the geographical location, the mean annual temperature of wastewater varies from about 10 to 21.1 º C. The temperature of a wastewater sample can be measured with the help of ordinary mercury or digital thermometer.

2.1.5 Odour

In wastewater, odours are of major concern, especially to those who reside in close proximity to a wastewater treatment plant. These odours are generated by gases produced by decomposition of organic matter or by substances added to the wastewater. Odour from fresh wastewater is less objectionable than the odour from wastewater that has undergone anaerobic decomposition. The most characteristic odour of stale or septic wastewater is that of hydrogen sulphide (H_2S), which is produced by anaerobic microorganisms that reduce sulphate to sulphide.

The malodorous compounds responsible for producing objectionable odours in water can be detected by diluting a sample with odour free water until the least detectable odour level is achieved. This is recorded as TON (Threshold Odour Number). The concentration of malodorous gases such as hydrogen sulphide, ammonia, mercaptans etc. emitted into the air from wastewater can be measured by any commercially available gas monitor.

2.2 Chemical Parameters

2.2.1 Alkalinity

Alkalinity is the capacity of water to neutralise acids. It results from the presence of hydroxides, carbonates, and bicarbonates of elements such as calcium, magnesium, sodium, potassium, or ammonia. Wastewater is normally alkaline, receiving its alkalinity from the water supply, the groundwater, and the materials added during domestic use. It is determined by titrating against a standard acid and the results are expressed in terms of calcium carbonate $CaCO_3$, mg/l as $CaCO_3$. For most practical purposes alkalinity can be defined in terms of molar quantities.

$$\text{Alk, eq/m}^3 = \text{meq/l} = [HCO_3^-] + 2[CO_3^{2-}] + [OH^-] – [H^+]$$

The corresponding expression in terms of equivalents is

$$\text{Alk, eq/m}^3 = \text{meq/l} = (HCO_3^-) + 2(CO_3^{-}) + (OH^-) – (H^+)$$

In practice, alkalinity is expressed in terms of calcium carbonate. To convert from meq/l to mg/l as $CaCO_3$, it is helpful to remember that

$$\text{Milliequivalent mass of } CaCO_3 = (100 \text{ mg/mmole}) / 2 \text{ meq/mmole} = 50 \text{ mg/meq}$$

Alkalinity plays an important role in the treatment of wastewater, as it indicates the buffer capacity of water. This affects the growth and activity of microbes present in activated sludge, which are responsible for the treatment of wastewater. It is also an essential parameter to be estimated to design and implement the corrosion and odour-control processes.

2.2.2 pH

The negative log of the hydrogen ion concentration is called pH (pH= - $\log_{10}$ [H^+]). The hydrogen-ion concentration is an important quality parameter of both natural water and wastewater. The pH of wastewater needs to remain between 6 and 9 to protect organisms. Acids and other substances that alter pH can inactivate treatment processes.

The pH of aqueous systems can be conveniently measured with a pH meter (see figure 4). Various pH papers and indicator solutions that change colour at define pH values are also used. The pH is determined by comparing the colour of the paper or solution to a series of colour of standard.

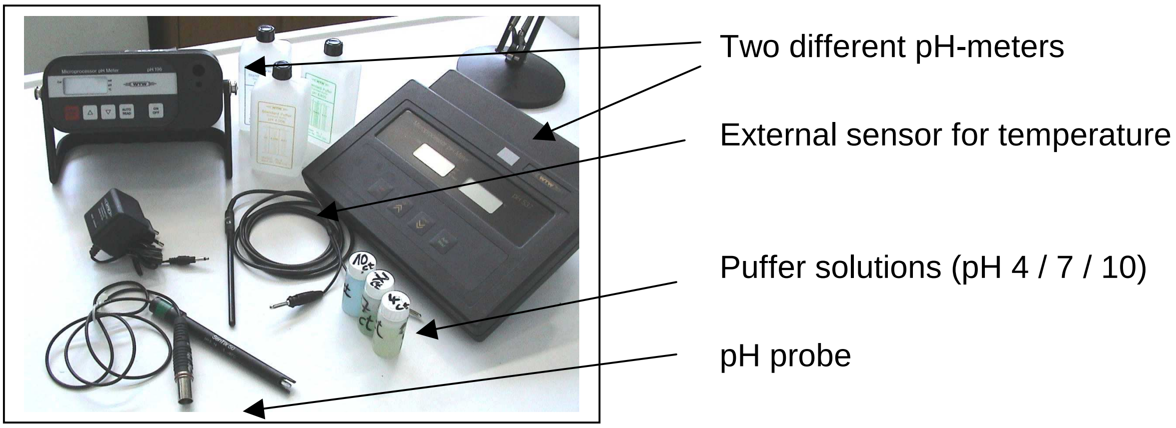


Figure 4: pH meter

Possible errors by measurement of pH can be followings:

- pH-sensor and meter are not connected properly,
- pH-glass electrode is polluted or damaged,
- Diaphragm of the reference electrode is black (Sulphide contamination),
- Reference electrolyte solution is used up,
- pH electrode is placed in distilled water and not in the same concentration and electrolyte solution,
- Wrong temperature for calibration and/or measurement,

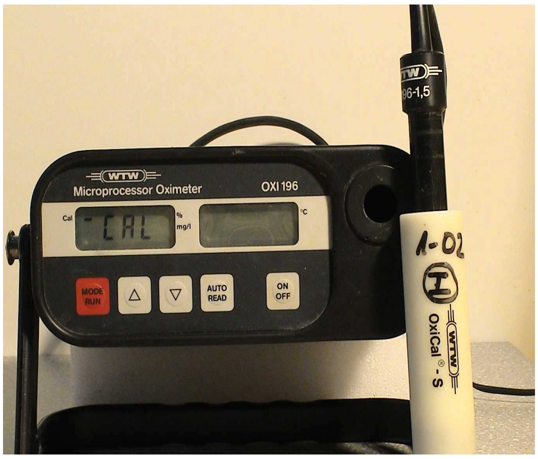
- Wrong or old puffer for calibration,
- probe or cable is broken.

2.2.3 Dissolved Oxygen (DO)

Dissolved oxygen is the amount of molecular oxygen dissolved in water. It is required for the respiration of aerobic microorganisms. However, oxygen is only slightly soluble in water.The actual quantity of oxygen (other gases too) that can be present in solution is governed by;

- the solubility of gas
- the partial pressure of the gas in the atmosphere
- the temperature
- the concentration of the impurities in the water (e.g., salinity, suspended solids, etc.)

The amount of DO decreases with increasing water temperature. So a cool or cold water can contain much more DO than the warm water. As a result, aquatic life in streams and lakes is placed under more oxygen stress during summer months than during the other seasons. DO can be measured using chemicals or oximeter (Figure 5).



Cleaning solution for regeneration, Cathode cleaner. electrolyte solution. new membrane

Figure 5: Oximeter with an electrode in the calibration vessel

To measure oxygen in liquids a minimum flow at the membrane is necessary. In the aeration tank the minimum flow is given in the current of the wastewater, in the laboratory you could attach a flow accessory on the probe and onsite you can move the probe in the water.

Possible errors by measurement of Oximeter can be followings:

- Membrane is contaminated or damaged,
- Electrolyte solution is used up,
- Insufficient flow,
- Sensor and meter are not connect properly,
- Temperature probe must be dry at the calibration,
- Sponge of the OXICAL-vessel must be moist (not dry or wet),
- probe or cable is broken.

2.2.4 Biochemical Oxygen Demand (BOD)

Biochemical Oxygen Demand is a sum parameter and the amount of oxygen required to oxidise organic matter present in the water biochemically. So BOD is an indirect measure of the concentration of organic contamination in water. BOD analysis does not oxidise all of the organic matter present in the waste; only the organics that are biochemically degradable during n days time period at 20℃ are oxidised. The day period is given as index in BOD_n. The standard for usual measurements is a 5-day period.

BOD_5 is the most widely used parameter of organic pollution applied to wastewater and is used:

- to determine the approximate quantity of oxygen that will be required to biologically stabilise the organic matter present,
- to determine the size of wastewater treatment facilities,
- to measure the efficiency of some treatment processes;
- to determine compliance with wastewater discharge permits.

For the measurement of BOD, different volumes of wastewater are mixed in special BOD bottles with a liquid called "dilution water". This may be final effluent of a wastewater treatment plant which still contains some microorganisms or primary clarifier effluent diluted with tap water; it has to be supplemented with nitrogen, e.g. urea, and phosphate, aerated for a period of 3 to 10 days prior to use for BOD analysis, which had been saturated with oxygen prior to BOD analysis by bubbling in air. Moreover, a nitrification inhibitor (e.g. allylthiourea) is added, because only the oxygen consumption due to biochemical oxdation of organic wastewater constituents - and not of ammonia - is desired to be determined. Also blanks are prepared (bottles containing only dilution water and nitrification inhibitor).

The BOD bottles are completely filled and sealed with a glass stopper in such a way that no more air bubbles are contained in the bottles. With every mixture a duplicate of bottles is prepared. In one bottle of each pair, the concentration of dissolved oxygen is determined (e.g. by means of an oxygen probe) immediately after mixing. The other bottle is stored for n days at 20℃ in the dark (to prevent photochemical reactions). At the end of this period, the concentration of dissolved oxygen is measured also in this bottle. The difference of oxygen concentration in the two bottles of a pair is the oxygen consumption (OC) (mg O_2/l). From the oxygen consumption of a particularly diluted wastewater sample and the oxygen consumption of the blanks (OC_{DW}), the BOD_n is calculated as follows:

$$BOD_n = DF \cdot OC - (DF - 1) \cdot OC_{DW}$$

with DF being the dilution factor ($V_{(diluted\ sample)}/V_{(sample\ before\ dilution)}$). BOD values determined for different dilutions should give a straight line when drawn as a function of the term $V_{(sample\ before\ dilution)}$. When points corresponding to low dilution factors (i.e. to high $V_{(sample\ before\ dilution)}$) in this graph are lying below the extrapolated line, this is a hint, that inhibition of microorganisms occurred in samples with low dilution. These values must not be applied for BOD determination!

2.2.5 Chemical Oxygen Demand (COD)

The equivalent amount of oxygen required to oxidise organic matter present in a water sample by means of a strong chemical oxidising agent is called chemical oxygen demand (COD). COD is also a sum parameter and is used to measure the content of organic matter of wastewater. The COD values include the oxygen demand created by biodegradable as well as non-biodegradable substances. As a result, COD values are greater than BOD. In comparison with BOD_5, COD measurement has an advantage in that it requires a short digestion period of about 3 hours rather than incubation of 5 days period required for BOD_5 measurement. For many types of wastes, it is possible to correlate COD with BOD. Once the correlation has been established, COD measurements can be used to good advantage for treatment-plant control and operation.

In the COD method, not the product (CO_2) formed by oxidation of the organic wastewater constituents is measured, but the consumption of the oxidant (calculated as oxygen O_2). Thus, an exact amount of oxidant has to be used for the oxidation of the organics in a given volume of a wastewater sample, and the excessive oxidant which is not consumed for complete oxidation of organics must be quantified. Complete oxidation postulates that the only oxidation product formed is CO_2 and not any organic intermediate with high carbon oxidation numbers. Although COD is given as mg of consumed oxygen per litre of wastewater, the oxidant used in the analytical procedure is not oxygen, but potassium dichromate ($K_2Cr_2O_7$) in concentrated sulfuric acid. The substance $K_2Cr_2O_7$ is a powerful oxidant in an acid milieu ($H_2Cr_2O_7$ is formed) at elevated temperature (148℃). Oxidation is the abstraction of electrons from a substance that is oxidized. As one molecule $K_2Cr_2O_7$ can accept 1.5 times more electrons than the molecule O_2, this is considerated by calculation.

The analytical standard procedure prescribes to place 50 ml of the wastewater sample in a 500-ml-refluxing flask, to add 1 g of $HgSO_4$ (caution: toxic!), 5 ml of a mixture of Ag_2SO_4 (which serves as a catalyst for the oxidation of the organics) in concentrated sulfuric acid (caution: corrosive!), to add subsequently 25 ml of a solution of the oxidant $K_2Cr_2O_7$ (caution: powerful carcinogen!) in concentrated sulfuric acid and to heat the mixture under reflux after vigorous mixing for two hours. The $K_2Cr_2O_7$ that has not been consumed for oxidation is then quantified by titration with an aqueous solution of $Fe(NH_4)_2SO_4$ with known concentration. The residual $K_2Cr_2O_7$ oxidizes the Fe^{2+} of the titrant $Fe(NH_4)_2SO_4$ to give Fe^{3+}. When all the residual $K_2Cr_2O_7$ is consumed (reduced by Fe^{2+}), the indicator ferroin, which has to be added to the wastewater/$K_2Cr_2O_7$ mixture prior to titration, turns from blue-green to reddish brown. At this end-point of titration, the volume of the $Fe(NH_4)_2SO_4$ is read from the burette and the residual amount of the oxidant $K_2Cr_2O_7$ after oxidizing the organic constituents in the wastewater sample can be calculated. By this, the consumption of $K_2Cr_2O_7$ during oxidation - and its oxygen equivalent - are calculated, giving the COD.

Besides problems with working safety (use of the carcinogenic $K_2Cr_2O_7$), there are also some analytical problems, because $K_2Cr_2O_7$ does not only oxidize organic, but also some inorganic molecules or ions. Chloride, which is a normal constituent of wastewaters, is oxidized by $K_2Cr_2O_7$ forming Cl_2 gas. In order to prevent oxidation of chloride, it is masked by the addition of $HgSO_4$. Chloride bound to Hg^{2+} is not oxidized by $K_2Cr_2O_7$. However, the addition of mercury sulfate to all samples for COD determinations generates a large amount of toxic waste in laboratories for wastewater analyses (some laboratories purify this liquid waste stream by ion exchange giving the ion exchange regenerates to recycling companies for mercury and also for silver and chromium recovery). If the chloride concentration in the wastewater sample exceeds 1 g/l, the chloride has to be removed prior to COD analysis from the sample by heating it after addition of sulfuric acid and removing the formed hydrochloric acid from the gas phase by absorption to alkaline materials. But there are other substances which can cause troubles with the COD analysis: If the wastewater contains e.g. bromide, iodide, sulfite, Fe^{2+}, Co^{+} or hydrogen peroxide, these reducing agents will also be oxidized by $K_2Cr_2O_7$. This $K_2Cr_2O_7$ consumption, however, is not caused by organics leading to misinterpretations about the content of organics of the wastewater. Another problem is that not every organic substance is completely oxidized under the conditions of COD analysis. Many nitrogen-containing heterocycles (e.g. pyridine) consume significantly less $K_2Cr_2O_7$ than theoretically assumed.

There are also cuvette tests for COD analyses available from several companies. These cuvette tests offer the advantage, that smaller volumes of reagents (and also of wastewater samples) are used limiting the toxic waste of laboratories

2.2.6 Total Organic Carbon (TOC)

Another means for measuring the organic matter present in water is the TOC test, which is especially applicable to small concentrations of organic matter. Wastewater content of carbon bound in organic molecules is the TOC (total organic carbon). Organic carbon comprises nearly all carbon compounds except a few carbon species which are looked at as inorganic (carbon dioxide, hydrogen carbonate, carbonate, cyanide and some further examples which are not commonly found in wastewaters). For detection of organic carbon in aqueous samples, the whole sample is subdued to oxidation (commonly by incineration of a particular volume of the wastewater sample in the presence of a catalyst at 900℃ using CO_2-free air). The CO_2 formed by incineration of the organic wastewater constituents is quantified in the off-gas of the furnace using an infrared cell (CO_2 absorbs infrared light at a wavenumber of 2349 cm^{-1}, corresponding to a wavelength of 4257 nm) by comparison with measurements using aqueous calibration solutions of a pure organic compound with known concentration. The theoretical TOC of such a calibration solution can be calculated as follows (for the calculation, the formula, the molar mass M and the mass concentration m/V of the standard compound have to be known using the atomic weight of carbon [12 g/mol] and the number of carbons z in the standard compound) using phenol as an example for a standard substance:

Standard compound: phenol
Formula: C_6H_6O
Molar mass of standard compound: (6 x 12 + 6 x 1 + 16) g/mol = 94 g/mol
Carbon mass per mol of standard compound: *z* x 12 g/mol = 6 x 12 g/mol = 72 g/mol
Carbon mass portion of standard compound mass: (72 g/mol)/(94 g/mol) = 0.766
Phenol mass concentration of standard solution: 200 mg/l
Theoretical TOC of standard solution: 0.766 x 200 mg/l = 153.2 mg/l

However, although the analytical method described above will deliver appropriate results if performed with standard solutions in deionized water, it will not work with real wastewater samples or solutions of organics in tap water, because these matrices also contain inorganic carbon compounds (mainly hydrogen carbonate). The carbon bound in inorganic molecules or ions is designated as total inorganic carbon (TIC). The sum of TOC and TIC gives total carbon (TC). As wastewater usually contains hydrogen carbonate (or dissolved carbon dioxide or carbonate, depending on pH), the TIC has to be removed prior to TOC analysis. This is easily obtained by acidification of the sample and stripping the formed CO_2 with CO_2-free air. However, this method also removes volatile organic compounds and can only be applied if no volatile organics are present in the wastewater sample. In the presence of volatile organics TOC has to be calculated after analysis of TC and TIC by subtraction of both concentrations. TOC analyzers exhibit high technical standards and are thus rather expensive. A German company also offers cuvette tests for TOC analysis which is performed using a photometric method.

2.2.7 Interrelationship between BOD, COD and TOC

Typical values for the ratio of BOD/COD for untreated municipal wastewater are in the range from 0.3 to 0.8 (see in table 3). If the BOD/COD ratio for untreated wastewater is 0.5 or greater, the waste is considered to be easily treatable by biological means. If the ratio is below about 0.3, either the waste may have some toxic components or acclimated microoorganisms may be required in its stabilization. The corresponding BOD/TOC ratio for untreated wastewater varies from 1.2 to 2.0. In using these ratios it important to remember that they will change significantly with the degree of treatment the waste has undergone, as reported in Table 3.

Table 3: Comparison of ratios of various parameters used to characterize wastewater

Type of wastewater	BOD/COD	BOD/TOC
Untreated	0.3 – 0.8	1.2 – 2.0
After primary settling	0.4 – 0.6	0.8 – 1.2
Final effluent	0.1 – 0.3	0.2 – 0.5

2.2.8 Chlorides

Domestic wastewater is a rich source of chlorides, because human excreta, mainly urine, is rich in chloride. It does not present a major pollution threat. But, Chloride ion concentration is an important factor to be considered if treated effluent is used for irrigation. High chloride concentration disturbs the osmotic balance between the plants and the soil, which affects the growth of the plants. The level of chlorides in wastewater sample is determined by the titration of the sample with mercuric nitrate in the presence of an indicator.

2.2.9 Nitrogen

Nitrogen compounds with environmental relevance frequently analyzed in wastewater are ammonia, nitrite, nitrate, and Kjeldahl nitrogen. Ammonia discharged to surface water can be nitrified in the aqueous environment if nitrifying microorganisms are present. The nitrifying bacteria consume dissolved oxygen for this process, thus depleting the oxygen content of the surface water with the consequence of massive dying of fish. Moreover, if the pH of the surface water is in the alkaline range, NH_3 is formed which is toxic towards fish. The nitrate ion represents a nutrient leading to eutrophication of surface water, and nitrite is toxic and can react with amines (formed e.g. from amino acids of proteins) to yield N-nitosoamines which represent powerful carcinogens. Kjeldahl nitrogen is a sum parameter of compounds containing the nitrogen atom with an oxidation number of -3 (ammonia, amines and many other organic nitrogen compounds). It thus comprises organic nitrogen compounds besides ammonia nitrogen. This is also an important nitrogen parameter, because organic nitrogen compounds can be metabolized to ammonia (this conversion can also take place in surface water). Analytical procedures for the mentioned important nitrogen parameters are given in detail e.g. in the "Standard Methods" (Greenberg et al. 1985). Their principles will be described briefly in this chapter.

As many wastewater analyses (not only for nitrogen compounds) are photometric procedures, a short information about photometry will be given. Photometry uses light as an analytical tool. As particular substances (analytes) absorb photones of different wavelengths to different extents, the wavelength (or colour) of the light applied for photometric analysis affects the specificity of the analytical procedure for a given analyte. The specificity can be increased by converting the analyte by reaction with certain reagents to form coloured products, because (besides the colour) also the reaction with a given reagent is specific for the analyte (other wastewater constituents would not react at all with the reagents used for conversion of a particular analyte). For example, ammonia can be converted to an intensely blue indophenol derivative by the following reactions:

$$NH_4^+ + OH^- \rightarrow NH_3 + H_2O$$

$$NH_3 + OCl^- \rightarrow NH_2Cl + OH^-$$

$$NH_2Cl + \text{Phenol} \rightarrow \text{Indophenol (intensely blue)}$$

The last reaction is catalysed by Mn^{2+} ions. For obtaining the blue product, an aliquot of the wastewater sample is mixed with a small volume of aqueous $MnSO_4$ solution. Then the mixture is stirred and hypochlorous acid reagent and finally an alkaline aqueous phenol solution ("phenate reagent") is added. After 10 min the colour formation is complete for these particular reactions. The coloured product exhibits a maximum absorption at 630 nm (the complementary light causes the blue colour). The solution is transferred to a cuvette which is irradiated with light exhibiting a wavelength of 630 nm (satisfactory results are obtained in the 600 to 660 nm region for this analytical procedure) and an intensity of I_O in a photometer. In the photometer, the intensity of the light entering (I_O) as well as the light leaving the cuvette (I) is determined (by means of a photodiode or a photomultiplyer) as shown schematically in figure 6. The absorbance, i.e. $\log(I_O/I)$, is linearly related to the indophenol concentration as given by the Beer-Lambert law:

$$\text{absorbance} = \log(I_O/I) = \varepsilon \cdot c \cdot d$$

With the proportionality constant ε (molar absorptivity or molar extinction coefficient), the length d of the way of the light through the cuvette (frequently 1 cm) and the molar concentration c of the coloured substance, resp. the concentration of the analyte in the sample (as one molecule of ammonia will yield one molecule of the coloured substance, the absorbance will also be linearly related to the ammonia concentration in the wastewater or in calibration solutions, resp.).

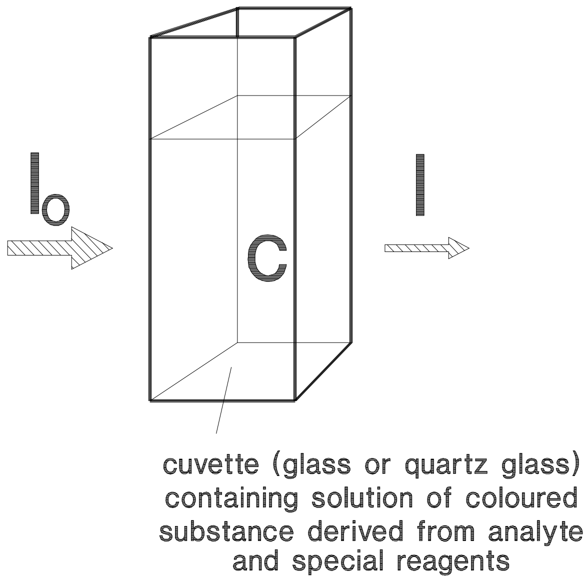


Figure 6: Principle of photometric analysis measuring the decrease of intensity of light that passes a solution of a substance (concentration: c) that absorbs light of the applied wavelength; I: intensity after passing the cuvette; I_o: intensity of the light before passing the cuvette.

The colourless nitrite ion NO_2^- is also transformed to a coloured substance prior to photometric analysis. A standard method used for nitrite analysis suitable for determinations down to 1 µg NO_2^-N/l is the reaction of nitrite at pH 2 (formation of nitrous acid) with sulfanilic acid to give a diazonium salt which reacts with another reagent, (1-naphthyl)-ethylenediamine, in order to form a reddish purple azo dye that can be detected photometrically at 543 nm. For quantification the nitrite concentration in wastewater samples, standard solutions containing known nitrite concentrations are also analyzed in the same way. As for all the other analytical methods mentioned here, the exact procedure can be read in the "Standard Methods" (Greenberg et al. 1985).

As for other analytes, also for nitrate determination several analytical methods can be applied. Greenberg et al. (1985) describe the chromotropic acid method as one of the possible procedures. Two molecules of nitrate react with one molecule of chromotropic acid (4,5-dihydroxy-2,7-naphthalene sulfonic acid) and the absorbance of the product is measured at 410 nm. The method interferes with nitrite. The nitrite ion is destroyed by reaction with urea which is also added to the test assay.

The German standard procedure for nitrate analysis utilizes the reaction of nitrate with 2,6-dimethylphenol under acid conditions to form 4-nitro-2,6-dimethylphenol with an absorbance maximum at 324 nm.

As already mentioned, the Kjeldahl method determines nitrogen in the trinegative state. Thus, it does not account for nitrogen in compounds like azide, azine, azo, hadrazone, nitrate, nitrite, nitrile, nitro, nitroso, oxime, and semi-carbazone (Greenberg et al. 1985). In the Kjeldahl method, the amino nitrogen of many organic nitrogen compounds is transformed to $(NH_4)_2SO_4$ in the presence of H_2SO_4, K_2SO_4, and $HgSO_4$ (this acts as a catalyst for the conversion) by boiling the mixture of wastewater sample and reagent solutions in a flask until fumes are occurring. A mercury ammonium complex generated in this procedure is decomposed by the addition of sodium thiosulfate/sodium hydroxide reagent after digestion of the organic nitrogen compounds. Ammonia and ammonium are also present as $(NH_4)_2SO_4$ after treatment. Finally, the flask used for digestion is connected to a steamed-out distillation apparatus, and the ammonia which has been generated from $(NH_4)_2SO_4$ by addition of hydroxide solution is distilled to a receiving flask containing a boric acid solution. Afterwards the distilled ammonia is determined by acid/base titration. If it is to be analysed by the above-mentioned phenate method for ammonia determination, the receiving flask must contain sulfuric acid. If small sample volumes have to be analysed for Kjeldahl nitrogen, an all-glass micro-Kjeldahl distillation apparatus (figure 7) is used for distillation of formed (and original) ammonia.

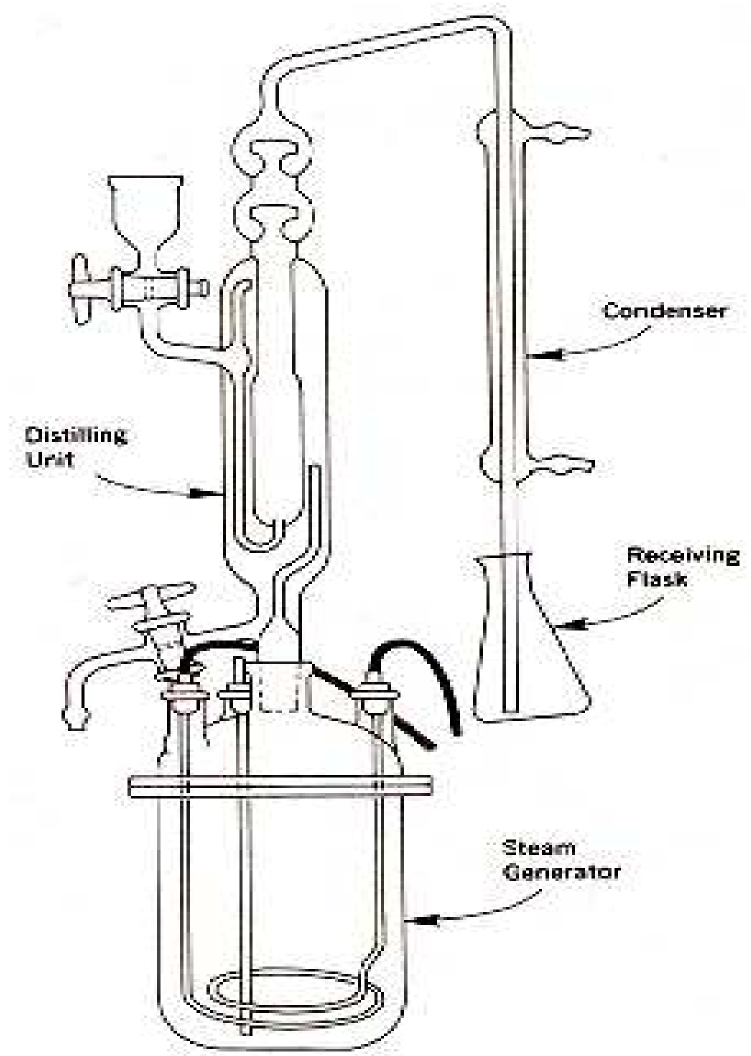


Figure 7: Micro-Kjeldahl distillation apparatus; Greenberg et al. (1985).

2.2.10 Phosphorus

Phosphorus is essential to the growth of algae and other biological organisms. The amount of phosphorus compounds present in wastewater discharge has to be controlled in order to avoid noxious algal blooms occurred in surface water. The usual forms of phosphorus found in aqueous solutions include the orthophosphate, polyphosphate, and organic phosphate. Three groups of phosphorus compounds have to be distinguished in phosphorus analysis of aqueous samples. The ortho-phosphate anion PO_4^{3-}, poly- and metaphosphates (examples see figure 8) which can be hydrolyzed to form ortho-phosphate, and phosphorus compounds which will not yield ortho-phosphate by hydrolysis but by oxidative treatment. The latter group is mainly represented by organic phosphorus compounds. The sum of all three phosphorus species is designated as total phosphorus.

The ortho-phosphate anion is again determined by photometry after it has been transformed by addition of ammonium molybdate, potassium antimonyl tartrate and ascorbic acid to yield the intensely blue compound "molybdenum blue" (Greenberg et al. 1985) which is quantified by means of a photometer at 880 nm using phosphate calibration solutions of known phosphate concentrations.

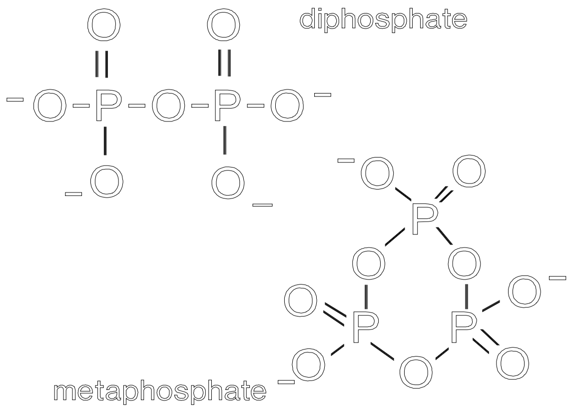


Figure 8: Two examples of acid-hydrolyzable phosphates: diphosphate, $P_2O_7^{4-}$, and metaphosphate, $P_3O_9^{3-}$

The sum of ortho-phosphate and acid-hydrolyzable phosphorus is determined nearly in the same way except a hydrolysis step prior to quantification of original and hydrolysis-generated ortho-phosphate. The hydrolysis is performed by gentle boiling of the wastewater sample after addition of a mixture of concentrated H_2SO_4 and concentrated HNO_3 (Greenberg et al. 1985). After cooling and neutralization with NaOH solution, the ortho-phosphate can be analyzed following the procedure given above.

Determination of total phosphorus requires oxidation as well as hydrolysis prior to ortho-phosphate analysis. This is realized by boiling the wastewater sample after addition of concentrated HNO_3, evaporation on a steam bath, addition of 70 % perchloric acid and concentrated HNO_3, boiling until the mixture clears. After cooling the mixture, NaOH solution is added and the ortho-phosphate is determined as given above (Greenberg et al. 1985).

2.2.11 Oil and Grease

Oils, fats, waxes and fatty acids are the major constituents included in this category in domestic wastewater. The presence of a significant amount of oil and grease in wastewater hinders the transportation of wastes through pipelines. It causes scum in aeration basins of activated sludge plants, which interferes with the biological oxidation of wastes and produces a low quality settling sludge.

These substances are determined by extracting them with an organic solvent 1,1,1-trichloroethane. The two immiscible solvents (organic solvent and water) make separate layers. The solvent containing the oil and grease fraction of the wastewater is separated from the aqueous layer. It is dried and evaporated to determine the extractable residue.

2.2.12 Gases

Gases commonly found in untreated wastewater include nitrogen (N_2), oxygen (O_2), carbon dioxide (CO_2), hydrogen sulfide (H_2S), ammonia (NH_3), and methane (CH_4). The first three are common gases of the atmosphere and will be found in all waters exposed to air. The latter three are derived from the decomposition of the organic matter present in wastewater

2.2.13 Sulphur

The sulphate ion occurs naturally in most water supplies and is present in wastewater as well.
Sulphate is reduced biologically under anaerobic conditions to sulphide, which in turn can combine with hydrogen to form hydrogen sulphide (H_2S).
The following generalised reactions are typical.

$$\text{Organic matter} + SO_4^{2-} \xrightarrow{\text{bacteria}} S^{2-} + H_2O + CO_2$$

$$S^{2-} + 2H^+ \longrightarrow H_2S$$

The H_2S accumulated in sewers can be oxidised to sulphuric acid, which is corrosive to sewer pipes.

2.2.14 Adsorbable organic halides (AOX)

Adsorbable organic halides (AOX) is an organic sum parameter comprising such organics that contain chlorine, bromine or iodine (not fluorine!) atoms and are adsorbable to activated carbon. For AOX determination a particular volume of the wastewater sample is agitated sufficiently long with powdered activated carbon. Subsequently the activated carbon is separated by filtration using a membrane filter which retains the activated carbon (adsorption can also be executed in small activated carbon columns which are treated - after adsorption has been completed - in the same way as the loaded activated carbon removed by filtration). Then the membrane filter is incinerated together with the activated carbon in a stream of pure oxygen at temperatures around 900℃. The halogen atoms origin ally bound in organics adsorbed to the activated carbon form HCl, HBr, or HI, resp., which are contained in the exhaust gas of the incineration furnace and can be absorbed e.g. in acetic acid. Microcoulometric titration, an electrochemical quantification method, analyses chloride, bromide, or iodide, resp., of these acids. Bromide and iodide are calculated as chloride equivalents (one mol bromide or iodide is looked at as one mol chloride and is calculated as chloride mass), and the final chloride mass determined is related to the volume of the wastewater sample which had been subdued to activated carbon adsorption. The result is mg AOX (chloride)/l wastewater. For details of the method, see Greenberg et al. (1985).

In the AOX analysis procedure, artefacts can easily be produced: First, also inorganic chloride adsorbs to a certain amount to activated carbon. This adsorbed inorganic chloride will also be detected e.g. by microcoulometric analysis of the incineration off-gass and may result in the so-called "chloride error". Secondly, in wastewaters with high TOC mainly represented by non-halogenated organic compounds a competition of halogenated and non-halogenated organic compounds for adsorption sites on the activated carbon occurs leading to a very low extent of halogenated organic molecules being adsorbed. This can be prevented by dilution of the wastewater sample. However, by dilution also the AOX is diluted which is disadvantageous if the AOX content of the sample is decreased to be below the detection limit of the method. AOX analyses must be performed in laboratory rooms where no halogenated organic solvents are used at all, because these volatiles would also adsorb on the activated carbon during the AOX procedure. In recent years, AOX analyses in the Institute of Wastewater Management of Hamburg University of Technology had been performed in a laboratory where a thermostatized chamber was located. When there was a leakage in the cooling system of the chamber, some fluorochlorohydrocarbons were volatilized in the laboratory leading to severe analytical errors in AOX determinations.

Other parts of organics contained in wastewaters (usually comprised in TOC or COD) are the organic sum parameters hydrocarbons, phenols, anionic surfactants, neutral surfactants, cationic surfactants etc. Methods for analyzing these organic sum parameters are also given in the "Standard Methods" (Greenberg et al. 1985).

2.3 Selected other parameters

The world of chemical analyses - even that of environmental or more restricted that of wastewater analyses - is hardly to survey. For many analytes, there exist several analytical methods, and additionally wastewaters contain innumerable different kinds of constituents. The routineously measured wastewater parameters are mainly given above. But these are really the minority of possible parameters.

For the determination of metals, there exist special methods as flame emission photometry (e.g. important for the fertilizer component potassium). In this procedure the aqueous sample is transferred into a flame where the metals are electronically excited resulting in an emission of light of a particular wavelength. This emission can be detected and used for quantification of the concerning metal ion.

A similar method is also useful for the determination of some toxic heavy metals (atomic emission spectrometry/inductively coupled plasma, AES/ICP). The aqueous solution is pumped into a small plasma generated by high frequency fields where the metals are electronically excited leading to emission of light of that wavelength which is characteristic for the particular metal of concern. With this method, several metals can be determined simultaneously.

On the other hand, aqueous solutions of metal salts can also absorb distinct wavelengthes of light, when they are heated to very high temperatures (flame or graphite furnace) and converted from ions to atoms by this. The light absorbed by the atoms can be used for quantification of particular metal ions in aqueous solutions like wastewaters. The method is called atomic absorption spectrometry (AAS). Solids have to be digested prior to AAS analysis if their metal content is to be analyzed. Details for such methods can be read in the "Standard Methods" (Greenberg et al. 1985).

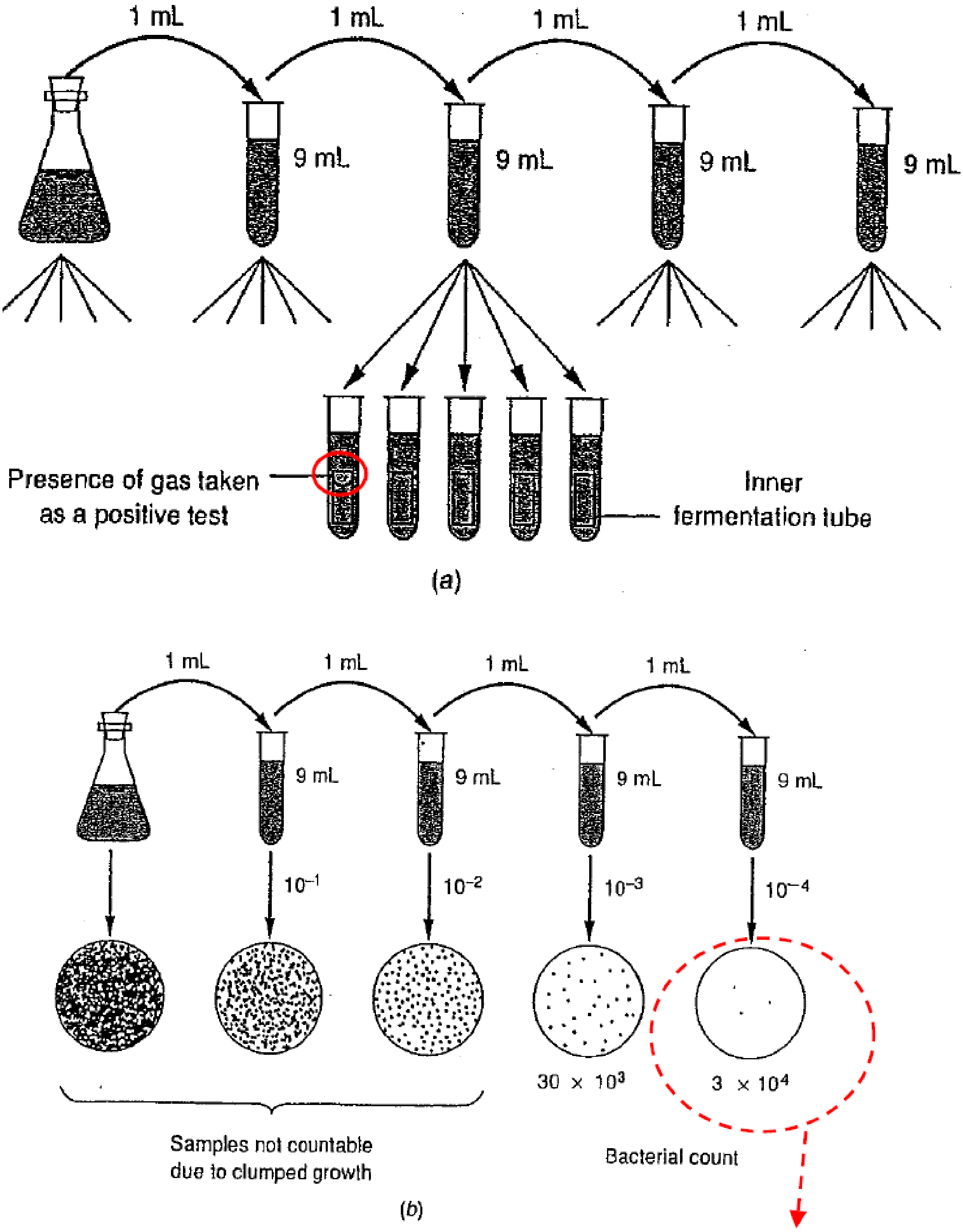
Sometimes, there is interest in the concentrations of particular organic compounds contained in wastewaters. For such analyses, gas chromatography is a useful tool, but very complex in execution. For many gas chromatographic methods, wastewater samples have to limits for particular trace organics. and the final concentrate is then analyzed. A very small volume of the concentrate (in the range of one µl) is transferred to the so-called injector of the gas chromatograph by a syringe. The injector is heated to temperatures in the range of 200℃ and flushed by the inert carrier gas (very often helium is used). At these high temperatures the total solution evaporates at once and the analytes as well as the extractant are transported by the carrier gas to a separation device, the so-called column. The column is usually a capillary made of fused silica (a material that has substituted glass which had been used earlier for manufacturing capillaries for gas chromatography) of some 10 m length. The inner wall of the capillary is lined by thin films of particular polymers which control the separation characteristics of the column. Different analytes (as well as the extractant) show different interactions with the polymer film material and thus exhibit different velocities passing the column. The temperature of the column also affects separation of analytes and varies - depending on the separation problem - between room temperature and around 300℃. It can also be changed during the chromatographic run ("temperature program"). At the end of the column the carrier gas (and the analytes as well as the extractants arriving at different times) are detected by devices like flame ionisation or electron capture detectors giving signals which are related to the concentrations of the analytes in the extract. Very useful are mass spectrometers for detection, because the detected mass fragments of the analytes can serve as "fingerprints" resulting in identification of particular organic compounds after comparison to computerized mass spectra of known organics.

However, not every organic compound can be analyzed by gas chromatography. If the boiling point of an organic is very high (> 400℃) the analyte is not sufficiently volatile to enter the column of the gas chromatograph and it will stay in the injector being subdued to thermal decay. That is why injectors have to be cleaned from time to time. It has been shown that only a minority of organic wastewater constituents are susceptible to gas chromatography. Gulyas (1997) could only identify 1 to 2 % of the TOC of biologically treated municipal wastewater as particular organic compounds by gas chromatography/mass spectrometry. Even in an untreated oil reclaiming wastewater only 2 % of TOC corresponded to particular organics identified in a dichloromethane extract of this wastewater (Gulyas and Reich, 2000).

Microbiological parameters of wastewaters are extremely important for judging their pathogenic potential. On the other hand, there exist also microorganisms which are useful for wastewater purification. The principal microorganisms of concern in water and wastewater include bacteria, fungi, algae, protozoa, worms, rotifers, crustaceans and viruses (Tchobanoglous and Schroeder 1987). Methods for the detection of pathogenic microorganisms are available. However, indicator organisms for faecal contamination are rather used than tests for pathogens, because procedures for the isolation of certain pathogenic bacteria are tedious and complicated and are not recommended for routine use (Greenberg et al., 1985). Therefore, indicator organisms are determined with the coliform group being a principal indicator of faecal bacteria. The coliform group density in waters is looked at as a criterion of the degree of pollution and thus of sanitary quality. For microbiological analyses, culture media are used allowing the microorganisms contained in waters to grow under certain conditions resulting in an amount of cultured bacteria which can be detected by inspection and quantified by counting the grown bacteria colonies. It has to be noted that different bacterial species have different nutrient and environment requirements. This selectivity is very useful when it is desired to enumerate one or a very few species of bacteria to the exclusion of others. Therefore, nutrient medium and environmental conditions have to be carfully selected. For the coliform group of bacteria used as an indicator for faecal contamination of waters and probable presence of pathogens there exist particular media which can be prepared and sterilized in the microbiological laboratory. For more convenient microbiological analyses, several of these media are also commercially available. Prerequisites for microbiolgical laboratories can be found in the "Standard Methods" (Greenberg et al., 1985).

For the determination of bacteria in waters with low bacterial content, in general three techniques are available: the membrane-filter technique, the solid medium technique (plate count method) and the liquid medium technique (Tchobanoglous and Schroeder, 1987). For details of execution of bacterial counts, see Greenberg et al. (1985). Applying the membrane-filter technique, a known volume of water is filtered over a membrane filter with 0.45 µm pore width. Then the filter is removed from the filtration unit and transferred to a small petri dish containing a sterile absorbent pad saturated with a suitable culture medium. The filter membrane is placed face up on the culture medium. After incubation in the inverted position, the bacterial colonies are counted and the counts are related to the volume which had been filtered (Tchobanoglous and Schroeder, 1987).

For waters with higher numbers of bacteria (e.g. the effluent of a wastewater tretament plant or river water receiving the effluent or even raw sewage) the other two methods are suitable which include dilution steps of the water containing the bacteria (see figure 9).



For dilution 10,000=10^4, CFU = 3 x 10^4 , CFU/mL = 3 x 10^4 / mL

Figure 9: Illustration of methods to obtain bacterial counts: (b) use of a solid medium; (a) use of a liquid medium (Tchobanoglous and Schroeder 1987)

In the plate count method (see figure 9b) the first operation is preparation of 10-fold dilutions of the sample. Of each dilution as well as of the original sample 1 ml is pipetted into separate sterile petri dishes. Subsequently 12 to 20 ml of liquified culture medium is poured into each petri dish. After mixing medium and sample the mixture is allowed to solidify and subsequently the petri dishes are inverted and incubated at 35℃ for 48 hours. The next operation is counting of the developped bacterial colonies. For quantification, only dishes with colony numbers between 30 and 300 are utilized. At higher numbers of colonies clumped growth of bacteria will occur resulting in too low numbers of counted colonies.

Coliforms are capable of fermenting lactose with the production of an abundance of gas. This effect is utilized in counts of coliforms given in figure 9a. Again, 10-fold dilutions of the sample are prepared. Of each dilution 1 ml is transferred to the test tubes in multiplicate. The test tubes contain the fermentation medium and an inverted gas collection tube. After a 24 hour period of incubation at 44.5℃, gas observed in the inner fermentation tube indicates the presence of coliforms in the diluted sample. For example, if a 10-fold serial dilution is made and growth, as measured by gas production, is observed in the 10^{-n} but not in the $10^{-(n+1)}$ dilution, then it can be concluded that the sample contains at least 10^{n} cells per ml but less than 10^{n+1} cells per ml.

Another group of parameters useful for judging the quality of effluents of wastewater treatment plants is toxicity. Toxicity determination comprises a huge variety of tests because the test organisms can be varied (even using parts of living organisms like cell cultures) and the endpoint of toxic action can also be varied (using different metabolic events in the organism, occurrence of different diseases, damages or finally death of the investigated organism). For characterizing toxicity of waters, several tests using organisms living in water (e.g. algae, ciliated protozoa, daphnia, corals, annelids, crustaceans, aquatic insects, mollusks, fish) have been standardized (Greenberg et al. 1985). Tragically, also toxicity tests with humans are run (which of course are unintentional) in epidemiological studies which try to find associations e.g. between constituents of drinking water (chemical hazardous substances as well as pathogenic microorganisms) and excessive mortalities in terms of particular diseases in collectives consuming the drinking water of concern. However, these epidemiological studies are no routineously applied "toxicity tests" because they require huge efforts and usually exhibit high statistical uncertainties.

3 Sampling and preparation techniques of wastewater samples

Representative sampling of wastewater streams is decisive for correct modelling of wastewater treatment processes. While in laboratories usually high efforts are made to execute chemical analyses of wastewater samples with high accuracy, wastewater sampling is sometimes carried out by people who are not trained in sampling. Thus, experts assume that errors in wastewater analyses caused by mistakes during sampling are several orders of magnitude higher than by analytical errors in the chemical laboratory (Sommer, 1995).

Different kinds of sampling are possible: grab (or catch) samples and composite samples (a mixture of grab samples collected at the same sampling point at different times) can be taken. Both kinds of sampling can either be carried out manually or automatically. Automatic samplers are being used increasingly. They are effective and reliable and can significantly increase the frequency of sampling. Especially for composite samples taken during long periods (days, weeks), automatic samplers are convenient and help to save manpower. An example is outlined in figure 10. With this type a variable number of constant volumes of single samples can be combined to composite samples. At desired times, which can be programmed by means of a control unit, the vacuum pump A is switched on automatically until the sample reaches the level indicator sensor C in the dosing vessel D. Then the level indicator gives a signal to switch off the vacuum pump. The sample flows back through the tube B until the level in the vessel D is reached which is given by the length the tube B is inserted into vessel D (adjustable). Then the valve E is opened automatically and the sample is flowing into the desired bottle H (also programmed via control unit of the automatic sampler). In many parts of the world, composite samples representing a 24-h period are considered standard. In Germany, for many control parameters composite samples consisting of five grab samples collected within a two hours period are according to regulations.

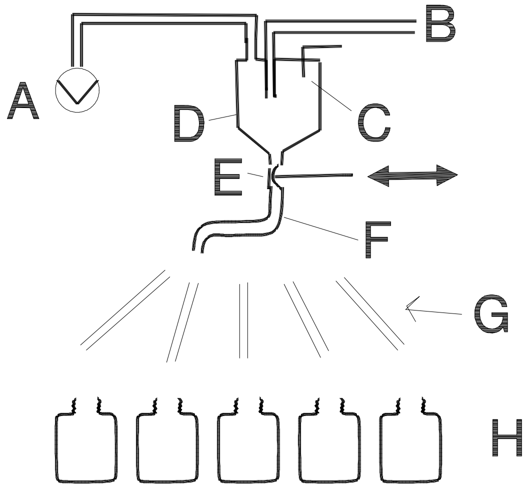


Figure 10: Scheme of an automatic sampler taking samples by means of vacuum; A: vacuum pump; B: pipe for sample transport from wastewater stream; C: level indicating sensor; D: dosing vessel; E: valve; F: cock which is moved by steps by a small motor in order to select sample containers H for different composite samples; G: channels for distribution of samples to sample bottles H; Gulyas (1999).

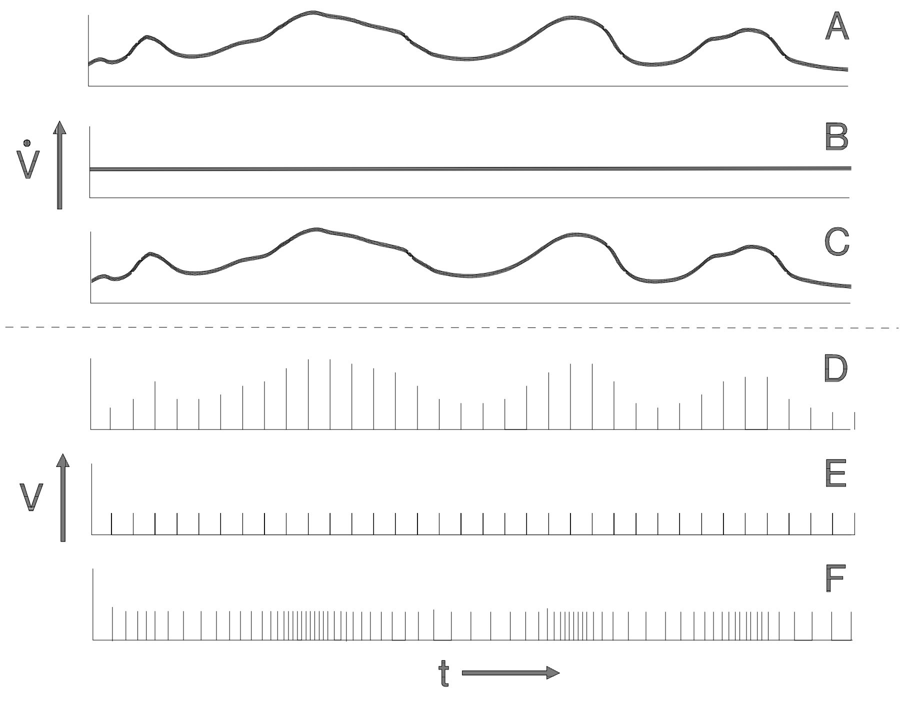


Figure 11: Different types of sampling using automatic samplers; A: volume flow of the wastewater stream which has to be characterized; B and C: continuous sampling modes; D, E, F: discontinuous sampling modes; for details see text; Gulyas (1999).

Figure 11 shows the volume flow of a wastewater stream (A) and different types of composite samples (B to F). For continuous sampling, pumps are used either with a continuous flow (time-continuous sampling, A) or with a flow which is adapted to the flow of the wastewater stream (flow-continuous sampling, B). In the schemes D to F (discontinuous sampling) at particular intervals grab samples are taken (being combined to form composite samples) in different ways: In scheme D the frequency of taking grab samples is constant, but the volume of each grab sample is adapted to the volume flow of the wastewater stream (flow-proportional sampling); in sampling mode E frequency as well as volume of grab samples are constant (time-proportional sampling); in scheme F the volume of each single sample is constant, but the frequency is controled by the flow of the wastewater (high sampling frequency during high wastewater flows, low sampling frequency during low wastewater flows, volume-proportional sampling). For sampling modes C, D, and F a flow meter is needed to determine the wastewater flow. The flow meter must be able to transfer its signals to the automatic sampler in order to control flow (mode C), volume (mode D), or frequency (mode F) of grab samples. The automatic sampler drawn schematically in figure 10 can only be applied for sampling modes E and F, because the volume of each grab sample cannot be varied during the sampling period and because it is a device for discontinuous sampling. It has to be noted, that automatic samplers have to be cleaned before and after sampling campaigns. Careful maintenance is a prerequisite for appropriate function.

Table 3 shows different conditions of wastewater flow and concentrations of wastewater constituents and the suitable sampling mode to yield representative samples.

***Table 3: Selection of appropriate sampling mode (from several possibilities given in figure 9) yielding representative samples with different conditions concerning wastewater flow and concentration of wastewater constituents*.**

Concentration	**Flow of wastewater** **constant**	 **varying**
constant	grab sample	grab sample
varying	composite sample following mode B or E	composite sample following mode C, D, or F

Besides sampling times, also the location of sampling is very important in order to obtain representative samples. It is recommended to sample below the surface of the wastewater in order to avoid contamination of the sample with materials with a lower density than water which are eventually enriched at the surface but not representative for the bulk wastewater stream. It should also be avoided to take samples directly at the walls or at the floor of e.g. wastewater channels or tanks, because in this case solid substances fixed at the walls (growing biofilms) will be added to the sample although they are not representative for the wastewater stream.

If suspended wastewater constituents are to be analysed care has to be taken, because particle size is easily affected by sampling measures. By transferring mechanical energy to samples (e.g. by shaking or by pumping) two effects can occur with the particles: flocculation or destruction of flocs leading to a greater particle number but lower particle diameters. This can lead to artefacts when particle properties are measured which correspond to particle size: e.g. determination of settleable solids or particle size distribution. For the determination of these parameters, samples taken manually and with care are favorable. Moreover, these parameters should be measured immediately after sampling, before flocculation or floc destruction has occurred.

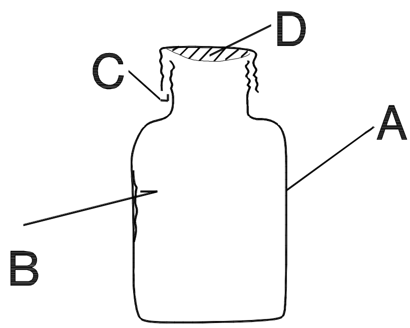


Figure 12: Analytical errors caused by unsuitable sample containers; A: unsuitable container materials; B: impurities; C: leaky seals; D: unsuitable gaskets; Gulyas (1999).

There are also particular requirements concerning the containers for collection and storage of samples (see figure 12.): First of all, sample bottles have to be clean (to prevent sample contamination) and dry (in order to prevent sample dilution). Cleaning should be performed in the laboratory prior to sampling following standard cleaning procedures. Besides contamination, impurities (B in figure 12.) can also cause adsorption of analytes (i.e. the substances which are to be analyzed in the sample) leading to analytical results below the true concentrations of the analytes in the wastewater. The material (A in figure 12.) of the sample container may also affect the results of analyses: analytes can be adsorbed by unsuitable container materials, sometimes they can pervaporate through the material (e.g. halogenated organic solvents in wastewaters can permeate the walls of polyethylene bottles resulting in too low results or they can contaminate the sample if they diffuse from the air in the laboratory into the bottle), and some constituents of container walls (e.g. plasticizers in PVC bottles) may migrate into the sample leading to sample contamination (resulting in too high results for organic sum parameters like total organic carbon). When sample containers are not tightly sealed (C in figure 12) either volatile analytes can leave the bottle. On the other hand, a laboratory environment bearing relatively high concentrations of volatiles may cause contamination of the sample. Long term storage of the samples with leaky seals may result in water evaporation from the sample bottle leading to increased concentrations of all non-volatile analytes. Unsuitable gaskets of seals (D in figure 12) may also cause problems either with contamination of the sample (e.g. organic materials) or with adsorption of analytes. Another aspect is the transparency of the container material: Wastewater constituents which are susceptible to photoreactions require bottles which prevent the sample from light (using brown glass of Teflon bottles). Generally, samples should not be allowed to stand in the light, but always stored in the dark.

As most wastewaters are not at all sterile, it can be assumed that biochemical processes (which are desired in biological treatment stages) will not stop when the wastewater sample is transferred to a bottle. Examples for such processes are nitrification (oxidation of ammonia to nitrite or nitrate if still oxygen is dissolved in the sample resulting in too low ammonia and too high nitrite, or nitrate concentrations determined), denitrification (reduction of nitrate or nitrite to nitrogen gas resulting in too low nitrate or nitrite concentrations determined) or oxidation of organic wastewater constituents (resulting in errors of organic sum parameters analyzed in the sample). To prevent biochemical reactions, the microorganisms in the wastewater sample have to be killed or at least their metabolic activity has to be inhibited. This can be obtained by preserving the samples. Preservation can be realized by the addition of substances which are inhibiting or toxic towards microorganisms (acids, bases, mercury salts, azide) or by reducing the temperature (storage of samples in refrigerators or freezers), thus decelerating biochemical reactions.

For different analysts there might be different optimum preservation procedures. For additional details for preservation of samples see appendix in page 40. This means that sometimes a sample has to be divided and the sample parts must be preserved in different ways each adapted to the parameters that are aimed to be analyzed. In the past, there have been attempts to find optimum preservation methods for several wastewater routine parameters. The "Working Party on Stabilization of Samples from the Hydrochemistry Team of the German Chemists Association" (1981) analyzed primary clarifier effluent of a municipal wastewater treatment plant for different parameters after different storing periods and applying different preservation methods (see table 4) and compared the analyses to those executed with the same samples directly after sampling. By this, they could determine the periods of stability for several parameters under different preservation conditions (storing at room temperature without any addition of preservatives and with addition of acid or base or mercury chloride and storing in a freezer).

In the "Standard Methods" also effective preservation methods are given for several parameters (Greenberg et al. 1985). It has to be mentioned that freezing is not a good preservation method for samples to be analyzed for suspended solids. It can be observed, that even in filtered samples after freezing and thawing solids are generated. These solids are a consequence of flocculation of colloidals (dissolved macromolecules like humic substances). During the freezing process more or less pure ice is formed at the walls of the sample bottle leading to increasing concentrations of dissolved wastewater constituents in the remaining solution. The more ice freezes the more concentrated the residual solution will become. Macromolecules come so close to each other that some of them "stick" together and will no longer be dissolved because of the huge size of the agglomerates. When the whole sample is frozen, these solids are also frozen in the ice, but after thawing they are not re-dissolved, but stay solids. Another fact that has to be remembered when applying freezing as preservation is to avoid glass bottles because they can be destroyed during freezing the aqueous sample and can no longer protect the sample against contamination or evaporation of water molecules.

Table 4: Recommendations of the "Working Party on Stabilization of Samples from the Hydrochemistry Team of the German Chemists Association" (1981) for preservation of primary clarifier effluent for analyzing different parameters

Parameter	Preservation Method	Period of stability of parameter [d]
Oxidation with $KmnO_4$	no preservation -18 to -22℃ acidified (pH 2) alkaline (pH 12) $HgCl_2$	0 32 16 8 8
COD	no preservation -18 to -22℃ acidified alkaline	0 32 0 0
TOC	no preservation -18 to -22℃ acidified alkaline	0 32 2 8
BOD	no preservation -18 to -22℃ acidified alkaline	0 32 4 8
ammonia	no preservation -18 to -22℃ acidified alkaline $HgCl_2$	0 0 16 32 32

nitrate	no preservation -18 to -22℃ acidified alkaline $HgCl_2$	0 8 1 4 0
sulfate	no preservation $HgCl_V$	0 32
anionic surfactants	no preservation acidified $HgCl_2$	0 0 32

Efficiency of particular preservation methods strongly depends on concentration of microorganisms in the samples. Therefore, preservation recommendations given in the literature may not always be suitable and applied preservation methods should be verified with samples routineously collected. When using chemical preservatives like acids etc. one should take care, that certain analytes can no longer be determined in a sample preserved in such a way. It is impossible to measure e.g. nitrate or total nitrogen in a sample that had been preserved by addition of nitric acid. Chloride cannot be determined if hydrochloric acid had been used as a preservative.

A couple of parameters are recalcitrant against preservation and have to be measured immediately after sampling. Such parameters are given in table 5.

Table 5: Parameters which cannot be stabilized by sample preservation and have to be measured immediately after sampling at the sampling location or directly in the wastewater

Parameter	**Measures to be taken**
turbidity	immediate inspection and documentation; analytical quantification should be carried out on the same day
settleable solids	immediate analysis using Imhoff cone
suspended solids	filtration and gravimetric analysis must be performed as soon as possible
colour	immediate inspection and documentation
odor	immediate check and documentation
concentration of dissolved oxygen	analysis with oxygen probe
pH	analysis with pH probe
conductivity	analysis with conductivity probe
nitrite	transport samples as fast as possible to laboratory for analysis; reflectometric analysis at sampling location
temperature	directe determination in the wastewater

Each step of handling the samples has to be documented in the sampling protocol which should also contain the sample designation (which has to be marked also on the sample container), date and day time of sampling, sampling location, name of person collecting the samples, purpose of sampling, mode of sampling (grab or composite sample etc.), results of measurements performed at the sampling site, sample preparation measures (e.g. sedimentation of sample), preservation procedure(s), sample storing conditions until delivery to laboratory, comments upon reference samples simultaneously collected, comments about subsequent changes occurring in the sample, comments about deviations from routineously performed sampling (e.g. application of another automatic sampler, more frequent transfers of samples to other bottles than usually done), observations at sampling site (weather, wastewater irregularities as foam, bulking sludge, odor etc.), comments about irregularities observed on the sampling site (e.g. construction operations within a treatment plant etc.). Sampling documentation forms can serve as check lists.

For further analyses in the laboratory, samples must be transported as soon as possible to the laboratory. For keeping the samples unchanged during the transport, the sample containers should be tightly sealed, kept cool (e.g. using a cooling bag - which should be exclusively used for sampling but not for food transport for safety reasons) and dark. In vehicles used for sample transport, samples must be protected against being tilt over. If samples are shipped by mail or express services, by railway, ship or aeroplane, special safety measurements have to be taken. The bottles must be sealed absolutely tight and protected against shock in order to avoid leakages of the sample bottles.

It is clear that sampling of wastewater (and also of other media) has to be carefully prepared (providing sampling equipment like suitable sample bottles in sufficient number etc.). There must be a good communication between sampling staff and the analytical laboratory concerning number of samples, parameters which must be analyzed, time of delivery of samples to the laboratory, because the laboratory has to organize the enforcement of the analyses as well as to provide storing space in refrigerators or freezers. The samples as well as the sampling protocols have to be received by the laboratory staff in a responsible manner because of registration and eventual transfer of some samples to other laboratories for special analyses.

Working safety has to be obeyed not only in laboratories, but also during sampling (e.g. marking samples with symbols for hazardous materials if harmful preservatives like concentrated acids or bases or even toxic materials like $HgCl_2$ are added to samples).

Another step which is often performed prior to sample analyses is sample homogenization. This is necessary when samples which contain solids are divided. Measures have to be taken that the divided samples are identical with the original sample. This is not possible if a sample contains e.g. settleable solids and is not sufficiently agitated during sample division. Then the solids will settle, the sample is no longer homogeneous and the sample is divided into one part being poor in solids and the other one being more concentrated in solids than the original sample. This can be avoided by transferring an aliquot from the stirred sample. Sometimes high speed stirring devices have to be used in order to keep the sample in a homogeneous state during sample division, see also the presentation (slides of lesson A1).

4 Statistics

For design of wastewater treatment plants, a couple of chemical parameters of the collected wastewaters have to be analyzed following the above-mentioned procedures. For example, for designing the nitrification process, the wastewater content of ammonia is relevant. As concentrations of wastewater constituents are not constant, it is necessary to know how the relevant parameter varies with time (day-time, weekly time-course, seasonal deviations). Of course, also the volume flow of the wastewater is important, to calculate the mass flows of the relevant parameters. But which of the measured concentrations (or mass flows) should be taken into consideration? Is it good to select the highest value determined e.g. within a year? Or the mean? Using the maximum parameters determined will lead to "oversize" wastewater treatment processes which will cause high investment as well as high operational costs. A reasonable amount of the operational costs are caused by energy consumption. Thus, oversized treatment processes are not ecologically beneficial.

On the other hand, one of the most serious deficiencies results when the design of a treatment plant is based on average flow rates and average concentration of design-relevant wastewater constituents, with little or no recognition of peak conditions (Tchobanoglous and Burton 1991). Therefore, in Germany commonly that concentration of a parameter is used for design that is not exceeded by 85 % of all values determined within a campaign of measurements (85 percentile). However, this requires sufficient data being analyzed to yield a statistical safety of 95 % (Bever et al. 1993). Statistical analysis of flow data is given by Tchobanoglous and Burton (1991).

A method that can be used for deriving design parameters from a large amount of determined concentrations of one parameter is the method of Groche (1977).

lfd Nr. i	3i−1	x_i	Σ%	lfd Nr. i	3i−1	x_i	Σ%
1	2	4,5	1,8	26	77	15	74,8
2	5	5,5	4,8	27	80	15,5	77,7
3	8	6	7,8	28	83	16	80,6
4	11	6,5	10,7	29	86	17	83,5
5	14	8	13,6	30	89	18,5	86,4
6	17	8	16,5	31	92	24	89,3
7	20	8	19,4	32	95	25	92,2
8	23	8,5	22,3	33	98	25,5	95,1
9	26	9	25,2	34	101	41	98,1
10	29	9	28,2	35	104		
11	32	9	31,1	36	107		
12	35	9,5	34,0	37	110		
13	38	10	36,9	38	113		
14	41	10	39,8	39	116		
15	44	10,5	42,7	40	119		
16	47	11	45,6	41	122		
17	50	11	48,5	42	125		
18	53	11,5	51,6	43	128		
19	56	12	54,4	44	131		
20	59	12	57,3	45	134		
21	62	13	60,2	46	137		
22	65	13,5	63,1	47	140		
23	68	14	66,0	48	143		
24	71	14,5	68,9	49	146		
25	74	14,5	71,8	50	149		

Figure 13: An example for recording wastewater parameters x_i (BOD_5) analysed in a wastewater stream during a certain period) in a table in ascending order and deriving the part of all values that are equal to or less than the indicated value x_i following the method described by Groche (1977)

In this method, a table is created containing all analysed data of a design parameter x_i (BOD_5 in the depicted example) in ascending order (see figure 13, 3rd column). In the first column of the table in figure 13 the rank serial number i is written starting with number 1. From the rank serial number i, a term (3·i - 1) is calculated and written into the 2nd column. This term divided by a term (3·n + 1) with n being the number of all analytical data obtained within the campaign gives the part of all values, that are equal to or less than the indicated value x_i:

$$\sum \% = \frac{(3 \cdot i - 1) \cdot 100}{(3 \cdot n + 1)}$$

These values Σ% are noted in the 4th column. Finally, the data Σ% can be drawn as a function of x_i using log-probability paper (see figure 14). The dashed lines drawn in figure 14 give a statistical certainty of 95 % and are dependent on the total number of analyses performed (n). For an infinite number of analyses, this is given for the 85 percentile value (corresponding to an x_i of 17.7 mg BOD_5/l in the given example). However, as only 34 data were available in this particular example, a statistical certainty of 95 % is not obtained with the 85 percentile. The helping line for this statistical certainty is intersected by the drawn line at an x_i of 21.5 mg BOD_5/l giving the tolerance limit for the determined 85 percentile BOD_5 in this example. The helping lines are drawn using the right-hand ordinate, the so-called probits. The probits are depending on the number n of all analytical data of the parameter of concern measured in the campaign. Table 6 gives the probits as a function of the number of all data (n).

Table 6: Probits corresponding to the number of n of all available data of one parameter taken into consideration for design of treatmant processes; Bever et al. (1993)

n	7	10	15	20	30	40	50	100	∞
probits	7.29	6.97	6.72	6.60	6.47	6.41	6.36	6.26	6.04

Another aspect of statistics in chemical analyses is the complex of accuracy, reproducibilty, and detection limits of analytical procedures. Scattering of results of multiple analyses performed with one sample reflects sources of errors caused by the experimentator's actions (taking aliquot volumes from samples e.g. by pipetting, dosing reagents, contaminations of technical devices and reagents needed for the analyses etc.) as well as by inconstancies of technical devices used during the analytical procedure (e.g. instabilities of lamps - especially when aged - or photomultipliers in photometers). These errors are of increased relevance the smaller the concentration of analytes is. For analytical experts, Funk et al. (1995) is recommended as further reading material.

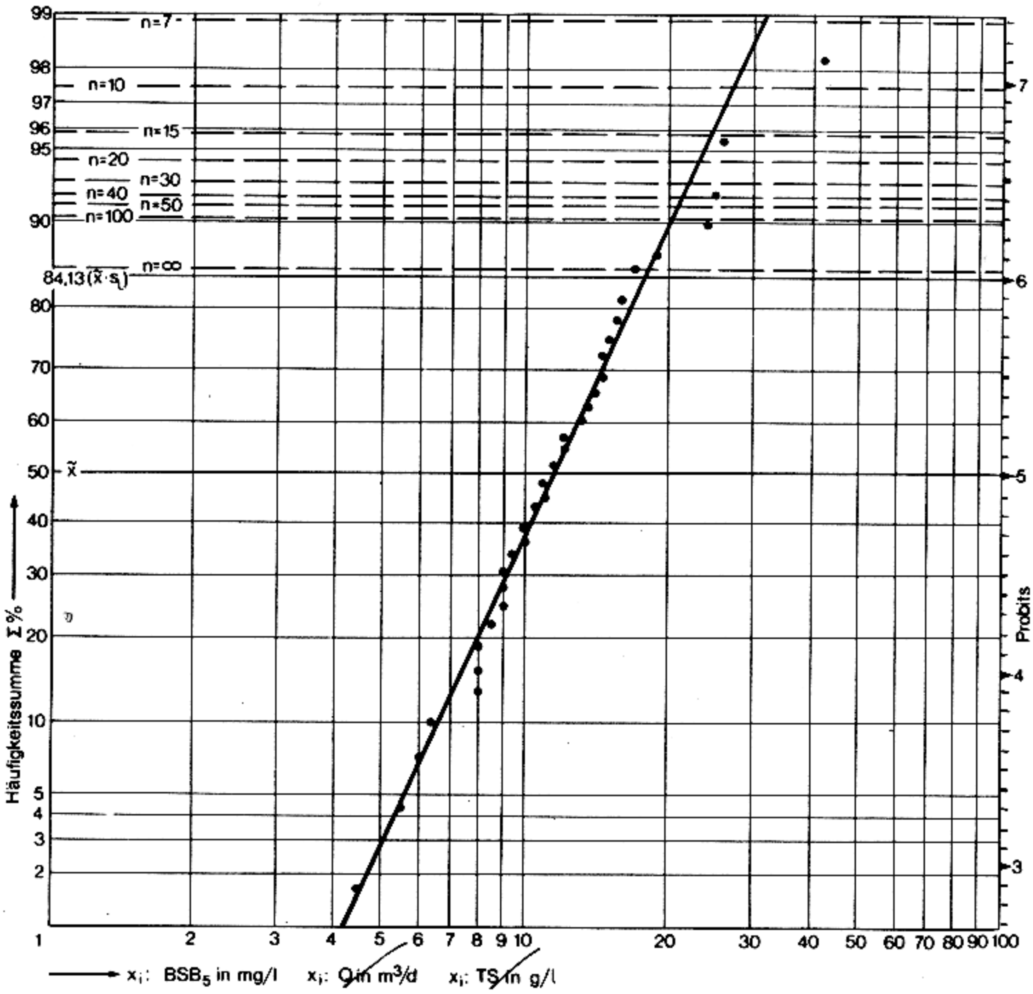


Figure 14: Example for applying the method described by Groche (1977) for deriving the 85 percentile of 34 BOD$_5$ analyses of a wastewater (**see figure 13*****)***

5. Working safety

An important issue in analytical laboratories is working safety, because many hazardous materials are used during analytical procedures. Safety aspects for laboratories are described by Hawkins (1988) while Spellman (1997) gives useful advices especially for the environmental laboratory. Moreover, in the "Standard Methods" a chapter about safety in laboratories is contained (Greenberg et al. 1985). Not only work in laboratories is health-threatening, but also sampling of wastewater (Gulyas 1999). First of all, pathogens imply an important risk during sampling. Therefore, measures have to be taken to keep minimum hygienic standards for sampling staff (water-tight gloves, protection clothes only worn in the wastewater-near environment but not in homes or during meals etc., disinfectants). Small wounds occurring during sampling have to be disinfected at once. Drinking and eating must be avoided during sampling. Moreover, sewers are risky because of the development of toxic gases like H_2S. Therefore, it is dangerous to enter sewers alone and without securing (fixing the person entering the sewer by a rope which is hold tight by a second person outside the sewer giving the possibility to remove the sampling person from the sewer in case of swooning or falling). Another important risk in sewers is the possible generation of methane gas in anaerobic zones. For detecting this gas, carrying along of methane sensors is recommended in sewers. Electrical devices used during sampling (e.g. pumps) must be secure from explosion. When corroding sample preservatives (concentrated acids or alkaline solutions) are used for sample stabilization, goggles must be available on the sampling site. Because of all these reasons, the sampling staff have be instructed concerning safety once a year. Vaccination of the sampling staff against wastewater-born diseases is advisable.

6. Controlling of process of a wastewater treatment plant

Figure 15 shows the activated sludge process for wastewater treatment. In the figure, some monitoring units, and sampling points of the process are given.
Some parameters for controlling the process of the activated sludge system are pH, dissolved oxygen concentration (DO) and acid capacity with electrodes. The pH value and acid capacity are often used for dosage of liquids to stabilise the activated sludge process. The concentration of dissolved oxygen is used to control the activity of the aeration system. If the aeration system produce more oxygen than the process needs, the operation costs increase.

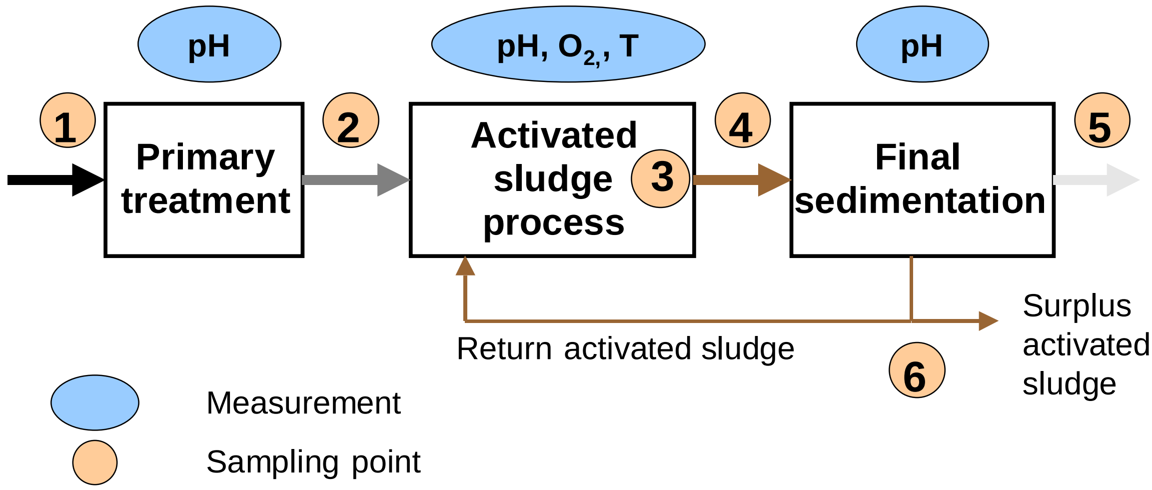


Figure 15: Flow chart of the activated sludge process

To get informations of the efficiency of the wastewater purification, taking samples at every stages of the process (influent, effluent, aeration tank, etc.) should be necessary. Parameters e.g. like ammonium, nitrate, nitrite, biochemical oxygen demand (BOD_t), chemical oxygen demand (COD), suspended solids (SS), the mixed liquor suspended solids (MLSS) and the sludge volume index (SVI) should be analysed regularly. (For further information: *http://www.atv-dvwk.de/download/betriebspers-klaeranl.pdf)*

Control measurement, monitoring and your own work

Support and control of the technical units as well as care and attention of human work are prerequiresite for the good working process. By creating a monitoring list of the maintenance of measurements could be helpful to organise the support and control e.g. of pH, oxygen and automatically working sampling units. A journal for sampling and the results of analyses will complete the monitoring.

Taking samples with human error and technical failure

The sampling points 1, 2, 4, 5 and 6 as shown in figure 15 can be piped with a bypass (by closing closed the valve) to take grab samples or can be connected with an automatically working sample taking system to take composite samples. At sampling points 3 a grab sample will be taken directly out of the aeration tank to determine the concentration of the mixed liquor suspended solids (MLSS) and the sludge volume index (SVI).

In the following you will find some hints for taking samples:

- Use a clean glass or plastic bottle for samples
- Label a bottle (e.g. point and kind of sampling, date and time, name of sample collector, parameters of analyses)
- Do not touch the inner of the bottle with your fingers (contamination)
- Through the first flush out of a pipe away and than take your sample
- Stir the sample before you fill it into the flask
- Fill the bottle up to the top. Oxygen in the flask let continue a biological process and the concentration of ammonium will decrease and the concentration of nitrate will increase
- Take care that the volume of the samples will be big enough for analyses
- Carry the sample as soon as possible to the laboratory or analyse it onsite (biological degradation still takes place!)
- Cool the sample, do not leave it in the sun
- Sample should be stirred, homogenised or filtrated before you start the analyse (depends on the kind of parameter for analyses)
- Check and clean automatically working sampling units frequently
- Control the cooling system (wrong temperature will change the ingredients
- Take care that the whole volume of the connected samples will not be bigger than the volume of the flask

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http://www.atv-dvwk.de/download/betriebspers-klaeranl.pdf
http://www.italocorotondo.it/tequila/module2/analysis/method_analysis.htm

Strongly recommended

http://www.chemeng.queensu.ca/courses/CHEE370/lectures/

Appendix

Determination	Container	Sample size mL	Preservation	Storage recommended/ Regulatory (1)
Acidity	P, G(B)	100	Refrigerate	24 h / 14 d
Alkalinity	P, G	200	Refrigerate	24 h / 14 d
BOD	P, G	1000	Refrigerate	6 h / 48 h
Boron	P	100	None required	28 d / 6 months
Bromide	P, G	-	None required	28 d / 28 d
Carbon, organic, total	G	100	Analyze immediately or refrigerate and add HCl to pH<2	7 d / 28 d
Carbon dioxide	P, G	100	Analyze immediately	Stat/ N.S.
COD	P, G	100	Analyze as soon as possible or add H_2SO_4 to pH<2, refrigerate	7 d / 28 d
Chlorine, residual	P, G	500	Analyze immediately	0.5 h / Stat
Chlorine dioxide	P, G	500	Analyze immediately	0.5 h / N.S.
Chlorophyll	P, G	500	30 d in dark	30 d / N.S.
Color	P, G	500	Refrigerate	48 h / 48 h
Conductivity	P, G	500	Refrigerate	28 d / 28 d
Cyanide				
Total	P, G	500	Add NaOH to pH>12, refrigerate in dark	24 h / 14 d (24 h If sulfide present
Amenable to chlorination	P, G	500	Add 100 mg $Na_2S_2O_3$/ L	Stat / 14 d (24 h If sulfide present
Fluoride	P	300	None required	28 d / 28 d
Hardness	P, G	100	Add HNO_3 to pH<2	6 months / 6months
Iodine	P, G	500	Analyze immediately	0.5 h / N.S.
Metals, general	P(A), G(A)	-	For dissolved metals filter immediately, add HNO_3 to pH<2	6 months / 6months
Chromium VI	P(A), G(A)	300	Refrigerate	24 h / 24 h
Copper by colorimetry				
Mercury	P(A), G(A)	500	Add HNO_3 to pH<2, 4ºC, refrigerate	28 d / 28 d

Nitrogen				
Ammonia	P, G	500	Analyze as soon as possible or add H_2SO_4 to pH<2, refrigerate	7 d / 28 d
Nitrate	P, G	100	Analyze as soon as possible or refrigerate	48 h / 48 h (28 d for chlorinated samples)
Nitrate + nitrite	P, G	200	Add H_2SO_4 to pH<2, refrigerate	None / 28 d
Nitrite	P, G	100	Analyze as soon as possible or refrigerate	None / 48 h
Organic Kjeldahl	P, G	300	Refrigerate, add H_2SO_4 to pH<2	7 d / 28 d
Oil	G	500	Analyze as soon as possible, refrigerate	6h / N.S.
Oil and grease	G, wide-mouth calibrated	1000	Add H_2SO_4 to pH<2, refrigerate	28 d / 28 d
Organic compounds				
Pesticides	G (S), TFE-lined cap	-	Refrigerate; 1000 mg ascorbic acid/ L if residual chlorine present	7 d / 7 d until , 40 d after extraction
Phenols	P, G	500	Refrigerate, add H_2SO_4 to pH<2	7 d / 28 d
Purgeables by purge and trap	G, TFE-lined cap	50	Refrigerate, add HCl to pH<2, 1000 mg ascorbic acid/ L if residual chlorine present	7 d / 14 d
Oxygen, dissolved:	G, BOD bottle	300		
Electrode			Analyze immediately	0.5 h / Stat.
Winkler			Titration may be delayed after acidification	8 h / 8 h
Ozone	G	1000	Analyze immediately	0.5 h / N.S.
pH	P, G	-	Analyze immediately	2 h / Stat.
Phosphate	G(A)	100	For dissolved phosphate filter immediately; refrigerate	48 h / N.S.
Salinity	G, wax seal	240	Analyze immediately or use wax seal	6 months / N.S.
Silica	P	-	Refrigerate, do not freeze	28 d / 28 d
Sludge digester gas	G, gas bottle	-	-	N.S.

Solids	P, G	-	Refrigerate	7 d / 2-7 d see cited reference
Sulfate	P, G	-	Refrigerate	28 d / 28 d
Sulfide	P, G	100	Refrigerate, add 4 drops 2N zinc acetate/100 mL, add NaOH to pH>9	28 d / 7 d
Taste	G	500	Analyze as soon as possible, refrigerate	24 h / N.S.
Temperature	P, G	-	Analyze immediately	Stat. / Stat.
Turbidity	P, G	-	Analyze same day; store in dark up to 24 h, refrigerate	24 h / 48 h

Refrigerate= storage at 4 ºC, in the dark.; P= plastic (polyethylene or equivalent); G= glass; G(A) or P(A): rinsed with 1+1 HNO_3; G(B)= glass, borosilicate; G(S)= glass rinsed with organic solvents; N.S.= not stated in cited reference; stat= no storage allowed; analyzed immediately.

(1)Environmental Protection Agency, Rules and Regulations. *Federal Register 49, No.209, October 26, 1984.* See this citation for possible regarding container and preservation requirements.

CHARACTERISTIC, ANALYTIC AND SAMPLING OF WASTEWATER

Holger Gulyas
Claudia Wendland

Domestic wastewater sources

Urine

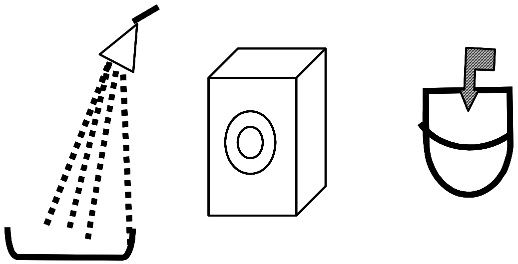
Faeces

Toilet paper (if used)

Flush water

black water (from toilets)

domestic wastewater



greywater

kitchen, shower, wash basin and laundry

Domestic wastewater sources

Volume l/(P*year) / Yearly Loads kg/(P*year)	Greywater 25.000 -100.000	Urine ~ 500	Feaces ~ 50 (option: add biowaste)
N ~ 4-5	~ 3 %	~ 87 %	~ 10 %
P ~ 0,75	~ 10 %	~50 %	~ 40 %
K ~ 1,8	~ 34 %	~ 54 %	~ 12 %
COD ~ 30	~ 41 %	~ 12 %	~ 47 %
	Treatment → Reuse / Water Cycle	Treatment → Fertiliser	Biogas-Plant Composting → Soil-Conditioner

Domestic wastewater characteristics

From Henze 1982, 2001

Analysis parameters		Wastewater type			
	Unit	Concentrated*	Moderate	Diluted	Very diluted
BOD5	mg O_2/l	350	250	150	100
COD	mg O_2/l	740	530	320	210
TOC	g C/m^3	250	180	110	70
Suspended Solid	g SS/ m^3	450	300	190	120
Volatile Suspended Solid	g VSS/ m^3	320	210	140	80
Alkalinity	eqv/ m^3 *	37	37	37	37
Conductivity	mS/m **	120	100	80	70
Total Nitrogen	g N/ m^3	80	50	30	20
Total Phosphorous	g P/ m^3	23	16	10	6
Fecal coliforms (E.coli)	CFU/100ml	$5*10^8$			10^6
Fecal streptococci	CFU/100ml	10^8			10^6

* COD of Jordanian Wastewater = 1600-1930 mg/l (Halalsheh 2002)

Greywater characteristic

	Germany [Nolde 1996]		Sweden [Fittschen 1997]	USA [Brandes 1978]
	using water saving devices	using water saving devices, without kitchen greywater		
BOD_5 (mg/l)	280-360	150-250	164,6*	162
COD (mg/l)	500-600	250-430	361	366
TOC (mg/l)	-	-	-	-
N_{total} (mg/l)	8-18	-	18,1	-
P_{total} (mg/l)	2,5-4,5	-	3,9	-
Fecal coliforms (E.coli) (CFU/ml)	10^2-10^6	10^4-10^6	-	-
Fecal streptococci (CFU/ml)	-	-	-	$1,4*10^6$

Blackwater characteristic

Parameter	Vacuum toilet 0.7-1.0 l/flush [Wendland et al 2003]	Flushing toilet 4-6 l/flush [Otterpohl 2003]
COD (mg/l)	10.760	1.827
TOC (mg/l)	3.300	
N_{total} (mg/l)	1.540	274
P_{total} (mg/l)	254	46
K (K_2O) (mg/l)		85
Fecal coliforms (E.coli) (CFU/100ml)	$2*10^8$	

Preservation techniques of wastewater samples

Parameter	Preservation Method	Period of stability of parameter [d]
Oxidation with $KMnO_4$	no preservation -18 to -22°C acidified (pH 2) alkaline (pH 12) $HgCl_2$	0 32 16 8 8
COD	no preservation -18 to -22°C acidified alkaline	0 32 0 0
TOC	no preservation -18 to -22°C acidified alkaline	0 32 2 8
BOD	no preservation -18 to -22°C acidified alkaline	0 32 4 8

Parameter	Preservation Method	Period of stability of parameter [d]
ammonia	no preservation -18 to -22°C acidified alkaline $HgCl_2$	0 0 16 32 32
nitrate	no preservation -18 to -22°C acidified alkaline $HgCl_2$	0 8 1 4 0
sulfate	no preservation $HgCl_2$	0 32
anionic surfactants	no preservation acidified $HgCl_2$	0 0 32

Recommendations of the "Working Party on Stabilization of Samples from the Hydrochemistry Team of the German Chemists Association" (1981) for preservation of primary clarifier effluent for analyzing different parameters

Exercise: Sample preparation and sample division and its impact on the TOC analyse

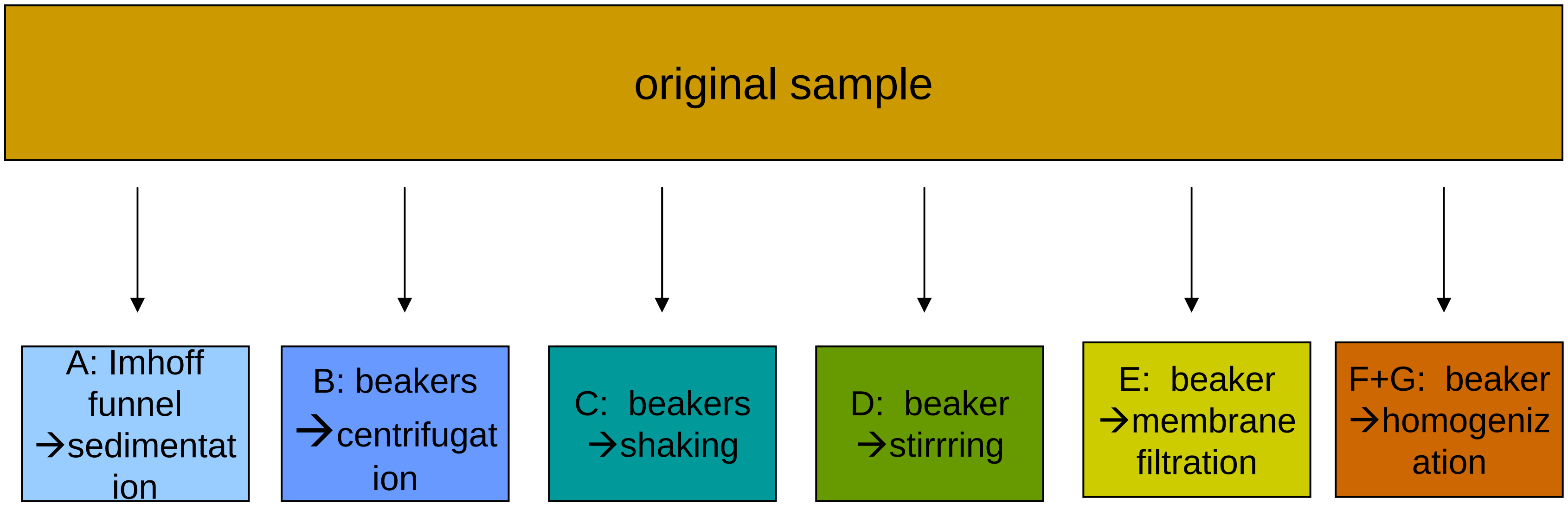
Introduction

Wastewaters usually contain particles. The kind of partitioning a wastewater sample will influence the result of the wastewater analyses. Usually not the entire sample shipped to the laboratory will be analysed for a particular wastewater parameter, but only a small part of the sample. The **kind of partitioning** will especially **influence the analytical results** when particles suspended in the wastewater contain analytes to be determined in a particular analytical procedure. When there are flocs with organic material present in the wastewater which will be either enriched or partially lost by partitioning the sample (which is an important step during sample preparation), organic sum parameters of the sample like TOC or COD will show higher or lower concentrations.

For showing these effects a wastewater sample with suspended particles has to be divided into 6 subsamples. These subsamples (A-G) will be pretreated differently and analysed for TOC.

Division in 6 subsamples

One sample was taken from a municipal wastewater treatment plant in a container. From this container sub-samples are poured into different receptacles. **Before each pouring of wastewater sample, the container has to be shaken vigorously** in order to ensure that the original sample is homogeneous before taking a sub-sample!



Sample A

First, one liter of the original sample is poured from the container to an Imhoff funnel A. At this time a stop-watch is started. Then the Imhoff funnel is allowed to stand quietly in a wooden rack. After exactly 30 min the volume of flocs sedimented to the bottom of the funnel is read. Moreover, two time 50 ml of the supernatant in the funnel close to the liquid surface are transferred to two TOC analyser sampling tubes by means of a 50ml glass pipette and a Peleus ball. The glasses are marked with "A1" and "A2". Later these glasses with sub-samples are put into the autosampler of a TOC analyser.

TOC Analyser

original sample → Imhoff funnel (1L) → 30 min → Sample A with sedimented flocs → transfer → **A1** (50mL) / **A2** (50mL)

Sample B

150 ml of the sample are transferred to two polyethylene centrifugation beakers each by means of a graduated cylinder. The centrifugation beakers are then closed with their screw caps, inserted opposite one another into the rotor by means of particular fixing devices, and finally centrifuged for 15 min at 4000 rounds per minute. After the rotor has come to a standstill, the centrifugation beakers are taken out from the rotor very carefully in order to avoid mixing of the pellet with the supernatant. From the supernatant of each beaker 50 ml are transferred to TOC sampling glasses (marked "B1" and "B2") by a glass pipette.

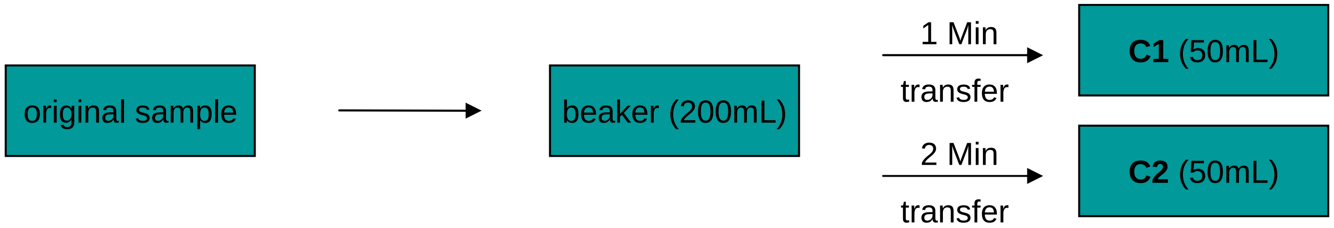
Centrifuge

original sample → centrifugation beaker (150mL) → equalize → centrifugation beaker (150mL) → transfer → **B1** (50mL)

original sample → centrifugation beaker (150mL) → equalize → centrifugation beaker (150mL) → transfer → **B2** (50mL)

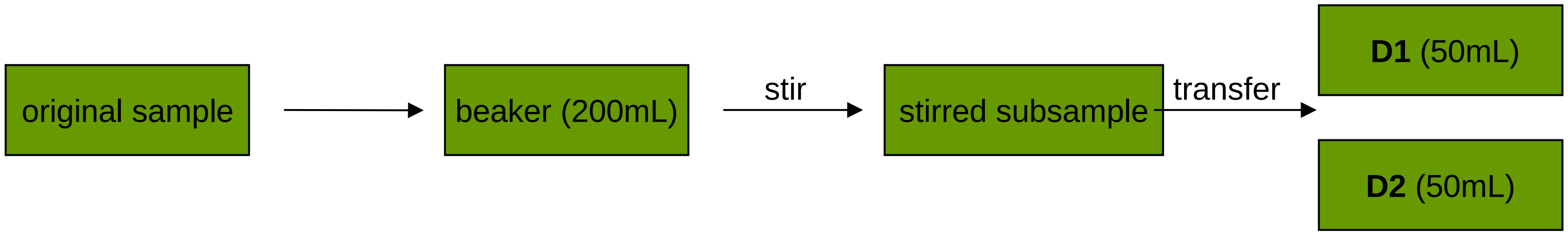
Sample C

200 ml of the sample are poured into beaker C. The sample in the beaker is not agitated at all in this experiment! After about one minute a 50 ml sample is pipetted from the beaker into the TOC sampling glass "C1", after another minute without agitation, another 50 ml sample is transferred to TOC sampling vial "C2" by means of a glass pipette. Also these samples will be analyzed for their TOC concentration later on.



Sample D

200 ml of the sample are poured into beaker D (using the 200 ml mark of the beaker). In contrast to beaker C, beaker D contains a magnetic stirrer bar and is placed on a magnetic stirrer. From this stirred sub-sample 50 ml are transferred to TOC sampling glasses "D1" and "D2" each being analysed in the TOC analyser later on.



Sample E

200 ml of the sample are poured into beaker E. This beaker is not stirred and is allowed to stand for a 30 min for sedimentation of particles before about 120 to 150 ml of the supernatant with low particle content are transferred to a filtration funnel containing a cellulose acetate or cellulose nitrate membrane filter (pore width: 0.45 µm).

When membrane filtration is complete, from the filtrate 50 ml are transferred to TOC sampling glasses "E1" and "E2" each.

Filtration funnel

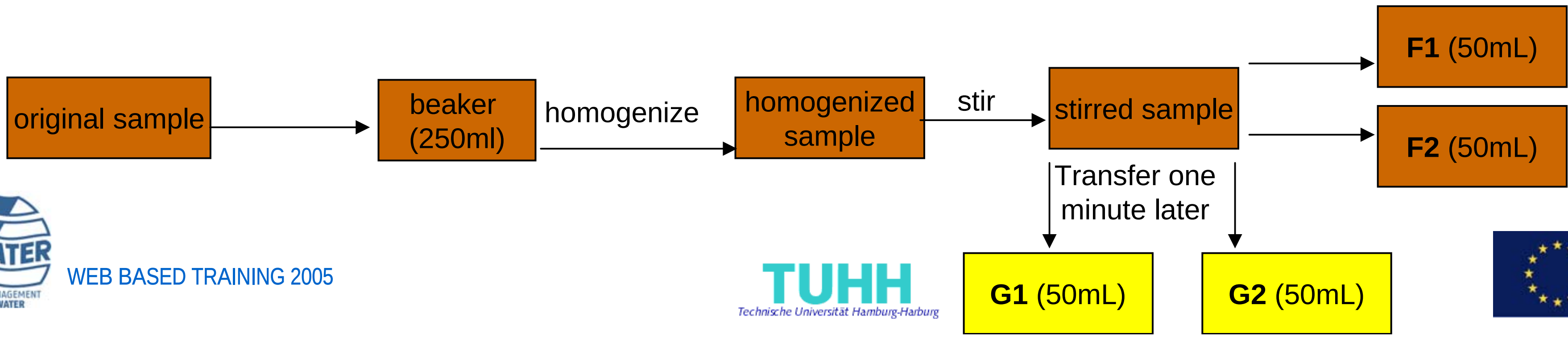
original sample → beaker (200mL) → 30 Min → sample E with sedimented particles → transfer → 120 – 150 ml to filtrration funnel → filtrate → **E1** (50mL) / **E2** (50mL)

Sample F and G

Homogenizer

250 ml of the original wastewater sample are poured into beaker F. Into this sub-sample a homogenizer with rapidly rotating blades ("Ultraturrax") is inserted.

The Ultraturrax is operated for 2 min decreasing the particle size of the coarse suspended wastewater particles (consequently leading to smaller sedimentation velocities). After removing the Ultraturrax from the beaker a magnetic stirrer bar is added to the homogenized sub-sample, the beaker placed on a magnetic stirrer and stirred. From the stirred homogenized sub-sample 50 ml are transferred to TOC sampling glasses "F1" and "F2" each. The stirrer is switched of and after about one minute another sub-sample is transferred to a TOC sampling glass ("G1"). Another minute later once more 50 ml are transferred from the non-stirred homogenized sub-sample to TOC sampling glass "G2".



Results

The following results have been obtained in the laboratory for the different sample division methods with these three different wastewaters.

Sample	TOC [mg/l] Wastewater Sample #1	TOC [mg/l] Wastewater Sample #2	TOC [mg/l] Wastewater Sample #3
A1	35.7	54.1	34.3
A2	37.2	51.5	32.3
B1	20.9	18.7	27.7
B2	21.5	17.8	19.9
C1	753	583	83.7
C2	69.8	370	56.8
D1	458	736	621
D2	467	742	567
E1 (not analysed in duplicate)	20.1	19.6	17.7
F1	415	643	620
F2	445	721	596
G1	129	1,114	889
G2	102	149	330

Questions and solutions

Calculate means of TOC concentrations analysed in duplicate!

Calculate coefficients of variation.

(This is done usually with more analyses!)

	Wastewater Sample #1		Wastewater Sample #2		Wastewater Sample #3	
	Mean Mg/l	**Coefficient of variation**	**Mean** mg/l	**Coefficient of variation**	**Mean** mg/l	**Coefficient of variation**
A	36	2.9%	53	3.5%	33	4.2%
B	21	2.0%	18	3.5%	24	23.2%
C	411	117.4%	477	31.6%	70	27.1%
D	463	1.4%	739	0.6%	594	6.4%
E						
F	430	4.9%	682	8.1%	608	2.8%
G	116	16.5%	75	139.3%	610	64.9%

Note: coefficient of variation is: standard deviation / mean

Questions and solutions

Interprete different TOC means measured for one sample!

You can see that there are very high variations possible depending on the type of preparing and sampling.

e.g. The TOC analyses of A and B (supernatant after sedimentation and centrifugation) are very low because most of the particles are missing. The main TOC is located in the particles. The analyses of C and D show high coefficients of variations because they are not homogenised.

The analyses of E and B are relatively close together. So if the membran filtration is too complicated, it is also possible to centrifuge the sample. In the supernatant there are almost no particles. With analysing the supernatant, the mistake is very low compared to membrane filtration.

Questions and solutions

Calculate part of TOC associated to particles! Which types of sample preparation/division are appropriate for this calculation?

F is the most representative analyse for the original total COD of the sample and E is the membrane filtrated sample which means analyse without particles. So the difference of F and E is the part of TOC that is associated to the particles.

If you have further considerations about the experiment, please write a message and post it in Forum A!

The End

Lesson A 2

HYGIENE AND RISK MANAGEMENT

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Keywords
Basic Hygiene, Water and Faecal-Related Diseases, Conventional Sanitation, Ecological Sanitation, Risk Management

Table of content

Overview and Summary

Hygiene is the science of preventing and protecting the health of people through control of the environment i.e. our physical surroundings: air, water; and land, biological ecosystems: animals and plants, and social structures. Environment influences the health of human beings. Normally, humans can react physically, socially and mentally on changed environmental influences, in order to adapt oneself and herewith avoiding damages. But, there are also many environmental influences, which can overcome human's adaptation and defence capacity and cause diseases. There are two types of diseases: infectious and non-infectious. An infectious disease is one which can be transmitted from one person to another or, sometimes, to or from animals. All infectious diseases are usually caused by pathogenic organisms. Pathogens that are solely responsible for the transmission of diseases are mostly bacteria, viruses, protozoa and helminths and a disease is transmitted by the passing of these organisms from one person's body to another. The health problems related to environmental pollution are considered to be the result of contamination of water, food, and air with toxic chemicals. The resulting diseases are non-infectious.

Human excreta are the principal vehicle for transmission and spread of a wide range of infectious diseases. Therefore, wastewater has to be treated before discharging it to the environment in order to prevent and control the spread of diseases. The conventional approach of wastewater treatment has contributed to ensuring public health in industrial countries. However, due to the lack of financing for expensive conventional centralised sanitation system most of the wastewater is discharged without any treatment mostly in developing countries. This contributes largely about 1.2 billion people without access to clean drinking water. Almost 80 % of diseases throughout the world are water-related. Water-borne diseases account for more than 4 million infant and child deaths per year in developing countries. In ecological sanitation, human excreta is separated and treated at or near the source which avoids spreading of pathogens in the environment. The separated human excreta, which are easily biodegradable, can be treated biologically. When the organic matters decompose, due to self heating capacity heat is produced. This self produced heat will create self-hygienization of the organic matter. The mostly applied methods for the sanitisation of separated faecal waste are composting and dehydration.

In practice, complete elimination of pathogens may not be possible in any kind of sanitation. Therefore, secondary barrier such as personal, food and domestic hygiene must be included to destroy the pathogens completely. Hygiene awareness and proper education are the crucial points for faecal waste management. Additionally, guidelines and recommendations for the handling and reuse of wastewater can work as a tool to minimise risks.

1. General hygiene

1.1 Definition

Health is defined in the WHO (World Health Organization) constitution of 1948 as: a state of complete physical, social and mental well-being, and not merely the absence of disease or infirmity.

Hygiene is the science of preventing and protecting the health of people through control of the environment.

Environment is our surroundings described as physical surroundings (air, water and land), biological surroundings (animals and plants), and social surroundings.

1.2 Areas of hygiene

The Hygiene comprises the following areas:

- **Environmental hygiene:** it deals with the methods of defence from harmfulness (heat, cold, weather, rays, poison or pathogens) that originate from land, air and water.
- **Social hygiene:** it avoids damages of the social environment of the human being. In practice social and environmental hygiene are inseparable.
- **Individual hygiene:** it comprises of body cleaning and its clothing. Always keep your hands clean: after using the toilet, before cooking, before meals and after contact with raw or uncooked food wash your hands with **soap** or **detergent**
  Besides body cleaning, as mentioned above, there is clothing. The cloth should have good qualities. Enough rest, sleep, sport etc. belong to individual hygiene too.

- **Food hygiene:** it protects us not only from insufficient, unsuitable, rotten or poisoned food, but also changes our deficient dietary habit. Kitchen hygiene also belongs to food hygiene.
- **Occupational and domestic hygiene:** working and residing place should be hygienic.

1.3 Environmental influences and their impact on human health

Normally, humans can react physically, socially and mentally on changed environmental influences, in order to adapt themselves and thus avoiding damages. But, there are also many environmental influences, which can overcome human's adaptation and defence capacity and cause diseases.

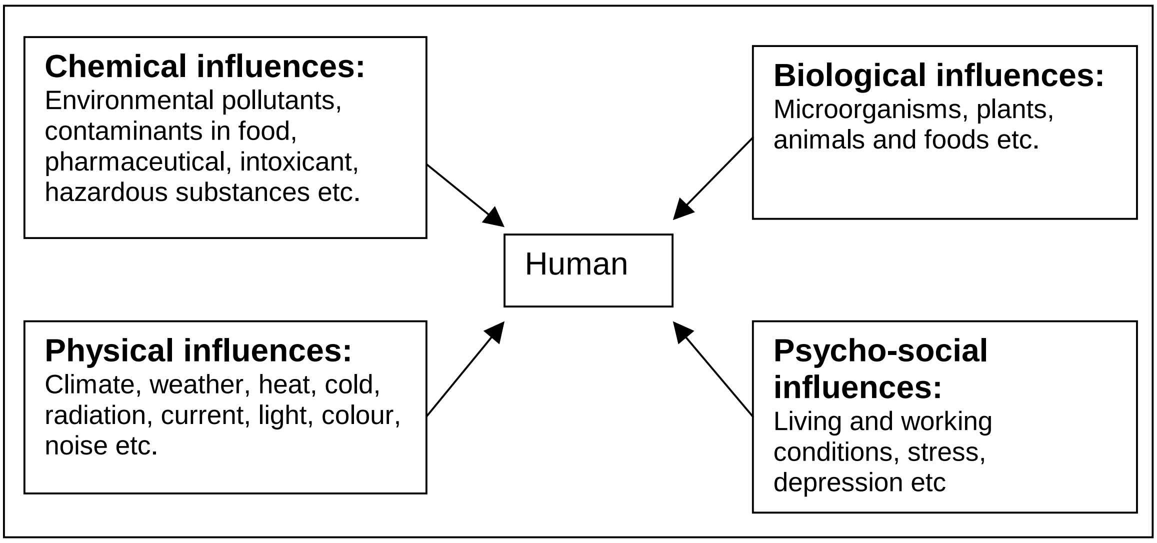

Figure 1: Environmental influences on human

1.4 Infectious and non-infectious diseases

1.4.1 Infectious diseases

An infectious disease is one, which can be transmitted from one person to another or, sometimes, to or from animals. All infectious diseases are usually caused by microbes. Most microbes are essential components of our environment and do not cause diseases. Those that cause diseases are called pathogenic organisms (pathogens). Pathogens that are solely responsible for the transmission of diseases are mostly bacteria, viruses, protozoa and helminths and a disease is transmitted by transfer of these organisms from one person's body to another.

1.4.1.1 Water-related infections

Water related infections are transmitted by water through following routes:

Water-borne: When the pathogen is ingested by a person drinking water, this is called water-borne transmission. One important control strategy is providing good quality of drinking water.

Water-washed: Water-washed route is related to the quantity of water. Good personal and domestic hygiene requires the availability and use of water for bathing, clothes washing and utensil washing.

Water-based: A water based disease is one, whose pathogens spend part of their lifecycle in the water, usually in a snail or other aquatic animals. The water-based diseases are all caused by parasitic worms. Pathogens usually enter the water from faeces and urine of infected persons.

Water related insect vector: in this transmission mechanism insects, which breed in water or bite near water, spread diseases.

Table 1 shows types of water-related transmission route for infections, causes and the control strategies..

Table 1: Water-related infection: transmission and control strategy (Carincross and Feachem, 1993)

Transmission Route	***Diseases***	***Control***
Water borne	Cholera Typhoid Dysenteries Diarrhoeas Infectious hepatitis	Improve drinking water quality. Prevent use of other contaminated sources.
Water washed	Skin and eye infections Louse borne typhus	Increase quantity and use of water. Improve personal hygiene by increasing accessibility and availability of water.
Water based	Schistosomiasis (penetrating skin) Guinea worm (ingested)	Decrease contact with contaminated water in the environment. Control appropriate aquatic animals. Reduce excreta contamination of surface water.
Water related insect vector	Yellow fever River blindness Malaria Sleeping sickness	Eliminate breeding sites by improving Drainage. Keep people away from the breeding or biting sites. Use mosquito netting.

1.4.1.2 Classification of water-related infections

Each water-related infection can be assigned to one of the following categories:

Faecal-oral, water-washed, water-based and insect-vectored. Table 2 classifies major water-related infections and assigns them to their category in addition to linking them to the infectious agent that causes the disease.

Table 2: Classification of water-related infection (Carincross and Feachem,1993)

Category	***Infection***	**Pathogenic agent**
Fecal-oral	Diarrheas and dysentaries	
(water-born or water-washed)	*Amoebic dysentary*	Protozoon
	Campylobacter enteritis	Bacterium
	Cholera	Bacterium
	E. coli diarrhea	Bacterium
	Giardiasis	Protozoon
	Rotavirus diarrhea	Virus
	Salmonellosis	Bacterium
	Shigellosis	Bacterium
	Yersinosis	Bacterium
	Enteric Fevers	
	Typhoid	Bacterium
	Paratyphoid	Bacterium
	Poliomyelitis	Virus
	Hepatitis A	Virus
	Leptospirosis	Spirochete
Water-washed:	Infectious skin diseases	Miscellaneous
a) skin and eye infections	Infectious eye diseases	Miscellaneous
b) other	Louse-borne typhus	Rickettsia
Infectious skin diseases	Louse-borne relapsing fever	Spirochete
Water-based:		
a) penetrating skin	Schistosomiasis	Helminth
b) ingested	Guinea worm	Helminth
	Clonorchiasis	Helminth
	Others	Helminth
Water-related insect vector		
a) biting near water	Sleeping sickness	Protozoon
b) breeding in water	Filariasis	Helminth
	Malaria	Protozoon
	River blindness	Helminth
	Mosquito-borne	
	Yellow fever	Virus
	Dengue	Virus
	Others	Virus

1.4.1.3 Excreta-related infections

Diseases which are faecal-orally transmitted usually enter the environment by the excretion of faeces from infected persons.

Table 3: Classification of excreta-related infections

Category	**Infection**	**Patho-genic agent**	**Dominant transmission mechanisms**	**Major control measures (engineering measures in italics)**
Faecal-oral (non-bacterial) Non-latent, low infectious dose	Poliomyelitis Hepatitis A Rotavirus diarrhoea Amoebic dysentery Giardiasis Balantidiasis Enterobiasis Hymenolepiasis	V V V P P P H H	Person to person contact Domestic contamination	*Domestic water supply* *Improved housing* *Provision of toilets* Health education
Faecal-oral (bacterial) Non-latent, medium or high infectious dose, moderately persistent and able to multiply	Diarrhoeas and dysenteries *Campylobacter enteritis* *Cholera* *E. col i diarrhoea* *Salmonellosis* *Shigellosis* *Yersiniosis* Enteric fevers *Typhoid* *Paratyphoid*	 B B B B B B B B	Person to person contact Domestic contamination Water contamination Crop contamination	*Domestic water supply* *Improved housing* *Provision of toilets* *Excreta treatment prior to re-use or discharge* Health education
Soil-transmitted helminths Latent and persistent with no intermediate host	Ascariasis Trichuriasis Hookworm Strongyloidiasis	H H H H	Yard contamination Ground contamination in communal defacation area Crop contamination	*Provision of toilets with clean floors* *Excreta treatment prior to land application*
Beef and pork tapeworms Latent and persistent with cow or pig intermediate host	Taeniasis	H	Yard contamination Field contamination Fodder contamination	*Provision of toilets* *Excreta treatment prior to land application* Cooking and meat inspection
Water-based helminths Latent and persistent with aquatic intermediate host(s)	Schistosomiasis Clonorchiasis Diphyllobothriasis Fasciolopsiasis Paragonimiasis	H H H H H	Water contamination	*Provision of toilets* *Excreta treatment prior to discharge* *Control of animals harbouring infection* Cooking
Excreta-related insect vectors	Filariasis (transmitted by *Culex* *pipiens* mosquitoes) Infections in Categories I-V.especially I and II, which may be transmitted by flies and cockroaches	H M	Insects breed in various faecally contaminated sites	*Identification and elimination of potential breeding sites* Use of mosquito netting

B: Bacterium V: Virus H: Helminth P: Protozoon M: Miscellaneous

Those of the excreta related disease, which are also water-related, can be controlled by improvements in water supply and hygiene. But these and the other excreta-related diseases can also be affected by improvements in excreta management. If we classify these excreta-related diseases by their routes of transmission in and through the environment, it becomes clearer that intervention measure might be most effective in controlling or preventing the disease. Table 3 shows the classification of excreta-related infections

1.4.1.4 Transmission routes of pathogens

The routes of infection with the pathogens found in faeces are illustrated in figure 2. The arrows indicate the routes of pathogen transmissions, whereas the crossing bars represent barriers to prevent the spread of pathogens. The physical barriers can be applied to intercept the routes of transmission. An effective primary barrier can prevent pathogens spreading. However, secondary barrier like personal hygiene and food hygiene must be sufficiently implemented to prevent spreading diseases. Before the pathogens gain access to the environment, there are many primary prevention facilities, which can effectively block their pathway.

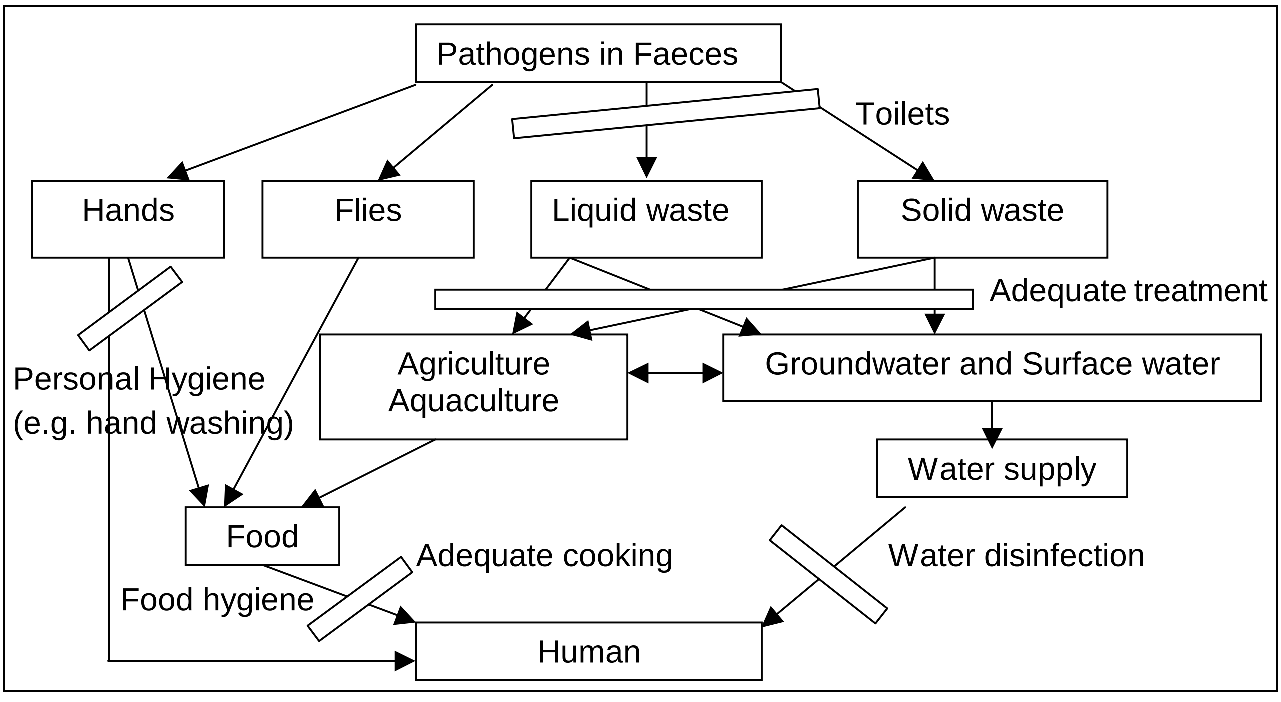

Figure 2: Routes of Pathogens transmission from faeces to human (Adopted from Franceys et al., 1992 and modified)

1.4.1.5 Survivability rate of pathogens in environment

Survival of the pathogens in the environment is of great concern in the management of faecal waste. Within the environment and treatment methods, they have varying survivability rate (see table 4). Survivability rate of pathogens is controlled by many factors such as:

- competition for food (limited food sources limit microbial numbers);
- predator-prey relationships (some organisms consume others as food sources);
- antagonism (some organisms produce toxic substances which inhibit other organisms);
- environmental conditions (Oxygen concentration, nutrient levels, temperature, moisture, pH).

In order to eliminate pathogens, faecal containing waste must be treated in a controlled environment, where the above mentioned factors act effectively. This can be done in many ways. However, low-tech and low-cost are the deciding factors.

Table 4: Survival time (d) of pathogens in day by different disposal/treatment conditions (adapted from Esrey et al., 1998)

Condition	Bacteria	Viruses	Protozoa*	Helminths**
Soil	400	175	10	many months
Crops	50	60	not known	not known
Night soil, faeces, sludge 20-30 ^{O}C	90	100	30	many months
Composting Anaerobic at ambient temperatures	60	60	30	many months
Thermophilic composting 50-60 ^{o}C maintained for several days	7	7	7	7
Waste stabilisation ponds Retention time > 20 days	20	20	20	20

* excluding Cryptosporidium parvum
** mainly Ascaris; other parasitic eggs tend to die quicker

1.4.2 Non-infectious Diseases

The health problems related to environmental pollution are considered to be the result of contamination of water, food, and air with toxic chemicals. The resulting diseases are non-infectious. Some non-infectious illnesses associated with toxic chemical pollution have a relatively sudden and sever onset, and the acute or immediate health effects can be readily traced to a specific contaminant. Heavy metals are particularly notorious in this regards. Other non-infectious diseases may take years to develop and can involve chronic or long-lasting health problems. Generally, various synthetic organic substances cause this type of problem, even in extremely small concentrations. Some organics are considered to be carcinogenic, having the potential to cause cancer in humans.

2. Wastewater management and associated hygienic risk

2.1 Conventional sanitation

Due to disease risks caused by faecal wastewater, in large European cities sewers were constructed to drain the wastewater away from the people's surroundings to the nearby water courses, and ultimately into the sea. Later it was found that discharging raw wastewater had deteriorated aquatic environment of the receiving water body, and at the same time it caused diseases to the people, who received their drinking water from the same river downstream. Because of drinking water contamination, epidemics of cholera had periodically caused heavy losses of life in large European cities. The outbreak of cholera in 1892 for instance, took place all over in Hamburg, where drinking water supply was extracted from the river Elbe. To protect these rivers from the pollution as well as the public health from water borne diseases, the wastewater was since then treated at the end of the sewer before discharging it into the river. This tradition has been widely established as a standard way of managing wastewater world wide. However, most of the wastewater is discharged without any treatment mostly in developing countries.

Centralised wastewater management systems have been built and operated for more than hundred years. In the mean time, because of advanced technological development, the wastewater management has reached a high standard in many industrialised countries. However, in developing countries the present situation is still similar to that of the currently industrialised countries in the 19th century in many respects. About 95 % of wastewater in developing countries is still discharged without any treatment into the aquatic environment . This contributes largely about 1.2 billion people without access to clean drinking water. Almost 80 % of diseases throughout the world are water-related. Water-borne diseases account for more than 4 million infant and child deaths per year in developing countries.

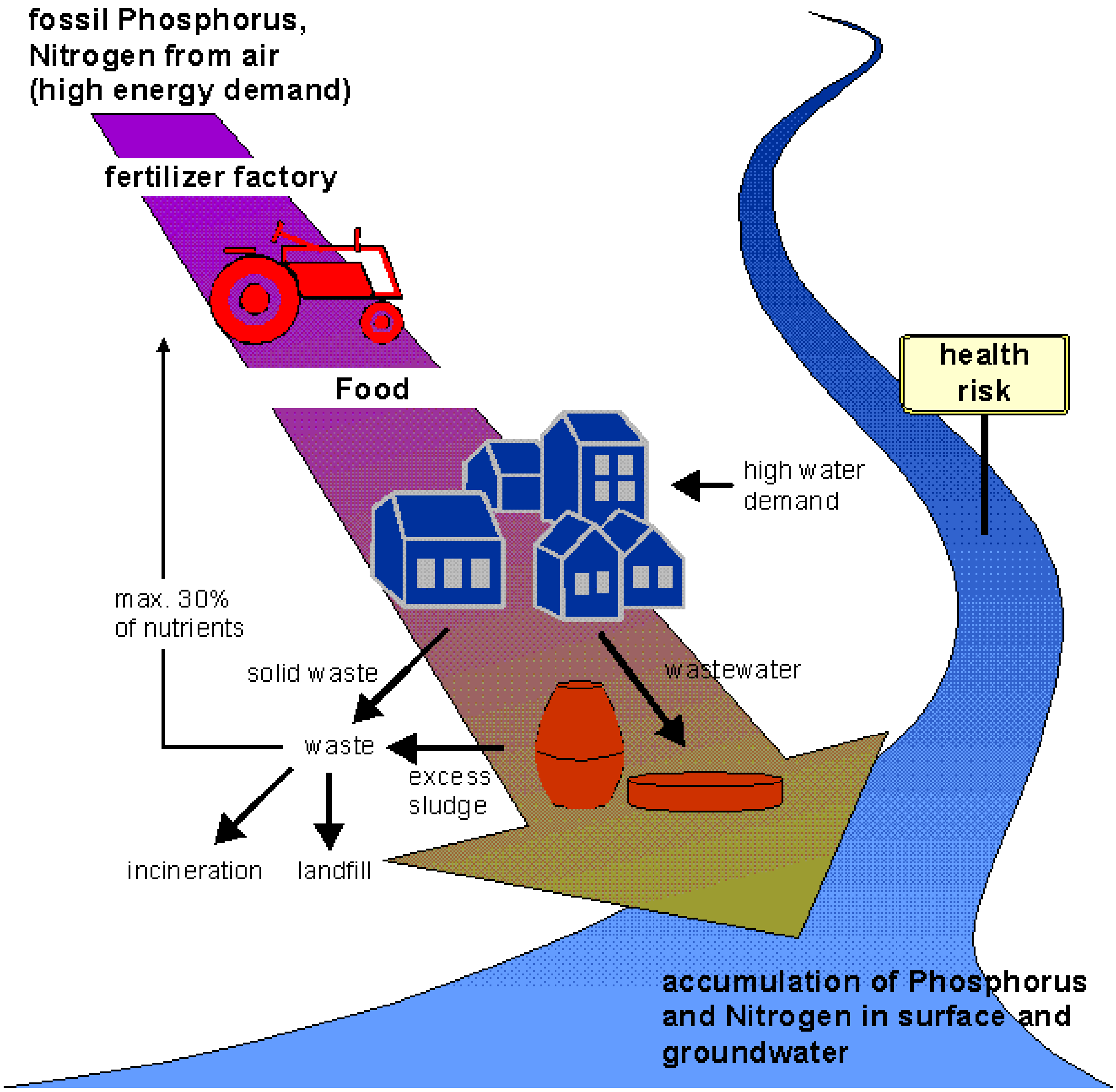

Figure 3: Conventional Sanitation System (source Otterwasser GmbH)

In conventional sanitation systems, a huge amount of fresh water is used as a transport medium and a sink to dispose of wastes (see figure 3). In this process a small amount of human faeces is diluted with a huge amount of water. Therefore, it is hardly possible to prevent contaminants from emitting into surface and ground water bodies. As a result a huge amount of fresh water is contaminated and deemed unfit for other purposes. Moreover, due to the pollution and hygienic problems in receiving waters, surface water can no longer be used as a source for drinking water supply. Huge investments have to be made to improve the surface water quality in order to use it as drinking water.

Conventional sanitation systems show clear deficiencies in recovery of nutrients and organic matter, which are valuable fertiliser and soil conditioner respectively. Even the best affordable treatment plants discharge those to the aquatic environment, where they are lost for ever and cause severe problems. Those nutrients, which are captured in sludge, are often contaminated with heavy metals such as Cadmium (Cd) and organic compounds such as PCB (polychlorinated Biphenyl), which pose potential toxic risks to plants, animals and humans. Therefore, large amounts of sewage sludge are disposed of in landfills or incinerated. Only a smaller part is applied to agricultural land.

Also decentralised sanitation systems, such as pit toilets, septic tanks, etc. cause pollution i.e. nutrients and pathogens seeping from these systems contaminate the groundwater and nearby surface water - they cannot destroy pathogens. Basically septic tanks are designed only to collect household wastewater, settle out the solids and anaerobically digest them to some extent, and then leach the effluent into the ground, not to destroy pathogens contained in wastewater. Therefore, septic tank systems can be highly pathogenic, allowing the transmission of disease causing bacteria, viruses, protozoa and intestinal parasites through the system. It is reported that there are 22 million septic system sites in the USA issuing contaminants such as bacteria, viruses, nitrate, phosphate, chloride, and organic compounds into the environment. Another problem is home chemicals with hazardous constituents, which are discharged to toilets and contribute to severe groundwater contamination in sanitation using septic tanks. According to the EPA, states of the USA reported septic tanks as a source of groundwater contamination more than any other source, with 46 states citing septic systems as sources of groundwater pollution (see figure 4), and nine of them to be the primary source of groundwater contamination in their state. It has to be noted that occasionally problems with broken septic tanks occur leading to infiltration of nearly untreated wastewater.

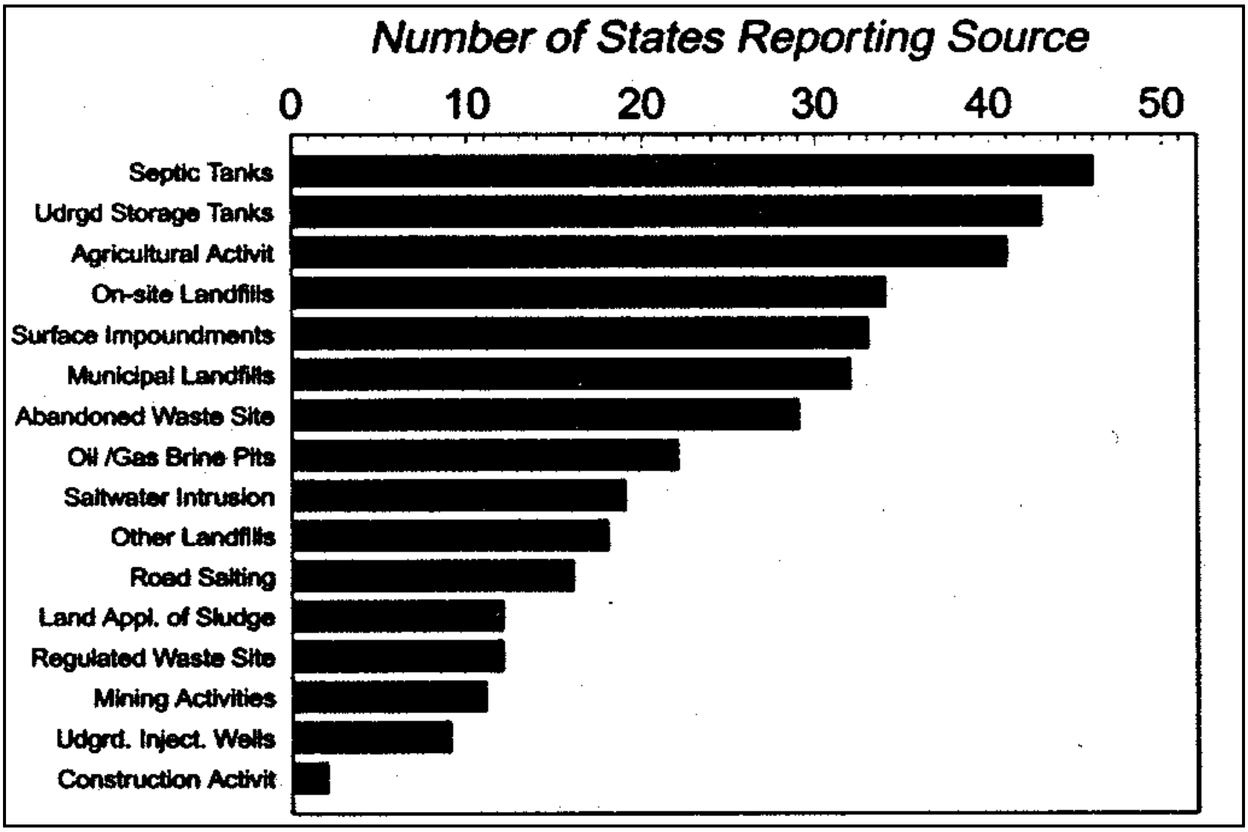

Figure 4: Reported sources of groundwater contamination in the United States (Jenkins, 1994)

2.2 Ecological sanitation

Human faeces contain most of the pathogens with a potential of causing diseases. Therefore, source control of faeces from household wastewater prevents these disease-causing pathogens gaining access to water bodies where they survive longer than on land and pose a long-term threat to human health. The most beneficial is when it is kept separated at source which avoids dilution of faeces. The separated solid fractions, which are easily biodegradable, can be treated biologically. When organic matter is decomposed oxidatively, heat is produced due to self heating capacity. This self produced heat will create self-hygienization of the matter.

The mostly applied methods for the sanitation of separated faecal waste are composting and dehydration. Treatment methods based on dehydration can reduce pathogens effectively, because there is a rapid pathogen destruction at moisture content below 25 %. Composting of a sufficient amount of fresh and easily degradable organic materials can produce heat, which raises the temperature of the materials. At the temperature of 60 ℃ and above, most of the pathoge ns are destroyed. Low temperature composting takes long time to kill the pathogens. The rate of reduction of pathogens is significantly dependant on time and temperature. The higher the temperature of the materials, the shorter the time for destroying the pathogens and vice versa. The factors such as a high pH, competition for food, antibiotic action and the toxic by-products of decomposing organism play a significant role in eliminating or reducing pathogen.

Feachem et al. (1983) stated that three months retention time will kill all of the pathogens in a low-temperature composting toilet except for worm eggs (Table 5).

Table 5: Pathogens survival by composting (Feachem et al., 1983)

Pathogens	**Composting Toilet (3 months retention time)**	**Thermophilic Composting**
Enteric Viruses	Probably eliminated	Killed rapidly at 60°C
Salmonellae	A few may survive	Killed in 20 hrs. at 60°C
Shigellae	Probably eliminated	Killed in 1 hr. at 55°C
E.coli	Probably eliminated	Killed rapidly above 60°C
Cholera vibrio	Probably eliminated	Killed rapidly above 55°C
Leptospires	Eliminated	Killed in 10 min. at 55°C
Estamoeba histolytica cysts	Eliminated	Killed in 5 min. at 50°C
Hoohworm eggs	May survive	Killed in 5 hrs. at 50°C
Roundworm(Ascaris)eggs	Survive well	Killed in 2 hrs. at 55°C
Schistosome eggs	Eliminated	Killed in 1 hr. at 50°C
Taenia eggs	May survive	Killed in 10 min. at 59°C

There is a synergistic correlation between time and temperature (see figure 5). The hatched areas refers to safety zone, where due to the combination of time and temperature all pathogens will be killed. Also the factors such as competition for food, predator-prey relationships and antagonism help to reduce or eliminate pathogens.

Desiccation by drying and adding high-alkaline additives is the best way to kill pathogens. Addition of ash helps in raising pH and decreasing moisture of faecal material. Both of them shorten the surviving time of pathogens. There are also other additives such as saw dusk, dry soil etc. Plant ash is the most effective additive to eliminate pathogens.

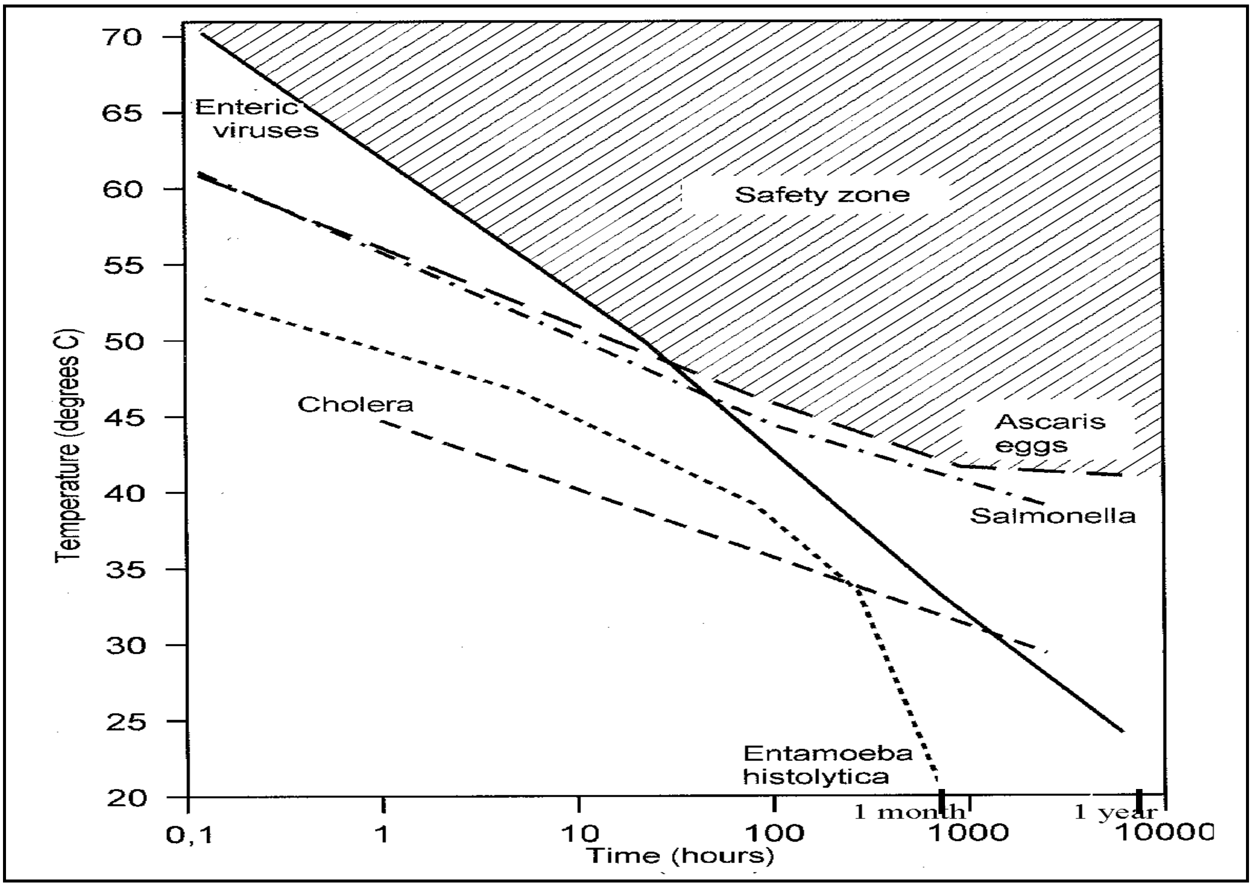

Figure 5: Combination of time and temperature of pathogens elimination. Hatch area represents complete pathogens elimination due to the combined effect of time and temperature (Feachem et al., 1983)

In summary, the die-off rate of the pathogens depends on the environmental condition of the place where they reside. The following factors are lethal to most of the pathogens:

- high pH (> 9)
- Low moisture contain (< 25%)
- High temperature (> 55 ^{O}C) over more than 10 hours
- Long retention time (> 6 months)
- Ammonia and high salt content
- Limited nutrients (competition for food)
- predator-prey relationships
- antagonism

High pH can be obtained by adding alkaline material such as ash or lime (but lime is not preferable) that reduces the moisture additionally. Moisture can be lowered by drying. Solar dryer can be used for this purposes, also high temperatures can be achieved at least part of the year in hot climate regions. High ammonia and salt can be obtained from urine. Long retention time, ammonia and high salt content, limited nutrients availability, predator-prey relationships and antagonism can be obtained in multi-chamber batch composting process.

The hygiene risk associated with urine is quite small compared to that with faeces. The fate of the pathogens entering into urine collection tank due to faecal contamination in urine diversion toilets is of vital importance for the hygiene risks related to the handling and reuse of the urine. For urine mainly temperature and the elevated pH (~9) in combination with ammonia has been concluded to affect the inactivation of micro-organisms. Bacteria like *Salmonella* (i.e. Gram-negative bacteria) were inactivated rapidly, whereas viruses were hardly reduced at all at low temperatures (4-5℃), (see table 6).

Table 6: Inactivation of microorganisms in urine, given as T90-values (time for 90% reduction) in days (Höglund,2001)

	Gram-negative Bacteria	Gram-positive Bacteria	*C.*parvum	Rhesus rotavirus	S.typhimurium phage 28B
4℃	1	30	29	172[a]	1 466[a]
20℃	1	5	5	35	71

a Survival experiments performed at 5℃.

In practice, complete elimination of pathogens may not be possible in any kind of sanitation. Therefore, secondary barrier such as personal, food and domestic hygiene must be included to destroy the pathogens completely. Therefore, hygiene awareness and proper education are the crucial points for on-site faecal waste management.

2.3 Sustainable Sanitation

If the above mentioned ecological sanitation can fulfil furthermore as well social en ecological m requirements it is called "sustainable sanitation". Such a sanitation is also form the hygienic point of view desirable, due to the fact, that it includes also other aspects, which save health in order to a risk management. Some further aspects of sustainable sanitation are (see also figure 6):

- Closing and separating the cycles of water and nutrients; avoidance of hygienic problems due to the separation of faeces from the water cycle
- Reclamation of nutrients (phosphorus and nitrogen) for agricultural use and hence saving of resources and energy (for the production of artificial fertilizer)

- Considerable savings of freshwater through the use of water saving toilet systems (vacuum, separating or dry toilets)
- Energy production (biogas) instead of energy consumption (for carbon degradation in sewage plants)
- Savings of construction, operation and maintenance costs compared to the conventional central sewerage systems
- Sophisticated modular system, which can be adapted perfectly to local social, economical and environmental conditions
- Easier operation and maintenance compared to centralized technology; local job creation

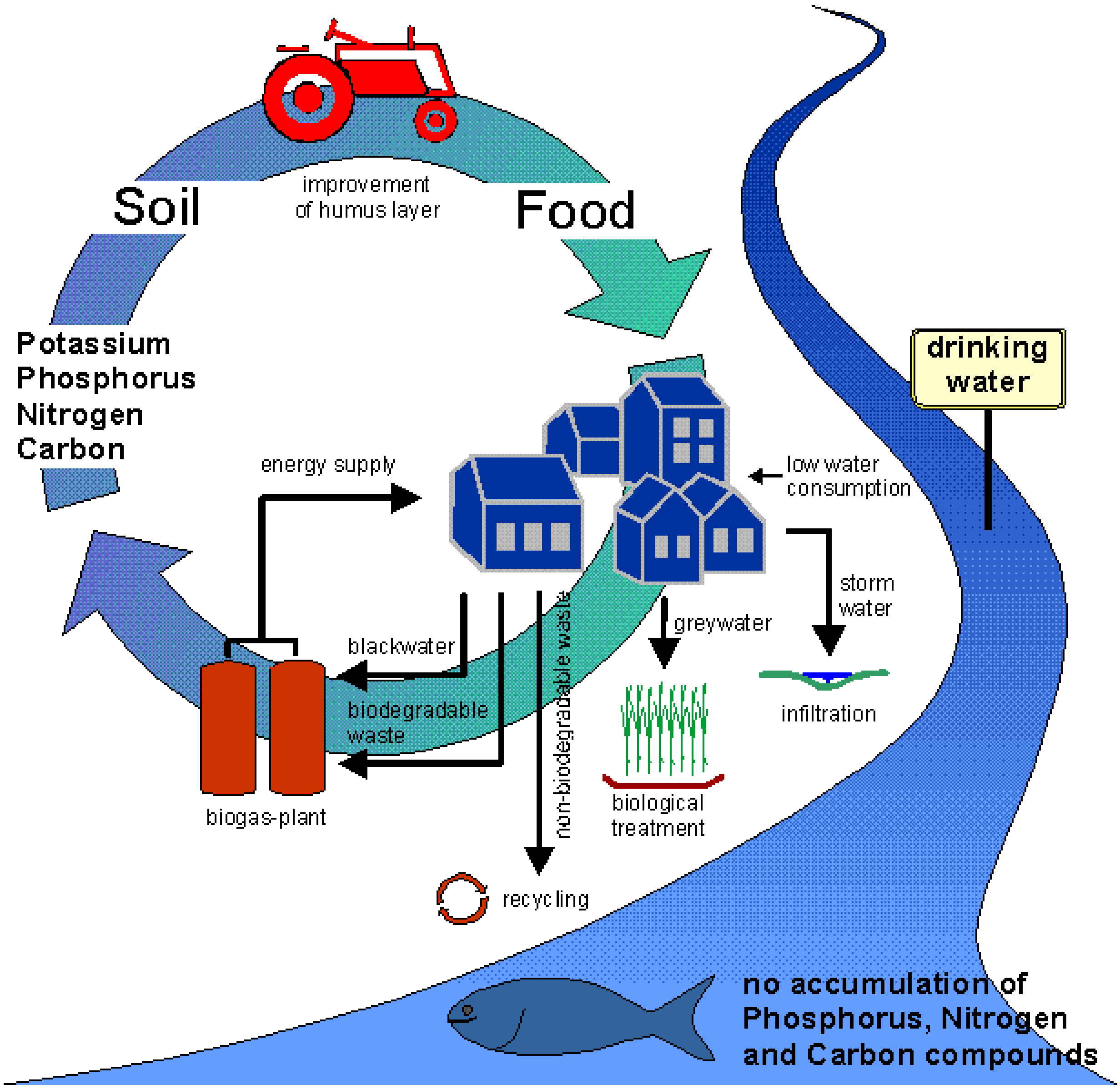

Figure 6: Sustainable Sanitation System (source Otterwasser GmbH)

3 Risk management through guidelines

Guidelines and recommendations for the handling and reuse of wastewater can work as a tool to minimise risks. Currently, it is recommended that the sanitised faecal matter is covered after application and not used as fertiliser to vegetables, fruits or root crops that are consumed raw, excluding fruit trees. At household level, urine can be used directly, but in a large-scale system it should be stored for a month at 20℃ prior to apply in agriculture. For vegetables, fruits or root crops that are consumed raw, a withholding period of one moth should be additionally applied i.e. one month should pass between fertilisation and harvest (see for details in Schönning and Stenström, 2004). Definite guidelines in ecological sanitation for safe handling and reuse of urine and faeces are required to minimise health risk. There are already existing guidelines for reuse of wastewater and faecal sludge in agriculture. The World Health Organisation (WHO) has developed guidelines for wastewater reuse in agriculture. Faecal coliforms and intestinal nematode eggs are used as pathogen indicators. For restricted irrigation, WHO recommends the treated wastewater should contain no more than one human intestinal nematode egg per litre. For unrestricted irrigation, WHO recommends the same helminth egg value, and additionally no more than 1000 faecal coliform bacteria per 100 ml of treated wastewater. Similar principles were applied to the derivation of guidelines for the use of excreta in agriculture. It is essential that the treated sludge contains no more than one helminth egg per kilogram and no more than 1000 faecal coliforms per 100 g. In USA, EPA guidelines for bio-solids are classified as class “A” (pathogens below detectable level) or class “B” (pathogens detectable, but do not pose a threat to public health). In Germany bio-waste Ordinance (Ordinance on the Utilisation of Bio-wastes on Land used for Agricultural, Silvicultural and Horticultural Purposes) requires that endproduct must be free of Salmonellae. Council of the European Communities Directive No. 86/278/EEC has not included guidelines for microbial hygienic risk for reuse of sludge, but only for heavy metals concentrations in soil, in sludge and maximum annual quantities of heavy metals that can be introduced into the soil. However, in ecological sanitation heavy metals are not a big concern, since human excreta contain approximately the same amount of heavy metals as food. Therefore, there is no risk of heavy metal accumulation in soil due to these fertilisers. The issue of pharmaceutical residue in excreta has to be addressed here, indeed.

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HYGIENE AND RISK MANAGEMENT

Dr. Deepak R. Gajurel

General Hygiene

Definition

Health: a state of complete physical, social and mental well-being, and not merely the absence of disease or infirmity.

Hygiene: the science of preventing and protecting the health of people through control of the environment.

Environment: our physical surroundings (air, water and land), biological surroundings (animals and plants), and social surroundings.

General Hygiene

Areas of Hygiene

Environmental hygiene: it deals with the methods of defence from harmfulness (heat, cold, weather, rays, poison or pathogens) that originate from land, air and water.

Social hygiene: it avoids damages of the social environment of the human being.

Individual hygiene: it comprises of body cleaning and its clothing. Always keep your hands clean: after using the toilet, before cooking, before meals and after contact with raw or uncooked food wash your hands with **soap** or **detergent**.

General Hygiene

Areas of Hygiene

Food hygiene: it protects us not only from insufficient, unsuitable, rotten or poisoned food, but also changes our deficient dietary habit. Kitchen hygiene also belongs to food hygiene.

Occupational and domestic hygiene: working and residing place should be hygienic.

General Hygiene

Environmental Influences on human

Normally, **humans** can react physically, socially and mentally on changed **environmental influences**, in order to adapt themselves and thus avoiding damages. But, there are also many environmental influences, which can overcome human's adaptation and defence capacity and cause diseases.

General Hygiene

Environmental Influences on human

Chemical Influences:
pollutants, contaminants in food, pharmaceutical, intoxicant, hazardous substances etc.

Biological influences:
Microorganisms, plants, animals and foods etc.

Human

Physical influences:
Climate, weather, heat, cold, radiation, current, light, colour, noise etc.

Psychosocial influences:
Living and working conditions, stress, depression etc

Diseases

Infectious

- Transmitted from one person to another or, sometimes, to or from animals.
- All infectious diseases are usually caused by Pathogens (Bacteria, Viruses, Protozoa and Helminths)

non-infectious

- Health problems related to environmental pollution are considered to be the result of contamination of water, food, and air with toxic chemicals. The resulting diseases are non-infectious.

Diseases

Infectious

Water-related infections

•**Transmission routes:**

Water-borne

Cholera, Typhoid, Dysenteries, Diarrhoeas, Infectious hepatitis

Water-washed

Skin and eye infections

Louse borne typhus

Water-based

Schistosomiasis

Guinea worm

Water related insect vector

Yellow fever, River blindness, Malaria

Sleeping sickness

Excreta-related infections

•Diseases which are faecal-orally transmitted usually enter the environment by the excretion of faeces from infected persons.

Diseases

Classification of water-related infection

Category	Infections
Faecal-oral: (water-born or water-washed)	Diarrheas and dysentaries, *Amoebic dysentary,Campylobacter enteritis,Cholera, E. coli diarrhea, Giardiasis, Rotavirus diarrhea, Salmonellosis, Shigellosis, Yersinosis,* Enteric Fevers *Typhoid, Paratyphoid*, Poliomyelitis, Hepatitis A, Leptospirosis
Water-washed: (skin and eye infections, and other Infectious skin diseases)	Infectious skin diseases, Infectious eye diseases, Louse-borne typhus, Louse-borne relapsing fever
Water-based: (penetrating skin,ingested)	Schistosomiasis, Guinea worm, Clonorchiasis others
Water-related insect vector: (biting near water, breeding in water)	Sleeping sickness,Filariasis Malaria, River blindness, Mosquito-borne, *Yellow fever, Dengue others*

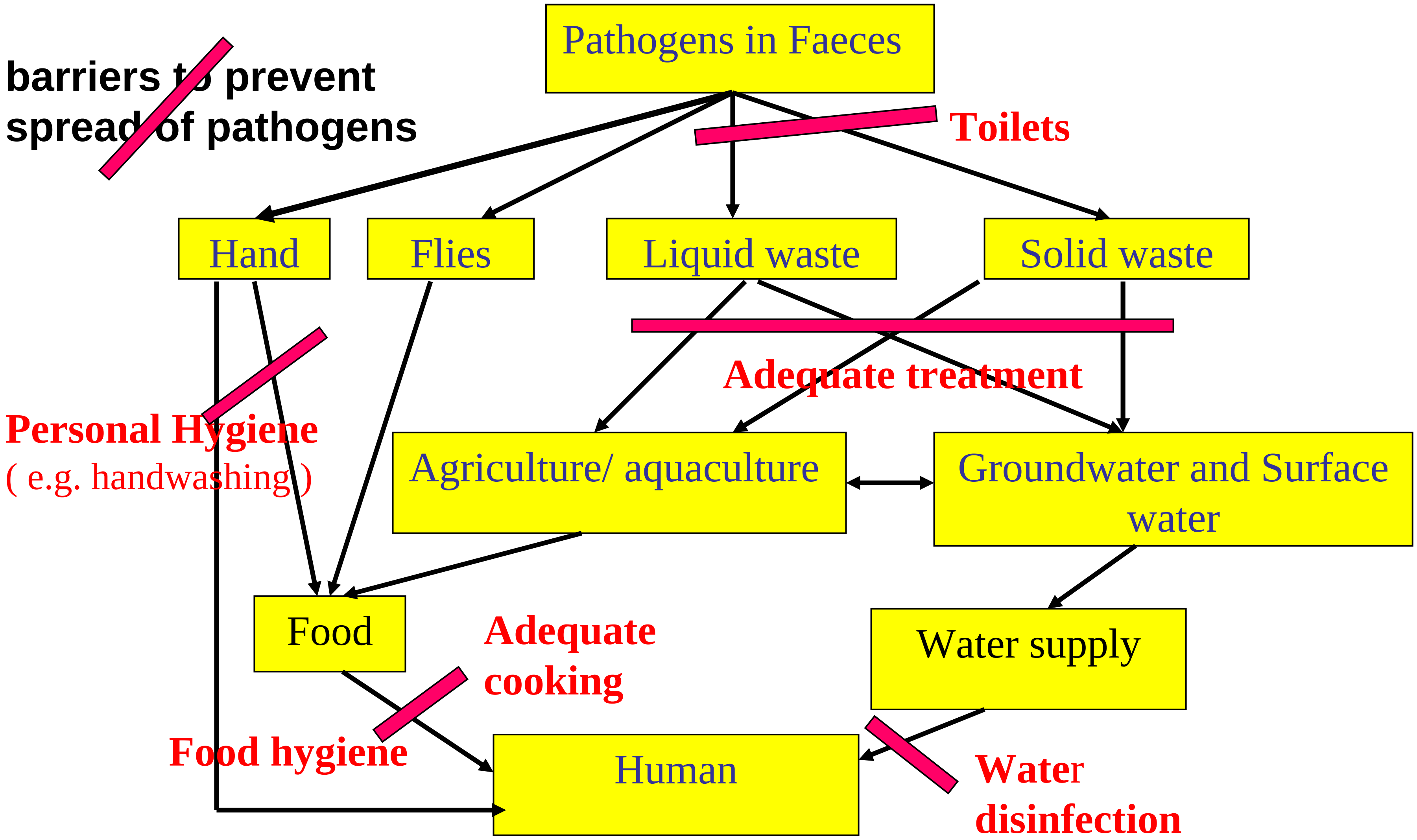
Diseases

Classification of excreta-related infections

Category	Infections
Faecal-oral: (non-bacterial)	Poliomyelitis, Hepatitis A, Rotavirus diarrhoea, Amoebic, dysentery, Giardiasis, Balantidiasis, Enterobiasis, Hymenolepiasis
Faecal-oral: (bacterial)	Diarrhoeas, Dysenteries, *Campylobacter enteritis, Cholera, E. coli diarrhoea, Salmonellosis, Shigellosis, Yersiniosis,* Enteric fevers, *Typhoid, Paratyphoid*
Soil-transmitted helminths:	Ascariasis, Trichuriasis, Hookworm, Strongyloidiasis
Beef and porktapeworms:	Taeniasis
Water-based helminths:	Schistosomiasis, Clonorchiasis, Diphyllobothriasis Fasciolopsiasis, Paragonimiasis
Excreta-related insect vectors:	Filariasis

Routes of Pathogens Transmission from Faeces to Human

(Adopted from Franceys et al. 1992 and modified)



Survivability rate of pathogens in environment

Factors affecting survivability rate of pathogens:

- Competition for food
- Predator-prey relationships
- Antagonism
- Environnemental conditions

In order to eliminate pathogens, faecal containing waste must be treated in a controlled environment, where the above mentioned factors act effectively.

Survivability rate of pathogens

Survival time (d) of pathogens in day by different disposal/treatment conditions **(Esrey et al., 1998)**

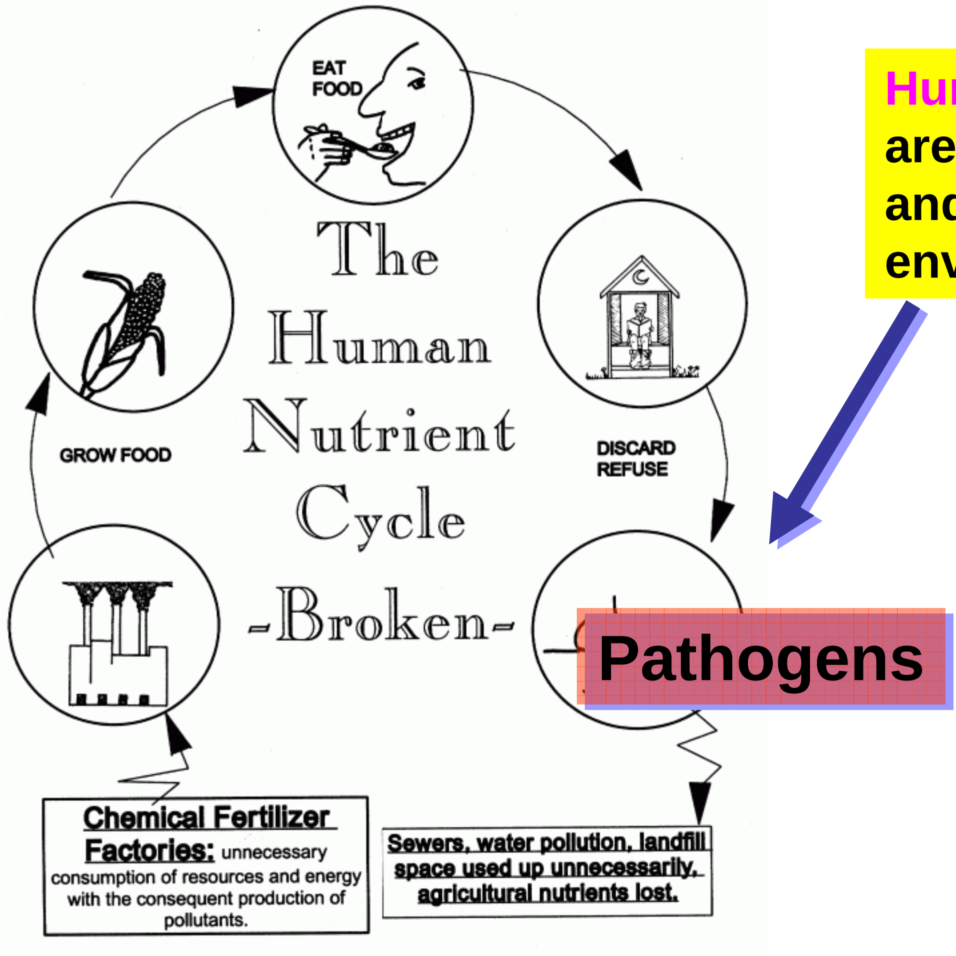
Condition	Bacteria	Viruses	Protozoa*	Helminths**
Soil	400	175	10	Many months
Crops	50	60	not known	Not known
Night soil, faeces, sludge 20-30 ^{o}C	90	100	30	Many months
Composting Anaerobic at ambient temperatures	60	60	30	Many months
Thermophilic composting 50-60 ^{o}C maintained for several days	7	7	7	7
Waste stabilisation ponds Retention time > 20 days	20	20	20	20

* excluding Cryptosporidium parvum

** mainly Ascaris; other parasitic eggs tend to die quicker

Wastewater management and associated hygienic risk

Conventional Sanitation



Human excreta containing pathogens are mixed with large amount of water and discharged into open aquatic environments

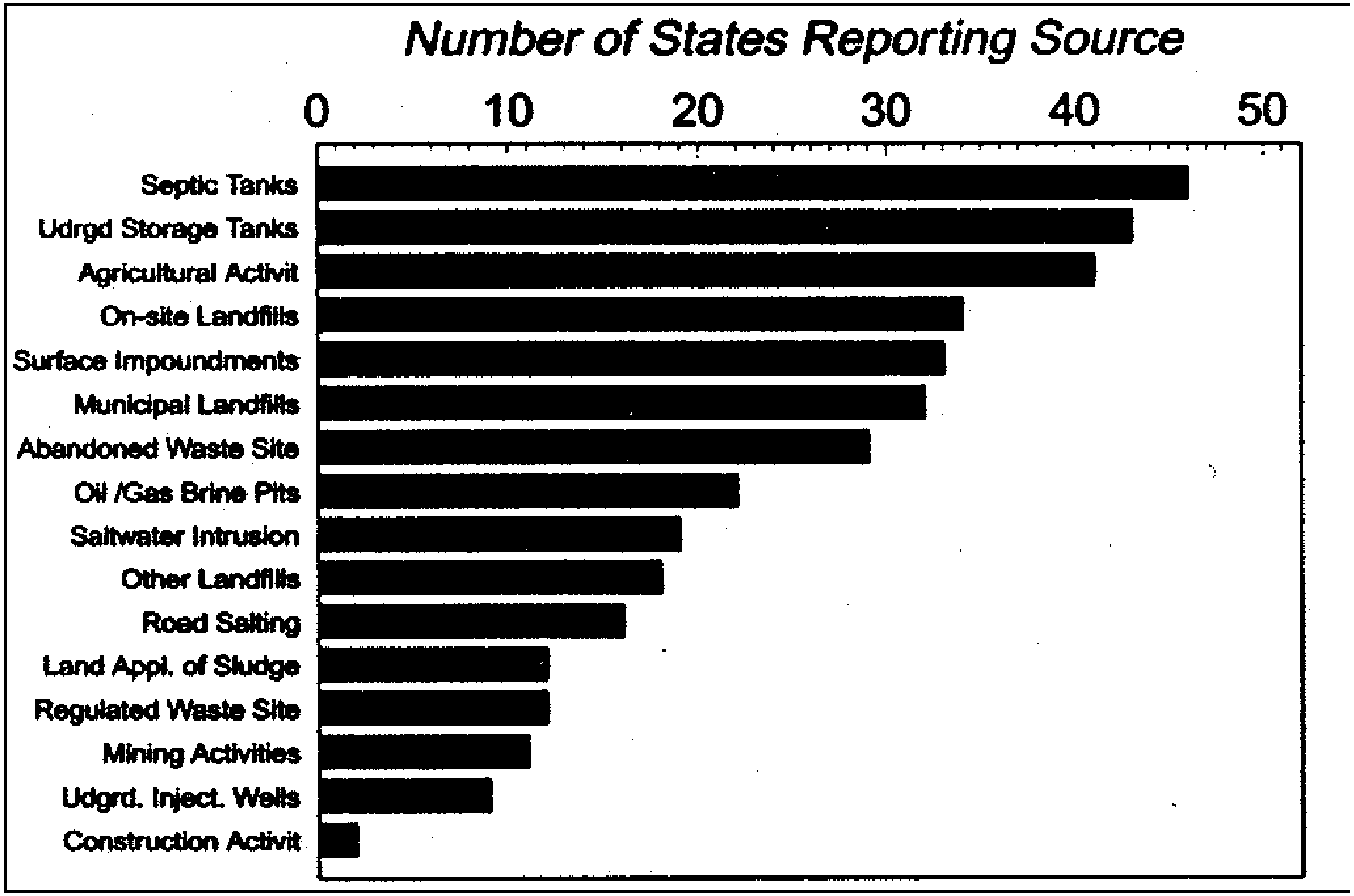
Responsible for 4 million infant and child deaths per year in developing countries

(Source: Lubis, 1999)

(Source: Jenkins, 1994)

Wastewater management and associated hygienic risk

Conventional Sanitation

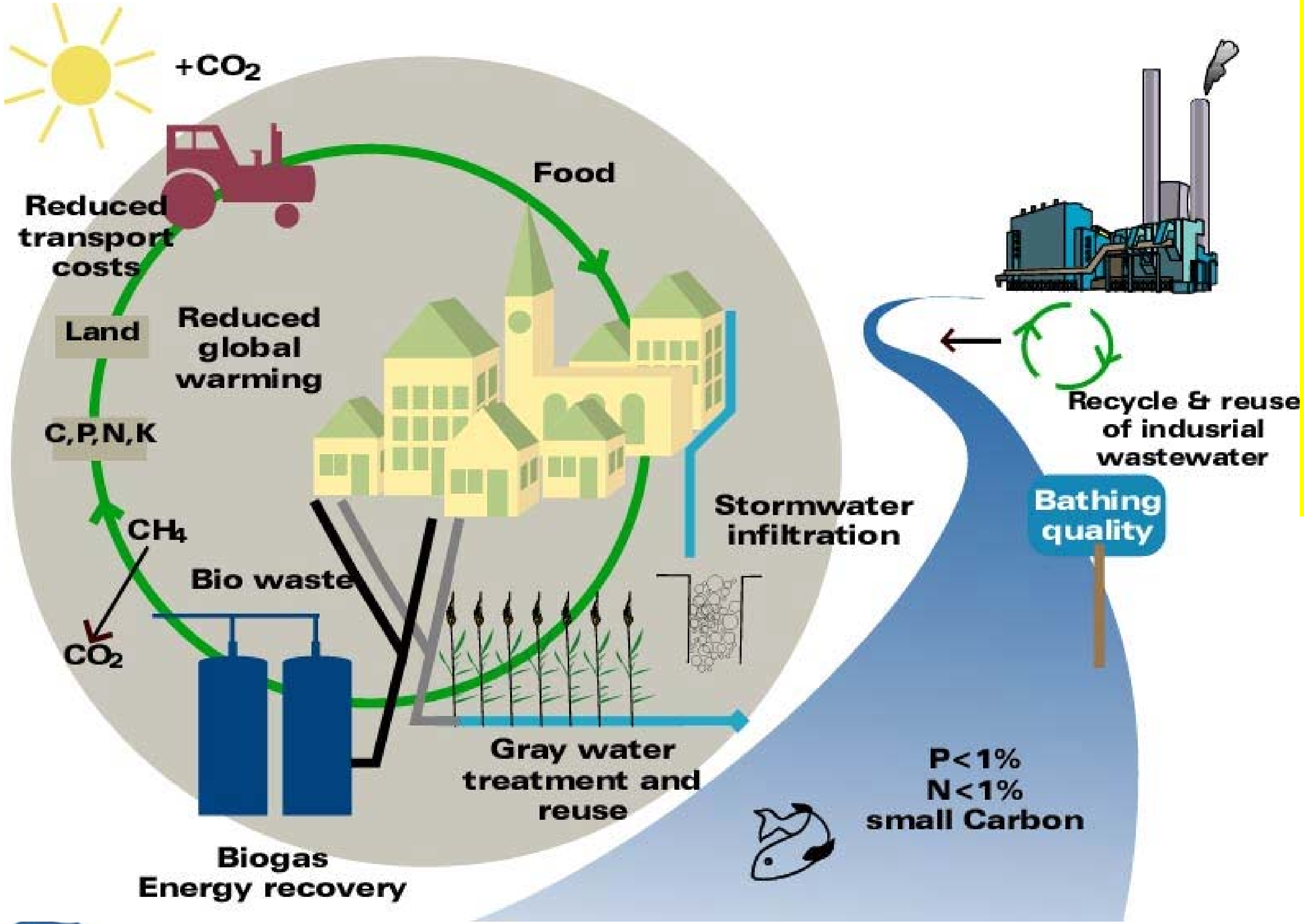


Reported sources of groundwater contamination in the United States

(Source: Jenkins, 1994)

Wastewater management and associated hygienic risk

Ecological sanitation



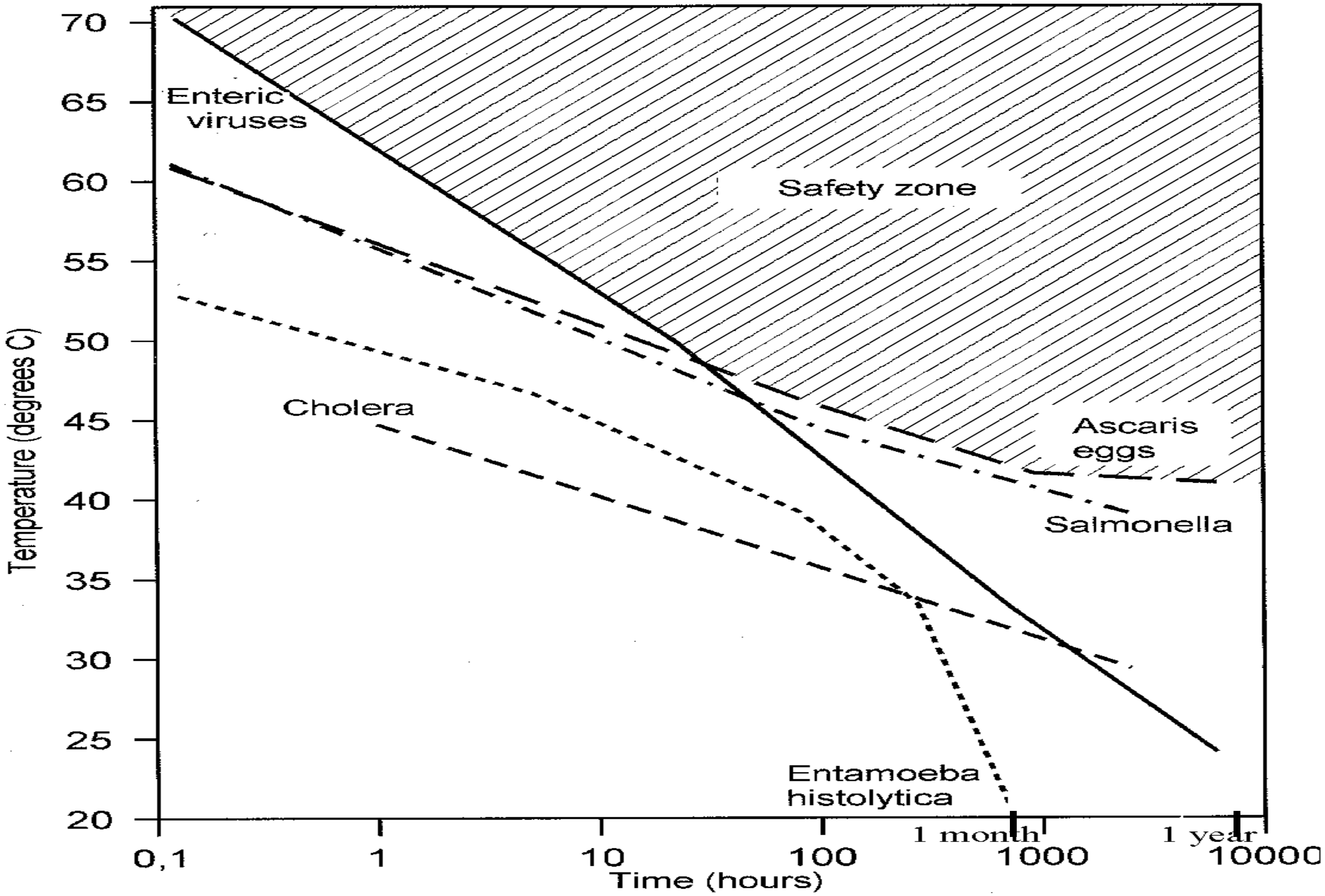
Human excreta are captured at source and kept

in a closed environment and sanitised with

Storage/composting/ dehydration/ anaerobic digestion with heating etc.

Wastewater management and associated hygienic risk

Ecological sanitation



Combination of time and temperature of pathogens elimination. Hatch area represents complete pathogens elimination due to the combined effect of time and temperature (Feachem et al., 1983)

Wastewater management and associated hygienic risk

Ecological sanitation

Pathogens survival by composting (Feachem et al., 1983)

Pathogens	Composting Toilet (3 months retention time)	Thermophilic Composting
Enteric Viruses	Probably eliminated	Killed rapidly at 60°C
Salmonellae	A few may survive	Killed in 20 hrs at 60°C
Shigellae	Probably eliminated	Killed in 1 hr.at 55°C
E.coli	Probably eliminated	Killed rapidly above 60°C
Cholera vibrio	Probably eliminated	Killed rapidly above 55°C
Leptospires	Eliminated	Killed in 10 min. at 55°C
Estamoeba histolytica cysts	Eliminated	Killed in 5 min. at 50°C
Hoohworm eggs	May survive	Killed in 5 hrs. at 50°C
Roundworm(Ascaris)eggs	Survive well	Killed in 2 hrs. at 55°C
Schistosome eggs	Eliminated	Killed in 1 hr. at 50°C
Taenia eggs	May survive	Killed in 10 min. at 59°C

Ecological sanitation

Pathogens survival by desiccation

Desiccation by **drying** and **adding high-alkaline additives** is the best way to kill pathogens.
There are also other additives such as **saw dusk, dry soil**
Plant ash is the most effective additive to eliminate pathogens.

Pathogens survival by anaerobic digestion

Since, in anaerobic digestion, self heating of the organic material does not take place, **extra heating is required for eliminating pathogens** contained in the faecal materials.

For complete elimination of pathogens, temperatures **above 55 °C** must be maintained for 10 days

Ecological sanitation

Factors lethal to most of the pathogens:

- high pH (> 9)
- Low moisture contain (< 25%)
- High temperature (> 55 ^{O}C) over more than 10 hours
- Long retention time (> 6 months)
- Ammonia and high salt content
- Limited nutrients (competition for food)
- predator-prey relationships
- antagonism

Ecological sanitation

For urine mainly **temperature** and the elevated **pH (~9)** in combination with ammonia has been concluded to affect the **inactivation of micro-organisms**. Bacteria like *Salmonella* (i.e Gram-negative bacteria) were inactivated rapidly, whereas viruses was hardly reduced at all at low temperatures (4-5°C)

Inactivation of microorganisms in urine, given as T90-values (time for 90% reduction) in days (Höglund,2001)

	Gram-negative Bacteria	Gram-positive Bacteria	*C.*parvum	Rhesus rotavirus	S. typhimurium phage 28B
4°C	1	30	29	172[a]	1 466[a]
20°C	1	5	5	35	71

A SURVIVAL EXPERIMENTS PERFORMED AT 5°C.

Wastewater management and associated hygienic risk

In practice, complete elimination of pathogens may not be possible in any kind of sanitation. Secondary barrier such as personal, food and domestic hygiene must be included to destroy the pathogens completely. Therefore, hygiene awareness and proper education are the crucial points for on-site faecal waste management.

Risk management through guidelines

Guidelines and **recommendations** for the handling and reuse of wastewater can work as a tool to minimise risks.

It is recommended:

sanitised faecal matter is covered after application and not used as fertiliser to vegetables, fruits or root crops that are consumed raw, excluding fruit trees.

At household level, urine can be used directly, but in a large-scale system it should be **stored for a month at 20°C prior to apply in agriculture**.

For vegetables, fruits or root crops that are consumed raw, a withholding period of one moth should be additionally applied i.e. **one month should pass between fertilisation and harvest** minimise health risk.

Risk management through guidelines

The World Health Organisation (WHO) guidelines for wastewater reuse in agriculture:

For restricted irrigation, the treated wastewater should contain **no more than one human intestinal nematode egg per litre**. For unrestricted irrigation, the same **helminth egg** value, and additionally **no more than 1000 faecal coliform bacteria per 100 ml** of treated wastewater.

Similar principles were applied to the derivation of guidelines for the use of excreta in agriculture. The treated sludge contains **no more than one helminth egg per kilogram** and **no more than 1000 faecal coliforms per 100 g.**

Risk management through guidelines

In **USA, EPA** guidelines for bio-solids are classified as **class ”A”** (pathogens below detectable level) or **class ”B”** (pathogens detectable, but do not pose a threat to public health).

In **Germany** bio-waste Ordinance (Ordinance on the Utilisation of Bio-wastes on Land used for Agricultural, Silvicultural and Horticultural Purposes) requires that **end product must be free of Salmonellae.**

In **ecological sanitation** heavy metals are not a big concern, since human excreta contain approximately the same amount of heavy metals as food. Therefore, there is no risk of heavy metal accumulation in soil due to these fertilisers.
The issue of pharmaceutical residue in excreta has to be addressed here, indeed.

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The End

EFFICIENT MANAGEMENT OF WASTEWATER

Lesson B1

RESOURCE MANAGEMENT SANITATION

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Keywords
Anaerobic digestion, Bio-gas, Black water, Brown water, Composting/Vermicomposting, Composting/dehydrating toilet, Ecological sanitation, Grey water, Rottebehaelter, Sorting toilet, Vacuum toilet, Yellow water,

Table of content

Overview and summary

Human excreta contain valuable plant nutrients as well as organic matter and can be converted into fertiliser and soil conditioner for agriculture. Thus, **reuse of human excreta reduces the production of chemical fertiliser** which is energy intensive, causes environmental problems and draws on very limited fossil resources. Additionally, the **surface water is preserved** which is otherwise polluted by discharging human excreta into it. Because of high dilution, it is hardly possible to recover good amount of nutrients in conventional sanitation systems. Even modern wastewater treatment plants that are hardly affordable for developing countries emit nutrients into water bodies where they cause eutrophication. Also, pathogens contained in faeces can spread to the aquatic environment causing disease to people.

A high amount of nutrient recovery is possible with source control in households. With the application of Resource Management sanitation it is possible to keep human excreta in non-diluted or little diluted form which provides good condition for high levels of nutrient recovery as well as for effective sanitisation. The systems that are applied in Resource Management sanitation for the source control are **composting/dehydration toilets, sorting or no-mix toilets as well as vacuum toilets**. In composting/dehydration toilet systems either a toilet with urine diversion or no urine diversion is used. In case of no urine diversion toilet, faeces and urine with or without toilet paper depending on the user's habit drop into the composter located just below the toilet. In urine diversion toilet, urine is collected separately and kept in a storage tank until it is ready for use in agriculture. Urine diversion is crucial for dehydration toilets. The non-diluted faecal materials are dehydrated with the help of heat (solar radiation), ventilation and the addition of dry materials.

The no mix toilet usually has two bowls, the front one for urine and the rear one for faeces. Each bowl has its own outlet from where the respective flow is piped out and treated separately. Urine is stored in an underground tank for sanitisation prior to its reuse in agriculture whereas faeces with toilet paper if used are discharged either into Aquatron system or Rottebehaelter system for solid liquid separation and treatment. The end product of both systems requires post-treatment prior to its reuse. The vacuum toilet uses only 1 litre flush water to flush faeces, urine and toilet paper and the mixer called black water is transported to the biogas plant with the help of a vacuum system. Biogas can be used for heating and lighting whereas sludge can be used in agriculture after sanitisation. Resource Management sanitation systems have been increasingly used around the world. In this lesson, some applications worldwide are presented as well. Also treatment methods for other domestic wastewater that originates from kitchen, shower, wash basin and laundry are discussed.

1. Material flows in domestic wastewater

1.1 Different sources

Different particular wastewater streams are forming the domestic wastewater (see figure 1). The wastewater originating from toilets is called black water and can be further divided into yellow water (urine with or without flush water) and brown water (toilet wastewater without urine). Additionally, grey water is that part of domestic wastewater which originates from kitchen, shower, wash basin and laundry (for more details see Lesson A1).

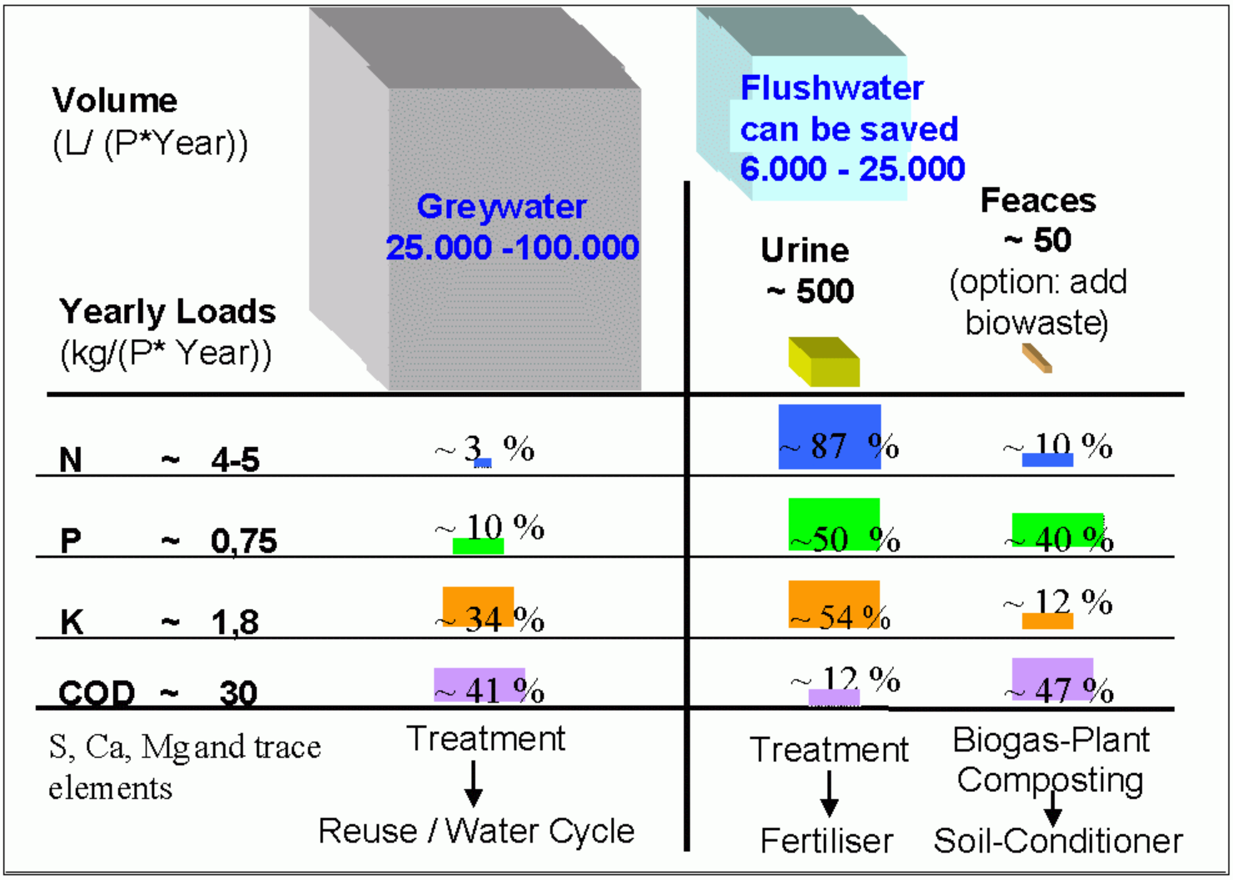
Figure 1: Sources of domestic wastewater (Samwel 2005)

1.2 Characteristics of different streams

The typical characteristics of the streams of domestic wastewater, shown in table 1 clearly characterize that yellow and brown water contain most of the nutrients discharged to sewers in the conventional sanitation. This means that they are generally wasted instead of being used as fertilizers (except the small portion of nutrients being contained in sludge which is used sometimes as fertilizer after sanitisation).

Due to pathogens, brown water poses high health risk, but it represents a very small volume flow in domestic wastewaters (only 50 litres are excreted per person per year). In conventional systems, this small volume is mixed with other streams of domestic wastewater with higher volume flows: yellow water (tenfold volume flow compared to faeces) and grey water. Grey water volume flows depend on habits. That is why a wide range is given for grey water volume flow: 25,000 to 100,000 litres per person per year. Table 1 is related to Central European patterns. Of course, also extremely smaller grey water volume flows per person can be found, especially in regions with water scarcity. Additionally toilet flush water has to be taken into consideration (which might be up to 10 litres per toilet use).

Table 1: The typical characteristics of the streams of domestic wastewater (Compiled from: Geigy, Wissenschaftliche Tabellen, Basel 1981, Vol.1, Larsen and Gujer, 1996 and Fittschen and Hahn, 1998)



It is very impressive that the large volume flow of grey water is accompanied by comparably small nutrient mass flows (about 3 % of the total nitrogen mass flow and 10 % of the total phosphorus mass flow (phosphorus concentration can still be lowered by using phosphorus free detergents) discharged with domestic wastewater). However, about one third of the potassium (which is also important for plant growth and a limited fossil fertilizer component) mass flow of domestic wastewater is contained in grey water. Because of the large volume flow of grey water (compared to yellow and brown water), its potassium concentration is quite low (commonly below 10 mg/l), however. Because of its low contribution to mass flow of the nitrogen and phosphorus in domestic wastewater and its high volume flow grey water turns out to belong to the ***water cycle*** and represents a splendid source for wastewater reuse. As grey water contains nearly half of the organic load of domestic wastewater, this is the main group of pollutants to be removed from grey water before its eventual reuse. Therefore, treatment of grey water is far cheaper than treatment of total domestic wastewater as there is no need of costly nitrification and denitrification processes mostly practiced in modern municipal wastewater treatment plants.

The scheme clearly demonstrates that greatest part of the nutrients nitrogen, phosphorus and potassium of domestic wastewater are contained in the comparably small volume flow of yellow water. Moreover, urine contains trace metals required for plant growth. Only about 10 % of the organics of domestic wastewater are urine borne. From these reasons, yellow water has to be taken into consideration as fertilizer, and is thus related to the ***food cycle*** rather than to the water cycle.

Brown water contributes greatly to the phosphorus load of domestic wastewater and can thus also be considered as fertilizer. Moreover, the organic solids make brown water a splendid candidate as a soil conditioner after suitable treatment. Therefore, also brown water is belonging to the ***food cycle.***

1.3 Yellow water as fertilizer

Separate collection of yellow water is possible with sorting toilet (see figure 7 and 8). Among the flows of wastewater, yellow water contains most of the nutrients (table 1). One person produces on average 3.92 kg of nitrogen, 0.38 kg of phosphorous and 0.97 kg of potassium per year. These nutrients, such as nitrogen in the form of urea, phosphorus as super phosphate and potassium as an ion, are in a form which are ideal for uptake by plants (Esrey et al.; 1998). Beneficially, urine contains very low levels of heavy metals and pathogens. These heavy metal concentrations are much lower than those of most chemical fertiliser. In Sweden, for instance, urine contains less than 3.2 mg cadmium per kg of phosphorus compared to 26 mg Cd/kg of phosphorus in commercial fertiliser and 55 mg Cd/kg of phosphorous in sludge (Esrey, 2000).

In the conventional wastewater treatment systems, instead of utilising the yellow water for plant nutrition, it is wasted. In modern municipal wastewater treatment plants, nitrogen compounds (most of them originating from yellow water) is removed with the costly nitrification and denitrification process. Even with the high inputs of money, a reasonable amount of nitrogen compounds (especially nitrate) escapes with the effluents of treatment plants and causes eutrophication in water bodies. In high-tech treatment plants, most of the nitrogen compounds are converted to N_2, which is itself a raw material for high energy consuming nitrogen fertilizer synthesis (e.g. in natural-gas based ammonia plants).

Even the best affordable treatment plants discharge over 20 % of nitrogen, over 5 % of phosphorus and more than 90 % of potassium to the aquatic environment where they are lost for ever and cause severe problems (Otterpohl et al., 1997). Those nutrients, which are captured in sludge are often contaminated with heavy metals such as Cadmium (Cd) and organic compounds such as PCB (polychlorinated Biphenyle), which pose potential toxic risks to plants, animals and humans (Metcalf and Eddy, 1991). Therefore, large amounts of sewage sludge are disposed of in landfills or incinerated. Only a smaller part is applied to agricultural land.

Due to following reasons wasting of yellow water is not sustainable:

1st: Production of fertiliser is energy intensive, draws on very limited fossil resources and causes environmental problems. Generating nitrogen (N) from air requires a considerable amount of energy. Mining and refining the raw materials for phosphate production generates a huge amount of hazardous wastes. Reserves of phosphate (P) and potassium (K) are definitely limited on a time scale of only a couple of human generations especially with regard to economic constraints. Moreover, also sulphur is a limited fossil resource and is required by plants. Also sulphur is contained in yellow water. Therefore, we should use the human resource "Anthropogenic Nutrient Solution" (ANS; Larsen and Gujer, 1996) yellow water as fertiliser which contains reasonable amounts of these nutrients.

2nd: If yellow water is wasted (i.e. it is added to municipal wastewater), it will either contribute to eutrophication of surface waters because of its nutrient content or it will even lead to groundwater contamination (high nitrate concentrations can be generated by transformation of ammonia, and sometimes high nitrate concentrations are detected in ground waters contaminated with domestic wastewater - they can lead to lethal methemoglobinemia of babies drinking water from such contaminated sources).

3rd: Even if domestic wastewater is treated in modern treatment plants, adding yellow water to wastewater is disadvantageous Residual nitrogen compounds (mainly nitrate) escape with the effluents even of very efficient wastewater treatment plants and contribute to surface water eutrophication. But the main disadvantage of adding yellow water to municipal wastewater is that a great deal of energy consumption for operating activated sludge tanks is required for ammonia removal (aeration for nitrification). Removal of phosphate from municipal wastewater requires an additional biological stage and/or precipitation stages (addition of iron or aluminium salts). It is assumed that nutrient removal requires about 50 % of energy consumption in German wastewater treatment plants (Rakelmann 2002). It is clear that production of electric power is contributing to the greenhouse effect and leads to emission of air pollutants.

4th: Because of its content of nutrients, yellow water can substitute a reasonable amount of synthetic fertilizers. It is assumed that about 50 % of crops needed by human beings can be fertilized with human excreta. When yellow water is wasted, this means additional energy consumption for fertilizer production.

(See definitions of "sustainable development" under: http://www.gdrc.org/sustdev/definitions.html)

1.4 Brown water as soil conditioner

It can be seen in a map (figure 2) provided by the FAO that Soil degradation caused by human activities is alarming worldwide. About 38 % of globally used agricultural land is degraded- mostly in Asia, Africa and South and Central America (Esrey, 2000). The main causes of soil degradation are: erosion, fertility decline, overcropping and use of synthetic fertiliser. Since synthetic fertiliser does not contain organic matter which prevents soil erosion, reuse of brown water as soil conditioner plays important role to reduce the soil degradation as brown water contains most of the organic solids in domestic wastewater (see table 1).

Like yellow water, separate collection of brown water is possible with sorting toilet (See figure 7 and 8). As faeces are the predominant source of pathogens of all streams of domestic wastewater, they have to be sanitised prior to their use as soil conditioner. However, killing of pathogens is facilitated when faeces are collected separately. Possible treatment techniques are dehydration (utilization of solar energy) or composting. Together with organic solids helping to prevent soils from desertification, also nutrients are transferred to agricultural fields with processed brown water.

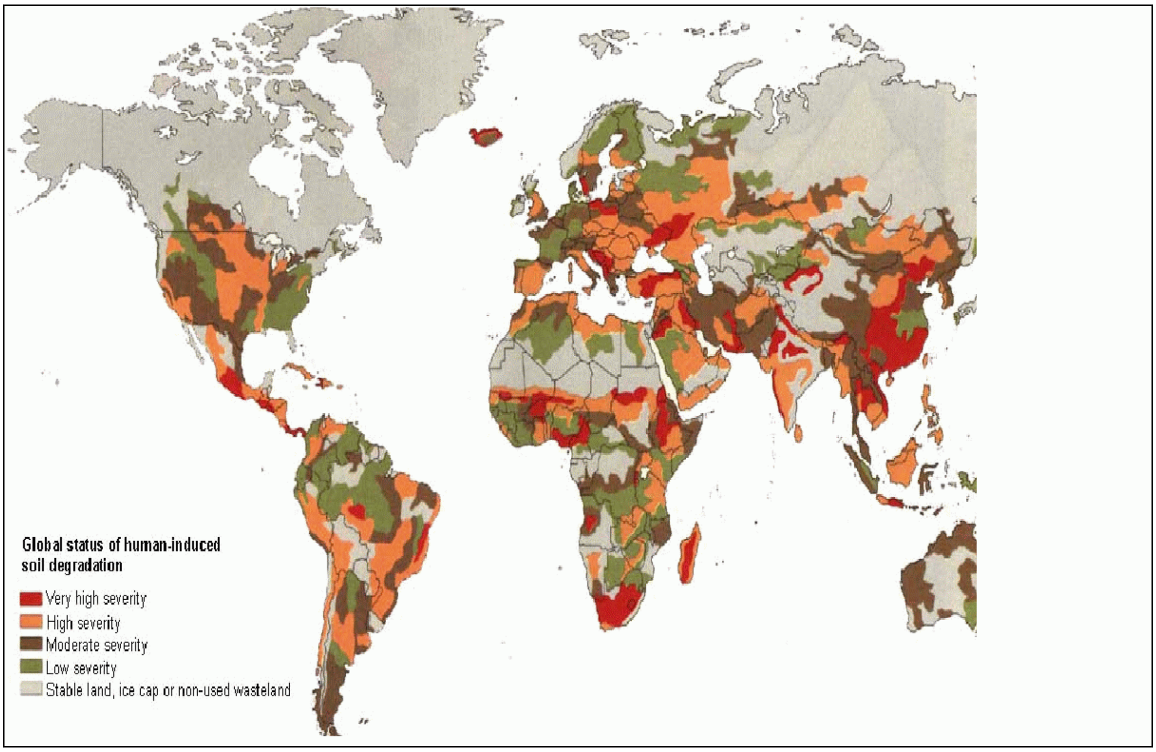


Figure 2: Map of global status of human-Induced soil degradation

2. Conventional sanitation systems and their limitations

Due to disease risks caused by faecal wastewater, in large European cities sewers were constructed to drain the wastewater away from the people's surroundings to the nearby water courses, and ultimately into the sea. Later, it was found that discharging raw wastewater had deteriorated aquatic environment of the receiving water body and at the same time it caused diseases to the people who received their drinking water from the same river downstream. Because of drinking water contamination, epidemics of cholera had periodically caused heavy loss of life in the large European cities (Evans, 1987). The outbreak of cholera in 1892 , for instance, took place all over in Hamburg where drinking water supply was extracted from the river Elbe. To protect these rivers from the pollution as well as the public health from water borne diseases, the wastewater was since then treated at the end of the sewer before discharging it into the river. This tradition has been widely established as a standard way of managing wastewater worldwide. However, most of the wastewater is discharged without any treatment mostly in developing countries.

In centralised wastewater management systems, household wastewater together with municipal and industrial wastewater, storm water as well as infiltration/inflow water is collected and transported a long way to central treatment plants where it is treated and disposed/reused (figure 3). This system has been built and operated for more than hundred years. In the mean time, because of advanced technological development, the wastewater management has reached high standard in many industrialised countries. However, in developing countries the present situation is still similar to that of the currently industrialised countries in the 19th century in many respects. About 95 % of wastewater in developing countries is discharged without any treatment into the aquatic environment (WIR, 1992). This contributes largely about 1.2 billion people without access to clean drinking water. Almost 80 % of diseases throughout the world are water-related. Water-borne diseases account for more than 4 million infant and child deaths per year in developing countries (Lubis, A.-R., 1999). In New Delhi, India, more than 50 % of the raw wastewater is still discharged into the river Yamuna, from where the city draws its water supply (Narain, 2002).

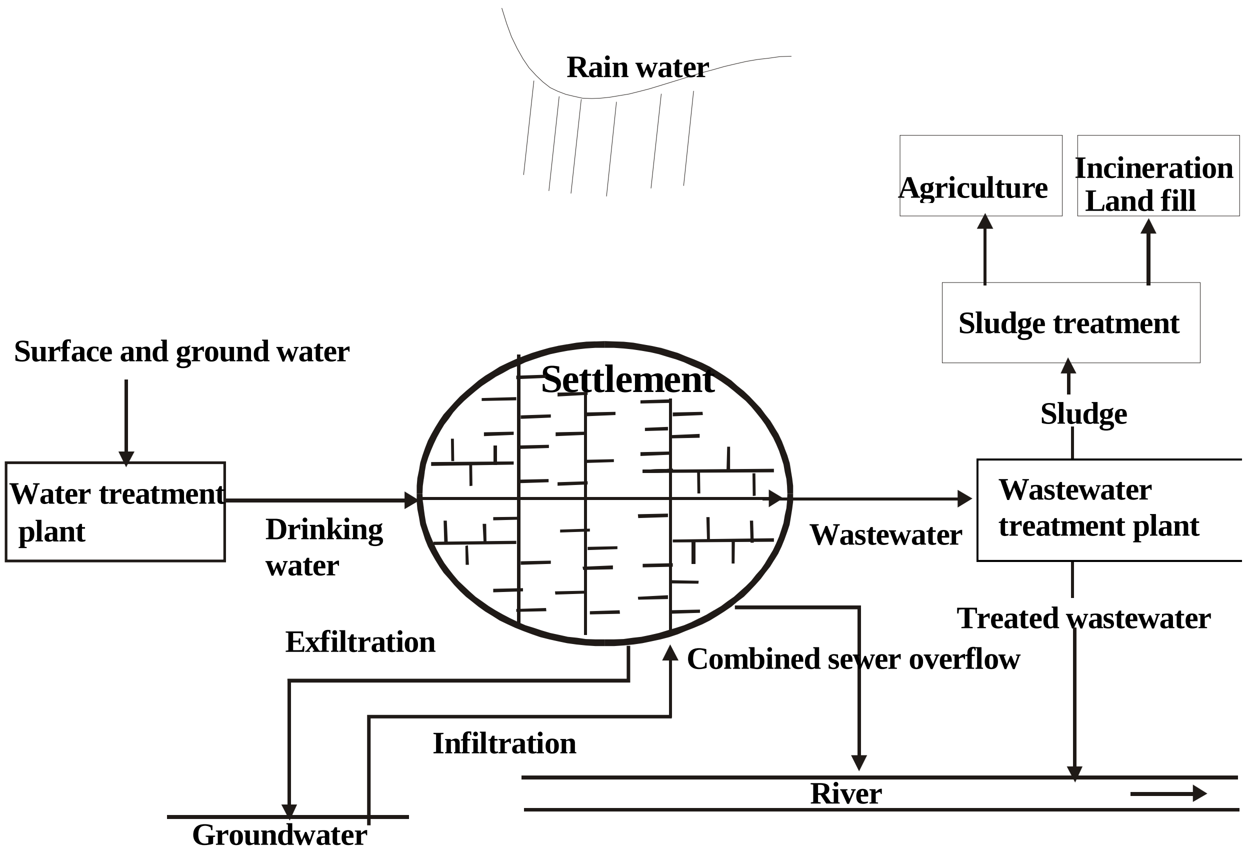


Figure 3: Traditional centralized system of water supply and wastewater treatment

In households, the nutrients that are brought in in the form of food are converted into human excreta and kitchen waste. In conventional sanitation systems, a huge amount of fresh water is used as a transport medium and a sink to dispose of these wastes. In this process a small amount of human faeces is diluted with a huge amount of water. Therefore, it is hardly possible to prevent contaminants from emitting into surface and groundwater bodies. As a result a huge amount of fresh water is contaminated and deemed unfit for other purposes. Moreover, due to the pollution and hygienic problems in receiving waters, surface water can no longer be used as a source for drinking water supply. Huge investments have to be made to improve the surface water quality in order to use it as drinking water.

In the industrial countries, a large amount of money has been already spent to build up and maintain these conventional sanitation systems. In Germany it has been estimated that large investments are still necessary for repairing, rebuilding and extending existing systems in the coming years (Hiessl, 2000). About 80 % of the overall expenditures for sewerage systems go to the collection and transportation of wastewater to the central treatment plant, where only about 20 % of the overall expenditures is spent.

Although construction, maintenance and operation of sewers are very costly parts of the centralised wastewater treatment systems, more than 90 % of the population in Germany are already connected to sewer systems (Wilderer and Schreff, 2000). Experience shows that centralised sewerage systems can be extremely expensive for regions with a low population density, since costs of construction, operation and maintenance of long sewers are to be covered by a small number of inhabitants. These costs are obviously unaffordable for the major part of the population mostly living in developing countries. Thus, it is irrational to plan central sewerage for all rural and peri-urban regions of developing countries. Even in the USA, the complete coverage with sewerage systems is not possible or desirable, for both geographical and economical reasons (Crites and Tchobanoglous, 1998).

Even with the high inputs of money for construction, maintenance and operation, this end-of-pipe concept is producing linear mass flows (figure 4). It shows clear deficiencies in recovery of nutrients and organic matter, which are valuable fertiliser and soil conditioner. As it is already mentioned that even the best affordable treatment plants discharge considerably large amount of nutrients to the aquatic environment where they are lost for ever and cause severe problems. Those nutrients, which are captured in sludge are often contaminated with heavy metals such as Cadmium (Cd) and organic compounds such as PCB (polychlorinated Biphenyle), which pose potential toxic risks to plants, animals and humans. Therefore, large amounts of sewage sludge are disposed of in landfills or incinerated. Only a smaller part is applied to agricultural land.

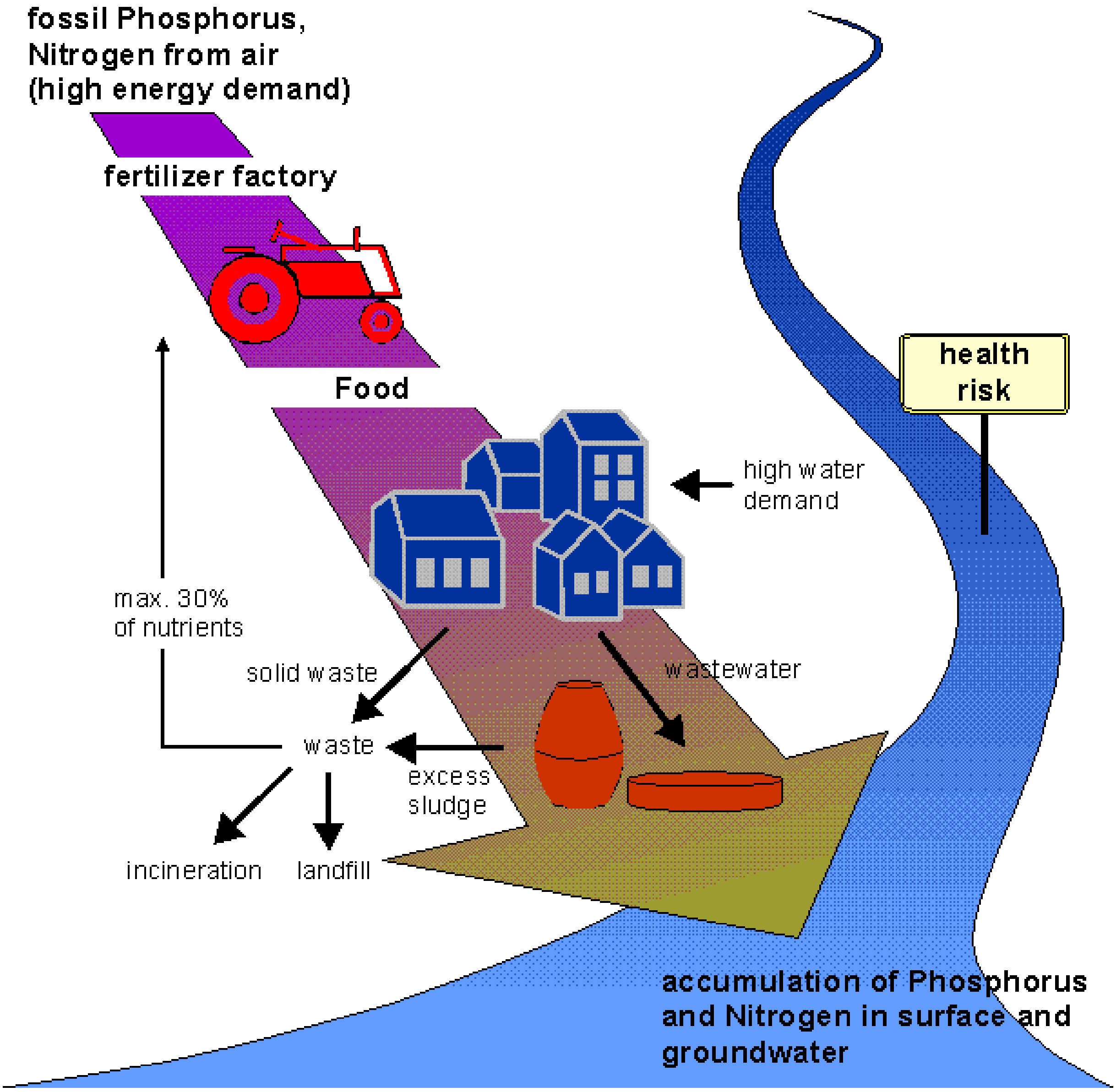


Figure 4: Material flows in the conventional sanitary concept (source Otterwasser GmbH)

3. Conventional decentralised sanitation systems – benefits and limitations

In decentralised systems, wastewater from individual houses is collected, treated and disposed / reused at or near the point of its origin. The most important benefits of this system compared to the centralised system are:

- there is no need of laying sewers for the transportation of sewage as in the centralised treatment plant, which is normally located far from the point of the origin of the sewage; construction, maintenance and operation of sewers are very costly parts of sanitation systems;
- there is far lower dilution of sewage than in the centralised system, which creates possibilities to reuse treated wastewater and nutrients.

Therefore, decentralised wastewater treatment technologies will play a significant role, if they are low-cost and allow reuse. There are many existing decentralised wastewater treatment systems which have been widely used worldwide. However, all of them cause pollution i.e. nutrients and pathogens seeping from these systems contaminate the groundwater and nearby surface water, they cannot destroy pathogens and deprive agriculture of valuable nutrients and soil conditioner from human excreta. Moreover, some systems require expensive tanker-trucks to pump and transport the sludge deposited at the bottom of the system far away. In large cities, transportation distances are normally long, since suitable sites for treatment and disposal can mostly be found at the outskirts of cities. Transportation of relatively small faecal sludge volumes (5 - 10 m^3 per truck) through congested roads over long distances in large urban agglomerations is not suitable, neither from an economical nor from an Ecological point of view (Montangero and Strauss, 2002).

Most of the people in urban and peri-urban areas of Asia, Africa and Latin America and peri-urban areas of industrialised countries use conventional decentralised sanitation systems (On-site sanitation systems), notably septic tank systems. Even in the USA, 25 percent of the houses are served by septic tank. Basically septic tanks are designed only to collect household wastewater, settle out the solids and anaerobically digest them to some extent, and then leach the effluent into the ground, not to destroy pathogens contained in wastewater. Therefore, septic tank systems can be highly pathogenic, allowing the transmission of disease causing bacteria, viruses, protozoa and intestinal parasites through the system. It is reported that there are 22 million septic system sites in the USA issuing contaminants such as bacteria, viruses, nitrate, phosphate, chloride, and organic compounds into the environment (Jenkins, 1994). Another problem is home chemicals with hazardous constituents which are discharged to toilets and contribute to severe groundwater contamination in sanitation using septic tanks. According to the EPA, states of the USA reported septic tanks as a source of groundwater contamination more than any other source, with 46 states citing septic systems as sources of groundwater pollution (figure 5), and nine of them to be the primary source of groundwater contamination in their state. It has to be noted that occasionally problems with broken septic tanks occur leading to infiltration of nearly untreated wastewater.

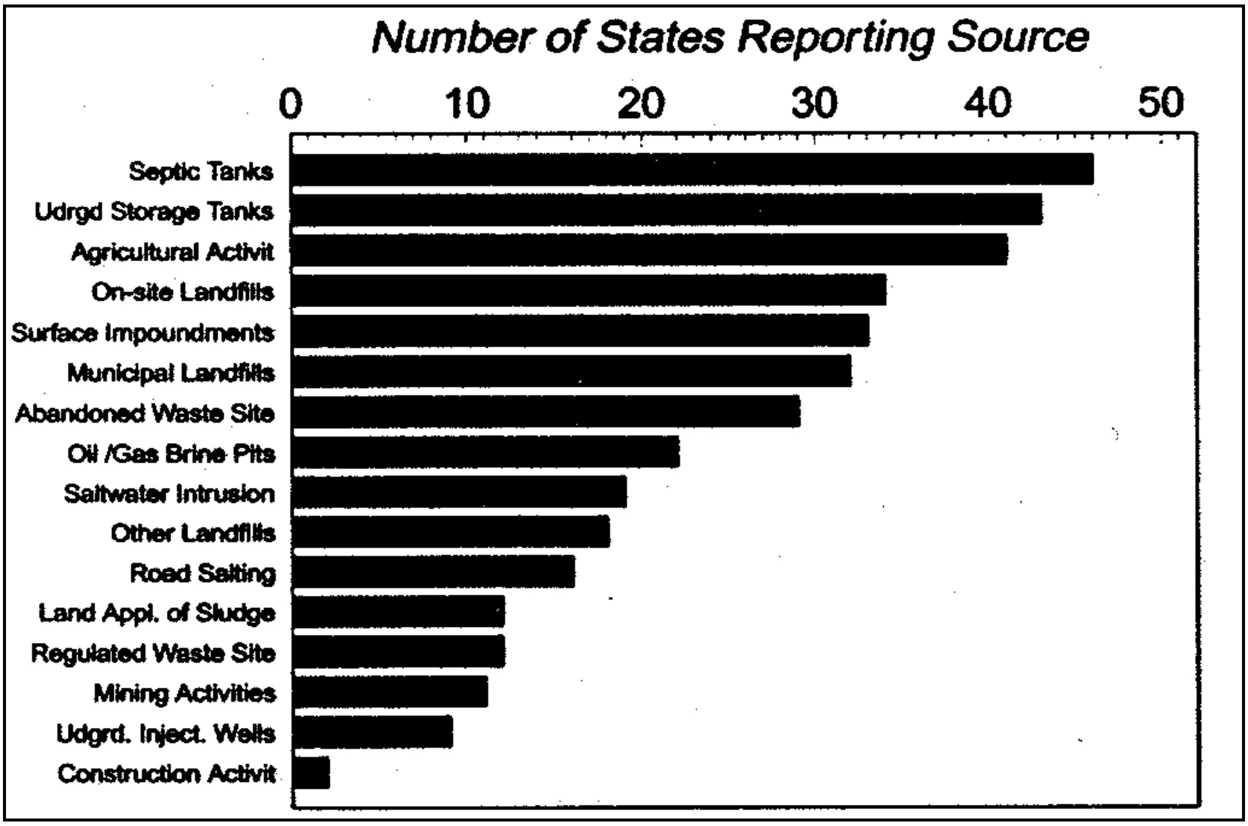


Figure 5: Reported sources of groundwater contamination in the United States (Jenkins, 1994)

The incomplete anaerobic decomposition in septic tanks results in unpleasant odour that spreads in the surrounding. Many households often add chemicals into septic tank to reduce odour. These chemicals have adverse effects on the decomposition process and ultimately in environment.

4. Resource Management Sanitation

4.1 Background

All conventional wastewater treatment systems usually deprive agriculture, and hence food production, of the valuable nutrients contained in human excreta, since the design of these systems is based on the aspect of disposal. In households, resources are converted into wastes. When the systems we have designed fail to reconvert the waste back into resources, they don't meet the important criteria of sustainable sanitation (Esrey, 2000). Thus, the future sanitation designs must aim for the production of fertiliser and soil conditioner for agriculture rather than waste for disposal (Otterpohl, 1999). Nutrients and organic matter in human excreta are considered resources, food for a healthy ecology of beneficial soil organisms that eventually produce food or other benefits for people. One person can produce as much fertiliser as necessary for the food needed for one person (Niemcynowicz, 1997). Therefore, the new approach should be designed in such a way that it could reconvert the waste we produce into resources free of pathogens in reasonable costs without polluting aquatic environment.

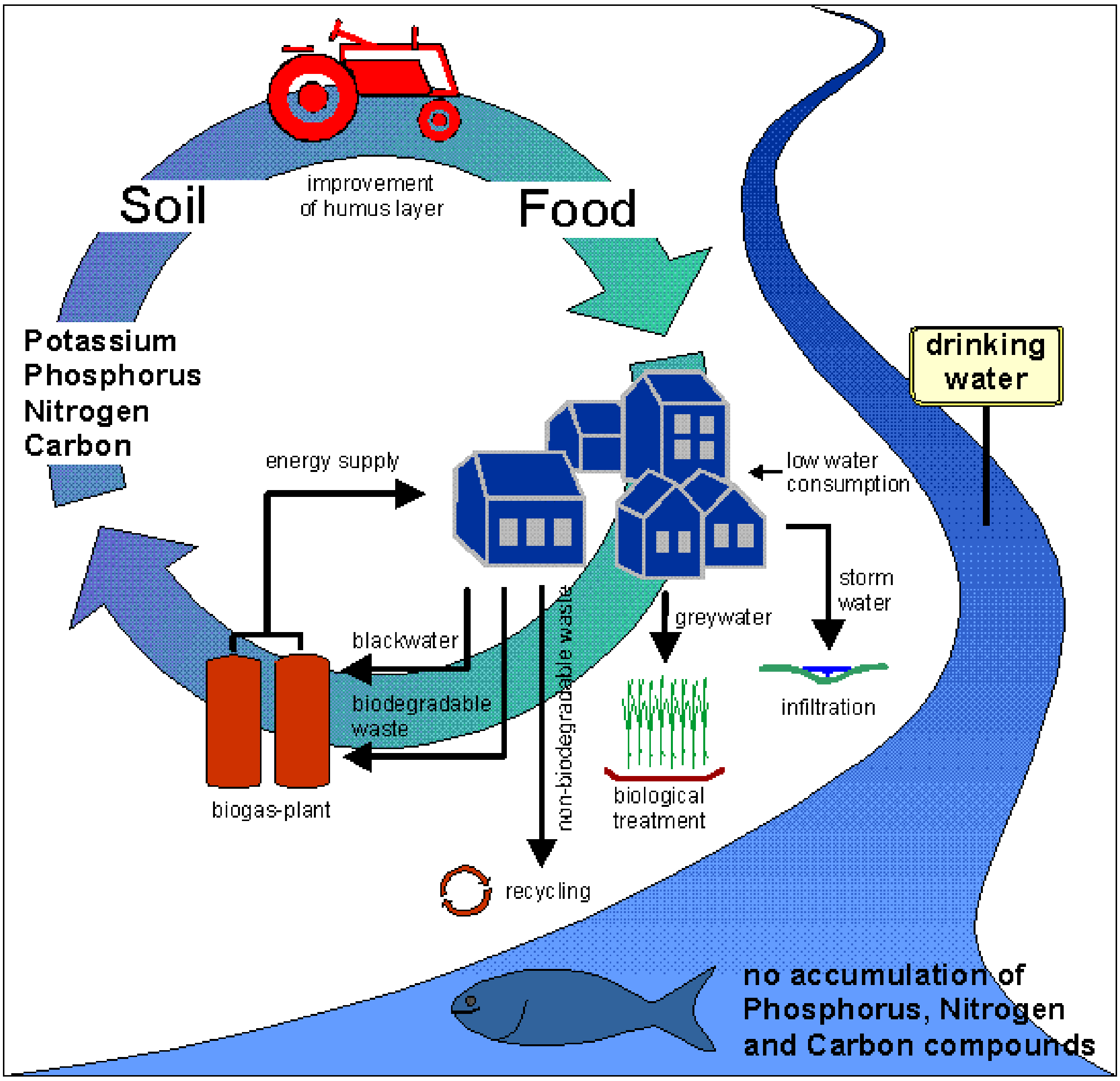


Figure 6: Material flows in resource management sanitation (Source: Otterpohl et al., 1997)

Figure 6 illustrates a possible scenario for closing the nutrients cycles and simultaneously preserving fresh water from pollution. This scenario can be achieved with the application of resource management sanitation, base on ecological principal. There are numerous advantages of resource management sanitation compared to conventional sanitation (Werner et al., 2002; Otterpohl, 2001; Esrey et al., 1998). The major advantages of them are :

- reuse of human excreta as fertiliser and soil conditioner; water and energy;
- preservation of fresh water from pollution as well as low water consumption;
- preference for modular, decentralised partial-flow systems;
- design according to the place, environment and economical condition of the people;
- hygienically safe;
- preservation of soil fertility;
- food security;
- low cost (ecological, economical and health cost);
- reliable.

Resource management sanitation bases on the concept of source control. High levels of nutrient recovery are possible with the concept of source control in household (Otterpohl et al., 1999; Henze et al., 1997; Esrey et al., 1998). The technologies to realise source control have already been developed (Otterpohl, 2001; Esrey et al., 1998). **Sorting toilet** is a suitable technology to separate the urine and faeces at source (see figure 7). Usually, the toilet has two bowls, the front one for urine and the rear one for faeces. Each bowl has its own outlet from where the respective flow is piped out. The flush for the urine bowl needs little water (0.2 l per flush) or no water at all, a mechanical device closes the urine pipe when users stand up whereas flushing water for faeces bowl can be adjusted to the required amount (about 4 to 6 l per flush). However, in the present system separate collection is efficient only when men sit down while urination. Recently, there is a new development in Norway for separating urine even when men stand up while urination.

Figure 7: Sorting toilet (Source: Ruediger)

Figure 8 : Vacuum toilet (Source: Ruediger)

Vacuum toilets as shown in figure 8 has been used in aeroplanes and ships for many years and is increasingly used in trains and flats for water saving. It uses 1 l water per flush and is independent of gravity. The black water is transported by air and pressure differential (vacuum) instead of water and gravity to bio-gas plant. Water is used only for rinsing the bowl, not for transporting the faeces. Limited vertical lifts and long horizontal transportation of the black water are possible. Noise is a concern with vacuum toilets but modern units are not much louder than flushing toilets and give only a short noise.

Composting / dehydrating toilet needs 0.2 l water per flush, only for cleaning the toilet seat. There are also urine diversion composting or dehydration toilets (figure 9). These low-flush and non-flush toilets save not only water, but also produce low diluted or dry faecal material that is easier to manage than highly diluted faecal wastewater as in conventional systems.

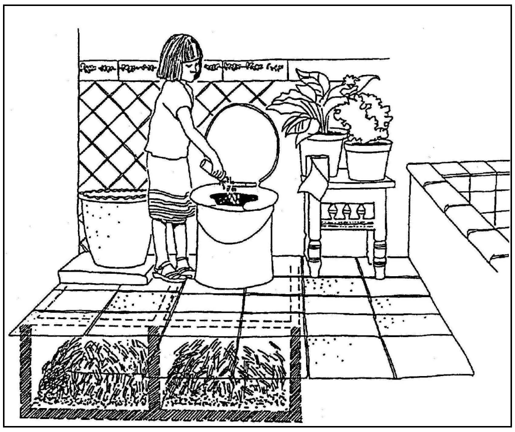


Figure 9: Double-vault toilet with urine diversion (Source: Esrey et al., 1998)

4.2 Bellagio statement

In February 2000, there has been an experts consultation arranged by the Water Supply and Sanitation Collaborative Council (WSSCC) which resulted in the formulation of the so-called ***"Bellagio Statement"*** ("Clean, healthy and productive living: a new approach to environmental sanitation"), which gives some insight into philosophy and basics of Resource management sanitation. The statement contains the following principles (EAWAG/SANDEC 2000):

1st: "Human dignity, quality of life and environmental security at household level should be at the centre of the new approach, which should be responsive and accountable to needs and demands in the local and national setting."

2nd: “In line with good governance principles, decision-making should involve participation of all stakeholders, especially the consumers and providers of services.“

3rd: “Waste should be considered a resource, and its management should be holistic and form part of integrated water resources, nutrient flows and waste management processes.“

- “Inputs should be reduced so as to promote efficiency and water and environmental security.“
- “Exports of waste should be minimised to promote efficiency and reduce the spread of pollution.“
- “Wastewater should be recycled and added to the water budget.“

4th: “The domain in which environmental sanitation problems are resolved should be kept to the minimum practicable size (household, community, town, district, catchment, city) and wastes diluted as little as possible.“

Also a ***Workshop on "Ecological Sanitation in a Recycling Society"*** in August 2000 organized by the associations Sida, UNDP, and SIWI addressed the potential of resource management sanitation to overcome water scarcity and wasting resources:

- "Water is an increasingly scarce resource and to continue to use clean *drinking water as a means to transport human waste* ***is not environmentally sustainable***."

- "Linear approaches to problems, in which *resources* are used and converted into wastes, only *to be disposed of*, represent a *failure in human ingenuity* and a flaw in technology design."

This statement emphasizes that linear matter flows (i.e. they end in disposing of any matters as waste in the end instead of organizing matter flows in cycles realizing reuse achieving almost "zero emission" scenarios) should be changed - also in sanitation schemes.

- "In order to *create a recycling society*, we need to *capture the wastes*, *render them safe and return them to productive resources again*. Resource management sanitation is based on natural ecosystems. It contributes to environmental health and human well-being by reducing disease transmission and disposal of wastes, by recovering and recycling water and nutrients for increasing food security."

- "Most cities and towns in the Third World will neither have access to the required quantities of water, nor will they be able to generate financial resources for investments in extensive sewerage networks and treatment plants. ***Resource management sanitation is far more feasible financially and ecologically than conventional approaches to sanitation*** by reducing external inputs into a closed-loop system and by empowering people, providing for local livelihoods, and enhancing community cohesion."

This statement also points out that resource management sanitation helps to save financial resources, because it is a closed-loop system.

- "If coverage can be increased, *resource management sanitation can serve as the missing link to sustainable urban development*, reverse the unconscious pattern of linear thinking and actions, and be a technical solution that protects ecosystems and harmonises with natural systems."
- "There is a *big need for research to further develop affordable and sustainable solutions*, based on an eco-system approach, *for the management of human excreta*."

As resource management sanitation scenarios are discussed since last few years, it is clear that research is needed in this field. However, how many research activities have been developed in conventional sanitation?

Finally, an introduction to Resource management sanitation given by Steven A. Esrey also renders the most important characteristics of Resource management sanitation:

“Why do people want sanitation today? The most common reason given is for better health. People also want it for convenience, privacy, efficiency, dignity and status among other reasons. We want cars too for transportation. We want convenience, privacy, efficiency, dignity and status as well.

Just like a car and a highway system reflect our culture and values, the toilets and sanitation systems installed around the world also reflect our culture and values. Unfortunately, they reflect a culture of linear flow of resources, waste generation and disposal.

Resource management sanitation is also reflective of a culture and values, albeit an alternative one. It is an alternative philosophy, one with ecological design and systems thinking. Thus, resource management sanitation is more than a toilet or a technology. It is an alternative view of life of how we should live on this planet. It is about restoring communities, protecting cultures, preserving resources, and protecting biodiversity. This is how most of humanity lived until last century.

Resource management sanitation systems are designed on the cyclical principles of natural ecosystems. External inputs into the system, like water, and 'wastes' that exit the system, like nutrients, are reduced to a minimum or eliminated. Thus, resource management sanitation systems are designed to render pathogens harmless close to where people excrete them, use no or little water, and recover and recycle nutrients**.**

By adhering to these principles, resource management sanitation systems help to solve some of society's most pressing problems - infectious disease, environmental degradation, water scarcity and the need to recover and recycle nutrients for plant growth. In doing so, it also helps to restore soil fertility, conserve fresh water and protect marine environments.

Those promoting and resource management sanitation systems take an ecosystems approach to the problem of human excreta. Urine and faeces are considered valuable resources, with distinct qualities, that are needed to restore soil fertility and increase food production. Prior to recycling nutrients, urine and/or faeces may need to be processed. Many of the plant nutrients in urine are readily available to be taken up by plants, while most of the pathogens causing illness are in the faeces. Thus, it makes sense to divert urine from faeces to keep urine relatively sterile, while making it easy to process and treat feaces to render them harmless. Faeces, which contain most of the carbon in excreta, can be rendered harmless by several processes and returned to the land as a soil conditioner as well as returning other valuable nutrients."

4.3 Issues of resource management sanitation

The four issues addressed by resource management sanitation (microbial risks and environmental degradation, water scarcity, malnutrition, and wasting of financial resources) lay down the tasks of Ecosan schemes:

Excreta must be handled safely and also chemical contaminants from domestic wastewater must be contained in compartments as small as possible (again: "dilution is no solution"), water scarcity has to be overcome by reusing the reclaimed part of domestic wastewater related to the water cycle (i.e. greywater), nutrients from human excreta should be recycled for increasing agricultural yields, and saving money (not only by avoiding high investment for sewers, but also needing less synthetic fertilizers because of utilizing nutrients from human excreta).

4.4 Source separation as a key issue in resource management sanitation

The aforementioned aims can be achieved by source control in sanitation! Source separation of different streams of domestic wastewater helps to prevent pathogens from faecal matter to be spread in the environment, utilizing nutrients from yellow water, and preventing grey water from being further contaminated with nutrients, faecal pathogens, and contamination with hazardous substances from industrial wastewaters making it a suitable source for being reused - even for high quality demand like groundwater recharge.

The issue of source control requires some special pre-requisites: separate pipes for yellow, brown and grey water, no-mix toilets for separate collection of yellow and brown water and low volumes for toilet flushing.

Generally, there are different options for source separation. A simple scheme would be the separation of grey water from black water, requiring two separate pipe systems in the home (one for grey water, one for black water). Low volumes of toilet flush water are helpful in further treatment of black water solids in order to sanitise them. For certain sanitation techniques (dehydration, composting), the black water solids have to be separated from the liquid phase. One possibility for sanitisation the entire black water is anaerobic digestion, which also offers the possibility of harvesting biogas.

The second option is to collect all three sources of domestic wastewater separately: grey water, yellow water, and brown water. This option requires three different types of pipes in the home (for grey water, yellow water, and brown water). In such a scheme, the excellent fertilizer “yellow water“ is collected very purely.

Source separation of different particular domestic wastewater flows (related to the nutrient as well as to the water cycle) facilitates sanitisation of human excreta as well as nutrient recovery from excreta – and also purification of the grey water stream.

4.5 Treatment systems for brown and black water

There are two types of treatment systems, namely dry and wet systems for the treatment of brown and black water. Dry systems use no flush water whereas wet systems use flush water, but only very low amounts just to transport faecal matter to the treatment plant located close to the origin of faecal matter. The non-diluted or less diluted faecal matter has to be sanitised before reuse in agriculture. This can be done with composting, dehydration, vermicomposting and anaerobic fermentation/digestion. In the following sections the theoretical background of these processes is briefly discussed.

4.5.1 Composting

Composting is the biological decomposition of the organic matter under controlled aerobic conditions. The basic composting process is shown in figure 10. The main factors affecting the aerobic decomposition of organic matter by microorganisms are oxygen, moisture and nutrients. Carbon and nitrogen are essential for microbial growth and activity. Carbon is the principal source of energy, and nitrogen is needed for cell synthesis. Other important factors that can slow down the composting process are temperature and pH. Temperature is the result of the microbial activity as well as the influence of the surrounding temperature, mass of the composting materials and heat loss.

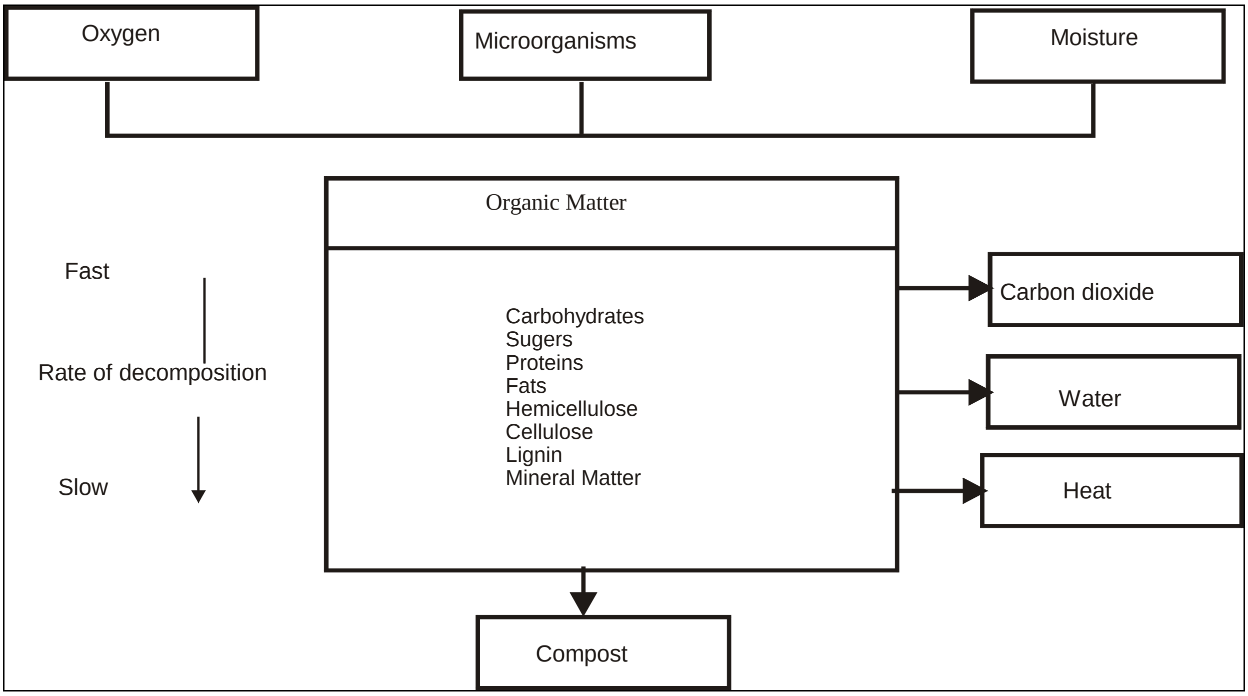


Figure 10: The composting process (Source: Epstein, 1997)

In the process of composting, microorganisms break down organic matter and produce carbon dioxide, water, heat, and compost. In addition, ammonia and other volatile compounds are emitted to the atmosphere. However, in comparison to CO_2 and H_2O these represent a very small amount.

All organic material will eventually decompose. The rate at which it decomposes depends on the physical as well as chemical factors. The optimal condition for composting is shown in table 2.

Table 2: Overview of optimal condition for composting

Parameters	Optimal level for household organic waste	Optimal level for Fibrous or bulky materials such as straw or wood chips
Moisture	50 - 60 %	For straw: 75 - 85 %, for wood chips: 75 - 90 %
C:N ratio	25 - 30: 1	For woody materials: 35 - 40 : 1
pH	6 - 8	
Temperature	Thermophilic (> 45 ℃)	
Oxygen	5 - 15 % of air	
Particle size	Good Structural stability	
Time	Depend on temperature Longer for temperature<45 ℃ Shorter for temperatur > 45 ℃	

4.5.1.1 Composting of faecal materials

The composting of faecal materials follows the same biological processes as the composting of other organic waste. Therefore, the optimal conditions for the composting of faecal matter are a C:N ratio of 25 - 30:1 and a moisture content of 50 - 60 % (Table 3). However, the composition of human faeces shows low C:N ratio and a high water content. Besides, human faeces have a low structural stability. Therefore, only materials with a high C:N ratio, low moisture content and high structural stability should be added to faecal materials. Straw, bark and wood chips are considered to be good bulking agents.

Table 3: Overview of conditions for composting in sanitation

Condition → Parameters ↓	**No or little functioning**	**Slow functioning**	**Optimal functioning**	**Slow functioning**	**No or little functioning**
Moisture	< 25 %	< 35 – 40 %	50 – 60 %	70 %	70 % anaerobic
C:N ratio		< 25:1 (nitrogen loss)	25 – 30: 1	> 30:1	
Temperature	< 15 ℃	< 45 ℃	> 45 – 60 ℃ <	70 ℃ >	75 ℃
pH		> 8 (nitrogen loss)	6-8	5 - 6	< 5
Oxygen		< 5 % of air anaerobic	> 10 % of air		
Time			< 45 ℃ 1 year > 45 ℃ 2 month		
Particle size			structural materials: bark, wood chips, straw etc.		

4.5.1.2 Dehydration

Dehydration means to remove water. Therefore, unlike composting, dehydration is the controlled physical process of dewatering moist materials. Dehydration is effective if faecal materials are separated at source without any dilution, since a great part of the liquid phase of faecal materials has not to be evaporated off at all. Therefore, urine diversion is crucial for dehydration. Esrey et al. (1998) claimed that treatment methods based on dehydration can reduce pathogens effectively. There is a rapid pathogen destruction at moisture contents below 25 %. Dehydration processes can be accelerated with the help of heat (solar radiation), ventilation and the addition of dry materials.

4.5.1.3 Vermicomposting

Vermicomposting is the process in which organic materials are converted into humus using earthworms that break down the organic materials. Earthworms are voracious feeders on organic wastes and while utilising only a small portion for their body synthesis they secrete a large part of these consumed waste materials in a half digested form. Since the intestines of earthworms harbour wide ranges of microorganisms, enzymes, hormones etc., these half digested vermicasts decompose rapidly and are transformed into a form of vermicompost that is homogenous, rich in plant nutrients with superior plant growth characteristics and increases water holding capacity of the soil (Appelhof, 1997; Edwards, 1995). Moreover, pathogens cannot survive the vermicomposting process (Edwards, 1995).

The earthworms species: Eisenia fetida and Eisenia andrei are most commonly used for the vermicomposting. Other suitable species include Lumbricus rubellus, Eudrillus eugenie and Perionyx excavatus. The latter two species are from Africa and Asia and cannot withstand low temperatures.

In the composting process, the organic materials have to be turned regularly or aerated in some way in order to maintain aerobic conditions. In vermicomposting, the earthworms, which survive only under aerobic conditions, take over both the roles of turning and maintaining the organic materials in an aerobic condition, thereby lessening the need for expensive engineering. The major constraint to vermicomposting is that, in contrast to composting, vermicomposting systems must be maintained at temperatures under 35 ℃. Exposure of the earthworms to temperat ures above this, even for short periods, will kill them. To avoid such overheating careful management is required. The processing of organic materials occurs most rapidly at temperatures between 15 ℃ and 25 ℃, at moisture content of 70 to 90 % and pH of 6.5 - 7.5 (Edwards, 1995). Outside these limits, earthworm activity and productivity, and thus the rate of waste processing, falls dramatically.

4.5.1.4 Anaerobic digestion/ fermentation

Anaerobic fermentation is an oxidation process, in which organic compounds, such as e.g. livestock manure and toilet waste, are converted by microbiological processes in absence of oxygen (O_2) to methane (CH_4) and carbon dioxide (CO_2). The produced biogas (~ 55 - 75% CH_4) can be used for cooking, heating and light. The methane production contributes to the BOD reduction in digested sludge. It is possible to apply high loading rates to the digester and even recalcitrant materials (e.g. lignin) can be degraded.

Anaerobic digestion produces lower amounts of sludge (3 - 20 times less than aerobic processes), since the energy yields of anaerobic bacteria are relatively low. Most of the energy derived from substrate breakdown is found in the final product, CH_4. As regards to cell yields, 50% of organic carbon is converted to biomass under aerobic conditions. The net amount of cells produced per metric ton of COD destroyed is 20 - 150 kg [44.1-330.75lbs], as compared to 400 - 600 kg [882-1323lbs] for aerobic digestion. (http://www.united-tech.com/wd-anaerobicdigestion.html). But the process is slower than the aerobic digestion, it is much more sensitive to upsets by toxicants, and the start-up of the process requires a long period of time.

Anaerobic digestion is affected by temperature, retention time, pH, chemical composition of wastewater, competition of methanogens with sulfate-reducing bacteria, and the presence of toxicants. The complete anaerobic digestion is considered to take place in three phases (figure 11):

Hydrolysis: particulate material is converted to soluble compounds that can be hydrolyzed further to simple monomer that are used by fermentation performing bacteria.

Fermentation (also acidogenesis): amino acids, sugars, and some fatty acids are degraded further to acetate, hydrogen, CO_2, and propionate and butyrate.
Methanogenesis (carried out by methanogens): acetate is split into methane and CO_2; CO_2 reacts further with hydrogen to methane; and acetic acids that are produced in this phase are also transformed to methane.

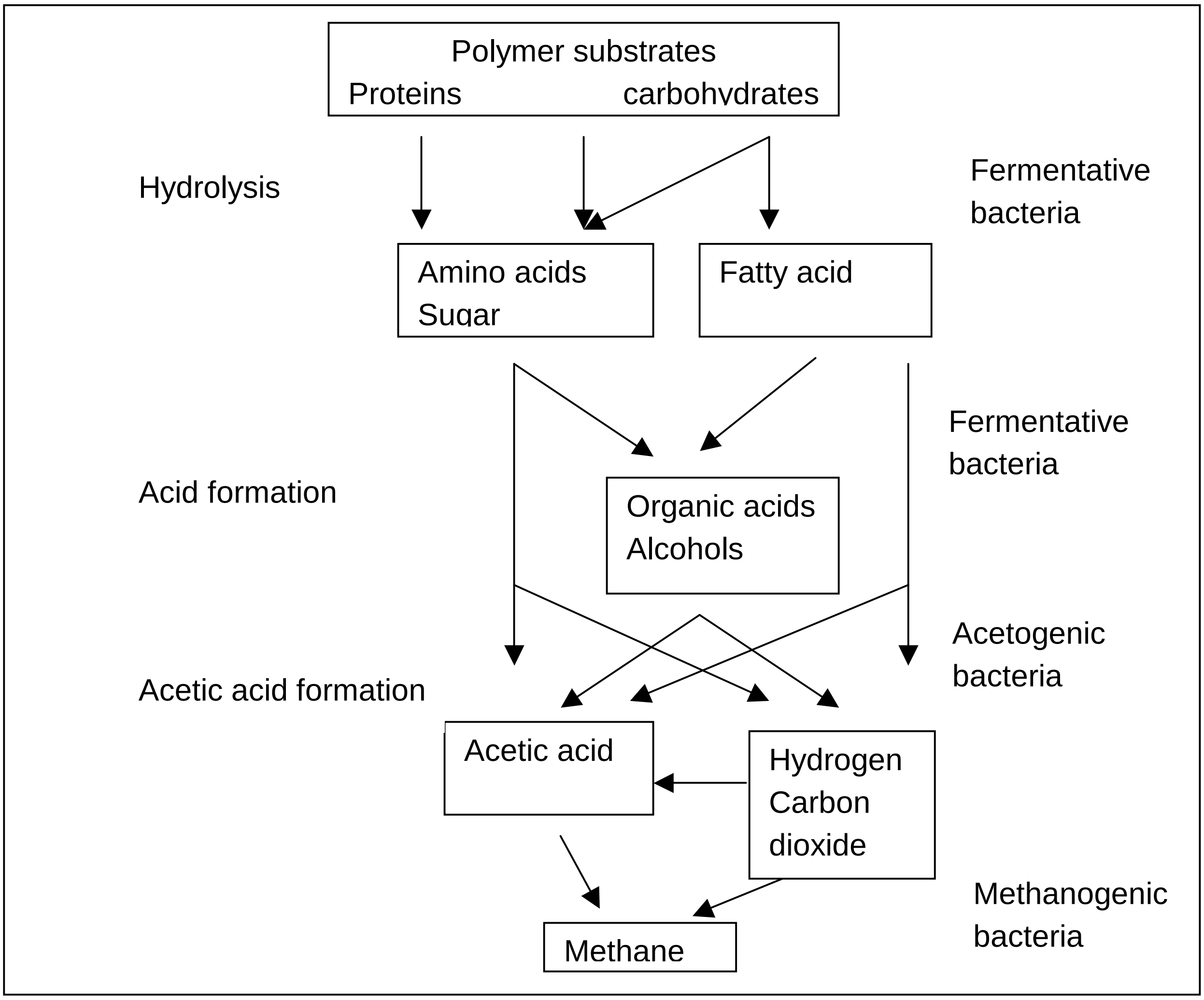


Figure 11: Steps of anaerobic digestion (Bilitewski et al., 1994)

Process temperature affects the rate of digestion and should be maintained in the mesophillic range 35 - 40 °C (95 - 105 °F) with an optimum of 100 °F. It is possible to operate in the thermophillic range 55 - 65 °C (135 to 145 degrees F), but the digestion process is subject to upset if not closely monitored.

Thermophilic digestion operates at temperature ranges of 50-65°C [122°F-149°F]. It allows higher loading rates and is also conductive to greater destruction of pathogens. One drawback is its higher sensitivity to toxicants. Because of their slower growth as compared with acidogenic bacteria, methanogenic bacteria are very sensitive to small changes in temperature.

The hydraulic retention time (HRT), which depends on wastewater characteristics and environmental conditions, must be long enough to allow metabolism by anaerobic bacteria in digesters. The retention times of mesophilic and thermophilic digesters range between 25 and 35 days but can be lower.

Most methanogenic bacteria function in a pH range between 6.7 and 7.4. Acidogenic bacteria produce organic acids, which tend to lower the pH of the bioreactor. Under normal conditions, this pH reduction is buffered by the bicarbonate that is produced by methanogens. Under adverse environmental conditions, the buffering capacity of the system can be upset, eventually stopping the production of methane. Acidity is more inhibitory to methanogens than of acidogenic bacteria. An increase in volatile acid levels thus serves as an early indicator of system upset. Monitoring the ratio of total volatile acids (as acetic acid) to total alkalinity (as calcium carbonate) has been suggested to ensure that it remains below 0.1.
(http://www.united-tech.com/wd-anaerobicdigestion.html)

A wide range of toxicants is responsible for the occasional failure of anaerobic digesters. Inhibition of methanogenesis is generally indicated by reduced methane production and increased concentration of volatile acids.

4.5.2 Composting and dehydration toilet systems

In composting toilet systems either a toilet with urine diversion or no urine diversion is used (see overview in figure 12). In case of no urine diversion toilet, faeces and urine with or without toilet paper depending on the user's habit drop into the composter located just below the toilet. In urine diversion toilet, urine is collected separately and kept in a storage tank until it is ready for use in agriculture or just treated in a soak pit or evapotranspiration bed. However, leaching from soak pit can cause heavy groundwater pollution. Faecal materials are composted or dehydrated for a long time and reused as fertiliser and soil conditioner in agriculture.

In composting toilets, low temperature composting occurs because only a small amount of materials enters every day, which is not sufficient to prevent the heat loss from the heap (Gajurel, 1998). Moreover, aeration, which is a very important factor in the composting process, is poor inside the material of the composting toilet, even if material with high structural stability is added, because structural material cannot be mixed with faeces properly unless they are turned mechanically. As a result, aerobic micro-organisms cannot find proper environment to work actively. Because of low temperatures in composting toilets, other methods such as a long retention time and ash as an additive among others are applied to kill pathogens.

Urine diversion is crucial for dehydration toilets. The non-diluted faecal materials (faeces and toilet paper if used) drop into the dehydrating vault located just below the toilet and are dehydrated with the help of heat (Solar radition), ventilation and the addition of dry materials.

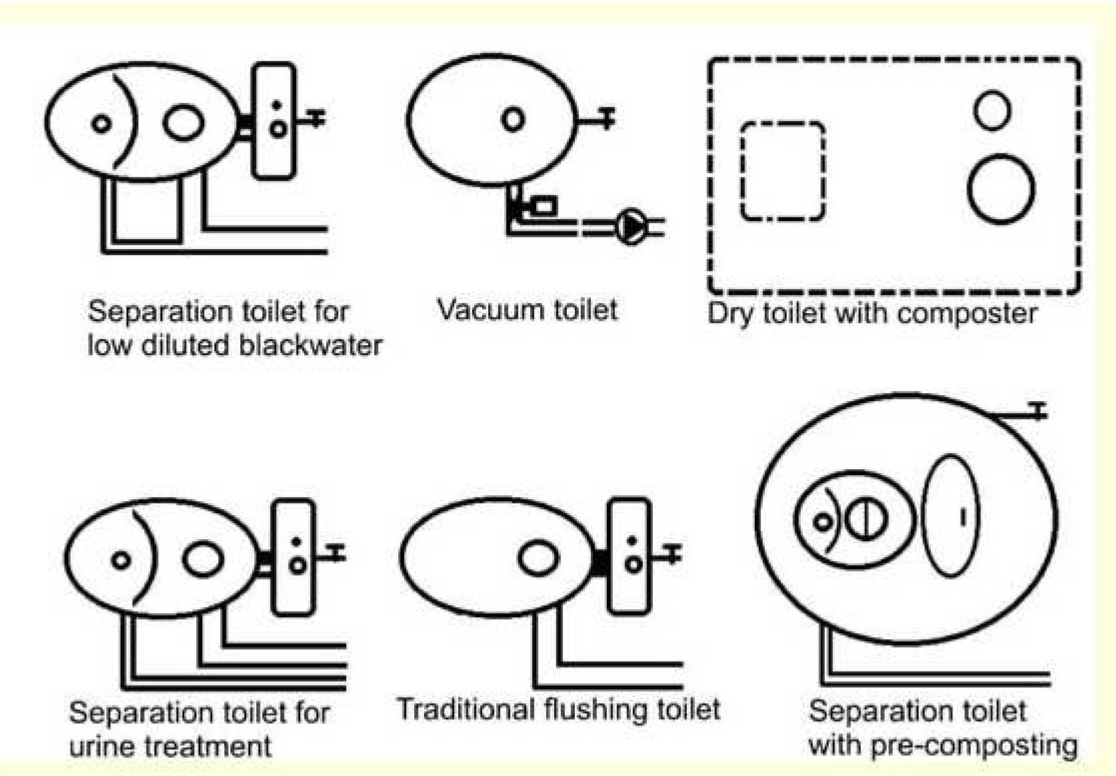
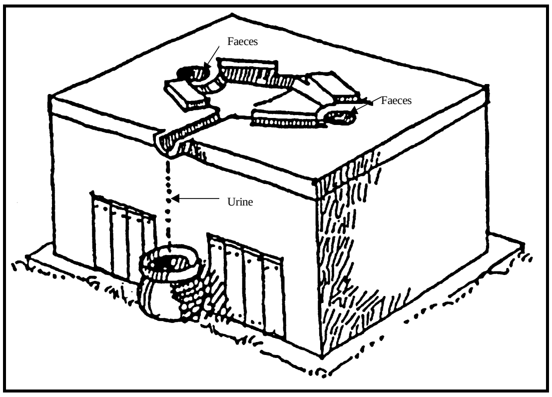


Figure 12: Overview of toilet systems for source control sanitation (Otterpohl 1999 - www.gdrc.org/uem/waste/oldenburg.html)

4.5.2.1 Existing dehydration toilet systems

Different forms of dehydration toilets have been in used in many parts of the world. However, all use the same basic principle of dehydration. Dehydration toilets are mostly used in Vietnam, Mexico, China, El Salvador, Ecuador, Yemen, South Africa and India. Double-Vault dehydrating toilets as shown in figure 13, which consist of two alternately used vaults constructed above the ground, have been widely used in Northern Vietnam since 1954, and adapted models were implemented in Mexico, Central America and Sweden (Esrey et al., 1998). In this toilet, urine is diverted to a collection tank or soak pit under the toilet vault or outside the toilet and faeces drop into one of the two vaults located below the toilet's seat. When one vault is full, it is sealed and another vault is used. Dry materials like ash or soil or a mixture of sawdust/lime or soil/lime are added after the defecation. The added dry material assists the desiccation process and raises the pH, which aids in pathogen reduction.

Central American and Mexican version of Vietnamese double-vault toilets have been successfully applied in urban areas of El Salvador and Mexico (Moe et al., 2001 and 2003). These toilets are usually attached to the house, sometimes even placed inside the house. The double-vault toilet as shown in figure 9 is built in a bathroom of a modern, high standard house in the city of Cuernavaca, Mexico. A urine diverting mobile toilet bowl is placed just above the opening of one of the two chambers located below the bathroom. When the first vault is full, it is sealed and the bowl is moved to the opening of another empty vault. The vaults are accessible from outside the house.



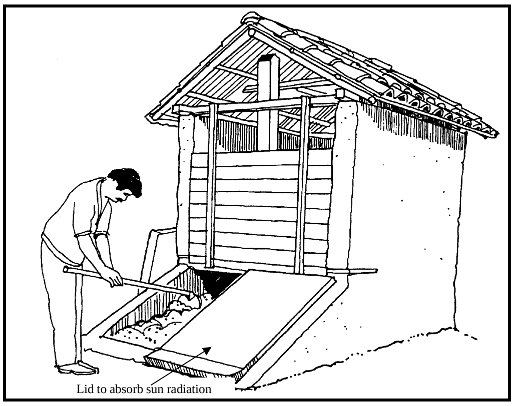


Figure 13: Vietnamese double-Vault Dehydrating toilet (left) and double-vault toilet with solar heater (right) (Source: Esrey et al., 1998)

The double-vault toilet without urine diversion has been used in a dry region of Ecuador. The vault is covered with a lid made up of a wooden frame covered with thin galvanised iron painted black in order to absorb the sun's radiation and increase the vault temperature and rate of dehydration (figure 13 right). Sawdust or ash is added after every defecation as in the urine diversion system.

The single-vault dehydrating toilet uses a passive solar panel to increase the chamber temperature and rate of dehydration. The addition of dry materials after defecation is required as in the double-vault dehydrating toilet. In this system, the faecal materials that are accumulated below the toilet's seat are shift to the rear of the chamber with a hoe or rake. There are also systems, which have been equipped with a pusher to shift the faecal materials to the rear of the vault (figure 14). After some months, the dry materials which are collected at the rear of the chamber are shovelled into a sack and stored outside the toilet until reuse.

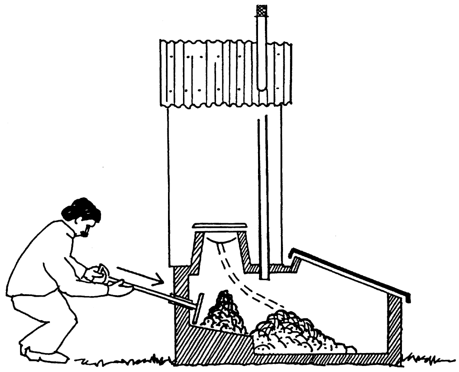


Figure 14: Single-vault toilet equipped with a pusher (Source: Esrey et al., 1998)

German Technical Co-operation (GTZ) with the company Otterwasser has implemented some dehydrating toilets in Mali, West Africa (see figure 15).

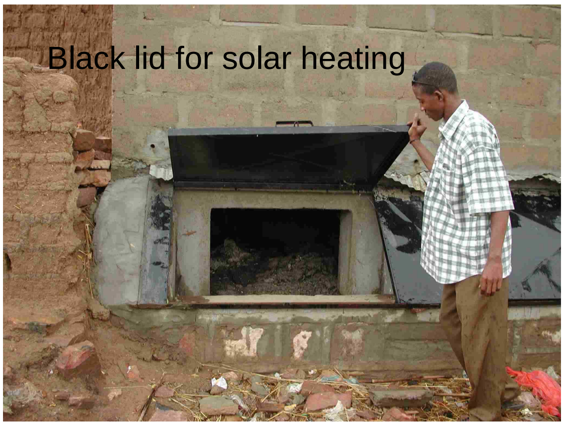


Figure 15: Dehydration toilet in Male, West Africa

Dehydration toilet is very beneficial for regions of warm climate. However, also in Sweden there are a number of dehydration toilets on the market for many years (Del Porto and Steinfeld, 1999). WM Ekologen system, for example, is based on urine diversion and dehydration. This system has been used in indoor bathrooms.

By now tens of thousands of urine diversion ecosan toilets have been built in China (Xianghong and Jiang, 2003; Jiang, 2000). Ash, soil and lime are added after the use of the toilet. The urine-diversion squatting pan and mechanical ash dispensers are provided in the systems (figure 16). Many of the toilets are built inside the dwelling, and often upstairs.

Figure 16: Squatting pan urine diverting toilet with double-vault from China

The main principles for good functioning of dehydration toilets are:

- it should be built above the ground to avoid entering and contamination of groundwater;
- urine diversion is beneficial;
- two vaults system with alternative usage is advantageous;
- vault should be heated with solar by covering each chamber with black lids;
- wash water has to be kept out;
- post-composting after collecting the dehydrated faecal materials can be required.

4.5.2.2 Effectiveness of existing dehydration toilet systems

Sanitation based on dehydration prevents pollution, destroys pathogens and recycles human excreta as fertiliser . These systems seem to be an effective method to deal with human excreta because they keep faeces that contain pathogen causing diseases in a small volume in a closed environment for a long time in order to be sanitised before re-use. Not only they prevent pathogens and nutrients entering into water bodies, but they also produce an end product that is rich in nutrient and is a good soil conditioner.

As mentioned before, these systems have been increasingly applied in many parts of the world mostly in rural areas and small communities. Experts working in the field have made mostly positive experiences. Especially in dry climates dehydration toilets have been found effective regarding pathogens destruction, volume reduction of faecal material and maintenance. In dehydration toilets there is less chance of flies breading and odour development since faecal materials are dried by solar heater and by adding dry materials.

Many years of practical experience, technological development have shown that resource management sanitation based on dehydration is an effective means to convert human excreta into fertiliser and soil conditioner as well as to destroy pathogens. To maximise efficiency, both of pathogen destruction and of nutrient reuse the systems should be provided with separate collection of urine and faeces at source. So far the effective methods for pathogens destruction in faecal material are dehydration and high pH. By the addition of dry materials (ash, soil, lime) moisture is absorbed and pH is raised. Solar heating accelerates the dehydration.

4.5.2.3 Existing composting toilet systems

The Clivus Multrum composting toilet shown in figure 17 is a continuous system and features a single chamber, in which combined processing of urine, faeces and organic household waste takes place (Del Porto and Steinfeld, 1999). The composting chamber is provided with a slanting floor, air conduits and at the lower end a storage space. A tube connects the toilet seat riser with the receptacle. There is a constant draught due to natural convection from an air intake in a vault, through which the air conduits, and out via a vent pipe. This system has a separate chute for the household organic waste. Because of the slopping floor, the content of the vault slowly slides down from the fresh deposits at the upper end to the storage part of the vault.

Figure 17 : Clivus Multrum composting toilet (Source: Clivus Multrum)

The TerraNova composting toilet system of Berger Biotechnik, Germany is also a single chamber continuous system. Based on the Clivus Multrum, this system has been increasingly used in single family houses and ecological settlements in Germany (figure 18). In the ecological settlement Waldquelle near the city of Bielefeld there are about 70 systems in operation for single family and terraced houses as well as multi-storey buildings even up to the 5th floor.

Another type of the composting toilet called twin-bin net composting toilet was used first time on the Pacific Islands (Del Porto and Steinfeld, 1999). It consists of two chamber constructed above the ground and inside each chamber a fishing net is suspended by hooks from the side of the chamber (figure 19 left). On the fishing net, a mat woven from coconut palm fronds is placed in order to separate the solid from liquids. The net also allows air to enter into the composting materials from all sides. In the chamber, coconut husks, small wood chops, leaves or vegetable food scrapes are added through the seat riser or drop hole periodically. The liquid that accumulates on the floor of the composting chamber is evaporated by air flow and wicks made from old clothing or is drained to an evapo-transpiration bed adjacent to the composting chamber. Air flow inside the chamber is provided with a large diameter vent pipe that draws air up through the pile from an intake opening located below the net along the rear wall of the vault.

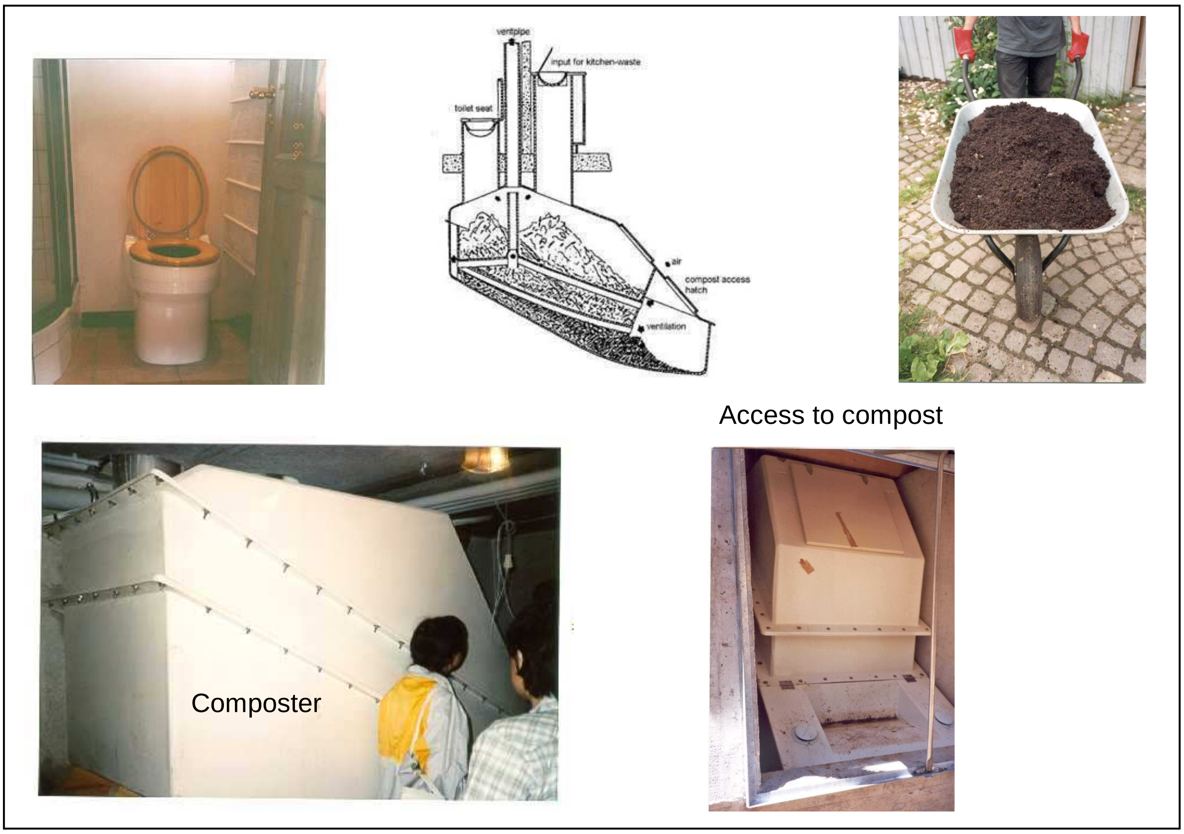


Figure 18: Composting toilet in Eco-settlement Braamwisch, Hamburg

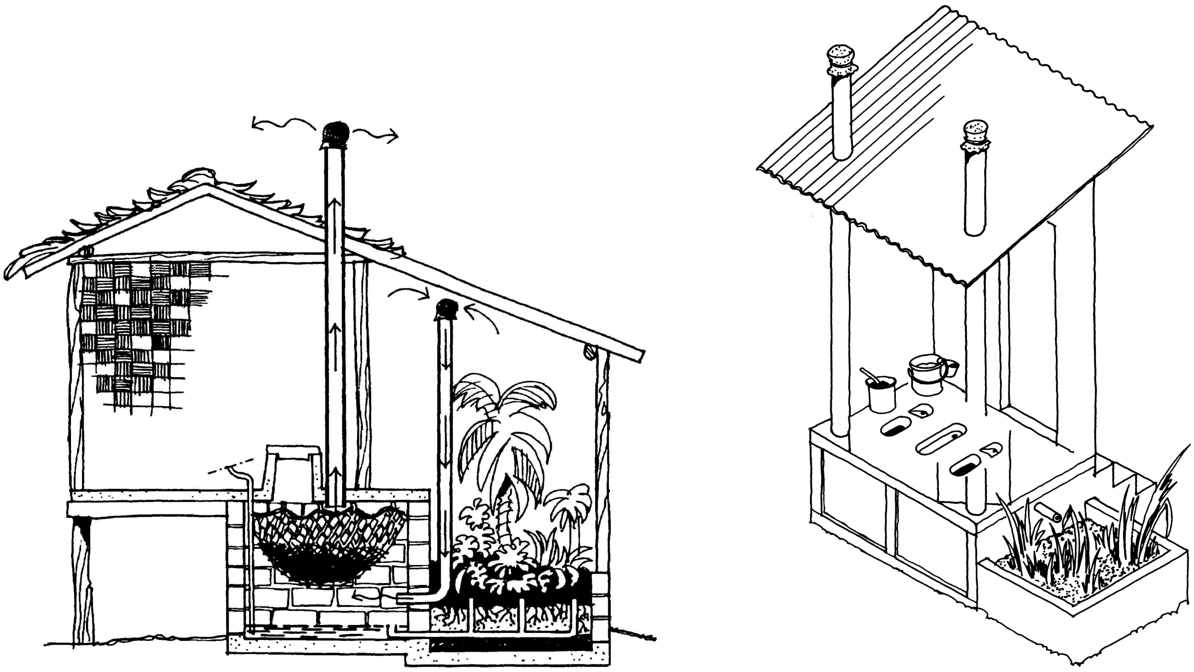


Figure 19: Twin-bin net composting toilet in the pacific islands (left) and Kerala double-vault toilet developed by Paul Calvert (right) (Source: Esrey et al., 1998)

In Kerala, India, the Vietnamese type double-vault composting toilet with urine diversion as shown in figure 19 (right) has been applied. Since most of the Indian people are washers, water used for anal cleaning is diverted along with urine to the evapo-transpiration bed. Over each vault there is a drop hole for faeces and a funnel for urine. Between the two vaults there is a trough over which anal cleaning is performed. The materials added for enhancing composting are straw, leafy material and paper scraps. A handful of ashes is sprinkled over the faeces after each uses.

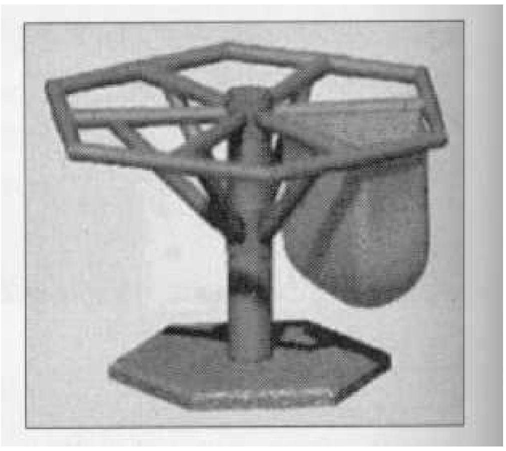


Figure 20: Dryloo composting toilet (Source: Del Porto and Steinfeld, 1999)

Dryloo composting system as shown in figure 20 consists of a rotating PVC frame upon which six woven polyethylene bags are hung. These bags are used alternately and serve as faecal matter composter. It is placed in a watertight container just below the toilet stool. A fan and a vent pipe are provided in the system.

There are also other types of composting toilet systems either batch or continuous systems such as Minimus, Weelie Batch, Nature-loo and Rota-loo. They are increasingly used in Australia (Pollard et al., 1997).

4.5.2.3 Effectiveness of existing composting toilet systems

Like dehydration toilet, sanitation systems based on composting are an effective method to deal with human excreta because they keep faeces that contain disease causing pathogens in a small volume in a closed environment for a long time in order to be sanitised before reuse. They also produce compost that is rich in nutrients and is a good soil conditioner.

These systems have been increasingly applied in many parts of the world, mostly in rural areas and small communities. However, very few investigations on the composting toilets have been carried out so far (Naudascher, 2000). Investigations on pre-composting of faeces along with toilet paper and bark in small scale composting toilets showed that decomposition takes place in composting toilets, but only slowly because many factors that influence the composting process are, unlike in the pile system, difficult to be optimised in the composting toilet (Gajurel, 1998). Turning of the pile in the pile system helps for air circulation. It may not be practical in the present design of composting toilets. Moreover, because of the small amount of material entering every day and heat loss from the system, the temperature in composting toilets is more or less same to ambient temperature. The maximum temperature measured in the Multrum composting toilet was 32 ℃ (Jenkins, 1994). Anothe r study by Redlinger et al. (2001) in the state of Chihuahua, Mexico, showed that temperature measured in single-vault solar composting toilet was equal to or similar to ambient temperature. The reasons they found were 1) the composting pile in the toilet was not large enough to trap heat to maintain the high temperature required for aerobic thermophilic bacterial growth, 2) users did not regularly adjust the moisture levels of the compost pile with water or soak materials, and 3) users did not regularly adjust pile oxygen content by stirring or turning over the pile.

Because of low temperature and slow decomposition, the materials in composting toilets should be kept in the vault for a long time in order to kill pathogens and to stabilise the composting materials. The pre-composted faecal material from the composting toilet has self heating capacity of about 60 ℃. Therefore , it can be further composted in pile systems with other organic waste, in which many parameters influencing thermophilic composting can be optimised, so that high temperature can be obtained in the pile. Pathogen free stable compost is desirable for its application as fertiliser and soil conditioner.

Especially in dry climates dehydration toilets have been found more effective than composting toilets regarding pathogens destruction, volume reduction of the faecal material and maintenance. In dehydration toilets, because of dry conditions there is less chance of flies breading and odour development. However, the end product produced by the composting process is an excellent soil conditioner, free of pathogens when the optimal conditions are achieved and sufficient retention time is given. Therefore, development of composting toilets that can maintain optimal condition for composting of faeces is required.

4.5.2.4 Vermicomposting toilet system

Some toilets use earthworms to decompose faecal matter and kitchen organic waste (figure 21). The Dowmus system in Australia is partially filled with active compost at the time of installation and inoculated with beneficial soil organisms in particular tiger and red composting worms (Ho and Mathew, 1998). There is no heating element and the system is not intended to operate above 35 ℃, to protect the worms. The process depends more on soil organisms and worms rather than on the thermophilic microorganisms for composting. It can also take other household organic matters provided they are cut into small pieces.

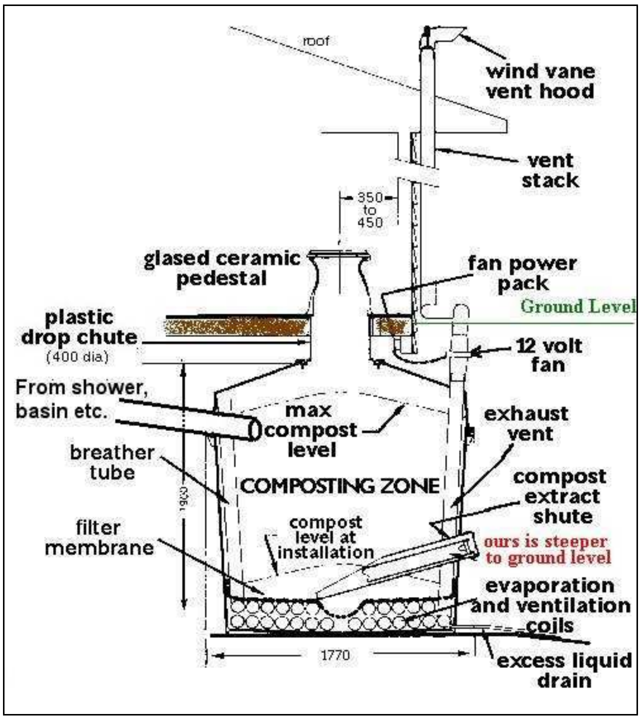


Figure 21: Dowmus composting system with worms (Source: Dowmus)

A Vermi-processing toilet has been field tested for 8 years in India and was found to be a novel low water-use toilet for safe processing of human excreta without odour and fly problem. It is started off by putting 5 kg of vermicastings in the pit. The operation of the toilet employing the pit is very simple and hygienic as the human excreta will be completely converted to vermicastings (Bhawalkar and Bhawalkar, 1991). In the USA, Redworm (Eisenia and Lumbricus rubellus) has been added in the Clivus Multrum composting toilet (Rockefeller, 1995). Because of low moisture in the toilet, daily misting with water is required for maintaining optimal moisture content. The effect of redworms on the degradation process in the toilet has been remarkable. Most of the faecal matters and kitchen wastes were flat, worm castings covered the entire surface. Recently, the Dowmus vermifiltration system has been developed for domestic wastewater and kitchen organic waste treatment in Australia (Bajsa et al., 2002). This system has a composting tank from which the liquid is drained. Vermicomposting is used for the treatment of the tank contents. However, since ammonia is sensitive to worms, urine should be diverted.

4.5.2.5 Vacuum toilet-biogas plant system

Vacuum toilets produce little diluted black water which is transported by the vacuum system to a bio-gas reactor in which black water is treated anaerobically together with bio-waste from kitchens. A well managed anaerobic digester should produce 1 m^3 gas/m^3 volume. The biogas mixture is about 70 % methane and 30 % carbon dioxide (Doelle, 1998). The methane can be used as a source of renewable energy and can be used to produce electricity as well as cooking and lighting gas. The sludge, which is rich in nutrients and organic matter can be used after sanitisation in agriculture as a fertiliser. Vacuum toilet-biogas plant systems have been applied in following projects:

Settlement Flintenbreite, Luebeck, Germany: An integrated sanitation concept with vacuum toilets, vacuum sewers and a bio-gas plant developed by OtterWasser GmbH has been implemented in the settlement Flintenbreite, peri-urban area of the city of Luebeck (figure 22). The settlement was planned for 350 inhabitants and is connected to a bio-gas reactor for black water treatment (Otterpohl et al., 2001). Vacuum toilets and vacuum pipes are used for black water collection and transportation. The little diluted black water is transported to the bio-gas reactor in which black water is treated together with bio-waste from kitchens. The bio-gas is used to operate the heat and power generator. After the treatment the hygienic end product is used as fertiliser.

Black water mixed with shredded bio-waste is sanitised by heating the feed to 55 °C for 10 hours. The energy is further used by the digester that is operated mesophilic at around 37 °C. The relatively small amount of water added to the black water keeps the volumes small enough for transportation. There is a 2-weeks-storage tank for the collection of the digester effluent. Bio-gas is stored in the same tank within a balloon that gives more flexibility in operation. The fertiliser will be pumped off by a truck and transported to a farm that has a seasonal storage tank for 8 months.

Solar Passive Building „Wohnen & Arbeiten“, Freiburg-Vauban, Germany: about 40 inhabitants in the 4-storey-building „Wohnen & Arbeiten“, are connected to the sanitation system as in Flintenbreite (Panesar and Lange, 2003). Black water is collected with vacuum toilets and transported to the bio-gas plant by vacuum sewers. In the biogas plant, organic wastes are added to the black water with the help of a feeding device. The biogas plant is connected to the internal gas system of the house; it provides cooking gas for the households. The sludge is stored in a storage tank for the fertiliser. At the beginning grey water was treated with an aerated sand filter, but due to technical problems, it was later replaced by a membrane-filter-module.

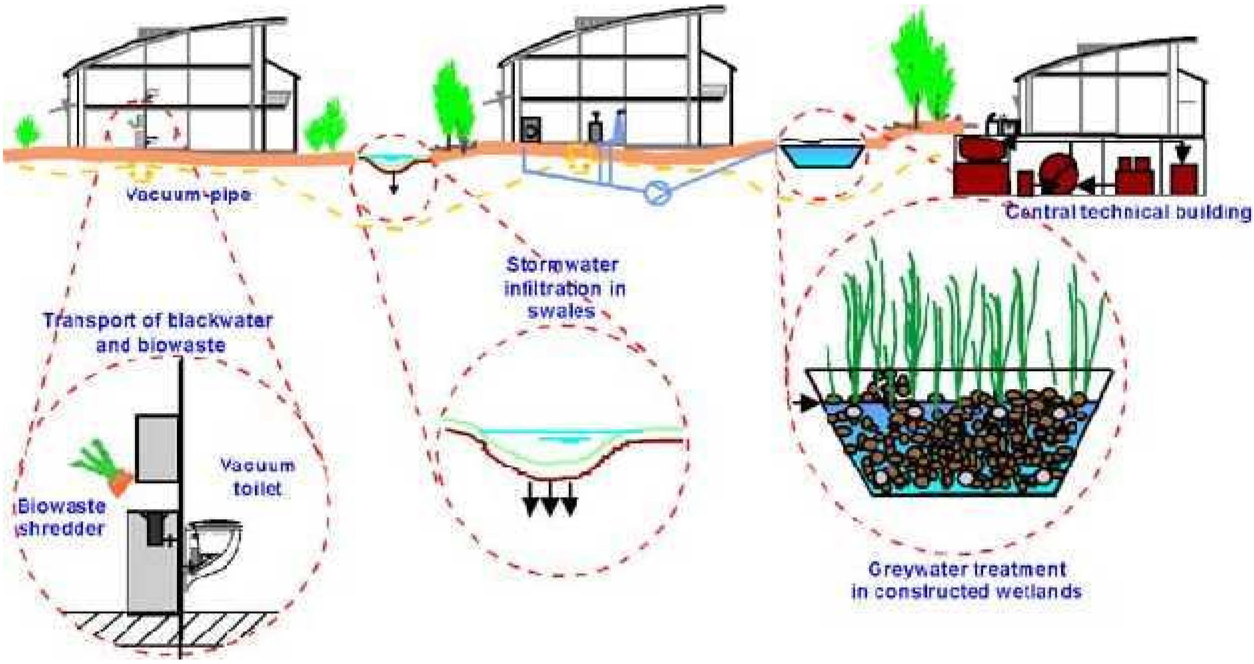


Figure 22: Vacuum -bio-gas system, greywater bio-filter and rainwater infiltration (Otterpohl, 2001)

Norwegian experience with water saving toilet - storage tank - thermophilic aerobic reactor: in Norway, unlike in the projects in Germany, a different type of toilet is used for black water collection (Skjelhagen, 1999). The toilet does not need water for transportation, only about 0.2 l per flush for cleaning the toilet. The black water is stored under the toilet bowl until it contains 20 - 25 l and is flushed by gravity to a storage tank that is located not farther than 10 m from the toilet. Grey water is treated in a compact treatment plant consisting of sludge collecting filter bag, filter and UV. The organic waste is stored in a closed sub-surface tank in which bio-mass produces acids that lowers pH below 5. As a result the waste remains conserved. There is no production of gases.

After a year of storage, the black water, grey water sludge and semi-liquid organic waste are pumped by a truck-tanker and transported to a pre-storage tank. The tank content is sanitised and stabilised in a thermophilic aerobic reactor with a processing temperature of 55 - 60 ℃ and kept in a post-storag e tank before application in agriculture. No energy is added for heating the bio-mass.

Also, at the agricultural university of Norway 24 student apartments have been connected to a recycling system based on aerobic sanitisation of black water with organic household waste, collected using a vacuum toilet system and rendering an odourless and sanitised fertiliser slurry (Jenssen, 2001).

Picture from Tan Lap village, close to Hanoi (figure 23) shows an anaerobic digester for decomposing the manure of at least 5 pigs and black water of one family. The biogas is used for cooking and light, the effluent is used as fertilizer. The biogas can be transported via PVC-tubes to houses up to 100 meters away. It can be directed by valves to the gas stove or the gas lamp in the kitchen. The methane produced displaces the use of firewood (estimated at 2500 kg per family per year, for which families spend between $ 5 and $ 10 per month). The plants also improve sanitation and promote cleaner air.

Figure 23: Biogas production and use in Vietnam

4.5.3 Solid-liquid separation systems

With the sorting toilet, faeces with toilet paper (if used and put in the bowl) is flushed with 4 - 6 l water to the tank where the solid and the liquid phase are separated and treated separately. There are many varieties of processes used in liquid-solid separation. They are usually based on two principal modes of separation: 1) filtration (gravity, vacuum, pressure and centrifugal), in which the solid-liquid mixture is directed towards a filter medium (screen, woven cloth, membrane etc.). The liquid phase flows through the filter medium while solids are retained, either on the surface or within the medium and 2) sedimentation or settling in a forces field (gravitational and centrifugal) whereby advantage is taken of differences in phase densities between the solid and the liquid. The solids are allowed to sink in the fluid under controlled conditions. In the reverse process of flotation, the particles rise through the liquid, by virtue of a natural or induced low solids densities.

In decentralised wastewater treatment systems, septic tanks, which are based on the principal of sedimentation are widely used for solid-liquid separation (Crites and Tchobanoglous, 1998). A new development is Aquatron (figure 24) which is manufactured and applied in Sweden for separating solid matters from toilet wastewater (Del Porto and Steinfeld, 1999). When the toilet is flushed, the flush water with faeces and toilet paper enters the top of the polyethylene module, which is constructed to initiate a whirlpool effect in the upper container. Here, by centrifugal force, part of the liquid, which moves to the outer wall and ultimately out of the system, is separated while the solids drop down in the middle into the composter beneath it.

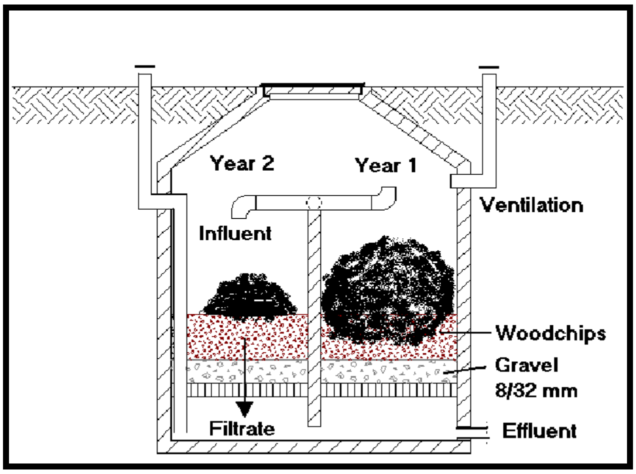
Figure 24: The whirlpool, surface tension separator Aquatron and its function where the faecal water (FW) is separated into liquids and solids (Vinnerås, 2002, http://www.aquatron.se***)***

The Aquatron is a commercial separation system adopted for separation of faeces from faecal water. The efficiency of the system depends on correct installation. The disintegration of faecal particles should be minimised. An easy way to reduce disintegration is by shortening the length of the system, especially by decreasing the vertical drop and a smoother bend between vertical and horizontal transport of the faecal water. When using the system in a multi-storey building, one way of doing this is to install an Aquatron on each floor.

4.5.4 Rottebehaelter systems

Rottebehaelter as a component of decentral systems has been increasingly used in Austria, Germany and Switzerland for domestic wastewater pre-treatment. Since its application is until now only limited to German speaking countries, there is no English word for it, but can be called pre-composting tank. However, in this work the term "Rottebehaelter" is used to make clear to which system it refers. It was first introduced by Dr. Joachim Niklas, OEKOTEC, and Mr. Peter Stolz, AREAL, in Germany. Today there are also other companies including Mall-Beton offering this system.

A Rottebehaelter consists usually of an underground monolithic concrete tank having two filter beds at its bottom or two filter bags that are hung side by side and used alternately in an interval of 6-12 months (figure 25) (Gajurel, 2003).



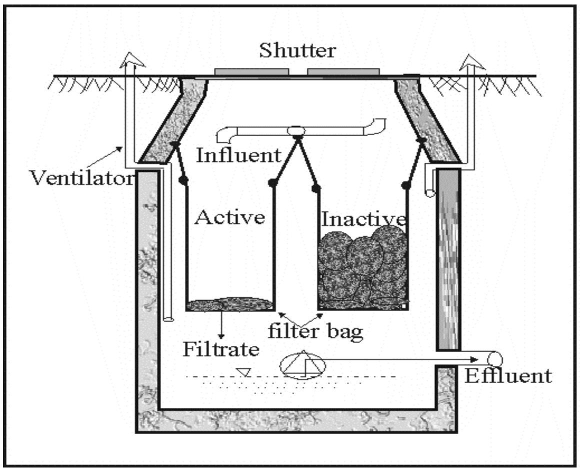
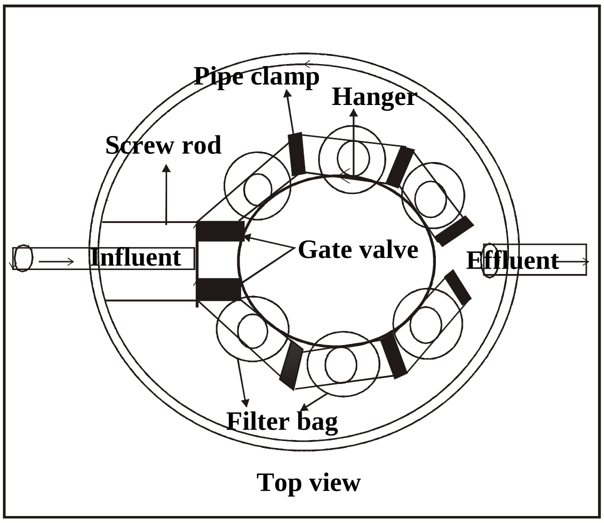


Figure 25: Rottebehaelter systems (left: filter bed system, right: filter bag system)

It is watertight and structurally sound in order to avoid entering of extraneous groundwater in it and leakage of the filtrate into the groundwater which would cause groundwater pollution. The top opening is covered by a prefabricated concrete slab and provided with ventilation so that air can enter. A shutter for changing the filter bag or emptying treated material, adding bulking agents such as straw, bark etc. into the retained materials, inspection and cleaning has been provided on the covering of the tank.

The influent is discharged into one of the two filter beds or filter bags retaining solid materials while draining the liquid. The principal role of the filter medium (filter bed or filter bag) is to cause a clean separation of particulate solids of the influent with no additional energy consumption. The filter medium is designed to recover a valuable solid product. Therefore, attempts are made to create a surface deposition of the solids in a recoverable form. When the influent is discharged into the filter bed or filter bag a filter cake is formed at the bottom. Its depth increases during the filtration due to deposition of solid material on its surface.

There is also another kind of Rottebehaelter, in which six filter bags are hung side by side. This is used only in Austria (figure 26 and 27). Unlike the previously described Rottebehaelter, two pipes with a slope of 5 % are clamped inside the Rottebehaelter, under which filter bags are hung side by side in their mountings. There are three filter bags for each pipe. The influent is alternately distributed to both pipes by a means of diversion. The influent is first diverted into one of two pipes where three empty filter bags are hung in such a way that when one is full, the influent flows to next filter bag and so on. The solid materials in the influent are retained while liquid passes through the filter bag and is collected at the bottom of the Rottebehaelter.



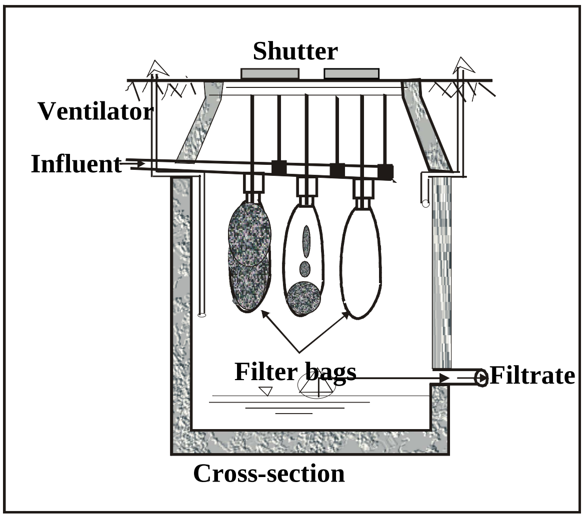


Figure 26: Rottebehaelter with several filter bags system (left: top view , right: cross-section)

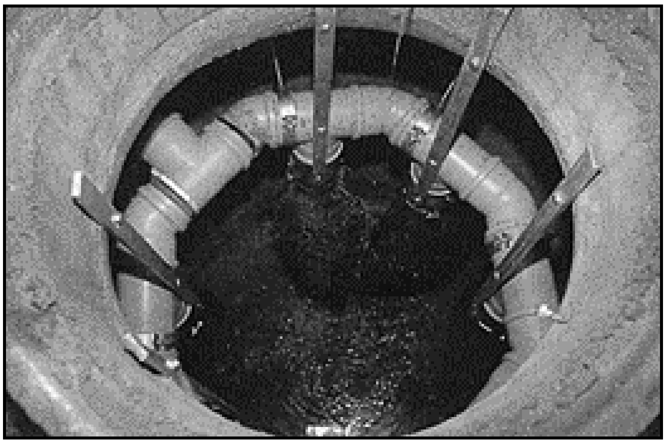


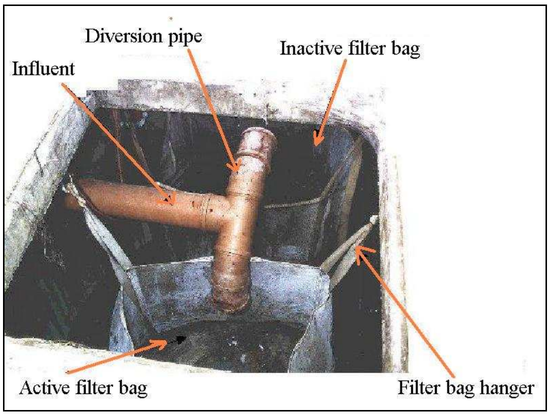
Figure 27: Existing Rottebehaelter with several filter bags in Austria (Ambros et al., 1998)

The filtrate that is collected at the bottom of the Rottebehaelter is periodically pumped or piped (at a good gradient) for further treatment. Normally, the pre-treated filtrate in the Rottebehaelter is further treated in constructed wetlands adjacent to the Rottebehaelter and then discharged into the water bodies nearby. For reuse tertiary treatment is needed. The solid materials, which are retained in the filter medium, are bio-degradable and during the filling phase and silence phase (the filled one is left in a silence phase for degradation) decomposition takes place. Because of the degradation, the volume of the material in the filter bag or filter bed will be reduced.

Compared to Rottebehaelter with a filter bed at its bottom, the filter bag system has some advantages. In the filter bag the outer part of the material is always in aerobic condition, because it has a continuing contact with air. Therefore, there is no or only little odour nuisance. Moreover, handling of treated material is not so difficult as in filter bed systems because material is collected in the filter bag which can be taken out easily. Regarding the handling, Rottebehaelter with several filter bags is simpler than other systems. Because the material is distributed into 6 filter bags instead of only two, each bag is 3 times lighter than in other systems. However, since the filter bag is attached to the influent pipe, there is no opening in the filter bag. Therefore, adding bulking agents like straw or bark, which is important for composting of retained materials, is not possible unless they are added through the toilets.

4.5.4.1 Existing Rottebehaelter systems in Germany

Rottebehaelter with two filter bags or two filter beds system has been increasingly used in rural areas of Germany for the domestic wastewater treatment (figure 28). This system is mostly installed in individual houses for 4 - 40 inhabitants. There are a couple of places where the system is connected to more than 200 inhabitants. However, in Belzig a system with filter bed was installed for several hundred people.



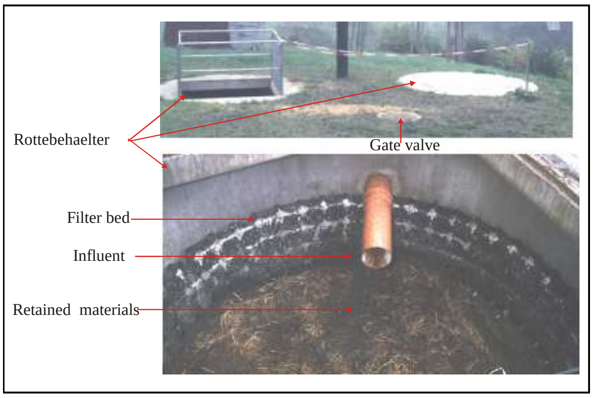


Figure 28: Rottebehaelter with filter bags (Left) and with filter beds (Right)

Most of the Rottebehaelter systems are constructed near residential buildings. The domestic wastewater is discharged into one of the two empty filter bags having a pore size of 1 - 2 mm and made up from non-biodegradable material. The solid materials are retained in the filter bag which is usually filled up in 6 – 8 months. As soon as the filter bag is full, the flow is diverted manually to the next empty filter bag. The filled bag is left for further dewatering and degradation in order to get volume and pathogens reduction as well as a dry material. After 6 - 8 months, the bag with pre-treated materials is taken out through the shutter located on top of the Rottebehaelter and further composted with other household and garden organic waste in a local composter for a year prior to its use in the garden. The filtrate drops down to the bottom of the Rottebehaelter. The collected filtrate is pumped periodically or piped (for a site of good gradient) to the constructed wetland. After treatment in the constructed wetland, it is discharged into the water courses nearby. At some places it is collected in a pond in the garden.

This system has also been implemented in the pilot project in Lambertsmuehle near Cologne city in Germany as a component of resource management sanitation in 2000 (figure 29). The Lambertsmuehle, a historical water mill, has been put under preservation since 1983. It has been reconstructed to a museum. Due to the restoration of the building the wastewater treatment had to be reconstructed as well. The new concept of source control and reuse has been installed for the treatment of wastewater from residents and museum visitors. The flow of nutrients and water in the system is shown in figure 30.

Figure 29: Rottebehaelter with two filter bags in the pilot project Lambertsmuehle

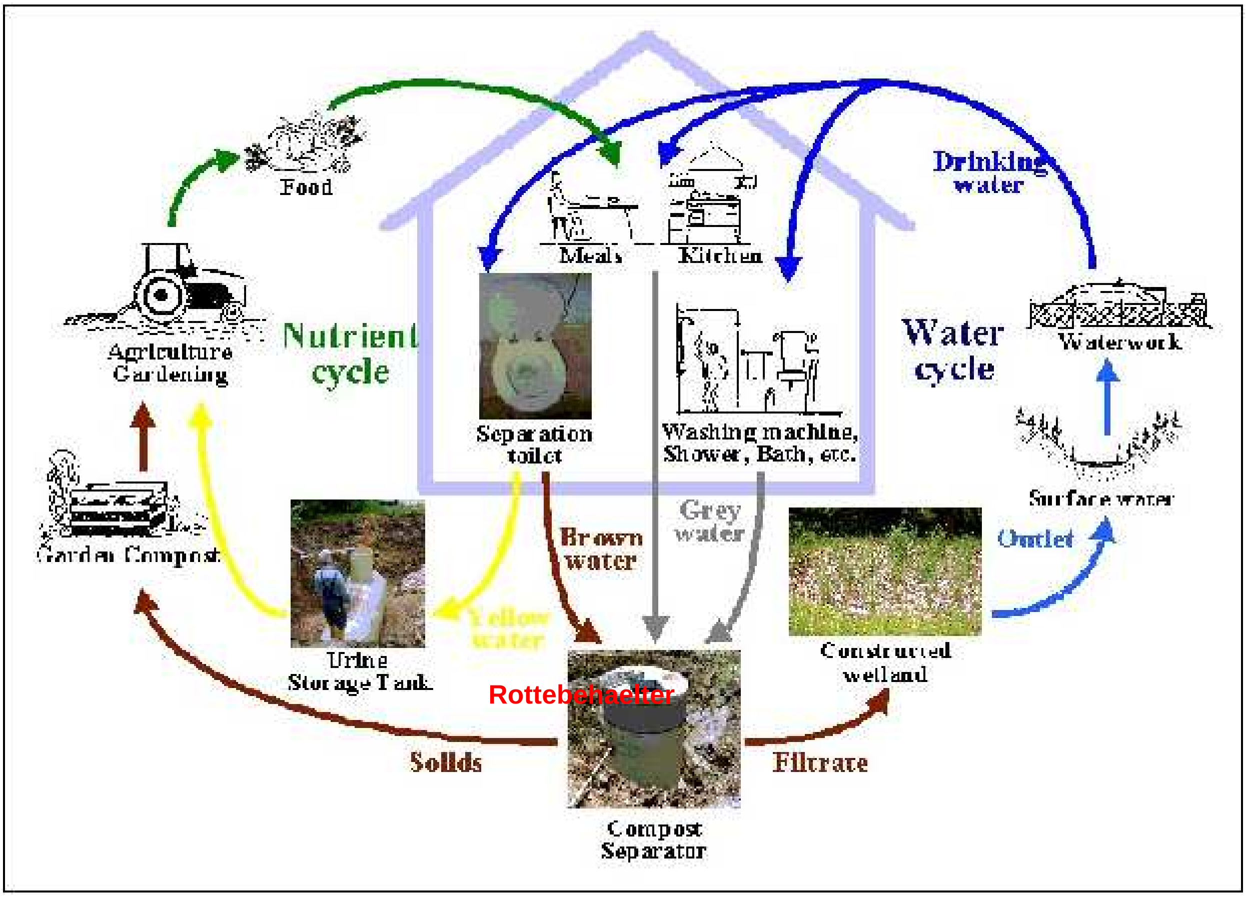


Figure 30: Flow scheme of water and nutrient recycling in the Lambertsmuehle pilot project (Oldenburg et al., 2003)

The wastewater is now separately captured at the source. The source separated flows are treated separately outside of the building. Newly developed sorting toilets where no water is needed for the urine flushing, a mechanical device closing the urine pipe when users stand up and water free urinals have been installed. Yellow water is collected and stored in the storage tank until it is used for agricultural purposes. For brown water, a Rottebehaelter system is used. The filtrate, due to urine separation, is nutrient poor, and is mixed with grey water at the bottom of the Rottebehaelter and treated in a constructed wetland. The effluent is discharged into the nearby water course .

4.5.4.2 Effectiveness of Rottebehaelter systems

The major advantages of the Rottebehaelter system over other systems such as septic tanks are that it does not deprive agriculture of the valuable nutrients and soil conditioner from human excreta and does not require expensive tanker truck. The system is low-cost and allows reuse of nutrients and soil conditioner in agriculture. Relatively dry and stable retained materials can be obtained in the Rottebehaelter with composting by adding sufficient amount of bark regularly as well as with vermicomposting by adding worms. The latter was more effective to reduce the moisture content and to accelerate the degradation of the retained materials. However, low temperature composting took place which needs more than a year to kill all pathogens specially Ascaris. Vermicomposting, however, is an effective process to sanitise faecal materials. The final product is hygienically safe as the human excreta will be completely converted to vermicastings. The typical analysis of the vermicast of wastewater sludge in Australia revealed that pathogens such as enteric viruses, parasite eggs and bacteria such as E.coli have been reduced to safe levels for use in the garden.

Figure 31: Fresh material (Left) and finished material after 3 months of vermicomposting

Compared to composting with adding bark in retained materials, vermicomposting has several benefits. In the Rottebehaelter, moisture content is too high for composting of the retained materials that are structurally poor, whereas this range of moisture content is optimal for worms to work effectively. Structural materials such as bark have to be added for composting. Adding bark regularly and sufficiently is not an easy job.

In a good functioning Rottebehaelter system, solid-liquid separation, dewatering, low temperature composting or vermicomposting can be achieved in one unit. It can be implemented where people use flush toilets. Therefore, the septic tank systems can be replaced by the ecologically and hygienically advantageous Rottebehaelter system for household wastewater treatment. There is no need to construct a new tank, since the existing tank can be modified, if the tank is watertight at least at the bottom where the filtrate is collected. The Rottebehaelter systems are most beneficial when they are integrated in resource management sanitation for rural and peri-urban areas where local post treatment and reuse is possible. This has ecological, economical and hygienic benefits.

It has to be stated that because maintenance is a crucial factor, removal and handling of the retained material has to be improved. In addition, proper procedures of further composting and usage should be established. The loss of water level does make it more appropriate for sites with a good gradient, otherwise an additional pump may be required. Compared to other systems such as septic tanks, there are major advantages.

4.6 Treatment systems for grey water

4.6.1 Biological treatment systems

Biological treatment methods are required to remove organic contamination. The mostly used methods are constructed wetlands, Sequence Bach Reactors, membrane bioreactors and biological aerated filter. Grey water treatment with vertical constructed wetlands with sizes of 2 m^2 per inhabitant in the Flintenbreite settlement, Luebeck has shown good performance (figure 32).

Constructed wetlands are cheap in construction and operation. Therefore, it has been widely used in Europe and transferred successfully to some developing countries. However, because of space scarcity, it is not always appropriate for densely populated urban areas. For these areas, sequence batch reactor (SBR), membrane bioreactors and biological aerated filter can be suitable. Treatment of grey water in small scale showed that SBR can greatly reduce organic matter, nutrients and turbidity SBR (Li et al., 2001).

In other investigations Shin et al. (1998) have found the performance of SBR on treating grey water satisfactory. Biological aerated filter (BAF) followed by membranes are installed at the Millennium Dome in London for the treatment and reuse of hand basin grey water (Hills et al., 2001).

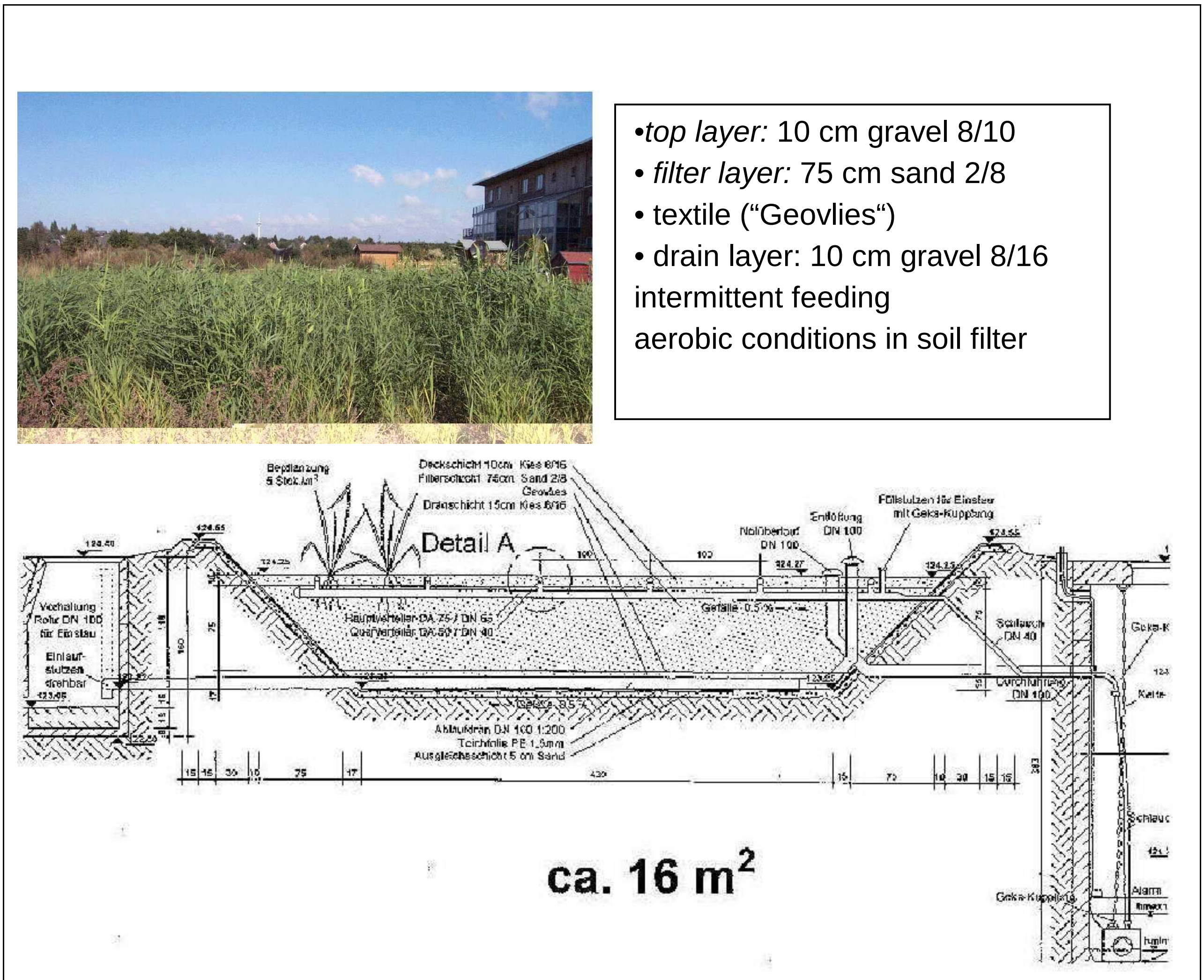


Figure 32: Constructed wetlands for grey water treatment in Flintenbreite-Luebeck

The biological process must be followed by a physical process in order to retain active biomass and to prevent the passage of solids into the effluent, if the effluent is for reuse purposes. Treatment with the membrane-bioreactors (MBR) will probably be the choice of the future, especially if reuse is intended. The MBR is the amalgamation of a suspended growth reactor and membrane filtration device into a single unit process. The process represents an intensification of traditional biological processes with the added advantage that the membrane retains particles including bacteria and viruses. Effluent from MBR treated grey water is typically solid-free, low in organic pollution and contains non-detectable levels of coliforms (Stephenson et al., 2000).

4.6.2 Physical and chemical treatment systems

Physical methods used for grey water treatment are sand filter, ultrafiltration, micro-filtration, reverse osmosis. Small scale experimental results have shown that grey water treated with combination of SBR (Sequence Batch Reactors) and slow sand filter has achieved the quality required for groundwater recharge (Li et al., 2001). In the study of Shin et al. (1998), the grey water treated with a combination of SBR and micro-filtration was suitable for reuse. Moreover, grey water treated with the combination of con-structed wetlands and chemical process (TiO_2–based photocatalytic oxidation) has achieved the European bathing water quality (Li et al., 2002).

4.7 Treatment systems for yellow water

4.7.1 Storage and reuse

Urine is relatively sterile and can be reused without further treatment (Wolgast, 1993). However, due to faecal contamination, pathogens have been found in yellow water; but in low concentration, which will pose low hygienic risk of using yellow water as a fertil-iser, if it is stored at least for 6 months before being used in agriculture land (Jönsson et al., 1999; Hellström and Johansson, 1999). Since the practising of separated collection of yellow water, farmers in Sweden have been collecting it in underground storage tanks for applying to their agricultural land (Jönsson et al., 1999).

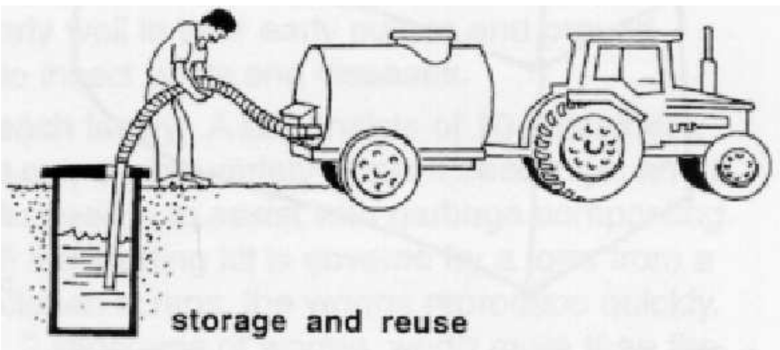


Figure 33: Practice of urine: storage and reuse or direct reuse

In Eco-village, Understenhöjden, Sweden, urine of 160 inhabitants is separated with urine separating toilets and collected in a collection tank. The collected urine is transported by tanker truck, once a year, to the storage tank, where it is sanitised prior to its use in agriculture. Similar to Eco-village Understenhöjden, 160 inhabitants in the Palsternacken housing state, Enskede in Sweden are connected to a urine separating system. Collected urine is transported once a year to a storage tank, where also the urine from eco-village, Understenhöjden is stored. Once the tank is full, it is closed and stored until it is ready for application in agriculture.

During the storage and transportation of urine, a large amount of unionised ammonia is formed due to decomposition of urea which also increases pH. The high pH causes precipitation of calcium, phosphate, struvite and calcite resulting 90 % of total nitrogen is present as ammonia, the pH is about 9 and 30 % of phosphorus is precipitated (Udert et al., 2003). The ammonia can evaporate while transportation and application in agriculture as fertiliser of urine solution (Hellström and Johansson, 1999). However, nitrogen loss can be prevented by ammonia oxidation; with the biological nitrification, urine can be stabilised (Udert et al. 2003). In the Pilot project Lambertsmuehle in Germany, urine from a family and museum visitors is separated with a newly developed sorting toilet where no water is needed for the urine flushing, a mechanical device closes the urine pipe when users stand up. The separated urine is collected and stored in the storage tank near the building until it is sanitised before it is applied in agriculture. Unlike in Sweden, in Lambertsmuehle, acidification is also used for sanitisation. In the storage tank the urine is acidified (pH< 5) with sulphuric acid to reduce microbial contamination, ammonia emissions and plant damage; however, it should not be used in excess to avoid yield losses due to high inputs of sodium choride (Simons and Clemens, 2003). Experiences from Sweden have shown that nitrogen loss during the storage is small and does not cause odour problem. The urine storage has been carried out without any extra conditioning.

In Mexico city, vegetables have been grown in containers using human urine as a fertiliser (Esrey et al., 1998). Urine is stored in a container for 3 weeks and is applied to the vegetables after diluting it with water on a ratio of 1:10. After several years of study it showed that plants fertilised with urine grew more rapidly and healthier than those grown with conventional agricultural techniques.

In a lab scale experiment, nutrient removal by different plants with different dilution of urine was studied (Prasapati and Gajurel, 2003). Results showed that Green Pea, Black Gram, Broad Bean, Cress, Spinach, Tintel, Mustard and Rape had high nutrients removal efficiency while using a ratio of 1:10 and 1:15. With the applied dilution, effluent still contained traces of N, P, K. Therefore, further dilution of source-separated urine could be applied for total nutrient recovery. This practice is good for a region where the farmland is near to the housing area; otherwise, transportation of large amounts of urine solution for longer distance has many negative environmental impacts (Hellström and Johansson, 1999).

4.7.2 Volume reduction and reuse

Recently, many methods for treatment and volume reduction of collected yellow water have been studied. One method is dewatering by evaporation with and without nitrification and freeze concentration (Gulyas, 2004). By freezing, it is possible to concentrate 80 % of nitrogen and phosphorus in 25% of the original volume (Ban et al., 1999). By nitrification in combination with drying, it is possible to concentrate over 70 % of the nitrogen in 10 % of the original volume (Hellström and Johansson, 1999). The production of Isobuthylaldehyde-di-urea IBDU and ammonia water from urine is possible. Urea can be converted to IBDU only after concentrating urine. With air stripping and absorption ammonificated urine can be treated very effectively and a solution of 10 % w/w of ammonia can be obtained (Behrendt et al., 2002). These methods could be beneficial, when a larger volume of urine solution has to be transported a long way to the agriculture farm. However, these methods have been investigated only in small scale so far.

4.8 Benefits of source separation in sanitation

Most of the benefits of Resource management sanitation should be clear from the preceeding sections. In the following, the advantages of Resource management sanitation toward conventional sanitation are summarized again.

Resource management sanitation combats hygienic risks (for details please refer Lesson A2)

Highest concentrations of pathogenic microorganisms are contained in brown water. As sanitisation of small volumes is easier than of the highly diluted entire wastewater streams, and source control sanitation leads to catchment of brown water with a far out lower water content than in domestic wastewater in conventional sanitation, resource management sanitation is a good means to reduce sickness and deaths from diarrhoea because of safe containment and hygienization of brown (or black) water (solids). This is a clear advantage. Separately collected faeces can be hygienized by dehydration (when there is no water available for pathogenic organisms, they will die). A good way to take the water away is utilization of solar heat. For this purpose, the solids of brown water are stored in a chamber which is covered with a black lid. This way is preferably feasible for warm regions. It has to be noted that faeces in Resource management sanitation schemes have to be safely kept away from eventually occurring stormwater (special care is required e.g. in regions with monsoon).

Another possibility to kill pathogens in faeces is composting. In this process the killing agent is heat. The diagram (figure 33) shows that the compost process has to last longer the lower the generated temperature is. As fungi are important actors for the composting process, aerobic conditions have to be ensured in the heap of faeces. For this purpose, addition of structured material like woodchips is helpful. A too high moisture content of the solids hinders oxygen to diffuse through the heap of excreta. Therefore, composting requires sufficiently dried blackwater solids (optimum moisture content for composting: 50 to 60 %). Addition of worms ("vermicomposting") loosens the material and enables better access of air into the heap. As too high concentrations of nitrogen inhibits the composting process (optimum C:N ratio: 25-30:1), divertion of urine makes composting of faeces more efficient.

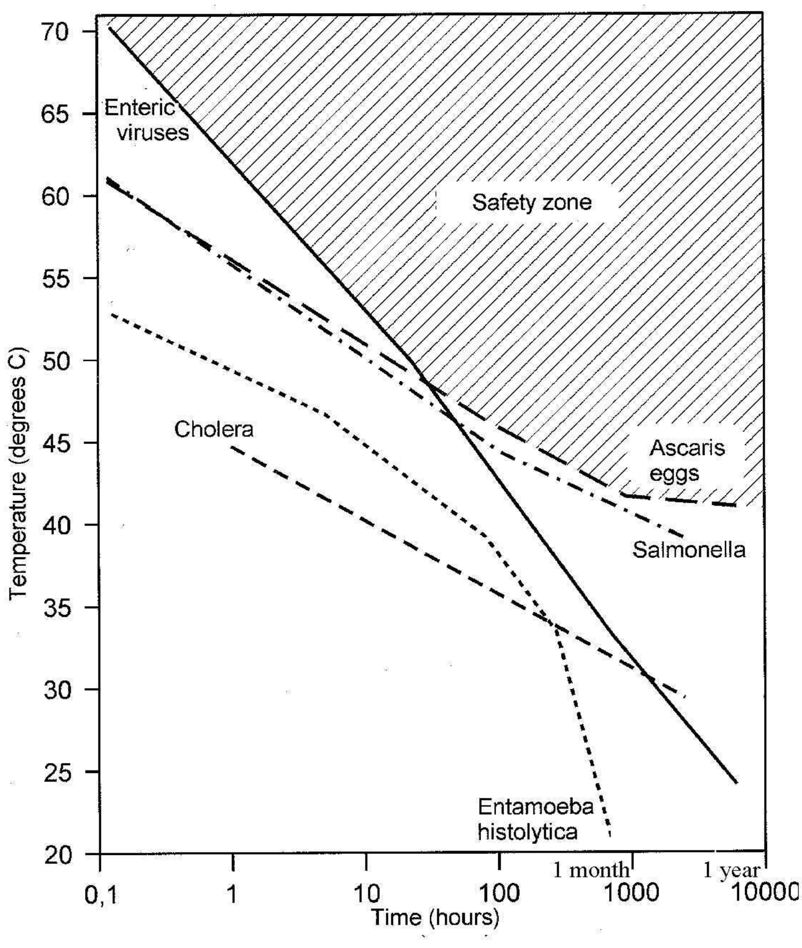


Figure 33: Combination of time and temperature of pathogens elimination. Hatch area represents complete pathogens elimination due to the combined effect of time and temperature (Feachem et al., 1983)

EcoSan helps to overcome malnutrition

The safe nutrients obtained from Resource management sanitation can be reused in agriculture and thus help to increase harvest yields and to combat malnutrition.

The nutrient cycle – closed

With implementation of Resource management sanitation, the food cycle can be closed leading to less environmental degradation and also to socio-economic advantages.

Wastewater reuse in Resource management sanitation

Wastewater reuse is facilitated because of using the less contaminated greywater which belongs to the water cycle (this can help to combat water scarcity). For example, in constructed wetlands, the separately collected greywater can be purified in a relatively simple way to a high quality.

Resource management sanitation avoids pollution of the aqueous environment

Pollution of the aqueous environment is reduced in resource management sanitation, as excreta flows do not come into contact with surface waters. Moreover, pharmaceuticals are not discharged to the water cycle-related greywater and can thus not enter surface waters. Groundwater contamination with pharmaceuticals by agricultural use of yellow water (and of hygienized brown water solids) will have to be investigated more intensively in future. But as concentrations of pharmaceuticals in separately collected yellow water are decreasing during storage (mainly at low pH; Strompen et al. 2003), this pathway is not thought to be threatening aquifers.

⇨ "If coverage can be increased, resource management sanitation can serve as the missing link to sustainable urban development, reverse the unconscious pattern of linear thinking and actions, and be a technical solution that protects ecosystems and harmonises with natural systems" Statement of the Sida/UNDP/SIWI Workshop 2000).

Socio-economic benefits of EcoSan

Also in socio-economic aspects, Resource management sanitation may contribute to some improvement:

- Jobs can be created (e.g. caretakers for resource management sanitation facilities, yellow and processed brown water transportation firms).

- There will be financial benefits (no sewers needed, energy necessary in wastewater treatment plants in conventional sanitation schemes is saved, a great deal of energy for fertilizer production can be saved).

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6. Ecosan internet links

A revised and enlarged edition of the book "Ecological Sanitation" can be downloaded from here:

http://www.ecosanres.org/PDF%20files/Ecological%20Sanitation%202004.pdf

http://www.sanicon.net/

http://www.gtz.de/ecosan

http://www.ecosanres.org

http://www.ecosan.org

http://www.tu-harburg.de/aww

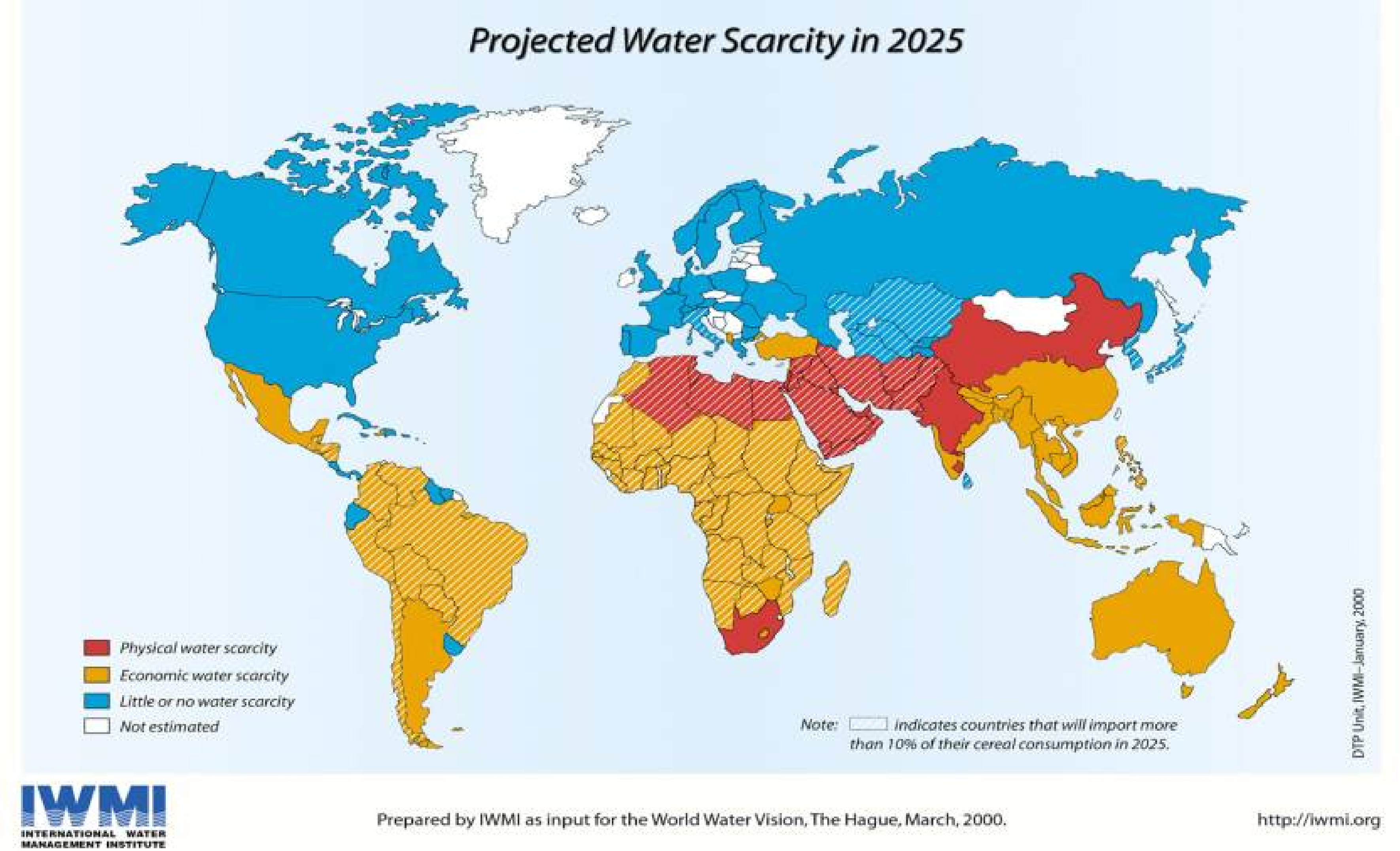
Innovative reuse oriented water concepts

high-, medium- and low-tech options

Univ. Prof. Dr.-Ing. Ralf Otterpohl
Director,
Institute of Municipal and Industrial Wastewater Management

TUHH

Technical University Hamburg-Harburg



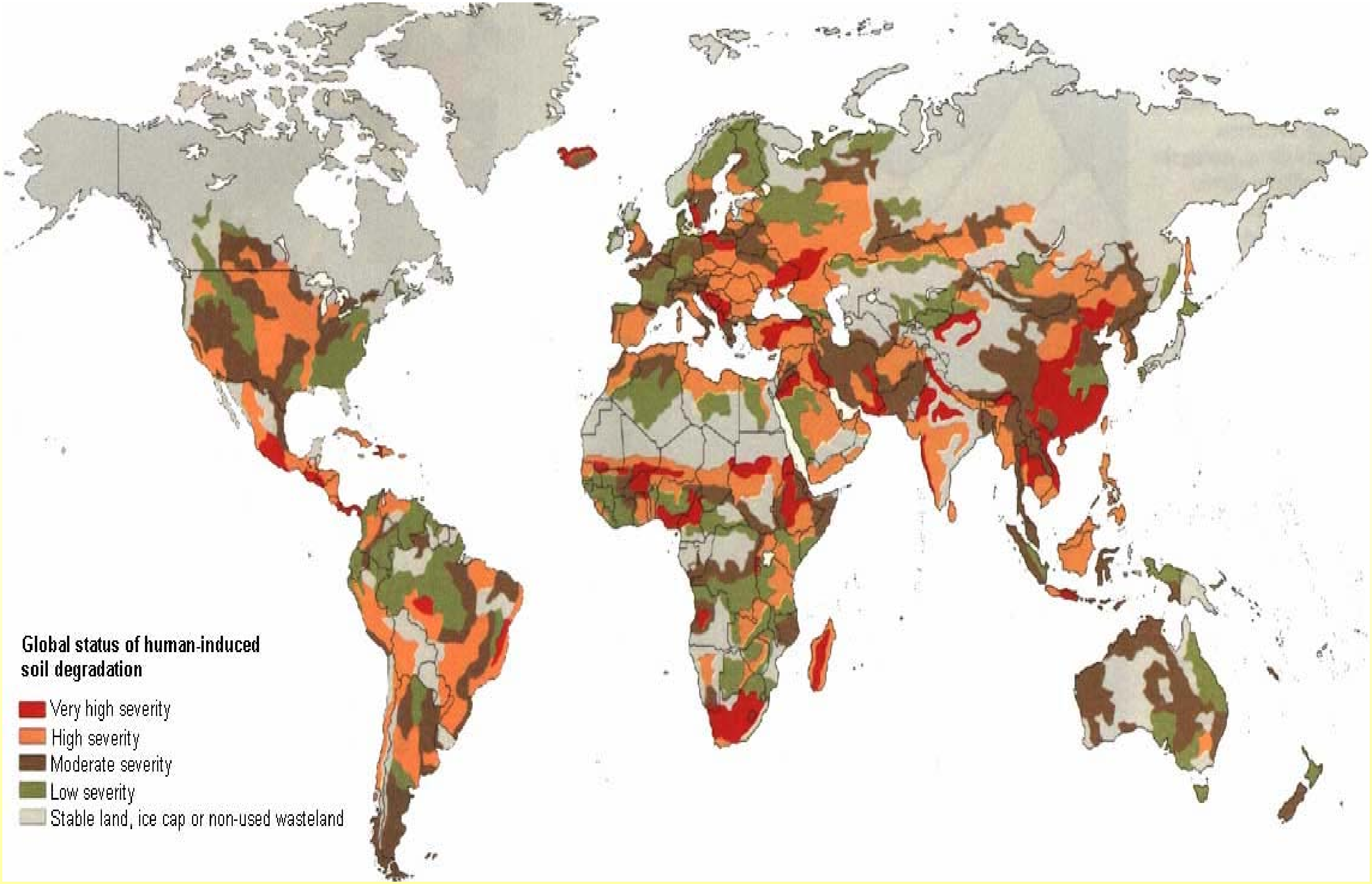
Major problems related to Wastewater (Miss)Management:

Pollution of Rivers, Lakes and the Seas

<u>Loss of Soil Fertility (dramatically underestimated)</u>

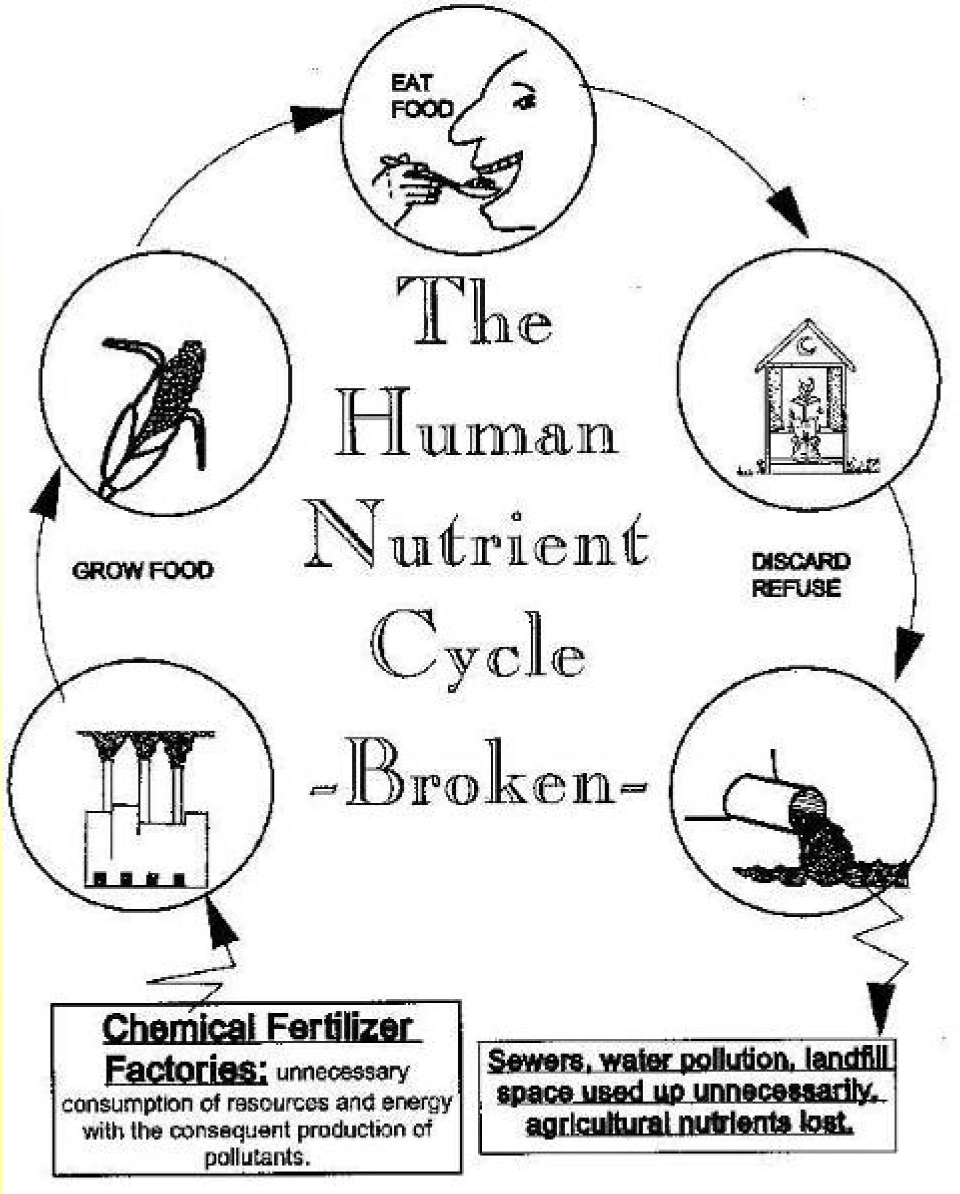
Inefficient Water Usage

organic matter back to the soil!



Loss of Soil Fertility (slow but dramatic, global scale)
counteraction by returning treated biowaste and faecals

(Map from WWW.FAO.ORG)

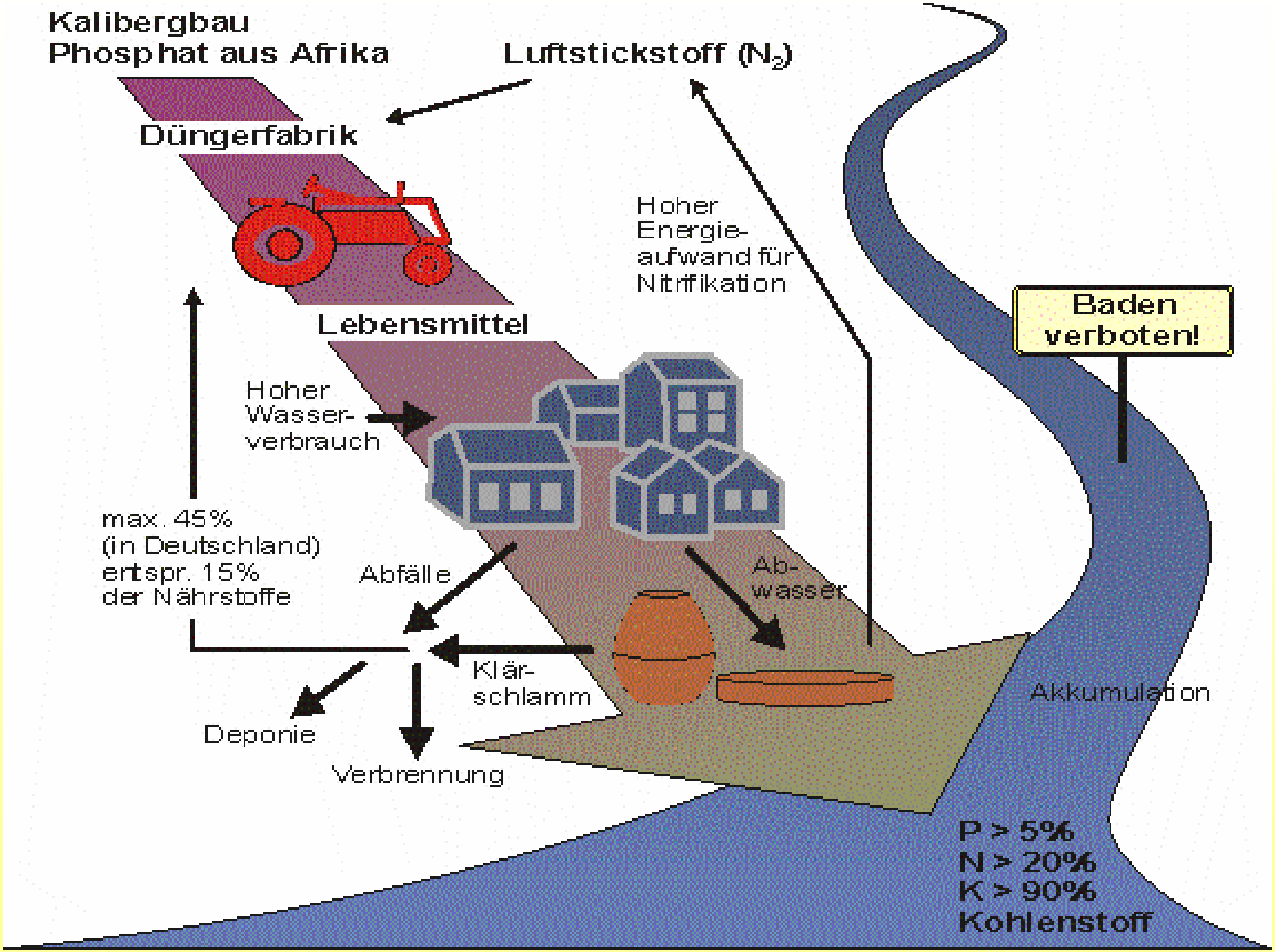


The Human Nutrients cycle - Broken

(Source: Jenkins, 1994)

water for all purposes...

Monsoon:
how does a sewerage system perform?



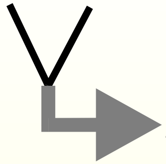
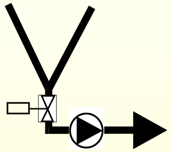
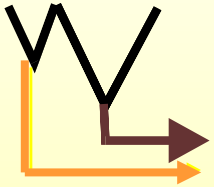
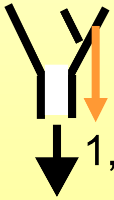
Kalibergbau
Phosphat aus Afrika
Luftstickstoff (N_2)
Düngerfabrik
Hoher Energie-aufwand für Nitrifikation
Lebensmittel
Baden verboten!
Hoher Wasser-verbrauch
max. 45% (in Deutschland) entspr. 15% der Nährstoffe
Abfälle
Ab-wasser
Klär-schlamm
Akkumulation
Deponie
Verbrennung
P > 5%
N > 20%
K > 90%
Kohlenstoff

TUHH
Technische Universität Hamburg-Harburg

Volume l/(P*year)	**Greywater** 25.000 -100.000	**Urine** ~ 500	**Feaces** ~ 50 (option: add biowaste)
		Flushwater can be saved 6.000 - 25.000	
Yearly Loads kg/(P*year)			
N ~ 4-5	~ 3 %	~ 87 %	~ 10 %
P ~ 0,75	~ 10 %	~50 %	~ 40 %
K ~ 1,8	~ 34 %	~ 54 %	~ 12 %
COD ~ 30	~ 41 %	~ 12 %	~ 47 %
S, Ca, Mg and trace elements	Treatment ↓ Reuse / Water Cycle	Treatment ↓ Fertiliser	Biogas-Plant Composting ↓ Soil-Conditioner

Geigy, Wiss. Tabellen, Basel 1981, Vol. 1, LARSEN and GUJER 1996, FITSCHEN and HAHN 1998

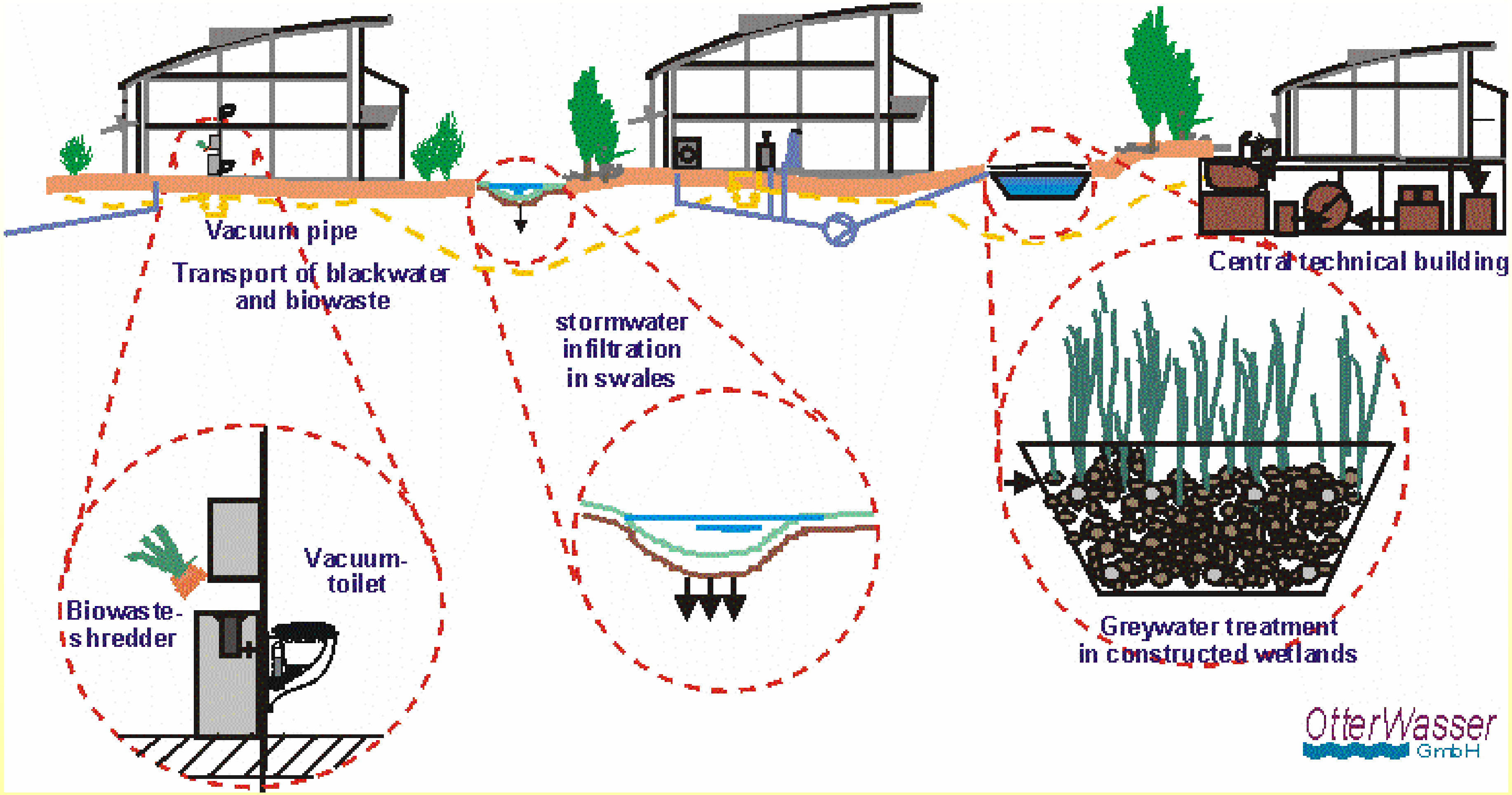
Toilets and resulting Dilution

Type of Toilet	Daily Flow per P.	Pro and Con's
Flushing toilet		+ widely accepted - waste of water - high dilution
Vacuum-toilet		+ low water demand + well developed (ships) - high-tec / expensive
Separating toilet		+ little water / little dilution + simple fertiliser reuse - little experience
Waterless Urinal		+ no water / no dilution - maintenance required
Composting-toilet Desiccation toilet		+ no water needed - high space demand - maintenance needed ++ Desiccation for hot climates

Ecological Settlement Lübeck-Flintenbreite

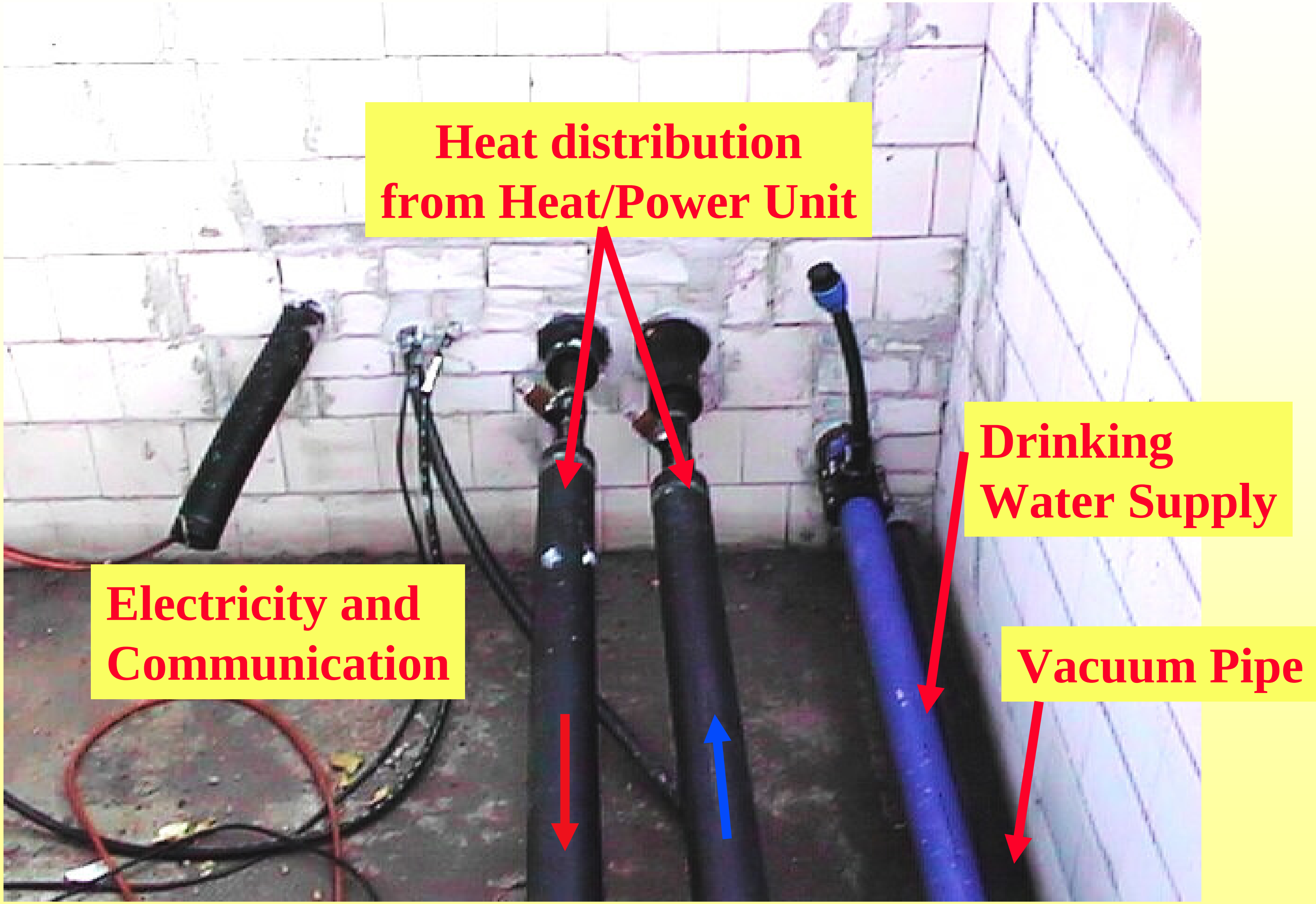
Double-Houses

Terraced Houses



Peri-Urban Settlement Lübeck-Flintenbreite (400 inhabitants)
Vacuum-Biogas-System for Blackwater plus Biowaste
Otterwasser GmbH, Lübeck www.otterwasser.de

Lübeck-Flintenbreite



Otterwasser GmbH, Lübeck, Germany

Community Building with central technical Devices
Lübeck-Flintenbreite

Cellar: Vacuumstation, Biowaste Grinder, Hygienisation, Biogas Plant
Above ground: Seminar/Party room, Office, 4 Flats and HPG
(Otterwasser GmbH, Lübeck, Germany)

design by
Otterwasser GmbH, Lübeck
www.otterwasser.de

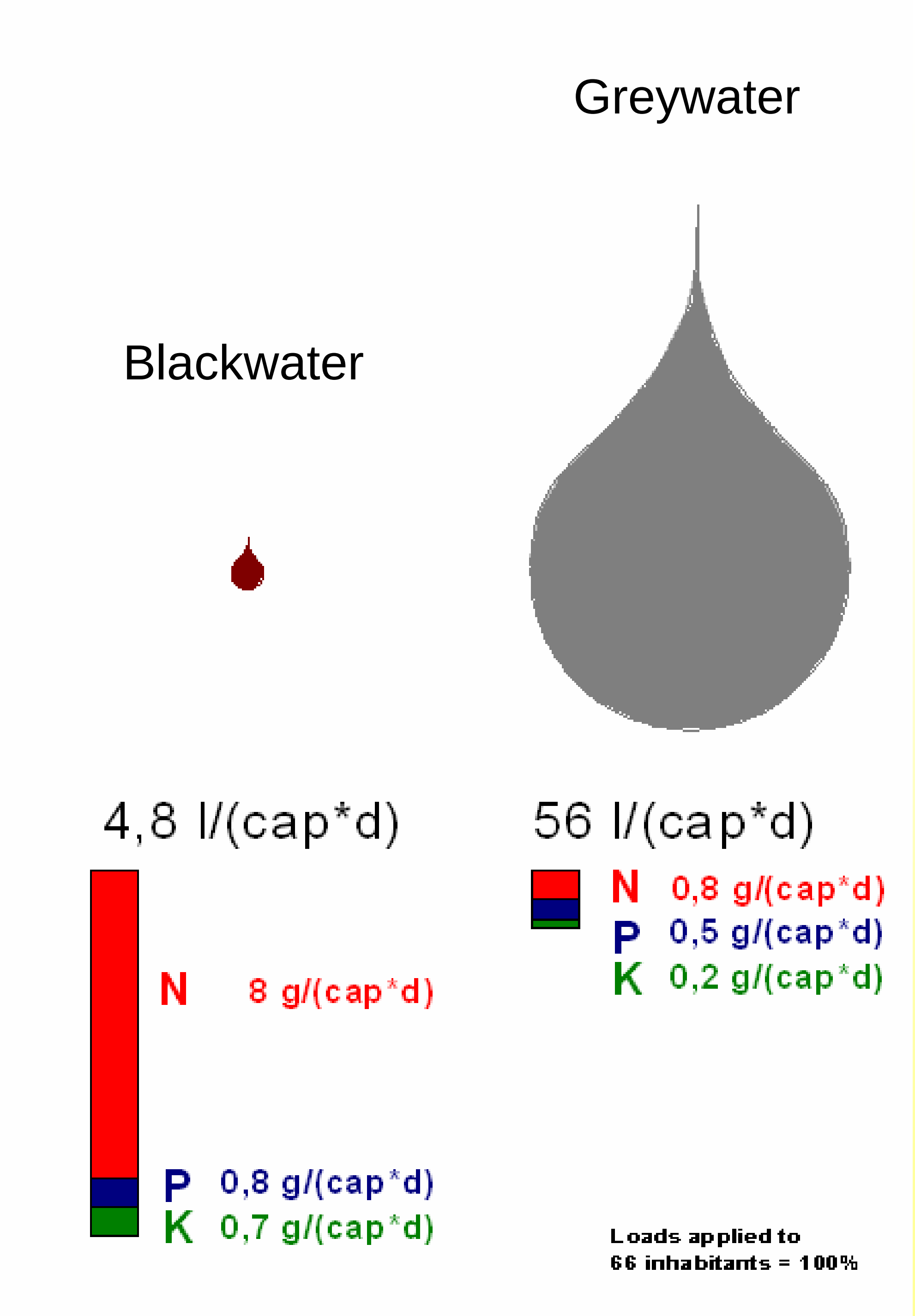
Vacuum Pumping Station for Blackwater

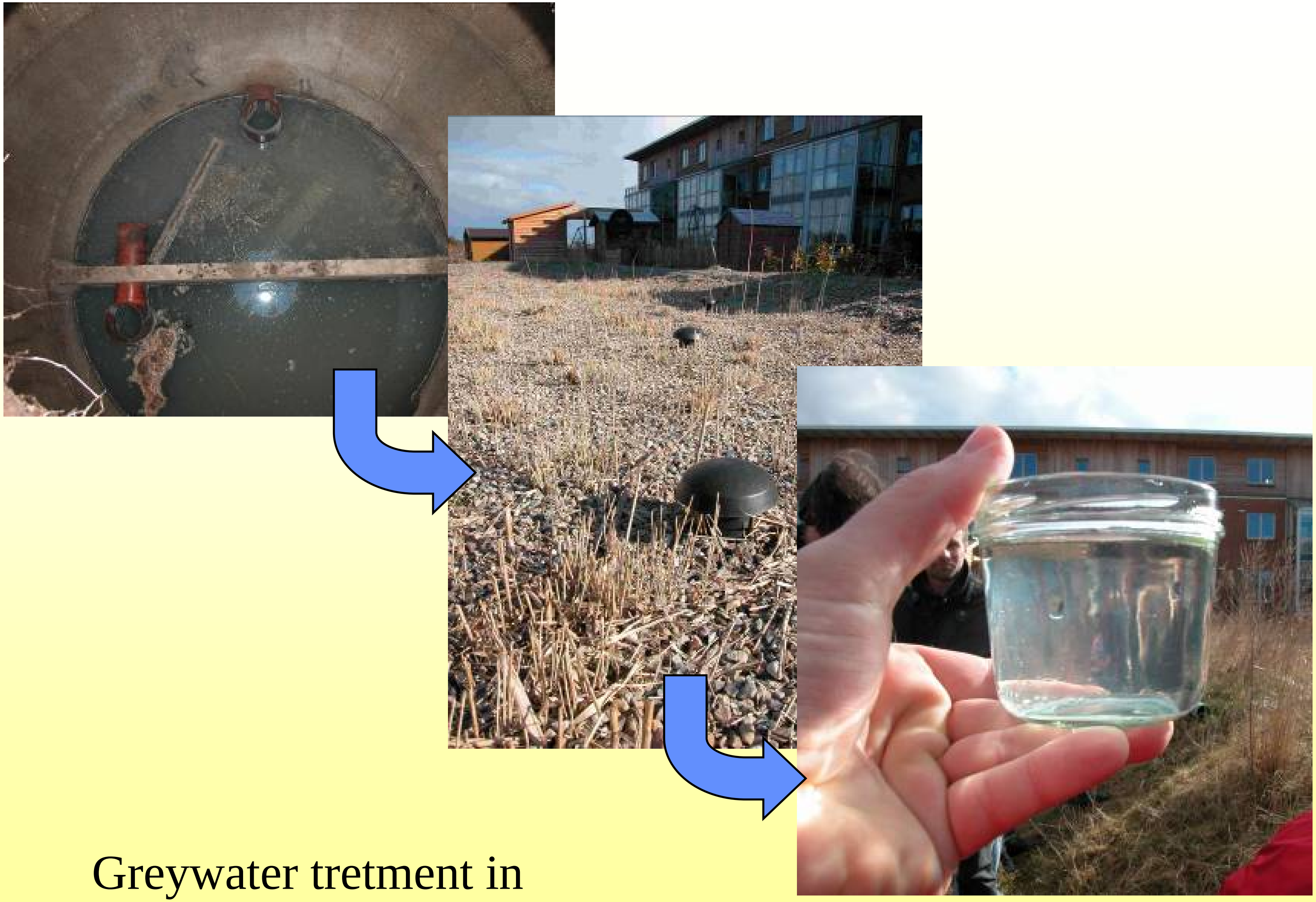
Sanitisation tank

Bio-Waste In
and Grinde

Nutrient loads in blackwater and greywater

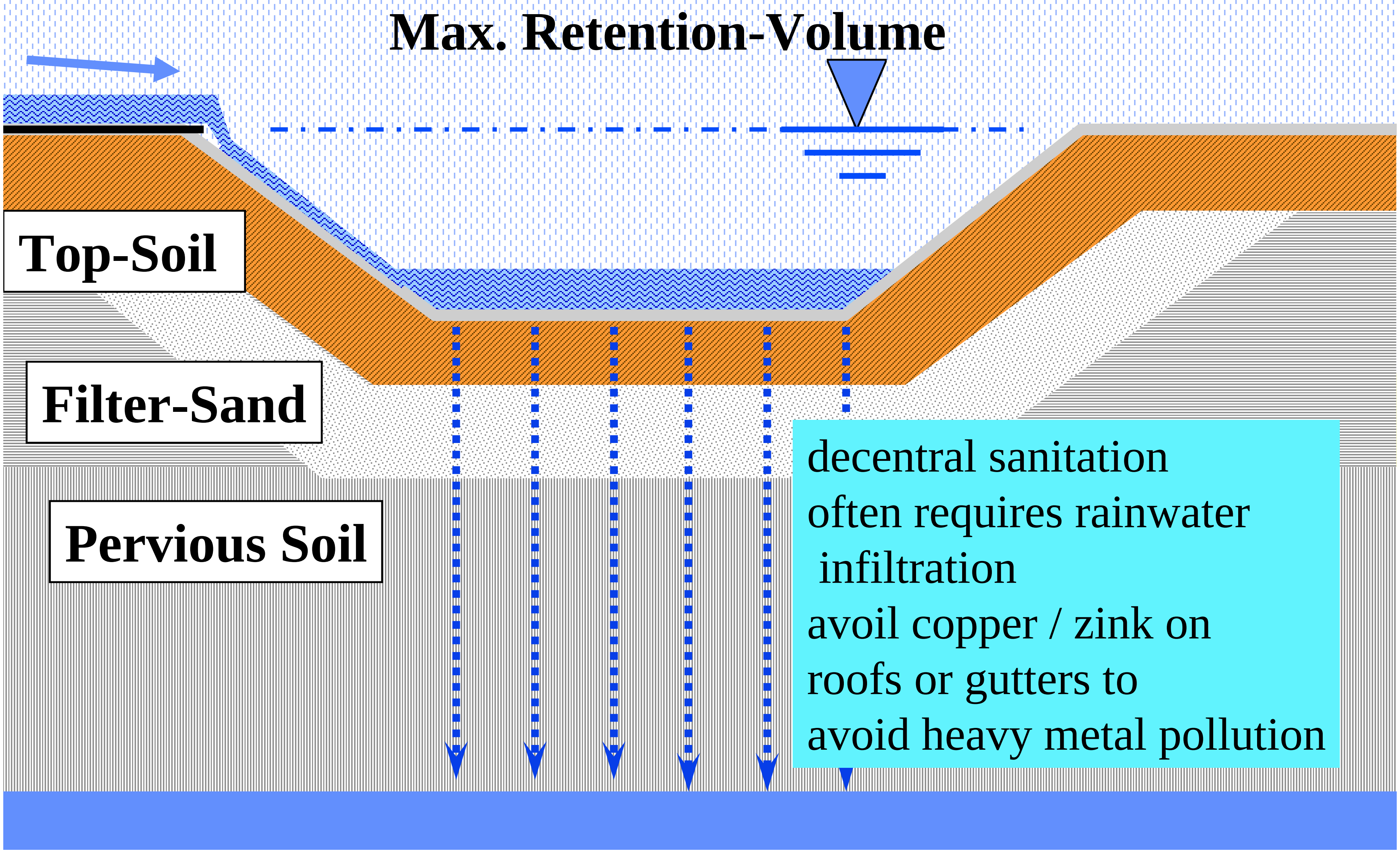
Lübeck Flintenbreite





Greywater tretment in constructed wetlands

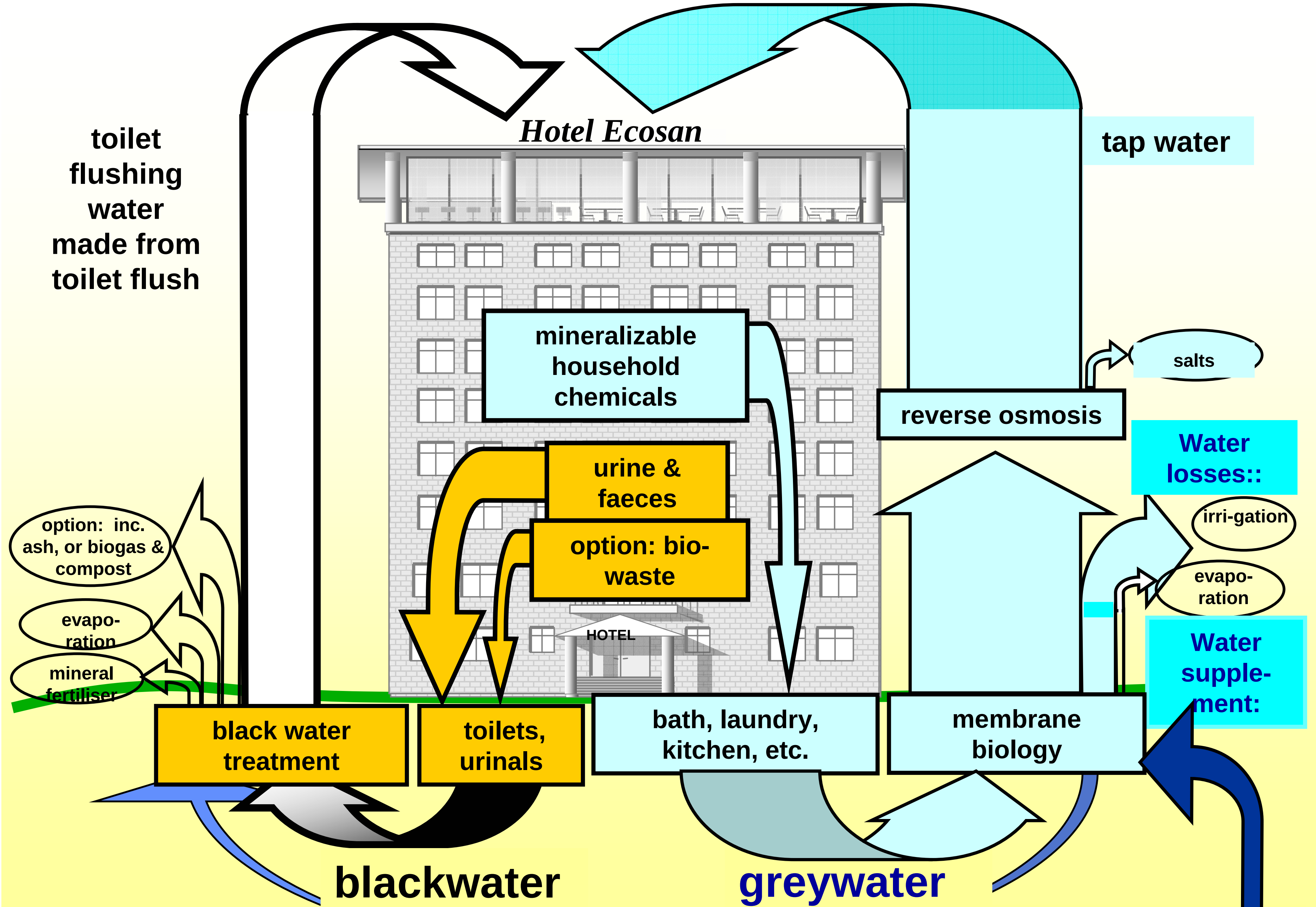
Rainwater Infiltration Swale



Project Freiburg Vauban, Germany: Arbeiten & Wohnen

Vacuum-Biogas-System for Blackwater/Biowaste
(One of the most energy-efficient houses worldwide)
ATURUS, Jörg Lange, Freiburg, Germany

www.vauban.de/aturus

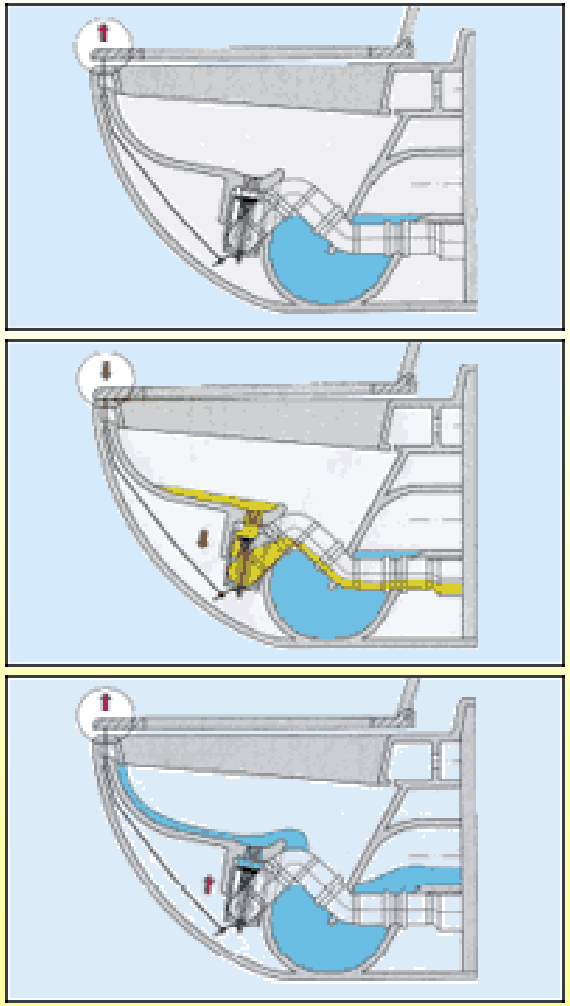


Patent Ulrich Braun
INTAQUA / TUHH

Blackwater digestion
research project of the
Institute of Wastewater Management
www.tuhh.de/aww

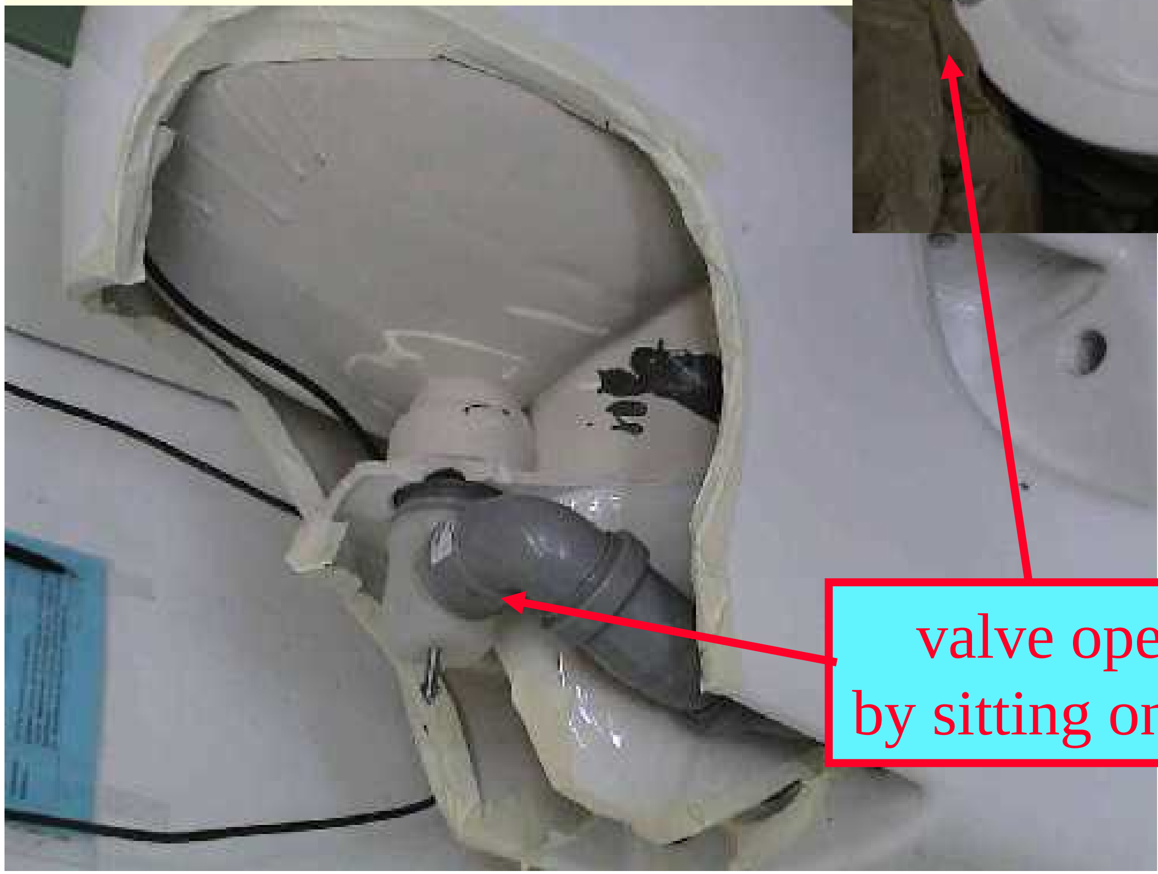
TUHH
Technical University Hamburg-Harburg

Roediger Sorting-Toilet



Non-diluting Urine collection www.roevac.de

Roediger Sorting-Toilet
waterless urine collection
patented by Ulrich Braun,
INTAQUA AG



Gustavsberg Sorting-Toilet

Urine sorting (house of Prof. Otterpohl, Germany)

No-Mix-Toilet with children seat   BB innovation, Sweden

Settlement „Palsternackan“, Sweden

Urine-Sorting Toilets and Yellow Water collection

Pilot Project "Lambertsmühle"

Initiative and Finance:

- Wupperverband and Verein Lambertsmühle

Develpement of the Sanitation Concept

- Otterwasser GmbH, Lübeck

Scientific consultation

- TUHH Inst. of Wastewater Management

Elements of the Sanitation Concept:

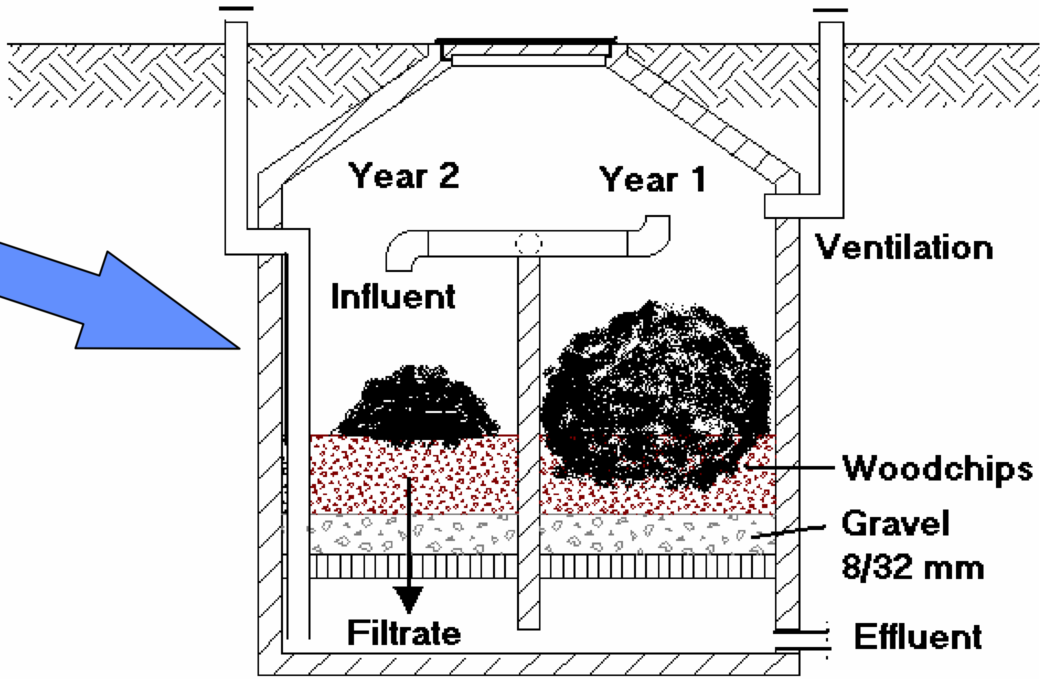
- Urine-sorting Toilets and waterless Urinals
- Storage Tank for Yellow Water
- Pre-Composting Tank (2 chambers, Filter Bags)
- Constructed Wetland for filtered Grey- and Brownwater

....adopted from the Swedish experience

Urine-Tank
10 Persons
(Glass-Resin)

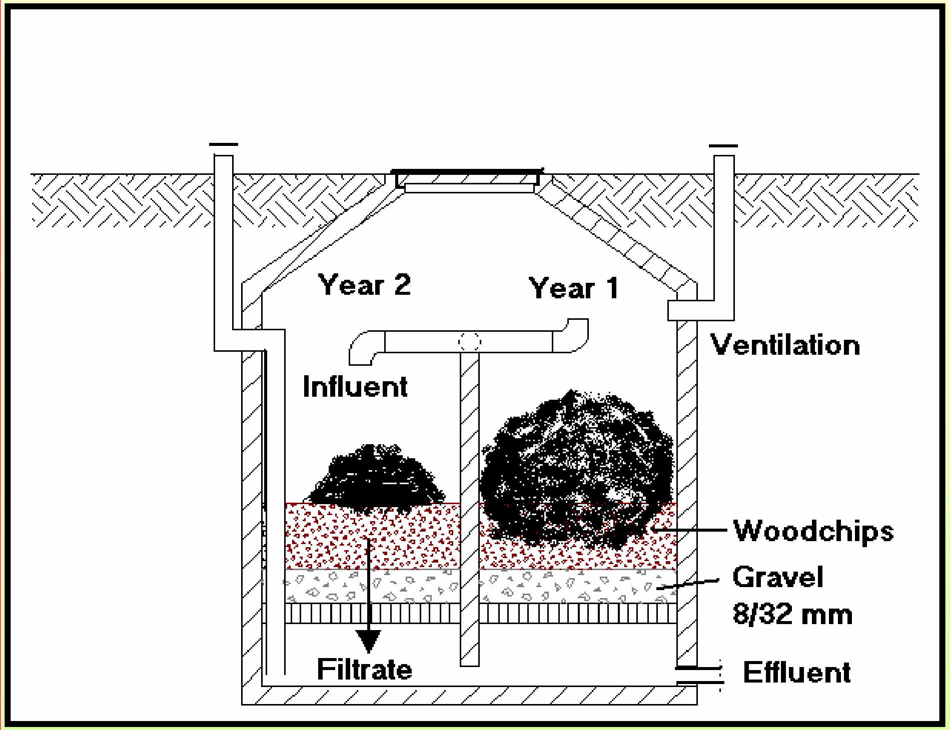
2-Chamber Composting Tank

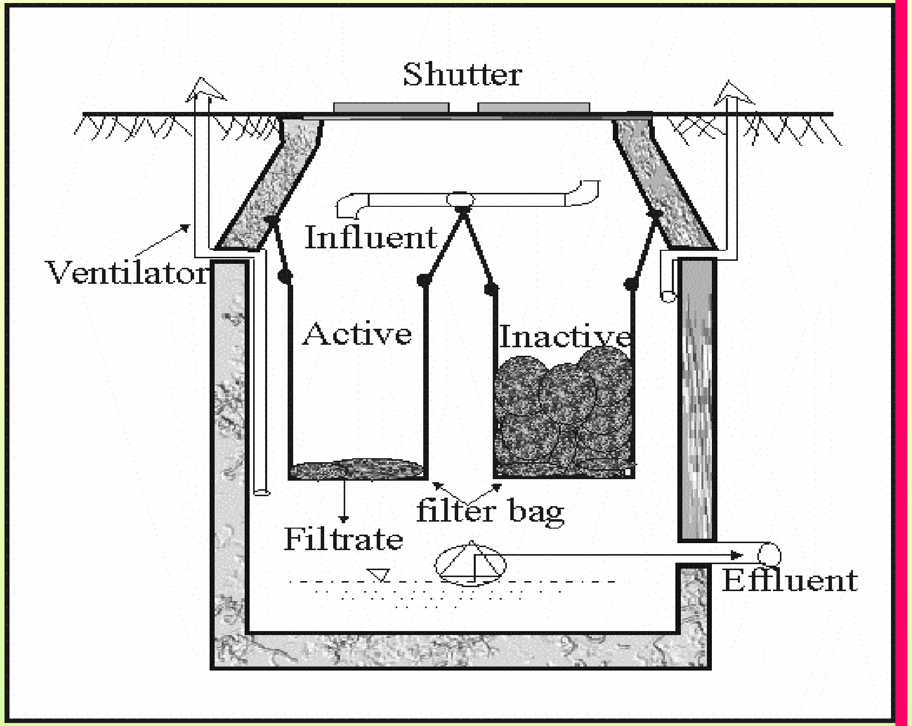
(Rottebehälter)



Research by TUHH
Technical University Hamburg
Prof. Dr.-Ing. Ralf Otterpohl
www.tuhh.de/aww

Brown water treatment and reuse





2-filter beds system

2-filter bags system

Pre-composting Tank or Rottebehaelter

+ small volume of solids
+ simple dewatering
+ little risk of methane emissions

- loss of water level
- post composting needed
- addition of bulking agent

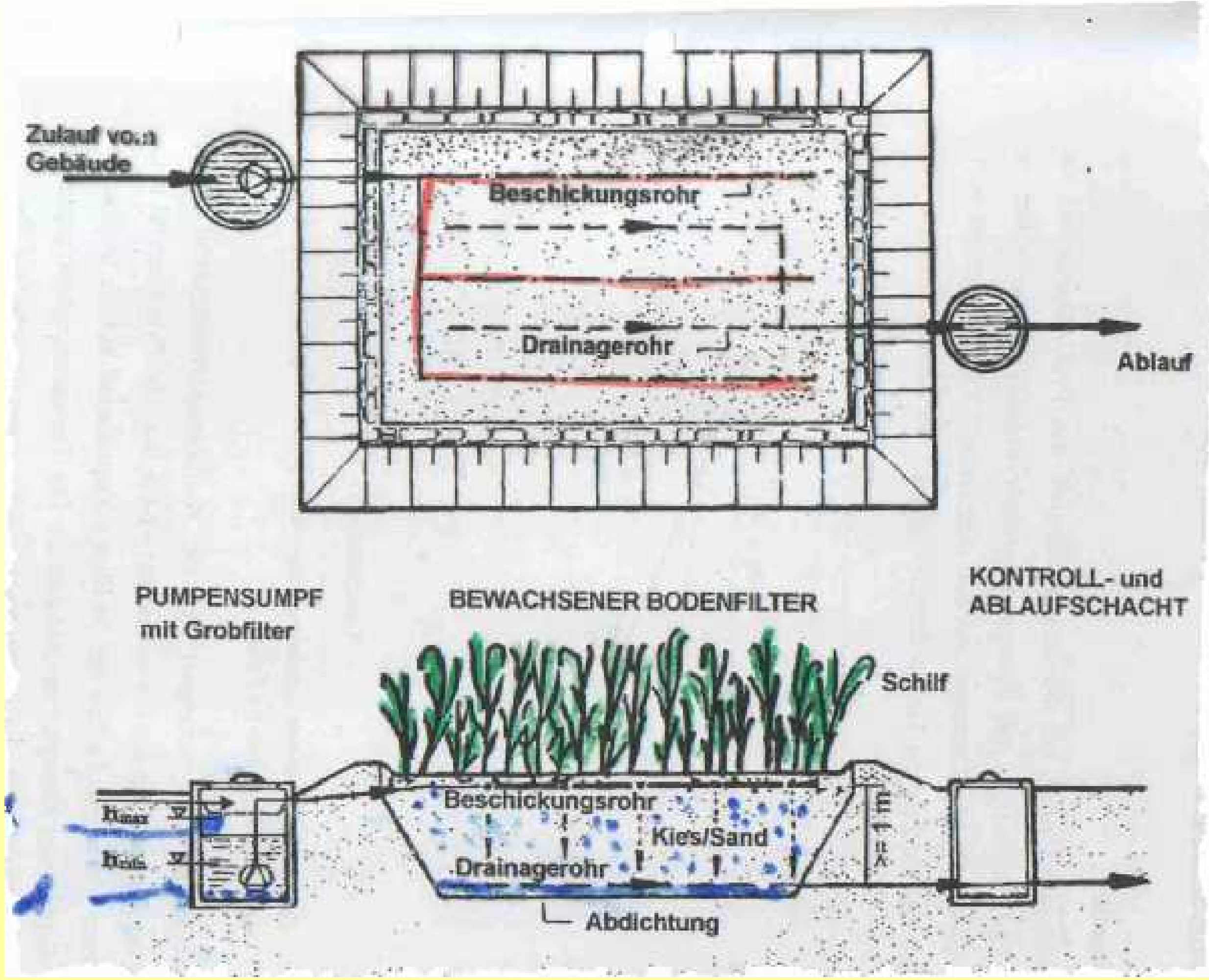

Rottebehaelter

pre-composting tank
research project of the
Institute of Wastewater Management
www.tuhh.de/aww

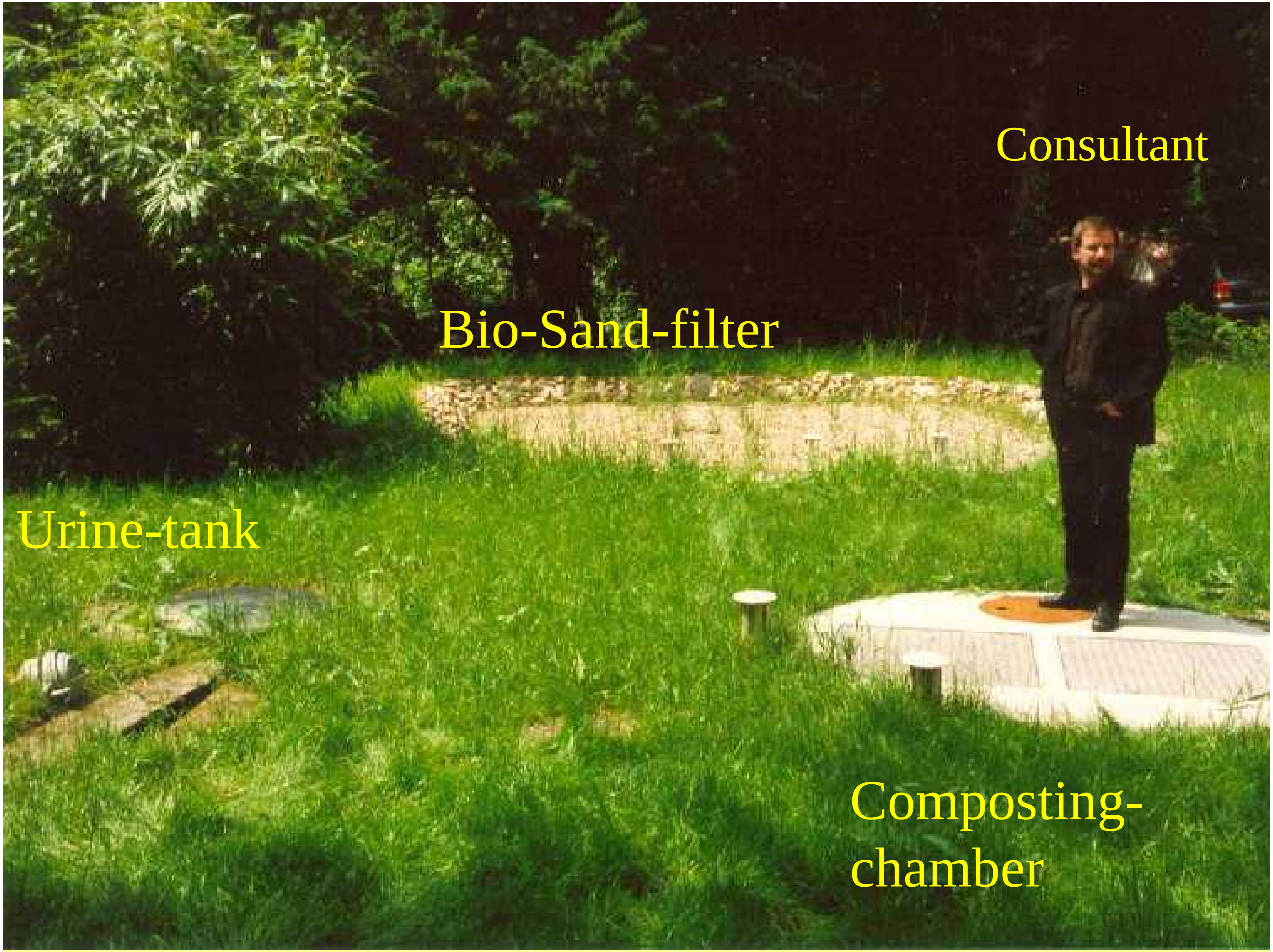
TUHH
Technical University Hamburg-Harburg

Constructed Wetland / Bio-Sandfilter:

1. vertical flow 2. water level at bottom 3. intermittant feeding



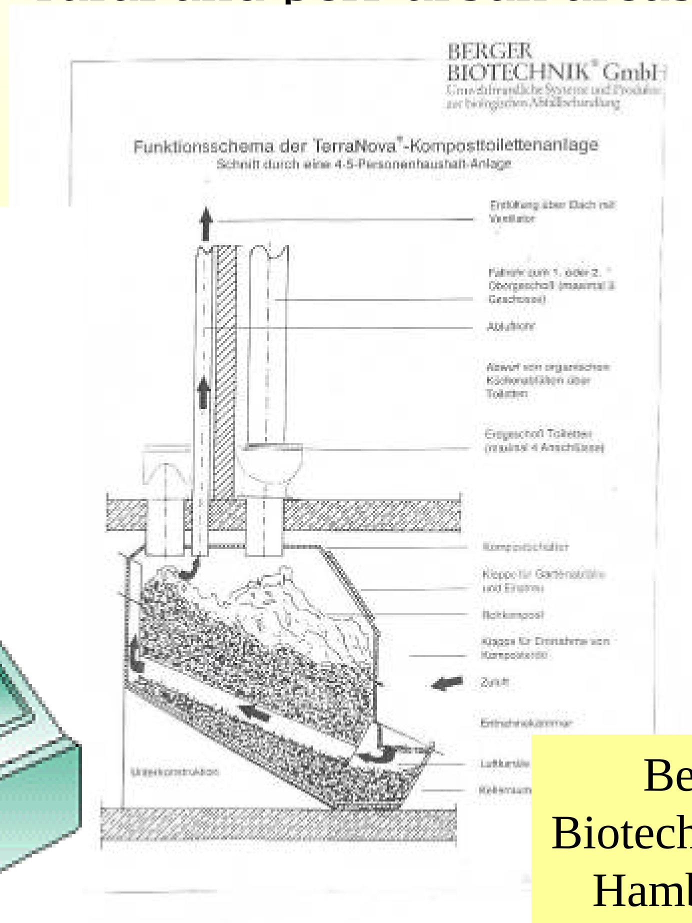
Otterwasser GmbH, Lübeck


Consultant
Bio-Sand-filter
Urine-tank
Composting-
chamber

Composting-toilets

- maintenance cruicial for function, some failures
- better with urine diversion and controlled moisturing
- rural and peri-urban areas

Clivus Multrum



Berger Biotechnik, Hamburg

One GRAM of faeces can contain

- **10,000,000 Viruses**
- **1,000,000 Bacteria**
- **1,000 Parasite cysts**
- **100 Parasite eggs.** (source: UNESCO, 2001)

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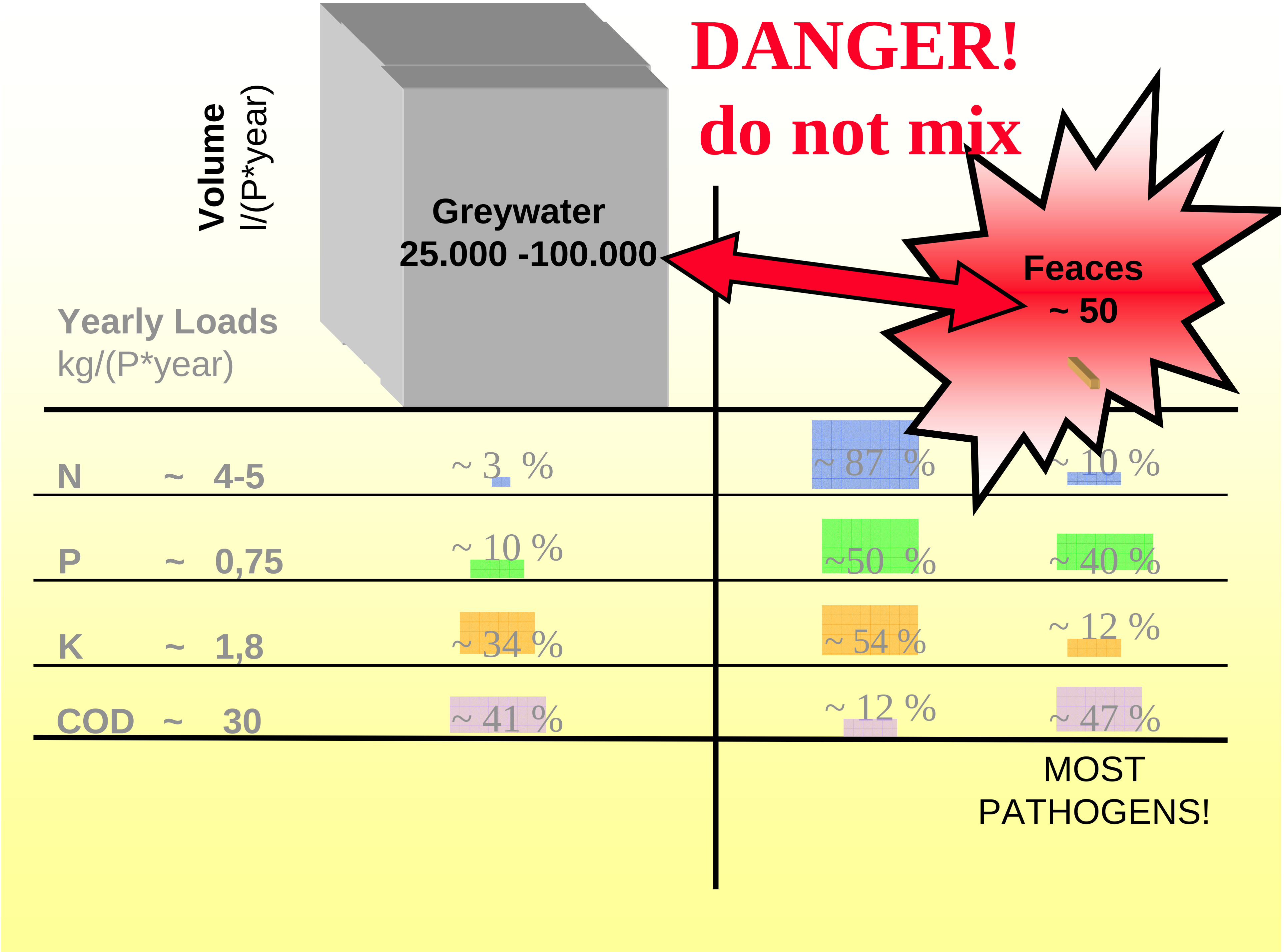
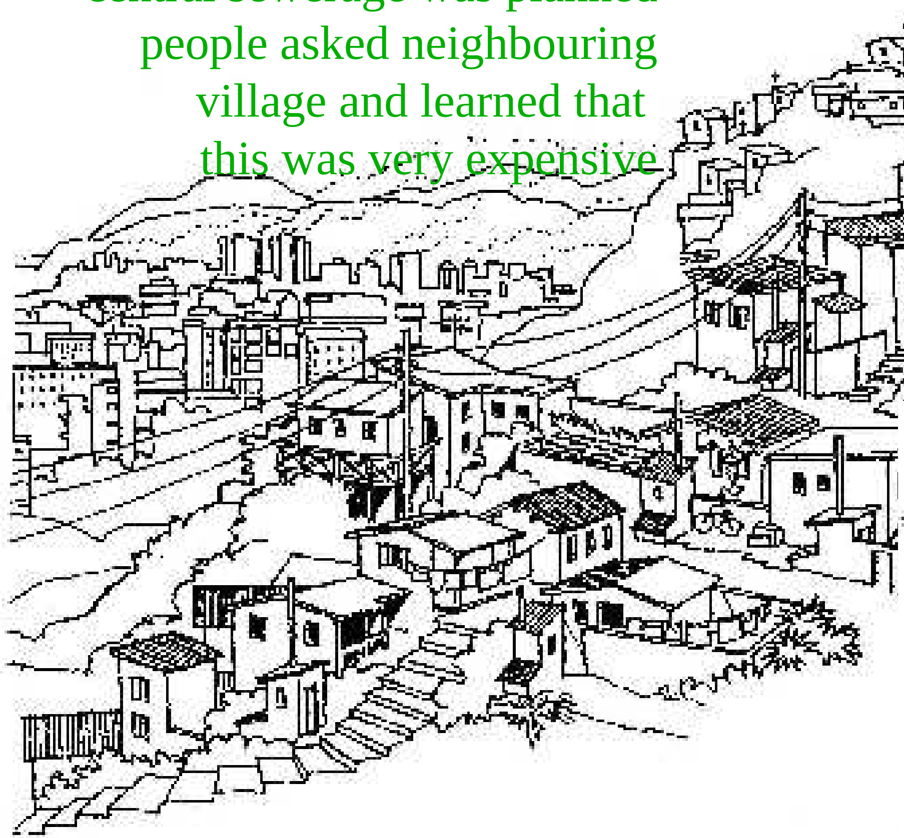
5 MILLION people die of polluted water every year (WHO)

Hygiene easy and cheap: Separation of faeces


DANGER!
do not mix
Volume
l/(P*year)
Greywater
25.000 -100.000
Feaces
~ 50
Yearly Loads
kg/(P*year)
N ~ 4-5
~ 3 %
~ 87 %
~ 10 %
P ~ 0,75
~ 10 %
~50 %
~ 40 %
K ~ 1,8
~ 34 %
~ 54 %
~ 12 %
COD ~ 30
~ 41 %
~ 12 %
~ 47 %
MOST
PATHOGENS!

central sewerage was planned
people asked neighbouring
village and learned that
this was very expensive



the earth toilets with urine
sorting made fertilizer available
costs where 1/3rd of neighbours

Dry Sanitation in Mexico
from Esrey et al.,
Ecological Sanitation, 1998

Espacio de Salud
Cuernavaca, Morelos
MEXICO


Photo: César Añorve

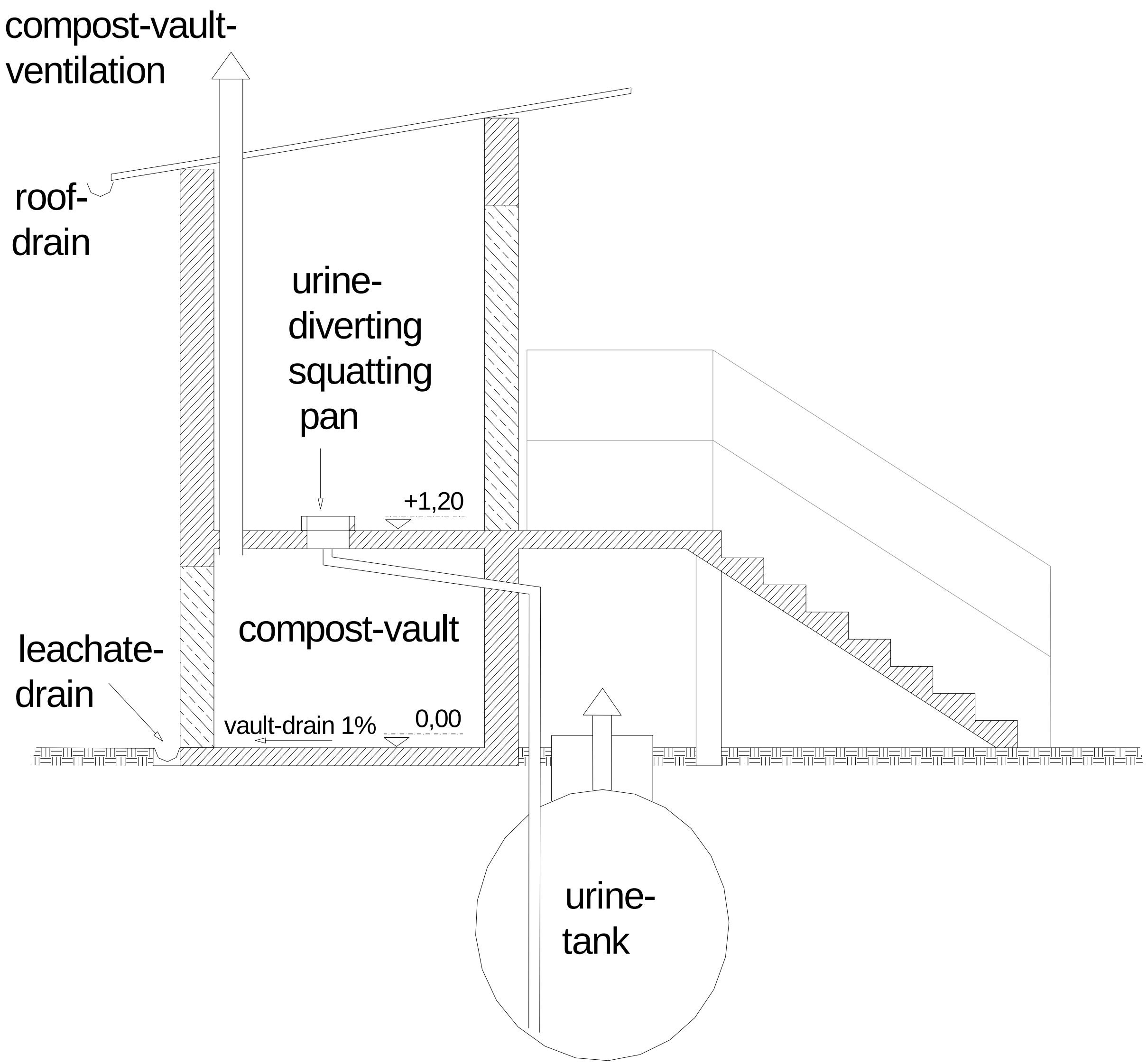

local production created job
and keeps money in the regio

Case-Study:

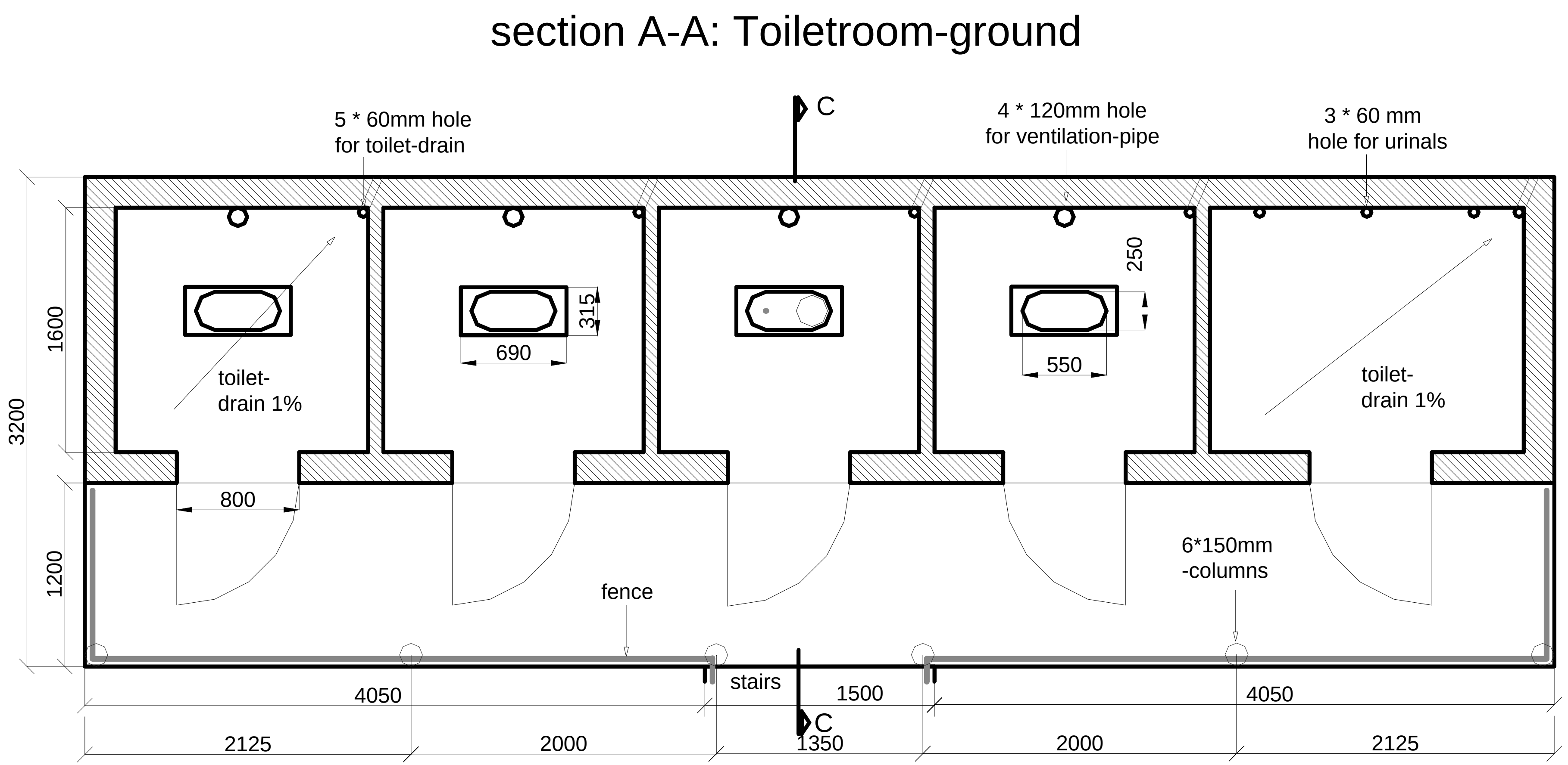
Garla Mare, Romania

Design and implementation
TUHH with WEFC (Women in Europe, NL, NGO)
Operates with success, demand for fertiliser

Cross-section toilet-house



Toilet for school



Equipped with the chinese squat toilet seat of Lin Jiang, Nanning

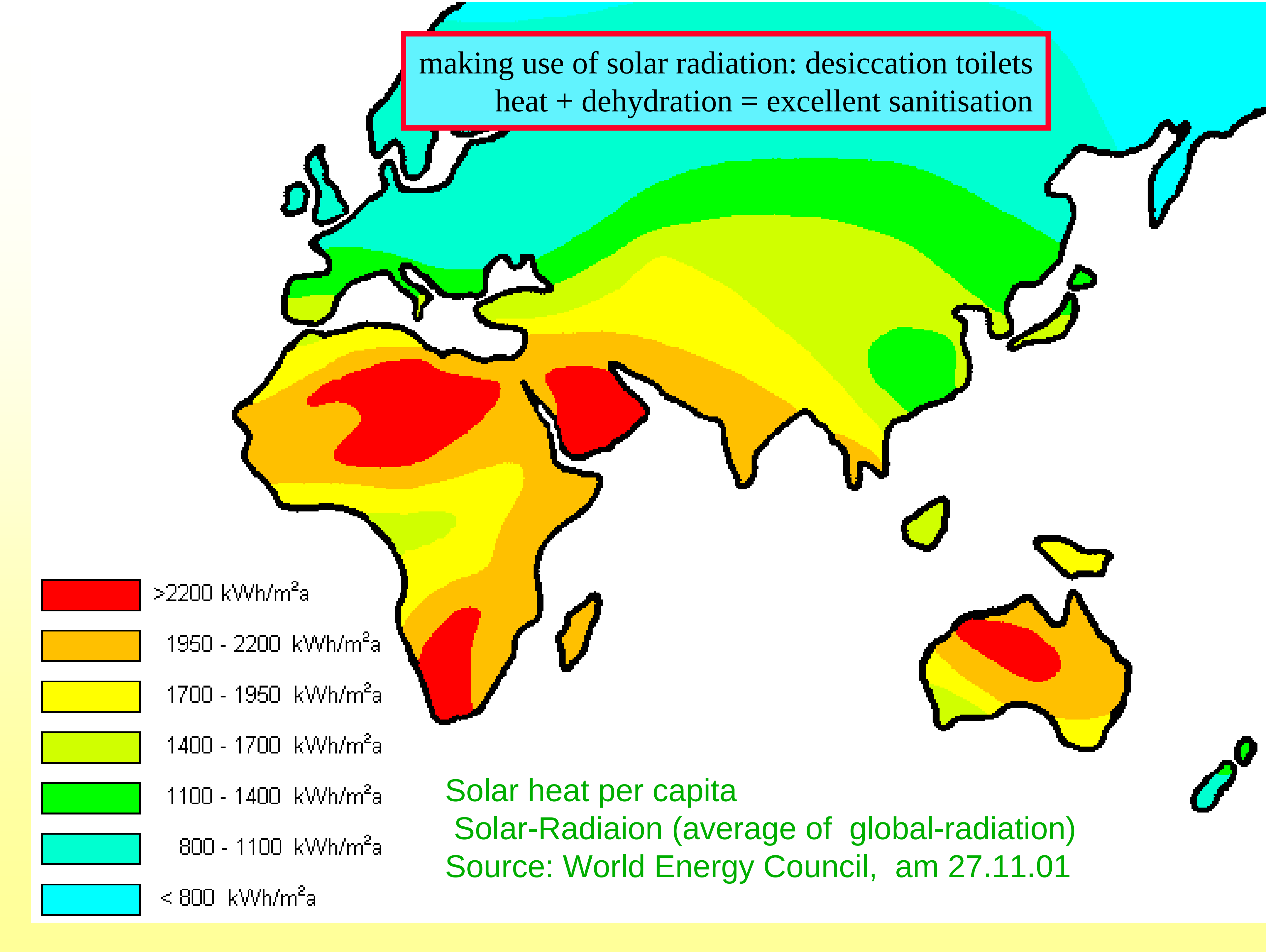
Finished Toilethouse in Romanian school

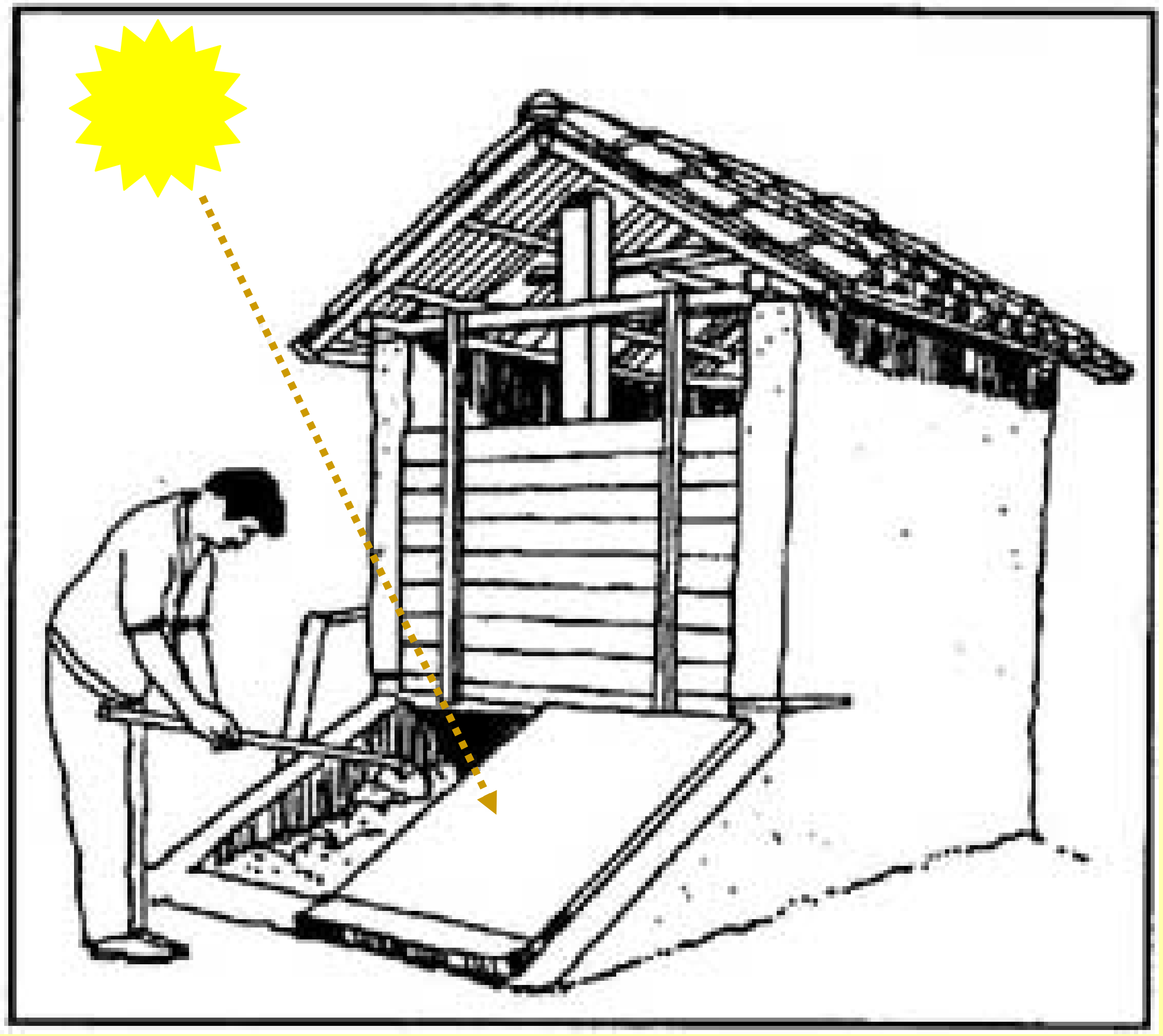
Urine tank, 2x6 month

Better NO ventpipes for urine-tank, small hole sufficient

Finished Toilethouse in Romanian school

TUHH
Technical University Hamburg-Harburg


making use of solar radiation: desiccation toilets
heat + dehydration = excellent sanitisation
>2200 kWh/m²a
1950 - 2200 kWh/m²a
1700 - 1950 kWh/m²a
1400 - 1700 kWh/m²a
1100 - 1400 kWh/m²a
800 - 1100 kWh/m²a
< 800 kWh/m²a
Solar heat per capita
Solar-Radiaion (average of global-radiation)
Source: World Energy Council, am 27.11.01



Solar Desiccation-Toilet

Low-Tech, very cheap, little maintainance required

(from Esrey et al., Ecological Sanitation, SIDA 1998)

the principles:
• building above ground to avoid water contact
• 2 chambers, each used for one year
• urine sorting required usage in agriculture
• ash/soil/lime can be added
• long term maintenance is the key to success

special care needed in societies with wet anal cleansing, separate bowl for washing

De-siccation Toilet
Mali, West Africa
GTZ / Otterwasser GmbH

Solar desiccation of feaces, Mali, West Africa (GTZ / Otterwasser)
black lids for solar heating
Chamber 2
built ABOVE soil !

design: Lin Jiang, China

Lin Jiang, Nanning, China

EcoSanRes,
China pilot projects

Each chamber/toilet is used for 6 to 12 month and idle for the same period www.ecosanres.org

EcoSanRes,
China pilot projects

Fertiliser usage in China

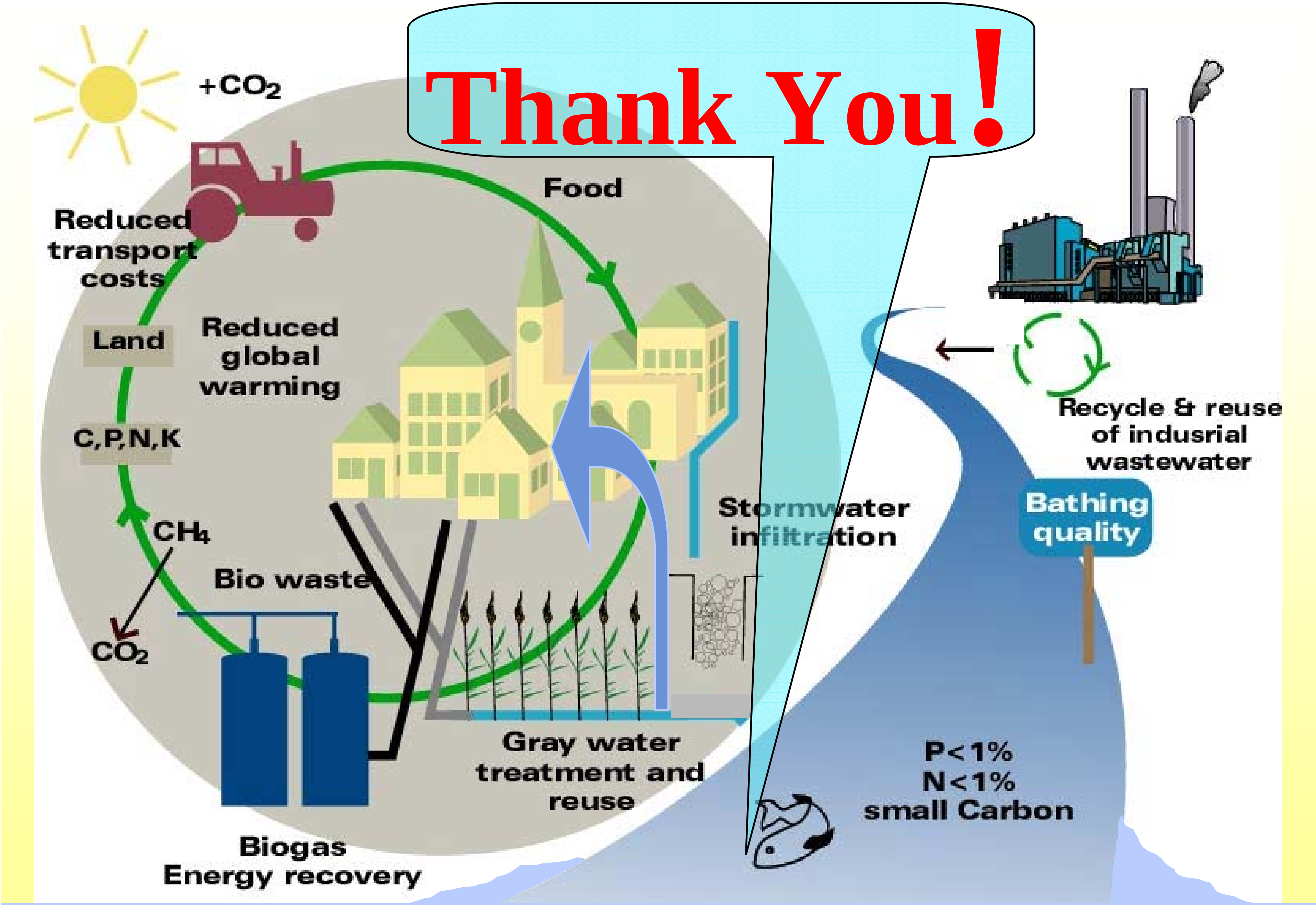
Blackwater of 900 Mio. rural Chinese people

→ 450 Mio tons of organic Fertiliser

Potential savings on commercial Fertilisers:
2,6 Billion US$ per year!

In addition soil improvement, protection of inland waters and the seas....

UNESCO, 2001



Ecological Sanitation: www.tuhh.de/aww and /susan www.gtz.de/ecosan www.ecosanres.org

Ecological Sanitation Options for different geographical and socio-economic conditions

	comments:
Dry Toilets	
• simple Bucket systems	rural low cost
• Pre-Composting-Toilets	more comfortable
• Large Chamber Composters	too wet or too dry
• Solar Desiccation Toilets (2 chambers)	hot climates, paper
• Earth Toilets (2 chambers)	comfortable
•	
Flush Toilets	
• Urine-Sorting in decentral and central systems	main step of nutient recovery
• Vacuum-Toilets and Transport	dense population
• Low-Flush with ‚Booster‘	more dilution
• Conventional Flush Sanitation and real agricultural reuse (nutrients)	ww not exclusive water source, HM

EFFICIENT MANAGEMENT OF WASTEWATER

Lesson B2

RAINWATER HARVESTING

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Hamburg University of Technology

Keywords
Ground water recharge, Infiltration, Rainwater, Rainwater use, Runoff agriculture, Stormwater, Water harvesting,

Table of content

Overview and summary of this lesson

The management of rainwater runoff represents an important aspect of water and wastewater management. Different methods exist in order to prevent flooding and erosion as well as to restore the natural hydrological water cycle. In contrast to off-site methods where the rainwater is collected, conveyed and discharged into waterways, rainwater infiltration and the use of rainwater by means of rainwater harvesting allow to address these issues and thus improve the water supply. This lesson covers some of the basic principles which are essential for the design of rainwater facilities. Then, rainwater infiltration techniques and their design are illustrated. The third part of this lesson introduces the concept and techniques of rainwater harvesting, which aims at storing stormwater runoff for the use in agriculture or domestic purposes. This lesson is rounded off with with the presentation of several Tunisian water harvesting techniques as they are applied in semi-arid and arid regions.

1. General aspects

1.1 Rainwater management alternatives

Stormwater management techniques have to be designed specifically for the types of effect that are wanted to be brought about. In general, following measures for management of rainwater are commonly used (Ferguson, 1998):

Use of rainwater / rainwater harvesting: Water harvesting is the direct capturing and use of runoff on-site. This can mean maintaining the water level in permanent ponds and wetlands or supplying water for irrigation and domestic purposes. For this the runoff either is stored and trickles away directly where the plants grow (runoff agriculture) or it is stored in tanks and reservoirs for later use.

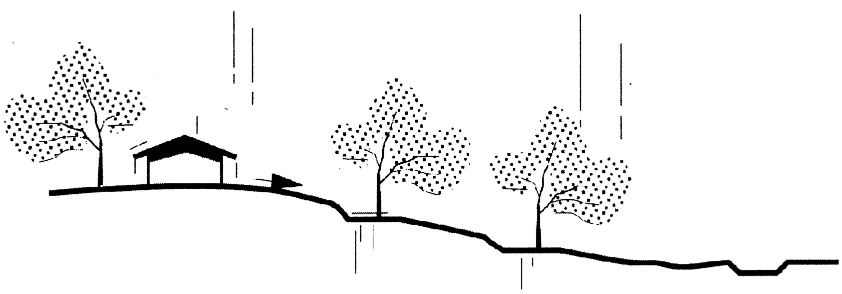

Figure 1: Water Harvesting (Source: Ferguson, 1998)

Infiltration of rainwater: Infiltration is the soaking of rainwater into the ground via infiltration basins. Infiltration restores natural hydrologic processes and addresses in addition to flooding and erosion also water quality, groundwater and water supplies. Almost always the water quality is improved by the filtration and transformation processes in the soil.

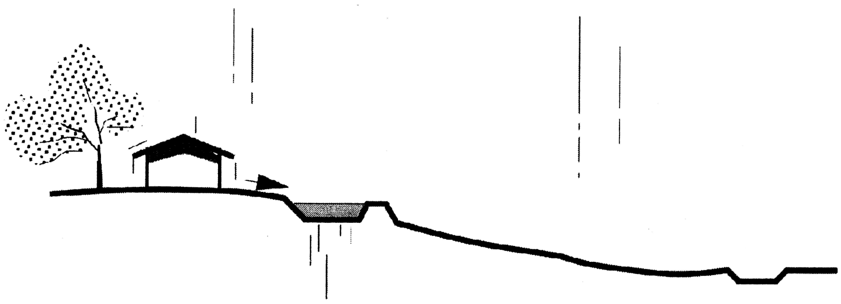

Figure 2: Infiltration (Source: Ferguson, 1998)

Conveyance: This is the moving of surface runoff from one place to another where it is eventually discharged to streams, lakes or bays. The facilities for conveyances are pipes and channels draining one into another. Please refer to lesson B1 for further information on the collection and conveyance of water.

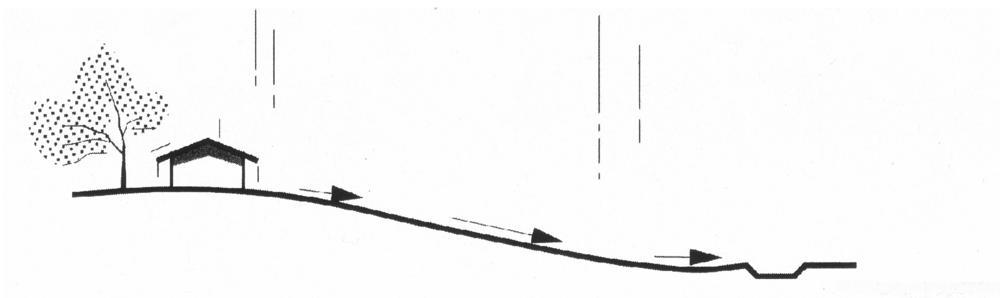

Figure 3: Conveyance (Source: Ferguson, 1998)

Detention: Detention aims at slowing down the rate of flow of surface runoff. The basic facility is a basin or storage reservoir with an outlet that temporarily stores storm runoff. Storage reservoirs, which delay the passage of water during storm events, reduce the peak flow rate and therefore decrease the risk of downstream flooding and erosion. Nevertheless, the total volume of flow is still allowed to run downstream, stretched out over time. Detention is a quantitative modification of conveyance. On its own it is inherently unable to address water quality, groundwater replenishment or water supplies. When water is stored in properly designed ponds and wetlands, suspended particles can settle out and the rainwater can be "treated". This is commonly called extended detention.

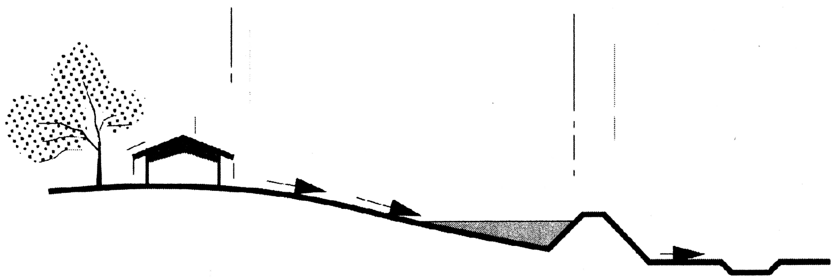

Figure 4: Detention (Source: Ferguson, 1998)

In this lesson the focus is on stormwater management techniques that are adapted to the natural hydrological cycle and that way help reduce the risk of flooding and erosion and improve the water availability. Therefore, stormwater infiltration (see section 3.2) as well as water harvesting techniques (See section 3.3) are illustrated in more detail.

1.2 Data needs/storm runoff

1.2.1 The design storm

Rainfall usually varies significantly with respect to time and geographical location. A rainfall event is characterised by the duration and the intensity or total quantity of rainwater that is falling down. A design storm on which the design of a wastewater management facility is based is a particular combination of rainfall conditions for which runoff is estimated. The magnitude of a design storm may be expressed as a total quantity of precipitation such as millimetres of rainfall or as a short-term intensity such as millimetres per hour. Intensity can be calculated by dividing the total quantity of precipitation by the catchment area and the duration of the rainfall event.

The recurrence interval is a way of expressing the probability that a storm of a given size or intensity may occur at a specific site. Recurrence interval, or frequency, is the average time between storms of a given magnitude. A 5-year storm is large enough that is has recurred, on the average, in only one of every 5 years in the local rainfall record. The probability of occurrence in any one year is the reciprocal of the recurrence interval. This means, the 5-year storm has a 20 percent chance of occurring in any one year, the 100-year storm has a 1 percent chance.

When choosing the design storm for designing a stormwater facility one needs to balance the risks and the costs. The selection of a large, infrequent storm as design storm reduces the risk of failure of the facility but increases the costs for construction and, thus, can make the facility uneconomical. For culverts and detention basins that drain local streets and prevent local drainage problems a 2- to 25-year recurrence interval is common. On the other hand, in extremely sensitive situations, where people's homes would be seriously damaged by flooding or their lives would be endangered, the most appropriate storm is the maximum probable storm, which can be larger than the 100-year storm. Usually local regulations specify the recurrence interval to be used. In Germany a 1-year recurrence interval and a duration of 15 minutes is used for the design of conveyance facilities, whereas infiltration systems are designed using a 5-year recurrence interval. Therefore, more intensive precipitation is used as a basis for the design of infiltration facilities in order to avoid the frequent failure of the systems.

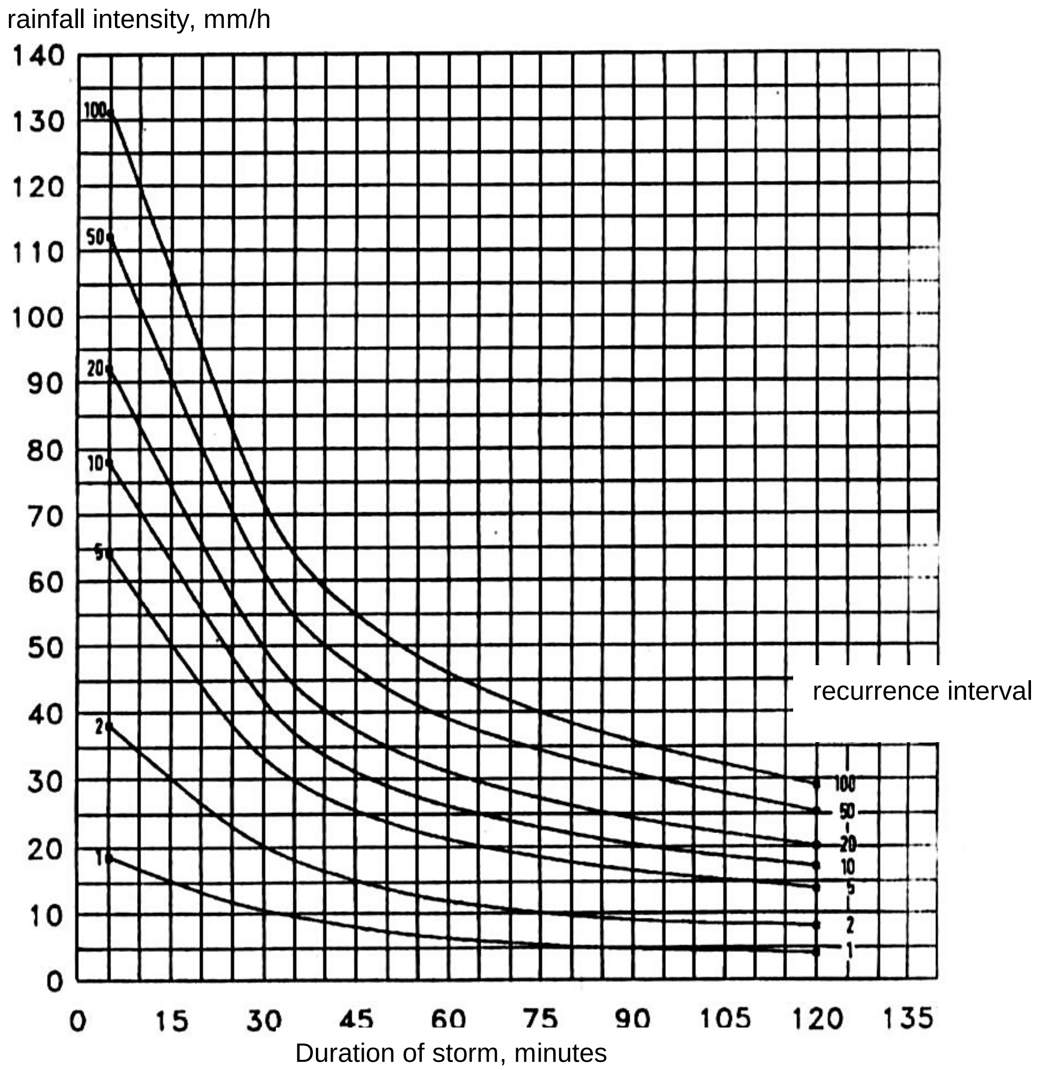

Figure 5: Example of an intensity-duration-frequency curve

Beside the recurrence interval, the duration of a storm is an important parameter. A storm that is short in duration can be very intense. As duration continues, high intensity is not maintained and therefore the average intensity decreases (See figure 5). In specifying a design storm, you must specify both recurrence interval and duration. Since every geographic location has a different rainfall pattern, local rainfall statistics can be useful to derive the absolute rainfall quantity of the design storm.

1.2.2 The drainage area

The drainage area, or watershed, is the land area that drains to the point at which you estimate runoff. Any rainfall runoff model requires you to identify the drainage area and to specify its size, soil, and condition. A drainage area is identified by defining its boundaries on a map. For this, you need to first identify exactly the location where you are going to estimate runoff. Then you need to draw the boundary starting from the outlet and moving uphill on each side by the shortest (steepest) possible path perpendicular to the contour lines. This procedure finally results in the delineation of the watershed. Having drawn a drainage area's boundary correctly, you are in a position to estimate its size and to characterise its land use and soils to meet the needs of the rainfall runoff model you are using.

1.2.3 Time of concentration

Runoff's travel time is one of the watershed characteristics that can strongly influence the rate of storm flow. If a given volume of runoff drains off a drainage area quickly, the peak rate of flow at the outlet is correspondingly high. Time of concentration is a special case of travel time. It is the maximum amount of time runoff from any point in a drainage area takes to flow to the outlet. Among a number of alternative paths that runoff could take from distant parts of a watershed, time of concentration is defined by the longest possible time, whether or not it involves the longest distance.

1.3 Design flow

Before a rainwater management facility is designed, the storm runoff should be established, which refers to the volumes and rates of flow in individual rainfall events.The actual volume of runoff reaching a rainwater management facility depends on several factors. These include the design storm, the size of the catchment area, the degree of development in the basin (i.e., amount of impervious surface) as well as the

the soil surface. It is often called "direct runoff", because it results from surface flow and other immediate responses to precipitation. A runoff gauging station would provide a direct, factual way to observe flows from a site in its existing condition. However, only few sites have gauging stations so that some sort of estimate is necessary. The estimate should be based on data about the site and general knowledge of runoff processes (Urbonas & Stahre, 1993). The factors affecting the runoff such as plant cover are combined in the runoff coefficient, which indicates the percentage of the total water volume actually becoming runoff. The runoff coefficient is also dependent on the slope of the area. For steep slopes as well as for impermeable soils or sealed areas the runoff coefficient has higher values. Table 1 shows runoff coefficients which can be used as approximations

Table 1: Runoff coefficients (Source: Ferguson & Debo, 1990)

Tye of surface or land use	**Runoff coefficient C**
Forest	0.1 - 0.3
Turf or meadow	0.1 - 0.4
Cultivated field	0.2 - 0.4
Bare earth	0.2 - 0.9
Pavement, concrete or asphalt	0.8 - 0.9
Flat residential, about 30% impervious	0.4
Flat residential, about 60% impervious	0.55
Sloping residential, about 50% impervious	0.65
Sloping, built-up, about 70% impervious	0.8
Flat commercial, about 90% impervious	0.8

For flat slopes or permeable soils use the lower values, for steep slopes or impermeable soils use the higher values.

If the catchment area consists of several areas with different land uses or surfaces, an average runoff coefficient is calculated according to the following formula:
with:

$$C_a = \frac{C_1 \cdot A_1 + C_2 \cdot A_2 + C_3 \cdot A_3 + ... + C_n \cdot A_v}{A_1 + A_2 + A_3 + ... + A_n}$$

A_1 ... A_n: partial areas in square meters or hectares
C_1 ... C_n: runoff coefficients for the respecitve partial areas

Runoff calculation can be based on following formula:

$$Q_T = C * I_T * A$$

with:

Q_T: runoff rate for a T-year storm, in liters/second
C: runoff coefficient, nondimensional
I_T: rainfall intensity for a T-year storm at a storm duration t, in liters/(second*hectare)
A: area of the catchment area, in hectares

The cumulative volume of rainwater over the storm duration can be calculated by multiplying the average runoff rate Q by the design storm duration t:

$$V_T = 3600 * Q_T * t$$

with:

V_T: total runoff volume at time t for a T-year storm, in liters
t: storm duration in hours

The total runoff volume for different design storms needs to be calculated by using different duration-intensity combinations for a given recurrence interval. Then, the largest runoff volume is used for the design of the rainwater management facility.

1.4 Water balance

A water balance, like a storm runoff estimation, establishes volumes and rates of flow. Storm runoff and water balance estimations supplement each other as tools for evaluation and design. Storm runoff estimation is needed to protect against, control and utilise runoff during individual storm events. Water balance estimations show the effects of land use and stormwater control on the local ecosystem. The underlying principle of the water balance is the change-of-volume concept, expressed in the following equation applied to any component of a landscape during any given increment of time:

storage = inflow - outflow

Any difference between inflow and outflow must be accounted for by a change in the amount of water stored. The inflow can include precipitation, stream flow or artificial irrigation. The outflow can include evapotranspiration, direct runoff, base flow and additional outflows such as withdrawals for water supply. Figure 6 illustrates these different flows and the water balance concept. The water balance is a way to evaluate the aggregate effect of the hydrologic regime.

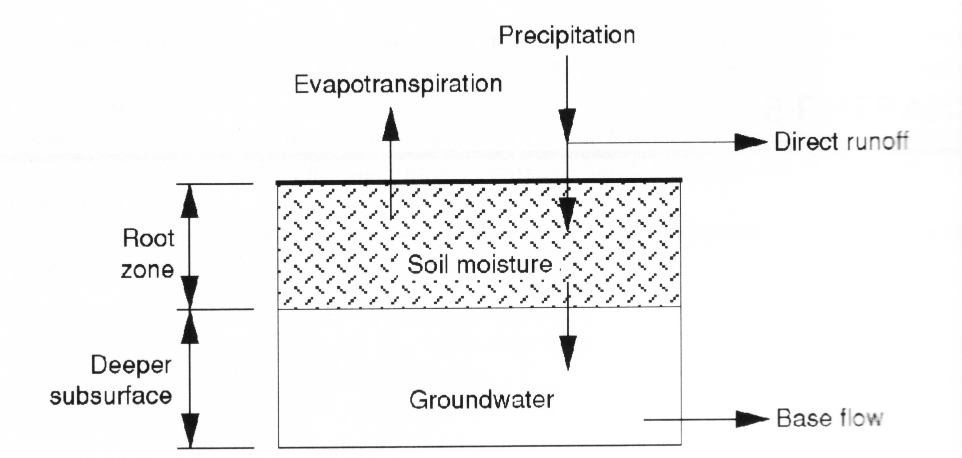

Figure 6: Water balance concept (Source: Ferguson, 1998)

1.5 Stormwater pollutants

Pollution of rainwater is caused by atmospheric pollution (such as emissions from industries and transport) as well as pollutants that are taken up during surface runoff. Among other things paper, oil, remainders of metals and rubbers, organic matter from vegetation and excrements can accumulate in the surface runoff. The main sources of anthropogenic pollution of rainwater is traffic and waste. The constituents vary in their nature and concentration according to local conditions.

Atmospheric rainwater is usually very pure and most contamination of the water occurs after contact with the catchment system. Rainwater from ground catchment systems is not recommended for drinking unless it is first boiled or treated. For the pretreatment of rainwater physical (such as sedimentation and filtration) and biological processes can be used. Biological treatment often occurs in biologically active soil filters or root zones. Please refer to the respective sections of this course for further information about physical and biological treatment processes.

2. Rainwater infiltration

The use of infiltration facilities represents an attractive opportunity to contribute to the recharge of groundwater and thus to minimise the interference of the natural water cycle. Stormwater infiltration returns surface flows to the subsurface and, thus, never aggravates flooding downstream. Additionally, a significant portion of the pollutant load of stormwater, which is normally directed to the receiving water, can be removed. If the soil through which water infiltrates contains any degree of clay or humus, the soil is a powerful filter that protects aquifers from contamination.

Some advantages of local rainwater infiltration are:

- recharge of groundwater
- preservation and/or enhancement of natural vegetation
- reduction of pollution transported to the receiving waters
- reduction of downstream flow peaks
- reduction of basement flooding in combined sewer systems
- reduction in the settlement of the surface in areas of groundwater depletion
- smaller storm sewers at a lesser cost

In some cases rainwater infiltration may have following negative impacts (Urbonas & Stahre, 1993):

- soils seal with time
- some infiltration facilities may not receive proper maintenance
- reliance on their operation may leave communities facing enormous capital costs in the future, if these systems begin to fail
- groundwater level may rise and cause basement flooding or damage to building foundations

2.1 Preconditions for infiltration

Regarding the site selection, a number of factors determine the suitability of a site for rainwater infiltration:

- Vegetative cover: Rainwater can be absorbed by plant roots and can be returned to the atmosphere through plant respiration. The soil-vegetation complex functions to a certain degree as a filter that reduces clogging of the surface pores of the soil.
- Soil type and conditions: Effective porosity and permeability are soil parameters that influence the infiltration process. Bedrock should not be within less than 1.2 meters of the infiltration surface.
- Groundwater conditions: Distance to groundwater and variation in groundwater levels are some of the information needed for planning infiltration facilities. It is recommended that the distance to groundwater is at least 1 meter.

2.2 Types of infiltration systems

There are a number of possibilities for decentralised or on-site infiltration systems, which are described in the following section. It should be noted that often combinations of the different systems are used.

2.2.1 Infiltration beds

Infiltration beds represent the simplest form of local infiltration. The rainwater is let run onto a vegetation-covered surface where it infiltrates. In areas with high groundwater table or fine-grained soils, infiltration can be very slow and may result in standing water.

2.2.2 Open ditches

The use of open ditches and swales adjacent to streets, roads, highways, and small parking lots is a special case of surface infiltration. The infiltration capacity depends on factors such as the porosity of the soil and the suspended solids load in the stormwater, and it may not be possible to infiltrate all the runoff into the ground using only swales and ditches, when the catchment area is too large compared to the available infiltrating surface. Good vegetation growth in open ditches is essential, since the vegetation re-aerates the soil surfaces when they become clogged with fine sediments carried by the runoff. In addition to swales and ditches percolation trenches can be installed.

Figure 7: Swale

Figure 8 : Infiltration ditch (Source: Universität Trier)

2.2.3 Percolation basins

A percolation basin is constructed by excavating a pit, filling it with gravel or crushed stone, and then backfilling over the top of the rock. The rock media provide the porosity for temporary storage of water so that it can then slowly percolate into the ground. Basins should not be submerged by groundwater, as this will hinder their proper function. In order to reduce the risk of clogging of the rocks by suspended particles, it is advantageous to filter the stormwater before it enters the rockfilled basin by passing either through a granular filter bed or a fine mesh geotextile material. The filter media needs to be removed and replaced from time to time.

2.2.4 Pipe trench

A pipe trench is a special case of a percolation basin where the stormwater is stored not only in the rock media, but in the pipe itself. Clogging can also occur in the pipe trench, so that filtering of stormwater should be part of each pipe trench installation.

2.3 Design of infiltration facilities

The design of infiltration facilities should be in such a way that the facility will contain the design inflow without overflowing. Generally, infiltration and percolation facilities will work best for small catchment areas and they should be designed conservatively, using low hydraulic loading rates. The design loading rates should be low enough to allow the water to drain away after a rainfall event.

When a site has been judged to be an acceptable candidate for an infiltration basin (see above, 'Preconditions for infiltration'), the next step is to find the required surface area and storage volume for the facility. The size of the infiltration surface depends on the infiltration rate, which differs for different soil types and should be obtained from infiltration tests at each site.

For the design of a percolation facility Darcy's Law is used for the estimation of the percolating water:

$$U = k * I$$

with:

U: flow velocity in meters per second
k: hydraulic conductivity in meters per second
I: hydraulic gradient in meters per meter

The hydraulic gradient can be assumed to be I=1m/m. The hydraulic conductivity k can be estimated according to table 2 below, but it is recommended to perform hydraulic conductivity tests at each individual site. The hydraulic conductivity is usually specified for saturated soil. For unsaturated soil the hydraulic conductivity k_u can be assumed to equal $k_u = 0.5 * k$.

Table 2: Hydraulic Conductivity of Several Soil Types (Source: Urbonas & Stahre, 1993)

Soil Type	**Hydraulic conductivity k [m/s]**
Gravel	10^{-3} - 10^{-1}
Sand	10^{-5} - 10^{-2}
Silt	10^{-9} - 10^{-5}
Clay (saturated)	$<10^{-9}$

Using Darcy's Law and the assumptions mentioned above, the outflow of a percolation facility can be estimated at:

$$Q_{out} = 0.5 * k * A_S$$

with:

A_S: percolation surface area
k: hydraulic conductivity in meters per second

The assumption that Q_{out} equals Q_{in} results in the estimation of the required percolation surface area A_s, for example, of an infiltration bed or an open ditch.
with:

$$A_S = \frac{A_{red}}{\frac{k \cdot 10^7}{2 \cdot I_T} - 1}$$

A_{red}: reduced catchment area ($A_{red} = A * C$) [m^2]
A: catchment area [m^2]
C: runoff coefficient (possibly as average) [-]
k: hydraulic conductivity [m/s]
I_T: rainfall intensity for a T-year storm at a storm duration t [l/(s*ha)]

The required storage volume V_{req} for swales, ditches and percolation basins is the difference of inflow and outflow multiplied by the duration of the rainfall event. Using iterative calculations the following equation is solved for several combinations of the duration-frequency graph until the maximum required volume is found. Usually a recurrence interval of 5 years is used for decentralised facilities and 10 years for central facilities. Another option is to simulate the behaviour of the infiltration facility using a long-term simulation based on real rainfall data for that specific region.

$$V_{req} = \left(\sum Q_{in} - \sum Q_{out}\right) \cdot t$$
$$V_{req} = \left[\left(A_{red} + A_S\right) \cdot 10^{-7} \cdot I_T - A_S \cdot 0.5 \cdot k\right] \cdot t \cdot 60 \cdot f_Z$$

with:

V_{req}: required storage volume [m^3]
A_S: percolation surface area, can be assumed to vary between 0.05 * A_{red} and 0.2 * A_{red} [m^2]
A_{red}: reduced catchment area (A_{red} = A * C) [m^2]
k: hydraulic conductivity in saturated zone [m/s]
I_T: rainfall intensity for a T-year storm at a storm duration t [l/(s*ha)]
t: duration of the rainfall event [min]
f_Z: safety factor (e.g. 1.2)

Concerning the calculation of percolation basins and pipe trenches it has to be noticed that A_S does not need to be included into the calculation of the catchment area, because the pipe surface is underground and does, therefore, not contribute to the catchment area.

2.4 Special considerations and maintenance of infiltration facilities

Regular maintenance is needed to ensure proper operation of infiltration systems. In general, these systems do not have a full-time inspection. Therefore, proper installation inspection and quality control procedures will sometimes have to be provided by the community. In order to keep the infiltration surface porous, vegetation growing on the infiltration zone needs to be maintained. As the facility ages and the surface soils become clogged, the top soil layers may have to be removed, replaced, and re-vegetated to restore the infiltration capacity.

Maintenance of percolation facilities is mainly related to keeping the inlet filter free from plugging. The filter fabric and sand layers need to be checked frequently and cleaned. After a couple of years it may become necessary to replace the rock media of the percolation facility, if the pores are filled by fine particles.

Infiltration rates in a newly constructed facility will be less than anticipated. Also ageing facilities may fail and will have to be repaired or replaced. Therefore, downstream conveyance system may need to handle more runoff, which should be kept in mind when constructing these facilities.

Clogging of infiltration systems is caused by fine eroded particles. Thus, it is very important to control erosion in the catchment area, for example, through the installation of splash pads at downspouts or the use of rock or paved rundowns.

The inflow of stormwater into the ground will affect the groundwater levels and water quality in the region. Therefore, this impact needs to be considered, for example, if rising groundwater levels are expected to be above basement floor elevations. Usually, the recharge of groundwater by nonindustrial stormwater has no serious impact on the water quality, so that the water can be used as drinking water supply. Nevertheless, there is the risk that toxic chemicals or other pollutants may enter the groundwater with the infiltrated stormwater (Urbanos & Stahre,1993).

3. Water harvesting techniques

Generally the term "water harvesting" comprises many techniques that are used to supply rainwater collected from surfaces (roofs, ground surface, rock surface) for domestic or agricultural use. It can be defined as "... the process of concentrating rainfall as runoff from a larger catchment area to be used in a smaller target area" (Oweis et al.,1999, p.2). Water harvesting techniques represent methods to provide water for irrigation, watering domestic smallstock or domestic purposes from other sources than (permanent) streams, rivers and pumped groundwater. Usually a rainwater system consists of three main components: a catchment area, a storage reservoir and a delivery system. The target area can be the soil profile of the cultivated area or some kind of reservoir or tank. Water harvesting is particularly relevant to areas where rainfall is insufficient to balance evapotranspiration of crops and to sustain a good pasture growth.

3.1 Benefits

Generally the low rainfall in arid and semi-arid areas is distributed with a high variability in space and time, which hinders profitable agriculture and creates instability in production. However, concentrating the scarce rainwater into smaller areas by means of water harvesting techniques allows economic agricultural production and can also improve drinking water supplies in arid regions. Surface water harvesting techniques that are well adapted to the ecological and social context have the potential to improve the productivity of arable and grazing land by increasing the yields and reducing the risk of crop failure. They are relatively cheap and can therefore be a viable alternative in regions where irrigation water from other sources is too costly. Water harvesting can reduce the use of groundwater, which is a valuable water source and needs energy for its exploitation. The collection of rainwater can even contribute to the recharge of groundwater tables (Prinz, 1999). Very often rainwater harvesting techniques help to prevent floods and to control soil erosion. Thus the systems allow not only a suitable irrigation in regions with scarce water sources but also an improvement of the hydrological equilibrium and the soil quality (Alaya et al., 1993).

3.2 Limitations

It should be paid attention to minimise side effects, since poorly designed and managed systems can lead to soil erosion, soil instability and local floods. Water harvesting techniques increase the water availability, yet the climatic variability can not be completely compensated. Years with extremely low precipitation still threaten the production, and torrential rainfalls can often lead to destructive runoff. Large storage tanks may be required in areas where the dry season is long. In addition, the rainwater may be contaminated, so that extra care should be taken when the collected rainwater is used as drinking water. The success of water harvesting projects is often based on farmer's experience and their willingness to adopt and accept the techniques (Prinz, 1999).

3.3 History

Water harvesting is almost 4000 years old: it began in the Bronze Age, when desert dwellers in the Middle East smoothed hillsides to increase rainwater runoff and built ditches to collect the water and convey it to lower lying fields. Archaeological findings and historical descriptions show that water harvesting played an important role in supporting a flourishing agriculture in many regions. A wide variety of hydraulic structures have been introduced during many centuries to make the land productive irrespective of its restrictive natural conditions. Presumably millions of hectares of land in dry areas, where rainfall is low and erratic in distribution, were once cultivated with water harvesting techniques, but many causes have brought a steady decline. Namely the preference of larger irrigation schemes and social changes like the migration of manpower are responsible for the common neglect of these techniques. But since water harvesting represents a sustainable method of providing non-costly water and improving the productivity of land that suffers from inadequate rainfall, the interest in these systems has increased during recent decades.

3.4 Harvesting methods

Surface water harvesting requires runoff producing areas with sufficiently high runoff coefficients and runoff receiving areas, where the water is utilised. The differences between the different harvesting methods lie mainly in the size of the systems.

Figure 9 Examples of micro-catchment water harvesting (contour bench terrace, bunds, Negarim system) (Source: FAO, 1999)

“Rainwater harvesting” is the collection and concentration of rainfall either from roofs and courtyards, from micro-catchments, or from macro-catchments. Water collected from paved, compacted or otherwise treated surfaces like rooftops is mainly used for domestic purposes and livestock watering. “Micro-catchment water harvesting” (see figure 9) stands for the collection of surface runoff from a relatively small catchment area (less than 1000 m^2). The water is stored in the root zone of an adjacent infiltration basin, that is planted with a single tree or bush or with annual crops. “Medium-sized” or “macro-catchment water harvesting” (figure 10) is the collection of water in larger catchment areas (1000 m^2 – 200 ha), that are located outside the cultivated areas. From there the runoff is conveyed to the cropping areas (Prinz, 1996).

Figure 10: Example of macro-catchment water harvesting (hillside conduit, photo: Klemm)

"Floodwater harvesting" is also referred to as large catchment water harvesting with catchments being many square kilometres in size. It includes the harvesting of water within the streambeds of ephemeral or seasonal rivers ("wadis") and the diversion of the wadi water. For this dams can be constructed within the riverbed, that block the water flow leading to an inundation of the valley bottom of the flood plain. Thus the water infiltrates and allows the use of the wetted area as cropping zone (See figure 15). "Floodwater diversion" (Figure 11) is the construction of dikes or other diversion structures forcing a part of the wadi water to leave its natural course and conveying it to nearby cropping areas. Since "floodwater harvesting systems" include a more complex structure of dams and distribution networks, relatively high technical input is required (Prinz, 1996).

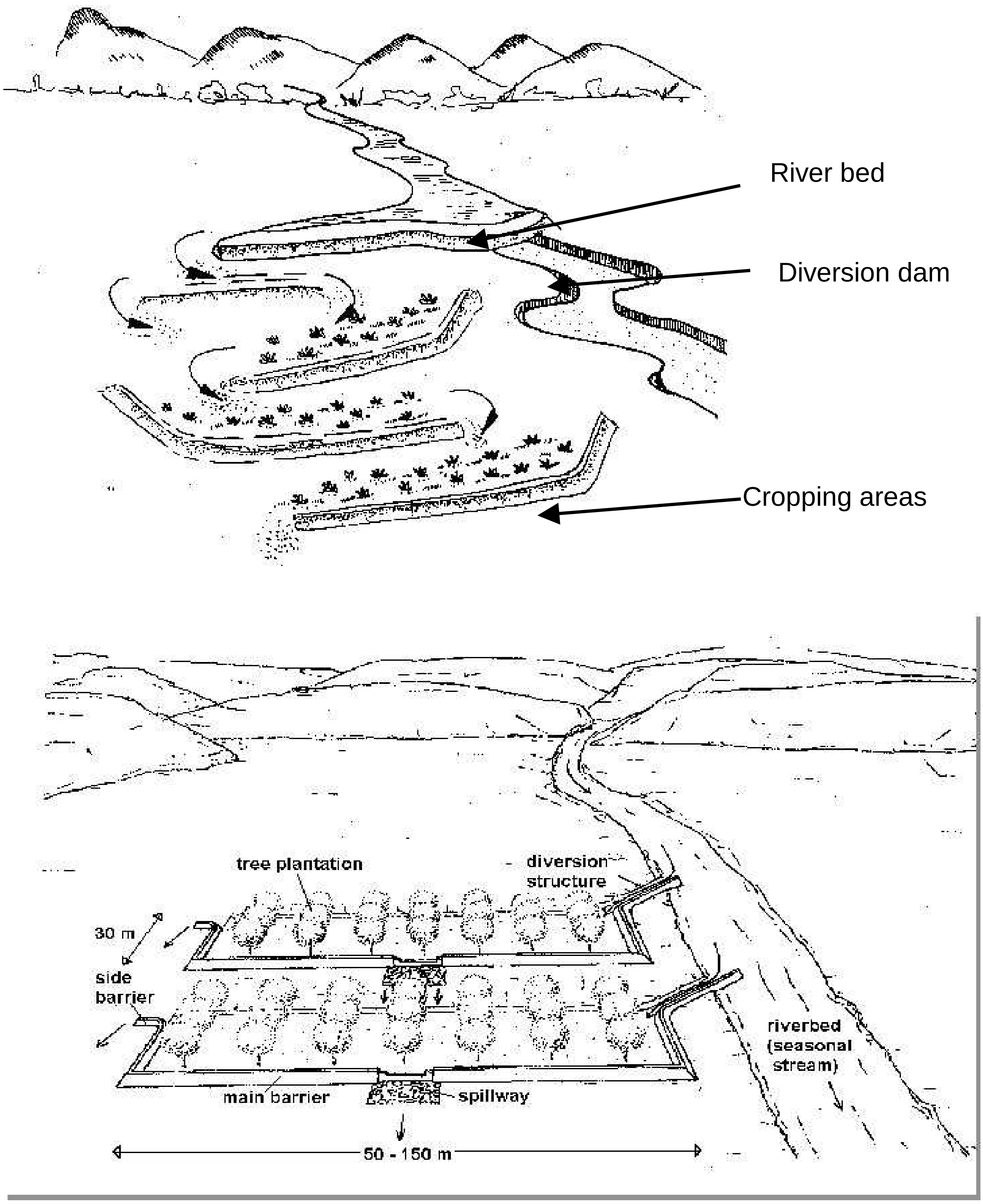

Figure 11: Examples of floodwater diversion (Source: FAO, 1999)

3.5 Water storage

Storage facilities allow the later use of runoff water as supplemental irrigation water. They can partly overcome the problem of the unreliability of rainfall. This also allows the prolongation of the cropping season or a second crop. The storage can be aboveground or underground. Surface storage, for example in ponds, has the disadvantage of evaporation losses as well as siltation and pollution. These drawbacks can be avoided by underground storage in cisterns, that can keep the water losses by evaporation and percolation minimal, if they are covered and have plastered walls. Siltation can be minimised by reducing erosion, or by installing a silt-trap through which the runoff passes before it flows into the storage tank. Storage facilities not only prevent the loss of runoff during periods of heavy rainfall but also play an important part in reducing floods and controlling soil erosion (Prinz & Wolfer, 1999). Storage reservoirs include various types of surface and sub-surface tanks, rock catchment dams, earth dams, and sub-surface or sand dams in sand rivers. Surface tanks can be made of ferrocement, bricks, reinforced concrete, metal, plastic, fibreglass and wood. Sub-surface tanks are usually made of ferrocement, concrete, brick and traditional clay linings. Furthermore, water harvesting dams can be built of soil, rock or sand.

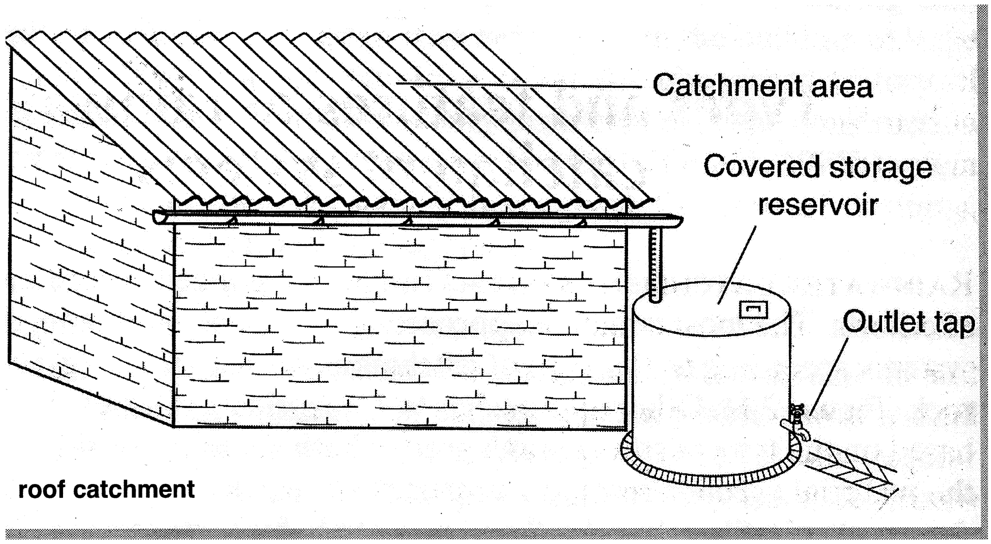

Figure 12: Rainwater storage tank (Source: Gould & Nissen-Petersen, 1999)

3.6 Design criteria

3.6.1 Runoff agriculture

The appropriate choice of a technique depends on the amount of rainfall and its distribution, soil type and depth, land topography and local socio-economic factors (Oweis et al., 1999). Loess and loess-like soils are ideally suited for rainwater harvesting because even after a small rainfall a crust is formed that promotes runoff. Slope affects the quantity and the quality of runoff. The most efficient water harvest is on small, gently sloping catchments (with a slope preferably between 1 % and 5 %).
The ratio of the surface of the catchment area (runoff producing area or impluvium) to the surface of the cropping zone is expressed by the factor CCR ("catchment to cropping ratio"). In the course of time the respective ratios became apparent for the different systems according to the climatic conditions. The factor can also vary depending on the characteristics of the watershed. When planning a water harvesting system the proper establishment of the CCR is very important in order to avoid an insufficient water supply or damages to the systems as a result of an outsized catchment area (Alaya et al., 1993).

The CCR is directly related to the mean annual precipitation quantity and the mean runoff coefficient of the region. It also depends on the water requirements of the crops. The knowledge of these three parameters is indispensable for applying rainwater harvesting systems on a serious technical foundation. The relation between CCR and the three factors is the following:

$$CCR \cdot C \cdot P = WR - P$$

or:

$$CCR = (WR - P) / (C \cdot P)$$

With:
CCR: area impluvium / area cropping zone [-]
P: mean annual precipitation [mm]
C: mean annual runoff coefficient [-]
WR: water requirements of the crops [mm]

3.6.2 Storage tanks

If the water harvesting system includes a storage tank, the tank needs to be sized correctly in order to give adequate storage capacity and at the same time minimize capital investment. The storage requirement will be determined by a number of interrelated factors such as the local rainfall data and weather patterns, catchment area, runoff coefficient, user numbers and consumption rates. The calculation of the storage capcity can either be based on the actual demand or the possible supply of rainwater (Hartung, 2002).

<u>Demand side approach:</u>

storage requirement R = C * n * d

with:
C: Consumption per capita per day
n: number of people
d: longest average dry period

<u>Supply side approach:</u>

annual available water W = A * C * R

with:
A: catchment/roof area
C: runoff coefficient
R: average annual rainfall

demand D = R as calculated above in the demand side approach

The storage requirement can be derived as maximum difference between the cumulative harvested water and the cumulative demand.

Storage tanks should be watertight with a solid, secure cover, a screened inlet, an overflow pipe and a covered manhole. The extraction system should be designed in such a way that the water quality is protected. The choice of a specific system depends on several factors such as for example:

- space availability
- option available locally
- local traditions for water storage
- cost - of purchasing new tank and of materials and labour for construction
- materials and skills available locally
- ground conditions
- patterns of usage

3.7 Traditional water harvesting techniques in Tunisia

The following section presents traditional water harvesting techniques as they are applied in Tunisia as examples for rainwater harvesting in semiarid and arid regions.

3.7.1 Meskats

The *meskat* system is a very ancient water harvesting technique that was already known and wide spread in the Roman era. This technique, which is typical for gentle slopes and low hills, is mainly found in the so-called Tunisian Sahel region, where a semiarid to arid climate with mean annual rainfall of about 300 mm prevails. The technique is an example for micro-catchment water harvesting techniques with relatively small catchment sizes. It is based on a catchment area or impluvium called “meskat” and a cropping zone (“mangaâ” or “mankaâ”) (see figure 13). The impluvium, generally about 500 m^2 in size, supplies additional water to a series of downstream plots, which are enclosed by small earth bunds (about 20 cm) and connected by spillways for discharging the excess water. In general the surface of the impluvium should be twice the cropping area, thus the catchment to cropping ratio (CCR) is 2:1 (Achouri, 1994). By breaking the runoff the *meskat* technique also contributes to the recharge of ground water as well as to the decrease of floods and water erosion.

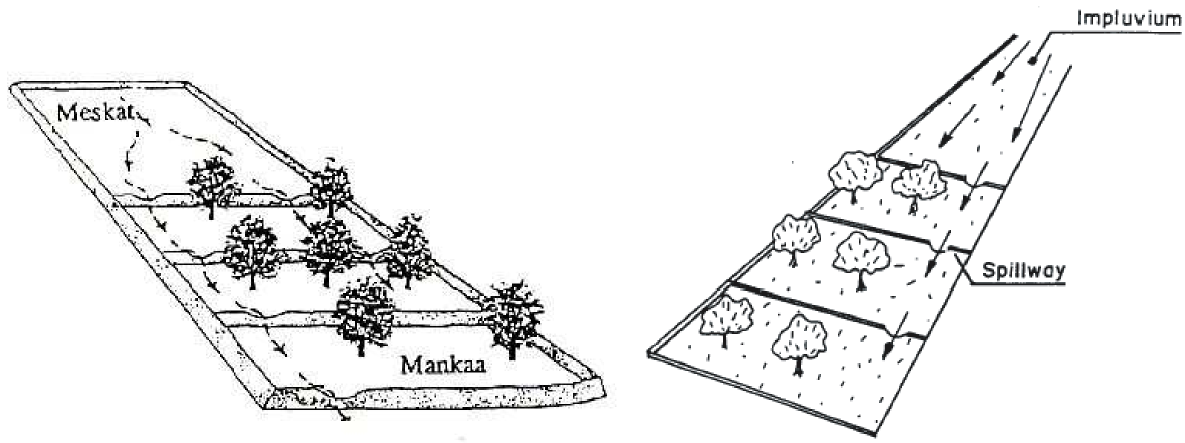

Figure 13: Meskat system (Source: Prinz, 1996 and Oueasser)

3.7.2 Mgouds

This floodwater diversion technique is very common in the plains adjacent to great wadis in Central Tunisia. It is a channel system based on the diversion of floodwater from its natural course in wadi beds to the nearby fields. The floodwater is diverted by solid dikes and lateral channels with minimal slope (“mgoud”) and then distributed by an extensive network of drainage channels to the irrigated area with fruit trees, cereals and vegetables (see figure 14). The crops are planted in parallel strips with a surface from 3 to 5 ha; each enclosed by small bunds and separated from the other strips by uncultivated land.

This kind of technique supplies water to the crops only after significant rainfalls. But even though low precipitation does not generate any runoff in the ravines or wadis and leaves the cropping zones completely dry, already one single shower with a high intensity can regenerate the river and supply the water reserves for a whole vegetation period (Alaya et al., 1993). Water-spreading systems like the *mgouds* need a careful design and engineering layout to withstand floods and prevent erosion. Since the deviated water is part of the wadi water, the relation between the surface of the impluvium and the cropped area (CCR) cannot be set up.

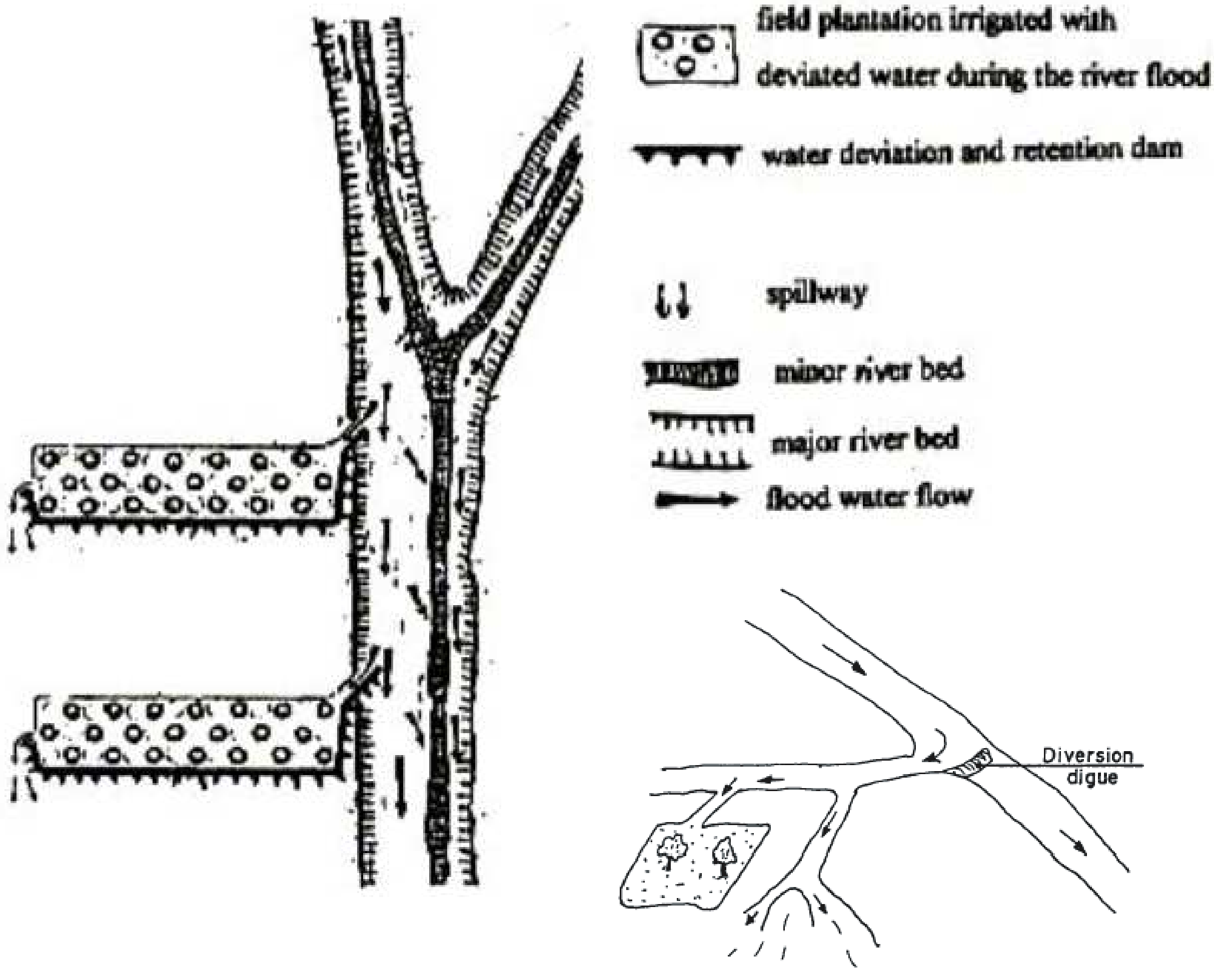

Figure 14: Mgoud system (Chahbani, 1997 and Oueassar)

3.7.3 Jessour

The technique of the *jessour (or jesr)* is known since antiquity as a way of exploiting the surface runoff water for agriculture in arid regions. It is a typical system of the highlands in the southeastern regions of Tunisia and constitutes the foundation of the agricultural activities in this zone. It is based on a retention dam made of earth or stone perpendicular to the runoff, behind which the crops, mainly fruit trees, are cultivated. The dam stops and stores the runoff and supplies in this way water to the crops.

Jessour (singular: *jesr*) are generally used in mountainous areas, where they are often built into wadis, but they are also constructed on plains. The dams encourage the infiltration of the rainwater, which not only intensifies the agricultural production but also recharges the ground water. During extreme rainfalls a part of the disastrous runoff can be retained behind the dams which helps to reduce the damage that may be caused by floods.

3.7.4 Components of the jessour system

A *jesr* is a small hydraulic unit which comprises several parts: the dam, the terrace and the catchment area or impluvium (see figure 15 and 16). It can have a dimension from a few hundred to a few thousand square metres.

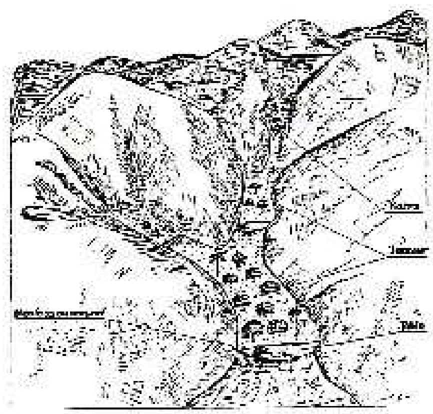

Figure 15: Jessour system (adapted from Belgacem, 1999)

Normally, the dam is constructed across the wadis or thalwegs. On gently sloping hills it is perpendicular to the slope. It aims at the retention of sediments, which contribute arable soil, as well as the accumulation of runoff water, which is essential for the cultivation in arid zones. The dam is either made of stones or of consolidated soil. Its length can reach up to 200 meters in wide valleys. The height of the dam can vary between 50 cm and 5 m. As figure 16 illustrates the cross section of the dam shows a more or less trapezoidal form. The longer base is formed by the surface of the slope.

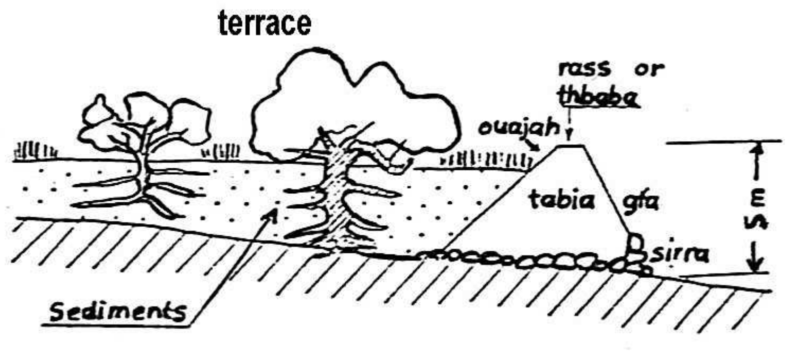

Figure 16: Cross section of a jesr (adapted from Belgacem, 1999)

Generally the dams are equipped with one or two spillways, that discharge the excess water to the downstream side of the jessour. The runoff water is collected up to a height of about 20 cm or more before it is discharged into a downstream *jesr* system via the spillway. According to the size of the impluvium several *jessour* connected with each other can be superposed. Some considerations have to be taken into account for the construction of a spillway. If the threshold of the spillway is too high, the *jesr* on the downstream side will not receive enough surplus water and its production will decrease. If the spillway is not wide enough, the dam is threatened by undermining and the appearance of holes. Besides, the breaking of one *tabia* results nearly unavoidably in flooding and the breaking of downstream dams as well. If on the contrary the threshold is too low or the spillway too large, the water and soil retention capacity is not sufficient and the yield of the *jesr* will be unsatisfactory.

Figure 17: Dam with spillway (Photo: Meinzinger)

The terrace stretches behind the dam on the upstream side and provides the surface for farming activities. Runoff water and eroded soil accumulates on this plain surface. The soil depth varies in relation to the dam and can reach as high as 2 m. The surface of the terrace is often less than 2 ha. The CCR varies normally from 4 to 6, but it can also reach values as high as 100 (Achouri, 1994).

3.7.4 Cisterns

The principal idea of cisterns or storage tanks is the collection of rainwater for storage and use as drinking water for domestic needs, animal watering or irrigation. A cistern is a man-made hole in the soil with a gypsum or cement coating to avoid vertical and lateral infiltration losses. Generally these underground reservoirs with capacities from 1 m^3 to 70000 m^3 occupy the outlet of a small catchment area (impluvium) that collects the rainwater. In a natural environment the impluvium is demarcated by one or more grooves or small stone bunds conveying the runoff water towards the opening of the storage tank. The water passes a decantation basin that retains plants, silt and other material that is carried by the runoff water. One or two openings in the covered top, which constitutes the protection against evaporation, allow the taking of water.

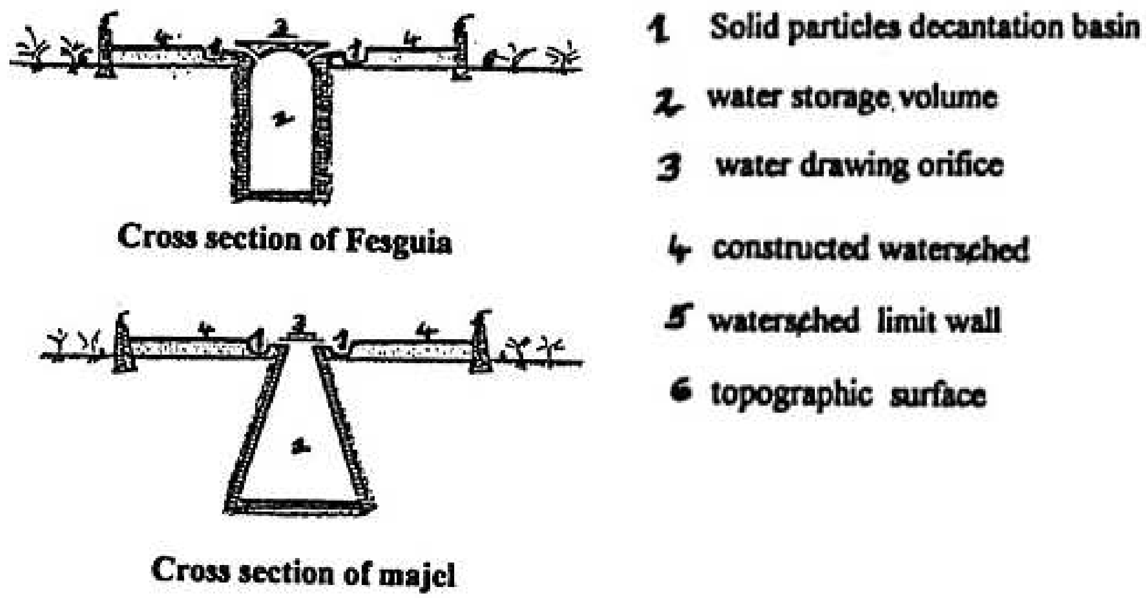

Figure 18: Cross section of majel and fesguia (Chahbani, 1997)

In Tunisia two different kinds of cisterns or storage tanks can be found: the “majel” and the “fesguia”. They are distinguished according to their form (see figure 18). Generally *fesguia* have a larger storage capacity, but their construction is accordingly more expensive.

3.7.4.1 Different types of cisterns

Integrated into buildings

The roof of the building is utilised as impluvium or catchment area before the rainwater is stored in the subterranean cisterns. Until the beginning of the last century the technique of collecting and storing rainwater in cisterns was essential for the supply of drinking water in urban areas, villages and isolated accommodations in several Tunisian regions (e.g. the islands of Jerba and Kerkenna and the mountainous regions or the arid plains in Central Tunisia). The city of Tunis had numerous cisterns, which were integrated into the accommodations or public buildings, with a total capacity of 12 million m^3.

Isolated, with sealed impluvium

Remains of the Roman era on the island of Kerkennah show that this type of cistern also has a very long tradition. The subterranean cisterns are surrounded by a sealed impluvium aiming at the increase of the runoff coefficient. This method is expensive but it has a long life expectancy. The surface area of the impluvium varies according to the precipitation of the region. More than 200 public cisterns of this kind exist on the island of Jerba. Each of them has a storage capacity in the order of 50 m^3 and an impluvium with a mean surface of about 250 m^2 (El Amami, 1984).

Natural impluvium

These cisterns are either open, if they are big, or covered, if they are smaller. The natural impluvium is protected and kept clean. It is sometimes cleared of vegetation and loose stones to reduce the interception of rain and the obstruction of overland flow. As figure 15 illustrates small ditches and stones collect and direct the rainwater to the cistern, which is equipped with a decantation basin for the removal of silt and an overflow.

Figure 19: Fsagui (left) and majel (right) with a natural impluvium (Photo: Meinzinger)

4. Exercises

4.1 Quetions

1. Please name at least four advantages of rainwater infiltration as opposed to conveyance and discharge into waterways

2. Calculate the total runoff volume for a 15-minutes rainfall with an intensity of 20 l/(s*ha) on a total area of 800 m^2 consisting of following partial areas with their respective runoff coefficients:

A_1: 500 m^2, C_1= 0.2
A_2: 200 m^2, C_2= 0.5
A_3: 100 m^2, C_3= 0.35

3. The runoff from an area with a size of 5000 m^2 is to be infiltrated in a swale. The infiltration surface should be 10 % of the impervious (or reduced) runoff area. The design storm should be a 5-year storm. Determine the required volume of the infiltration swale.

Additional information:

Runoff coefficient: C = 0.5
Hydraulic conductivity: k 0 $1*10^{-4}$ m/s
Safety factor: f_Z = 1.2
Rainfall intensity

	Probability of occurrence = 1	**Probability of occurrence = 0.2**	**Probability of occurrence = 0.1**
Duration t [min]	**I_T [l/(s·ha)]**	**I_T [l/(s·ha)]**	**I_T [l/(s·ha)]**
5	201,0	338,9	398,3
10	127,1	204,6	238,0
20	80,4	124,0	142,7

4.2 Answers and Solutions

1. Recharge of groundwater, preservation and/or enhancement of natural vegetation, reduction of pollution transported to the receiving waters, reduction of downstream flow peaks/flooding, reduction of basement flooding in combined sewer systems, reduction in the settlement of the surface in areas of groundwater depletion, smaller (or no) storm sewers at a lesser cost

2.

$$C_a = \frac{A_1 \cdot C_1 + A_2 \cdot C_2 + A_3 \cdot C_3}{A_1 + A_2 + A_3} = \frac{500 \cdot 0.2 + 200 \cdot 0.5 + 100 \cdot 0.35}{500 + 200 + 100} = 0.3$$

Q = C * I_T * A = 0.3 * 20l/(s*ha) * 0.08ha = 0.48 l/s

V = 3600 * Q * t = 3600s/h * 0.48 l/s * 0.25h = 432 l

3.

A_{red} = C * A = 0.5 * 5000m^2 = 2500 m^2

A_s = 0.1 * A_{red} = 250m^2

$$V_{req} = \left[(A_{red} + A_S) \cdot 10^{-7} \cdot I_T - A_S \cdot 0.5 \cdot k\right] \cdot t \cdot 60 \cdot f_Z$$

$$V_{req} = \left[(2500 + 250) \cdot 10^{-7} \cdot I_T - 250 \cdot 0.5 \cdot 10^{-4}\right] \cdot t \cdot 60 \cdot 1.2$$

5-year storm -> Probability of occurrence = 0.2

$$V_{req}(5\min) = \left[(2500 + 250) \cdot 10^{-7} \cdot 338.9 - 250 \cdot 0.5 \cdot 10^{-4}\right] \cdot 5 \cdot 60 \cdot 1.2 = 28.24m^3$$

$$V_{req}(10\min) = \left[(2500 + 250) \cdot 10^{-7} \cdot 204.6 - 250 \cdot 0.5 \cdot 10^{-4}\right] \cdot 10 \cdot 60 \cdot 1.2 = 30.64m^3$$

$$V_{req}(20\min) = \left[(2500 + 250) \cdot 10^{-7} \cdot 124.0 - 250 \cdot 0.5 \cdot 10^{-4}\right] \cdot 20 \cdot 60 \cdot 1.2 = 30.24m^3$$

-> the required volume is 30.64 m^3.

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The Family Cistern: 3,000 Years of Household Water Collection in Jordan: http://www.hf-fak.uib.no/smi/paj/Waahlin.html

General information on rainwater harvesting (main focus on India): http://www.rainwaterharvesting.org/

Rainwater Harvesting

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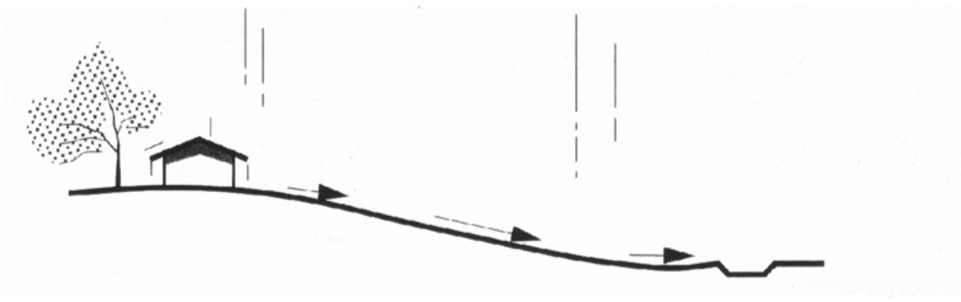
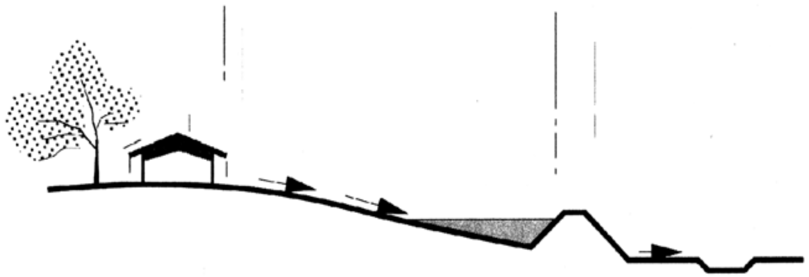
Rainwater Management Options

Conveyance

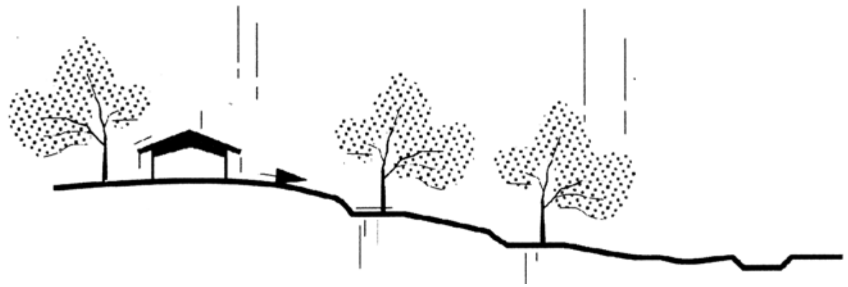


Infiltration

Detention



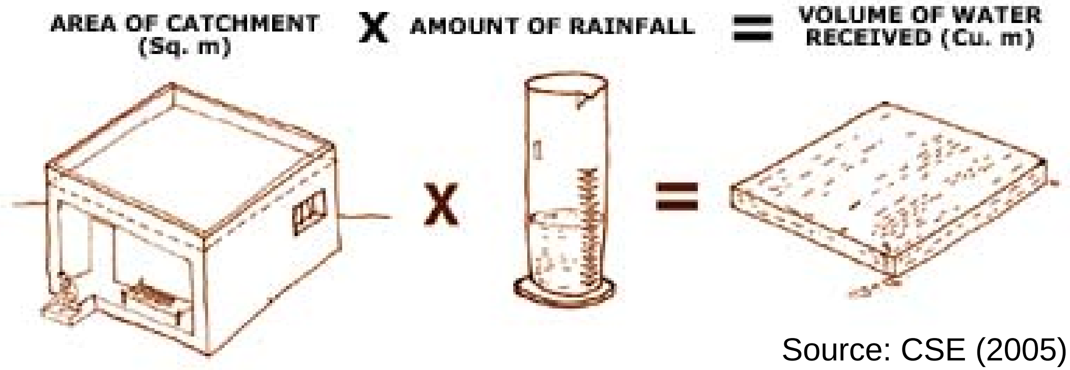
Rainwater Harvesting



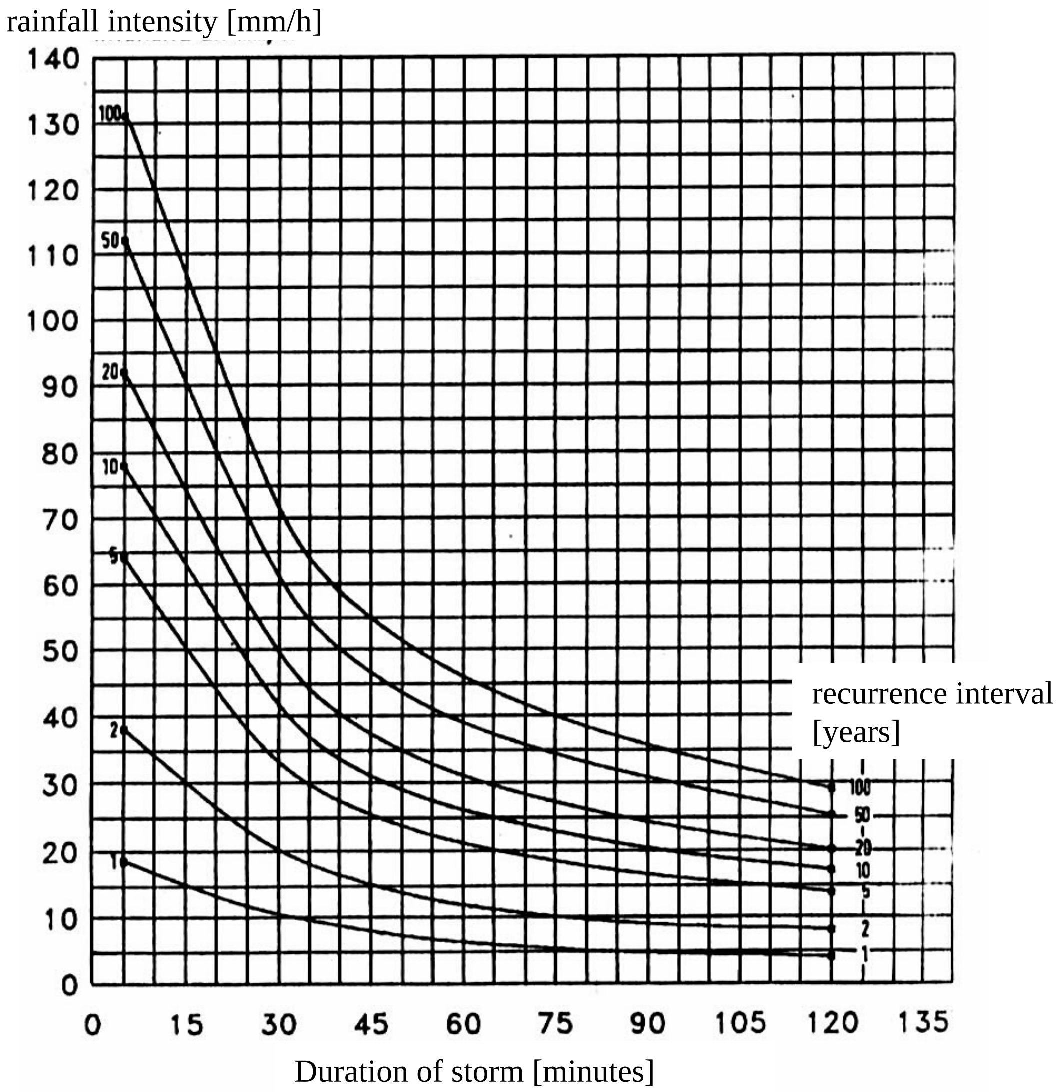
Source: Ferguson, 1998

Overview

- Runoff calculation
- Rainwater Infiltration
- Rainwater Harvesting



Source: CSE (2005)



Data Needs - The Design Storm

Rainfall event characterised by rainfall intensity & duration
-> total volume of rainwater

Recurrence interval for design storm is chosen balancing risks and costs

Example of an intensity-duration-frequency curve

Data Needs - The Design Flow

The total runoff volume is calculated based on:

- design storm
- size of the catchment area
- runoff coefficient: e.g.

Type of surface or land use	Runoff coefficient C
Forest	0.1 - 0.3
Turf or meadow	0.1 - 0.4
Cultivated field	0.2 - 0.4
Bare earth	0.2 - 0.9
Pavement, concrete or asphalt	0.8 - 0.9
Flat residential, about 30% impervious	0.4
Flat residential, about 60% impervious	0.55
Sloping residential, about 50% impervious	0.65
Sloping, built-up, about 70% impervious	0.8
Flat commercial, about 90% impervious	0.8

Runoff coefficients (Source: Ferguson & Debo, 1990)

For flat slopes or permeable soils use the lower values, for steep slopes or impermeable soils use the higher values.

Data Needs - The Design Flow

Runoff can be calculated using following formula:

$Q_T = C * I_T * A$

with:

Q_T: runoff rate for a T-year storm, in liters/second
C: runoff coefficient, nondimensional
I_T: rainfall intensity for a T-year storm at a storm duration t, in liters/(second*hectare)
A: area of the catchment area, in hectares

The cumulative volume of rainwater over the storm duration can be calculated by multiplying the average runoff rate Q by the design storm duration t:

$$V_T = 3600 * Q_T * t$$

with:

V_T: total runoff volume at time t for a T-year storm, in liters
t: storm duration in hours

Rainwater Infiltration

Some advantages of local infiltration:

- recharge of groundwater
- preservation and/or enhancement of natural vegetation
- reduction of pollution transported to the receiving waters
- reduction of downstream flow peaks
- reduction of basement flooding in combined sewer systems
- reduction in the settlement of the surface in areas of groundwater depletion
- smaller storm sewers at a lesser cost

Rainwater Infiltration

Possible drawbacks of local infiltration:

- soils seal with time
- pollutants may be transferred to soil and groundwater
- some infiltration facilities may not receive proper maintenance
- groundwater level may rise and cause basement flooding or damage to building foundations

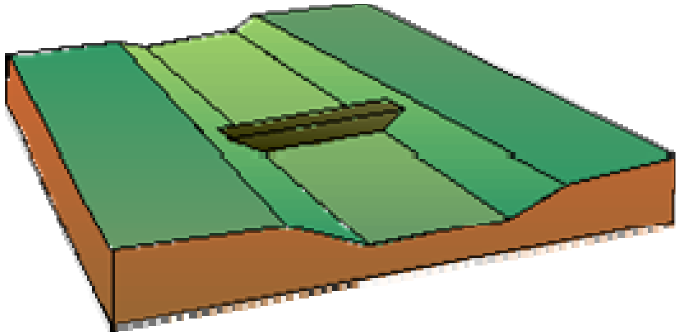
Source: Urbonas & Stahre (1993)

Preconditions for Rainwater Infiltration

- **Vegetative cover**: Rainwater can be absorbed by plant roots and can be returned to the atmosphere through plant respiration. The soil-vegetation complex functions to a certain degree as a filter that reduces clogging of the surface pores of the soil.
- **Soil type and conditions**: Effective porosity and permeability are soil parameters that influence the infiltration process (see slide “infiltration capacity”). Bedrock should not be within less than 1.2 meters of the infiltration surface.
- **Groundwater conditions**: Distance to groundwater and variation in groundwater levels are some of the information needed for planning infiltration facilities. It is recommended that the distance to groundwater is at least 1 meter.

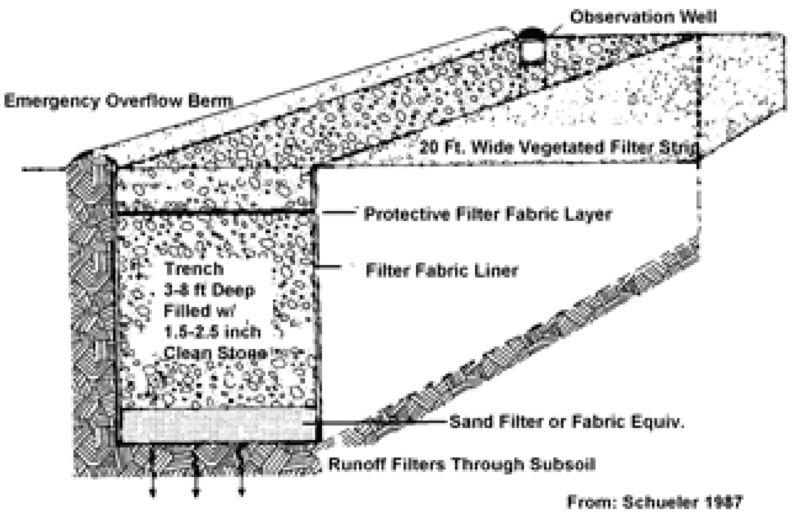
Types of Infiltration Systems - Vegetated Swales

Source: Beecham (2001)



Source: CASQA (2004)

Types of Infiltration Systems - Infiltration Trench



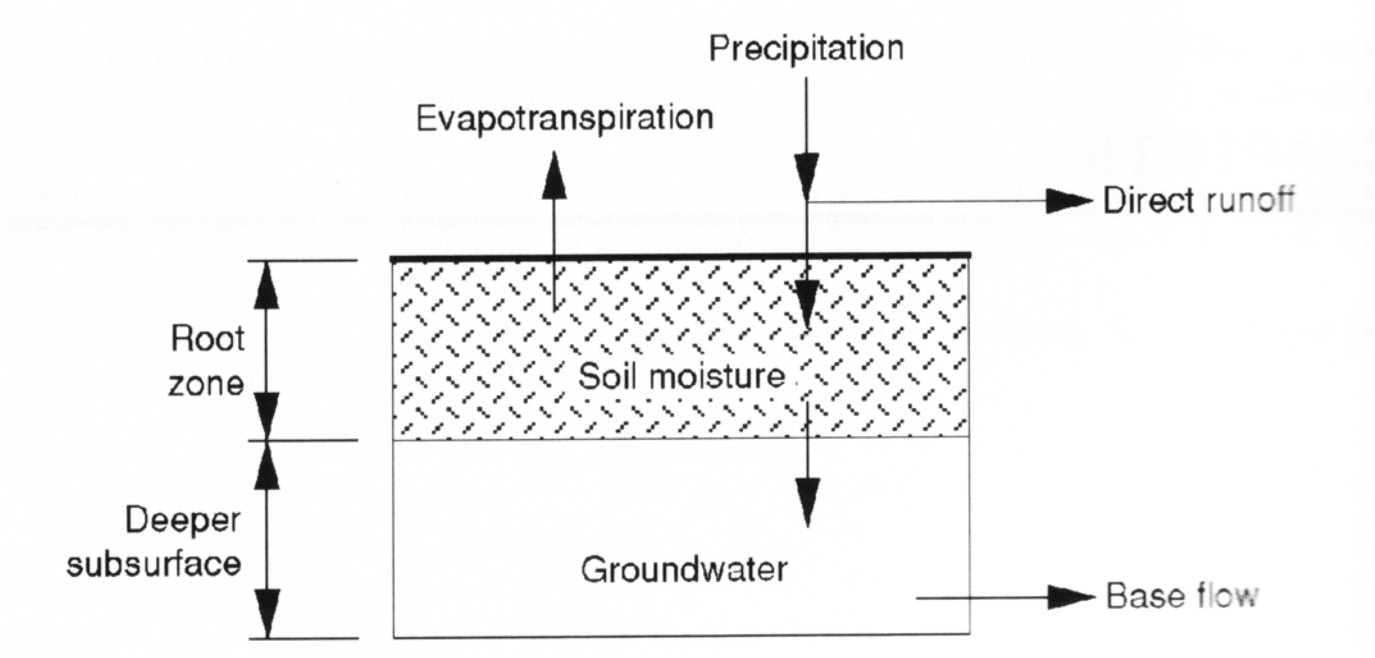
Source: Tanski (2000)

Source: CASQA (2004)

Source: Universität Trier (2004)

Design of Infiltration Systems

Water Balance: Storage = Inflow - Outflow



Source: Ferguson, 1998

Infiltration Capacity

Soil Type	**Hydraulic conductivity k [m/s]**
Gravel	10^{-3} - 10^{-1}
Sand	10^{-5} - 10^{-2}
Silt	10^{-9} - 10^{-5}
Clay (saturated)	$<10^{-9}$

Source: Urbonas & Stahre, (1993)

Darcy's Law: $U = k * I$

with:

U: flow velocity in meters per second

k: hydraulic conductivity in meters per second

I: hydraulic gradient in meters per meter ($\cong$ 1m/m)

Required Storage Volume

e.g. for swales, infiltration ditches etc.:

$$V_{req} = \left(\sum Q_{in} - \sum Q_{out}\right) \cdot t$$

$$V_{req} = \left[\left(A_{red} + A_S\right) \cdot 10^{-7} \cdot I_T - A_S \cdot 0.5 \cdot k\right] \cdot t \cdot 60 \cdot f_Z$$

V_{req}: required storage volume [m³]

A_S: percolation surface area, can be assumed to vary between 0.05 * A_{red} and 0.2 * A_{red} [m²]

A_{red}: reduced catchment area (A_{red} = A * C) [m²]

k: hydraulic conductivity in saturated zone [m/s]

I_T: rainfall intensity for a T-year storm at a storm duration t [l/(s*ha)]

t: duration of the rainfall event [min]

f_Z: safety factor (e.g. 1.2)

Rainwater Harvesting

Comprises many techniques that are used to supply rainwater collected from surfaces (roofs, ground surface, rock surface) for domestic or agricultural use.

Three main components:

- catchment area
- storage reservoir
- delivery system

Rainwater Harvesting

Benefits:

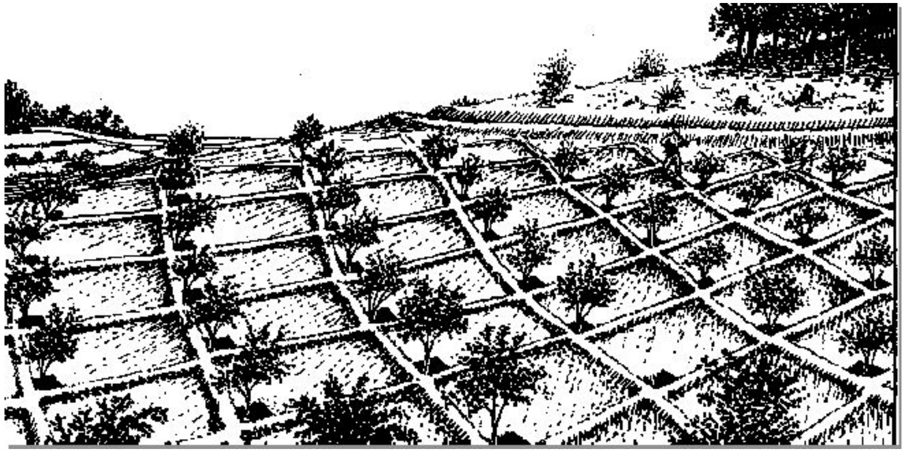
- Provision of inexpensive water, where there is inadequate groundwater supply or surface resources
- Recharge of groundwater
- Control of soil erosion and prevention of flooding

Limitations:

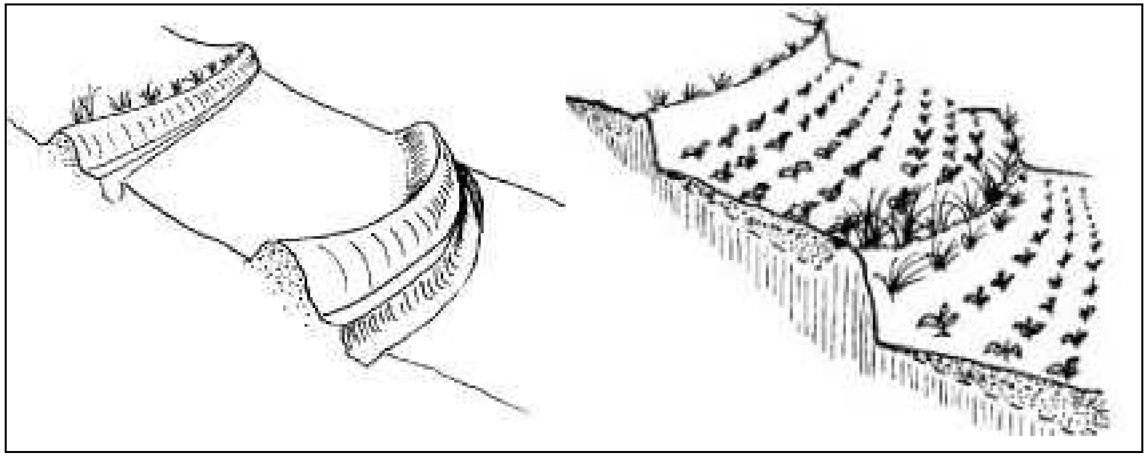
- Large storage tanks may be required
- Seasonal and interannual variations
- Possible pollution of rainwater

Examples of micro-catchment water harvesting

Source: FAO, 1999

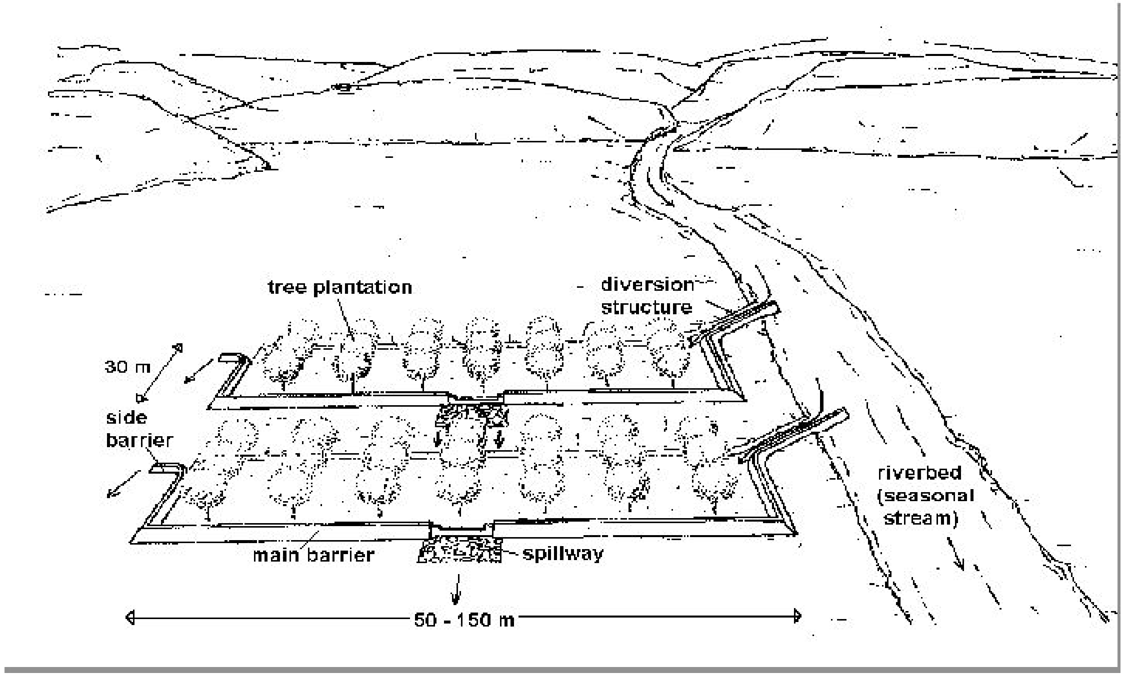


Source: FAO, 1999



Source: IIRR, 1998

Examples of macro-catchment water harvesting

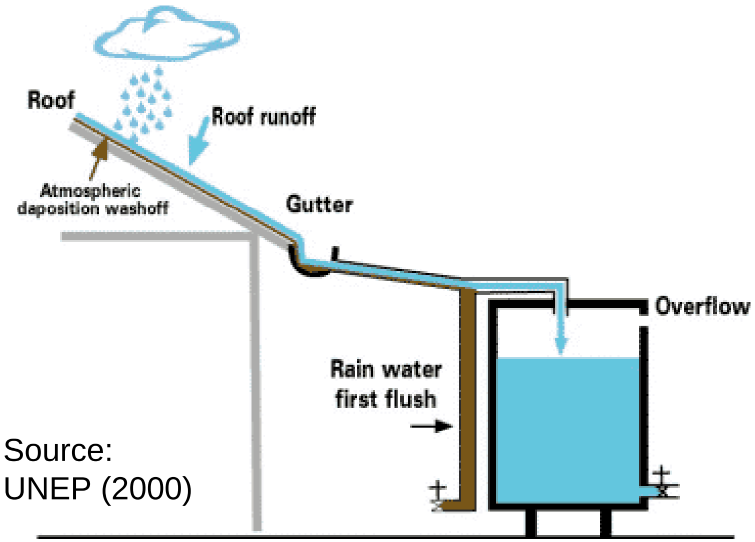


Source: FAO, 1999

Photo: Klemm

Photo: Meinzinger

Rainwater Storage Tanks



Source:
UNEP (2000)

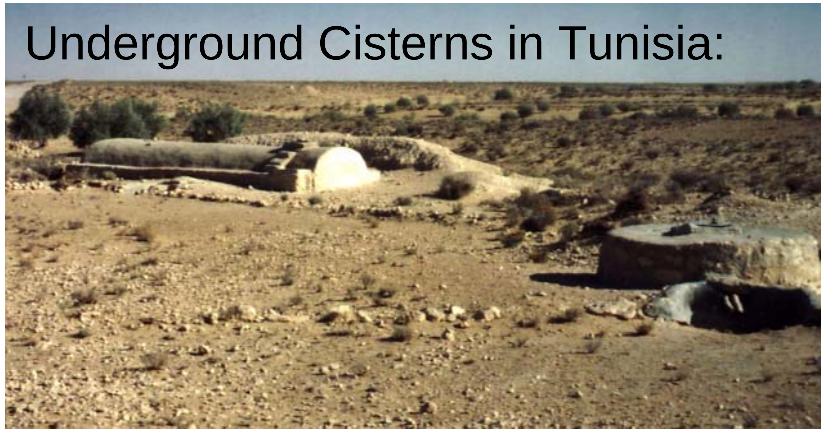
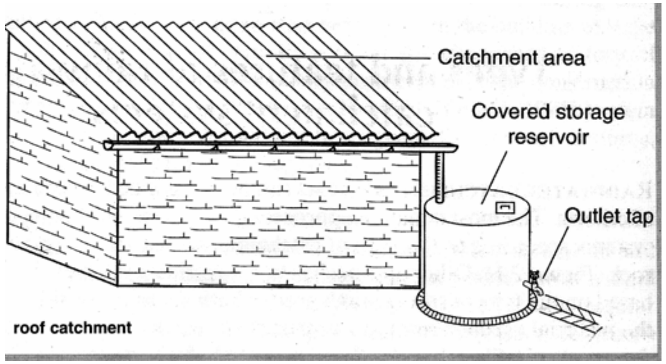


Photo: Meinzinger

Source:Opus One (2000)

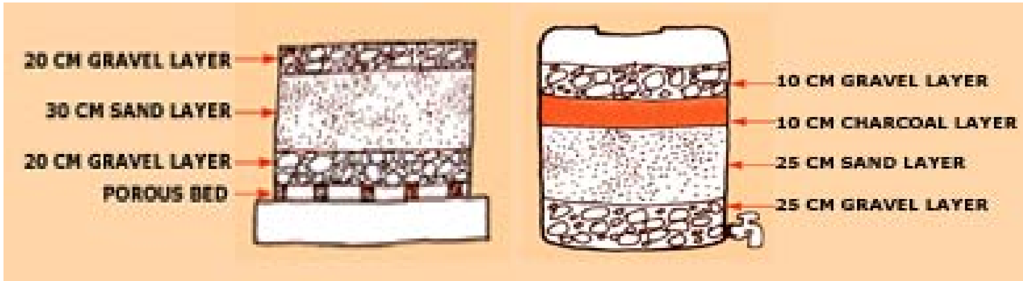
Source:NERD (2005)



Source: Gould & Nissen-Petersen, 1999

Storage Tanks

- Storage tanks should be watertight with a solid, secure cover, a screened inlet, an overflow pipe and a covered manhole
- Filters to remove suspended pollutants (examples):



sandfilter

charcoal filter

WISY Vortex Filter

WISY Floating Suction Filter

Source: CSE (2005)

Calculation of Storage Capacity

<u>Demand side approach:</u>

storage requirement R = C * n * d

with: C: Consumption per capita per day
n: number of people
d: longest average dry period

<u>Supply side approach:</u>

annual available water W = A * C * R

with: A: catchment/roof area
C: runoff coefficient
R: average annual rainfall

Demand D = R as calculated above in the demand side approach

The storage requirement can be derived as maximum difference between the cumulative harvested water and the cumulative demand.

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Lesson B3

Anaerobic sewage treatment

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Anaerobic, sewage, UASB, high rate systems, design, organic polymers

Table of content

Overview and Summary

Today sewage is the largest pollutant on a global scale, as particularly in developing countries, only a small fraction of the sewage produced is treated. Sewage treatment by conventional means, including secondary aerobic biological treatment, is efficient. But this efficiency is at the price of high capital and running cost and technology requirement. Alternatively, anaerobic treatment has been proven to be an admirable process and considered as the core of sustainable waste management. This lesson covers some of the fundamental principles of the anaerobic processes. Then the concept of high rate systems has been introduced and the advantages and drawbacks of applying those systems has been introduced. The application of the Upflow Anaerobic Sludge Blanket (UASB) reactor in tropical and low and moderate temperature countries has been presented. The key issues and approaches of UASB reactor design including guidelines for the design of the physical components of the reactor are discussed, in addition to a design example.

1. Introduction

1.1 Definition of anaerobic process

The fermentation process in which organic material is degraded and biogas (composed of mainly methane and carbon dioxide) is produced, is referred to as anaerobic digestion. Anaerobic digestion processes occur in many places where organic material is available and redox potential is low (zero oxygen). This is typically the case in stomachs of ruminants, in marshes, sediments of lakes and ditches, municipal land fills, or even municipal sewers.

The anaerobic ecosystem is the result of complex interactions among microorganisms of several different species. The major groupings of bacteria and reaction they mediate are:

- fermentative bacteria
- hydrogen-producing acetogenic bacteria
- hydrogen-consuming acetogenic bacteria
- carbon dioxide-reducing methanogens
- aceticlastic methanogens.

The reactions they mediate are presented in figure 2 and discussed in the following sections.

1.2 Anaerobic degradation of organic polymers

Most of the substrate in the complex wastewaters is present as particulate matter, e.g 45 – 75% of domestic sewage, and 80% in primary sludge. The main biopolymers in sewage are proteins, carbohydrates and lipids. The anaerobic degradation pathway of organic matter is a multi step process of series and parallel reactions. This process of organic matter degradation proceeds in four successive stages, namely (1) Hydrrolysis, (2) Acidogenesis, (3) Acetogenesis and (4) Methanogenesis. The processes are discussed below (see figure 1).

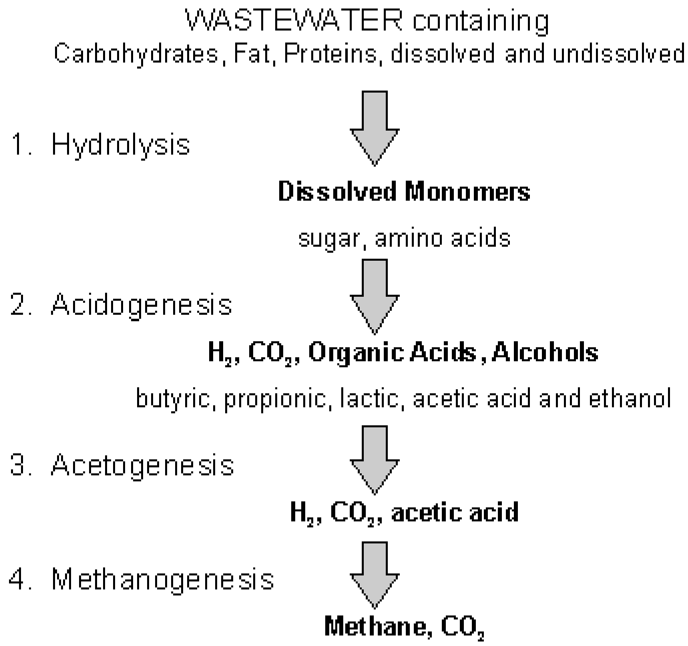


Figure 1: Anaerobic Microbiology

1.2.1 Hydrolysis

Since bacteria are unable to take up particulate organic matter, the first step in anaerobic degradation consists of the hydrolysis of polymers through the action of exo-enzymes to produce smaller molecules which can cross the cell barrier. During the enzymatic hydrolysis process, proteins are hydrolyzed to amino acids, polysaccharide to simple sugars and lipids to long chain fatty acids (LCFA). Hydrolysis is in most cases, notably with sewage as substrate, rate-limiting for the overall process of anaerobic degradation of organic matter and is very sensitive to temperature. For that reason, design of the anaerobic reactors for sewage treatment is usually based on the hydrolysis step.

1.2.2 Acidogenesis

During the acidogenesis, the hydrolysis products which are relatively small, soluble compounds are diffused inside the bacterial cells through the cell membrane and then are either fermented or anaerobically oxidized. These processes occur by a complex consortium of hydrolytic and non-hydrolytic microorganisms which are the source of energy for the acidifying population. The acidification products consist of a variety of small organic compounds, mainly so-called volatile fatty acids (VFA's) (acetate and higher organic acids (like propionate and butyrate), H_2, CO_2, some lactic acids, ethanol and ammonia (see figure 2). Given that VFA's are the main end products, fermentative organisms are usually designated as acidifying or acidogenic microorganisms.

1.2.3 Acetogenesis

The short chain-fatty acids, other than acetate, that are produced in the acidogenesis step are further converted to acetate, hydrogen gas and carbon dioxide by the acetogenic bacteria. β-oxidation is the mechanism of anaerobic oxidation of long chain fatty acids with as products hydrogen and acetate. The available H_2 and CO_2 is partly converted into acetate by the homoacetogenic bacteria. Both propionate and butyrate are important intermediates in anaerobic digestion, and then are converted by the hydrogen producing acetogenic bacteria into acetate and hydrogen (see table 1).

Table 1: Some acetogenic reactions (propionate and butyrate degradation) and the corresponding free energy change ($\Delta G^{o\prime}$)

Reactions	$\Delta G^{o\prime}$ (KJ/mole)
$CH_3\text{-}CH_2\text{-} COO^- + 3H_2O \rightarrow CH_3COO^- + HCO_3^- + 2H^+ + 2H_2$	+ 76.1
$CH_3\text{-}CH_2\text{-}CH_2\text{-}COO^- + 2H_2O \rightarrow 2\ CH_3COO^- + 2H^+ + 2H_2$	+ 48.1

The acetogenic bacteria are obligate hydrogen producers and their metabolism is inhibited by hydrogen. Studies carried out with these bacteria have shown the narrow association between the H_2-producing acetogenic bacteria and the H_2-consuming methanogenic bacteria, thereby regulating the H_2 level in their environment. This is of vital importance as these reactions are thermodynamically unfavorable (positive $\Delta G°'$) unless the hydrogen partial pressure is maintained at an extremely low pressure. Methanogenic bacteria utilize molecular hydrogen in the usual anaerobic digester so rapidly that the hydrogen partial pressure can be kept as low as 10^{-4} atm which is enough to ensure the active performance of the hydrogen producing acetogenic bacteria. This means that the degradation of higher fatty acids depends largely on the activity of methanogenic bacteria. Microbial association in which a H_2-producing organism can grow only in the presence of H_2-consuming organism are called syntrophic association. The coupling of formation and use of H_2 is called interspecies hydrogen transfer (HTS).

1.2.4 Methanogenesis

During the fourth and last stage of anaerobic degradation of organic matter, a group of methanogenic bacteria both reduce the carbon dioxide by hydrogen and decarboxylate acetate to form methane (CH_4) (figure 2). The methanogenic bacteria are obligate anaerobes, able to utilize only certain determined substrates. They use organic substrate or specific carbon source such as acetate, H_2 and formate. Some strains are autotrophic, using only CO_2 or CO as carbon source. Generally, 70 - 80 % of the methane formed from the organic materials originates from acetate. The rest is mainly derived from H_2 and CO_2.

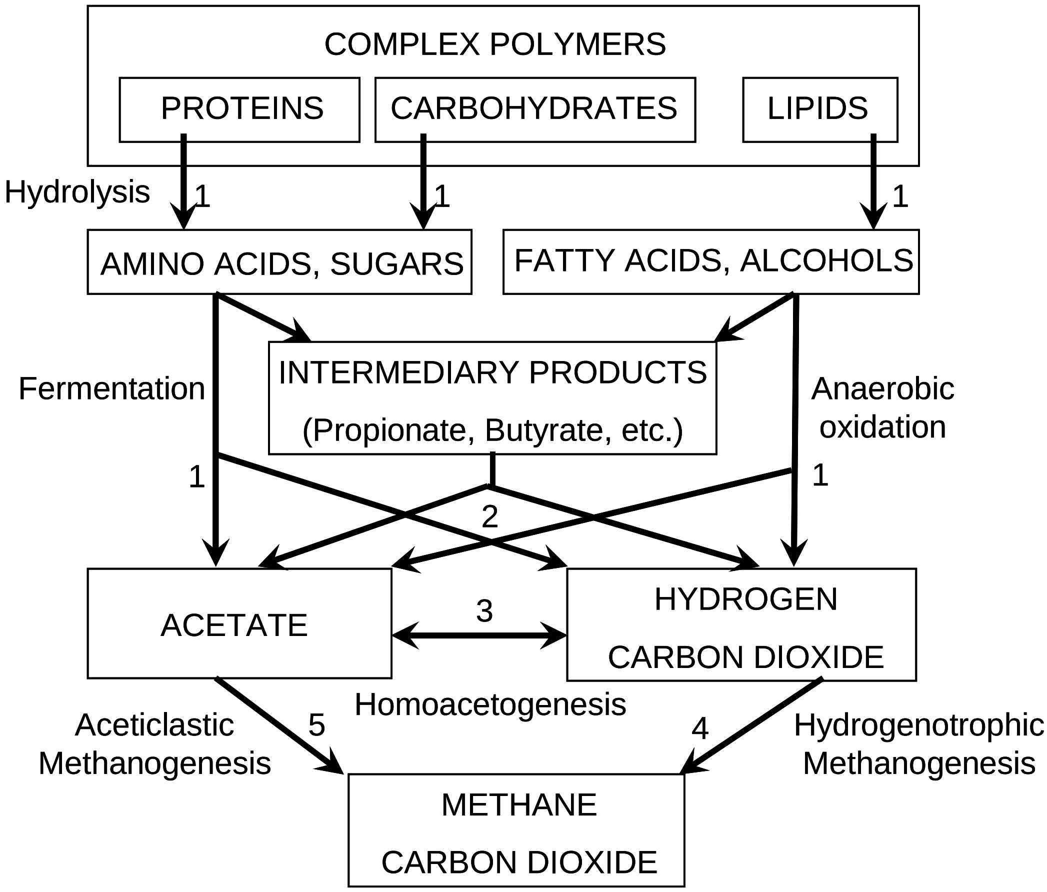


Figure 2: Reactive scheme for the anaerobic digestion of polymeric materials. Numbers indicate the bacterial groups involved, see sec. 1.1

2. Anaerobic Treatment technology

2.1 High rate systems

One of the major successes in the development of anaerobic wastewater treatment was the introduction of high-rate reactors in which biomass retention and liquid retention are uncoupled. The anaerobic high–rate systems enables the application of a relatively high loading rate, while maintaining long SRT at relatively short HRT due to sludge immobilisation. The main advantages and drawbacks of the anaerobic high rate systems applied for sewage treatment are shown in Table 2. In these systems, wastewater flows through the anaerobic sludge where purification takes place through complex bio - physical - chemical interrelated processes. Organic matter is converted into biogas and sludge.

Table 2: Advantages and drawbacks of anaerobic sewage treatment in anaerobic high rate systems

Advantages	Drawbacks
A substantial saving in operational costs as no energy is required for aeration; on the contrary energy is produced in the form of methane gas, which can be utilized for heating or electricity production. The process can handle high hydraulic and organic loading rates. Thus, the applied technologies are compact. The technologies are simple in construction and operation; so they are low cost. The systems can be applied everywhere and at any scale as little if any energy is required, enabling a decentralized application. The excess sludge production is low, well stabilized and easily dewatered so does not require extensive costly post treatment. The valuable nutrients (N and P) are conserved which give high potential for crop irrigation.	Need for post treatment, depending on the requirements for effluent standards. No experience with full-scale application at low/moderate temperatures. Considerable amount of produced biogas, i.e. CH_4 and H_2S remains in the effluent especially for low strength wastewater (sewage). Produced CH_4 during anaerobic sewage treatment is often not utilised for energy production.

Different high–rate systems were developed over the last three decades including the anaerobic filter, the upflow anaerobic sludge blanket (UASB), the fluidised and expanded bed reactors and the baffled reactors.

2.1 Upflow anaerobic sludge blanket (UASB) reactor

The UASB reactor is the most widely and successfully used high rate anaerobic technology for treating several types of wastewater. The success of the UASB reactor can be attributed to its capability to retain a high concentration of sludge and efficient solids, liquid and water phase separation. The UASB reactor consists of a circular or rectangular tank in which waste (water or sludge) flows in upward direction through an activated anaerobic sludge bed which occupies about half the volume of the reactor and consists of highly settleable granules or flocs. During the passage of this blanket the purification takes place by solids removal and then organic matter is converted into biogas and sludge. The produced biogas bubbles transfer to the top of the reactor, carrying water and solid particles (i.e. biological sludge and residual solids). These bubbles strike the degassing baffles at the upper part of the reactor, leading to an efficient gas - Solid separation (GSS). The solid particles drop back to the top of sludge blanket, while the released gases are captured in an inverted cone (GSS) located at the top of the reactor. Water passes through the apertures between the degassing baffles carrying some solid particle which settle there due to increase of the cross sectional area and return back to the sludge blanket, while water leaves the settlers over overflow weirs. A schematic diagram of the UASB reactor is shown in figure 3.

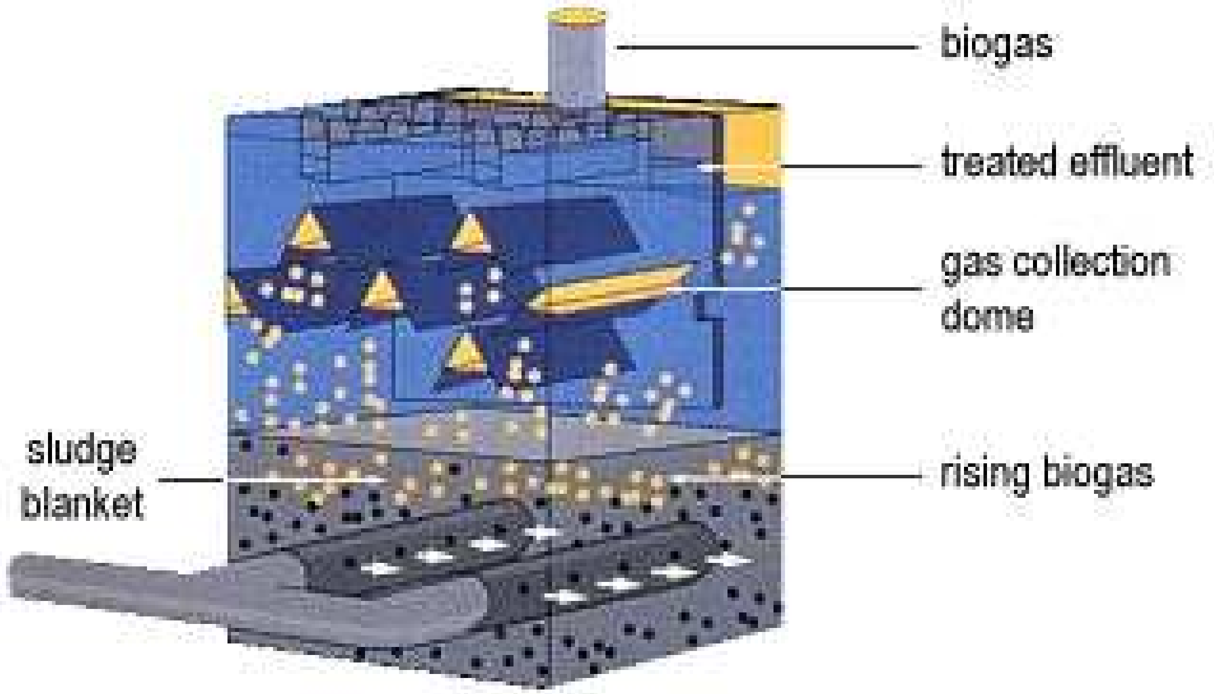


Figure 3: Schematic diagram of the UASB reactor

2.1.1 Application of the UASB Reactor in tropical countries

The experience with the applicability of the UASB reactor for sewage treatment in tropical countries started by the pilot plant constructed in Cali-Columbia during the period 1982–1983. The results obtained from the operation of the Cali plant showed the feasibility of the system under the prevailing environmental and sewage characteristics. After that, hundreds of UASB reactors for treatment of sewage at both full scale and pilot scale (Table 3 & 5) have been operational in several tropical countries like India, Columbia, Brazil and Mexico. The ambient temperature in these countries is rather high throughout the year (20-35 °C) and the wastewater strength is rather low.

2.1.2 Application of the UASB Reactor at moderate and low temperature

The application of the UASB reactor for sewage treatment is surely not limited to countries of hot climate. The results of several researches on bench scale and pilot scale systems operated at low temperatures have opened new perspectives (Table 4& 5) but no full-scale application has so far been realised.

Table 3: Results of anaerobic raw sewage treatment in pilot-scale UASB reactors under tropical conditions (≥20 °C) (from Mahmoud, 2002)

Volume	Temp	HRT	Influent CODt	% Removal		Reference
Liter	°C	(hr)	(mg/l)	CODt$	SS$$	
106	20-23	4	424	60	69	Vieira and Souza (1986)
120	20	18	550	55-75	-	Lettinga *et al.* (1980)
118	20	8	500	75a	-	Grin *et al.* (1983)
160	20	6	1076	64	88	Mergaert *et al.* (1992)
106	21-25	4.7	265	50	73	Vieira (1988)
106	35	4	300	65	61	Vieira (1988)

Table 4: Results of sewage treatment in pilot-scale UASB reactors at low temperature (≤20 °C) (from Mahmoud, 2002)

Volume	Temp	HRT	Influent CODt	% Removal		Reference
Liter	°C	(hr)	(mg/l)	CODt$	SS(CODss)$	
120	7-8	9-14	464-700	57	72	Man *et al.* (1986)
110	12-18	18	465	65	(73)	Monroy *et al.* (1988)
120	12-20	7-8	190-1180	30-75	60	Man *et al.* (1988)

Table 5: Some case studies from existing UASB plants with influent and effluent characteristics in different countries

Country	Volume	Temperature	HRT	Influent COD	Effluent COD$	% Removal
	m^3	°C	(hr)	(mg/L)	(mg/L)	COD
Colombia	64	24-26	4-6	267	110	65
Colombia	6600	25	5.2	380	150	60-80
Brazil	120	23	4.7-9	315-265	145	50-70
Brazil	67.5	23	7	402	130	74
Brazil	810	30	9.7	563	185	67
India	1200	20-30	6	563	146	74
Jordan	60	25	23-27	1600	600	62
Jordan	60	18	23-27	1400	700	51

$Calculated from the influent COD and removal efficiency

2.1.3 Design considerations of the UASB reactor

2.1.3.1 Retention time and temperature

The design and performance of an anaerobic reactor strongly depends on the solids retention time, operational temperature, and the biodegradability and concentration of the entrapped solids, which are interrelated parameters. Domestic sewage is a complex type of wastewater, characterised by a high fraction suspended solids and mostly of relatively low temperatures. The hydrolysis of retained particles is in general considered as the rate-limiting step of the overall digestion process and is highly influenced by process temperature and solids retention time. When using UASB reactors, the SRT should be long enough to provide methanogenic conditions as illustrated in Table 6. The reduction in operational temperature does not only retards the hydrolysis step but also leads to a significant decrease in the maximum growth and substrate utilisation rates.

Table 6: Hydraulic retention time *(HRT, in days) to be applied, to achieve the indicated SRT (days) assuming 50% or 75% CODss removal at the treatment of domestic wastewater with a concentration of 1 g COD/l of which 65% is suspended, at different % hydrolysis and sludge concentration in the UASB reactor of 15 g VSS/l (see sec. 3)*

% CODss removal	% Hydrolysis of removed SS	SRT				
		25	50	75	100	150
50	25	0.28	0.56	0.84	1.12	1.68
75	25	0.42	0.84	1.26	1.68	2.52
50	50	0.19	0.38	0.57	0.76	1.14
75	50	0.28	0.56	0.84	1.12	1.68
50	75	0.09	0.18	0.27	0.36	0.54
75	75	0.14	0.28	0.42	0.56	0.84

2.1.3.2 Organic loading rate and upflow velocity

A part from the calculation model proposed by Zeeman and Lettinga (1999) (see Table 6), the volume of the UASB reactor can be determined based on organic loading and upflow velocity. The reactor volume based on acceptable organic loading rate (OLR) is given by:

$$V = \frac{QxC}{OLR} \quad \textbf{(1)}$$

with:
V: volume of the reactor, m^3
Q: influent flow rate, m^3/d
C: influent COD, kg COD/m^3
OLR: acceptable organic loading rate, kg COD/m^3.d

The acceptable organic loading rate depends largely on the biodegradability of sewage, on the operational temperature and the average sludge retention time (See table 6). For design purposes OLR given in Tables 3 and 4 can be used for preliminary dimensioning of the UASB reactor under different sewage and environmental conditions. In addition to reactor sizing based on OLR, the upflow velocity (equation 2) should be less than the admissible upflow velocity (Table 6).

$$V_{up} = \frac{H}{HRT} \quad \textbf{(2)}$$

with:
Vup: upflow velocity, m/hr
H: reactor height, m
HRT: Hydraulic retention time, hr

2.1.3.3 Physical components

The major physical components of a UASB reactor that require careful consideration are the feed inlet distribution, outlet and gas collector. Some important design criteria of UASB reactors treating sewage are presented in Table 7. The required good contact between influent wastewater and sludge is achieved by the even feed distribution at the bottom of the reactor, the turbulence brought about by the natural biogas production and high upward velocity. The in-built Gas Solids Separator (GSS) installed at the top of the reactor takes care of separation/collection of the biogas. A number of important guidelines regarding the design of the GSS are given in Table 8.

Table 7: Some design criteria of UASB reactors treating sewage (see fig. 2)

Min. average HRT	4 hrs
height	4-5 m
Feed inlet points	1 inlet per 1 to 4 m^2
Feed distribution	Each inlet pipe from a separate compartment
Static pressure in feed inlet box	Up to 50 cm
Upflow velocity in aperture	Average daily 4 m/hr During 2-4 hrs 8 m/hr
Upflow velocity	0.5 m/hr

Table 8: Summary of tentative guidelines for the design of the gas-solids-separator device

- The slope of the settler bottom (i.e. the inclined wall of the gas collector) should be between 45-60 °.
- The surface area of the apertures between the gas collectors should be 15-20% of the reactor surface area.
- The height of the gas collector should be between 1.5-2 m at reactor heights of 5-7 m.
- To facilitate the release and collection of gas bubbles and to combat scum layer formation, a liquid-gas interface should be maintained in the gas collector.
- To avoid up-flowing gas bubbles to enter the settler compartment, the overlap of the baffles installed beneath the apertures should be 10-20 cm.
- Generally, scum layer baffles should be installed in front of the effluent weirs.
- The diameter of the gas exhaust pipes should be sufficient to guarantee the easy removal of the biogas from the gas collection cap, particularly in case of foaming.
- In the upper part of the gas cap, anti-foam spray nozzles should be installed in the case the treatment of the waste water is accompanied with heavy foaming.

Adapted from Lettinga and Hulshoff Pol (1991)

2.1.4 UASB reactor design for sewage treatment: design example

The final removal efficiency and conversion of organic compounds to methane gas in UASB reactors depend on both physical and biological processes. For sewage, removal of suspended solids occurs by physical processes like settling, adsorption and entrapment. The subsequent hydrolysis and methanogensesis of the removed solids depends on the process temperature and the prevailing SRT. Zeeman and Lettinga (1999) developed a model for the calculation of the HRT when a certain SRT is a pre-requisite, and this model can be used for preliminary sizing of a UASB reactor. The SRT is determined by the amount of sludge that can be retained in the reactor and the daily excess sludge production. The daily excess sludge production is determined by the biomass yield and the removal and conversion of suspended solids. At a certain temperature the SRT will determine whether methanogenesis will occur or not. So when the required SRT is known, the corresponding HRT can be calculated provided that the sludge concentration in the reactor (X), the fraction of the influent SS that is removed (R) and the fraction of the removed SS that is hydrolysed (H) are known. The HRT of a UASB reactor can be calculated with the following formulas:

SRT = X/Xp **(3)**

X: sludge concentration in the reactor (kg COD/m^3); 1 g VSS = 1.4 g COD
Xp: sludge production (kg COD/m^3.d)

Xp = O*SS*R*(1-H) **(4)**

O: organic loading rate (kg COD/m^3.d); SS = CODss / CODinfluent;
CODss: suspended COD
R: fraction of CODss removed

HRT = C/O (days) **(5)**

C: COD concentration in the influent (g COD/l)

HRT = (C *SS/X)*R*(1-H)*SRT **(6)**

SRT: sludge retention time (days)
H: fraction of removed solids that are hydrolysed

The previous model was used for the calculation of the required HRT for the application of a UASB reactor for sewage treatment Shams City where sewage temperature is 15 ºC. The total COD of the domestic sewage produced from Shams City is 1600 mg/L, of which 60% is in the suspended form (particle size bigger than 4.4 μm). Calculate the required HRT of a UASB reactor to treat this sewage.

The following input data were taken into consideration:
R = 0.8; around 85% of total suspended solids (TSS) removal efficiency can be achieved in a UASB reactor at an upflow velocity (Vup) of 0.6 m/hr.

SRT = 30 days; expected minimum SRT to achieve methanogenic conditions during winter time (data should be obtained fro literature or from available local data). At these conditions:

H = 0.15; 15% of the TSS can be hydrolysed.
X = 15 g VSS/l = 21 g COD/l
SS= 0.60
C = 1.600 g COD/l

Accordingly, the model calculation reveals that a HRT of 22 hour is required.

3. Comparison of anaerobic and aerobic treatment

In the wastewater engineering field organic pollution is measured by the weight of oxygen it takes to oxidize it chemically, referred to as the "chemical oxygen demand" (COD). COD is basically a measure of organic matter content or concentration. The best way to appreciate anaerobic wastewater treatment is to compare its COD balance with that of aerobic wastewater treatment, as shown in figure 4 below.

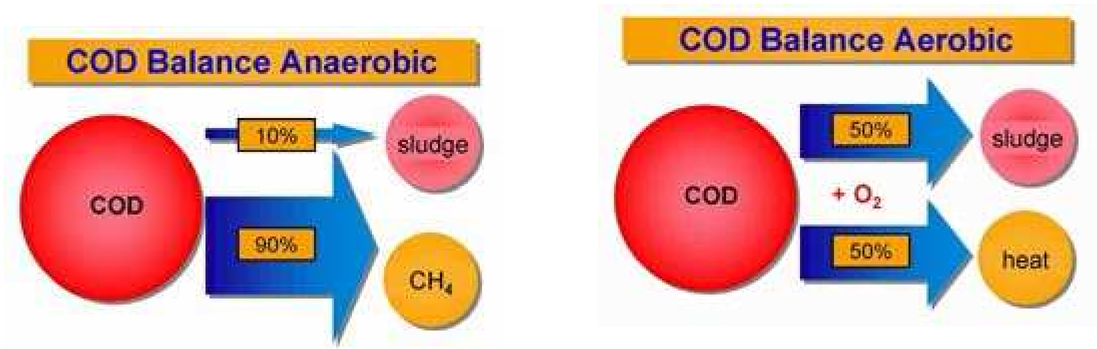


Figure 4. Comparison of the COD balance during anaerobic and aerobic treatment of wastewater containing organic pollution

The COD in wastewater during anaerobic treatment is highly converted to methane, which is a valuable fuel. Very little COD is converted to sludge. No major inputs are required to operate the system. Nevertheless it depends on stable preconditions as i.e. temperature to make the process stable.

The COD in wastewater during aerobic treatment is highly converted sludge, a bulky waste product, which costs lots of money to get rid of in developed countries with less area, but can be of interest as low-cost fertilizer in developing countries if the sludge is not contaminated. Elemental oxygen has to be continuously supplied by aerating the wastewater. The process itself can be more stable.

4. References

Lettinga, G. and Hulshoff Pol, L.W. (1991) UASB process design for various types of wastewater. *Water Sci. Technol.* 24(8), 87-107.

Mahmoud, N., 2002. Anaerobic pre-treatment of sewage under low temperature (15 °C) conditions in an integrated UASB-digester system PhD thesis, Department of Environmental Technology, Wageningen University, Wageningen, The Netherlands.

Zeeman, G., Lettinga, G., 1999. The role of anaerobic digestion in closing the water and nutrient cycle at community level. *Water Sci.Technol*., 39 (5), 187-194.

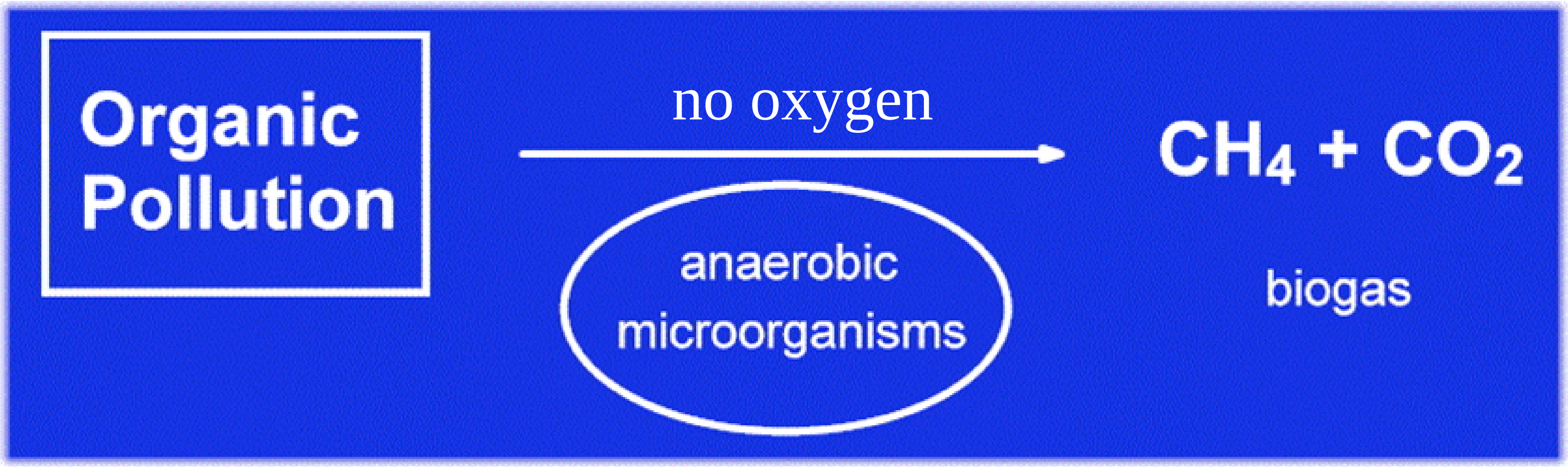
5. Links

- Anaerobic Granular Sludge Bed Technology Pages www.UASB.org
- Comparison of high-rate anaerobic wastewater treatment reactors: http://www.cepis.ops-oms.org/muwww/fulltext/repind54/anadow/anadow.html

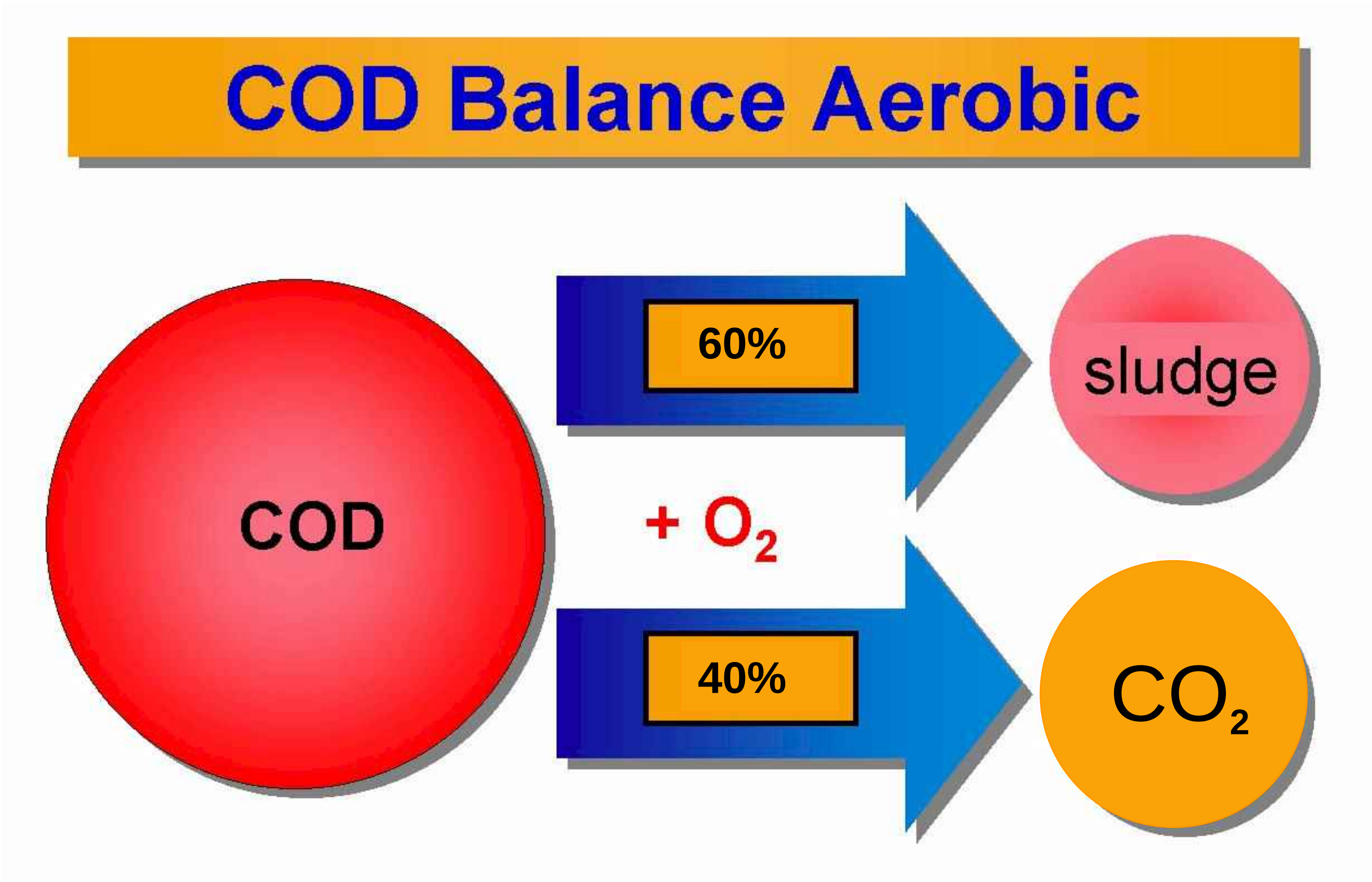
Treatment of Municipal Wastewater in Upflow Anaerobic Sludge Blanket (UASB) Reactor

Dr. Tarek Elmitvalli

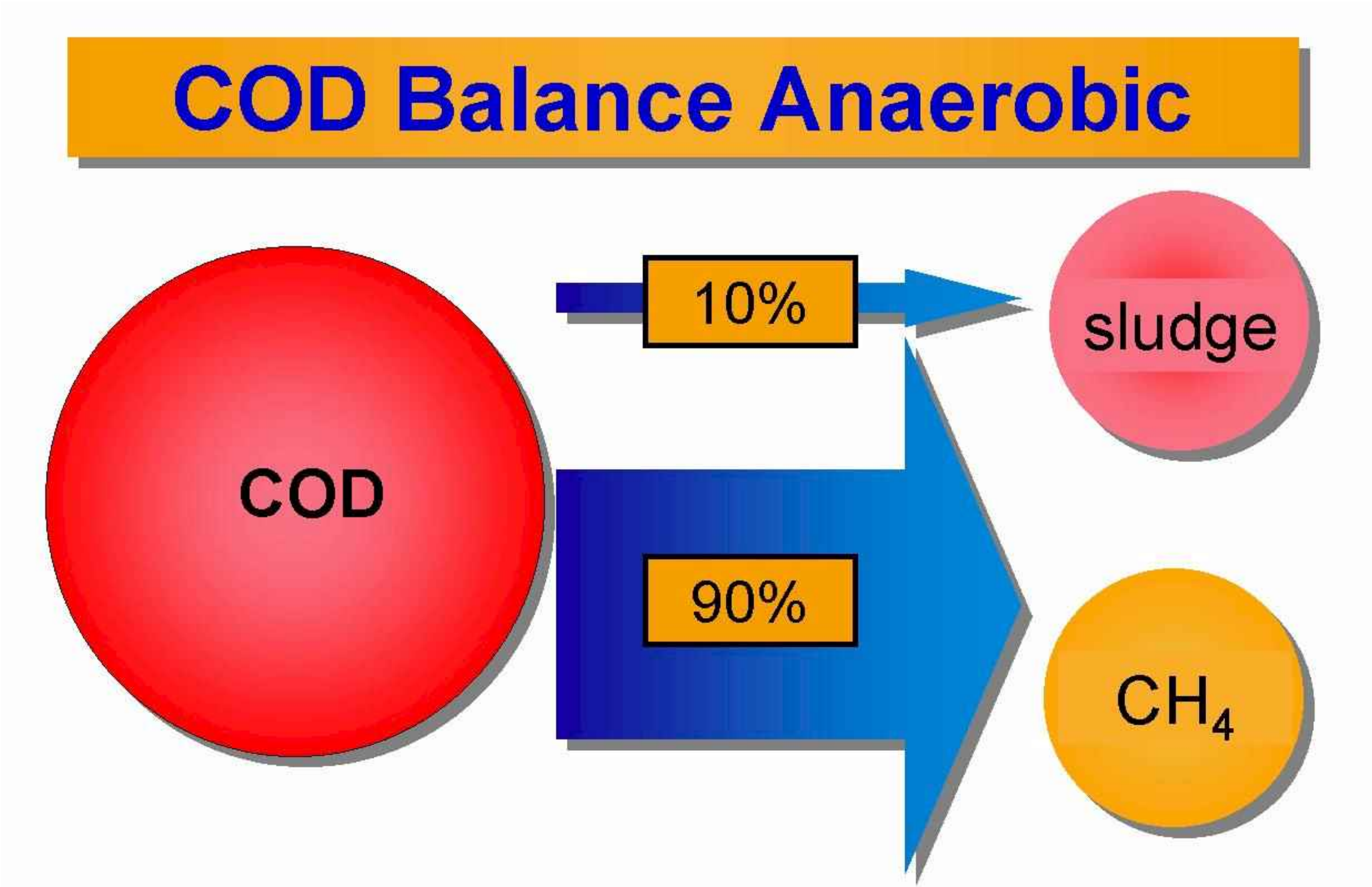
What is Anaerobic Biodegradation?



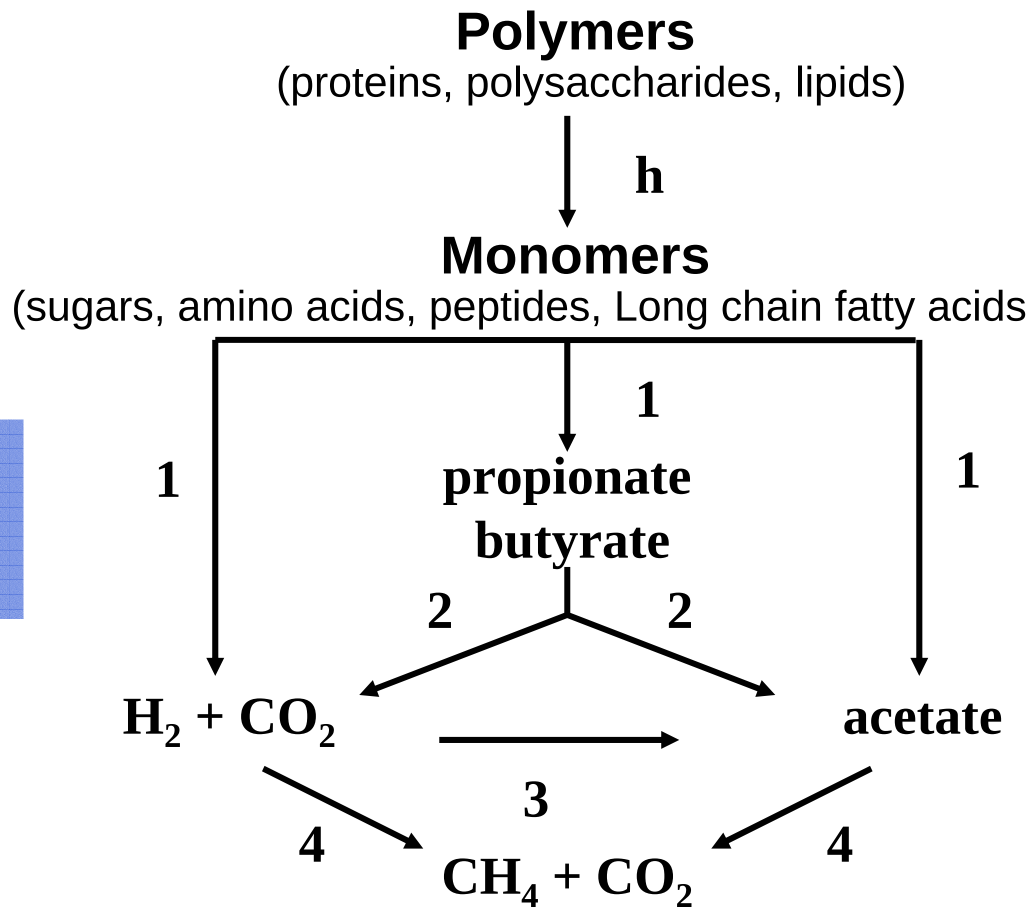
COD Balance Aerobic Biodegradation



COD Balance Anaerobic Biodegradation



Overview Anaerobic Biodegradation



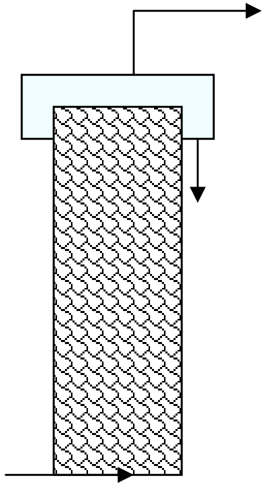
Methanogenic Consortium

h Hydrolytic enzymes
1 Fermentative bacteria
2 Syntrophic acetogenic bacteria
3 Homoacetogenic bacteria
4 Methanogens

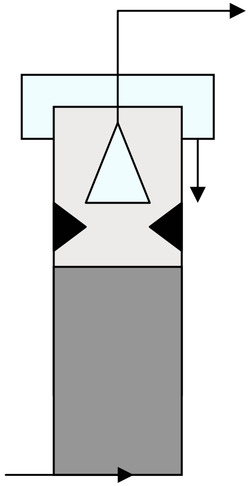
The benefits and drawbacks of anaerobic treatment of municipal wastewater in the high-rate anaerobic systems.

Benefits	Draw backs
1. Efficient in the removal of organic material especially for tropical regions (developing countries).	1. Long start-up period when seed sludge is not available, as the growth rate of methanogenic microorganisms is low.
2. Low construction cost and small land requirements as generally at temperatures >20^{o}C high loading rates can be applied.	2. Low pathogen removal.
3. Low operation and maintenance costs, as energy consumption is low and little equipment is needed.	3. Requirement for post treatment to reach the effluent standards, depending on the requirements for effluent standards.
4. Lower sludge production as compared to aerobic and physical-chemical treatment processes.	4. Low removal efficiency of particulate organic material at low temperatures.
5. Biogas production, which can be used for energy production.	5. Risk for odour nuisance from the reduction of sulphate to sulphide.

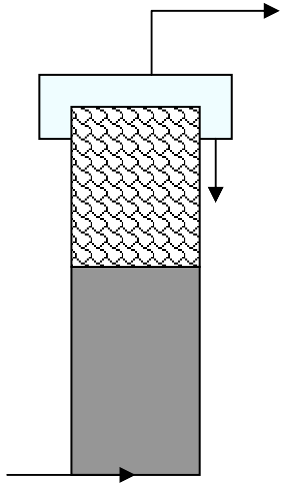
High-rate anaerobic systems



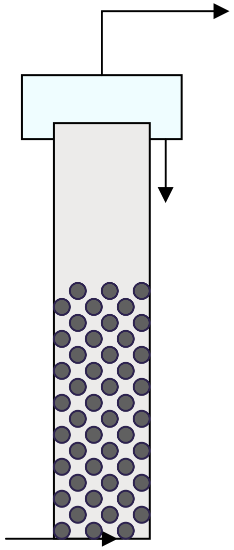
Upflow anaerobic filter (AF)



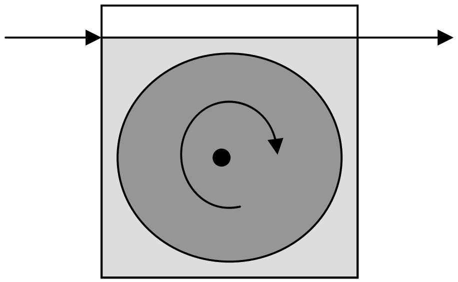
UASB reactor



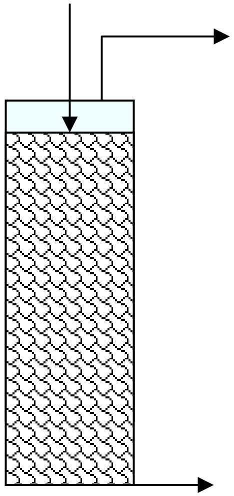
Anaerobic hybrid (AH) reactor



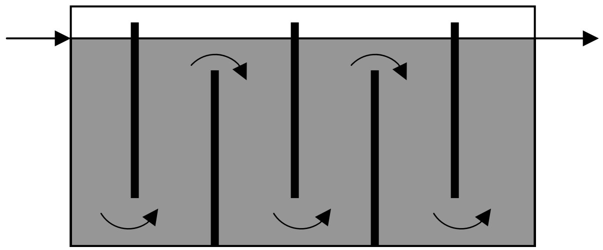
Anaerobic fluidised bed (AFB) reactor



Anaerobic rotating biological contactor

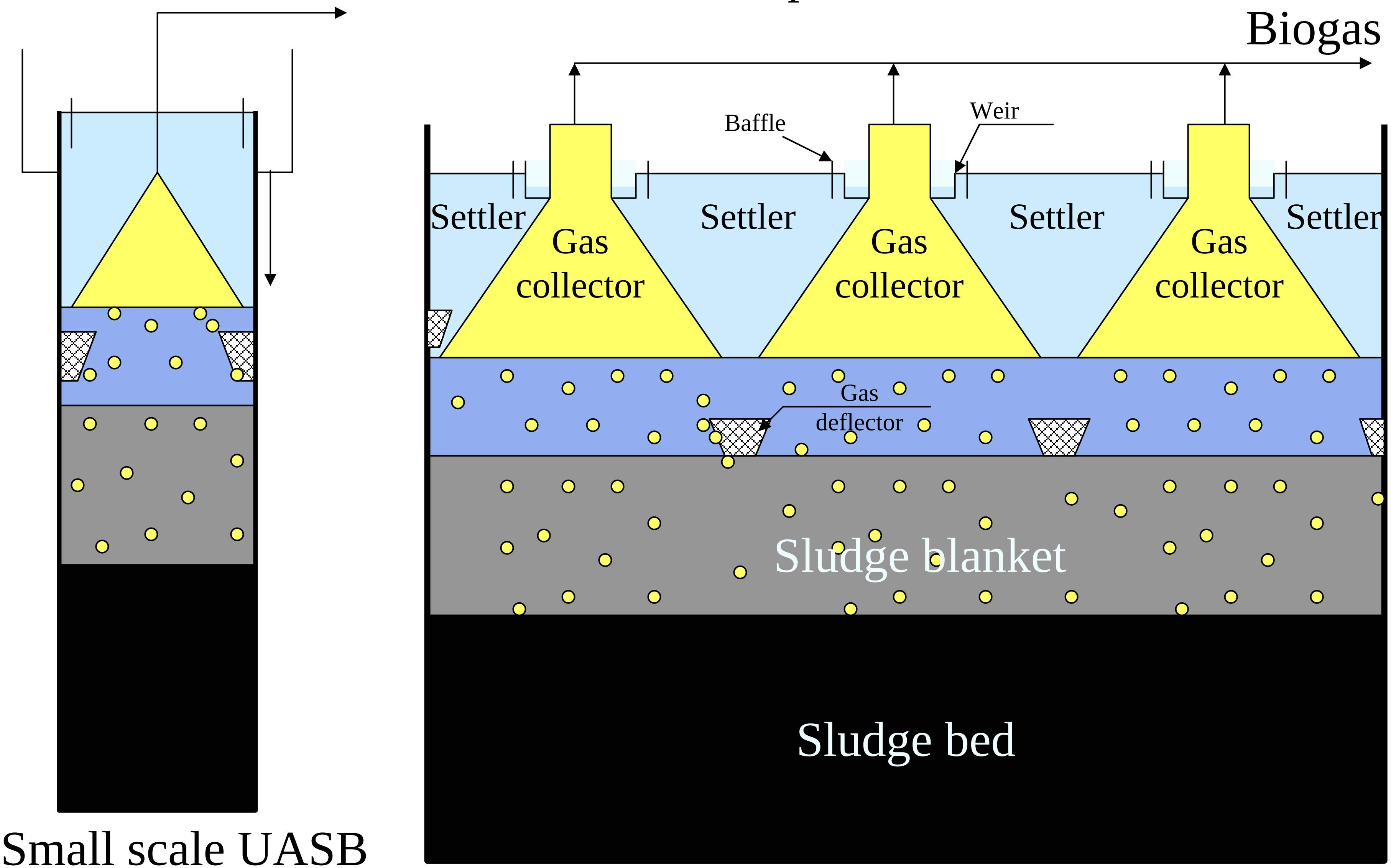


Down flow anaerobic filter



Anaerobic baffled reactor

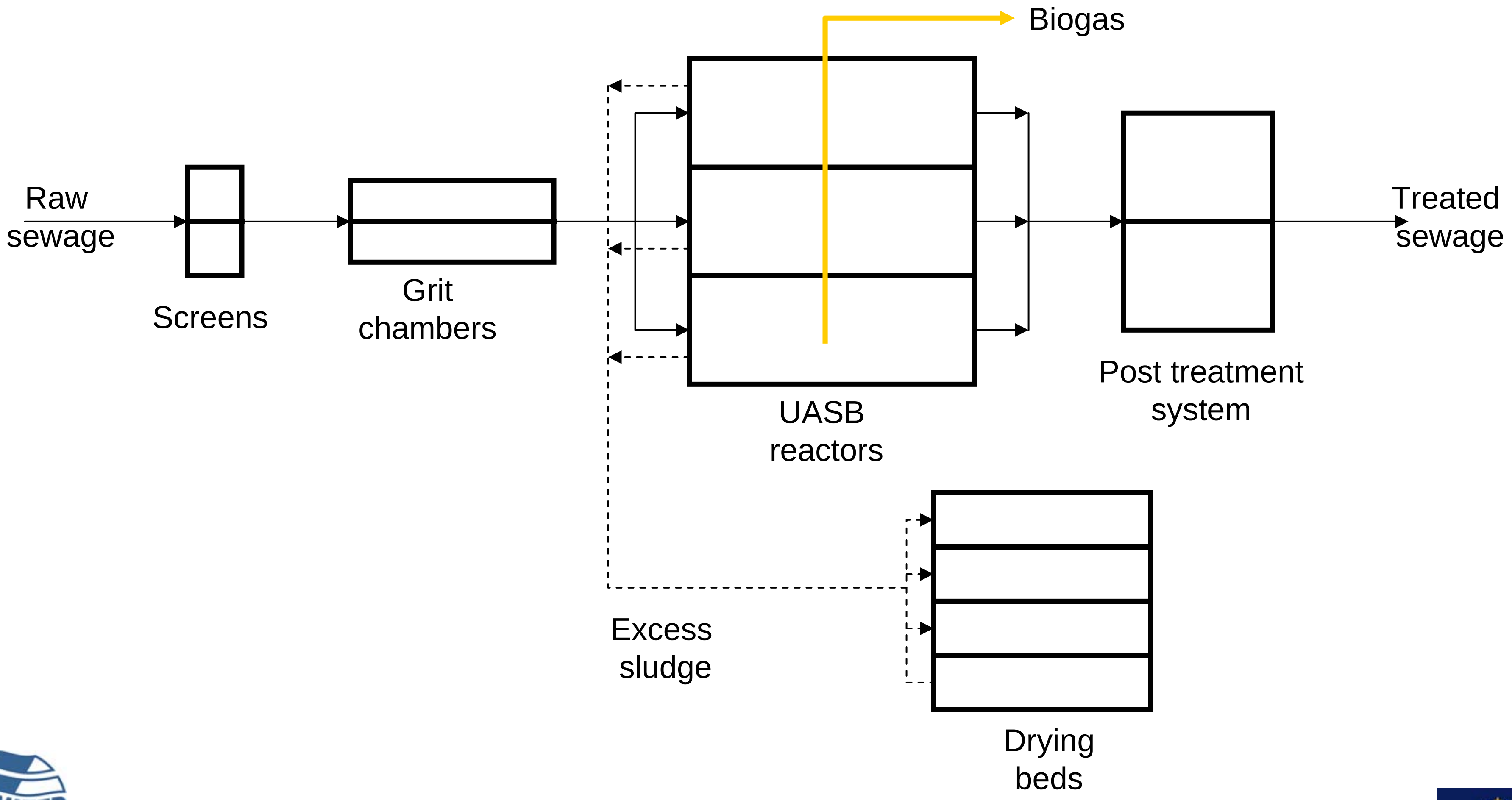
UASB reactor main components



Small scale UASB

Large scale UASB reactor

Basic configuration for the anaerobic treatment-plant of municipal wastewater



Factors affect on the removal of the dissolved organic matter in the UASB reactor

Although, the removal of dissolved matter is mainly a biological process, some physical aspects are also involved, like temperature, solubility of gases, wastewater viscosity.

At low temperature:-

A lower mixing will prevail in the sludge bed in systems operated at low temperatures, as the solubility of gases increases at declining temperatures.

Moreover, as viscosity increases at lower temperatures, more energy is required for mixing and diffusion of soluble compounds.

For optimization of soluble substrates removal at low temperatures: -

A high concentration of active biomass, a good contact between wastewater and biomass, and a good removal of SS are needed.

For treatment of raw or settled municipal wastewater at temperature > 15°C in the UASB reactor

HRT = 4 - 8 hours, (depending on the temperature and wastewater concentration)

Organic loading rate = 1 - 2 kg COD. m^{-3}. day^{-1}

Wastewater upflow velocity = 0.5 - 1.0 m/hour

<u>Average results in Latin America (Brazil, Mexico,..) and India</u>

COD removal	65 - 80 %
BOD removal	75 - 85 %
SS removal	75 - 85 %
Coliform removal	70 - 90 % (i.e. 1 log)
Helminth eggs	up to 100%

For treatment of raw or settled municipal wastewater at temperature < 15^{o}C in high-rate anaerobic systems

Hydrolysis is limited at low temperature

Options for treatment of raw or settled municipal-wastewater at temperature < 15°C in high-rate anaerobic systems

1. One-step UASB reactor

For one-step UASB reactor, long HRT is needed,

At low temperature, HRT = 12 - 24 hours,
depending on the influent COD concentration and wastewater temperature

COD removal = 45- 65 %

Options for treatment of raw or settled municipal wastewater at temperature < 15^{o}C in high-rate anaerobic systems

2. Two-step system: -

a. UASB + EGSB (expanded granular sludge bed), (Wang, 1994)

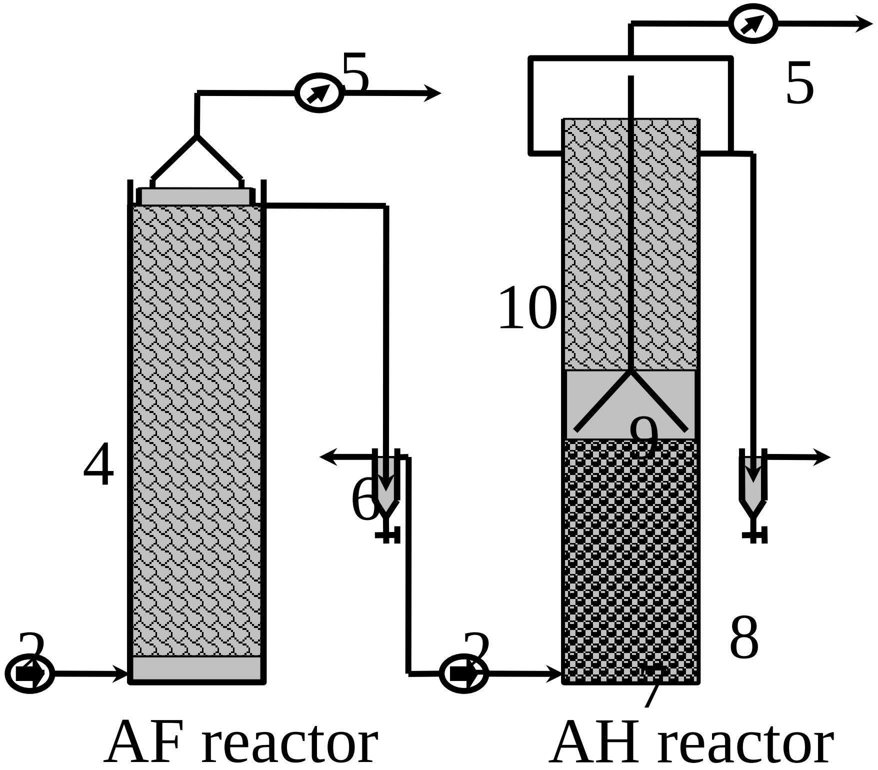
b. AF (anaerobic filter) + UASB (or AH, anaerobic hybrid), (Elmitwalli *et. al.*, 2002)

HRT

First step:- HRT = 3 - 4 hours

Second step:- HRT = 4 - 8 hours

COD removal = 50- 70 %



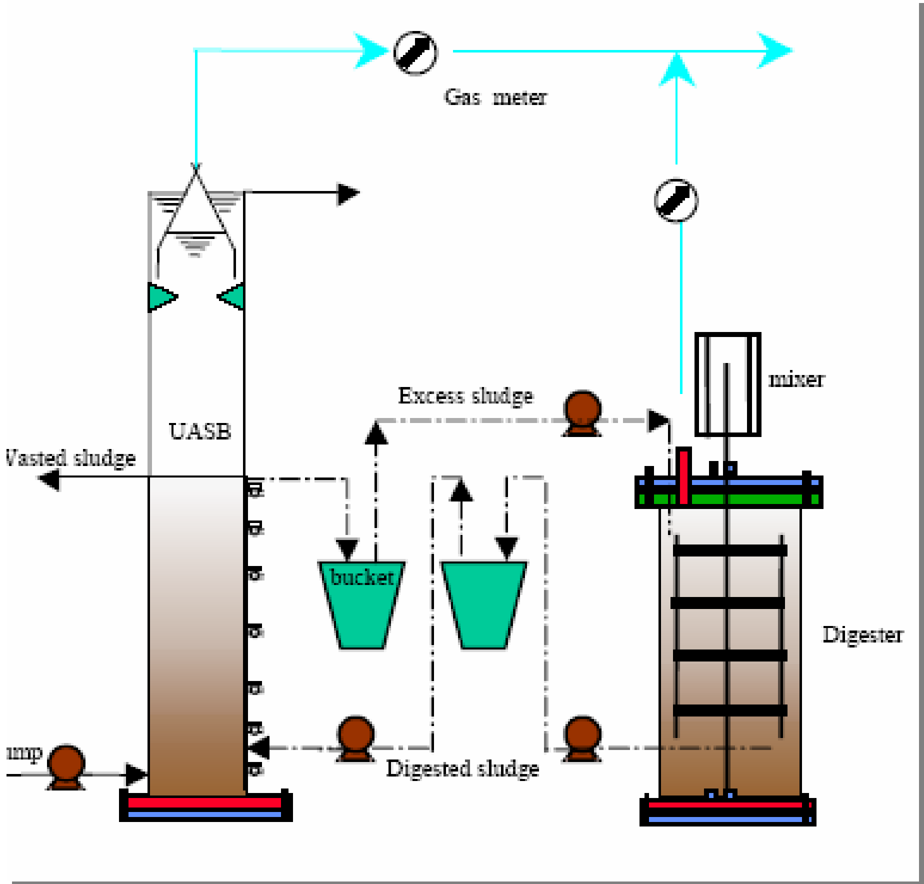
Options for treatment of raw or settled municipal wastewater at temperature < 15°C in high-rate anaerobic systems

3. UASB-Digester system (Mahmoud, 2002)

HRT of UASB = 6 - 8 h

HRT of the digester = 12 - 20 days

COD removal = 50- 70 %

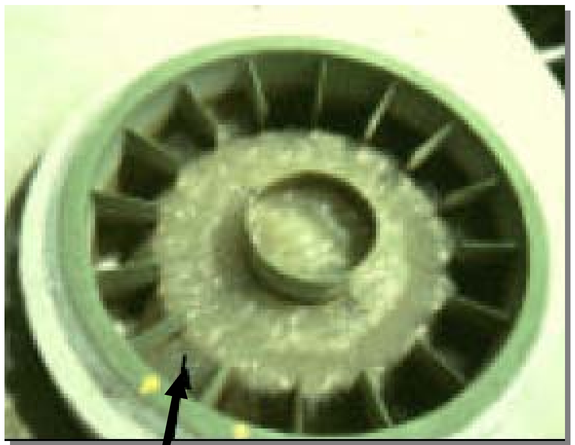


Feed inlet system for the UASB reactor

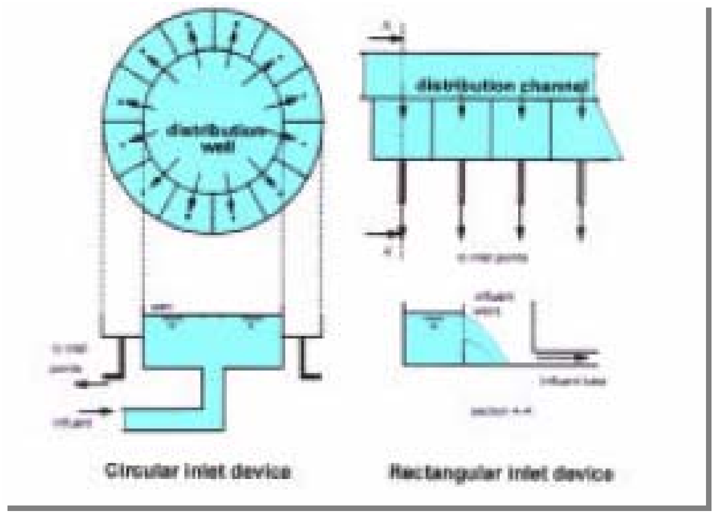
The main aim of feed inlet:-

1. To prevent channelling of the wastewater through the sludge bed,
2. To avoid formation of dead zones in the sludge bed.

Each inlet point serves (1- 2 m^2) in the bottom of the reactor



Clogged inlet tube



Internal view of 1200 m^3 UASB, Cali, Colombia

Inlet pipe

Gas liquid solids separator (GLSS) device in the UASB reactor

The main aim:-

1. Separation between the biogas, sludge and wastewater,
2. Prevent the wash-out of biomass,
3. Prevent the wash-out of floating sludge

Design considerations:-

1. The slope = 45 - 60^{o},
2. The height = 1- 2 m,
3. Construction material should be again corrosion, stainless steel, coated concrete, plastic
4. The overlap between the GLSS and deflector = 10 - 20 cm.

Gas liquid solids separator

Discharge of excess sludge

For discharge of the excess sludge, the following pipes should be installed in the UASB reactors:-

1. Nearby the bottom of the reactor,
2. In the middle of the reactor height,
3. Under the GLSS device, 0.5-1 m beneath the GLSS.

Post treatment of the anaerobically treated municipal wastewater

The aim: -

1. Removal of pathogen,
2. Removal of the nutrients, depending on the effluent standards.

The most applied systems for the post treatment:-

1. Pond, Duckweed, Wetland,
2. Tricking filter,
3. Rotating biological contactor,
4. Aerated lagoon,
5. Activated sludge process.

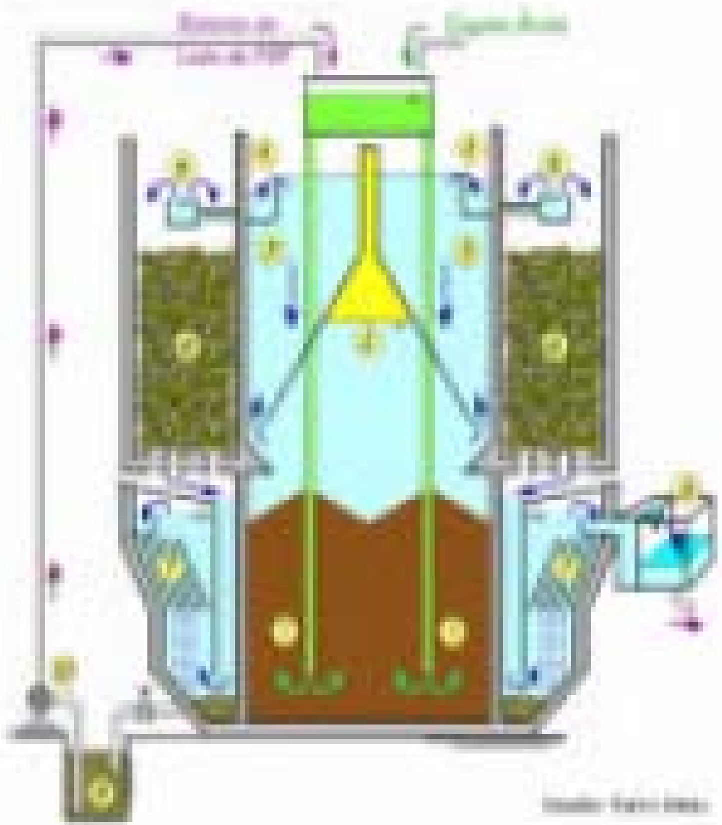
UASB + Trickling filter

UASB

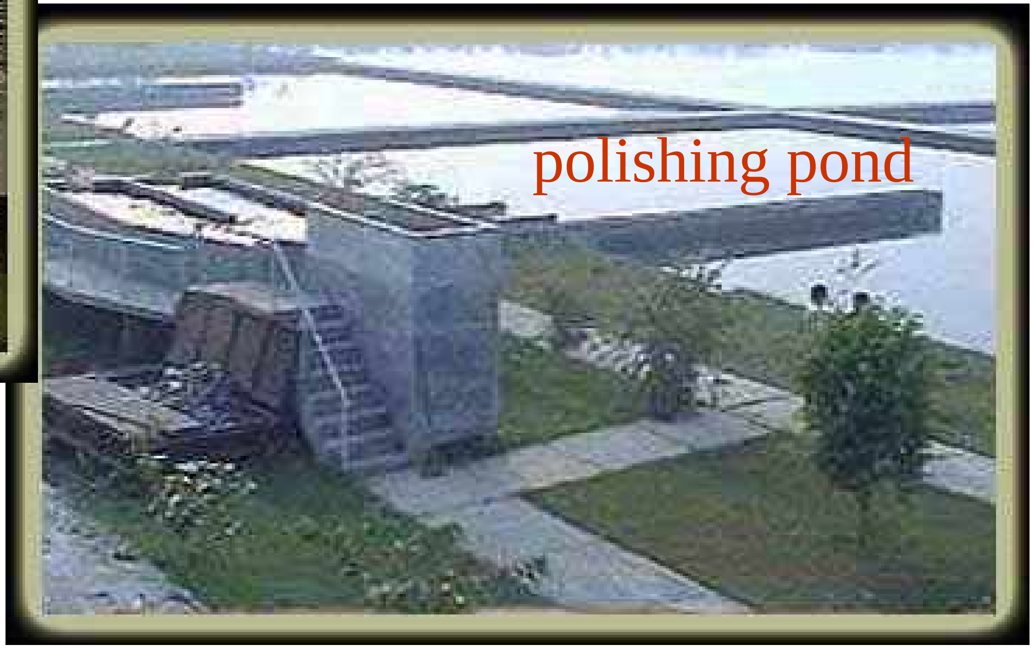
Screen

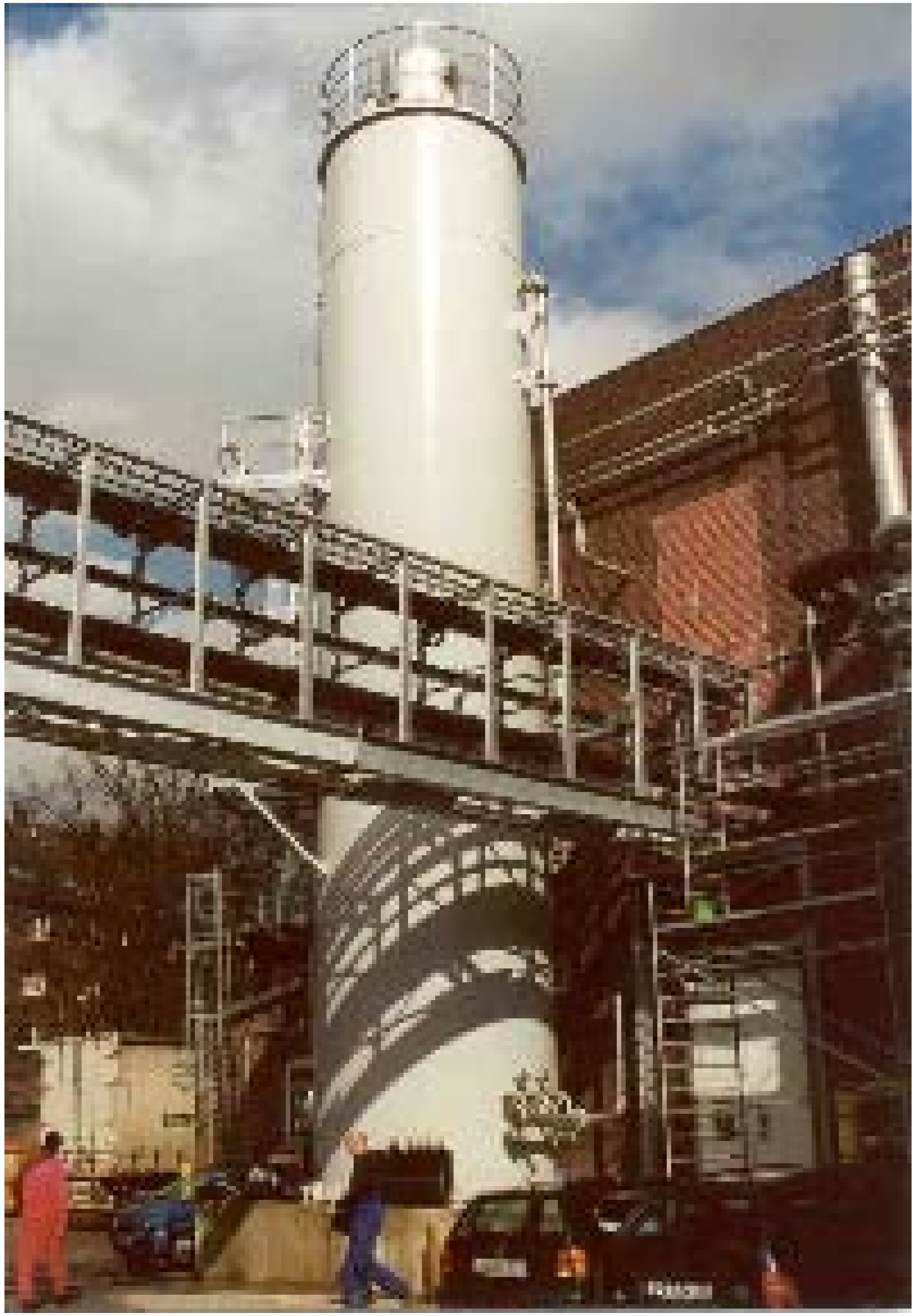
Trickling filter

UASB + Trickling filter



UASB + polishing pond



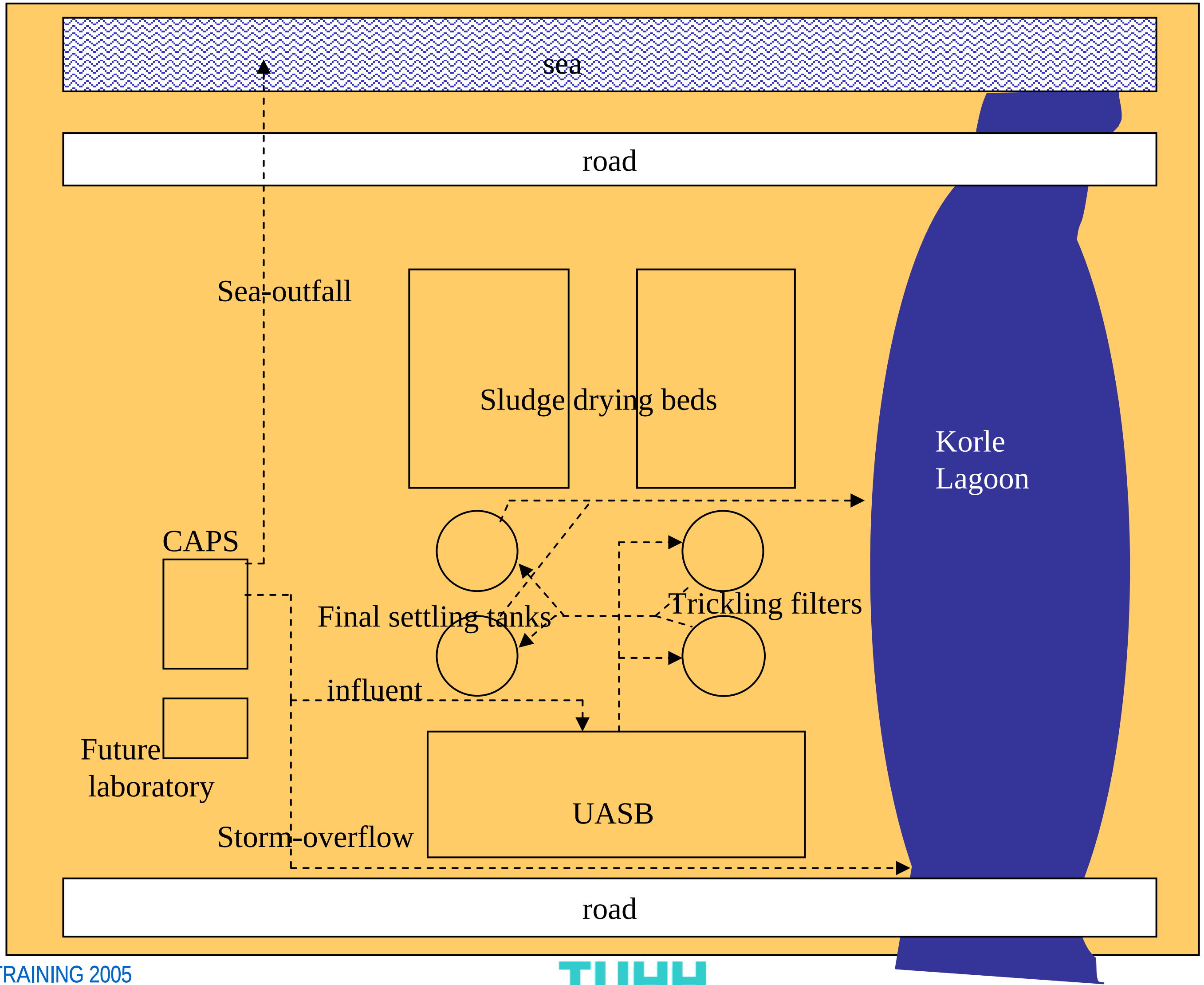


Papermill Schulte, Düsseldorf, Germany: closed water system

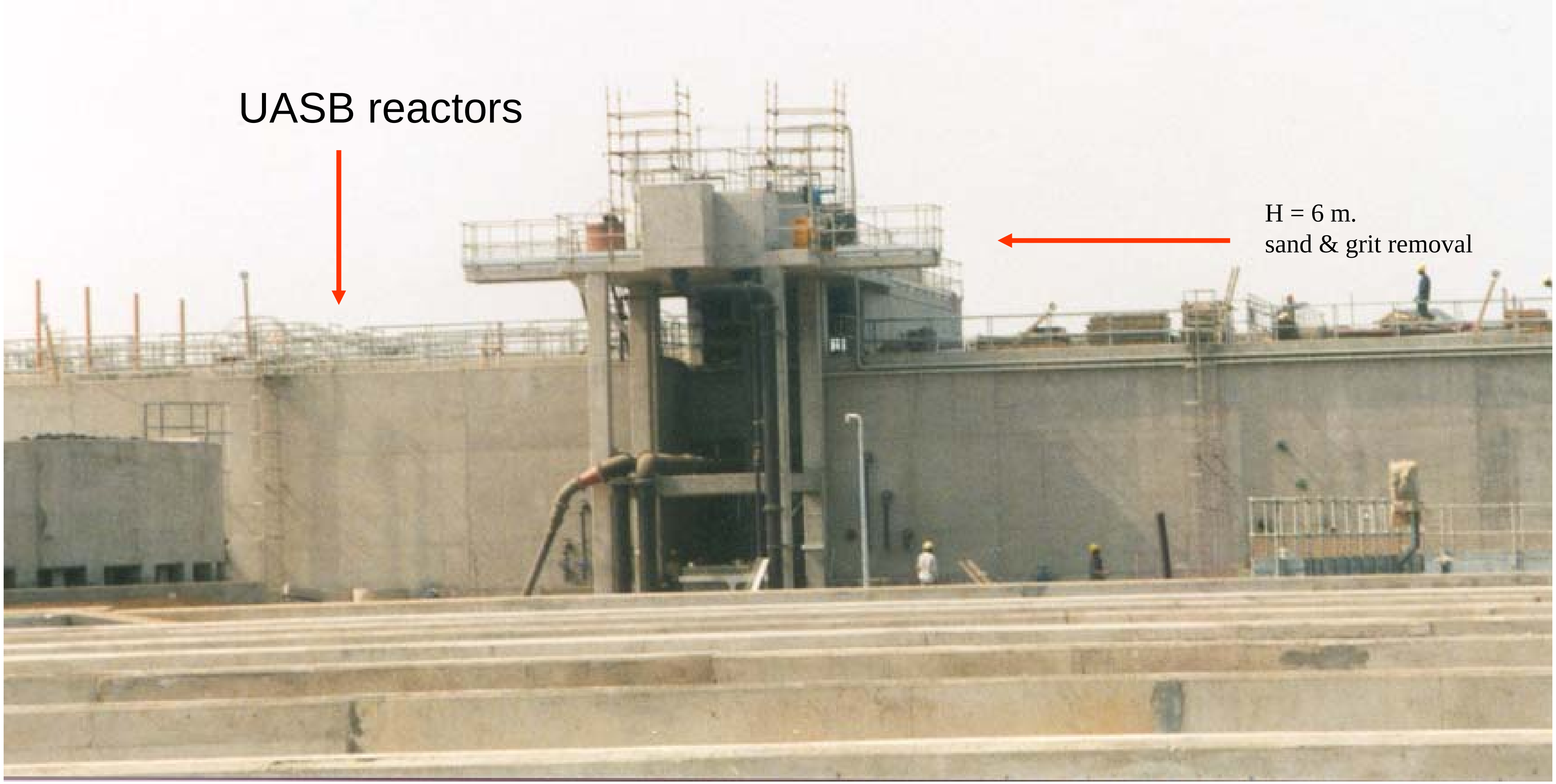
Pomdor AG - Sursee for distillery and fruit juice**, Switzerland**

Accra, Ghana: Plant overview for Municipal Sewage Treatment

COD: 1,600 mg/l (peak: 16,000 !)   pH fluctuates: 5 – 12 (!)
BOD: 1,000 mg/l (peak: 3,000 !)

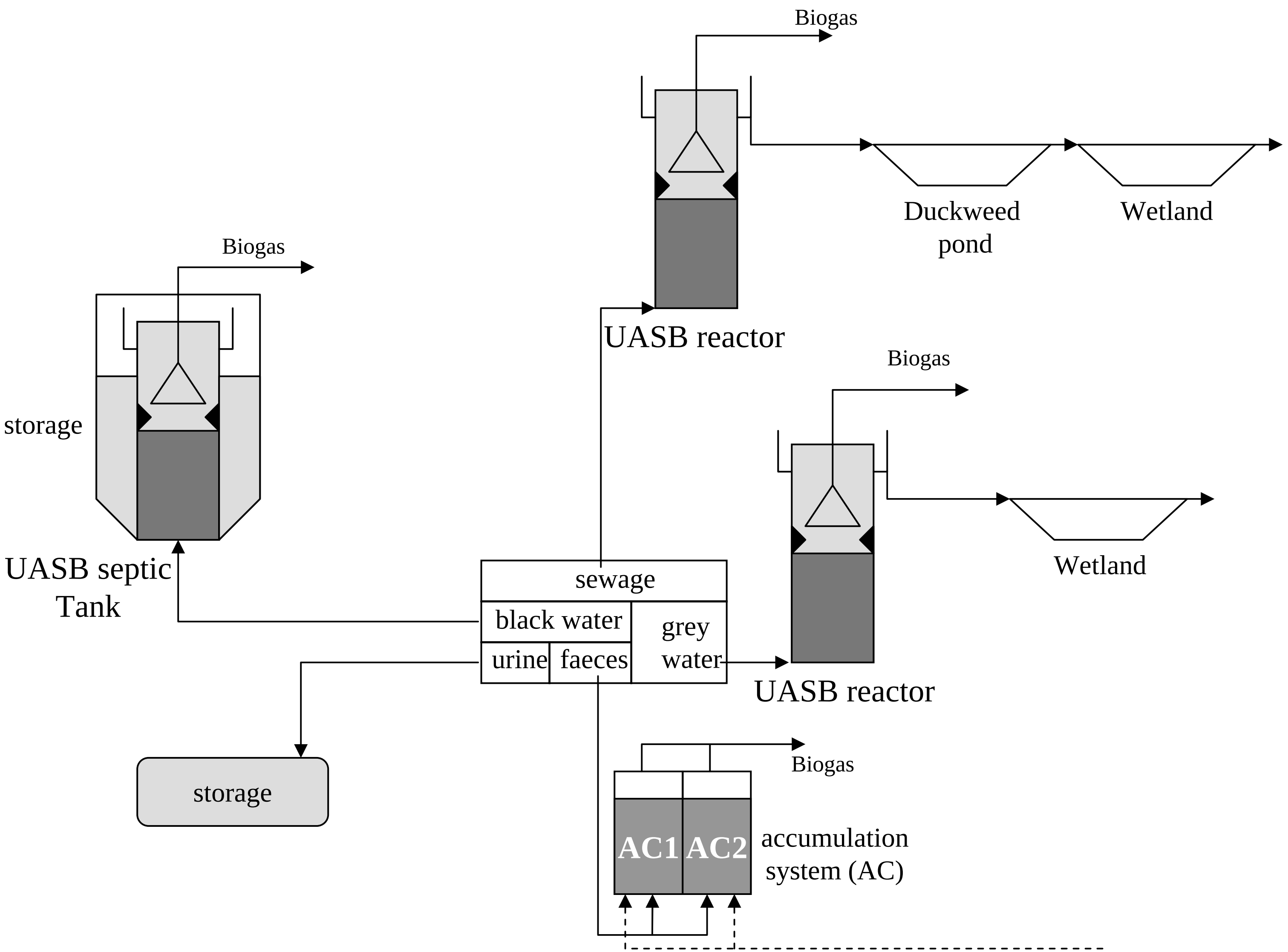


Accra, Ghana: 6500 m³ UASB for Municipal Sewage
UASB reactor volume 6 x 1100 m³



Modular Design UASB Reactors

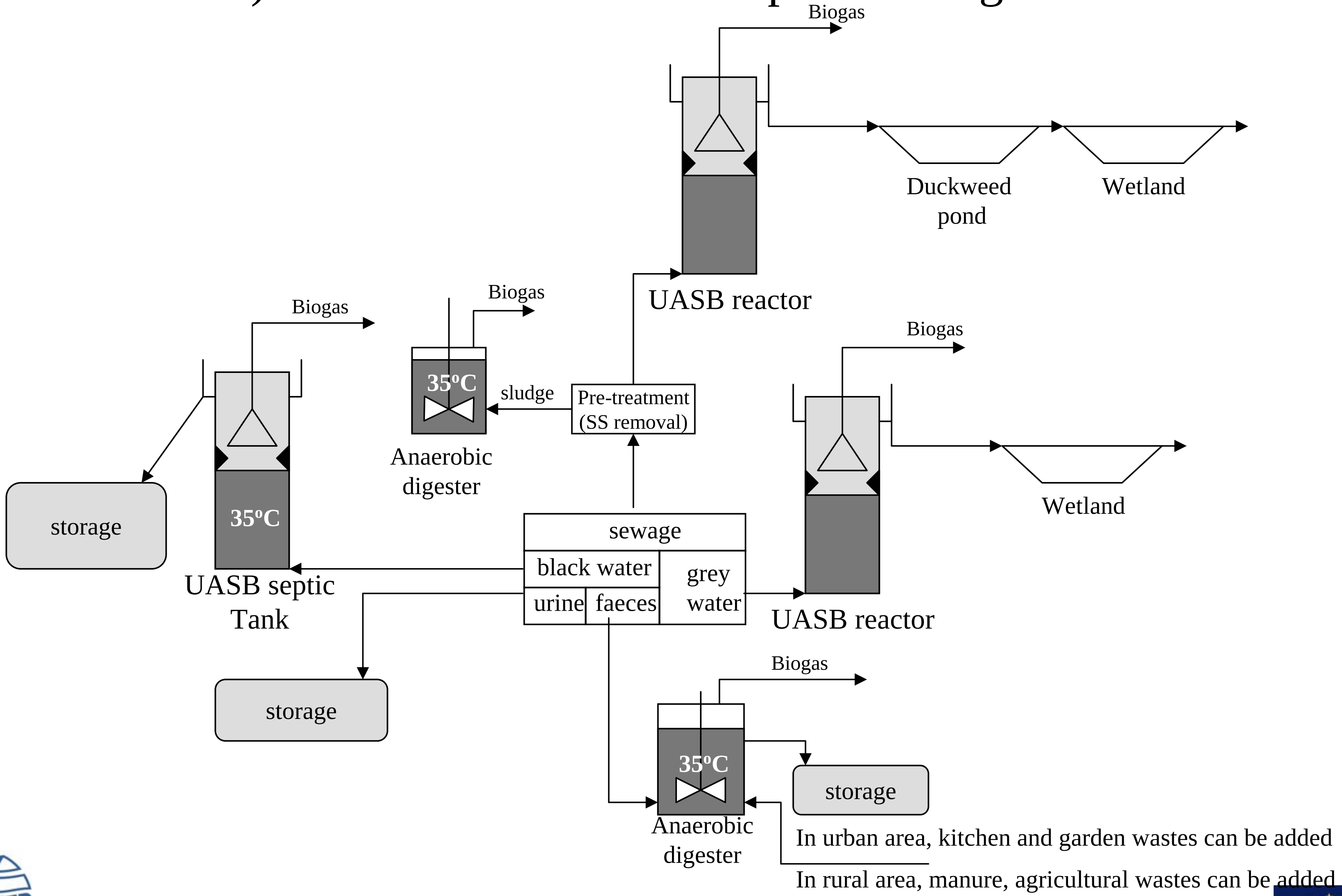
Application of the anaerobic treatment in ecological sanitation
A) in tropical and sub-tropical region



In urban area, kitchen and garden wastes can be added

In rural area, manure, agricultural wastes can be added

Application of the anaerobic treatment in ecological sanitation
B) in moderate and low temperature region



References

1. Elmitwalli T.A., Zeeman G., Oahn K.L.T. and Lettinga G. (2002) Treatment of domestic sewage in a two-step system anaerobic filter/anaerobic hybrid reactor at low temperature. *Water Research*, **36**(9), 2225-2232.

2. LeAF foundation(http://www.ftns.wau.nl/lettinga-associates/)

3. Mahmoud N. (2002). *Anaerobic pre-treatment of sewage under low temperature (15°C) conditions in an integrated UASB-digester system*. Ph. D. thesis, Sub-department of Environmental Technology, Wageningen University, The Netherlands.

4. Yamuna Action Plan (http://yap.nic.in/research-development.asp

5. Wang K. (1994) Integrated anaerobic and aerobic treatment of sewage. Ph. D. thesis, Department of Environmental Technology, Wageningen University, The Netherlands.

Lesson B4

Constructed Wetlands for Wastewater Treatment

Authors: Claudia Wendland and Nathasith Chiarawatchai

Institute of Wastewater Management
Hamburg University of Technology

Keywords
Constructed wetlands, planted soil filter, reed beds

Table of content

Overview and summary of this lesson

Constructed wetlands are one of the most promising treatment options for municipal wastewater with respect to the decentralised settlements, especially in rural and suburban areas, because they are low in cost and maintenance requirements with a good performance. They need more land compared to technical intensive treatment but less space than pond systems.

Constructed wetlands can be installed as two different technological systems according to its hydraulic regime: the free water surface (FWS) and subsurface-flow constructed wetlands, in which the latter can be further categorized to horizontal and vertical subsurface-flow (HSF and VSF). The FWS system in one sense is similar to a pond system incorporating with the emergent macrophytes. For SF system, the water is maintained below the surface of the wetland bodies, usually made up of gravel planted with the emergent macrophytes. In HSF, the flow is usually continuous thereby creating a saturated condition within the wetland body, whereas in VSF, the media is completely unsaturated due to intermittent feeding.

This lesson discusses the capabilities and limits between these constructed wetland systems and the management requirements to achieve the designed purpose. Design and proper operation are explained for some applications. Some future trends with focus on maximization of efficiency, cost minimisation, ecological sanitation and water reuse are presented as well.

1. Introduction

1.1 Terminology

Constructed wetlands are artificial wastewater treatment systems consisting of shallow ponds or channels which have been planted with aquatic plants and which rely upon natural microbial, biological, physical and chemical processes to treat wastewater. They have impervious clay or synthetic liners and engineered structures to control the flow direction, liquid detention time and water level. Depending on the type of system, they contain an inert porous media such as rock, gravel or sand [US EPA 2000].

Historically, constructed wetlands were already used since centuries to treat a variety of wastewaters such as municipal wastewater, urban runoff, agricultural drainage, etc. However, this lesson focuses mainly on the treatment of municipal wastewater or its separated flows such as greywater. The constructed wetlands according to this application are considered as a mayor treatment step, which usually need a pre-treatment and, depending on the reuse purpose, a post treatment.

This system can be divided into two types, on the one hand is free-water surface type (FWS) in which the water level is over the surface, and on the other hand is subsurface type (SF), in which the water level is maintained below the surface. The latter one can be further categorized into two types based on the pattern of flow, one with horizontal subsurface (HSF) and one with vertical subsurface flow (VSF) (Crites, et. al., 2000). The SF type can also be called “reed bed”. The illustration of each system can be seen in the figure below.

The free water surface constructed wetlands (FWS) closely resemble natural wetlands because they look like ponds containing aquatic plants that are rooted in the soil layer on the bottom. The water flows through the leaves and stems of the plants. Their design and operation is very close to pond systems.

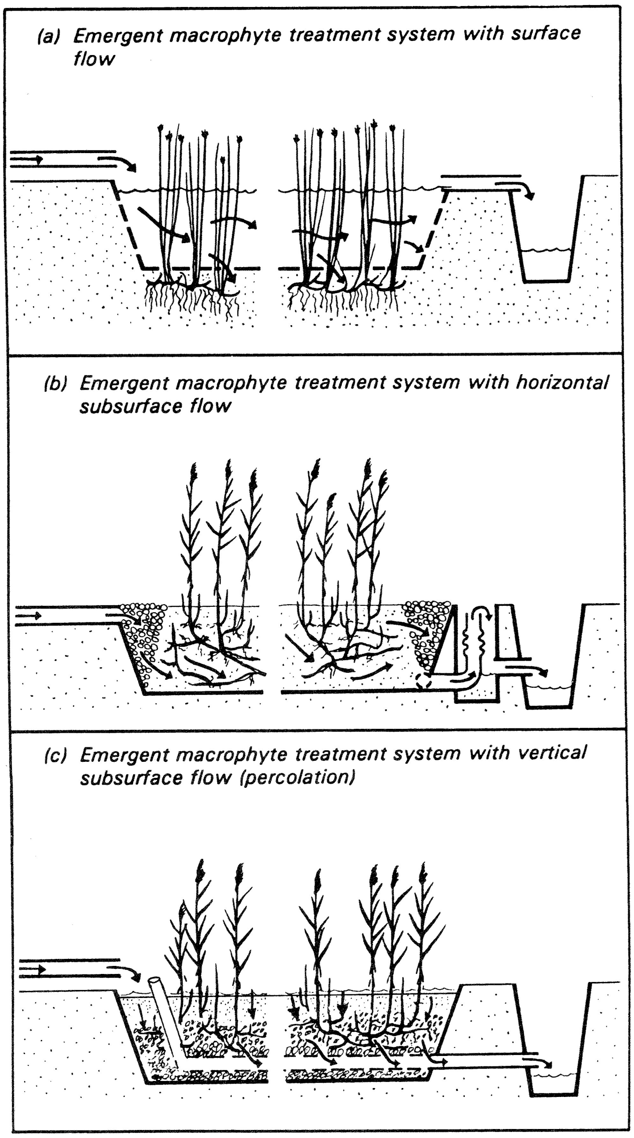


Figure 1: Schematic presenting each type of constructed wetlands which A: FWS, B: HSF, and C: VSF (Brix, 1993)

The focus of this lesson is based on the constructed wetlands with subsurface flow. This is due to several researches indicating that the pollutant removal efficiency is better than in FWS per unit of land, implying the area requirement is lower. These systems also pose no problem of mosquito or other insects breeding as well as the human, probably children, exposure to surface wastewater. Some disadvantages of this type are higher cost and have lower ecological value comparing to the FWS wetlands, which are of minor concerns.

The HSF and VSF systems do not resemble natural wetlands because they have no surface flow of water. They contain a bed of media which is typically gravel and sand, but also soil or crushed rocks can be also used. Within the media, emergent macrophytes are planted and the water is introduced beneath the surface of the media and is flowing through the roots and rhizomes of the plants. Conventionally, the flow in HSF systems is continuous, hence it creates a “saturated” condition within the wetland body whereas the flow in VSF systems is commonly intermittent, which results in an “unsaturated” and thus aerobic condition. Figure 2 depicts the photo of one VSF system in Hannover, Germany.

Figure 2: Unsaturated vertical flow constructed wetlands in Hannover, Germany

It should be noted that FWS and SF constructed wetlands work differently because the latter system does not support any aquatic wildlife. Some biological and chemical interactions only occur in an open water column and thus these will happen only in a FWS system. Moreover, constructed wetlands should not be mixed with created or restored wetlands which are not designed for wastewater treatment but have the function of wildlife habitat.

1.2 Application and Importance of Constructed Wetlands

Constructed wetlands are an appropriate technology for small communities in rural and suburban areas. Many rural projects with activated sludge plants failed because it was not properly operated, often no skilled stuff is available or the energy costs is no longer affordable. Constructed wetlands are principally using the same natural degradation processes and nutrient uptake but they are acting as extensive systems. There is wide acceptance and interest because of the following advantages (SWAMP 2002):

- Simple in construction, operation and maintenance
- Low operation and maintenance costs (low energy demand)
- High ability to tolerate fluctuations in flow
- High process stability
- Aesthetic appearance

Constructed wetlands are used in various fields and at various treatment levels. Nevertheless, this lesson deals mainly with the conventional use of constructed wetlands, which are to treat the pre-treated municipal wastewater, or so-called primary effluent. The typical treatment cycle is shown in Figure 3.

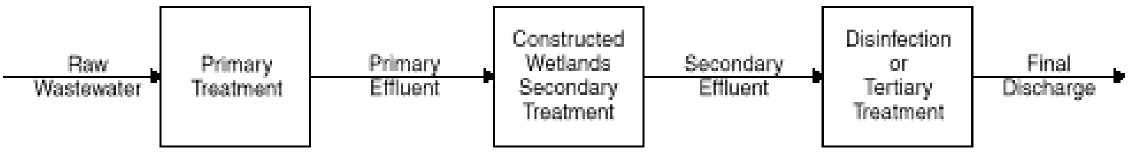


Figure 3: Constructed wetlands in the treatment cycle

In general, primary effluent constitutes of these characteristics; data shown in mg/l (adapted from Metcalf & Eddy, 2003)

BOD	COD	TSS	VSS	TN	TP
40-200	90-400	55-230	45-180	20-85	4-15

Constructed wetlands may also be applied for primary or tertiary treatment but these cases will only be mentioned in the last chapter of this lesson.

Constructed wetlands may need a post treatment particularly to completely remove nitrogen (nitrification and denitrification) and phosphorus, if the removal of both parameters is required in this region. Its capability to remove N and P has often been overestimated. Both aerobic and anoxic zones are necessary to perform complete nitrification and the subsequent denitrification. To remove significantly phosphorus the constructed wetlands must be enhanced by an accompanying P removal step, e.g. pre-precipitation in the pre-treatment unit. Recently, there are several researches running concerning the use of the constructed wetland with special P-absorbing capacity materials instead of normal gravel and sand as a substrate.

2. Understanding Constructed Wetlands

2.1 Removal Mechanisms

Treatment processes in wetland incorporate with several physical, chemical, and biological processes. The major physical process is the settling of suspended particulate matter which is a major cause of BOD reduction. The chemical processes involve adsorption, chelation, and precipitation, which are responsible for the major removal of phosphorus and heavy metals. In term of biological processes, the treatment is achieved by microorganisms (Gopal, 1999). Due to fixed film or free bacterial development, biological processes allow the degradation of organic matter, nitrification in aerobic zones and denitrification in anaerobic zones. The **microbiological activity** is the key parameter for their performance. The principle removal mechanisms in subsurface flow constructed wetlands for some constituents in wastewater are summarized in table 1.

Table 1: Principle removal and transformation mechanisms in subsurface flow constructed wetlands for the concerned constituents in wastewater (modified after Crites and Tchobanoglous, 1998)

Constituent	**Mechanisms**
Biodegradable organics	Bioconversion by facultative and anaerobic bacteria on plant and debris surfaces
Suspended solids	Filtration, sedimentation
Nitrogen	Nitrification/denitrification, plant uptake, volatilization
Phosphorus	Filtration, sedimentation, plant uptake
Heavy metals	Adsorption of plant roots and debris surfaces, sedimentation
Trace organics	Adsorption, biodegradation
Pathogens	Natural decay, physical entrapment, filtration, predation, sedimentation, excretion of antibiotics from roots of plants

For the role of plants in constructed wetland, they contribute to nutrient transformation, offer mechanical resistance to flow, increase the retention time, facilitate settling of suspended particulates, and improve conductance of water through the media as the roots grow. Particularly, the rhizomes of the reeds grow vertically and horizontally, opening up the soil to provide a hydraulic pathway through the media. Furthermore, they transport oxygen to the deeper layer of the media via the leaves and stems of the reeds down through the hollow rhizomes and out through the roots and hence help in oxidation and precipitation of heavy metals on the root surfaces (Gopal, 1999).

However, Hiley and Hadjichristova (1998) stated that it is still debated whether the plants contribute any oxygen or not. In order to maximize the benefit in SF wetland, the full depth of the media should be compatible with the full plant root penetration so that potential contact points could be available throughout the profile (Reed et. al., 1995). The most frequently used plants species are *Scirpus* sp. (bulrush), *Typha* sp. (cattail), and *Pragmites communis* (reeds). Their typical characteristics are described below (Crites and Tchobanoglous (1998) and Reed et. al. (1995)).

Table 2: Typical characteristics of some plant species used in constructed wetland

Characteristics	Bulrush	Cattail	Reeds
Distribution	Worldwide	Worldwide	Worldwide
Temperature, °C	16-27	10-30	12-23
pH range	4-9	4-10	2-8
Maximum salinity tolerance, ppt	20	30	45
Root penetration in gravel, m.	≈0.6	≈0.3	≈0.4
Habitat values	Seeds and rhizomes as a food source for several water birds, muskrat, nutria, and fish	Seeds and roots as a food source for water birds, muskrat, nutria, and beaver	Low food value for most birds and animals
Drought resistant	moderate	Possible	high
Growth	Moderate to rapid	Rapid	Very rapid

Note: ppt = parts per thousand

Plant uptake of nitrogen and phosphorus is not a significant removal effect because they are taken up and usually released during decay. While uptake rates are potentially high, harvesting plant biomass can remove nitrogen and phosphorus but no research shows a significant removal performance due to harvesting. Harvesting plants is anyhow limited to both HSF and VSF systems.

The detailed schematic of HSF constructed wetlands is shown in figure 4;

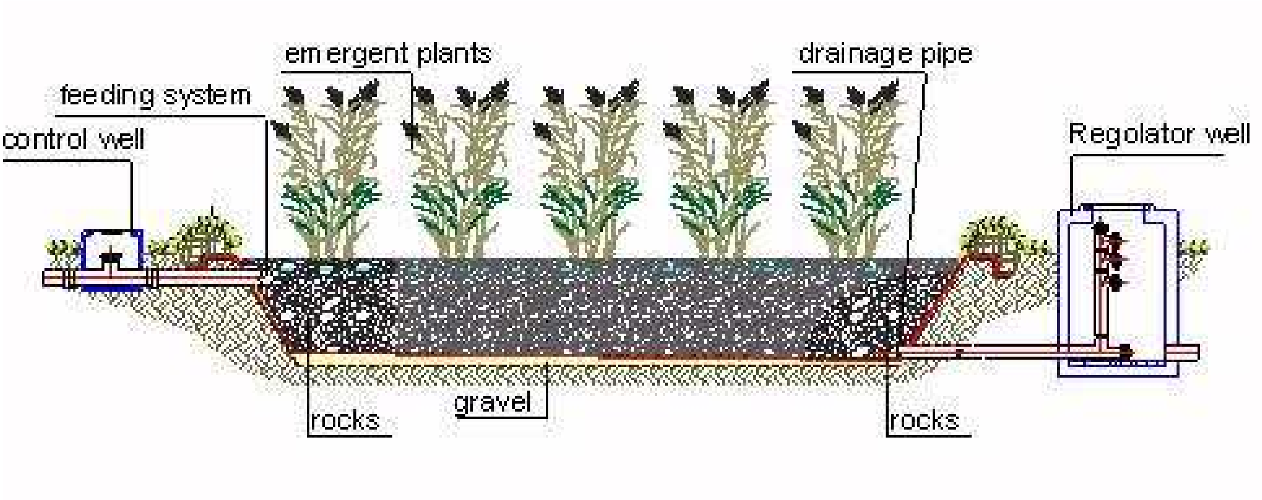


Figure 4: Detailed schematic of a horizontal flow system (HSF)

The VSF system illustrating more detail shown in figure 5 needs a well designed and constructed system to distribute the water equally over the whole area. The construction is therefore more expensive than for the horizontal flow systems. For VSF, **filtration** is also an important removal mechanism. The bed media must be carefully chosen according to the wastewater constitution.

The water level is always at the bottom. Its best performance can be achieved by intermittent feeding when aerobic and anoxic phases alternate. Due to the higher effort in designing and constructing the VF properly, the performance of these systems in term of COD and nitrification is much higher than in the other constructed wetland systems.

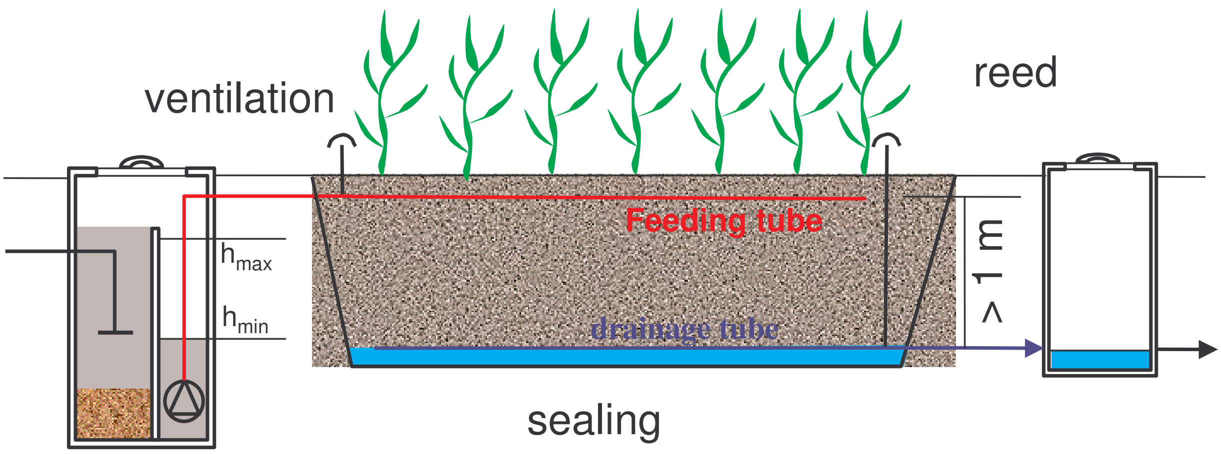


Figure 5: Detailed schematic of an unsaturated vertical flow system (VSF)

Waterborne pathogens including helminth, protozoa, bacteria and viruses are of great concern in assessing water quality. Pathogens in wastewater are usually associated with TSS and can be removed like TSS, mainly sedimentation. Thus removal of pathogens (measured by indicators) in wetlands appears to be correlated with TSS removal and hydraulic residence time (US EPA 2000). Analyses in constructed wetlands show a significant reduction of pathogens about two to three logs, which mean more than 99% removal which is significant but usually not sufficient to meet standards for water reuse.

2.2 Comparison tables among each type of CWs

The table below compares the effectiveness of each type of technology according to each environmental parameter.

Table 3: The effectiveness of each technology based on each parameter (European Commission, 2001)

Parameters	Organic matter (OM)	TKN	Total N	Total P	Microbial removal
Horizontal flow CW	Yes	Poor nitrification	Good denitrification	No	No
Vertical flow CW	Yes	Yes	No*	No	No
Free water surface CW	Average	Yes	Yes	Yes, the first years	yes

* In intermittent fed system a simultaneous N elimination takes place (see case study Lambertsmühle chapter 6.2).

3. Design and construction

3.1 Location

In general, wetland sites should be located outside of flood plains, or protection from flooding should be provided (Tchobanoglous and Burton 1991).

For reasons of possible odour nuisance, constructed wetlands should be placed in a reasonable distance to residential areas. The distance of 15-20 m to the nearest building is recommended. The constructed wetland should be secured against entry by unauthorised persons under local arrangements. They have to be marked clearly as wastewater treatment systems.

3.2 Primary treatment

A successful physical pre-treatment is necessary for a good performance of all constructed wetlands; exceptions are the FWS and see also Future Trends.

The influent has to free from coarse and floating material probably by screening them out. Unsatisfactory pre-treatment may lead to build-ups in the inflow area, to odour nuisances, to clogging of the filter or to blockages of the soakage links.

The pre-treatment can be realised as primary sedimentation in tanks, for small scale plants typically septic tanks are used. Imhoff tank is a possibility which reduces sludge production.

Ponds may be an option for pre-treatment, often used before a VSF system. The size of wastewater ponds for pre-treatment typically range from 1.5 – 4 m^2/PE. A partly reduction of COD, BOD and TSS < 100 mg/l can be achieved (SWAMP 2002).

3.3 Sealing

Constructed wetlands must be sealed at the bottom and sidewalls to avoid any groundwater pollution. As natural sealing there are different recommendations as shown in the following table:

Table 4: Recommendation for natural sealing of constructed wetlands

	SWAMP 2002	DWA 2004 Germany
Permeability coefficient k_f	< 10^{-7} m/s	< 10^{-8} m/s
Thickness of sealing	> 30 cm	> 60 cm

If natural soil is not available, an artificial layer with impermeable layer is required. The material should be acid resistant and alkali proof, frost and UV resistant, root and rodent resistant, non toxic, easy to carry and move and preferably made of recyclable materials (preferred HDPE or LDPE).

3.4 Construction and sizing of the bed

The design criteria for HSF constructed wetlands can be seen in the table below;

Table 5: Design criteria for horizontal flow submerged beds (HSF)

Criteria	Germany, DWA 2004	US EPA 2000	EC Guidelines CEMAGREF	United Kingdom, Cooper 1996
Surface area	5 m^2/pe minimum size 20 m^2		5 m^2/pe for BOD > 300 mg/l, otherwise 10 m^2/pe	5 m^2/pe** 0.5-1 m^2/pe***
Hydraulic surface load	40 mm/d			< 50 mm/d** < 200 mm/d***
Max organic load	*BOD: 8 g/(m^2*d)**	BOD: 6 g/(m^2*d)		
Depth	0.5 m			0.6 m

* calculated with 40 g BOD/(PE*d)
** for secondary treatment
*** for tertiary treatment

Apart from those specified in the presented guidelines, Rousseau et. al. (2004) performed a review concerning different design methods. In general, the rules of thumb suggested by several works can be served as a safe bed. However the investment costs tend to be higher due to conservative aspects of this approach.

For the vertical subsurface-flow type, the design criteria are shown below;

Table 6: Design criteria for vertical subsurface-flow constructed wetlands (VSF)

Criteria	**Germany, ATV 2004,**	**Lange & Otterpohl 1998**	**EC Guidelines CEMAGREF**	**United Kingdom, Cooper 1996**
Surface area	4 m^2/pe minimum size 16 m^2	1-2 m^2/pe for greywater	5 m^2/pe for BOD > 300 mg/l, otherwise 10 m^2/pe	5 m^2/pe** 0.5-1 m^2/pe***
Hydraulic surface load	80 mm/d			< 50 mm/d** < 200 mm/d***
Max organic load	COD: 20 g/(m^2*d)			
Depth	0.5 m			0.6 m

** for secondary treatment
*** for tertiary treatment

4. Operation and Maintenance

To ensure successful planting of constructed wetlands, there are several options available, namely seeds, pot grown plant, shoot with rhizomes/root or soil spread, which are suitable for all species (Nuttall et. al., 1997). Meanwhile, rhizomes option is suitable for *Phragmites, Typha,* and *Iris* spp whereas stem cuttings technique is suitable for *Phalaris* and *Glyceria* spp. Seeds can be relatively inexpensive to cover large areas but it is not suitable for the case of SSF constructed wetlands. In contrast, pot grown plants is considered to be more expensive but comes with several advantages, such as rapid tillering and cover, simple to plant, rapid development of dense cover if high planting density is applied, etc. Techniques accompanying with rhizomes are relatively inexpensive, but require higher horticulture skill and time consuming during preparation.

In order to ensure the successful operation, it is crucial to perform a monitoring of constructed wetland. At least influent and effluent quality, water levels, and microbial indicators have to be measured periodically.

Suggested monitoring parameters and frequencies are (Tchobanoglous, 1996)
Continuous; flow rate (in/out)

Weekly; Water Quality: DO, temp., BOD, COD, SS, particle size distribution, nutrients (in/out along CW) pH, conductivity (only in and out)
Monthly; Bacteria (in/out)

Quarterly; chlorophyll, metals, sediment characteristics (redox potential, salinity, pH, OM) (in/out along CW)
Annually; flow rate distribution (within CW), organics (in/out along CW)

Moreover, it may also be necessary to monitor any happening competition from weeds species by carefully monitoring and hand-weeding if such are presented. Insect and grazing damage can harmfully affect the emergent plants, which require some control measures such as fencing and some monitoring.

General management activities include regulating the water levels, reducing loadings for short- or long-term periods, harvesting of undesired plants species as well as subsequent replanting (Kadlec and Knight, 1996).

5. Future Trends

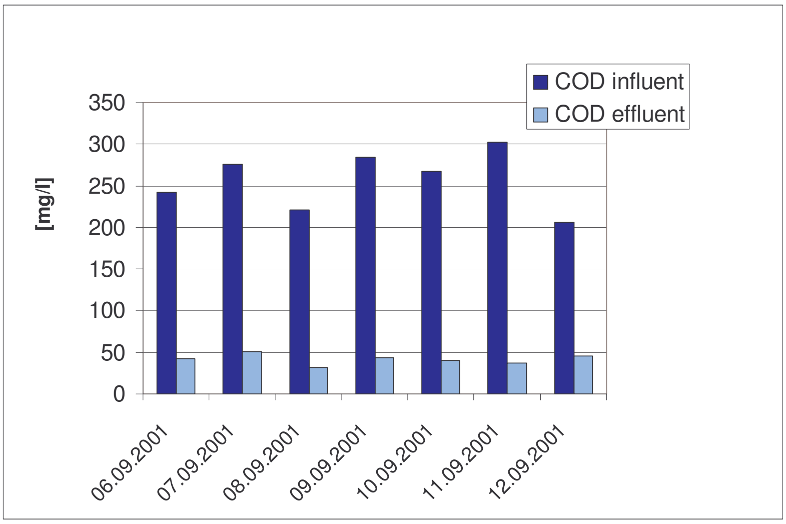
5.1 Hybrid system

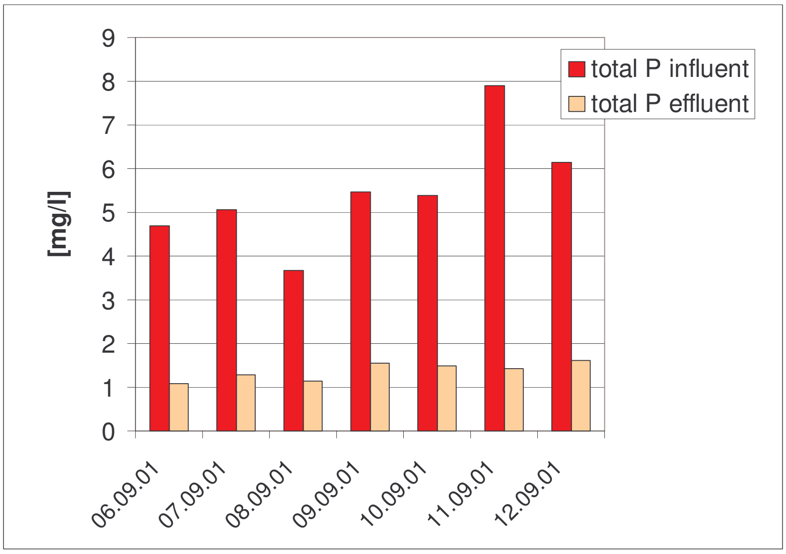
The system is proposed to compliment and overcome the drawback of each HSF and VSF technology. The idea is to put the VSF and HSF in series due to the fact that VSF is more effective in terms of low space requirement and nitrification, despite of poor denitrification due to its unsaturated nature and HSF is more effective in terms of bacteria removal and denitrification due to its saturated nature.
For more details concerning this kind of system please look in Cooper, 1999.

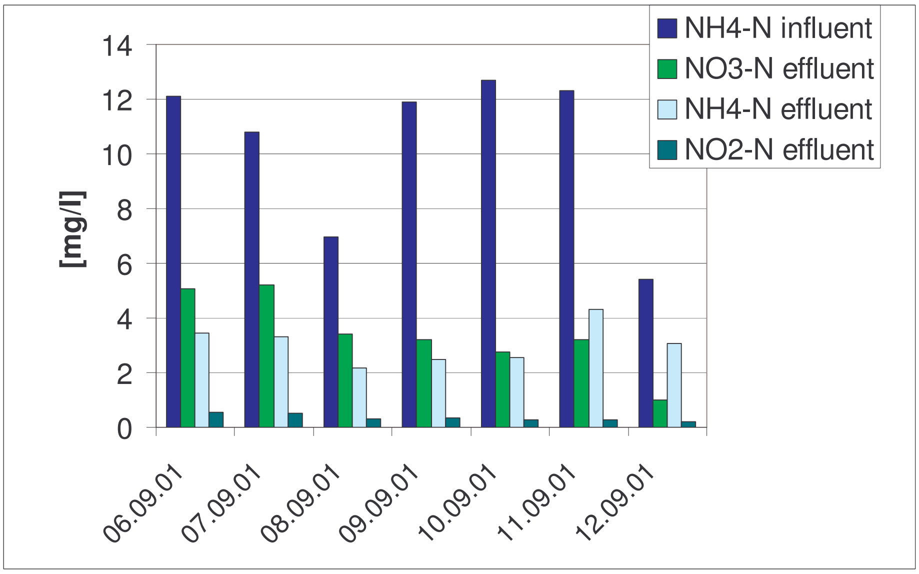
5.2 Greywater treatment

Lambertsmühle, Germany
In this pilot project, a source separation system of wastewater for a museum has been installed, see http://www.otterwasser.de/english/concepts/lande.htm.

In this case, greywater is separated from other wastewater streams and is treated with a vertical flow constructed wetland preceded by septic tanks. The required area is less than 2 m^2/PE. This system uses gravel as a substrate due to the idea that particle size should not be too fine in order to prevent clogging. After some month of start up (for biofilm growing and adopting) this system is very effective in reducing organic, nitrogen, and phosphorus. Performance of the system can be seen in the following diagrams:







Figures 6, 7 and 8: COD, N and P removal in the constructed wetlands Lambertsmühle

5.3 Constructed Wetlands without Sealing

The principal behind this concept is to combine the benefit of constructed wetland with another treatment technology so-called “groundwater percolation”. Generally, this system is applied as a polishing and reuse option so that parts of the pollutant will be treated during the infiltration and hence the groundwater will be recharged with treated and clean water. With this combination, the total land requirement for the overall treatment plant will be reduced as well as the polishing step can be integrated to the system without added cost and area.

5.4 Constructed Wetlands for raw wastewater

The French systems

In France, several VSF systems were adapted to treat raw wastewater by using gravel as a substrate. The system was developed by CEMAGREF (Institut de recherche pour l'ingénierie de l'agriculture et de l'environnement) and promoted by SINT (La Société d’Ingénierie Nature et Techniques) company. The idea behind this system is that sludge management can be simpler comparing to the conventional imhoff or digesting tank (Molle et. al., 2005).

It is recommended to divide the system into 2 stages,

1st stage: 3 filters with >30 cm of fine gravel (2-8 mm) as a 1st layer substrate

2nd stage: 2 filters with >30 cm of ($0.25 < d_{10} < 0.4$ mm) sand as a 1st layer substrate

Both stages also constitute of transition layer (2nd layer, 10-20 cm) and drainage layer (10-20 cm). The feeding phase generally lasts for 3 to 4 days, after that it is needed to rest for twice this time in order to maintain “unsaturated” (aerobic) condition within the wetland bodies as well as to mineralise the organic accumulated due to suspended solid (SS). The plant uses special-designed siphon to maintain the hydraulic condition without an external energy source, provided the appropriate topography. In term of its performance, significant removal of COD, TSS and almost complete nitrification can be expected (Boutin et. al., 1997). The sludge withdrawal should be performed approximately once every 10-15 years, and this has no subsequent effect to the regrowth of reeds from the rhizomes. Schematic of the first stage CW can be seen below;

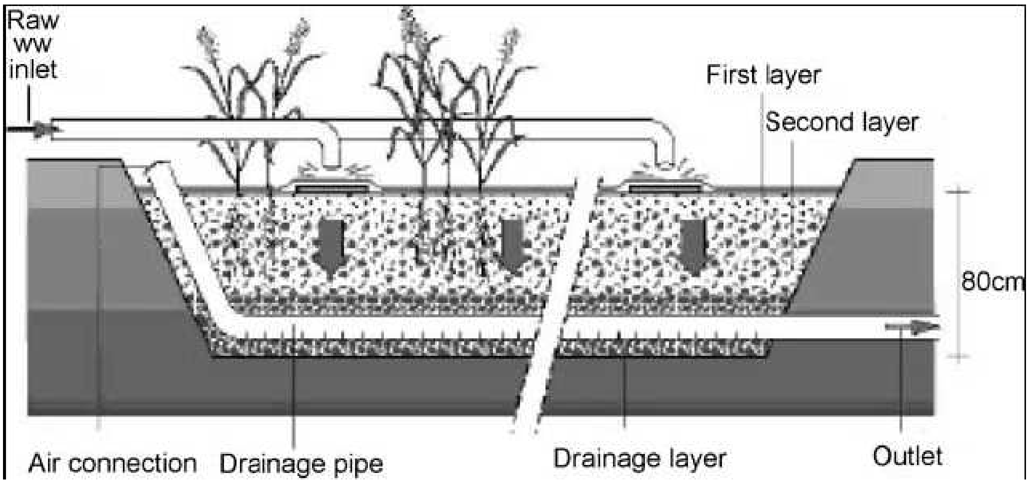


Figure 6: Schematic of the first stage French system (Molle et al., 2005)

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7. Further websites

Case study in Syria
http://www2.gtz.de/ecosan/download/ecosan-pds-015-Syria-HaranAlAwamied.pdf

Case studies Greywater treatment in Germany
http://www.otterwasser.de/english/concepts/lande.htm
http://www2.gtz.de/ecosan/download/ecosan-pds-004-Germany-Luebeck-Flintenbreite.pdf

General information about Constructed Wetlands
http://www.bodenfilter.de/engdef.htm

US EPA Manual
http://www.epa.gov/ordntrnt/ORD/NRMRL/Pubs/2001/wetlands/625r99010.pdf

EU Guide "Extensive Wastewater Treatment Processes"
http://europa.eu.int/comm/environment/water/water-urbanwaste/waterguide_en.pdf

EU project SWAMP focussing on natural wastewater treatment
http://www.swamp-eu.org/

CONSTRUCTED WETLANDS FOR WASTEWATER TREATMENT

Fabio Masi, Italy
Claudia Wendland, Germany
Nathasith Chiarawatchai, Germany

EMWATER
EFFICIENT MANAGEMENT OF WASTEWATER

TUHH
Technische Universität Hamburg-Harburg

Constructed Wetlands

DEFINITION:

"Constructed wetlands can be defined as engineered water saturated or unsaturated areas in which the natural removal processes for the water pollutants are reproduced and enhanced in order to optimize the purification performances"

EMWATER EFFICIENT MANAGEMENT OF WASTEWATER

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Classification

KIND OF USED MACROPHYTES

1. Floating macrophyte-based system
2. Submerged macrophyte –based system
3. Rooted emergent macrophyte –based system

KIND OF WATER FLOW DIRECTION

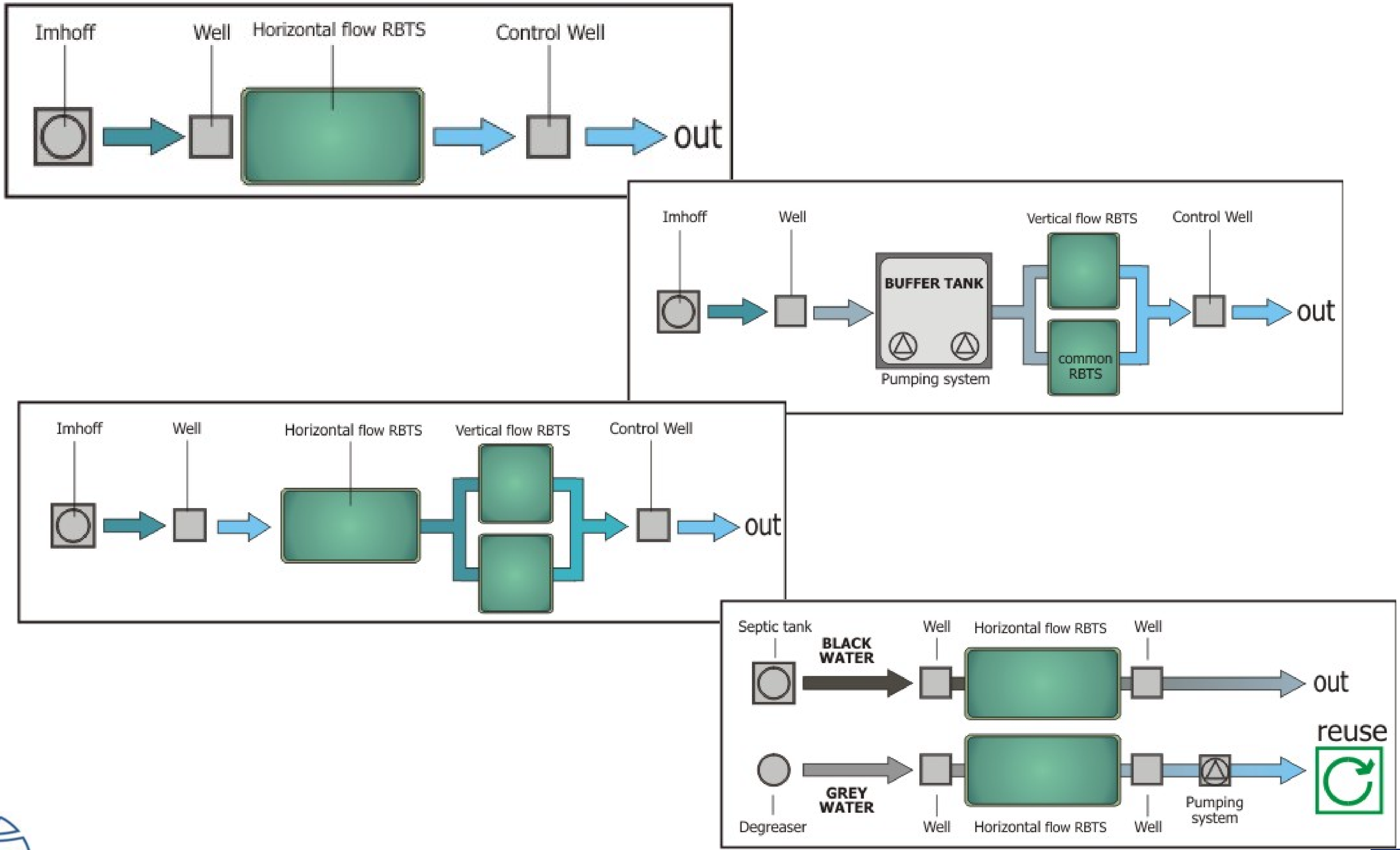
a) Systems with free water surface (FWS)

b) Systems with horizontal subsurface flow (HSF)

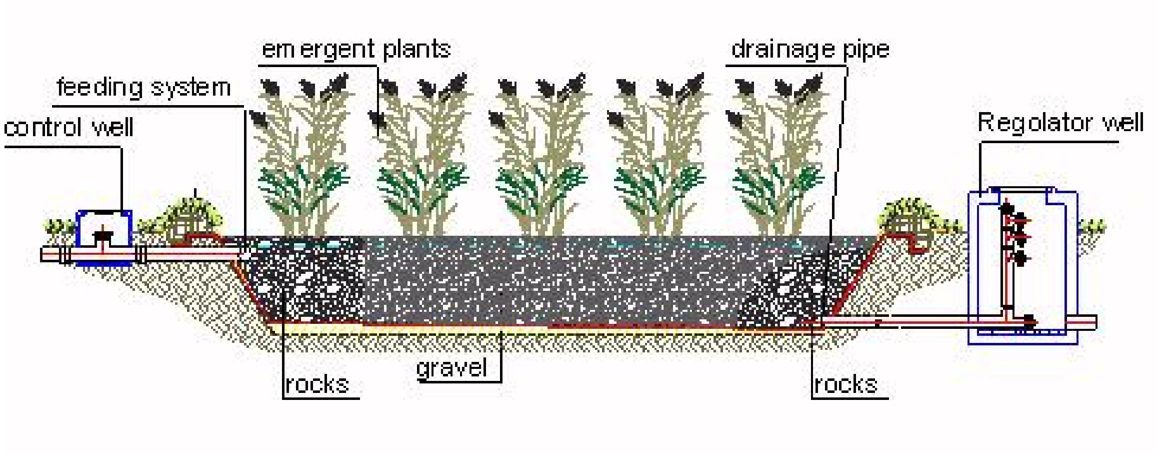
c) Systems with vertical subsurface flow (VSF)

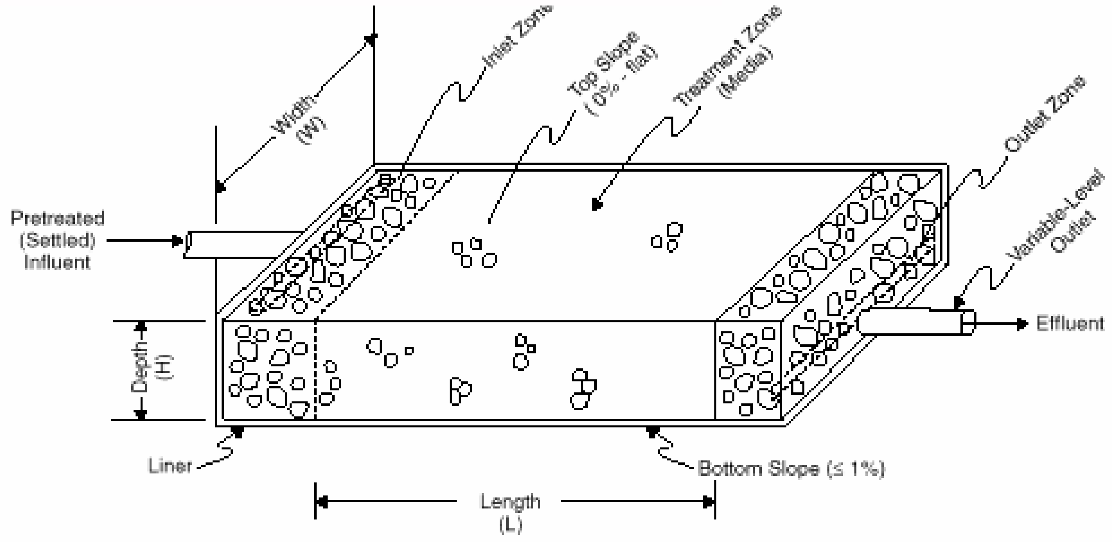
d) Hybrid systems (combinations of a,b,c)

Common configurations



Horizontal Flow Constructed Wetlands





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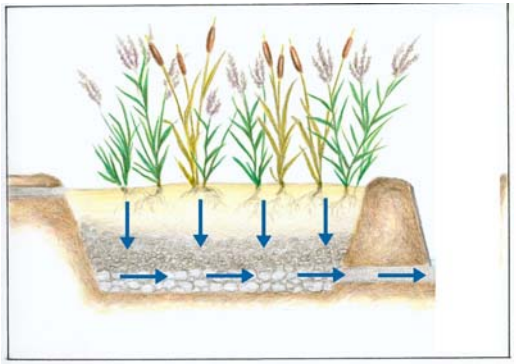
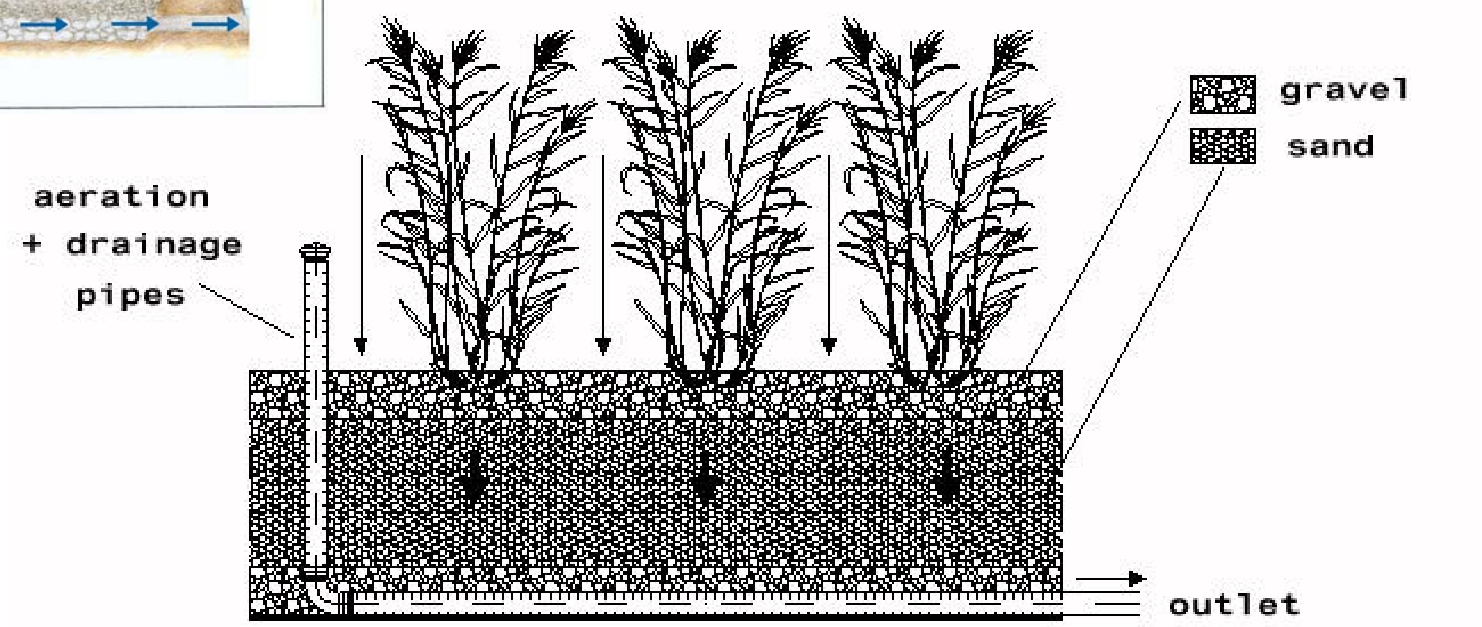
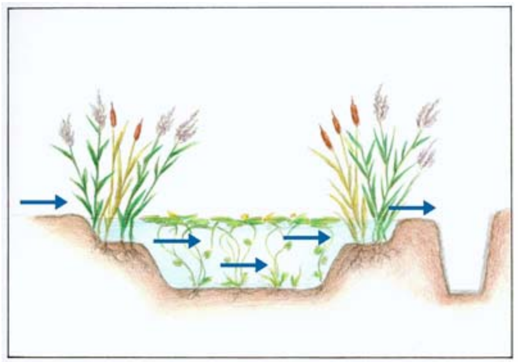
Vertical Flow Constructed Wetlands





Free Water Surface (FWS) Systems



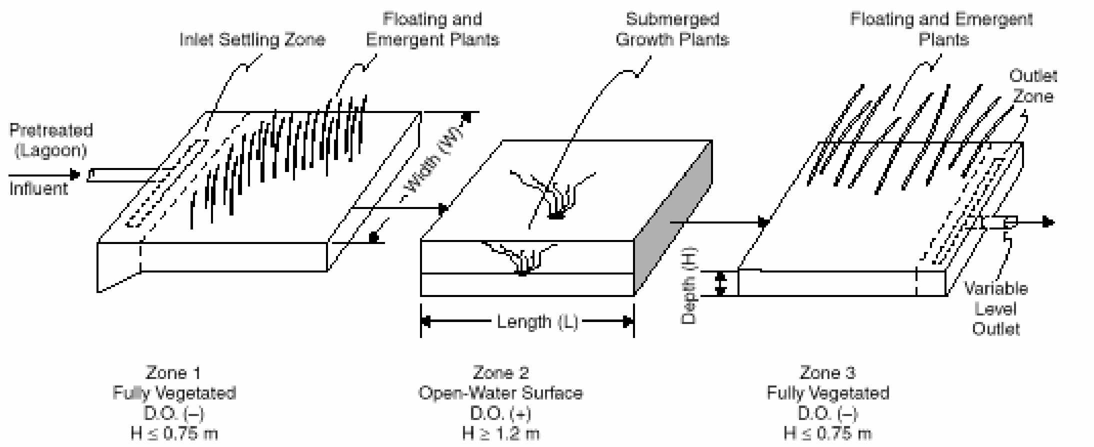
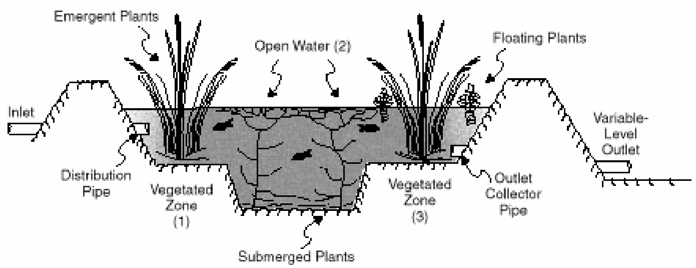


Figure 2-2. Elements of a free water surface (FWS) constructed wetland



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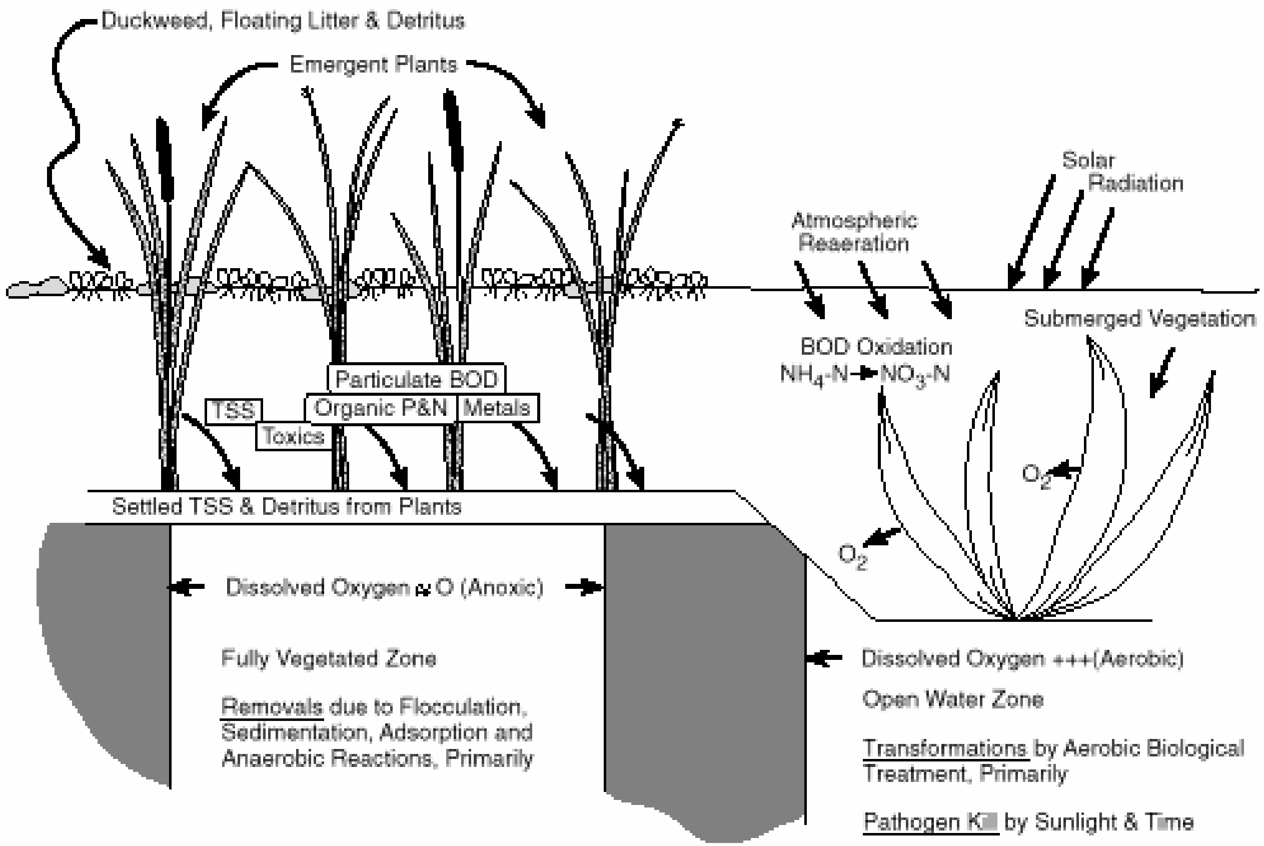
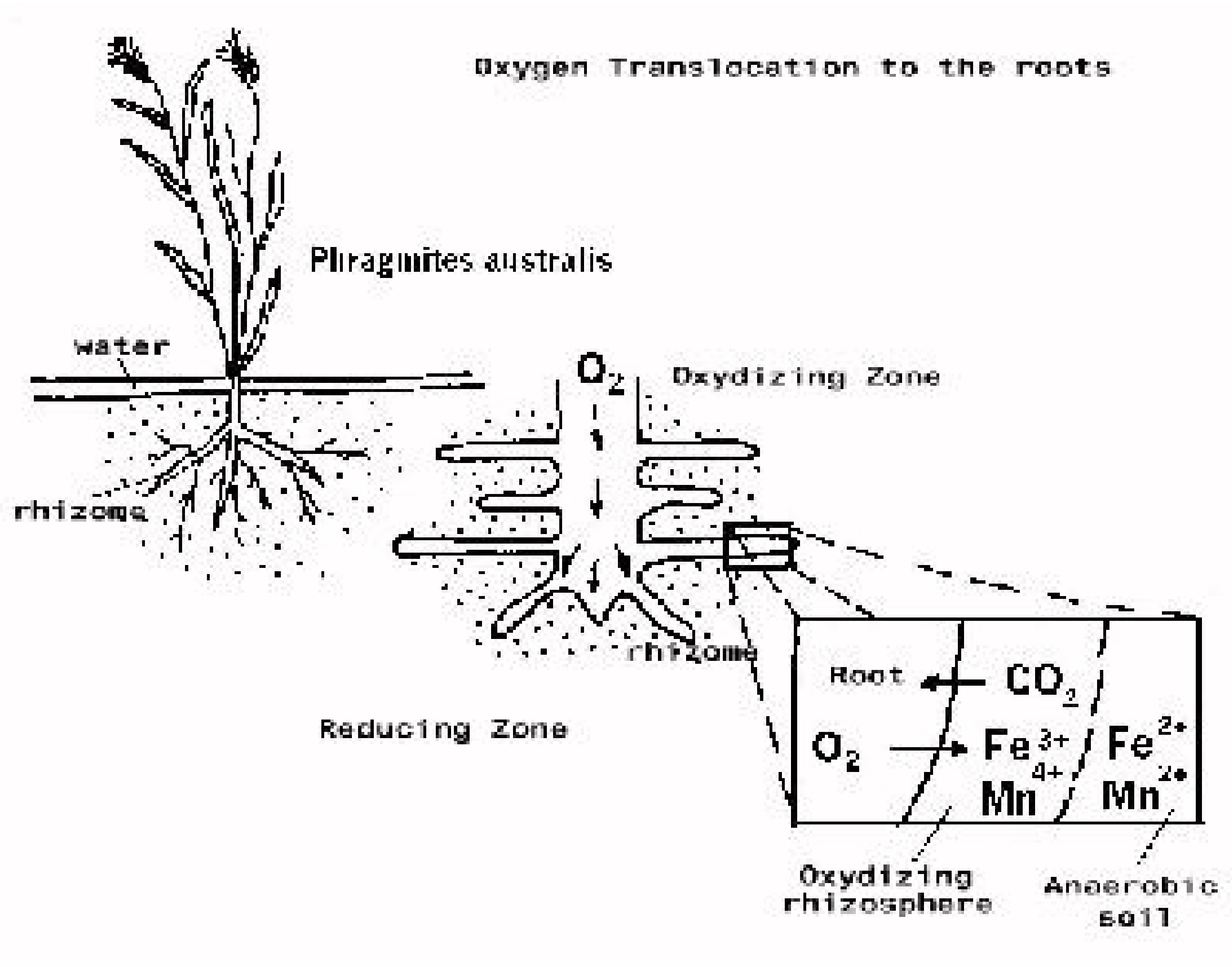
Removal mechanisms



Role of plants



Design Criteria

Hydrology

Hydraulic Retention Time

Hydraulic Loading Rate

Filling Media (porosity, hydraulic conductivity kf)

Redox conditions (aerobic, anaerobic, mix reactor)

Geometry of the bed

Waterproofing

Inlet and Oulet devices

Cells configuration (series and/or parallel)

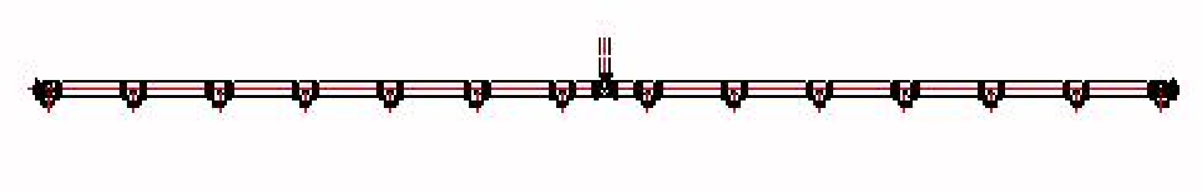
Choose of macrophytes

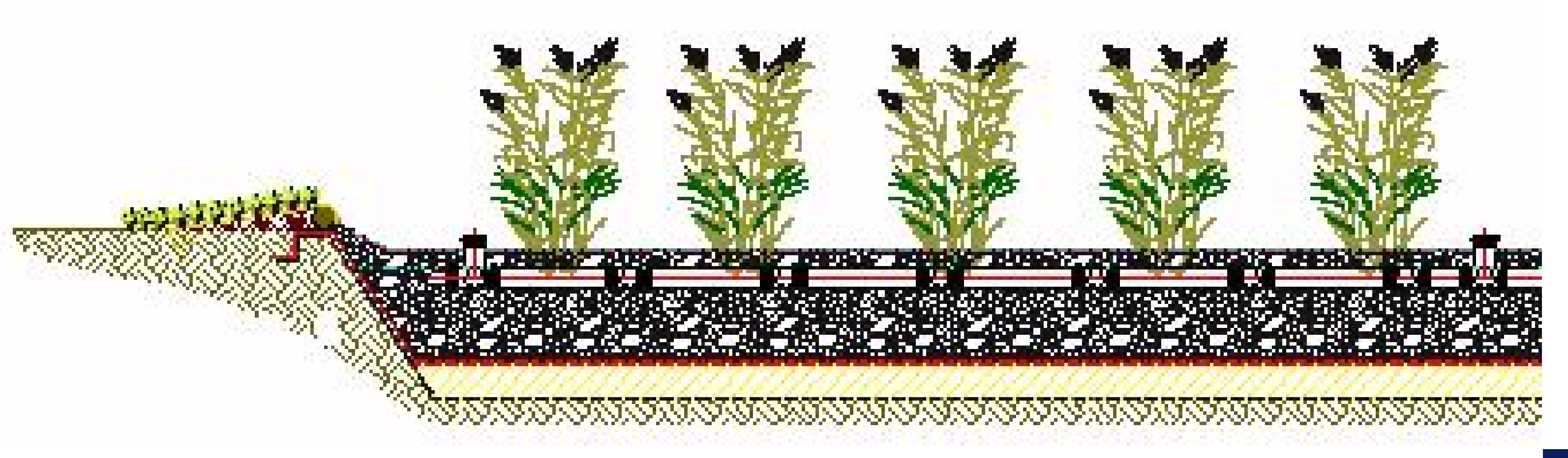
Treatment goals (in terms of specific pollutants overall removal)

HF systems design

Detailed Component Design:

Inlet device

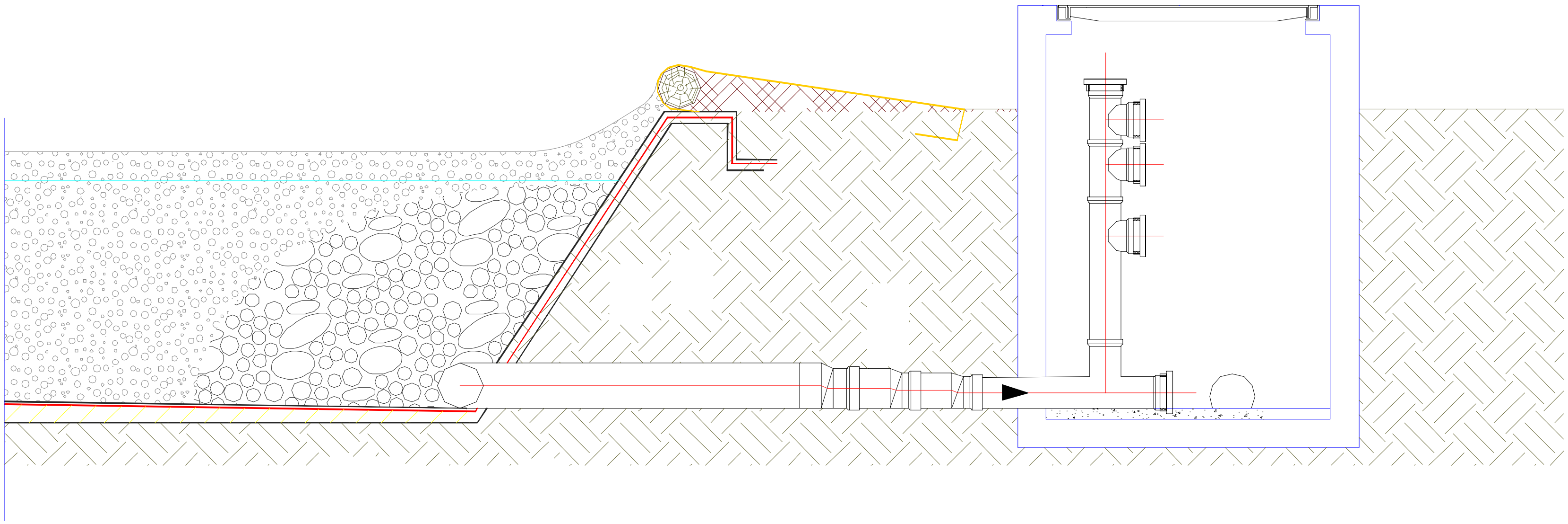




HF systems design

Detailed Component Design:

Oulet device



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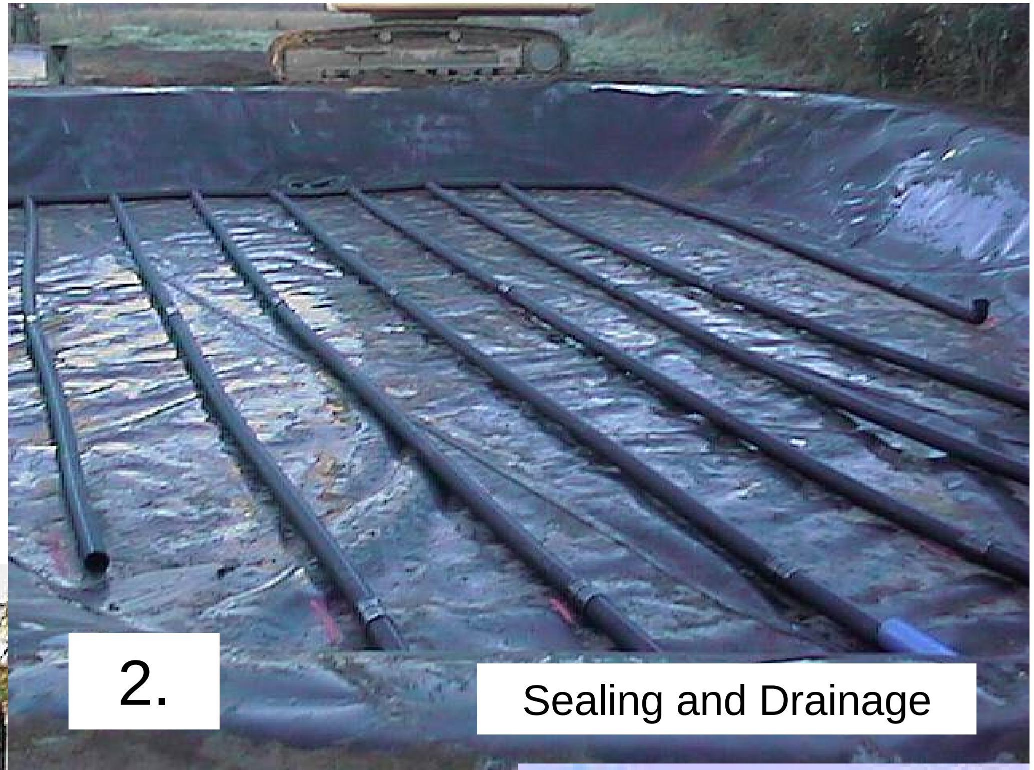
Vertical Flow CW Construction

Lübeck-Flintenbreite

www.flintenbreite.de/de/wasser1.html



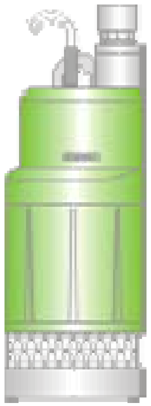
VF systems design

Feeding and distribution system

Syphons

Floating Valves

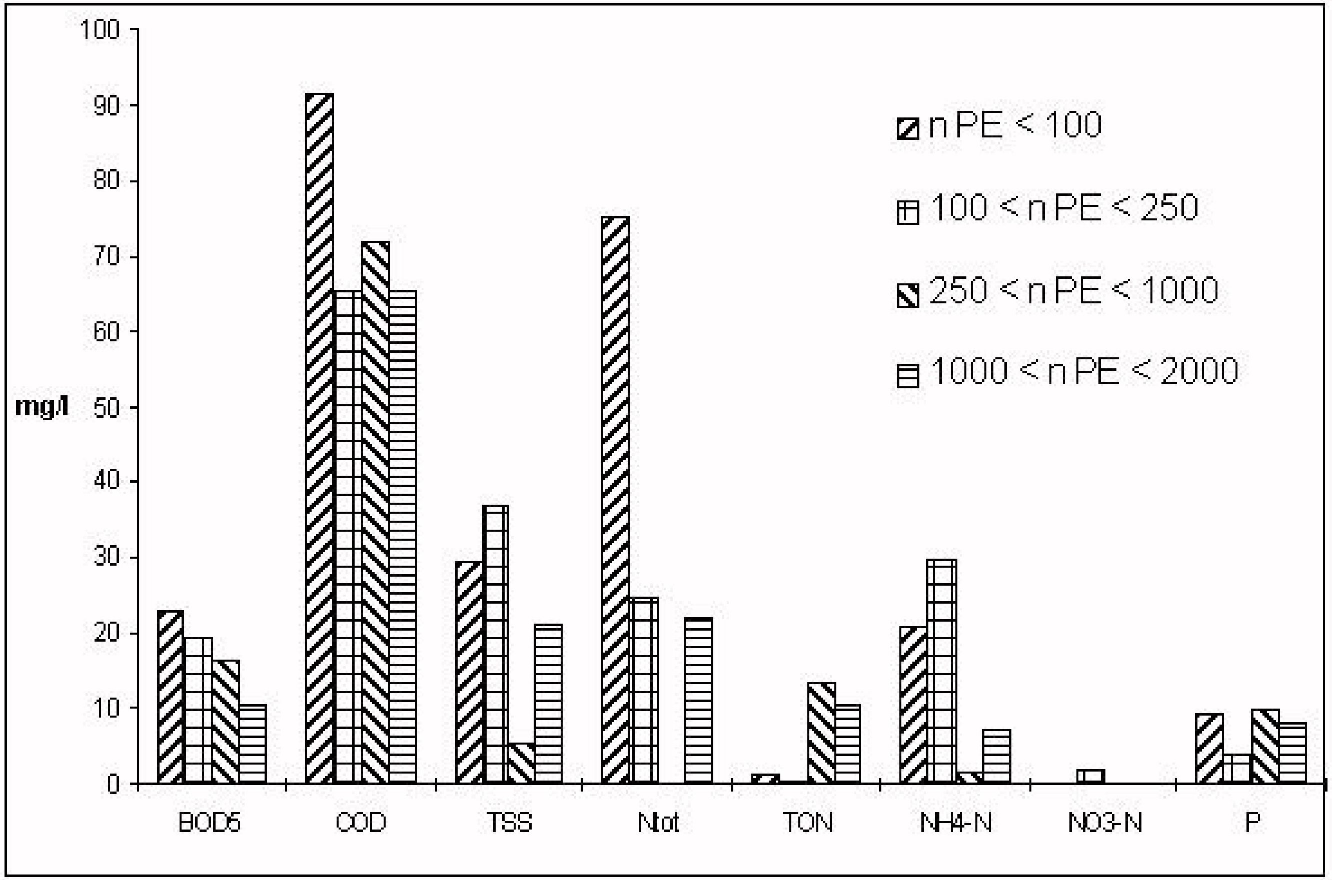
Distribution system



Electric Pumps

Performance

Mean outlet values on 213 european HF CWs for secondary treatment



1st Case study: Constructed wetland Haran-Al-Awamied, Syria

(A. Mohamed 2004)

- Combined public sewer system
- 7000 pe
- Pre treatment in a sedimentation tank
- 2-reed beds (68 m x 22 m x 1.5 m) for wastewater treatment
- A reed bed (20 m x 10 m x 1.8 m) for sludge treatment
- A 150 m^3 collection tank for treated water for irrigation purposes

http://www2.gtz.de/ecosan/download/ecosan-pds-015-Syria-HaranAlAwamied.pdf

Constructed wetland Haran-Al-Awamied Syria

A. Mohamed 2004

http://www2.gtz.de/ecosan/download/ecosan-pds-015-Syria-HaranAlAwamied.pdf

Parameter	Inlet	Outlet	Efficiency
COD mg/l	446	70	84%
BOD_5 mg/l	220	32	85%
PO_4-P mg/l	19,3	6,1	68%
NO_3-N mg/l	1	45	
Worm-Egg	-	1 egg/l	

2nd Case study: Treatment of „raw“ wastewater

French system by CEMAGREF: with 2 stages VSF

First stage of treatment: larger inlet size to prevent clogging

Molle et. al., CEMAGREF

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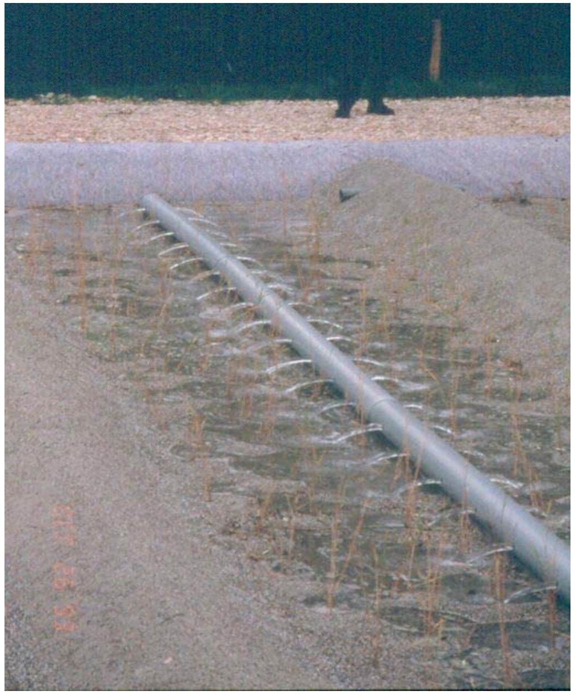
2nd Case study: Treatment of „raw“ wastewater

Second stage of treatment: finer inlet size to evenly distribute the wastewater



Molle et. al., CEMAGREF

EMWATER EFFICIENT MANAGEMENT OF WASTEWATER

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3rd Case study “Lambertsmühle”, Germany

Initiative and Finance:
- Wupperverband and Verein Lambertsmühle

Development of the Sanitation Concept
- Otterwasser GmbH, Lübeck

Scientific consultation
- TUHH Institute. of Wastewater Management

Elements of the Sanitation Concept:
- Urine-sorting Toilets and waterless Urinals
- Storage Tank for Yellow Water
- Pre-Composting Tank (2 chambers, Filter Bags)
- Constructed Wetland for filtered Grey- and Brownwater

EMWATER EFFICIENT MANAGEMENT OF WASTEWATER

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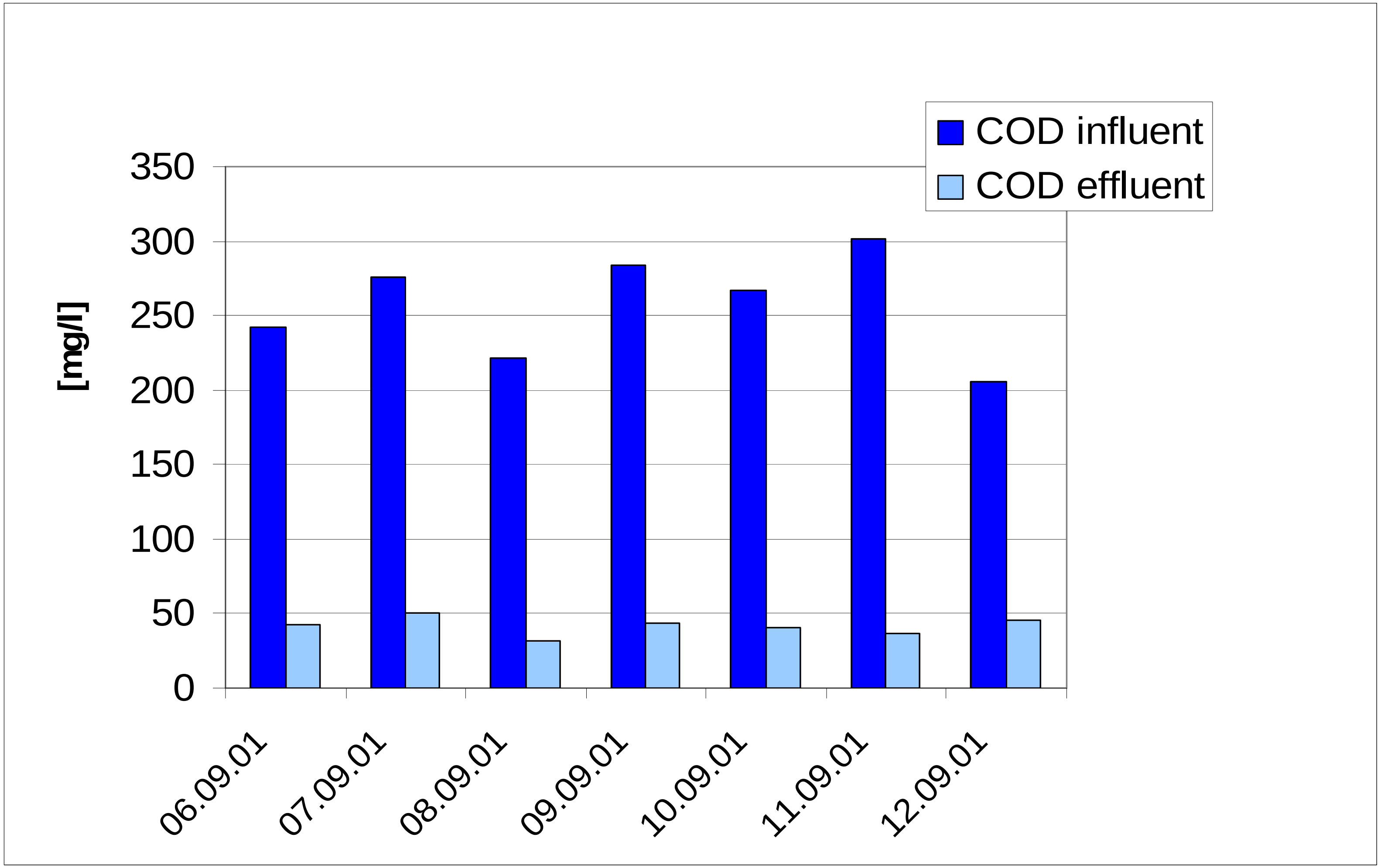
Pilot Project *Lambertsmühle*
Constructed Wetland - COD Concentrations



http://www.otterwasser.de/english/concepts/lande.htm

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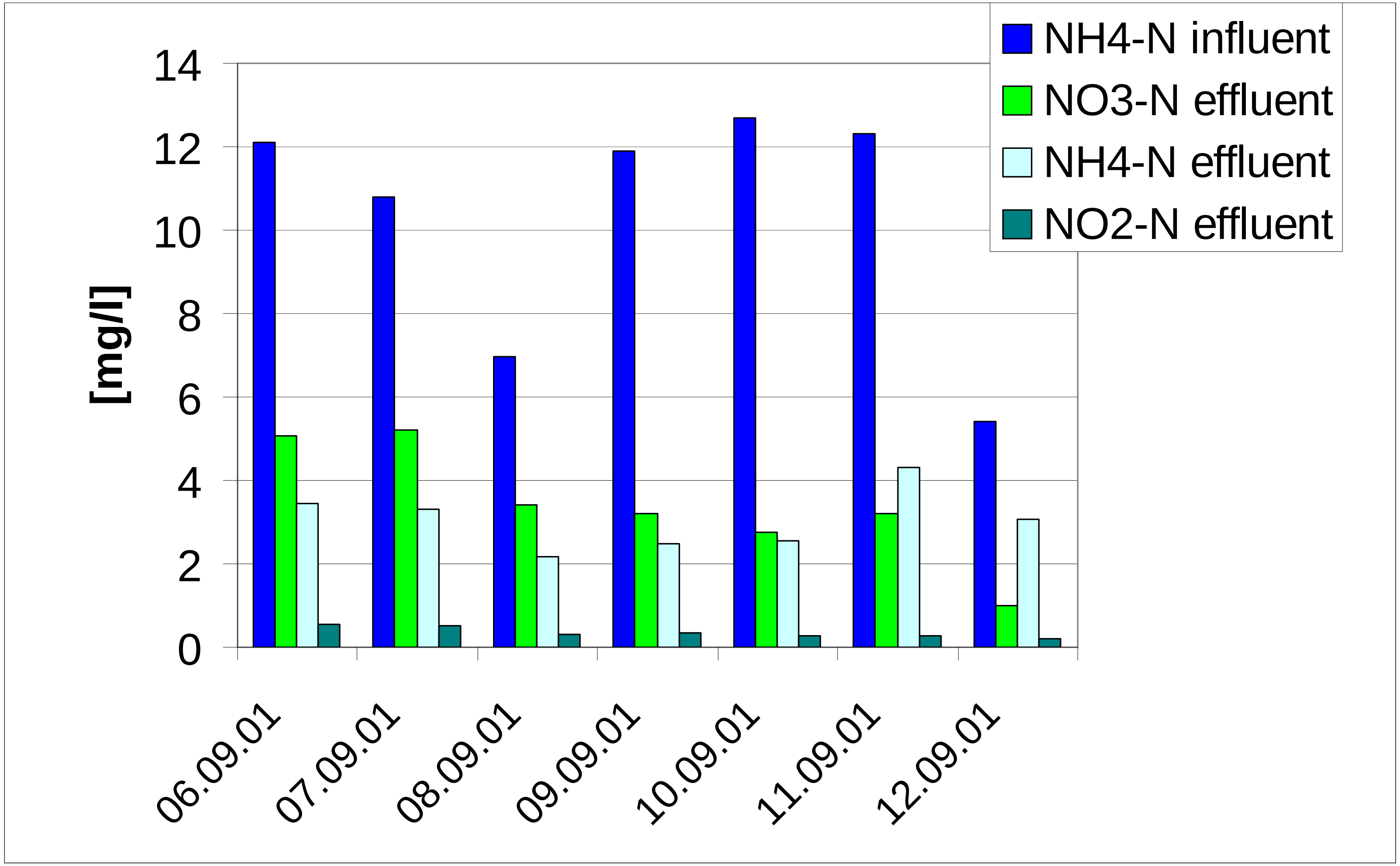
Pilot Project *Lambertsmühle*
Constructed Wetland - Nitrogen Concentrations



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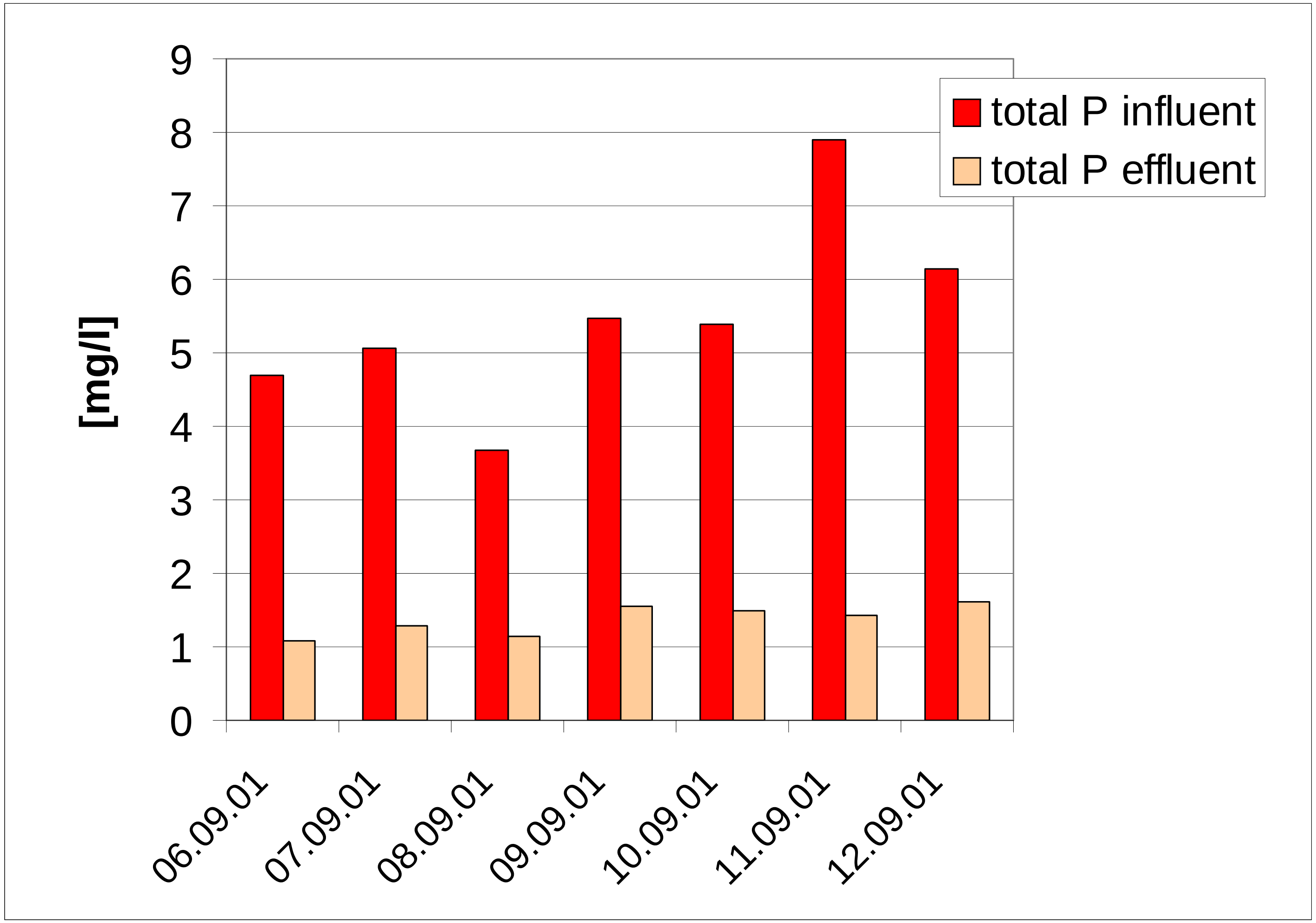

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THANK YOU

Lesson B5

SEWAGE SLUDGE TREATMENT

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sewage sludge, stabilisation, sludge thickening, sludge dewatering, sludge pumping, digestion

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Overview and summary of this Lesson

Sludge originates from the process of treatment of wastewater and is separated from the treatment process by sedimentation or flotation. Sewage sludge consists of water and solids that can be divided into mineral and organic solids. The quantity and characteristics of sludge depend very much on the treatment processes. Most of the pollutants that enter the wastewater get adsorbed to the sewage sludge. Therefore, sewage sludge contains pathogens (and heavy metals, many organic pollutants pesticides, hydrocarbons etc. if the sewage contains industrial influence). Sludge is, however, rich in nutrients such as nitrogen and phosphorous and contains valuable organic matter that is useful if soils are depleted or subject to erosion.

Options for sludge treatment include stabilisation, thickening, dewatering, drying. Sewage sludge is stabilised to reduce pathogens, to eliminate offensive odours and to inhibit, reduce or eliminate the potential for putrefaction. Moreover, stabilisation is used for volume reduction, production of usable gas (methane), and improving the dewaterability of sludge. Thickening, dewatering, drying are used to remove water from sewage sludge. Several techniques are used in dewatering devices for removing moisture. A technique close to nature and very effective is dewatering in drying beds. The principal advantages of drying beds are low costs, infrequent attention required, and high solids content in the dried product, especially in arid climates. Disadvantages are the large space required, effects of climatic changes on drying characteristics, labour-intensive sludge removal, insects and potential odours.

In this lesson source and characteristics of sewage sludge as well as methods of its treatment are discussed briefly. Natural treatment systems are focused. Also different options for sludge disposal are compared.

1. Sewage sludge quantity and characteristics

The sources of solids in a wastewater treatment plant vary according to the type of plant and its method of operation. Usually there are two sources of sewage sludge within the treatment process:

- solids in the affluent to the treatment plant which consist of settable organic matter and mineral substances which are not trapped in the grit chamber.
- biomass that has grown on the organic load (BOD)

Sewage sludge is separated from the treatment process by sedimentation or flotation. In many cases there is a primary sedimentation (primary sludge) and secondary sedimentation (secondary sludge). Smaller treatment plants often have only one sedimentation tank in which the entire sludge is separated from the treated water.

Sewage sludge consists of water and solids that can be divided into mineral and organic (volatile) solids. The quantity and characteristics depend very much on the treatment processes. The following table contains some of the most important information about sewage sludge for different treatment processes: the quantity per population equivalent (PE) and day, the water content and the percentage of volatile solids.

Table 1: Quantity and water content of sewage sludge from activated sludge plants

Process	**Specific production**	**Dried total solid content [TS]**	**Volatile solids [VSS]**
	[g TSS/(PE*d)]	%	% of TSS
Primary sludge (raw)	~45	2.5 - 7	60 – 75
Secondary sludge (raw) from trickling filters	~25	1 – 3	45 – 55
Secondary sludge (raw) activated sludge systems	~35	0.5 – 1.5	65 – 75
Aerobically stabilised primary and secondary sludge	~50 – 55	1.5 – 4	40 – 65
Anaerobically stabilised primary and secondary sludge	~50	0.8 – 2.5	40 – 55

As you can see, the biggest amount of sludge is produced by primary treatment which, of course highly depends on the hydraulic retention time in the primary sedimentation tank.

A big advantage of anaerobic wastewater treatment is the production of much less sludge than in aerobic systems because of low growing rates of anaerobic bacteria. If the primary and secondary treatment is replaced by an anaerobic step like a UASB reactor the sludge production is less than 10% of the aerobic system (see also lesson B3).

Among the unspecified “mineral” and “organic” solids are hazardous materials. Most of the pollutants that enter the wastewater get adsorbed to the sewage sludge. Therefore, sewage sludge contains heavy metals, many organic pollutants (pesticides, hydrocarbons etc.) and pathogens. The concentration depends on the industry, workshops or hospitals connected to the sewer system and their efforts to reduce the emission.

A very important class of substances are nutrients. Sewage sludge contains nitrogen (av. 2.6 % of TS), phosphorus (av. 2 % of TS), potash (av. 0.2 % TS). These elements, various trace elements and organic substances make sewage sludge a valuable fertilizer.

The purpose of sludge treatment is, besides hygienisation, to change the figures in the table above. Easily biodegradable volatile solids cause odour, that is why they should be reduced by stabilisation. A high water content (→ low percentage of total solids) makes the handling difficult, causes high cost for transportation and storage and should therefore be reduced.

2. Sludge pumping systems

Sludge produced in wastewater treatment plants must be conveyed from point to point in the plant in conditions ranging from a watery sludge to a thick sludge. Sludge may also be pumped off-site for long distances for treatment. For each type of sludge and pumping application a different type of pump may be needed.

Pumps can generally be divided into centrifugal pumps (with different impellers) and displacement pumps (progressive cavity (see figure1), rotary lobe, piston). Centrifugal pumps are suitable for high flow rates and low solid contents, the problem is choosing a proper size. At any given speed, centrifugal pumps operate well only if the pumping head is within a relatively narrow range. The variable nature of sludge, however, causes pumping heads to change. The selected pump must have sufficient clearance to pass the solids without clogging. Usual centrifugal pumps can cause the break up of flocculent particles in activated sludge. Good experiences in this respect have been made with screw-shaped impellers.

Table 2: Suitable pumps for sludge

Type of pump	Applicable for:	Advantages	Disadvantages
Centrifugal pumps	thin sludge (max. 2.5 - 3%)		
Nonclog	activated sludge	high volume, good efficiency	potential clogging (rags etc.)
Recessed impeller	sludge with solids or grit		lower efficiency
Chopper	primary sludge	reduces clogging	lower efficiency
Progressing cavity pump	thickened sludge dewatered sludge	defined flow rates acts as check valve	can run dry grit can cause high stator wear
Rotary lobe pump	thickened sludge dewatered sludge	defined flow rates acts as check valve	grit can cause high lobe wear
Piston pump	thickened sludge dewatered sludge	high pressure	discontinuous flow
Screw pump	activated sludge	good efficiency	limited height high capital costs space requirement
Screw	dried sludge		
conveyor belt	dewatered sludge dried sludge	good efficiency	high capital costs space requirement

Displacement pumps can convey dewatered sludge up to 30% TS. Displacement pumps have a fixed ratio between revolutions and flow rate. Any pipeline obstruction causes damages to the pipeline or pump. Generally check valves are not necessary. For primary sludge, a grinder normally proceeds progressive cavity pumps.

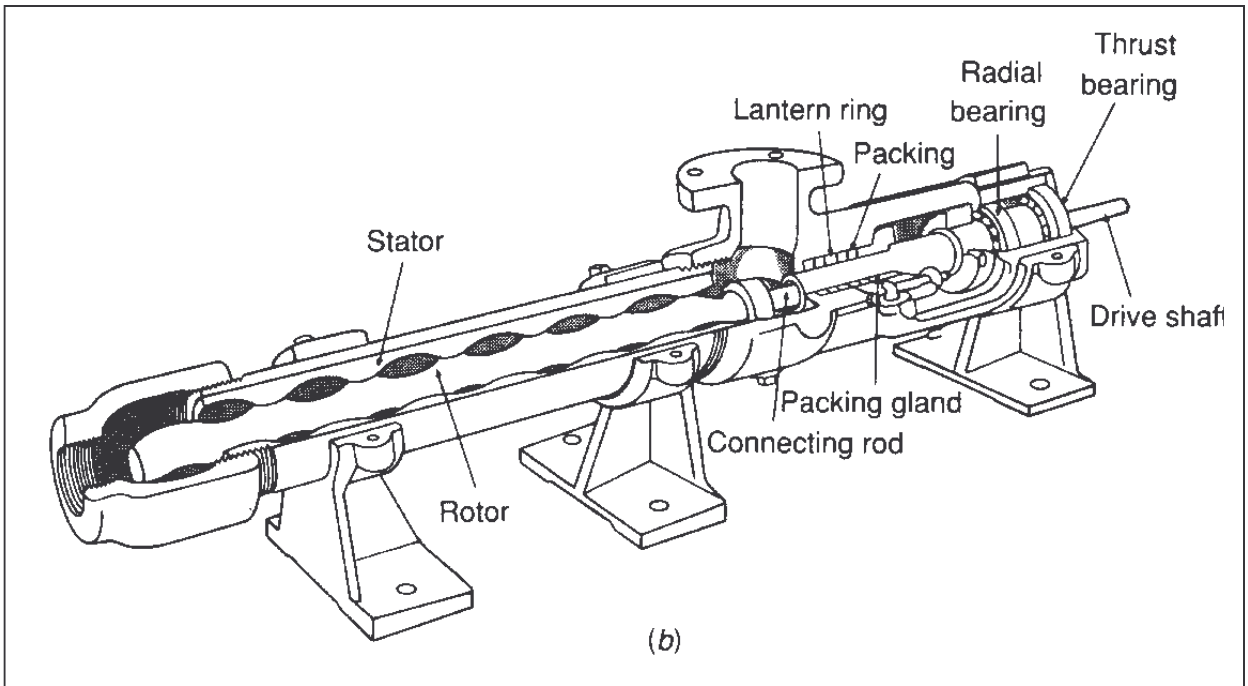


Figure 1: Scheme of a progressive cavity pump

3. Sludge stabilisation

Sewage sludge is stabilised to reduce pathogens, to eliminate offensive odours and to inhibit, reduce or eliminate the potential for putrefaction. The success in achieving these objectives is related to a reduction of the organic (volatile) fraction or the addition of chemicals to the sludge to render it unsuitable for the survival of microorganisms.

In addition to the health an aesthetic reasons mentioned above, stabilisation is used for volume reduction, production of usable gas (methane), and improving the dewaterability of sludge.

In some cases a sludge disinfection is required to meet the standard for agricultural reuse (see 3.4 to 3.6).

3.1 Simultaneous aerobic stabilisation

A very simple method to achieve a stabilised sludge is the simultaneous aerobic stabilisation. To provide growth conditions for the microorganisms for an adequate wastewater treatment, a certain solid retention time (→ sludge age) is necessary. It differs due to the temperature and the demanded nitrogen removal between approx. 4 and 12 days. If the sludge age is extended up to more than 20 days (Germany: 25 due to low temperatures) the content of organic matter, especially easily degradable organic matter, is reduced and the sludge is stabilised. This concept generally eliminates a primary sedimentation, solids from the effluent are treated in the aeration tank. This process approach is attractive for smaller communities, where space is not an issue and less complex operation is preferred. The large aeration tank volume provides good equalisation at high flow and loading occurrences and a high quality effluent is produced.

A disadvantage is the higher energy demand caused by the extension of the aerated time. The increased capital costs for the larger aeration tanks are in general more than compensated by the omitted facilities for an external stabilisation.

3.2 Mesophilic anaerobic digestion

Anaerobic digestion is among the oldest processes used for the stabilisation of sewage sludge. Anaerobic digestion involves the decomposition of organic and, on a low level, inorganic matter (principally sulphate) in the absence of oxygen. The main products are CO_2 and CH_4 (methane). With this digester gas most of the energy needs for the plant operation can be met. Methane is highly relevant to global climate change, thus uncovered digesters without methane use (and burning to CO_2) should be avoided. According to the four-step model the following processes are involved:

1. *hydrolysis*: particulate material is converted to soluble compounds that can then be hydrolysed further to simple monomers

2. *acidogenesis*: in this step, also called fermentation, amino acids, sugars and higher (long chain) fatty acids are degraded further to volatile fatty acids, alcohols, acetic acid, hydrogen, carbon dioxide, ammonia and sulphide.

3. *acetogenesis*: the volatile fatty acids and alcohols are degraded to acetic acid, hydrogen and carbon dioxide

4. *methanogenesis*: this step is carried out by a group of bacteria called methanogens. Two groups are involved in methane production. One group split acetic acid into methane and carbon dioxide. The second group, termed hydrogen-utilising methanogens, use hydrogen as the electron donor and carbon dioxide as an electron acceptor to produce methane.

See also figure 2.

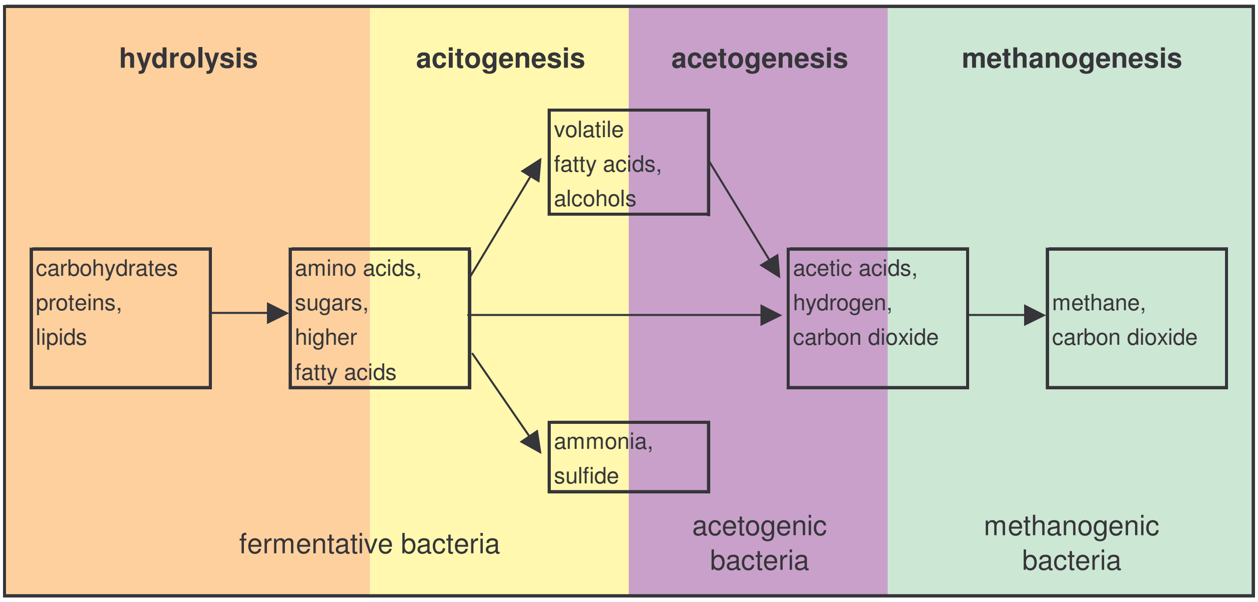


Figure 2: Four-step model of methane production

The microorganisms responsible for methane production are strict obligate anaerobes. They need darkness and heat speeds up their activity. Heated digesters are operated at 37°C (mesophilic) or 55°C (thermophilic).

As the four step model above shows, hydrogen is formed during the fermentative steps and consumed during methanogenesis. If process upsets occur and the methanogenic organisms do not utilise the hydrogen produced fast enough, the acetogenesis will be slowed with the accumulation of volatile fatty acids in the anaerobic digester and a possible reduction in pH. If an accumulation of volatile fatty acids is observed, the organic load has to be reduced. On the other hand the reaction

$$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$$

needs a certain H_2 - partial pressure to take place. Still the methanogenesis is the limiting step.

The important difference to the aerobic metabolism, where carbon dioxide is produced, is that highly energetic source substances are split into carbon dioxide and methane with high energy content. This makes obvious that the energy gain from the anaerobic reactions is very low. In consequence the growth of anaerobic bacteria is comparatively slow.

The volume ratio between CH_4 and CO_2 in digester gas is about 0.65 : 0.35 and differs according to different substrate compositions (proteins, lipids, carbohydrates).

The quantity of methane gas can be calculated using the following equation:

$$V_{CH_4} = (0.35) * Q/1000 * [(S_0 - S) - 1.42 P_x]$$

$$P_x = Y * Q (S_0 - S)/1000 / (1+k_d)$$

V_{CH_4} = volume of methane produced at standard conditions (0℃, 1 atm) [m³/d]

Q = flow rate [m³/d]

S_0 = COD in influent [mg/l]

S = COD in effluent [mg/l]

P_x = net mass of cell tissue produced per day [kg/d]

Y = yield coefficient [gVSS/gCOD] typical values: 0.05 to 0.1

k_d = endogenous coefficient [1/d] typical values: 0.02 to 0.04

The efficiency (ratio between S_0 to S) can be estimated to 50 to 70 %.

Note: The methane volume is calculated at normal conditions. At higher temperatures the gas volume increases according to the gas law. To compute the volume of digester gas, the methane volume has to be divided by the methane content, e.g. 0.65.

As a result of the degradation of organic matter and the conservation of the water there is a remarkable attenuation of TS during digestion. The change in TS follows the following equation:

$$TS = TS_0 * (100-VSS_0)/(100-VSS)$$

TS = total solids after digestion [kg]

TS_0 = total solids before digestion [kg]

VSS = volatile solids after digestion [% TS]

VSS_0 = volatile solids before digestion [% TS]

If the percentage of volatile solids (VSS) is reduced from 75% of TS to 50% of TS, the total solids will be halved. As a consequence the content of TS (%TS) will roughly halve as well. (Only roughly, because the sum of TS and water attenuates, too.) According to this fact it is advisable to keep the TS in the influent to a digester as high as possible. Therefore primary and secondary sludge have to be thickened in a static or mechanic thickener.

The design criteria for digesters are:

- retention time (20 to 25 days at 37℃)
- organic load (3 to 4 kg/(m^3*d))

Digesters have to be mixed, usually by mechanical mixing, biogas injection or mechanical pumping. A group of digesters can be seen in figure 3.

Figure 3: Ankara Sludge Digester

3.3 Aerobic digestion

Aerobic digestion is similar to the activated-sludge process. As the supply of available substrate is depleted, the microorganisms begin to consume their own phytoplasm to obtain energy for cell maintenance reactions. Cell tissue is oxidised aerobically to carbon dioxide, water and ammonia. The ammonia is subsequently oxidised to nitrate as digestion proceeds. In actuality only 75 to 80% of the cell tissue can be oxidised, the remaining 20 to 25% is composed of inert components and organic compounds that are not biodegradable. The biochemical changes in an aerobic digester can be described by the following equation (biomass: $C_5H_7NO_2$).

$$C_5H_7NO_2 + 7O_2 \rightarrow 5\ CO_2 + 3H_2O + HNO_3 \text{ (overall equation including nitrification)}$$

Aerobic digesters can be operated at ambient temperatures or at thermophilic conditions (55℃). Aerobic digestion is an exothermic process which can heat up the digester to 70℃ without additional heating if the tank is isolated and the organic load is sufficient. Because supplemental heat is not provided, the process is called autothermal.

Compared to anaerobic digestion there are some advantages (+) and disadvantages(-):

+ lower BOD concentrations in supernatant liquor
+ recovery of more of the basic fertilizer values in the sludge
+ operation is relatively easy
+ lower capital costs
- high power cost for supplying the required oxygen
- digested solids have poorer mechanical dewatering characteristics
- no useful by product (methane) is recovered

To meet high requirements for pathogen reduction, retention times at 15℃ and 20℃ have to be 40 and 60 days, respectively. At thermophilic conditions 6-8 days are sufficient.

3.4 Alkaline Stabilisation

Alkaline stabilisation is a method to render the sludge unsuitable for the survival of microorganisms by adding alkaline material (usually lime) and raising the pH to 12 or higher. An advantage is that a rich product results with substantially reduced pathogens. This sludge has to be applied in agriculture carefully, for it can disturb the pH in the soil, especially in sandy soils. A disadvantage is that the product mass is increased by the addition of lime and that at falling pH-values the microbial activity can restart and odours can be produced. If the sludge contains high ammonia (NH_4) concentrations, for example after anaerobic processes, the increased pH-value changes the NH_4/NH_3 equilibrium towards NH_3, which has a strong, unpleasant odour.

Among the chemical reactions that take place are the following ones:

$Ca^{2+} + 2HCO_3^- + CaO \rightarrow 2CaCO_3 + H_2O$

$2PO_4^{3-} + 6H^+ + 3CaO \rightarrow Ca_3(PO_4)_2 + 3H_2O$

$CO_2 + CaO \rightarrow CaCO_3$

3.5 Thermophilic anaerobic digestion

Thermophilic anaerobic digestion follows the same biological processes as mesophilic anaerobic digestion. It plays a minor role in sewage sludge stabilisation because of higher energy cost and bad odor production. However, many activities on thermophilic digestion are currently driven in the US by bans of Class B biosolids land application and requirements of Class A disinfection standards for biosolids (40 CFR Part 503; US EPA, 1993). Thermophilic digestion in full scale is usually run at temperature from 55-60^{0}C (Ahring, 1994, van Lier, 1996) where the methanogenic bacteria have a max growing rate.

Thermophilic anaerobic digesters consist (like mesophilic ones) of the following basic components: feedstock storage and handling system, digestion tank, gas and residue recovery systems. The digestion tank requires a mixing system which can either be mechanical or achieved by bubbling the biogas through the organic slurry. The digester can be either above or below ground level and should be insulated. In Northern Europe the digester would be fitted with internal heat exchangers to maintain temperatures close to the thermophilic optimum for the methane bacteria (about 55^{0}C). Thermophilic systems offer several advantages, including often higher methane production, faster throughput (smaller hydraulic retention time: 5-10 days), better pathogen removal and the prospect of compost production to a consistent standard. Disadvantages are reported as a more unstable process and more difficulties in operation like the tendency of foaming.

3.6 Pasteurization

In order to kill pathogens, pasteurization is a common technologie which can also be applied on sewage sludge. FAO requires a minimum of 30 minutes at 70℃ or minimum of 4 hours at 55° C (or appropriate intermediate conditions), followed in all cases by mesophilic anaerobic digestion (FAO, 1992). But in this case the hygienisation is not guaranteed because pathogens easily regrow in mesophilic conditions. It is more safe to pasteurize at the end of the treatment process.

4. Thickening/ dewatering of Sludge

Removal of water from liquid sewage sludge is divided into 3 different processes:

- thickening (up to approx. 9% TS)
- dewatering (up to approx. 35% TS)
- drying (up to approx. 100% TS)

At low TS contents the volume changes significantly with varying TS contents. If the TS goes up from 1 to 3%, the resulting volume is one third!

Gravity thickening shown in figure 4 is one of the most common methods in used and is accomplished in a tank similar in design to a conventional sedimentation tank. Normally, a circular tank is used, and dilute sludge is fed to a center feed well. The feed sludge is allowed to settle and compact and the thickened sludge is withdrawn from the bottom. Vertical pickets stir the sludge gently, thereby opening up channels for water to escape and promoting densification. The supernatant flow that results is drawn off and returned to either the primary settling tank, the influent of the treatment plant or a return-flow treatment process.

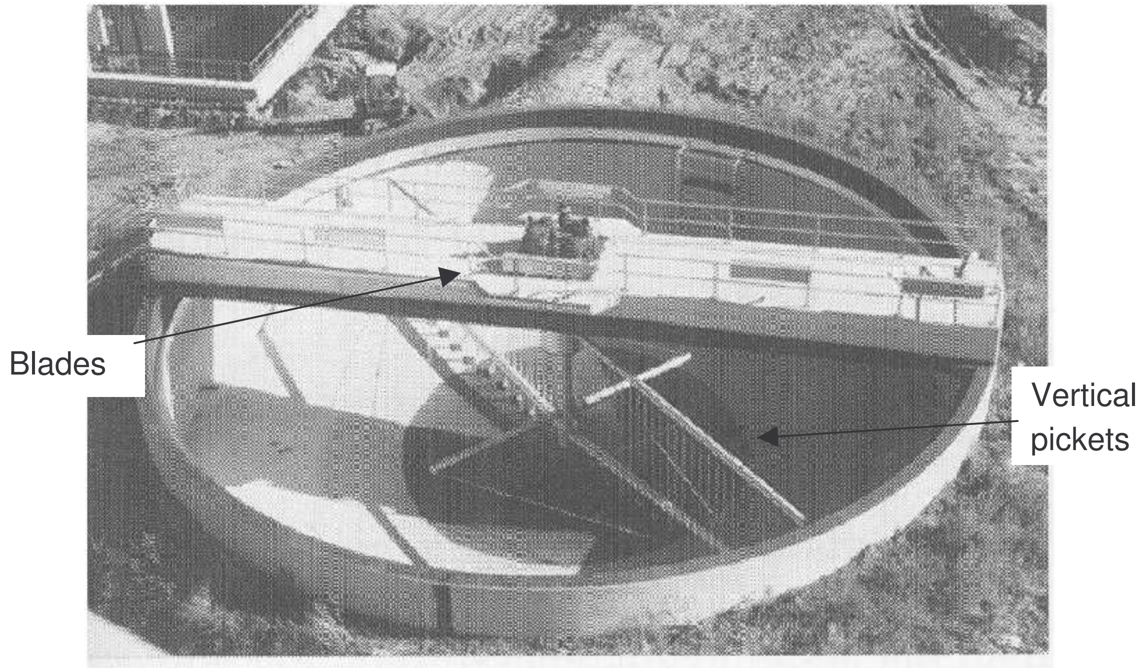


Figure 4: Gravity thickner

In gravity thickeners two zones can be distinguished: above the sludge blanket there is the sedimentation zone. Below the sedimentation zone is the compaction zone located, where the increased density of the sludge helps to “squeeze out” water. The mechanical compression rises with the height of the compaction zone.

4.1 Dimensioning of a static thickener

The dimensioning includes finding the required surface area and the volume of the thickener. The surface area can be calculated based on the solid loading rate [kg/(m²*d)] and the volume based on a maximum sludge retention time.

Table 3 shows achievable solid concentrations and solid loadings for various sludges. The daily solid load divided by the solids loading rate gives the required surface area.

Now the maximum hydraulic overflow rate at peak flow conditions has to be checked. Recommended maximum hydraulic overflow rates range from 0.6 to 1.5 m/h for primary sludges, 0.15 to 0.35 m/h for secondary sludges and 0.25 to 1.0 m/h for combined primary and secondary sludge. High hydraulic loadings can cause excessive solids carryover. Conversely, low hydraulic loading can cause septic conditions and odours and floating sludge can result. In the second case dilution water can help maintaining the optimal hydraulic loading. The height of the sedimentation zone should be generally 1 m.

To compute the volume of the compaction zone, the solid loading at thickened conditions has to be multiplied by the maximum retention time. For central Europe 36h are common, at warmer climates this value should be reduced. The solids concentration in the sludge blanket attenuates with increasing height, therefore the values for the concentration of thickened solids have to be reduced by the multiplication factor 0.75. On the bottom of the thickener 0.3 m should be added for the scrapers.

Table 3: Concentrations of different sludges and solids loadings

Type of sludge	**Solids concentration unthickened**	**Solids concentration thickened**	**Solids loading**
	[%]	[%]	[kg/(m²*d)
Primary sludge	2-6	5-10	100-150
Trickling filter sludge	1-4	3-6	40-50
Activated sludge	0.5-1.5	2-3	20-40
Extended aeration activated sludge	0.2-1.5	2-3	25-40
Primary and trickling filter sludge	2-6	5-9	60-100
Primary and activated sludge	0.5-1.5 2.5-4	4-6 4-7	25-70 40-80

Thickening can be achieved by mechanical devices, too. Examples are rotary-drums and gravity-belt thickeners. Solid contents up to 9% can be achieved. Centrifuges are suitable for both, thickening and dewatering. Disadvantages are the need for polymers, electrical energy and relatively high expenditures for operation personnel.

4.2 Dewatering

Dewatered sludge is generally easier to handle than thickened or liquid sludge. For some options for disposal or further treatment dewatering is necessary:

- mechanical sludge drying
- sludge composting
- landfilling
- trucking over longer distances

Several techniques are used in dewatering devices for removing moisture. Some of these techniques rely on natural evaporation and percolation to dewater the solids. In mechanical dewatering devices, mechanically assisted physical means (filtration, squeezing, capillary action, centrifugal separation, compaction) are used to dewater the sludge more quickly. The most important mechanical devices are:

- solid-bowl centrifuge (25 – 30%TS)
- belt-filter press (25 – 30%TS)
- recessed-plate filter press (30 – 40%TS)

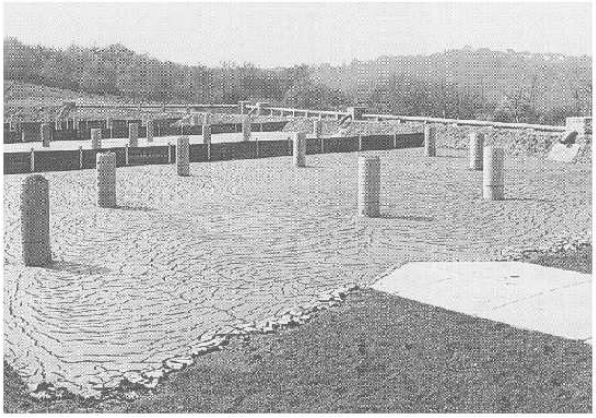
These techniques are not discussed here since they are economically and ecologically not feasible in small and rural waste water treatment plants.

A technique close to nature and very effective is dewatering in drying beds (figure 5). The principal advantages of drying beds are low costs, infrequent attention required, and high solids content in the dried product, especially in arid climates. Disadvantages are the large space required, effects of climatic changes on drying characteristics, labour-intensive sludge removal, insects and potential odours. The most common type are sand drying beds, where the sludge is placed on a bed 200 to 300 mm layer and is allowed to dry. Sludge dewaters by drainage through a drainage system consisting of gravel (200mm), coarse (75mm), fine sand (150 mm) and drainage pipes and by evaporation from the surface exposed to the air. To prevent water from percolating into the soil there has to be a sealing foil.

The drying area is partitioned into individual beds of a convenient size so that one or two beds will be filled in a normal loading cycle (depends on gravity thickener volume). The interior partitions commonly consist of two or three planks, one on top of the other, to a height of approx. 400 to 500 mm. They can be made of concrete, as well. The outer boundaries may be of similar construction or may be earthen embankments or concrete.

Table 4: Typical area requirements for open sludge drying beds (may differ due to extreme climates)

Type of sludge	**Required area**	**Sludge loading rate**
	[m^2/PE]	[kg TS/(m^2*a)]
Primary sludge, digested	0.1	120 - 150
Primary and trickling filter humus digested	0.12 – 0.175	90 - 120
primary and secondary sludge digested	0.16 – 0.23	60 - 100



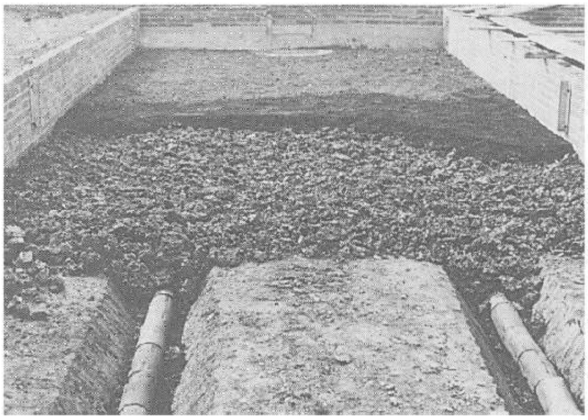


Figure 5: Sludge drying beds

An alternative to this simple sludge drying are sludge humification beds, where the drying process is supported by plants (figure 6). Furthermore biological activity is enhanced, stabilisation is continued and a soil-like character of the sludge is achieved.

Sludge humification beds are constructed like sludge drying beds, only the depth is increased to approx. 1m. Two different kinds of plants are use: reed or grass. Reed is planted into the humification beds and small amounts of sludge (2 – 2.5 kgTS/m²) are applied every two weeks and after 8 to 10 years the dewatered and humificated sludge can be taken out and used further.

Sludge humification with grass works a little different. A higher amount of sludge is applied to drying beds (20 – 25 kgTS/m²) and after some days of drainage grass is seeded into the sludge manually. The grass grows and the roots penetrate the sludge. They provide ventilation and dewatering in deeper layers (not only at the surface like at sludge drying). After a few months (3 – 7) another layer of sludge is applied onto the grass and grass is seeded again. This can be repeated for 2 to 5 years. The sludge is dewatered up to 40 – 60 %TS and pathogens are reduced significantly. An example of sludge after humification can be seen in figure 7.

Figure 6: Sludge humification plant in operation

Figure 7: Sludge after humification

5. Sludge Disposal and Agricultural Utilisation

Common options for sludge disposal and their major advantages and disadvantages are given in table 5.

Table 5: Sludge disposal systems and their advantages and disadvantages

Disposal option	Advantage	Disadvantage
Landfill	- no spreading of heavy metals	- no nutrient recovery - danger of groundwater infiltration
Incineration	- phosphorus recovery possible (but rarely done) - no spreading of heavy metals	- loss of nitrogen - expensive
Agricultural utilisation	- full nutrient recovery - cheap fertiliser - low disposal costs	- heavy metals and organic pollutants are applied, too - may be pathogens are spread
Application to disturbed land	- low disposal costs	- concentrated application of heavy metals and organic pollutants

Land application is likely to remain as a mayor option for the future, particularly for smaller plants in rural areas which are generally less contaminated by toxic compounds and close to disposal sites. However, agricultural use is subjected to a great variability over time, depending on crop type and weather conditions while sludge production is continuous. For this option, the presence of pathogens, heavy metals and organic contaminants is important. Risks from pathogens can be properly reduced by applying available technologies but costs vary widely depending on product quality criteria, local, social and economical structure. Heavy metals and organic micropollutants arise mainly from chemicals used in industry and households. They can be controlled through cleaner technologies, reduced use and spillage and processes in the treatment works

If agricultural utilisation is taken into account, impact on the environment and population has to be minimized by

- limitation of the applied amount
- further limitation of the applied amount according to the crop's nutrient demand
- restrictions for sludge rich in heavy-metals
- restricted access to farmland where biosolids have been applied for 30 days
- limitation of application to even areas (< 5 % slope)
- no application close to water bodies
- soil depth to groundwater > 1m
- setback distances to water supply wells (> 150 m) and surface water supply intake (> 750 m)
- pathogen reducing treatment (thermophilic processes, composting, humification)
- restrictions for the harvesting of crops and turf

As well as for water reuse applications, utilisation of sewage sludge can be a problem of acceptance in the society. For further information about public awareness see lesson E3.

6. Exercises

1. Which pumping systems are suitable for thickened sludge of 8% TS?

2. 100 m^3 of secondary sludge (8 kg/m^3) are thickened in a gravity thickener to 32 kg/m^3. How much is the percentage of TS? How much sludge volume is left?

3. Compute the required surface area and the depth of a round, static thickener:
   - primary sludge: 200 m^3, 2.5% TS withdrawn twice a day for one hour
   - secondary sludge: 500 m^3, 0.6% TS withdrawn continuously

Answers and Solutions

1. A displacement pump has to be chosen. The most suitable would be a progressive cavity pump or a rotary lobe pump.

2. 8 kg/m³ = $8^{o}/_{oo}$ = 0.8 %32 kg/m³ = $32^{o}/_{oo}$ = 3,2 %

   resulting volume: 100m³ * 0,8% / 3,2% = 25m³ equals ¼ !

3. Total solids: 200 m³/d * 0.025 * 1000 kg/m³ = 5000 kg/d

   500 m³/d * 0.006 * 1000 kg/m³ = 3000 kg/d

   (5000 kg/d + 3000 kg/d) / (200 m³/d +700 m³/d) = 11,4 kg/m³ = 1.14%

   → 700 m³/d, 8000 kg/d, 1.14% TS

- maximum solids load: see Table 3 → 55 kg/(m²*d)
- required surface: 8000 kg / 55 kg/(m²*d) = 145 m², Ø= 13,6 m
- hydraulic overflow rate primary + secondary sludge:

  [(200 m³/d) / (2 h/d) + (500 m³/d) / (24h/d)] / 145 m³ = 0.83 m/h < 1.0 /h
- hydraulic overflow rate secondary sludge

  [(500 m³/d) / (24h/d)] / = 0.14 (quite low, adding of process water could be considered)
- depth of compaction zone:

  achievable TS-concetration = 5% (table 3), overall 5% * 0,75 = 3.75 %

  sludge volume: 8000 kg/d / 37.5 kg/m³ = 213 m³/d

  volume of comp. zone: 213 m³/d * 36/24 = 320 m³

  depth: 320 m³ / 145 m² = 2.2 m
- overall depth: sedimentation + compaction + scrapers = 1.0 + 2.2 + 0.3 = 3.5 m

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CASE STUDY

SEWAGE SLUDGE CONVERSION IN EGYPT

July 2002

GTZ

German development agency http://www.gtz.de

IPP Consult, Hildesheim, Germany

http://www.ipp-consult.de

Table of contents

1. Introduction

The involvement of ipp-Consult regarding the introduction of an innovation to improve the quality of sewage sludge in Egypt lasted for a period of one and a half years and was initiated as a PPP-measure (Public Private Partnership), which was equally financed, by GTZ (Gesellschaft für Technische Zusammenarbeit) and ipp Consult. For the realisation of the project in Egypt, the University of Mansura, Egypt, as well as the staff of the private enterprise USDC of Mansoura became involved.

2. Current situation

Most cities in Egypt have treated their municipal sewage by technological treatment methods partially since the 1980's. Today, many small towns and municipalities in Egypt already have or plan their own sewage treatment plants. One aspect often neglected is the amount of sewage sludge produced and to be disposed of or re-used respectively.

There is an annual amount of 12 – 15 kg of solid matter in the sewage sludge per inhabitant in Egypt, which corresponds to a daily production of 35 – 40 g. The share of solid matter (organic and inorganic material produced within the sewage treatment process) depends on the pollution of the raw sewage and on the respective sewage treatment and sludge drainage system and is usually between 1 % and 3 %. Higher amounts of solid matter (4 – 10%) may be achieved by thickeners, which pre-drain the sludge mechanically and partially stabilise it.

3. Local Examples

A Local survey was conducted on six treatment plants in the Mansoura and Damietta Governorates in order to assess the related problems of sludge treatment and handling. The method of treatment adopted in all of the treatment plants is thickening followed by drying. All the plant operators that were interviewed complained of the large amounts of dry sludge produced together with its low market value and demand. The following pictures show the situation in plants that were visited.


Photo 1: Dried sludge stored besides the drying beds


Photo 2: Large lumps in overfilled drying beds

4. General Information about the project

The project „Sewage Sludge Conversion in Egypt“ was initiated and financed by the GTZ (German Society for Technical Co-operation) and the private firm ipp Consult from Germany. For technical, scientific and management support ipp Consult established a Co-operation with the Egyptian Consulting Enterprise USDC (Urban Study and Design Centre) in close relation with the National Academy for Scientific Research and Technology. The project was carried out from March 2001 to July 2002.

5. Background of Investigation

The contents of nutrients in the sewage sludge are considerably high and if treated in an adequate manner, the product can be used as a hygienically safe fertiliser of high quality. The main goals of the experiments was to find methods to convert sewage sludge from waste water treatment plants in different climatic regions in Egypt to a product of high quality, which can be applied in a safe and effective way in agriculture, public gardening and landscaping as well as for wood production.

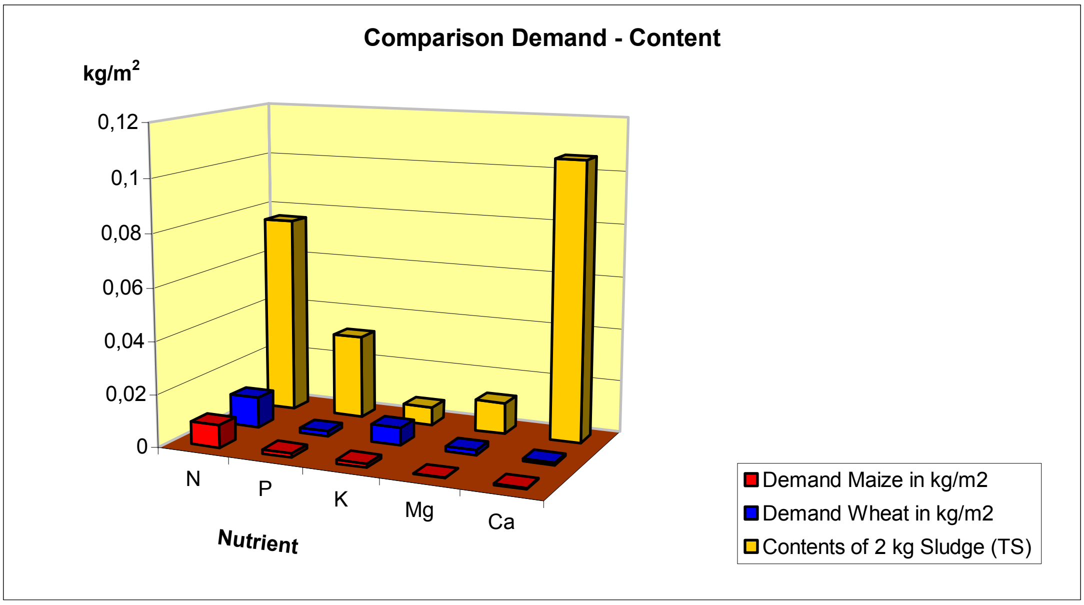

Fig.1: Comparison between the nutrient-demand of certain plants and average nutrient contents of sewage sludge

6. Sludge Product Requirements

To provide the safe and efficient application in agriculture, the sludge-product has to fulfil the following requirements:

- Safe handling during operation and transport
- Minimizing health risks for farmers
- Efficient and easy application in agriculture
- High fertilising value
- High acceptance by the users

7. Sludge Quality Considerations

To cover these requirements the sludge has to be evaluated considering its morphological, hygienic, chemical and physical as well as its aesthetical characteristics

- **Chemical-physical qualities**

  The physical-chemical qualities are important parameters for the evaluation of the fertilising value and the value of the sludge product as soil improver. Especially the fertilising value is important for the estimation of possible hazards in its application.

  The most important nutrients, which can be found in sewage sludge, are nitrogen, phosphorous and potassium. Especially in Egypt the contents of micronutrients like manganese, iron and zinc are of high importance because of the deficiencies of these compounds in soils in the new reclaimed lands as well as in the Nile Delta. Also the water storage capacity plays an important role in the sandy soils in the new lands.

  Too high or too low pH-values as well as too high contents of salts, expressed by the contents of chloride and sulphate lead to negative results in agriculture. The accumulation of heavy metals like lead, cadmium and chrome in soils and plants are potential hazards for the health of plants, animals and men.

- **Hygienic Characteristics**

  With the analysis of the concentration and presence of pathogenic germs and parasites in the product it is possible to make statements according to the hygienic safety of the product. The hygienic safety of the product is required above all during the emptying of the drying plants, the transport, and the distribution on the field as well as during the seeding and planting phase when humans are exposed to the product. A direct hazard for the consumer of agricultural goods does not exist because of the effect of auto-purification by the soil. The quality of the irrigation water plays in this case a role far more important.

- **Morphological quality**

  The morphological quality is an important criteria for the handling of sludge during the application on the field, especially the mixing with the soil. Large, hard lumps make it difficult to distribute and to mix the sludge-product in a homogenous manner. This can lead to negative effects according to the germination and growth of plants. Therefore the structure of the product should be crumbly and easy to break.

- **Aesthetical quality**

  The aesthetical quality is an important criteria for the successful sales management and advertisement of the product. A product that has excellent chemical-physical and hygienic qualities is often hard to promote if it shows bad aesthetical qualities (odour, consistence, colour).

8. Activities

The experiments were carried out in the wastewater treatment plants of Nawag (a village near Tanta) and El Minia in Upper Egypt to apply the methods under different climatic conditions. The main activities were to test different methods to convert sewage sludge and to apply the hereby-gained sludge-product in agricultural experiments to observe its qualities as fertiliser and soil conditioner.

Photo 3: Waste water treatment plant Nawag

Photo 4: Waste water treatment plant El Minia

Photo 5: Agricultural Research field with Sand in Nawag

Photo 6: Agricultural Research field with Sand in Nawag

The tested methods of sludge conversion were:

- Sludge conversion with grasses
- Sludge conversion with reed

Photo 7: Conversion with reed in Nawag

Photo 8: Grass conversion in Nawag

Both methods are acknowledged and applied in several European Countries and are considered as low-cost processes. Because of the different climate in Egypt according to temperature, Humidity and evaporation, it was necessary to examine the two processes according to their functionality and with respect to the operation and maintenance.

9. General information about the methods

The idea of sludge conversion

The principle of the Sewage Sludge Conversion is based mainly on the development of a different environment in the sludge. This shall be reached by the cultivation of certain plants, which create conditions, which facilitate the establishment of a soil-like environment. The metabolism of the micro- and macro-organisms leads to decomposition processes, which are comparable to the humification processes of compost.

Biochemical Background:

The cultivation of grass and reed on the sludge and the penetration of roots leads to the establishment of different groups of micro- as well as macro-organisms in comparison with the normal air drying of sewage sludge. It leads also to the additional aeration of the sludge. Beside the aeration effects, the penetration of roots has the effect of slacking of the sludge, which provides the crumbly structure of the product.

Photo 9: Decomposed Sludge from Nawag

Quality of the product

The product of both methods can be described as soil-like according to its structure, odour and colour. Analyses in Germany have shown that the product is hygienically safe and provides a high fertilising value.

10. Results of Investigation

The tests according to the methods of sewage sludge conversion in Nawag and El Minia have shown that both methods are applicable and can be operated successfully in Egypt although they have to be operated in a different way compared to the operation in Europe because of the climatic conditions in Egypt. Operational aspects have been investigated but not yet definitely determined to create an overall manual for the application of these methods.

The sludge product gained from the experiments showed mainly the same characteristics as in Europe. The agricultural experiments in both project locations have shown, that the biologically converted product has several decisive advantages in comparison to air-dried sludge.

Specific differences of Operation in Egypt

- **Sludge Conversion with grass**

After the first phase of the project it was clear, that the method couldn’t be applied and operated like in Germany. The limiting factor is the moisture and this has to be provided by irrigation. It is not necessary and it would not be economic to use fresh water.

Photo 10: Drainage water from the drying beds Nawag

Photo 11: Improvised irrigation facility

The polders can be irrigated with sludge water from the thickeners or sedimentation tanks as well as from the effluent or the drainage water from the polder itself. The polders have to be irrigated regularly especially in the first weeks of the grass development. False operation leads to negative results.

- **Sludge conversion with reed**

Until now not many differences could be observed. In very dry periods it can be expected that the reed needs water to recover from the charges. The reed reacts very sensitive to overcharging. The fillings have to be carried out very careful. Layers above 20 cm are not required and can be harmful for the plants. Careful observation of the reed plants is required. The reed polder can be operated constantly without change of operation until the polder is filled and can be emptied after a certain retention time.

Photo 12: Reed after overcharging

Photo 13: Reed bed after overcharging

<u>Main requirements of application in Egypt</u>

- **Sludge conversion with grass**
  - The existence or the installation of irrigation facilities according to the water, which will be used for irrigation. It is generally recommendable to install a system, which provides the irrigation form both sides of the polders. The irrigation by sprinkling has certain advantages but its application is more time and cost-intensive than the simple flooding of the polders.

- A detailed schedule of operation (Filling, Drying, Seeding, Irrigation) is required to guarantee the successful operation and maintenance of the polders
- The quality of the sludge charges should be homogenous, especially the age of the sludge as well as the degree of stabilisation
- The operation personnel has to be trained and instructed in an adequate manner

- **Sludge conversion with reed**
  - The requirements are similar to the conversion with grass, but an irrigation facility is not required, although water has to be provided for the cultivation phase and temporary flooding.

Quality of the product

The quality of the product of both methods is considered to be similar although only the product of the grass conversion could be analysed sufficiently. The analysis of the lower layer of sludge in the reed bed have shown that the morphological, chemical-physical, hygienic and aesthetical quality of the product can be expected to be similar to the product gained from the method of grass conversion.

Photo 14: Decomposed sludge in Nawag

The sludge product produced by the process in the period from September 2001 to June was analysed according to its morphological, chemical-physical, hygienic and aesthetical characteristics. It was found that the product fulfilled the requirements mentioned before:

- Morphology: "Soil-like", crumbly, the decayed grass provides structure
- Esthetical Characteristics: brown colour, earthy smell, no offensive odours
- Chemical and physical characteristics: neutral pH-value, high contents of organic material and macro-nutrients (nitrogen, phosphorous, potassium), considerable contents of micronutrients like zinc and iron as well as a good water storage capacity, and low concentrations of heavy metals (cadmium, copper, lead)
- Hygienic characteristics: low concentration of coliform germs directly after the finishing of decomposition, absence of Salmonellae and worm-eggs

The microbiological analysis has shown that the concentration of faecal coliforms, worm eggs and Salmonellae have decreased considerably after a conversion time of 2 month with a resting period of 2 weeks. Salmonellae could not be found in the sample of converted sludge whereas the dried sludge (drying time: more than 4 months) still has dangerous contents of this germ.

11. Comparison of the methods

Conversion with grass	Conversion with reed
Advantages	**Advantages**
- Production of a save and valuable sludge product which can be used for fertilising and soil improving - Low cost method - Flexible in operation according to operational errors	- Production of a save and valuable sludge product which can be used for fertilising and soil improving - Low cost method - Relatively easy to operate
Disadvantages	**Disadvantages**
- Necessity of providing an irrigation facility - Necessity of daily control and operation	- Low flexibility of the method according to operational errors - The reed reacts to overcharging very sensitive and can be affected by plagues - Remaining rhizomes in the product can cause growing of reed on the field after application. Reed is considered as a plague by the farmers and therefore the product can get discredited

The advantage of the sludge conversion with reed is the easier operation. Nevertheless the main disadvantages are putting the applicability of the method in question. The main problem is the fact that the replanting of reed is more difficult and time intensive than the re-seeding of grass.

The replanting of reed could become necessary because:

- The reed reacts to overcharging very sensitive and it is difficult to plant new reed on the polders while the process is not finished. Therefore it is necessary to be very careful during fillings because layers above 20 cm are not required and can be harmful for the plants
- The reed can be affected by certain plagues like the Stemdriller which causes the dying of the plant

Another problem are the remains of the roots respectively rhizomes in the sludge product. This can have negative effects affect in agriculture because new plants can develop from these remaining rhizomes. The farmers consider Reed as a plague and therefore the product can get discredited. The only way to eliminate the rhizomes in an effective and ecological way is to destroy them mechanically by chafcutters.

12. Agricultural Research

The agricultural research was carried out in Nawag and El Minia during June and July with the sludge product converted by grass as well as with air-dried sludge for comparison. The experiments were focused on the quality of the substrates as fertilisers in heavy soil from the Nile Delta in Nawag as well as pure sand in both locations.

Already the pre-investigation experiments in buckets have shown that the efficiency of even the only partly converted product, as fertiliser is considerably higher than the efficiency of the dry sludge. In the same time crops developed faster and more biomass in the soil mixed with converted sludge than in soil where the dried product was applied.

Photo 15: Results of the pre-investigation with barley in substrates of soil mixed with different percentages of sludge

Experiments with pepper weed have shown furthermore that the dried sludge contains considerable high concentrations of compounds, which are affecting the plants negatively whereas the tests with the converted product proved the absence of such compounds.

The results of the field tests have lead to similar conclusions. Of the 4 tested crops Maize (Durra), Millet (Durra Sucari), Ladyfinger (Okra, Bamia) and Garghir only Maize is developing similar in soils fertilised with converted and dried sludge although negative effects produced by high concentrations of air dried sludge can be also noticed. All other tested plants are developing slower in soil fertilised with dried sludge. In the plots with high concentrations of dried sludge, Ladyfinger, Sorghum and Garghir nearly have not developed at all.

Photo 16: Maize and Ladyfinger in Nawag after 4 weeks

Photo 17: Soghum and Ghargir in Nawag after 4 weeks

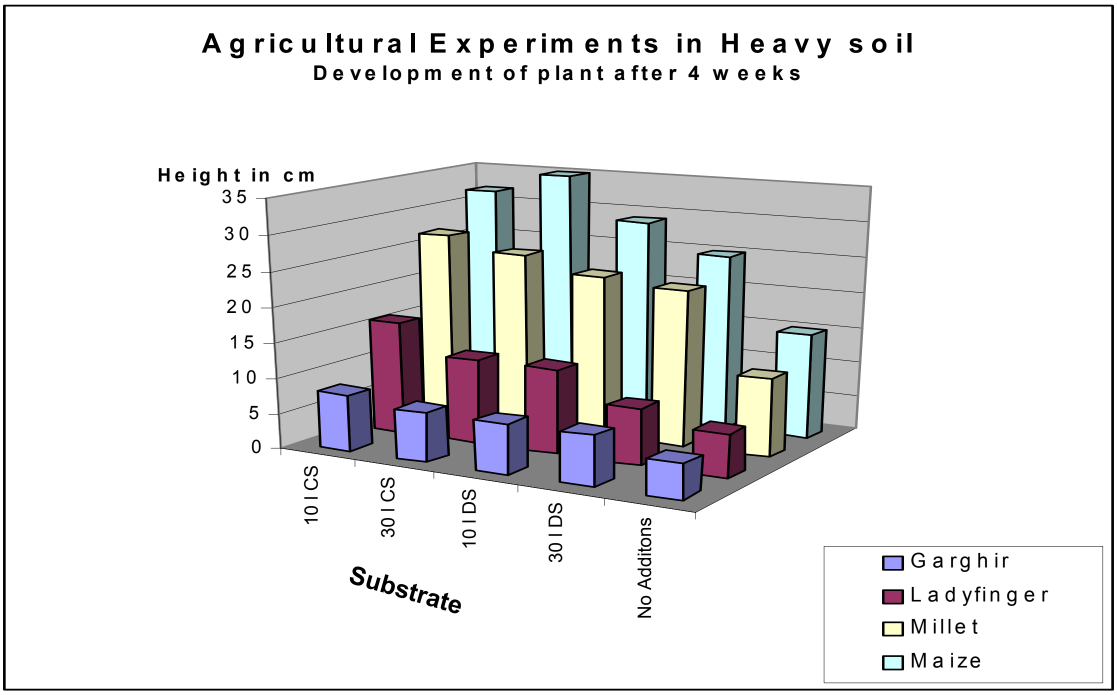

Fig. 2: Development of plants in Delta soil with various concentrations of dried and decomposed sludge after 4 weeks

Especially in the sand the converted product demonstrates its quality as soil conditioner because the plants have developed the same height and thickness as in the heavier soil from the Delta, in case of Okra even more. This shows that the converted product has a large ability to adopt and to store water

Photo 18: Development of Garghir (from left to right: Sand with 30 l dried sludge, Sand with 10 l dried sludge, Sand with 30 l converted sludge, Sand with 10 l converted sludge, Sand without additions)

Photo 19: Development of Ladyfinger (from left to right: Sand with 30 l dried sludge, Sand with 10 l dried sludge, Sand with 30 l converted sludge, Sand with 10 l converted sludge, Sand without additions)

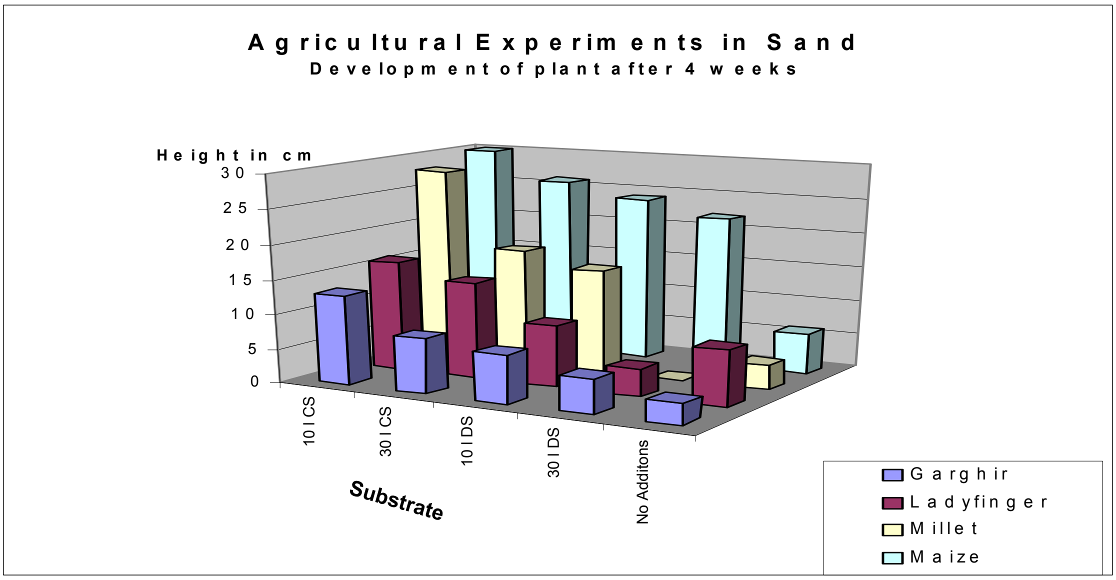

Fig. 3: Development of plants in sand with various concentrations of dried and decomposed sludge after 4 weeks

A meeting with local farmers on Tuesday 9th of June has shown that they are very interested in the product which the consultant presented in Nawag.




Photo 20 - 22: Presentation of the results to the Farmers in Nawag

13. Conclusions and Outlook

The experiments carried out in Nawag and El Minia have shown that it is possible to convert sewage sludge to a bio solid product of high fertilising value which can be applied in agriculture in a safe way.

As treatment method for sewage sludge, the consultant favours the conversion with grass although the operation requires more time and investments in comparison to the conversion with reed. The aspects that the product of the conversion method with reed will possibly be rejected by the farmers because of the contents of rhizomes in the reed as well as the lack of flexibility of this process in case of operational mistakes have led to this conclusion. Nevertheless it is recommendable to continue the investigation of the feasibility of this method in Egypt because it needs nearly no additional investments compared to sludge drying beds.

The results of the agricultural experiments are encouraging because the product, gained from the conversion polders showed the characteristics of a high quality fertiliser. If the process of grass conversion is operated in an adequate and effective way, the product could be a great benefit for the agriculture especially in the poor soils in the new reclaimed lands. Besides that, the method can be described as an important tool to close further the ecological circle of matter respectively the chain of nutrients.

If the product is promoted and can be sold for a reasonable prize, the necessary inversions and operation and maintenance cost can be amortised in short place.

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Lesson C1

Operation and management of wastewater treatment plants

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Keywords
Maintenance, Wastewater, Operation Sheets, Operation Troubles, Remedial Actions.

Table of Content

1. Overview and summary

This lesson is focused on the operation and maintenance of wastewater treatment plants: in the first part, the basic principles included into the *Operation and Management Manual* – the document that should always be annexed to any WWTP design – are presented; next section is addressed to the description of the main procedures to be usually applied for any WWTP operation, enlighting all the most common problems, troubleshootings and their solutions, related to all the treatment processes.

2. Operation and Maintenance Manual

The purpose of the Operation and Maintenance (O&M) Manual is to provide WWTPs' operators with the proper understanding of recommended operating techniques and procedures, and the references necessary to efficiently operate and maintain their facilities.

The O&M manual shall contain all information necessary for the plant operator to properly operate and maintain the collection, treatment and disposal systems in accordance with all applicable laws and regulations. A copy of the approved O&M manual shall be maintained at the treatment plant at all times.

The O&M manual shall include the following:

a) Introduction
b) Permits and Standards
c) Description, Operation and Control of Wastewater Treatment Facilities
d) Description, Operation and Control of Sludge Handling Facilities
e) Personnel
f) Sampling and Laboratory Analysis
g) Records and Reporting
h) Maintenance
i) Emergency Operating and Response Program
j) Safety
k) Utilities

2.1 Introduction

The introduction shall include a general description of the nature of the establishment (e.g. office park, commercial strip mall, etc.) that is served by the wastewater treatment plant (WWTP). Included with the introduction shall be the location of the WWTP and any environmentally sensitive areas, a locus map should be provided.

2.2 Permits and Standards

The Permits and Standards section shall discuss the type of permit issued and include a copy of all permits. A detailed description of responsibilities of the owner, operator and consulting engineer necessary to meet all permit conditions shall be provided.

2.3 Description of Wastewater Treatment Facilities Operation & Control

The substance of how to operate the treatment facility lies within this section. This section is intended to provide a description of the various treatment plant components and their function. Each component should be presented in a sequential order and discussed individually. The narrative should discuss the treatment system from the point of generation (including the conveyance system) through the treatment processes to final disposal.

The method for operating each unit of the treatment system shall be discussed in this section. For example, if pretreatment tanks are proposed then how often they require sludge removal should be mentioned.

The O&M manual shall include the manufacturer's operating, maintenance and repair instructions for all process units and appurtenances associated with the WWTF such as:
motors, pumps, valves, blowers, bearings, drive assemblies, control panels, electrical systems, alarms, piping, tankage, and equipment. This information can be incorporated into the body of the Operation and Control of Wastewater Treatment Facilities section or included as appendices. This section shall go on to provide detailed instructions on treatment plant operation including chemical storage and handling, process testing, standard operational mode, optional modes available (such as seasonal operations), process controls and safeguards.

If the WWTP includes storage of chemicals that are required as part of the treatment process (e.g. methanol) the O&M must provide information such as name, address, and telephone number for each chemical supplier.

2.4 Description of Operation & Control of Sludge Handling Facilities

All WWTPs generate waste solids that require handling separate from the wastewater treatment system. This section shall provide a description of the sludge handling and disposal requirements including the name and telephone number of the sludge disposal facility and record keeping requirements. For any process unit that either generates or stores waste solids an expected removal frequency and means of removal shall be provided.

2.5 Personnel

The owner of a WWTP must employ sufficient personnel to ensure the proper operation of the facility. A description of the number and qualifications of the personnel necessary for proper and continuous operation of the collection, treatment and disposal systems shall be given. It shall include the Grade of the Chief Operator and that of any backup or staff operators. The duties and responsibilities of the staff shall be provided. It shall include the number of days per week and hours per day the facility shall be staffed, holiday and weekend staff coverage, and on-call and emergency operating personnel.

2.6 Sampling and Analysis

A listing of all sampling (operational and compliance monitoring) and analyses required together with appropriate protocols for proper sampling, storage, transportation, and analysis shall be provided. In addition, a quality control/quality assurance plan shall be developed. The sampling and analysis plan must include a description of sampling that is reflective of the conditions of the permit for: influent, effluent, and eventually groundwater monitoring wells.

The plan must include the parameter that is being tested for (e.g. pH, BOD_5, COD, etc.), its frequency of testing (e.g. daily, weekly, monthly, etc), and the method for testing (e.g. Standard Methods, Official National Methods, etc.). The method of sampling (e.g. grab or composite) shall also be stated in the sampling plan. Process control testing and the parameter and frequency must also be incorporated. The sampling and analysis plan must include locations of where testing must be performed to ensure that process units are operating properly and efficiently. The sampling plan for the groundwater monitoring wells must state the location of the well and its designation number.

If analysis is done on site or transported to a certified lab then this must be so stated in the plan. Any on-site equipment such as pH meters must have documentation for the proper operation of such equipment including calibration information. If chemicals or buffer solutions are required for calibrating equipment they must be stored and handled according to manufacturer’s recommendations.

2.7 Records and Reporting

A listing of all reporting requirements and location and method of record keeping shall be included. The Records and Reporting section shall reference daily log of plant operations, process changes and equipment maintenance. Copies of daily logs as well as any inspection reports shall be kept at the facility at all times.

2.8 Maintenance

The Maintenance section shall include a list of spare parts and supplies that shall be available to the operator for the maintenance and repair of the treatment plant and related appurtenances. This section shall include a chart itemizing all equipment within the treatment facility and its associated maintenance action (e.g. lubricate motor bearings) and the frequency of such action (e.g. every 6 months). The chart should include provisions for including notes or comments by the operator. Included in this section shall be a lubrication chart, which details for all equipment routine inspections, lubrication and adjustment, which must be performed by the operator.

It should be noted that only equipment or materials associated with the treatment plant are allowed to be stored within the confines of the WWTP. The treatment plant should not be used as a storage structure for items not related to the WWTP.

2.9 Emergency Operations & Response

An emergency operating and response program shall be discussed. It shall detail procedures to be followed in the event of the following emergency situation: power failures, storms, flooding, hydraulic overload/ruptures, fire, explosions, equipment failure, spills of hazardous materials, maintenance shutdowns, and personnel injury. A description of who should be notified, and when, for each emergency situation shall be provided along with an appropriate telephone number.

The procedures to follow shall include information as to identifying the emergency condition, investigating the severity of the emergency, actions to be taken and notification of responsible authorities, corrective actions to rectify the situation, and necessary follow-up. Follow-up procedures should include feasible measures to prevent or minimize the likelihood of a similar situation from reoccurring.
At a minimum the following telephone numbers shall be incorporated into the Emergency Operations & Response Section: local fire department, local police department, ambulance, poison control center, Regional Office of the Department and local Board of Health. This section should state where the phone numbers would be posted within the treatment plant.

2.10 Safety

A description of proper material handling and precautionary safeguards shall be included. This shall include a listing of an instruction for use of all necessary safety and first aid equipment. An itemized list of safety equipment shall be provided. Training for personnel is a key component of a proper safety program. The Safety section must include what training (e.g. OSHA, first-aid, CPR) is required for all staff employed to work within the WWTP. All Material Safety Data Sheets (MSDS) for any chemicals stored on site must be included in the O&M as well as available within the WWTP.

2.11 Utility

A listing and directory providing names and notification requirements for water, electric, gas and telephone services shall be included in the O&M manual.

3. Wastewater treatment plant (WWTP)

Wastewater treatment or sewage treatment is the process that removes the majority of the contaminants from waste-water or sewage and produces both a liquid effluent suitable for disposal to the natural environment and a sludge. To be effective, sewage must be conveyed to a treatment plant by appropriate pipes and infrastructure and the process itself must be subject to regulation and controls. There are many and various forms of treatment processes. The site where the processes are conducted is called a wastewater treatment plant (WWTP). The flow scheme (see figure 1) of a conventional WWTP is generally the same in all countries and exists our of following physical-chemical elements:

- Mechanical treatment;
    - Influx (Influent)
    - Removal of large objects
    - Removal of sand
    - Pre-precipitation

- Biological treatment;
    - Oxidation bed (oxidizing bed) or Aerated systems
    - Post precipitation
    - Effluent

- Chemical treatment (this step is usually combined with settling and other processes to remove solids, such as filtration.

Besides the physical-chemical classification the technical classification is based on the steps, which are performed one by one other:

- **Primary treatment** (see figure 1): to reduce oils, grease, fats, sand, grit, and coarse (settle able) solids. This step is done entirely with machinery.
- **Secondary treatment** (see figure 1) is designed to substantially degrade the solved content of the sewage within a biological degradation system, such as activated sludge systems. These systems use the capability of microorganism to degrade solved components in water. The final step in the secondary treatment stage is to separate the used biological media from the cleared sewage water with a very low levels of organic material and suspended matter.
- **Tertiary treatment** or advanced treatment (not in figure 1) is yet not applied widely. It provides a final stage to raise the effluent quality to the standard required before it is discharged to the receiving environment. More than one tertiary treatment process may be used at any treatment plant. In most cases it is a further nitrogen or phosphate elimination and/or a disinfection. Additional steps like lagooning or constructed wetlands are also counted as tertiary step if they are used after secondary treatment.

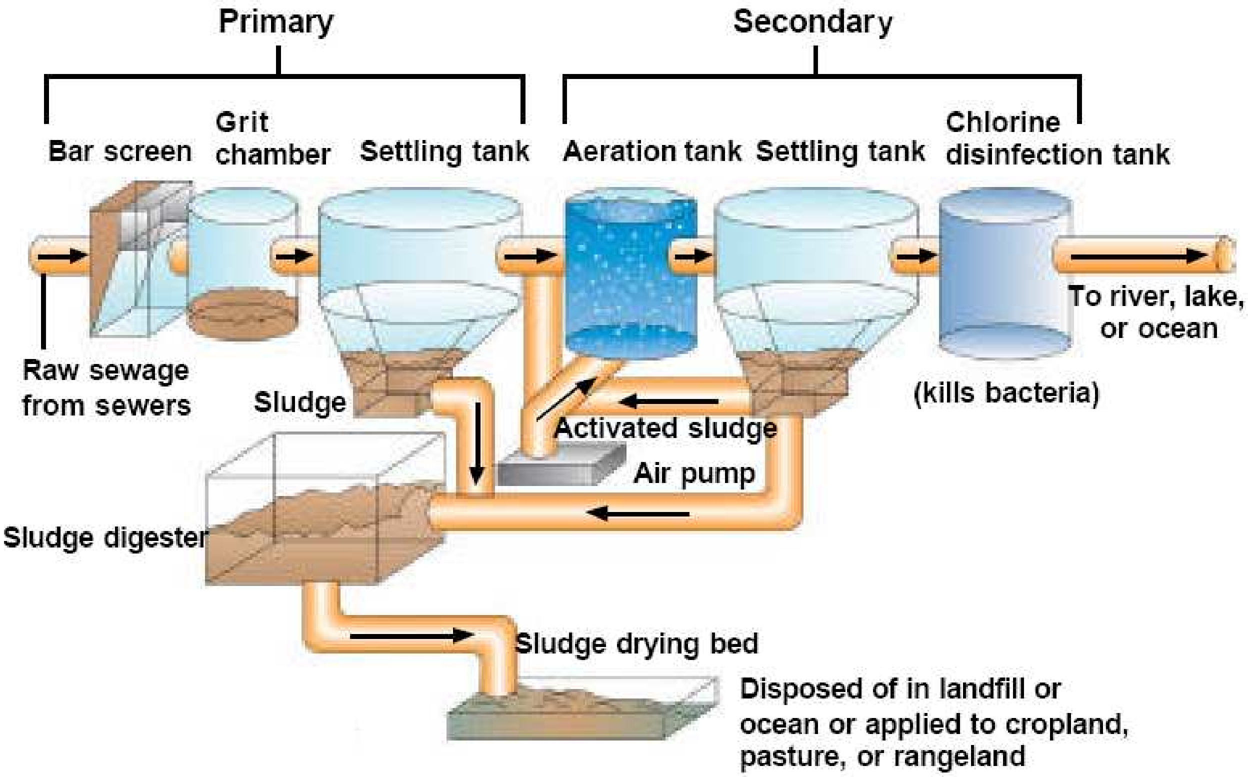

Figure 1: Wastewater treatment plant (Queens University 2004)

3.1 Screening

Screening is a primary treatment in a wastewater treatment process. Screenings are the material retained on bar racks and screens. The smaller the screen opening, the greater will be the quantity of collected screenings (see figure 2). In table 3.2 typical data on characteristics and quantities of screenings removed from urban wastewater with fine bar (mechanically cleaned). In table 3.1 some typical information about operations bar racks are reported.

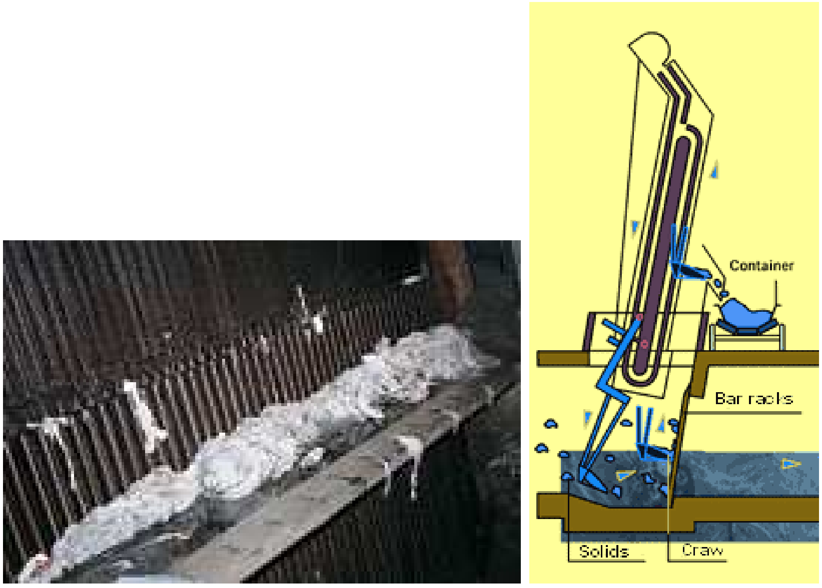

Figure 2: Example for a mechanical bar screen (Source: Entwässerungsbetriebe Mainz)

Tab. 3.1 Typical design information for manually and mechanically cleaned bar racks

		Manually cleaned	Mechanically cleaned
Bar size:			
Width	[mm]	5 – 15	5 – 15
Depth	[mm]	25 – 75	25 – 75
Clear spacing between bars	[mm]	20 – 60	10 – 30
Slope from vertical	[°]	45 – 60	70 – 90
Approach velocity	[m s^{-1}]	0.3 – 0.5	0.5 – 1
Allowable headloss	[m]	0.1 – 0.2	0.1 – 0.2

Tab 3.2 Typical information on the characteristics and quantities of screenings removed from urban wastewater with fine bar (mechanically cleaned)

Clear spacing between bars [mm]	Volume of screenings [m^3 PE^{-1} y^{-1}]	Suspended solids removal [%]	BOD_5 removal [%]
15	$2\ 10^{-3}$ – $4\ 10^{-3}$	1 – 3	-
10	$3\ 10^{-3}$ – $6\ 10^{-3}$	2 - 5	1 – 3

The quantity of collected screenings varies depending on the type of the screen and, in particular, on the type of sewer system and wastewater characteristics. Their efficiency depend on the spacing between the screen bars and is named as follows:

- Fine screening: spacing < 10 mm
- Medium screening: spacing 10 - 40 mm
- Coarse screening: spacing > 40 mm

Usually a fine screening is preceded by a medium or course screening for protection.

For coarse screens, the quantity of removed screenings ranges between 0.005 e 0.05 m^3 per 1000 m^3 of treated wastewater. These values, in case of combined sewers, could be much higher during storm events. For fine screens the quantity of removed screenings can reach value up to 0.3 – 0.5 m^3 per 1000 m^3 of treated wastewater.

The collected screenings characteristics are very different; generally the misture content ranges between 70 al 90 % and specific weight between 700 – 900 kg m^{-3}. In case of urban wastewater putrescible matter is contained within the screenings therefore they must be handled and disposed quite quickly.

The headloss increases when the screen collects material, and cleening operation are needed. The approaching velocity should be higher than 0.6 m s^{-1}, in order to avoid sand deposition or other suspended material. In table 3.1.3 a typical screen operation sheet is reported; the reporting frequency depends on the WWTP size; details on routine inspections, lubrication and adjustment, performed by the operator, should be reported as well.

Tab 3.1.3 Screen operation sheet

Month: ……..; Year: ……. ; Operator: ………………………; Item nr: ………………

Day	Hour	Flow rate [m^3 h^{-1}]	Screenings characteristics			Operational parameters		Notes
			Quantity [m^3 d^{-1}]	Moisture [%]	VS [%]	Headloss [mm]	Velocity [m s^{-1}]	
1								
2								
31								
Monthly mean								

3.1.1 Screening troubles and remedial actions

3.1.1.1 Sand accumulation in the screen channel

<u>Symptoms</u>
- Sand presence in the collected screenings
- Water level increase in the screening channel
- Sand reduction collected form the grit chamber

<u>Main causes</u>
- Reduced approach velocity
- Obstruction occurrence in the screening channel

<u>Investigations and analyses</u>
- Confine the area where sand accumulates
- Measure the approach velocity corresponding to the different wastewater flow rate;
- Examine the as-built drawings to check the presence of some shape irregularity in the approaching channel

<u>Remedial actions</u>
- If the approaching velocity is less than 0.5 m s^{-1} then an increase is needed: a temporary solution could be the flow rate increase through a recycle flow, a reduction of the screening channels (if there are more than two working in parallel) a water level reduction modifying the out flow weir
- Empty the screen channel and remove all the bottom irregularities

3.1.1.2 Solid transport though the screen

Symptoms
- Regular clogging of the pipes downstream the screen
- Finding inappropriate materials in the pump impeller shown by high electrical input and unusual noises

Main causes
- Solids removal not effective
- Unsuitable pumps
- Incorrect piping design or installation

Investigations and analyses
- Check the presence of solids in the water flow downstream the screen
- Check the pump water flow

Remedial actions
- As temporary solution reverse the pump rotational movement
- Modify the suction pipe setting up a protection barrier
- Replace the pump
- Modify the solid removal system upstream

3.2. Grit removal

The goal of grit removal is to separate gravel and sand and other mineral materials down to a diameter between 0.2 and 0.1 mm. Grit chambers are provided to (a) protect downstream moving mechanical equipment from abrasion (b) reduce formation of heavy deposits in pipe line and (c) reduce the frequency of digester cleaning caused by excessive accumulation of grit.

There are three general types of grit chamber:

1. horizontal-flow – rectangular configuration
2. horizontal-flow – square configuration
3. aerated; (see figure 3 and 4)

The use of vertical flow chambers have shown an insufficient separation of very fine grained sand fraction.

The quantity of removed grit will vary depending on the type of sewer system, the characteristics of the drainage area, etc. The amount of removed gravel is different plant by plant.

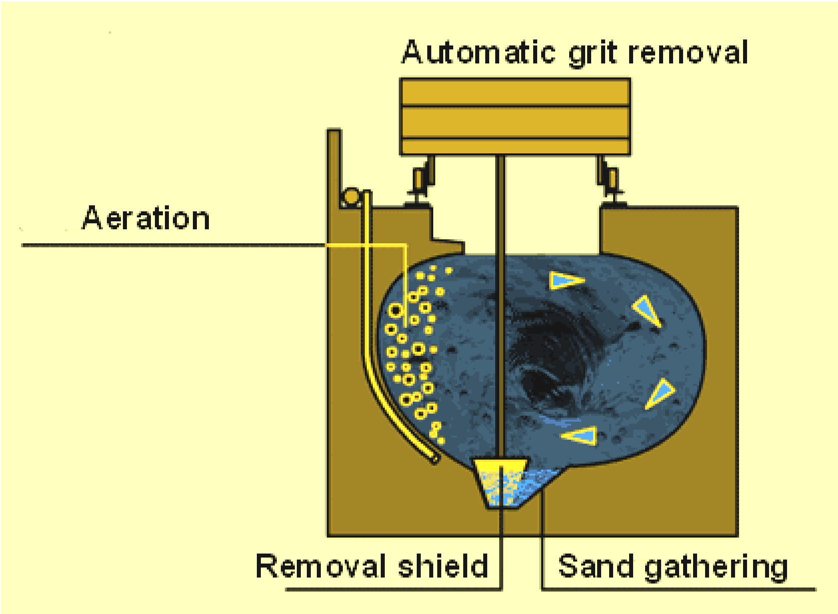

Figure 3: Example for an aerated grit chamber (Source: Entwässerungsbetriebe Mainz)

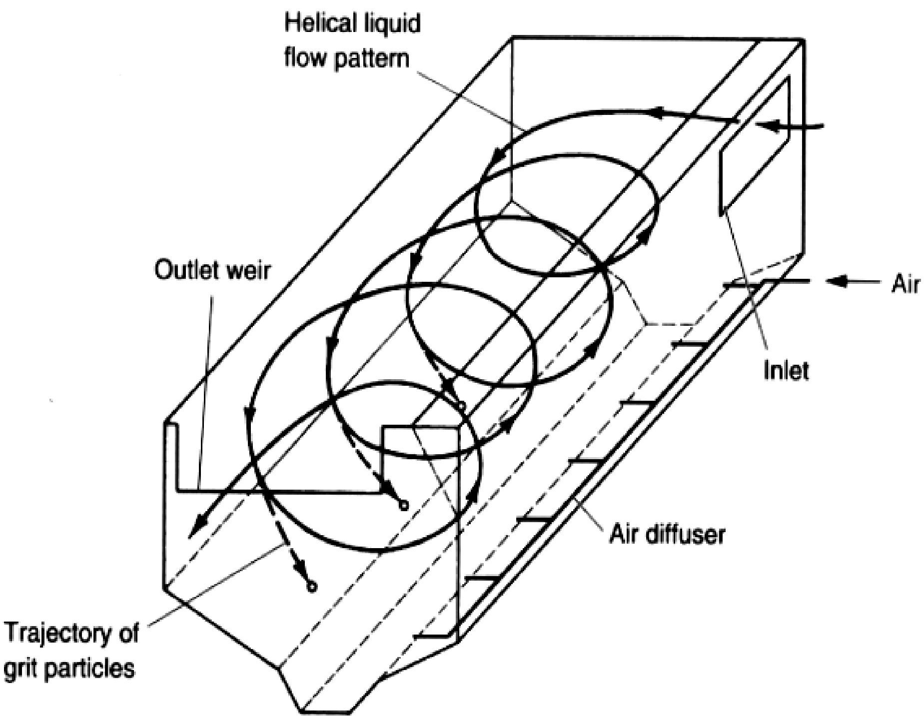

Figure 4: Aerated grit chamber (Crites and Tchobanoglous, 1998)

In aerated grit chambers, grit is removed by causing the wastewater to flow in a spiral pattern, as shown in figure 4. Air is introduced in the grit chamber along one side, causing a perpendicular spiral velocity pattern to flow through the tank. Heavier particles are accelerated and diverge from the streamlines, dropping to the bottom of the tank, while lighter organic particles are suspended and eventually carried out of the tank.

In table 3.2.1, some typical values by different authors for combined sewer systems are shown.

Tab. 3.2.1 Typical amounts of collected grit (combined sewer)

Volume of grit [l PE^{-1} yr^{-1}]	Volume of grit [l m^{-3}]	reference remark
40	0.02 - 0.2	ATV-Hanbuch, 1997 average: 0.06 l / m³
2.4 – 58.8		Londong, 1990
2		Imhoff, 1993 high-density areas
5		Imhoff, 1993 low-density areas
	0.01 – 0.1	Passino et al. (1999)
	0.004 - 0.2	Tchobanoglous, 2003 aerated grit chamber

Total amount of mineral material inside influx of grit chamber is between 10 and 60 g per m³ of wastewater (grain size ranges between 0.09 – 3.0 mm). The use of a sieve in upstream decreases mass of separated solids in grit chamber. (ATV-Handbuch, 1997).
In case of combined sewer, over a dry period (low flow velocity) sand can settle down in the sewer pipes: a hard rain causes an increasing flow speed and the sand is flushed into wastewater treatment plant. Thus, the highest amounts of sand reaches the plant with stormwater.

In case of separate sewer, the quantity of grit will be less than that expected for combined sewer (typical value is 0.5 l m^{-3} of wastewater). The moisture content of the collected grit ranges between 15 e 40 %; volatile content, on dry basis, ranges between 20-50 %.

In table 3.2.2 a typical grit chamber operation sheet is reported; the reporting frequency depends on the WWTP size; details on routine inspections, lubrication and adjustment, performed by the operator, should be reported as well.

Tab 3.2.2 Grit chamber operation sheet

Month: ……..; Year: ……. ; Operator: ……………………….; Item nr: ……………….

Day	hour	Flow rate [m^3 h^{-1}]	Removed grit			Operational parameter				Notes
			Quantity [%]	Moisture [%]	VS [% TS]	Velocity [m h^{-1}]	HRT [min]	Air flow rate [Nm^3 h^{-1}]	Power [kW]	
1										
2										
31										
Monthly mean										

3.2.1 Grit removal troubles and remedial actions

3.2.1.1 Grit transport though the grit chamber

<u>Symptoms</u>

- Rapid abrasion of moving mechanical equipment downstream the grit chamber
- High inert content in the biological aeration tank
- Quantity of collected grit smaller than normal conditions

<u>Main causes</u>

- High velocity and / or too short hydraulic retention time

<u>Investigations and analyses</u>

- Measure inorganic suspended solids inflowing and out flowing the grit chamber at different wastewater flow rates
- Measure the velocity corresponding to the different wastewater flow rates;
- Measure the air flow rate in case of aerated grit chamber

<u>Remedial actions</u>

- In the rectangular horizontal-flow grit chamber, increase the frequency of grit removal in order to increase the available water section
- Reduce the velocity of roll or agitation
- Increase the number of the grit chamber
- Reduce air flow rate in case of aerated grit chamber
- Replace the pump
- Modify the solids removal system upstream

3.2.1.2 High content of organic material in the collected grit

Symptoms
- Quantity of grit removed higher than the normal
- Dark colour of the grit removed
- Mixture more doughy than the normal
- Foul smell from the collected grit

Main causes
- Low velocity and / or too high hydraulic retention time

Investigations and analyses
- Analyse, daily, the volatile content in the collected grit
- Measure the velocity corresponding to the different wastewater flow rate
- Measure the air flow rate in case of aerated grit chamber

Remedial actions
- If possible, reduce the number of the grit chambers working in parallel
- In case of rectangular horizontal-flow grit chambers, reduce the water section or modify (reduce) the water level in the chamber by regulating the weir
- In case of aerated grit chamber increase the air flow rate
- Increase the velocity of roll or agitation

3.3 Sedimentation

The main goal of sedimentation is to remove readily settleable solids and floating materials (not removed in the upstream treatment phases) thus reducing the suspended solids content; so quiet conditions are set up in the sedimentation basin: collected solids are subsequently sent to the sludge treatment processes, and (in case of secondary sedimentation) partially recycled.

The sedimentation process takes place in a settling tank, which is a circular or rectangular basins made of concrete or iron, having the bottom lightly sloped towards a zone where the sludge is conveyed by appropriate withdrawal devices.

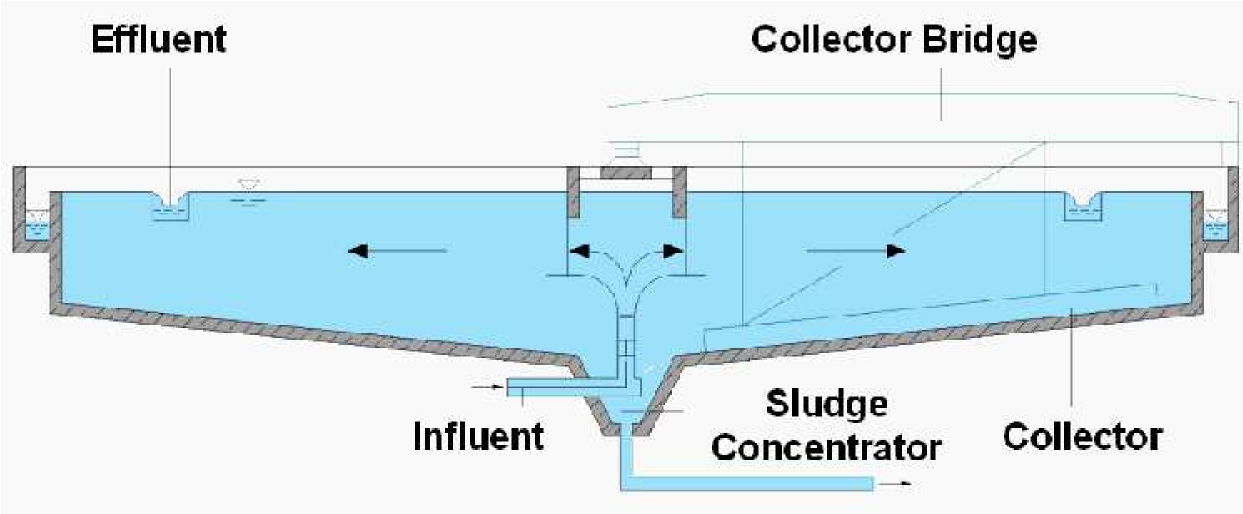

Figure 5: Example for a circular sedimentation tank (Source: Universität Stuttgart)

Sedimentation tanks are designed to operate continuously. Primary sedimentation tanks may provide the principal degree of wastewater treatment, or may be used as a preliminary step in further treatment of the wastewater. When used as the only means of treatment (not authorized in most developed countries), these tanks provide for removal of settle able solids and much of the floating material. When used as a preliminary step to biological treatment, their function is to reduce the load on the biological treatment units. Efficiently designed and operated primary sedimentation tanks should remove 50 to 65 percent of the suspended solids and 25 to 40 percent of the biochemical oxygen demand.

Tab. 3.3.1 Typical operational data (HRT and overflow rate) for different type of clarifier

	HRT [h]	Overflow rate [$m^3\ m^{-2}\ h^{-1}$]
Primary Sedimentation	1,5 – 2,0	0,8 - 1,2
Primary Sedimentation upstream the Trickling filters	3,0 – 4,0	0,5 - 0,8
Secondary Sedimentation downstream the Trickling filters	3,0	0,5 - 0,8
Secondary sedimentation	3,0	0,5

The BOD and TSS removal efficiency depends on the clarifier characteristics and on the above mentioned parameters. Basically, in a primary clarifiers, removal efficiency for BOD and TSS are mainly related to the hydraulic retention time (HRT) and the its influent concentration.

In table 3.3.2 a typical clarifier operation sheet is reported; the reporting frequency depends on the WWTP size; details on routine inspections, lubrication and adjustment, performed by the operator, should be reported as well.

Tab. 3.3.2 Clarifier operation sheet

Month: ……..; Year: ……. ; Operator: ………………………; Item nr: ……………….

Day	hour	Flow rate	Sludge characteristics			Operational parameter				Efficiency				Notes
			Quantity	TSS	VSS	Overflow rate	HRT	Weir loading rate	Solid loading rate	TSS in	TSS out	BOD in	BOD out	
		[$m^3 h^{-1}$]	[$m^3 d^{-1}$]	[$g m^{-3}$]	[$g m^{-3}$]	[$m h^{-1}$]	[h]	[$m^3 m^{-2} h^{-1}$]	[$kg m^{-2} d^{-1}$]	[$g m^{-3}$]	[$g m^{-3}$]	[$g m^{-3}$]	[$g m^{-3}$]	
1														
2														
3														
31														
Monthly mean														

3.3.1 Sedimentation troubles and remedial actions

3.3.1.1 Presence of septic sludge, containing bubble gas, on the water surface

<u>Symptoms</u>
- Presence of floating material on water surface
- Emanation of sulphides smell from clarifier

<u>Main causes</u>
- Sludge degradation due to high hydraulic retention time
- The trouble could take place in a limited zone of the clarifier due to the problems of the sludge collector mechanism.

<u>Investigations and analyses</u>
- Measure TSS in the settled sludge after sludge removal operation and if it is too high extend the extraction time
- Check the sludge collector mechanism

<u>Remedial actions</u>
- Increase the scraper velocity
- Increase the extraction time or the frequency of the sludge removal

3.3.1.2 Low settleable solids removal efficiency

Symptoms
- % removal lower than the normal
- Presence of suspended solids in the effluent

Main causes
- High overflow rate
- Presence of short-circuit in the clarifier

Investigations and analyses
- Measure TSS content in the clarifier inflow and outflow
- Measure HRT, overflow rate and compare with the design ones
- Check the possibility of dead zone presence and eventually evaluate with tracer test

Remedial actions
- If the trouble is caused by the high overflow rate, evaluate the possibility of realize another clarifier or equalization tank
- If the trouble is caused by short-circuit, modify the flow characteristics installing screens and enhancing the inlet and outlet distribution systems

3.3.1.3 Low floatable material removal efficiency

Symptoms
- Presence of oils and greases in the clarifier effluent

Main causes
- Incorrect skimmer operation

Investigations and analyses
- Check the state of the skimmer, and the correctness position
- Check the oil and grease content in the incoming wastewater and compare it with the design data

Remedial actions
- Install a screen in the clarifier: floating materials exceed the outlet weir, and therefore periodical screen cleaning operation are needed
- Install sprinkler in order to convey floating material to the extraction zone
- In case of wastewater containing high quantity of oil and grease evaluate the chance of installing a flotation unit upstream the clarifier

3.3.1.4 Excessive sedimentation in the clarifier approaching channel

Symptoms
- Solid presence in the clarifier approaching channel and/or distribution system

Main causes
- Low velocity in the approaching channel

Investigations and analyses
- Measure the approach velocity corresponding to the different wastewater flow rate;

Remedial actions
- Reduce the channel section or increase the turbulence in the approaching channel through recycled wastewater or air
- Enhance the grit chamber efficiency

3.3.1.5 Problems during sludge extraction

Symptoms
- Clogging of the extraction line
- Incorrect operation of the extraction sludge pumps
- Sand presence in the clarifier

Main causes
- High content of sand or clay
- Low velocity in extraction sludge line

Investigations and analyses
- Measure the sand and clay content in the collected sludge
- Evaluate flow velocity in the extraction pipe

Remedial actions
- Back-wash the clogged line
- Enhance the grit chamber efficiency
- Remove the sludge more frequently, trying to remove curves and valves
- If needed reduce the sludge pipe diameter

3.3.1.6 Sludge presence in the final effluent (secondary clarifier)

Symptoms
- High TSS content in the secondary clarifier effluent

Main causes
- Bad sludge settling characteristics
- High overflow rate
- Not properly functioning of the scraper

Investigations and analyses
- Measure the TSS content in the clarified effluent
- Measure the recycle and the waste sludge flow rate
- Check the installation correctness of the outflow weir, in particular the regularity along all the weirs

Remedial actions
- Enhance the weir layout and eventually place some screen wind
- Increase the sludge extraction and recycle flow rate

3.3.1.7 Floating sludge presence in the secondary clarifier

Symptoms
- High TSS content in the secondary clarifier effluent
- Floating sludge presence in the secondary clarifier

Main causes
- Denitrification process in the secondary clarifier

Investigations and analyses
- Assess the nitrification process measuring ammonia, nitrite and nitrate concentration in the effluent of the aeration tank
- Evaluate the HRT in the aeration tank
- Evaluate the sludge retention time in the clarifier

Remedial actions
- Reduce SRT
- Reduce sludge retention time in the clarifier

3.4 Activated Sludge

Activated sludge treatment step takes place into aeration tanks (activated sludge tanks), whose footprint shape has to be defined according to the aeration devices to be installed (see figure 6). Rectangular tanks have to be realised when diffused aeration devices are installed: the ratio width/height ranges between 1 and 2, the lowest values in the case of diffusors installed along only one of the tank's sides; all the edges have to be round shaped in order to avoid dead zones into the tank.

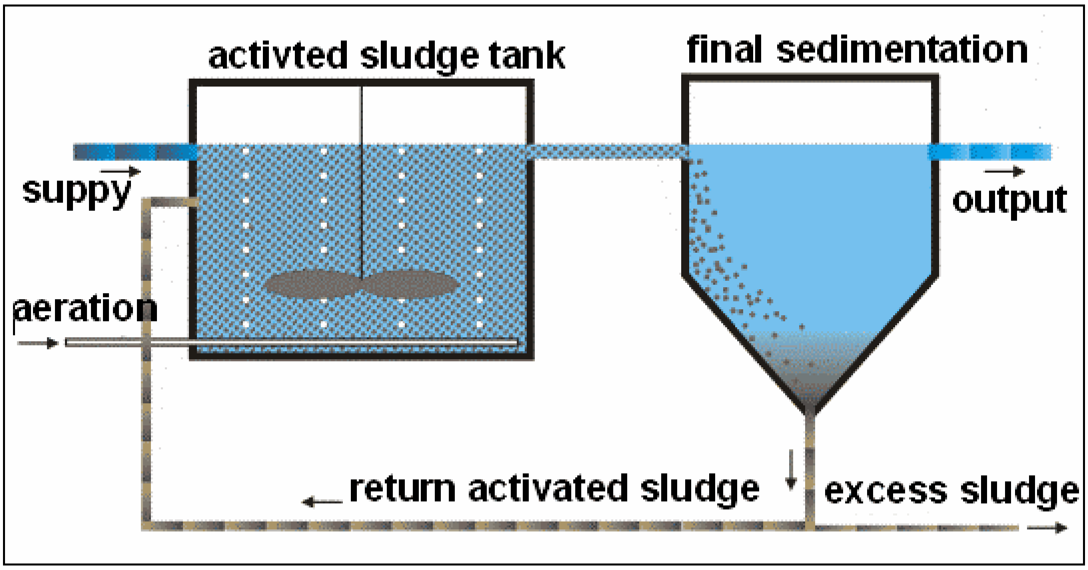

Figure 6: Example for an activated sludge process

The activated sludge process uses microorganisms to feed on organic contaminants in wastewater, producing a purified effluent. The basic principle behind all activated sludge processes is that as microorganisms grow within metabolizing soluted organic material. They form particles that clump together. These particles (flocks) in most cases are able to settle, so that they can separated with a simple settling process, which works according to the same principle as the pre-settling. Wastewater supply is mixed with return of activates sludge (see figure 6) containing a high proportion of organisms taken from the final sedimentation. This mixture is stirred and injected with large quantities of air, to provide the oxygen demand of microorganisms and keep solids in suspension. After a period of time, mixed liquor flows to a clarifier, which is in most cases a settling tank. In special cases also a flotation tank or membranes can be used to separate microorganisms. Partially cleaned water flows on for further treatment if needed. The resulting settled solids, the activated sludge, are returned to the first tank to begin the process again. Due to the fact, that during the process microorganisms grow, the excess sludge has to be removed out of the system to held the microorganisms concentration nearly constant.

When mechanical aeration devices are installed, circular shapes can be chosen as well, especially in the case of small WWTPs. In such cases, the ratio between the width (or the diameter) and the height can range from 1,5 to 5 according to the size of the mechanical aerator(s). A good rule is to split the whole reaction volume into different units (except for very small sized plants). Rectangular shaped tanks, when different units are placed side by side, offer the advantage to allow a lower footprint occupation.
Water level into the tanks is fixed through adjustable weirs (level excursion of about 10 cm, to be expected especially in case of mechanical aerators) to the secondary settling unit.

The tanks' bottom should have a slight slope to one or more shafts where submerged pumps aimed to the periodic tanks' empty for maintenance can be installed. Diffused aeration systems consist of submerged diffusors, air pipes and blowers. Each system has to be chosen according to the air bubbles size and to the air immission depth. Both these parameters affect the technical and the economical design in a very noticeable way: fine bubbles devices can increase the aeration efficiency due to the higher water-air contact surface but at the same time they are more expensive and an additional air pre-treatment is always required (air filtration and oil removal); moreover, the higher is the air immission depth the higher is the oxygen transfer rate, but the blower size increases as well.

During operation breaks, sludge settling can cause air blowers clogging, therefore the system should allow an easy removal of the air diffusors for maintenance. Usually, air diffusors are installed on the tanks' bottom, sometime only along one side in order to increase the turbolence inside the mixed liquor. Coarse bubbles devices consist of perforated pipes (5 -10 mm diameters) or coarse diffusors.

Aeration and Mixing mechanical devices consist of equipment that allow a deeper contact between air and mixed liquor into the tank. Basically, mechanical aerators can be classified into two types:

- *Mechanical aerators with vertical axis*
- *Mechanical aerators with horizontal axis*

Both of them can be classified into submerged and superficial ones.

Basic parameters that characterize the activated sludge process are:

- HRT, Hydraulic Retention Time into the aeration tank
- TSS into the mixed liquor
- Organic Load referred to the biomass
- Volumetric Organic Load
- SRT, Sludge Retention Time
- Recycle Ratio
- Type of flow into the tank (completely stirred, plug flow)
- Aeration System

Typical operational data for different activated sludge process are presented in table 3.4.1.

In table 3.4.2 a typical aeration basin operation sheet is reported; the reporting frequency depends on the WWTP size; details on routine inspections, lubrication and adjustment, performed by the operator, should be reported as well.

Tab. 3.4.1 Typical operational data for different activated sludge process

Process	Aeration system	Type of reactor	F/M $\frac{kgBOD}{kgMLVSS\ d}$	Volumetric loading rate $\frac{kgBOD}{m^3\ d}$	MLSS $\frac{kg}{m^3}$	HRT [h]	Solid Retention Time [d]	Air requirement $\frac{Nm^3}{kgBOD_{removed}}$	Recycle ratio [%]	BOD_5 removal efficiency [%]
Conventional (complete mix)	Air diffusion or Mechanical aerators	CSTR	0.2 – 0.6	0.8 – 1.9	3 - 6	3 - 5	5 - 15	35	25 – 100	85 – 95
Conventional (plug flow)	Air diffusion or Mechanical aerators	Plug flow	0.2 – 0.4	0.3 – 0.6	1.5 - 3	4 - 8	5 - 15	50 - 60	25 – 50	85 – 95
Extended Aeration	Air diffusion or Mechanical aerators	Plug flow or CSTR	0.05 – 0.15	0.15 – 0.4	3 – 6	18 – 36	20 – 30	75 – 110	75 – 150	75 – 95
Contact stabilization	Air diffusion or Mechanical aerators	Plug flow	0.2 – 0.6	0.9 – 1.2	1. – 3 4 - 10	0.5 – 1 3 - 6	5 - 15	50	25 - 100	80 – 90
High rate aeration	Mechanical aerators	Plug flow or CSTR	0.4 – 1.5	1.2 – 2.4	4 – 10	1 - 3	5 - 10		100 - 500	75 – 90
Step feed	Air diffusion	Plug flow	0.2 – 0.4	0.6 – 0.9	2 – 3.5	3 - 5	5 - 15	30 - 45	25 - 75	85 – 95
High purity oxygen	Mechanical aerators	CSTR	0.25 – 1	1.6 – 4	6 – 8	1 - 3	8 - 20		25 – 50	85 – 95

Tab 3.4.2 Aeration basin operation sheet

Month: ……..; Year: ……. ; Operator: ………………………; Item nr: ……………….

		Operational parameters									Treatment efficiency						
Day	Hour	Temperature (ML)	IIN flow rate	Recycle flow rate	Waste sludge flow rate	DO	MLVSS	HRT	SRT	F/M	Volumetric loading rate	Recycle ratio	IN	OUT	IN	OUT	Notes
		[°C]	[$m^3 d^{-1}$]			[$g m^{-3}$]	[$kg m^{-3}$]	[h]	[d]	$\frac{kgBOD}{kgMLVSS\ d}$	$\frac{kgBOD}{m^3\ d}$	[%]	[$g m^{-3}$]		[$g m^{-3}$]		
1																	
2																	
3																	
31																	
Monthly mean																	

3.4.1 Activated Sludge troubles and remedial actions

3.4.2.1 Sludge Bulking (filamentous microrganisms)

<u>Symptoms</u>

- High TSS content in the secondary clarifier effluent
- Filamentous microorganisms in mixed liquor

<u>Main causes</u>

- Low nutrient concentration in the incoming wastewater
- Toxic compounds in the incoming wastewater
- Wide pH and temperature oscillations
- High organic loading rate
- Insufficient aeration

<u>Investigations and analyses</u>

- Measure the Sludge Volume Index (SVI)
- Microscopic observations
- Check the C:N:P ratio or BOD_5:N:P ratio
- Measure temperature, pH and DO (in different sections of the aeration tank)
- Check F/M, volumetric organic loading rate, SRT
- Check toxic compounds in the incoming wastewater

Remedial actions
- Chlorine or oxygen peroxide dosage in the return sludge line (5 – 15 g Cl kg^{-1}SS d^{-1})
- Inorganic coagulants (cake, ferric chloride, etc.) dosage
- Increase SRT
- PH and DO
- BOD_5:N:P ratio correction in the incoming wastewater

3.4.2.2 Foaming

Symptoms
- Scum presence in the aeration basin

Main causes
- High content of foaming agents and/or oils and greases in the incoming wastewater

Investigations and analyses
- Evaluate the presence of *Nocardia* in the mixed liquor and in the foam
- Evaluate oil and grease in the influent wastewater
- Evaluate temperature oscillation in the aeration basin

Remedial actions
- Foam removal through water sprinkling
- Chlorine dosage

3.4.2.3 Air diffusers clogging

Symptoms
- Air flow rate reduction
- Increased headloss in the air line

Main causes
- High dust content in the air
- Oil content in the air due to air compressor faulty operation
- Rust presence in the air pipeline due to the condensing moisture
- Organic material growth or solids precipitation over air diffusers
- Solid deposition over air diffusers during aeration interruption

Investigations and analyses
- Check the dust, rust and oil content in the air flowing to the diffusers
- Check breaks presence in the air pipeline through which mixed liquor could enter during aeration interruption

Remedial actions
- Keep air compressors as much regularly operated as possible
- Check regularly the air filtration system
- Install oil trap on the air compressor
- Periodical maintenance of the air pipeline
- Enhance degritting and screening

3.4.2.4 Low DO value in the aeration basin

Symptoms
- Efficiency reduction
- DO reduction in the aeration basin; and temporary bulking
- Mixed liquor dark colour

Main causes
- Insufficient aeration
- Wide oscillation of the organic loading rate

Investigations and analyses
- Measure DO concentration in the aeration basin specially in the dead zones
- Measure wastewater flow rate and organic concentration during peak time

Remedial actions
- Increase the volume of the aeration basin (raising the water level)
- Increase the aeration

3.5 Anaerobic Treatment

Activated sludge treatment step takes place into aeration tanks, whose footprint shape has to be defined according to the aeration devices to be installed.

Wastewater load and temperature affect the feasibility of wastewater anaerobic treatment. Generally, COD concentration higher than 1550–2000 g m^{-3} and reactor temperature in the range of 25-35℃ are needed.
The principal advantages of anaerobic treatment can be summarised as in the following:

- Low running costs, mainly due to the lack of any aeration system
- High methane rich biogas production
- Low sludge production
- Less nutrients required by the process

The most diffused types of anaerobic reactor are:

- Anaerobic contact process;
- UASB (Upflow Anaerobic Sludge Blanket)
- Upflow and Downflow attached growth processes
- Fluidized Bed Reactor

Basing on the OLR (Organic Loading Rate) the anaerobic processes can be classified in low rate (up to 5 kg COD m^{-3} d^{-1}) and high rate reactors.
Start-up time to develop biomass inventory is essential, therefore seed sludge has to be chosen very carefully.
The anaerobic process is very sensitive and the main instability, at full scale plants, are due to wide variations of temperature, flow rate and organic loading rate.

The main process control parameters are listed below:

- Chemical and biological wastewater characteristics
- Temperature
- Organic Loading Rate
- Hydraulic Retention Time
- Biogas production

As a general advice, the type of anaerobic process to be applied has to be defined very carefully according to the specific site characteristics, taking into account all the factors that could affect the process, evaluating their average values and their variability. Process monitoring and control have to be guaranteed in order to prevent and avoid operational problems.

3.6 Lagoons

Suspended growth lagoons are shallow earthen basins varying in depth from 1 to 6m. The aerated lagoons depth ranges usually between 1.8 and 6m, mixing and aeration is provided through the use of slow-speed surface aerators mounted on floats. Non aerated lagoons can be classified in aerobic, facultative and anaerobic lagoons, depending on the main environmental conditions: biological conversion is carried out in aerobic and/or anaerobic conditions.

The aerobic lagoons depth usually ranges between 1 and 1.5m in order to guarantee sufficient oxygen concentration in the water. In facultative lagoons three different zones can be observed: superficial aerobic zone, anaerobic bottom zone (where settleable solids accumulate) and a facultative zone where biological processes are carried out by facultative bacteria. The anaerobic lagoon are deeper than the others and the main biological conversion is essentially anaerobic.

3.6.1 Lagoons troubles and remedial actions

3.6.1.1 Foul smell emanation due to high organic load

Symptoms
- Foul smell emanation from the lagoon
- pH and DO (Dissolved Oxygen) reduction trend

Main causes
- Biological oxygen demand higher than the available oxygen

Investigations and analyses
- Measure the pH and DO

Remedial actions
- Reduce the organic loading rate
- Install suitable aerator, converting the lagoon in an aerated lagoon

3.6.1.2 Abnormal mosquitoes growth

Symptoms
- Mosquitoes presence

Main causes
- Presence of stagnant water and/or dead zones in the lagoon where a abnormal common weed growth is observed

Remedial actions
- Remove common weed
- Use of insecticides (in this case the interruption of the incoming wastewater for 1 –2 days is needed)

Typical operational data for different lagoon are presented in table 3.6.1.

Tab. 3.6.1 Typical operational data for lagoon type

Lagoon		Depth [m]	OLR [kg BOD_5 ha^{-1} d^{-1}]	HRT [d]	BOD_5 removal [%]
Aerated		1.5 – 6		3 – 10	80 – 95
Non aerated	Aerobic	1 –1.5	40 – 120	10 – 40	80 – 95
	Facultative	1 – 2	20 – 80	7 – 30	80 – 95
	Anaerobic	2.5 - 5		20 - 50	50 - 85

In table 3.6.2 a typical lagoon operation sheet is reported; the reporting frequency depends on the WWTP size; details on routine inspections, lubrication and adjustment, performed by the operator, should be reported as well.

Tab 3.6.2 Lagoon operation sheet

Month: ……..; Year: ……. ; Operator: ……………………….; Item nr: ……………….

Day	Hour	pH		Temperature [℃]	Flow rate [m^3 d^{-1}]	DO [g m^{-3}]	HRT [d]	OLR [kg BOD_5 ha^{-1} d^{-1}]	TSS		BOD5			Notes
		in	out						In [g m^{-3}]	Out [g m^{-3}]	In [g m^{-3}]	Out [g m^{-3}]	Removal [%]	
1														
2														
31														
Monthly mean														

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OPERATION AND MANAGEMENT OF WASTEWATER TREATMENT PLANTS

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Keywords:
Maintenance, Wastewater, Operation Sheets, Operation Troubles, Remedial Actions

Operation and Maintenance Manual

The purpose is to provide WWTPs' operators with the proper understanding of recommended operating techniques and procedures, and the references necessary to efficiently operate and maintain their facilities.

The O&M manual shall include:

a) Introduction
b) Permits and Standards
c) Description, Operation and Control of Wastewater Treatment Facilities
d) Description, Operation and Control of Sludge Handling Facilities
e) Personnel
f) Sampling and Laboratory Analysis
g) Records and Reporting
h) Maintenance
i) Emergency Operating and Response Program
j) Safety
k) Utilities

Operation and Maintenance Manual

Introduction

General description: WWTP, location, sensitive areas, site map.

Permits and Standards

Type of permit, description of responsibilities of the owner, operator and consulting engineer.

Description, Operation and Control of WWT Facilities

Description of each WWTP component, their function and operating method, from the point of generation (including the conveyance system) through the treatment processes to final disposal.

Description, Operation and Control of Sludge Handling Facilities

Description of sludge handling and disposal requirements, including frequency and means of sludge removal from each unit process.

Personnel

Number and qualifications of the personnel, their duties and responsibilities. Weekly staff coverage and on-call and emergency operating personnel.

Operation and Maintenance Manual

Sampling and Laboratory Analysis

List of all samplings and analyses required, appropriate protocols for proper sampling, storage, transportation, and analysis. Quality control/quality assurance plan.

Records and Reporting

List of all reporting requirements, location and method of record keeping (daily logs)

Maintenance

List of spare parts and supplies needed for maintenance and repair. Chart itemizing all equipments, their associated maintenance action and the frequency of such action.

Emergency Operating and Response Program

Program detailing procedures to be followed in the events of emergency situation: emergency conditions, actions to be taken, responsible authorities, corrective actions.

Safety

Itemized list of safety and first aid equipment instruction.

Utilities

List of names and notification requirements for water, electric, gas and telephone services.

Screening

Design Data

		Manually cleaned	Mechanically cleaned
Bar size:			
Width	[mm]	5 – 15	5 – 15
Depth	[mm]	25 – 75	25 – 75
Clear spacing between bars	[mm]	20 – 60	10 – 30
Slope from vertical	[°]	45 – 60	70 – 90
Approach velocity	[m s^{-1}]	0.3 – 0.5	0.5 – 1
Allowable headloss	[m]	0.1 – 0.2	0.1 – 0.2

Screened Material characteristics

Clear spacing between bars [mm]	Volume of screenings [m^3 PE^{-1} y^{-1}]	Suspended solids removal [%]	BOD_5 removal [%]
15	2 10^{-3} – 4 10^{-3}	1 – 3	-
10	3 10^{-3} – 6 10^{-3}	2 - 5	1 – 3

A typical screen operation sheet should report details on routine inspections, lubrification and adjustment, performed by the operator.

Screening

Problem	Sand in the screen channel	Solid transport through the screen
Evidences	• Sand in the removed material • Increased water level in the channel • Less amount of sand removed by the sand- trap	• Regular clogging of the pipes downstream the screen • Finding inappropriate materials in the pump impeller
Causes	• Low speed in the channel • Obstacles in the channel	• Solids removal not effective • Incorrect piping design or installation
Tests-Analysis	• Measure the amount of sand in the channel bottom • Measure the speed for different flowrates • Verify the design of the channel	• Check the presence of solids downstream the screen • Check the pump water flow
Actions	• When < 0,5 m/s, the speed has to be increased by reducing the wet section in the channel	• Removal of all the blocked material • Replacement of the damaged moving parts

Grit Removal

The goal is to separate gravel and sand and other mineral materials down to a diameter between 0.2 and 0.1 mm.
There are three general types of grit chamber: ***horizontal-flow*** – of either ***rectangular*** or ***square configuration*** – and ***aerated***.
The quantity of removed grit will vary depending on the type of sewer system, the caracheristics of the drainage area, etc.

Typical amounts of collected grit (combined sewer)

Volume of grit [l PE^{-1} yr^{-1}]	Volume of grit [l m^{-3}]	reference remark
40	0.02 - 0.2	ATV-Hanbuch, 1997 average: 0.06 l / m^3
2.4 – 58.8		Londong, 1990
2		Imhoff, 1993 high-density areas
5		Imhoff, 1993 low-density areas
	0.01 – 0.1	Passino et al. (1999)
	0.004 - 0.2	Tchobanoglous, 2003 aerated grit chamber

Collected grit moisture content ranges between 15 e 40%; volatile content, on dry basis, ranges between 20-50 %.

Grit Removal

Problem	Sand in the effluent	Organic matter in the removed solids
Evidences	• Sand in the units process downstream the sand trap • Reduced amount of sand removed	• Excess of removed solids • Odours from the removed solids
Causes	• Low HRT (too high flow speed)	• High HRT (too low flow speed)
Tests-Analysis	• Measure inorganic SS in/out the sand trap at different flowrates • Measure the flowrate speed in the sand trap • If aerated, measure the air flowrate	• Measure the VSS in the removed solid fraction • Measure the flow speed in the channel • If aerated, measure the air flowrate
Actions	• Increase the wet section (water level) if possible • If mechanical, reduce the rotating speed	• Reduce the number of parallel units • Reduce the wet section (water level) if possible • If mechanical, increase the rotating speed

Sedimentation

The goal is to remove readily settleable solids and floating materials thus reducing the suspended solids content; so quiet conditions are set up in the sedimentation basin.
The sedimentation process takes place in circular or rectangular basins made of concrete or iron, having the bottom lightly sloped towards a zone where the sludge is conveyed by appropriate withdrawal devices.

Typical operational data for different type of clarifier

	HRT [h]	Overflow rate [$m^3\ m^{-2}\ h^{-1}$]
Primary Sedimentation	1,5 – 2,0	0,8 - 1,2
Primary Sedimentation upstream the Trickling filters	3,0 – 4,0	0,5 - 0,8
Secondary Sedimentation downstream the Trickling filters	3,0	0,5 - 0,8
Secondary sedimentation	3,0	0,5

Basically, in a primary clarifiers, removal efficiency for BOD and TSS are mainly related to the HRT and the its influent concentration

Sedimentation

Problem	Sludge floating on water surface	Low efficiency in floating solids removal
Evidences	• Solids on water surface • H_2S odour	• Floating solids in the effluent from the settler
Causes	• Rising sludge due to high retention time in the settler (also in parts of the tanks)	• Floating solids (oils and scums) removal devices do not work properly
Tests-Analysis	• Measure SST in the extracted sludge • Check the sludge extraction devices • Check dead zones in the settler	• Measure the oil content in different WWTP sections • Check the removal devices
Actions	• Increase the sludge extraction (duration, frequency, flowrate) • Repair or replace the sludge extraction devices	• Install devices to avoid floating solids discharge • Install efficient scum-skimmers • Improve oils removal in primary treatments (floatation)

Sedimentation

Problem	Sludge in the effluent	Floating sludge in the settler
Evidences	• Too high SS in the effluent	• Too high SS in the effluent • Evidence of floating sludge
Causes	• Not floc-structured sludge (bulking) • Too high Hydraulic Load • Failures in the sludge extraction devices	• Denitrification process in the settler
Tests-Analysis	• Measure turbidity and SS in the effluent • Check the sludge extraction flowrate and the proper working • Check the proper weirs design	• Measure nitrite and nitrate coming out from the activated sludge tank • Calculate SRT • Check the air flowrate
Actions	• Improve and modify the biological process avoiding • Modify/Maintain weirs and extraction devices • Increase sludge extraction flowrate	• Move the floated sludge • Reduce the SRT • Improve sludge extraction

Activated Sludge

Activated sludge treatment step takes place into **aeration tanks**, whose footprint shape has to be defined according to the aeration devices to be installed.

Rectangular tanks have to be realised when diffused aeration devices are installed. When mechanical aeration devices are installed, **circular shapes** can be choosen as well, especially in the case of small WWTPs.

- **Diffused aeration systems** consist of submerged diffusors, air pipes and blowers.
- **Mechanical aerators** can be with vertical axis or horizontal axis; both of them can be classified into submerged and superficial ones.

Basic parameters that characterize the activated sludge process are:

- HRT, Hydraulic Retention Time into the aeration tank
- TSS into the mixed liquor
- Organic Load referred to the biomass
- Volumetric Organic Load
- SRT, Sludge Retention Time
- Recycle Ratio
- Type of flow into the tank (completely stirred, plug flow)
- Aeration System

Activated Sludge

Typical operational data for different activated sludge process

Process	Aeration system	Type of reactor	F/M $\frac{kgBOD}{kgMLVSS\ d}$	Volumetric loading rate $\frac{kgBOD}{m^3\ d}$	MLSS $\frac{kg}{m^3}$	HRT [h]	Solid Retention Time [d]	Air requirement $\frac{Nm^3}{kgBOD_{removed}}$	Recycle ratio [%]	BOD_5 removal efficiency [%]
Conventional (complete mix)	Air diffusion or Mechanical aerators	CSTR	0.2 – 0.6	0.8 – 1.9	3 - 6	3 - 5	5 - 15	35	25 – 100	85 – 95
Conventional (plug flow)	Air diffusion or Mechanical aerators	Plug flow	0.2 – 0.4	0.3 – 0.6	1.5 - 3	4 - 8	5 - 15	50 - 60	25 – 50	85 – 95
Extended Aeration	Air diffusion or Mechanical aerators	Plug flow or CSTR	0.05 – 0.15	0.15 – 0.4	3 – 6	18 – 36	20 – 30	75 – 110	75 – 150	75 – 95
Contact stabilization	Air diffusion or Mechanical aerators	Plug flow	0.2 – 0.6	0.9 – 1.2	1. – 3 4 - 10	0.5 – 1 3 - 6	5 - 15	50	25 - 100	80 – 90
High rate aeration	Mechanical aerators	Plug flow or CSTR	0.4 – 1.5	1.2 – 2.4	4 – 10	1 - 3	5 - 10		100 - 500	75 – 90
Step feed	Air diffusion	Plug flow	0.2 – 0.4	0.6 – 0.9	2 – 3.5	3 - 5	5 - 15	30 - 45	25 - 75	85 – 95
High purity oxygen	Mechanical aerators	CSTR	0.25 – 1	1.6 – 4	6 – 8	1 - 3	8 - 20		25 – 50	85 – 95

Activated Sludge

Problem	Bulking Sludge	Foaming in the aeration tank
Evidences	• Solids in the treated effluent • Filamentous bacteria in the activated sludge	• Foam on the tank surface
Causes	• Biological unit under-loading • Toxic substances in the influent • Insufficient aeration	• Oils, greases and detergents in the influent
Tests-Analysis	• Measure SVI • Microscopic observations • Check the BOD:N:P ratio • Measure T, pH, O_2 in the tank • Check the organic load	• Measure tensio-actives • Measure SS and O_2 in the aeration tank • Observe *Nocardia* in the sludges
Actions	• Chlorinate the sludge recycling (5-15 $gCl_2\ kg^{-1}\ SS\ d^{-1}$) • Add chemicals • Increase SRT • Inoculate sludge • Realise a selector	• Remove foams mechanically • Use water to remove foams • Add Chlorine in the aeration tank

Activated Sludge

Problem	Low oxygen in the tank	Variable organic load
Evidences	• Reduced treatment efficiency • Low oxygen concentration • Bulking and dark sludge	• SVI variability • SRT variability
Causes	• Insufficient aeration • Organic Load fluctuation	• Organic load fluctuations • SSV fluctuation in the aeration tank
Tests-Analysis	• Measure O_2 in the tank • Check influent characteristics	• Measure SVI • Measure SSV in the aeration tank • Measure all the flowrates
Actions	• Increase aeration • Install oxygen-based control devices • Increase the aeration tank volume	• Modify plant operation in order to stabilise control parameters (especially SRT)

Anaerobic Treatment

The most diffused types of anaerobic reactor are:

- ✓ Anaerobic contact process;
- ✓ UASB (Upflow Anaerobic Sludge Blanket)
- ✓ Upflow and Downflow attached growth processes
- ✓ Fluidized Bed Reactor

Basing on the OLR (Organic Loading Rate) the anaerobic processes can be classified in low rate (up to 5 kg COD m^{-3} d^{-1}) and high rate reactors.

Wastewater load and temperature affect the feasibility of wastewater anaerobic treatment. Generally, COD concentration higher than 1550 – 2000 g m^{-3} and reactor temperature in the range of 25-35°C are needed.

The main process control parameters are listed below:

- ➢ Chemical and biological wastewater characteristics
- ➢ Temperature
- ➢ Organic Loading Rate
- ➢ Hydraulic Retention Time
- ➢ Biogas production

Lagoons

Suspended growth lagoons are shallow earthen basins varying in depth from 1 to 6m.

The **Aerated Lagoons** depth ranges usually between 1.8 and 6m, mixing and aeration is provided through the use of slow-speed surface aerators mounted on floats.
Non Aerated Lagoons can be classified in aerobic, facultative and anaerobic lagoons, depending on the main environmental conditions: biological conversion is carried out in aerobic and/or anaerobic conditions.
The aerobic lagoons depth usually ranges between 1 and 1.5m in order to guarantee sufficient oxygen concentration in the water. The anaerobic lagoons are deeper than the others and the main biological conversion is essentially anaerobic.

Typical operational data for different lagoons

Lagoon		Depth [m]	OLR [kg BOD_5 ha^{-1} d^{-1}]	HRT [d]	BOD_5 removal [%]
Aerated		1.5 – 6		3 – 10	80 – 95
Non aerated	Aerobic	1 –1.5	40 – 120	10 – 40	80 – 95
	Facultative	1 – 2	20 – 80	7 – 30	80 – 95
	Anaerobic	2.5 - 5		20 - 50	50 - 85

Lagoons

Problem	Foul smell emanation due to high organic load	Abnormal mosquitoes growth
Evidences	• Foul smell emanation from the lagoon • pH and DO (Dissolved Oxygen) reduction trend	• Mosquitoes presence
Causes	• Biological oxygen demand higher than the available oxygen	• Presence of stagnant water and/or dead zones in the lagoon where a abnormal common weed growth is observed
Tests-Analysis	• Measure the pH and DO	• Observation of weed growth
Actions	• Reduce the organic loading rate • Install suitable aerator, converting the lagoon in an aerated lagoon	• Remove common weed • Use of insecticides (in this case the interruption of the incoming wastewater for 1 –2 days is needed)

Lesson C2

Operation Costs of wastewater Treatment Plants

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Keywords

Operation Costs, Personnel, Maintenance, Maintenance Strategy, Energy, Energy Analysis, Chemicals & Materials, Disposal

Table of Content

1. Introduction

The objective of the installation and operation of wastewater treatment systems is to assure an environmentally friendly effluent quality meeting the determined border values. The high costs for construction, maintenance and operation of conventional treatment systems exert economic (and social) pressure, even in developing countries. Therefore, all over the world engineers look for creative, cost-effective and environmentally sound ways to control water pollution. Wastewater technology has been improved substantially during the last few decades.

When selecting a wastewater system, initially many processes are theoretically competitive. To determine the most economical alternative a cost-effectiveness-analysis including investment costs and operation costs has to be conducted [Tsagirakis et al, 2003; Medina, 2005]. For example a simple treatment system with low investment costs may have high operational expenses and therefore will be the alternative with the highest total costs.

An evaluation done early during the design process has the advantage of providing an early warning if an alternative design is too costly relative to the available resources, saving the trouble of preparing final designs for those technologies that are outsides the bounds of affordability. The evaluation can be seen as an early screening of the options, which have passed the basic tests of technical and social feasibility.

This module will give detailed information about operation costs for wastewater treatment systems. The main components, which are affecting the extend of operation costs, are identified.

2. Operation Costs

2.1 General

Operation costs can be differentiated as personnel costs, maintenance costs, energy costs, chemicals and material costs, disposal costs and miscellaneous costs for administration, insurance, discharge duty (if exists), external services etc..

There are many factors affecting operation costs [Bohn, 1993], accordingly operation costs may differ widely:

- Size and load of the plant
- Topography and geographical situation of the site (e.g. affecting pumping energy costs)
- Characteristics of wastewater and the discharge norm

- Technologies and the selected treatment process
- Type of sludge treatment and way of disposal
- Energy supply and energy recycling
- Degree of automation, measurement and process control
- Organization of the plant and its management

Figure 1 shows the composition of operation costs for a selected wastewater treatment plant of a capacity of 5,000 p.e. (population equivalent). It can be noticed, that the cost for personnel, maintenance, energy and sludge disposal are decisive categories as these account for most of the operation costs. In the following sections each single category of operation costs are discussed in more detail.

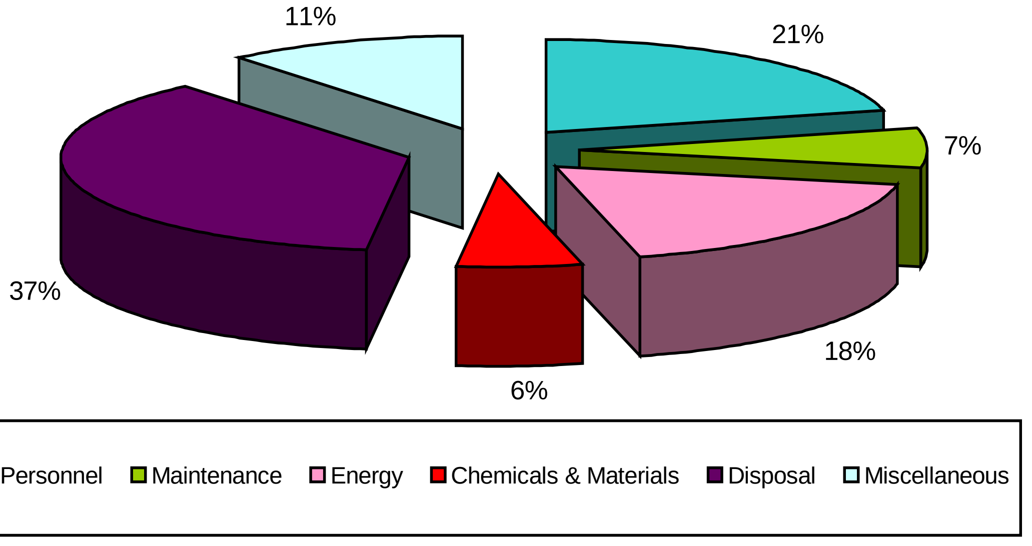

Figure 1: Composition of operation costs for a wastewater treatment plant of 5,000 p.e. in Germany [Halbach, 2003]

For rough calculation it can be assumed, that operation costs may amount up to 50% of the total costs for wastewater treatment. In average for wastewater treatment plants in Europe with more than 10,000 p.e., the specific operation costs will amount up to 25–35 €/p.e. and year. Smaller installations can achieve more than twice of that number.

As it has been the case in Europe, the more restrictive the discharge norms are – for example concerning nitrogen and phosphorous content –, the more demanding the treatment must be. That means that more technical requirements (like longer treatment times, conversion of existing structures or building of new ones) are needed to achieve the limit values. Such extra requirements represent more operational expenses as well.

2.2 Factors of Operation Costs

The figures 3 and 4 illustrate exemplarily the influence of the selected technology and the size of the plant on operation costs. In principle, low-tech systems as wetland systems or stabilization ponds with high land requirements have very low energy consumption and result in relatively low total operation costs. On the opposite, high-tech systems like activated sludge systems or chemical treatment can only be operated with high expenditures of energy and other operation costs. It can be noticed that the specific operation costs of small wastewater treatment plants are remarkably higher than of larger treatment plants. This is a result of economy of scale of all categories achieved in larger sizes of installations.

2.3 Operation Costs in Relation to total Costs of WWTP !

Regarding the total costs of a wastewater system operation costs play an important role. Operation costs are the expenses related to the operation, maintenance and monitoring of the plant, once it was constructed. These costs will be incurred in a regular basis along the service life. Exemplarily, figure 2 shows the cost composition of wastewater systems in Germany divided up in capital and operation costs [ATV, 2003]. Easily it can be seen, that operation costs can amount up to 50 % of the total annual costs. Therefore during the evaluation of process alternatives the consideration of operation costs is of crucial importance. Disregarding this conclusion will result in costs, which are neither adequate nor affordable for the customers. For example the treatment process may be interrupted or totally turned off due to e.g. high energy costs, which can not be paid to the local power authority.

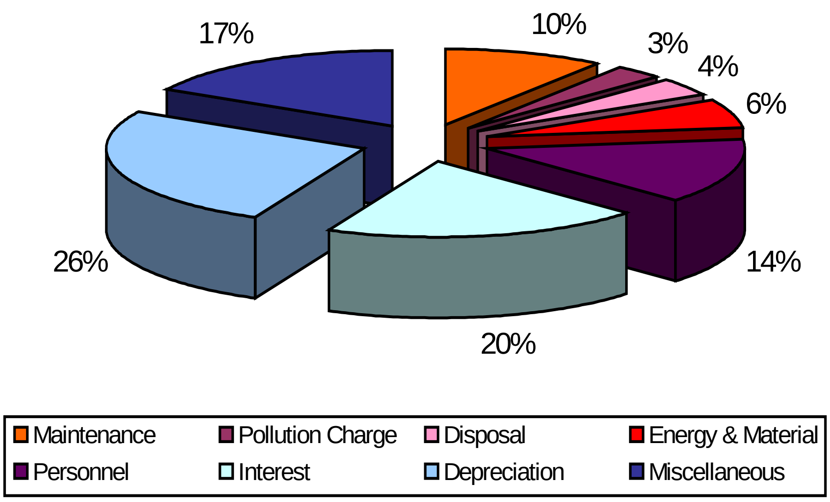

Figure 2: Composition of total annual costs for wastewater systems in Germany [ATV, 2003]

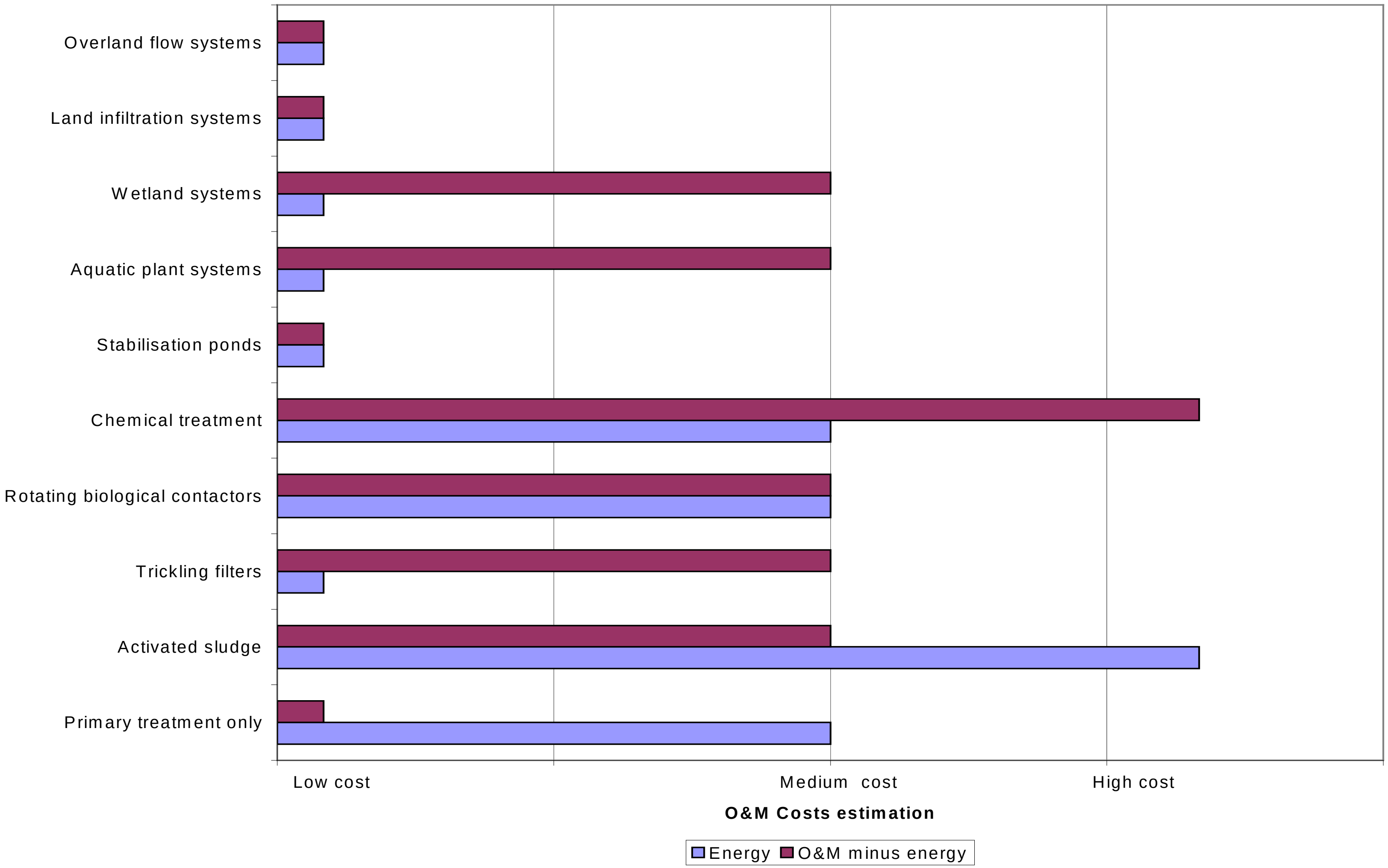

Figure 3: Comparison of operation costs operation (O&M) for different types of secondary treatment options [Kampet, 2000]

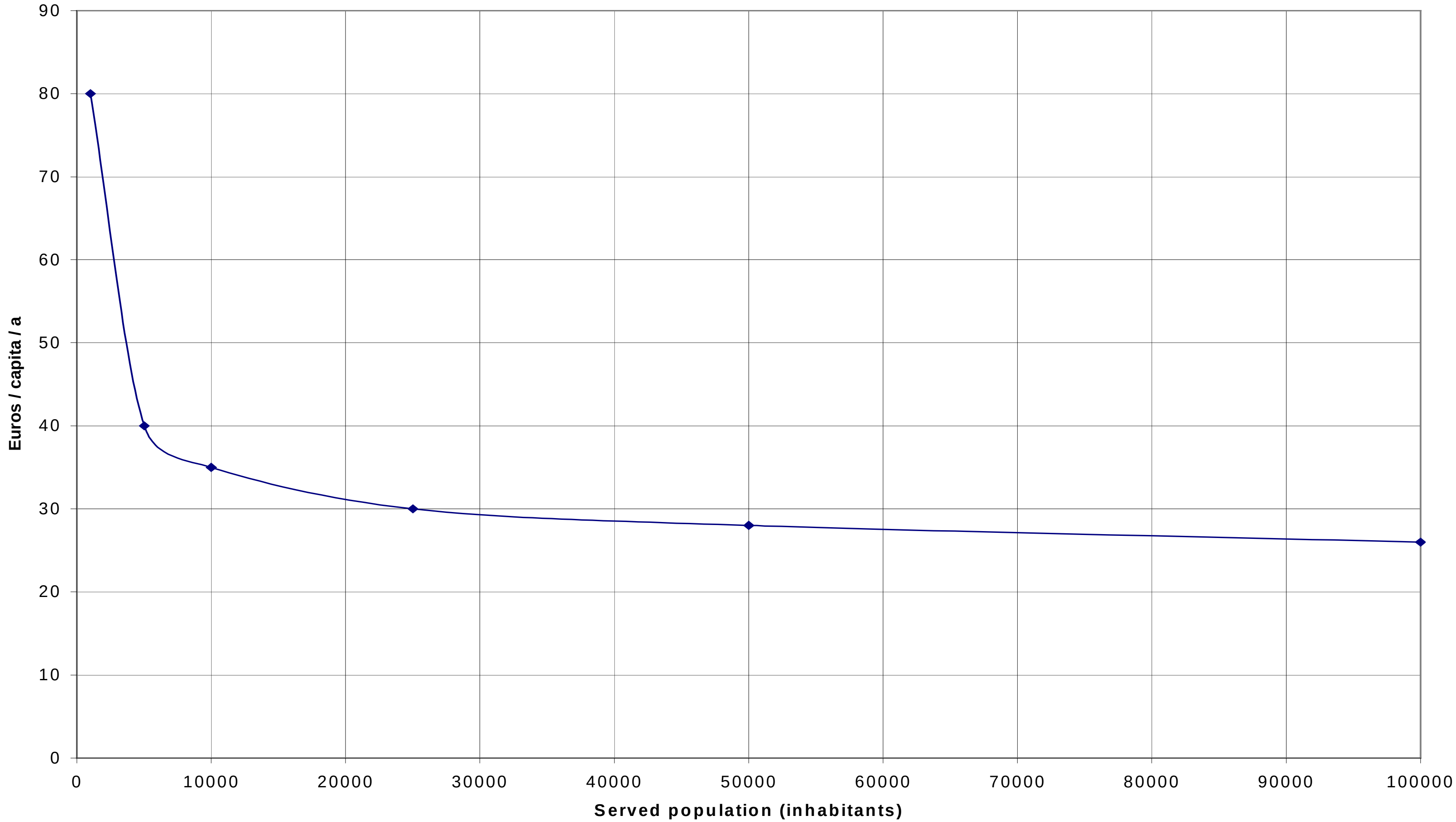

Figure 4: Operation costs for wastewater treatment plants related to the size of the plant [Kampet, 2000]

2.4 Operation Costs in Relation to total Costs of WWTP !

Regarding the total costs of a wastewater system operation costs play an important role. Operation costs are the expenses related to the operation, maintenance and monitoring of the plant, once it was constructed. These costs will be incurred in a regular basis along the service life. Exemplarily, Figure 1 shows the cost composition of wastewater systems in Germany divided up in capital and operation costs [ATV, 2003]. Easily it can be seen, that operation costs can amount up to 50 % of the total annual costs. Therefore during the evaluation of process alternatives the consideration of operation costs is of crucial importance. Disregarding this conclusion will result in costs, which are neither adequate nor affordable for the customers. For example the treatment process may be interrupted or totally turned off due to e.g. high energy costs, which can not be paid to the local power authority.

3. Personnel

The costs for personnel of wastewater treatment systems depend significantly on the size of the treatment plant, the selected technology and the level of automation. The table below shows the personnel costs subject to the treatment capacity of wastewater treatment plants [Reicherter, 2003].

< 10.000 p.e.	35 – 40 % of total operation costs
10.000 – 100.000 p.e.	25 % of total operation costs
> 100.000 p.e.	15 % of total operation costs

Costs for personnel normally comprises salaries/wages, pension and insurance costs. A typical working week consists of five working days per week, with a month’s leave over a year. Depending on a system’s requirements, there can be one, two or three eight-hour shifts for specific position. The operation personnel mainly is occupied with activities related to process control, in average 30 % of the working time is spend for maintenance activities. The cost to the employer of an annual salary including insurance depend on the wage level of each state or district, in which a treatment facility is located.

Kemper et al (1994) showed that in developing countries the cost of personnel in the wastewater treatment sector is proportionately higher than for developed countries. In average in Greece the cost of personnel is 48% of the total cost for operation of a treatment plant. For France the figure is 24 %, for Great Britain 38%. On the other hand, in Mexiko and Costa Rica, personnel costs are 68% of the total.

The qualification of operation staff is of crucial importance for an adequate and professional operation. There is a high need for a profound education and special training as a essential prerequisite. Plant operators can make a plant of poor and insufficient design perform well, conversely, they can cause the best design plant to perform poorly [Michel et al., 1969]. Smaller treatment plants employ fewer scientific personnel and fewer unskilled laborers, with higher number of technical personnel. There are likely to be two reasons for this: At first because small treatment plants are less complicated and easier to operate, secondly for small towns it is difficult to find higher educated personnel with scientific education, relying instead on local personnel.

Chemical engineers and chemists are the most dominant graduate employees in wastewater treatment plants. Chemical, electrical and mechanical engineers mainly work as control engineers, while technologists are in charge of the technical supervision. Technologists come from technical colleges which do not have university status. Ideally, a wastewater treatment plant would have an input from all kind of professionals. However, this is unfeasible for all but the very large installations and for centralized agencies with a number of plants under their jurisdiction.

3.1 Number of Employees

The major parameters that influence the number of operational staff employed are:

- the size of installation,
- the treatment processes and systems,
- the degree of automation,
- productivity efficiency of personnel,
- managerial efficiency and
- others.

In principle, it can be noticed that small wastewater treatment plants need more personnel per p.e. than larger ones. This is a result of economy of scale achieved in larger sizes of installations. In addition, in small and medium size plants, conventional systems are more costly in terms of personnel in comparison with extended aeration plants. An other factor that dominantly influences personnel costs is the degree of automation. Although automation requires considerable capital cost as well as specialized personnel to operate the plant, there is a concomitant reduction in the number of employees needed.

A good example is the analysis of economic data pertinent to existing municipal wastewater treatment plants (MWTP) in Greece, which has been carried out by Tsagirakis et al (2003). On the basis of data on personnel from 66 activated sludge systems the relationship between p.e. and t.p.e. and the number of personnel employed in MWTP has been analyzed (Figure 5). The figure shows the number of the p.e. equating to one person employed in a MWTP. It can be noticed that small installations need more personnel per p.e. than larger ones. This is a result of economy of scale achieved in larger plants. In addition, in small and medium size plants, conventional systems are more costly in terms of personnel in comparison with extended aeration plants.

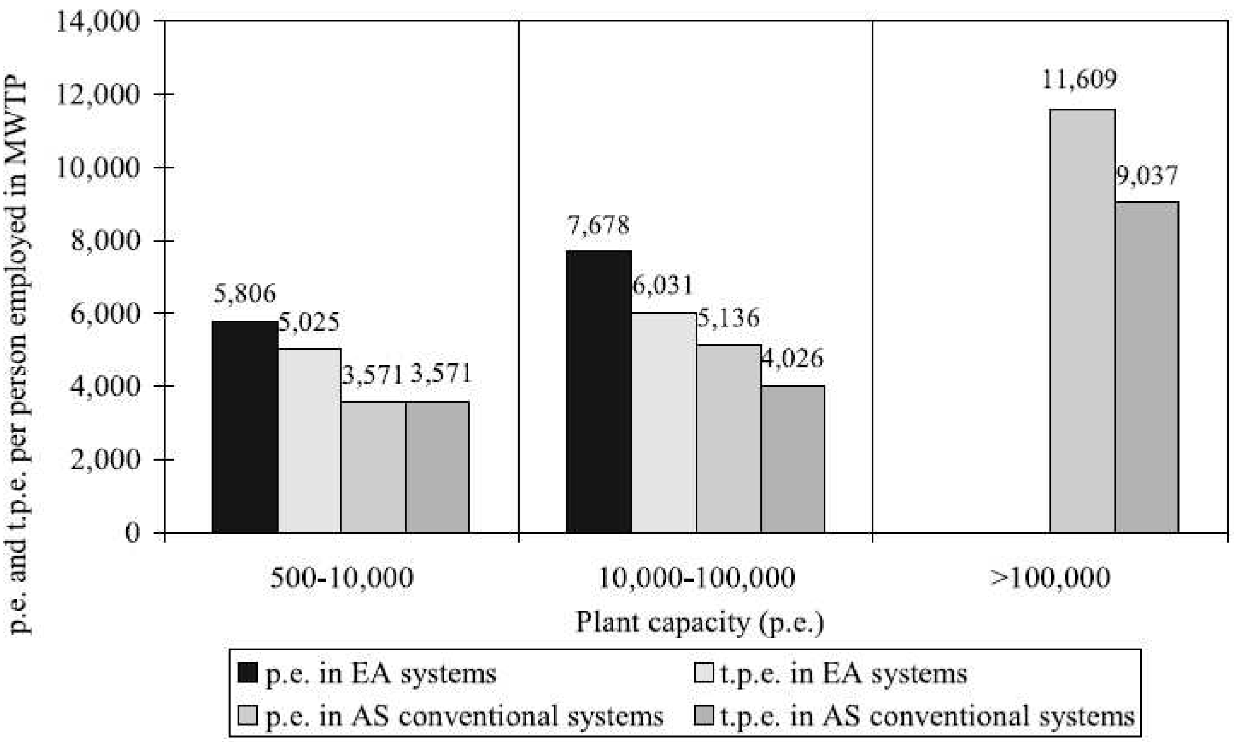

Figure 5: Employees per p.e. and t.p.e. in relation to their size; (EA = Extended Aeration; AS = Activated Sludge) [Tsagarakis et al, 2003]

4. Maintenance

The costs for maintenance of wastewater treatment plants usually amount up to 15–25 % of the total operation costs. Thus, the organization and strategy of maintenance activities play an important role for the agency.

Maintenance costs include the following: repairs on mechanical, electrical, electronic and civil parts and minor or major replacements like small or large parts for pumps, blowers or motors. They include internal personnel costs, material expenses and external services. Quantities of spare parts kept in stock and purchasing deals also influence the total maintenance costs.

For a first calculation maintenance costs can be derived from the investment costs as follows:

- Civil Constructions	0.5 – 2.0 % of investment costs per year
- Renovations of Civil Constructions	2.0 – 4.0 % of investment costs per year
- Mechanical Equipment	2.0 – 6.0 % of investment costs per year
- Electrical and Electronical Equipment	2.0 – 6.0 % of investment costs per year

The above given cost assumptions are very roughly and have to be specified for each particular project. They depend mainly on the chosen maintenance strategy of the agency.

Maintenance is an important activity that should be performed in any type of facility, thus it is necessary for proper functioning and prevents damages whose repairing can be very expensive. Even low-tech options demand maintenance activities. Maintenance should be considered in a regular time basis (semestral, annual) into the costing and budget of the project.

Wastewater systems often suffer from a history of inadequate investment in maintenance and repair often due to large part of “out-of-sight, out-of-mind” nature which poses an inherent problem. This stands for both sewer systems as well as treatment facilities. The lack of proper maintenance results in the deterioration of the installed equipment and the construction itself.

The purpose of maintenance programs is to maintain design functionality (capacity and integrity) and / or to restore the system components to the original condition and thus functionality. The ability to effectively operate and maintain a wastewater treatment system depends mainly on site conditions, proper design (including selection of appropriate materials and equipment), construction and inspection, testing and acceptance, and system start-up.

Operation staff should already be involved at the beginning of each project, including planning, design, construction, acceptance and start-up. When the system is designed with future maintenance considerations in mind, the result is a more effective program in terms of maintenance costs and performance.

4.1 Maintenance Strategy

Maintenance for wastewater systems can either be preventive/predictive or corrective activity. Effective maintenance programs are based on knowing what components make up the system, where they are located and the condition of the components. With that information, preventive/predictive maintenance can be planned and scheduled, rehabilitation needs identified, and long-term improvement programs planned and budgeted. High-performing agencies have all developed performance measurements of their maintenance program and track the information necessary to evaluate performance.

Commonly accepted types of maintenance include the following classification:

Corrective Maintenance (Those maintenance activities are also called reactive):

Maintenance classified as corrective, including emergency maintenance, is reactive. Only when equipment or system fails maintenance is performed. A corrective maintenance is characterized by the inability to plan and schedule work, the inability to budget adequately, the poor use of resources and a high incidence of equipment and system failures.

Preventive / Predictive Maintenance (Those maintenance activities are also called proactive):

Preventive Maintenance being defined by a programmed, systematic approach. This type of maintenance will always result in improved system performance except in the case where major chronic problems are result of design and/or construction flaws that can not be corrected by operation and maintenance activities. Major elements of preventive maintenance programs are planning and scheduling, records management, spare parts management, cost and budget control and training program for the involved personnel.

Predictive maintenance is a method of establishing baseline performance data and monitoring performance criteria over a period of time so that failure can be predicted and maintenance can be performed on a planned, scheduled basis.

In reality, every agency operates their system using a combination of corrective and emergency maintenance, preventive maintenance and predictive maintenance methods. The goal should be to reduce the corrective and emergency maintenance efforts by performing preventive maintenance that will minimize or even eliminate system failures and optimize operation cost.

Optimizing the operating costs, however, does not only mean having an optimum treatment process. Working effectively also means to optimize the operation of each individual part of the facility – for example, considering the cost of a measuring point is comprised of only 25% investment costs (planning, purchasing, commissioning) but 75% general operating costs, preventive and reactive maintenance costs: Obviously, there is great potential for cost reduction over the entire life cycle of the whole treatment system (see figure 6)

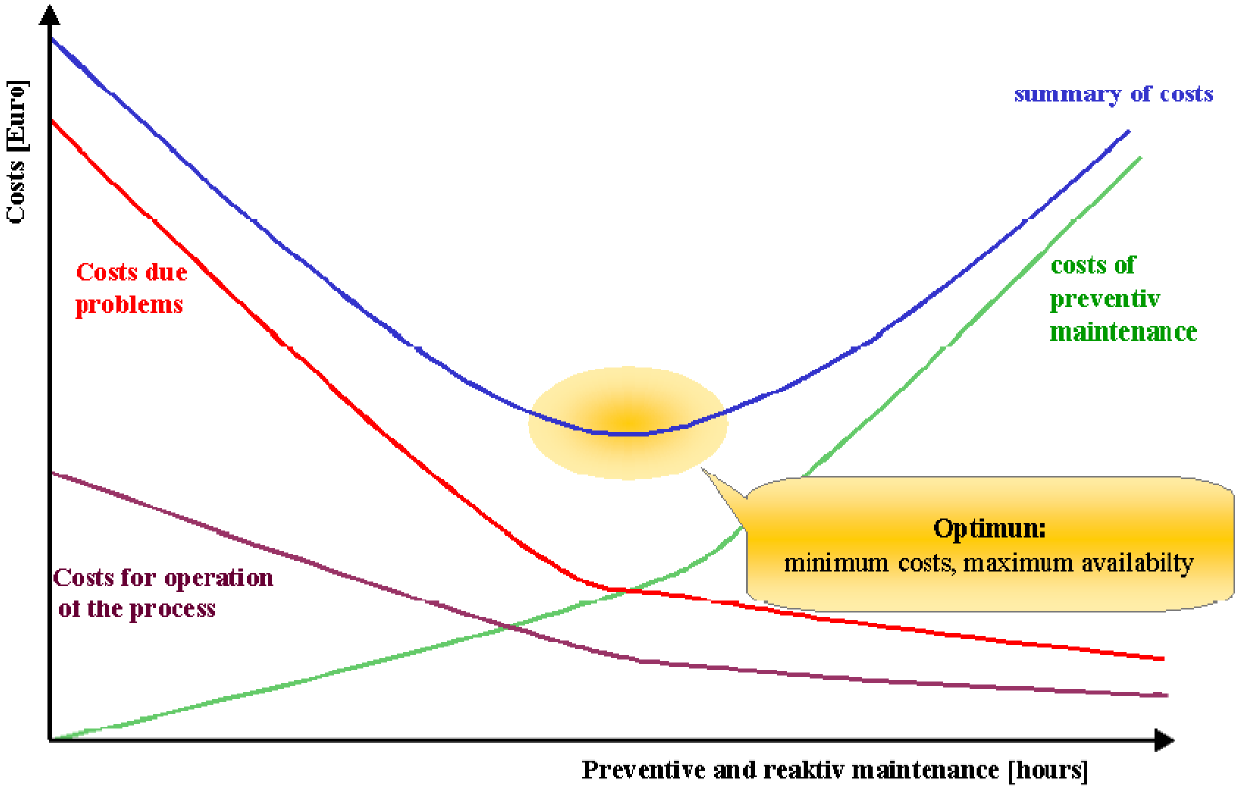

Figure 6: Costs and maintenance seen as a whole; the optimum is achieved from the best relationship between costs and availability [Müller, 2003]

5. Energy

Energy consumption is a major contributor to the operation cost of wastewater systems and therefore is an important parameter for choosing a treatment technology. The costs for energy usually amount up to 10–30 % of the total operation costs. Energy costs include the consumption (and internal production) of electricity, gas, oil and district heating. In sewer collection systems energy is used for transportation by pumping stations in case of a lack of sufficient hydraulic gradients. Aeration is considered to be the main energy consumer in the wastewater treatment process.

Due to different tariff structures all over the world, average costs for energy consumption of wastewater treatment systems can not be given. There are many different combinations of off-rates and peak-rates of the power utilities existing. For example in Israel the peak rates are fourth times the rates of off-peak rates, resulting in high incentive for energy consumption during off-peak period [Kadar and Siboni]

For a first calculation energy costs can be derived from the total amount of pumped wastewater and the population equivalent of the treated wastewater as follows [Bohn, 1993, NRW, 1999]:

- Pumping Stations[1]	10 – 15 Wh /m³
- Screens	0.3 – 0.5 kWh / (p.e. &.a)
- Aerated Sand Traps	1.7 – 2.2 kWh / (p.e. &.a)
- Preliminary Sedimentation Tanks	0.4 – 0.6 kWh / (p.e. &.a)
- Aeration Tanks	17.2 – 25.8 kWh / (p.e. &.a)
- Secondary Sedimentation Tanks	1.2 – 2.3 kWh / (p.e. &.a)
- Thickener	0.7 – 1.1 kWh / (p.e. &.a)
- Sludge Dewatering Devices	3.0 – 4.0 kWh / (p.e. &.a)
- Digestion[2]	2.4 – 2.9 kWh / (p.e. &.a)

The above given assumptions for energy demand are very roughly and have to be specified for each particular project. They mainly depend on the size and the type of the chosen treatment process (possibly including digestion with the utilization of produced biogas). Target values for energy consumption are set up by Halbach (Figure 7), which demonstrates that the specific energy demand per p.e. remarkably declines from small to large treatment plants.

The operator has to challenge with energy as one of the main cost components of the treatment plant. Thus, for best results of energy cost reduction

- energy conservation,
- process efficiency,
- aeration devices and oxygen transfer,
- process flow configuration,
- bio-gas quantities,
- bio-gas utilization and
- time of day consumption of energy

should be optimized.
Modification of existing wastewater treatment plants can reduce the current energy costs remarkably. Optimization of oxygen transfer, primary sedimentation, utilization of bio-gas from the primary and secondary waste sludge, while considering in both cases the tariff of the power utilities, can reduce energy cost to a minimum. The self-produced electricity is best used during peak tariff hours. Because in a typical wastewater treatment plant there are other energy consumers such as pumps, electrical motors etc., the electricity produced can be used during peak time. In some nations e.g. in Germany or Israel it is also possible to sell electricity back to the power utilities.

[1] Example for 3 m pressure head
[2] Gas utilization and energy production <u>not</u> included

Because gas production is some what regulated during the day, it seems a good idea to buffer bio-gas by the use of a gasholder. A multitude of energy efficient equipment, technologies and operating strategies like energy-efficient motors, variable frequency drivers or electrical load management systems are available to reduce energy costs in wastewater facilities.

Automation and control is an other important factor that influences the overall energy demand. On-line alterations to the aeration times according to the on-line requirements of the system can save a substantial amount of energy.

Firstly the implementation of measures and steps toward reduction of energy cost will generate investment costs, but those costs will likely be amortisised in a few years.

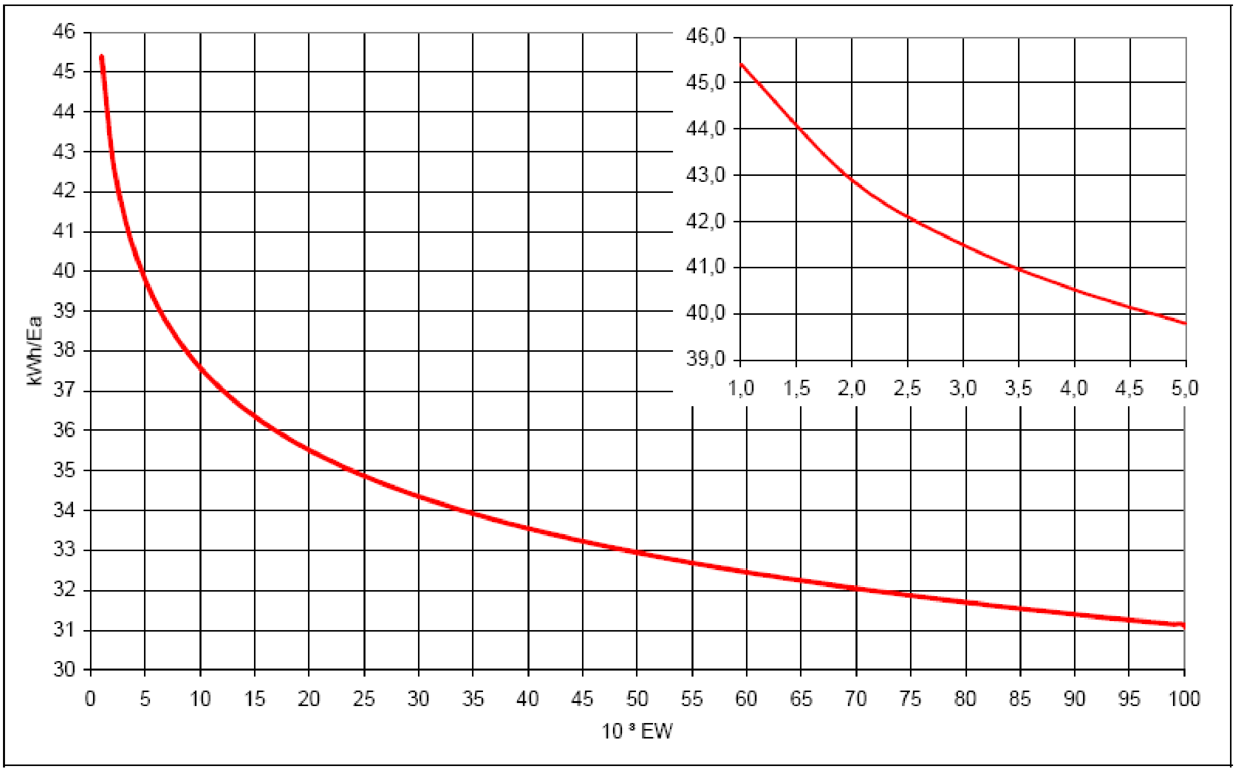

Figure 7: Target values for the specific energy demand subject to the treatment capacity (EW ~ E ~ p.e.) [Halbach, 2003]

5.1 Main Contributor to Energy Costs

Approximately 75% of the needed energy is consumed in the biological aerated reactor. Air or oxygen is introduced to the reactor to provide the inflow wastewater the oxygen to sustain the necessary level of biological activity. The demand of oxygen within a biological reactor can be met in various ways, but most aeration devices currently being used in activated sludge process may be classified as either diffused, dispersed, or surface aeration systems. Figure 8 shows the composition of energy demand of different components of the wastewater treatment process.

The treatment process produces effluents with low level of carbonaceous organic and low level of suspended solids. At the same time, however, excess sludge is being produced. Although excess sludge being a nuisance, bio-gas (CH_4 + CO_2) with a high energetic value might be generated under anaerobic digestion. The bio-gas may be used for heating the digester, to produce steam, to produce electricity, or to run direct drive equipment. By this up to 60 – 75 % of the total electrical energy demand and about 100 % of the thermal energy demand of the treatment plant can be covered.

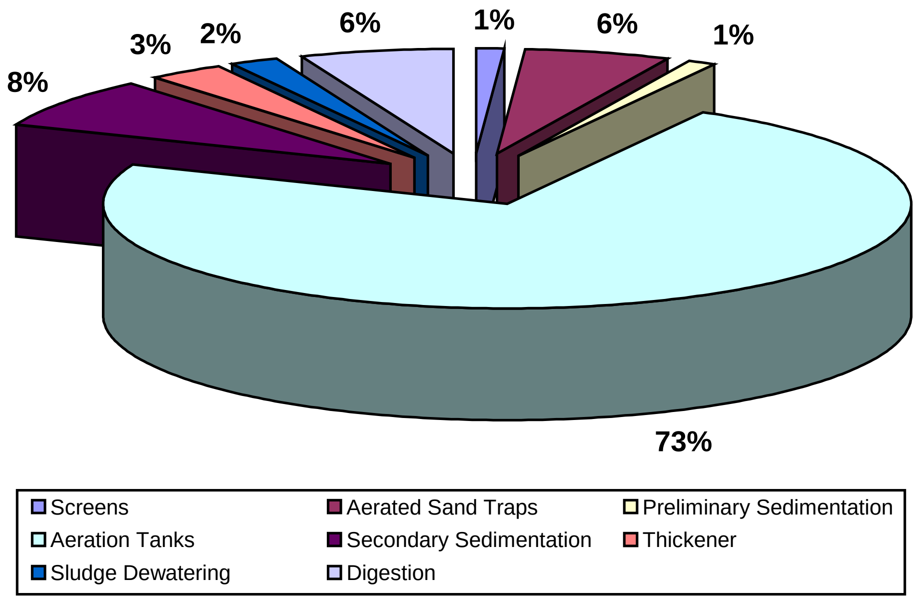

Figure 8: Composition of energy demand of different process components of wastewater treatment plants [Bohn, 1993]

5.2 Energy Analysis as a Tool for Energy Costs Reduction

To find out, which measures will be most favorable for the reduction of energy costs, an energy analysis can be carried out [NRW, 1999]. In Germany and in Swiss such analysis are successfully applied since many years on more than 100 wastewater treatment plants.

The energy analysis is carried out as a double-level analysis. In a first step, overall data of the plant as well as relevant energy consumption data of plant units like aeration step, sludge treatment etc. are recorded, evaluated and compared with best practice data from similar treatment plants. The aim of this first step is to find out in an "low-budget" way, whether there is some potential for energy saving existing. If so, the second step comprises the detailed analysis of each relevant electrical consumer of the plant and the sludge digestion, the gas utilization process (if existing) and the electrical power tariff system. The analysis will result in detailed recommendations for single optimization measures. The recommendations are divided up into short-termed measures, medium-termed measures and depending measures (measures which are connected e.g. to overall changes in process technology or renovation strategies).

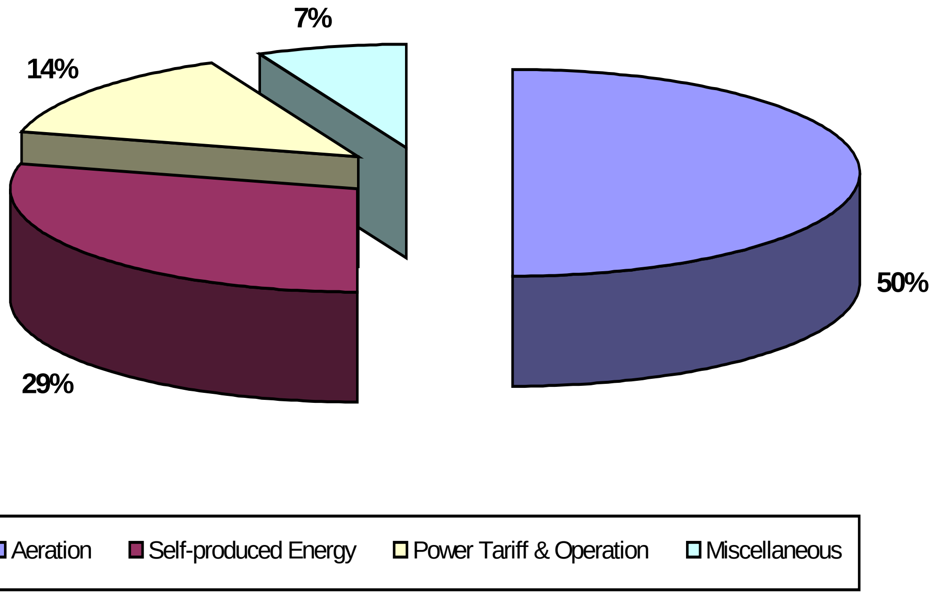

Figure 9: Energy savings related to proposed measures in 47 wastewater treatment plants in Germany [Kaste, 2003]

Detailed analysis of 47 wastewater treatment plants in Germany of 2,500 – 1,000,000 p.e. identified an energy cost saving potential between 5 and 100 % (average 34 %). Providing the realization of all proposed measures, about 2.3 m € could be saved per year [Kaste, 2003]. As expected, the main reduction in energy costs can be achieved by optimizing the aeration step (Figure 9) . Energy being produced of a renewable source or biological material like sewage sludge and being sold to the power utility is financially promoted by the state of Germany. Thus, in Germany all measures in this area will extremely contribute to the energy savings as to be seen in the figure. But also optimizing the operation of the electrical consumers under consideration of the tariff system and contract negotiations with the power utility can be very profitable.

6. Disposal

The costs for disposal consist of the disposal of sewage sludge, screenings, sand and municipal waste. The disposal costs can differ between 15 and 50 % of the total operation costs. Due to very low part on the total operation costs for screenings, sand and municipal waste, only sludge disposal will be discussed in the following.

Generally, disposal costs depend to a large degree on

- the size of the treatment plant,
- national regulations for the disposal of organic materials like sewage sludge,
- local conditions and market price conditions respectively.

Sludge originates from the process of treatment of waste water. Due to the physical-chemical processes involved in the treatment, the sludge tends to concentrate heavy metals and poorly biodegradable trace organic compounds as well as potentially pathogenic organisms (viruses, bacteria etc) present in waste waters. Sludge is, however, rich in nutrients such as nitrogen and phosphorous and contains valuable organic matter that is useful when soils are depleted or subject to erosion. In particularly the organic matter and nutrients are the two main elements that make the spreading of this kind of waste on land as a fertilizer or an organic soil improver suitable.

Sludge treatment and disposal operations on a local or regional basis need careful planning to ensure that the strategy undertaken is environmentally acceptable, reliable and cost-effective. Sludge quantities and quality have to be assessed now and into the future. Disposal options for sludge have to be analyzed by an environmental assessment approach which studies the accessibility of all outlets, environmental legislation and attitudes of collaborating agencies and the public at large. Other wastes which may compete with sludge for disposal outlets must be considered.

Outlets which involve recycling and beneficial use of sludge are advantageous but may not be practical. Sludge treatment must be evaluated in relation to the disposal options available. Sludge treatment centres, treating sludge from several surrounding wastewater plants, may be required especially if thermal drying or incineration are likely options. Economic evaluation has to consider capital and operating costs of sludge treatment and transport and other costs associated with disposal.

Practical experience with sludge disposal in different European countries (S, DK, G, F, CH) can be summarized as follows [EWA 2001, European Commission 2002]:

- Policy aspects as decision making procedures and continuity in political strategy play a key role in the different countries. There is a strong relation between these political factors and the costs for sludge disposal. Even very elaborated legal frameworks with very stringent quality criteria can have detrimental effects on the selection of sludge disposal routes.

- For large treatment plants in agglomerations sludge disposal after incineration can be an economically and ecologically sound solution. The development of low cost small incineration plants meeting advanced off gas standards is in progress.
- Co-incineration of sludge with cement and solid waste can result in economically sound solutions. In regard to P-recovery it does not represent a sustainable solution.
- Sludge disposal of dewatered sludge in landfills should be avoided as it results in long term monitoring requirements especially for ammonia leaching.
- For the very large number of small treatment plants (e.g. <20.000 PE) landspreading / agricultural use of sewage sludge seems to be the most economical and sustainable solutions as long as source abatement of possibly hazardous substances is successful. Landspreading of semi-solid and landspreading of solid sludge entail on average the lowest total cost (110 – 160 €/ton dry matter incl. external&internal costs).
- Landspreading of composted sludge, use of sludge in land reclamation and use of sludge in silviculture record intermediate total costs (210 – 250 €/ton dry matter).
- Landfilling, mono-incineration and co-incineration of sludge with other wastes entail the highest costs (260 – 350 €/ton dry matter).

6.1 Sludge Disposal Regulations

Sewage sludge, also known as biosolids, is what is left behind after water is cleaned in waste treatment works. It is high in organic content and plant nutrients and, in theory, makes good fertilizer. However, most developed countries regulate its use because it also can contain a multitude of metals, organic pollutants, and pathogens. The application of sewage sludge to land, especially on agricultural lands, has been contentious since the late 1980s, when national and international clean water regulations prohibiting the ocean dumping of sludge were first enacted.

Millions of tons of sewage sludge generated each year must go somewhere. If not applied to land, most sludge would have to be burned in incinerators or landfilled. U.S. total annual production of sludge is stable or only growing slowly; however, in Western Europe, where tougher clean water laws are beginning to take effect, sludge production is growing significantly, as small communities build and improve waste treatment plants to comply. Although opponents of sludge use have many grievances, one of their main concerns is the long-term buildup of heavy metals in the soil. Over time, they argue, metals such as cadmium, zinc, and copper could build up to levels high enough to damage agricultural soils. Some opponents advocate a full-scale ban on the use of sludge as fertilizer. But for others, who acknowledge its benefits, the question is: At what levels do heavy metals cause harmful effects?

The European Union (EU) is beginning work on a new sludge directive that will lower permissible limits for heavy metals. Another EU directive, which sets absolute values for contaminants in food, could also drive down permitted levels of metals in sludges. Draft standards for some metals taken up by plants, in particular, cadmium in wheat, are set so low that to meet them, sludge cadmium levels would have to be significantly lower than current EU requirements. U.S. regulations for metals in sewage sludge are also slated for scrutiny. EPA is planning to commission a review of the science behind the regulations.

Table 1: Sewage sludge generation rates and disposal methods in different countries [EPA, 1999]

		Disposal method (%)			
Country	**Amount (million tons dry solids/yr)**	**Application to land**	**Land filling**	**Incineration**	**Other**
Austria	320	13	56	31	0
Belgium	75	31	56	9	4
Denmark	130	37	33	28	2
France	700	50	50	0	0
Germany (West)	2500	25	63	12	0
Greece	15	3	97	0	0
Ireland	24	28	18	0	54
Italy	800	34	55	11	0
Luxembourg	15	81	18	0	1
Holland	282	44	53	3	0
Portugal	200	80	13	0	7
Spain	280	10	50	10	30
Sweden	180	45	55	0	0
Switzerland	215	50	30	20	0
United Kingdom, 1991	1107	55	8	7	30
United States	6900	41	17	22	20

7. Chemicals and Materials

Costs for chemicals and material include the purchase costs of one or more of the following:

- Polymers, alum and lime for sludge conditioning
- NaCl, Cl_2, O_3 for disinfection
- $FeCl_2$, $FeCl_3$, AlCl for precipitation of phosphorous
- Methanol, ethanol for denitrification
- Reagents for laboratories
- Oil and gas for machinery and vehicles
- Others

The costs of chemicals and materials usually range between 5 – 7 % of the total operation costs. The costs mainly depend on the characteristics of wastewater and the discharge norm, the selected chemicals, correct dosing, quantities kept in stock and purchasing deals. The market situation and the price structure for chemicals differ strongly. Even in Germany there are different price structures due to transportation and availability. The total costs have to be specified for each particular project.

8. Miscellaneous

This type of costs comprise all costs, which can not be assigned to the other cost types:

- Internal laboratory services
  Self-monitoring and analysis of water authorities
- Pollution charges
- Pollution charges are often levied by local or national governments on the discharge of water into the environment, i.e. mostly into surface waters. They are usually imposed on operators of treatment plants and industrial dischargers. The charges are generally calculated based on actual quantities and/or pollution loads of the effluent. There is a variety of charging systems into place to determine the pollution charges on wastewater discharge. For treatment plants the pollution charge is often calculated based on the number of inhabitants served by the plant or the pollution load of specific chemical, biological and biochemical parameters. Additional information are given in Lesson D4.
- Administrative costs like insurances, office equipment etc.
  In some municipalities administrative costs are paid centrally, in some these costs are allocated to the wastewater treatment plant.

- Rents and tenancies
  Some municipality own their land and buildings and have theses costs on their capital budget. Others pay rents and tenancies.
- External costs for consultants, maintenance works, laboratory analysis

The miscellaneous costs can differ between 5 and 15 % of the total operation costs. If pollution charges have to be paid to the authorities, pollution charges are the main contributor to the total miscellaneous costs (4 - 8 %).

9. Exercise

As we have learned in this lesson, operation costs of wastewater treatment plants are influenced by many factors and can differ in a wide range. Accordingly, reliable cost calculations can only be worked out on the basis of detailed data from the plant.

Running through the whole of one particular wastewater treatment project as an exercise would go beyond the scope of this E-Learning course. That's why the following exercise is based only on few data and shall mainly put you into the position to successfully deal with the relevant costs components and to investigate the most important influencing factors.

Please estimate the possible range of operation costs per year (€/a) of a new municipal wastewater treatment plant with a capacity of 10,000 p.e.. Discuss the main influencing factors on the operation costs.

The exercise should be carried out considering the following assumptions:

- The plant is located in southern Europe. It is operated as a conventional activated sludge system without sludge digestion. The produced sludge is utilized in agriculture as fertilizer.
- The costs to the employer of an annual salary, including insurance, is assumed to be 20,000 € per year.
- The investment costs amount to 2.7 m €. They are divided up into 50/35/15 % on construction/mechanical equipment/electrical equipment. Maintenance costs are assumed to amount up to 15 – 25 % of the total operation costs.
- The average energy tariff amounts up to 0,10 €/kWh.
- The daily volume of wastewater per p.e. is assumed to be 75 l.

Results

Unit	*Range of Operation Costs*
Personnel	*60,000 – 80,000 €/a*
Maintenance	*15,000 – 85,000 €/a*
Energy	*25,000 – 37,000 €/a*
Disposal	*35,000 – 70,000 €/a*
Chemicals & Materials	*14,000 – 17,500 €/a*
Miscellaneous	*3,500 – 25,000 €/a*
Total Operation Costs	***156,000 – 322,000 €/a***

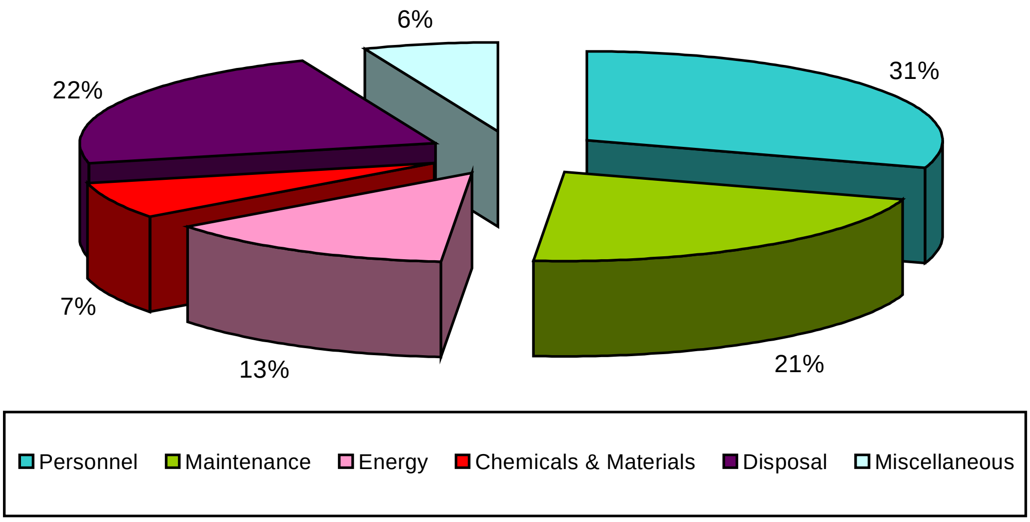

Figure 10: Results of exercise / Average composition of operation costs

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OPERATION COSTS OF WASTEWATER TREATMENT PLANTS

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Keywords

Operation Costs, Personnel, Maintenance, Maintenance Strategy, Energy, Energy Analysis, Chemicals & Materials, Disposal

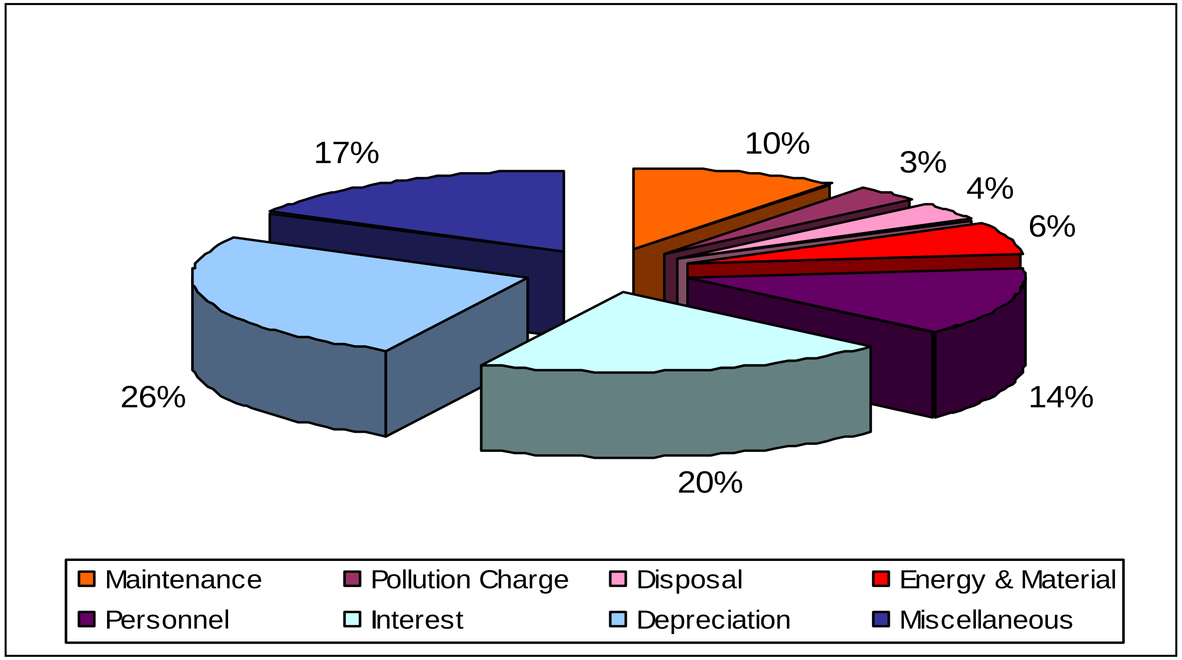
Operation Costs in Relation to Total Annual Costs

- Operation costs are the expenses related to the operation, maintenance and monitoring of the plant

- Operation costs can amount up to 50 % of the total annual costs.

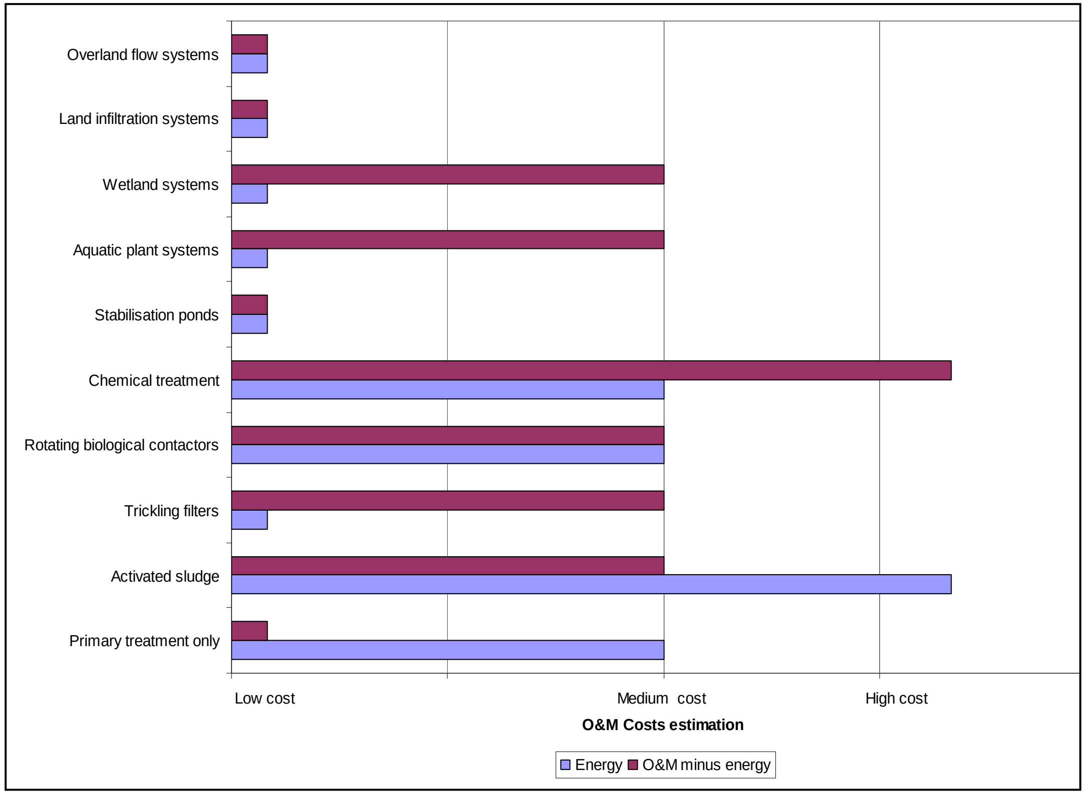
- The evaluation of operation costs during the evaluation of of process alternatives is of crucial importance.

Composition of total annual costs for wastewater systems in Germany [ATV, 2003]



Factors affecting Operation Costs

- Size and load of the plant
- Topography and geographical situation of the site (affecting pumping energy costs)
- Characteristics of wastewater and the discharge norm
- Technologies and the selected treatment process
- Type of sludge treatment and way of disposal
- Energy supply and energy recycling
- Degree of automation, measurement and process control
- Organization of the plant and its management



Comparison of operation costs O&M for different types of secondary treatment options [Kampet, 2000]

Personnel

The major parameters that influence the number of operational staff employed are:

- the size of installation,
- the treatment processes and systems,
- the degree of automation,
- productivity efficiency of personnel,
- managerial efficiency and
- others.

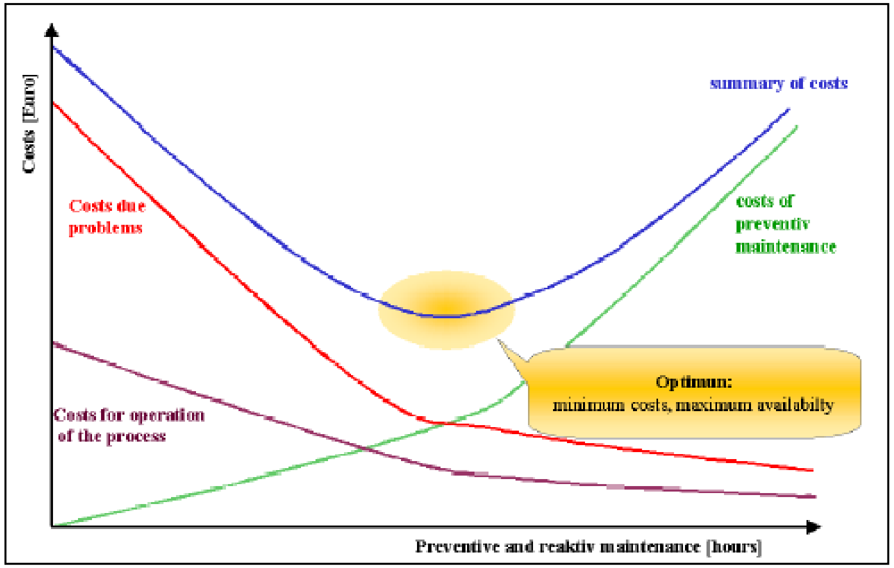
Personnel costs subject to the treatment capacity of wastewater treatment plants [Reicherter, 2003].

< 10.000 p.e.	**35 – 40 %** of total operation costs
10.000 – 100.000 p.e.	**25 %** of total operation costs
> 100.000 p.e.	**15 %** of total operation costs

Maintenance

The costs for maintenance of wastewater treatment plants usually amount up to **15 – 25 %** of the total operation costs.

Civil Constructions	0.5 – 2.0 % of investment costs per year
Renovations of Civil Constructions	2.0 – 4.0 % of investment costs per year
Mechanical Equipment	2.0 – 6.0 % of investment costs per year
Electrical and Electronical Equipment	2.0 – 6.0 % of investment costs per year

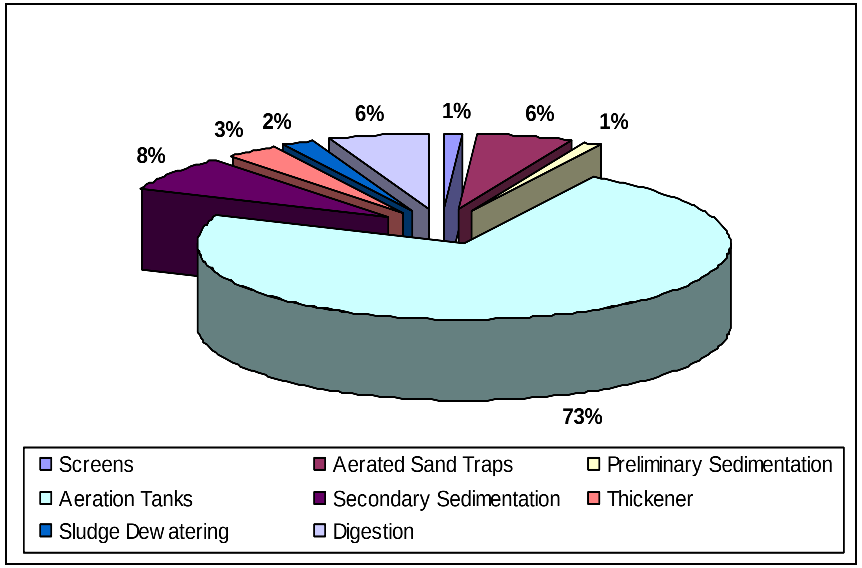


Costs and maintenance seen as a whole; the optimum is achieved from the best relationship between costs and availability [Müller, 2003]

Energy

The costs for energy usually amount up to **10 – 30 %** of the total operation costs.

-	Pumping Stations	10 – 15 Wh /m³
-	Screens	0.3 – 0.5 kWh / (p.e. &.a)
-	Aerated Sand Traps	1.7 – 2.2 kWh / (p.e. &.a)
-	Prel. Sedimentation Tanks	0.4 – 0.6 kWh / (p.e. &.a)
-	Aeration Tanks	17.2 – 25.8 kWh / (p.e. &.a)
-	Sec. Sedimentation Tanks	1.2 – 2.3 kWh / (p.e. &.a)
-	Thickener	0.7 – 1.1 kWh / (p.e. &.a)
-	Sludge Dewatering Devices	3.0 – 4.0 kWh / (p.e. &.a)
-	Digestion	2.4 – 2.9 kWh / (p.e. &.a)



Composition of energy demand for different process components of wastewater treatment plants [Bohn, 1993]

Disposal

The costs for disposal consist of the disposal of sewage sludge, screenings, sand and municipal waste. The disposal costs can differ between **15 and 50 %** of the total operation costs.

Generally, disposal costs depend to a large degree on

- the size of the treatment plant,
- national regulations for the disposal of organic materials like sewage sludge,
- local conditions and market price conditions respectively.

Practical experience with sludge disposal in different European countries (S, DK, G, F, CH) can be summarized as follows:

- For the very large number of small treatment plants (e.g. <20.000 PE) landspreading / agricultural use of sewage sludge seems to be the most economical and sustainable solutions as long as source abatement of possibly hazardous substances is successful. Landspreading of semi-solid and landspreading of solid sludge entail on average the lowest total cost.
- Landspreading of composted sludge, use of sludge in land reclamation and use of sludge in silviculture record intermediate total costs.
- Landfilling, mono-incineration and co-incineration of sludge with other wastes entail the highest costs.

Chemicals and Material

The costs of chemicals and materials usually range between **5 – 7 %** of the total operation costs.

The costs mainly depend on the characteristics of wastewater and the discharge norm, the selected chemicals, correct dosing, quantities kept in stock and purchasing deals.

The market situation and the price structure for chemicals differ strongly.

- Polymers, alum and lime for sludge conditioning
- NaCl, Cl_2, O_3 for disinfection
- $FeCl_2$, $FeCl_3$, AlCl for precipitation of phosphorous
- Methanol, ethanol for denitrification
- Reagents for laboratories
- Oil and gas for machinery and vehicles
- Others

Miscellaneous

Miscellaneous costs can differ between **5 and 15 %** of the total operation costs.

If pollution charges have to be paid to the authorities, pollution charges are the main contributor to the total miscellaneous costs (4 - 8 %).

- Internal laboratory services
  Self-monitoring and analysis of water authorities
- Pollution charges
  Pollution charges are often levied by local or national governments on the discharge of water into the environment. There is a variety of charging systems into place to determine the pollution charges on wastewater discharge. For treatment plants the pollution charge is often calculated based on the number of inhabitants served by the plant or the pollution load of specific chemical, biological and biochemical parameters.
- Administrative costs like insurances, office equipment etc.
  In some municipalities administrative costs are paid centrally, in some these costs are allocated to the wastewater treatment plant.
- Rents and tenancies
  Some municipality own their land and buildings and have theses costs on their capital budget. Others pay rents and tenancies.
- External costs for consultants, maintenance works, laboratory analysis

Lesson D1

Guidelines and Standards for Wastewater Reuse

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Keywords
Wastewater reuse, Guidelines, Regulations, Standards

Table of content

Overview and summary

Due to water shortage, wastewater reuse has gained great importance in many parts of the world. Wastewater reuse practices have become valuable source in water resources management. As an independent source of water, reclaimed water can increase the reliability of water supply. Reclaimed wastewater requires effective measures to protect public health and the environment. Strong wastewater reuse guidelines and regulations are developed for the purpose. It is difficult to establish wastewater guidelines and regulations that can suit all regions in the world. Among the broad reasons for this as limiting factors, are economics of countries relating chosen treatment technologies and additionally, the local context of a region must be taken into consideration in settings. Almost all wastewater reuse guidelines and regulations are bacteriological-based. Some of them consider biochemical parameters.

In this lesson you will comprehend the importance as well as the necessity of setting wastewater reuse guidelines and regulations. You will be aware of arising problems for getting universal valid standards. You will get an overview of guidelines and regulations existing worldwide and regionally.

1. Introduction

The reuse of wastewater is one of the main options being considered as a new source of water in regions where water is scarce. However wastewater reuse can also be linked with human health risks – for farmers as well as for crop consumers - as wastewater can contain enteric viruses, pathogenic bacteria and protozoa. Some chemical wastewater components, such as nitrogen, and phosphorus, may have both positive and negative effects on plant growth, crop yields, and the environment. Others, such as suspended solids, high salt levels loads, can be disadvantageous for agricultural soils and irrigation infrastructure. In order to reduce negative impacts, many countries have adopted standards and guidelines, that regulate wastewater reuse in agriculture.

In the planning and implementation of water reclamation and reuse, the intended water reuse applications dictate the extent of wastewater treatment required, the quality of the reclaimed water, and the method of water distribution and application. Regulations issued for wastewater reuse in agriculture focus principally on sanitary and environmental protection, and usually refer to: wastewater treatment technology, reclaimed wastewater quality, irrigation practices, and control of areas or crop types where reclaimed water is used. The requirements are based primarily on defining the extent of needed treatment of wastewater together with numerical limits on bacteriological quality, turbidity and suspended solids.

However, the standards required for the safe use of wastewater and the amount and type of wastewater treatment needed are contentious. The cost of treating wastewater to conform to high microbiological standards can be so prohibitive that in many developing countries the use of untreated wastewater is effectively unregulated. Therefore, the health and environmental protection measures need to be tailored to suit the local balance between affordability and risk.

They should be:

- realistic in relation to local conditions (epidemiological, socio-cultural and environmental factors),
- affordable, and
- enforceable.

Where economic constraints limit the level of wastewater treatment that can be provided, a disease-control approach has been suggested, potentially using less strict microbiological guidelines and more management measures for health protection. A range of *health protection measures* including crop restriction, irrigation technique, human exposure control and chemotherapeutic intervention should all be considered in conjunction with partial wastewater treatment. In some cases, community interventions using health promotion programs and/or regular chemotherapy programs could be considered, in particular where no wastewater treatment is provided or where there is a time delay before treatment plants can be built.

Bahri 2002 has suggested that countries with substantial problems in treating wastewater in an adequate manner should undertake intermediate steps to mitigate the negative impacts:

- Introduce crop restrictions and standards for effluent reused for irrigation and other uses
- Apply source control of contaminants
- Apply appropriate irrigation, agricultural, harvest and public health practices that limit risks
- Improve extension and outreach activities to all stakeholders
- Upgrade the effluent quality from treatment plants
- On-farm use of storage and stabilization ponds
- The medium-term goal should be prohibition of all irrigation use of untreated wastewater.

2. Important Criteria

The most important criteria for evaluation of suitability of treated wastewater for irrigational use are as follows:

- Health aspects
- Salinity (especially important in arid zones)
- Heavy metals and harmful organic substances

In addition to standards regarding biological and chemical loads of wastewater, regulations can include best practices for wastewater treatment and irrigation techniques as well as regarding crops and areas to be irrigated.

2.1 Health parameters

Predominantly with domestic sewage the issue of contamination with bacteria or viruses is extremely important. However, also with industrial wastewater pathogens might occur and should at least once in the beginning be analyzed. Total coliform and fecal coliform organisms are often used as indicators for microbiological contamination of wastewater. Nematode eggs are used as an indicator for parasite microbiological standards for wastewater reuse in agriculture (see table 1). They are often set in conjunction with specified requirements for treating wastewater. There are currently several alternative approaches to establishing microbiological guidelines for reusing wastewater (see textbox below). These have different outcomes as their objectives: the absence of fecal indicator bacteria in the wastewater, the absence of excess cases of enteric disease in the exposed population and a model generated risk which is below a defined acceptable risk.

Table 1: Different approaches to set microbiological standards for wastewater reuse

The absence of fecal indicator bacteria in the wastewater	This approach has led to guidelines that require zero fecal coliform bacteria/100 ml for water used to irrigate crops that are eaten raw in addition to a requirement for secondary treatment, filtration and disinfection. The United States Environmental Protection Agency (US EPA) and the US Agency for International Development (USAID) have taken this approach, and consequently have recommended strict guidelines for wastewater use .
No measurable excess cases in the exposed population: epidemiological perspective	The objective of this approach is that there should be no actual risk of infection—that is, there should be no measurable excess risk of infection attributable to the reuse of wastewater as evaluated using scientific evidence, especially from epidemiological studies. This was the approach adopted in the 1989 WHO guidelines, for which epidemiological evidence was used (when available); However, results from any given study are generally specific to the time and place of that study. Extrapolation of the results to other times and other locations — as is necessary when they are used for regulation—depends on making assumptions about the changes to variables, such as contact with wastewater, which might affect the outcome. In scientific terms, assessment of actual health risks continues to be a controversial matter; there are either too few epidemiological studies available to permit any precise weighting of risks or the studies are not sufficiently practice-orientated to permit the results to be translated into concrete policy.
A model-generated risk that is below a defined acceptable risk	In this approach an acceptable risk of infection is first defined — for example, for the microbial contamination of drinking-water supplies. The US EPA has set annual risk of 10^{-4} per person. Once the acceptable annual risk has been established by the regulator, a quantitative microbial risk assessment (QMRA) model is used to generate an estimated annual risk of infection. A microbiological quality guideline limit would then be set so that the model produces an estimate of an annual risk which is below the regulator's acceptable annual risk.

Presently, researchers are divided between two schools of thought on the question of the appropriate level of nematodes and fecal coliform in wastewater that should be used for irrigation. The two schools of thought are: the less stringent epidemiological evidence school led by the WHO and the "no risk school" led by the US. The "no risk" philosophy cannot be adopted by many countries, especially developing countries, which cannot find financial resources for expensive treatment systems, but badly require wastewater for irrigation. Under the "no risk" scenario, the only options left for these countries would be, either no wastewater reuse or wastewater reuse (illegal) without any regard for the tough (and thus impractical) guidelines.

Differentiating between the potential risk and actual risk of contracting a disease is another issue in developing appropriate guidelines. The actual health risk depends on three more factors namely:

- time of survival of pathogens in water or soil,
- infective dose, and
- host immunity.

The risks to populations are dependent on the irrigation method used. Health risks from irrigated crops are greatest when spray or sprinkler irrigation is used, and the risk to field workers is greatest when flood or furrow irrigation is used. However, other potential sources of crop contamination should also be considered such as crop handling, transportation and the sale of products in unhygienic markets. Consumers can themselves make an important contribution to minimizing risks by, for instance, complying with sanitary standards in processing and using wastewater, i.e. by handling it on the basis of the information available. (Also see chapter 3.3)

2.2 Chemical parameters

In addition to biological parameters, regulations often include chemical parameters in order to protect human and environmental health, but also to provide for long-term soil productivity and functioning of irrigation schemes. Table 2 gives some examples of wastewater components' impacts in irrigational use.

In developing countries, salinity is usually the dividing line between water suited or unsuited for irrigation uses. High salt concentrations are an indication of highly concentrated wastewater, a factor typical for arid countries. Heavy metal concentrations are as a rule still relatively low in developing countries and are not yet responsible for any major problems. High salt concentrations in irrigation water hamper the water intake of crops and lead to yield losses for many crops. In addition, high sodium contents in loamy soils lower their permeability for water, which results in lower soil aeration. The consequences of these effects are also yield losses. In the case of high subsoil permeability, there is an additional risk of groundwater salinisation.

Another important aspect is wastewater nutrient content. Raw wastewater contains nitrogen, phosphate, and potassium in concentrations sufficient to cover or even exceed overall plant fertilization needs. The presence of trace elements and organic matter also favors plant growth and raises soil humus levels. These substantial advantages for farmers are offset in part by environmental risks consisting in the danger of nitrate-leaching. Other agro-biological risks are bound up with the fact that nitrogen can, in later phases of growth, have negative effects on plant growth. The nitrogen, however, stimulates undesirable algae growth on cultivated soils. Appropriate management methods are called for here. In table 2 the most important water quality parameters and their significance are listed.

Table 2: Physico-chemical parameters, their significance and approximate ranges for treated wastewater [SAR= Sodium adsorption ratio]

Parameter	**Significance**	**Approximate Range in Treated Wastewater**
Total Suspended Solids (TSS)	TSS can lead to sludge deposits and anaerobic conditions. Excessive amounts cause clogging of irrigation systems Measures of particles in wastewater can be related to microbial contamination, turbidity. Can interfere with disinfection effectiveness	< 1 to 30 mg/l
Organic indicators TOC Degradable Organics (COD, BOD)	Measure of organic carbon Their biological decomposition can lead to depletion of oxygen. For irrigation only excessive amounts cause problems. Low to moderate concentrations are beneficial.	1 – 20 mg/l 10 – 30 mg/l
Nutrients N,P,K	When discharged into the aquatic environment they lead to eutrophication. In irrigation they are beneficial, nutrient source. Nitrate in excessive amounts, however, may lead to groundwater contamination.	N: 10 to 30 mg/l P: 0.1 to 30 mg/l
Stable organics (e.g. phenols, pesticides, chlorinated hydrocarbons)	Some are toxic in the environment, accumulation processes in the soil.	
pH	Affects metal solubility and alkalinity and structure of soil, and plant growth.	
Heavy metals (Cd, Zn, Ni, etc.)	Accumulation processes in the soil, toxicity for plants	
Dissolved inorganics (TDS, EC, SAR)	Excessive salinity may damage crops. Chloride, Sodium and Boron are toxic to some crops, extensive sodium may cause permeability problems	

2.3 Restriction according to origin and use of wastewater

Apart from biological and chemical parameters, irrigation practice guidelines are used to minimize negative impacts of wastewater reuse in agriculture.

2.3.1 Crop restriction

Crop restriction is often practiced in conjunction with wastewater treatment so that lower quality effluents can be used to irrigate non-vegetable crops (see table 3).

Although this appears straightforward, in practice it is often difficult to enforce. It can only be done effectively where a public body controls the use of wastewater and laws providing for crop restricted are strictly enforced, where there is adequate demand for the crops allowed under crop restrictions and where there is little market pressure in favor of excluded crops (i.e. salad and other crops eaten uncooked). Crop restriction requires much less costly wastewater treatment and may be favored for this reason alone (but wastewater treatment engineers need to discuss this clearly with the appropriate regulatory agency and local farmers).

2.3.2 The irrigation technique

The irrigation technique can be chosen to reduce the amount of human exposure to the wastewater. In general, health risks are greatest when spray/sprinkler irrigation is used, as this distributes contamination over the surface of crops and exposes nearby population groups to aerosols containing bacteria and viruses (the opposite occurs with nematode eggs, which tend to be washed off during spray irrigation). This technique should be avoided where possible, and if used, stricter effluent standards apply (see table 3). Flood and furrow irrigation exposes field workers to the greatest risk, especially if earth moving is done by hand and without protection. Localized irrigation (inc. drip, trickle and bubbler irrigation) can give the greatest degree of health protection by reducing the exposure of workers to the wastewater. A period without irrigation before harvest (1-2 weeks) can allow die-off of bacteria and viruses such that the quality of irrigated crops improves to levels seen in crops irrigated with fresh water, as shown by Vaz da Costas Vargas et al. (1996). However, it is not practical in unregulated circumstances since farmers will probably not stop irrigation of leafy salad crops 5 days or more before harvest. Replacing partially-treated wastewater with fresh water for a week or so before harvest is not a reliable way of improving crop quality since re-contamination of the crops from the soil has been found to occur. Use of ending of irrigation before harvest is more feasible with fodder crops which do not need to be harvested at their freshest, and could enable the use of lower quality effluents.

Table 3: 1989 WHO guidelines for using treated wastewater in agriculture [a]

Category	Reuse conditions	Exposed Group	Intestinal nematodes [b] (arithmetic mean no. of eggs per liter) [c]	Fecal coliforms (geometric mean no. per 100 ml) [c]	Wastewater treatment expected to achieve the required microbiological guideline
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks [d]	Workers, consumers, public	≤ 1	≤ 1000	A series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees [e]	Workers	≤ 1	No standard recommended	Retention in stabilization ponds for 8–10 days or equivalent helminthes and fecal coliform removal
C	Localized irrigation of crops in category B if exposure to workers and the public does not occur	None	Not applicable	Not applicable	Pretreatment as required by irrigation technology but not less than primary sedimentation

a In specific cases, local epidemiological, socio-cultural and environmental factors should be taken into account and the guidelines modified accordingly.
b Ascaris and Trichuris species and hookworms.
c During the irrigation period.
d A more stringent guideline limit (□ 200 fecal coliforms/100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.
e In the case of fruit trees, irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should not be used.

2.3.3 Human exposure control

The groups potentially most at risk from wastewater reuse in agriculture are the farm workers, their families, crop handlers, consumers of crops, and those living near wastewater-irrigated areas. The approach required to minimize exposure depends on the target group. Farm workers and their families have higher potential risks of parasitic infections. Protection can be achieved by low-contaminating irrigation techniques, together with wearing protective clothing (e.g. footwear for farmers and gloves for crop handlers) and improving levels of hygiene both occupationally and in the home can help to control human exposure. Provision of adequate water supplies for consumption (to avoid consumption of wastewater) and for hygiene purposes (e.g. for hand washing) is important. Consumers can be protected by cooking vegetables, and by high standards of personal and food hygiene.

3. International Experiences in Formulating Guidelines

A comparison of international standards might help to develop guidelines for the reference area within each particular project. In many countries like USA and Spain only regional standards exist. A very limited number of European countries have guidelines or regulations on wastewater reclamation and reuse because first they usually do not need to reuse water and second their rivers have a sufficient dilution factor.

The US and Saudi Arabia have, in the context of their technical standards, set a number of individual limit values for microorganisms and chemicals. This type of differentiation was pioneered by California, which as early as 1918 undertook some initial efforts concerning the reuse of wastewater; and later, with the growth of technical potentials, the US further differentiated and tightened up these regulations, the final outcome being extremely low limit values (California State Water Code). These strict limit values have no grounds in medical science and take considerable effort to monitor and enforce. The 1989 WHO guidelines (see chapter 3.1) reflect this view.

Many developing countries focus on use restrictions in their legislation. Often, for example, such regulations ban wastewater irrigation for vegetables that can be eaten raw, or for edible plant parts in general, and require a minimum time interval between irrigation and crop harvest. The main problem with such use restrictions is that they cannot be monitored without functioning oversight agencies. The serious problems involved in monitoring use restrictions have led several countries, including Mexico (see chapter 3.4) and Tunisia (see chapter 4.1), to combine these two approaches: use restrictions plus easy-to-measure limit values for chemical and biological sum parameters (BOD_5 and COD) and micro-organisms, a practice that has given rise to a comprehensive and yet uncomplicated approach that, while doing justice to minimum safety needs, is still comprehensive enough to be generally conducive to the strategy of wastewater reuse.

3.1 WHO (1989)

The World Health Organization (WHO) has recognized both the potential and risk of untreated wastewater use and so has developed guidelines for policy makers attempting to legislate permission for the safe use of wastewater. In the 1989 guidelines (see table 4), the WHO acknowledged that most previous standards were unnecessarily high for public health protection and do not reflect reality of wastewater use on the ground. The WHO is currently revising their guidelines on wastewater reuse. Publication of the revised version is expected in 2004.

The main features of the 1989 WHO guidelines for wastewater reuse in agriculture are as follows:

- Wastewater is considered as a resource to be used, but used safely.
- The aim of the guidelines is to protect against excess infection in exposed populations (consumers, farm workers, populations living near irrigated fields).
- Fecal coliforms and intestinal nematode eggs are used as pathogen indicators.
- Measures comprising good reuse management practice are proposed alongside wastewater quality and treatment goals; restrictions on crops to be irrigated with wastewater; selection of irrigation methods providing increased health protection, and observation of good personal hygiene (including the use of protective clothing).
- The feasibility of achieving the guidelines is considered alongside desirable standards of health protection.

Many countries have welcomed the guidance from WHO standards and guidelines. France, for example, used a similar approach in setting guidelines, which were published in 1991. These are similar to those of WHO in defining analogous water categories (called A, B and C in the WHO guidelines; table 4) and microbiological limits, but complement them with strict rules of application. For example, for category A in the French guidelines, the quality requirement must be complemented by the use of irrigation techniques that avoid wetting fruit and vegetables, and for irrigation of golf courses and open landscaped areas, spray irrigation must be performed outside public opening hours.

As noted above, the WHO guidelines continue to be the benchmark target for decision makers in developing the wastewater recycling sector, however, as demonstrated, goals need to be in line with the capabilities of the country in question. Some countries have modified the microbiological criteria to suit local epidemiological and economic circumstances, as, for example, Mexico (see chapter 3.4)

3.2 FAO Guidelines for agricultural use (1985)

In contrast to the WHO guidelines that focus mainly on the protection of human and public health, the FAO has developed a field guide for evaluating the suitability of water for irrigation. Guideline values given identify potential problem water based on possible restrictions in use related to 1) salinity, 2) rate of water infiltration into the soil, 3) specific ion toxicity, or 4) to some other miscellaneous effects. The guide is intended to provide guidance to farm and project managers, consultants and engineers in evaluating and identifying potential problems related to water quality. It discusses possible restrictions on the use of the water and presents management options which may assist in farm or project management, planning and operation. Guiding values for salinity and other characteristics of wastewater are given in table 4. However, the FAO guidelines must be seen as orientation values that are in no way intended to replace case-to-case assessments.

***Table 4: Guidelines for Interpretations of Water Quality for Irrigation** (adapted from University of California Committee of Consultants 1974)*

Potential Irrigation Problem				Units	Degree of Restriction on Use		
					None	**Slight to Moderate**	**Sever-e**
Salinity *(affects crop water availability)*[2]							
	EC_w			dS/m	< 0.7	0.7 – 3.0	> 3.0
	(or)						
	TDS			mg/l	< 450	450 – 2000	> 2000
Infiltration *(affects infiltration rate of water into the soil. Evaluate using EC_w and SAR together)*[3]							
SAR	= 0 – 3	**and EC_w**	=		> 0.7	0.7 – 0.2	< 0.2
	= 3 – 6		=		> 1.2	1.2 – 0.3	< 0.3
	= 6 – 12		=		> 1.9	1.9 – 0.5	< 0.5
	= 12 – 20		=		> 2.9	2.9 – 1.3	< 1.3
	= 20 – 40		=		> 5.0	5.0 – 2.9	< 2.9
Specific Ion Toxicity *(affects sensitive crops)*							
	Sodium (Na)[4]						
	surface irrigation			SAR	< 3	3 – 9	> 9
	sprinkler irrigation			me/l	< 3	> 3	
	Chloride (Cl)[4]						
	surface irrigation			me/l	< 4	4 – 10	> 10
	sprinkler irrigation			me/l	< 3	> 3	
	Boron (B)			mg/l	< 0.7	0.7 – 3.0	> 3.0
	Trace Elements (see Table 21)						
Miscellaneous Effects *(affects susceptible crops)*							
	Nitrogen (NO_3 - N)[5]			mg/l	< 5	5 – 30	> 30
	Bicarbonate (HCO_3)						
	(overhead sprinkling only)			me/l	< 1.5	1.5 – 8.5	> 8.5
	pH				**Normal Range 6.5 – 8.4**		

[2] ECw means electrical conductivity, a measure of the water salinity, reported in deciSiemens per metre at 25°C (dS/m) or in units millimhos per centimetre (mmho/cm). Both are equivalent. TDS means total dissolved solids, reported in milligrams per litre (mg/l).
[3] SAR means sodium adsorption ratio. SAR is sometimes reported by the symbol RNa. At a given SAR, infiltration rate increases as water salinity increases. Evaluate the potential infiltration problem by SAR as modified by ECw. Adapted from Rhoades 1977 and Oster and Schroer 1979.
[4] For surface irrigation, most tree crops and woody plants are sensitive to sodium and chloride.
[5] NO_3 -N means nitrate nitrogen reported in terms of elemental nitrogen (NH_4 -N and Organic-N should be included when wastewater is being tested).

me/l = milli equivalent per litre (mg/l ÷ equivalent weight = me/l); in SI units, 1 me/l= 1 milli mol/litre adjusted for electron charge. mg/l = milligram per litre ≈ parts per million (ppm).

3.3 US EPA (1992)

The US-Environmental Protection Agency (US-EPA) in their 1992 guidelines has recommended the use of much stricter standards for wastewater use in the USA, than those recommended by the WHO. The main guideline is that fecal coliforms should not exceed 14 MPN/100 ml in any sample, which in practice means not detectable. Secondary treatment should be used followed by filtration (with prior coagulant and/or polymer addition) and disinfection. In addition, the US-EPA guidelines set standards indicating the type of treatment required, the resultant water quality specifications, and the appropriate setback distances. The elements of the guidelines applicable to reuse in agriculture are summarized in table 5.

Table 5: US-EPA/USAID Guidelines for agricultural reuse of wastewater (adapted from suggested guidelines for water reuse *(US-EPA/USAID, 1992) [Source: EPA, Process Design Manual: Guidelines for Water Reuse, Cincinnati, Ohio, 1992: Report No. EPA-625/R-92-004]* [1]

Types of Reuse	Treatment	Reclaimed Water Quality	Reclaimed Water Monitoring
Urban Reuse All types of landscape irrigation (e.g. golf courses, parks, cemeteries).	• Secondary [2] • Filtration • Disinfection	• pH = 6-9 • ≤ 10 mg/l BOD • ≤ 2 NTU • No detectable FC/100 ml [3] • 1 mg/l Cl_2 residual (min.)	• pH - weekly • BOD - weekly • Turbidity - continuous • Coliform - daily • Cl_2 residual -continuous
Agricultural Reuse – Food Crops Not Commercially Processed Surface or spray irrigation of any food crop, including crops eaten raw	• Secondary [2] • Filtration • Disinfection	• pH = 6-9 • ≤ 10 mg/l BOD • ≤ 2 NTU • No detectable FC/100 ml [3] • 1 mg/l Cl_2 residual (min.)	• pH - weekly • BOD - weekly • Turbidity - continuous • Coliform - daily • Cl_2 residual -continuous
Agricultural Reuse – Food Crops Commercially Processed	• Secondary [2] • Disinfection	• pH = 6-9 • ≤ 30 mg/l BOD • ≤ 30 mg/l SS • ≤ 200 FC/100 ml [4] • 1 mg/l Cl_2 residual (min.)	• pH - weekly • BOD - weekly • SS - daily • Coliform - daily • Cl_2 residual -continuous
Types of Reuse	**Treatment**	**Reclaimed Water Quality**	**Reclaimed Water Monitoring**
Agricultural Reuse – Non Food Crops Pasture for milking animals; fodder, fiber and seed crops	• Secondary [2] • Disinfection	• pH = 6-9 • ≤ 30 mg/l BOD • ≤ 30 mg/l SS • ≤ 200 FC/100 ml [4] • 1 mg/l Cl_2 residual (min.)	• pH - weekly • BOD - weekly • SS - daily • Coliform - daily • Cl_2 residual -continuous

Legend: SS= suspended solids; FC= fecal coliforms

Footnotes:

1 These guidelines are based on water reclamation and reuse practices in the U.S., and they are especially directed at states that have not developed their own regulations or guidelines. While the guidelines should be useful in many areas outside the U.S., local conditions may limit the applicability of the guidelines in some countries.

2 Secondary treatment processes include activated sludge processes, trickling filters, rotating biological contractors, and many stabilization pond systems. Secondary treatment should produce effluent in which both the BOD and SS do not exceed 30 mg/l.

3 The number of fecal coliform organisms should not exceed 14/100 ml in any sample.

4 The number of fecal coliform organisms should not exceed 800/100 ml in any sample. Some stabilization pond systems may be able to meet this coliform limit without disinfection.

For irrigation of crops likely to be eaten uncooked, no detectable fecal coliforms/100 ml are allowed (compared to ≤ 1000 FC/100 ml for WHO), and for irrigation of commercially processed crops, fodder crops, etc, the guideline sets ≤ 200 FC/100 ml (where only a nematode egg guideline is set by WHO). No nematode egg guideline is specified by US-EPA. Actual standard setting is the responsibility of individual states in the USA, and different US-States take different approaches (some specify treatment processes, others specify water quality standards) and a range of standards are in use. Standards in several countries have been influenced by American standards, especially the Californian standards.

3.4 Mexico (1996)

In Mexico, microbiological and chemical standards for wastewater reuse in agriculture have developed considerably over the last 15 years. Existing guidelines were reviewed in 1991, 1993, and again in 1996. Particular attention was paid to (1) the cultivation of vegetables and other crops eaten raw, (2) the importance of wastewater reuse in agriculture as a form of wastewater treatment and disposal, and (3) the diversity of treatment processes available to achieve the guidelines.

The final revision of the microbiological standards occurred in 1996, resulting in the introduction of NOM-001-ECOL-1996 (see table 6) "that establishes the maximum permissible limits of contaminants in wastewater to be discharged into national waters and onto national soil". As in the WHO guidelines, fecal coliforms are used as the indicator to determine pathogenic contamination. The maximum allowable limit in wastewater discharges to national water or property, as well as wastewater application to soils (for agricultural irrigation) is 1,000 and 2,000 (most probable number, MPN) of fecal coliforms per 100 ml, for monthly average and daily average, respectively. To determine parasitic contamination, helminth eggs are used as the indicator. The maximum allowable limit in wastewater application to soils (for agricultural irrigation) is one helminth egg per liter for restricted irrigation, and five helminth eggs per liter for unrestricted irrigation, following the technique established in annex 1 of these regulations.

Table 6: Mexican Standard NOM-001-ECOL-1996 governing wastewater reuse in Agriculture

Irrigation	Fecal Coliforms /100 ml (MPN)	Helminth eggs/liter
Restricted	1000_m - 2000_d	≤ 5
Unrestricted	1000_m - 2000_d	≤ 1

(m=monthly mean, d=daily mean, MPN=most probable number)
Note: Unrestricted irrigation is defined as permitting irrigation of all crops, whilst restricted irrigation excludes salad crops and vegetables that are eaten raw.

The new standard, with a single set of parameter limits regardless of the discharge source, was designed to be achievable with the technology and resources available at present and in the near future in Mexico and to be more realistically policed, by reducing the amount of monitoring required. The limits imposed within the standard were designed to be sufficient to protect "at-risk" groups according to currently available literature. Revision of many of the possible treatment processes resulted in the proposed microbiological standards. A stricter helminth standard would have required conventional treatment plants to use filters and this would have carried significant financial implications.

The concentration of basic contaminants, heavy metals and cyanides in wastewater discharges to national water or property, may not exceed the value indicated as the maximum allowable limit in annex tables 2 and 3 of these regulations. The allowable range for pH is 5 to 10 units.

3.5 Recommendations to review WHO standards (2000)

Blumenthal et al. recommend a review of the current WHO guidelines. They base their recommendation on their appraisal of recent research evidence based on a combined approach using empirical epidemiological studies supplemented by microbiological studies of the transmission of pathogens in conjunction with a model-based quantitative risk assessment for selected pathogens.

Their research leads to the conclusion that for unrestricted irrigation, there is no evidence to suggest a need to revise the fecal coliform guideline limit of ≤ 1000 fecal coliform bacteria/100 ml. However, there is epidemiological evidence that the guideline limit for nematode eggs (≤ 1 egg/l) is not adequate in conditions that favor the survival of nematode eggs (lower mean temperatures and the use of surface irrigation), and it needs to be revised to ≤ 0.1 egg/l in these conditions. For restricted irrigation, there is evidence to support the need for a guideline limit for exposure to fecal coliform bacteria to protect farm workers, their children and nearby populations from enteric viral and bacterial infections. The appropriate guideline limit will depend on which irrigation method is used and who is exposed. For example, if adult farm workers are exposed to spray or sprinkler irrigation, a guideline limit of ≤ 10^5 fecal coliform bacteria/ 100 ml is necessary. A reduced guideline limit of ≤ 10^3 fecal coliform bacteria/100 ml is warranted when adult farm workers are engaged in flood or furrow irrigation and when children under age 15 are regularly exposed through work or play. Where there are insufficient resources to meet this stricter guideline limit, a guideline limit of ≤ 10^5 fecal coliform bacteria/100 ml should be supplemented by other health protection measures. The guideline limit for nematode eggs (≤ 1 egg/l) is adequate if no children are exposed, but a revised guideline limit of ≤ 0.1 egg/l is recommended if children are in contact with wastewater or soil through irrigation or play. The evidence reviewed does not support the need for a separate specific guideline limit to protect against viral infections, and there was insufficient evidence to support the need for a specific guideline limit for parasitic protozoa.

Therefore, Blumenthal et al. suggest revised microbiological guidelines for treated wastewater use in agriculture as shown in table 7.

Table 7: Recommended revised microbiological guidelines for treated wastewater use in agriculture [a]

Category	Reuse Conditions	Exposed group	Irrigation technique	Intestinal nematodes [b] (arithmetic mean no of eggs per liter [c])	Fecal coliforms (geometric mean no per 100 ml [d])	Wastewater treatment expected to achieve required microbiological quality
A	*Unrestricted irrigation* A1 Vegetable and salad crops eaten uncooked, sports fields, public parks [e]	Workers, consumers, public	Any	≤ 0.1[f]	≤ 10^3	Well designed series of waste stabilization ponds (WSP), sequential batch-fed wastewater storage and treatment reservoirs (WSTR) or equivalent treatment (e.g. conventional secondary treatment supplemented by either polishing ponds or filtration and disinfection)
B	*Restricted irrigation* Cereal crops, industrial crops, fodder crops, pasture and trees [g]	B1 Workers (but no children <15 years), nearby communities	(a) Spray/ sprinkler	≤ 1	≤ 10^5	Retention in WSP series inc. one maturation pond or in sequential WSTR or equivalent treatment (e.g. conventional secondary treatment supplemented by either polishing ponds or filtration)
		B2 As B1	(b) Flood/ furrow	≤ 1	≤ 10^3	As for Category A
		B3 Workers including children < 15 years, nearby communities	Any	≤ 0.1	≤ 10^3	As for Category A
C	Localized irrigation of crops in category B if exposure of workers and the public does not occur	None	Trickle, drip or bubbler	Not applicable	Not applicable	Pre-treatment as required by the irrigation technology, but not less than primary sedimentation.

[a] In specific cases, local epidemiological, socio-cultural and environmental factors should be taken into account and the guidelines modified accordingly.

[b] Ascaris and Trichurisspecies and hookworms; the guideline limit is also intended to protect against risks from parasitic protozoa.

[c] During the irrigation season (if the wastewater is treated in WSP or WSTR which have been designed to achieve these egg numbers, then routine effluent quality monitoring is not required).

[d] During the irrigation season (feca coliform counts should preferably be done weekly, but at least monthly).

[e] A more stringent guideline limit (4200 fecal coliforms/100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.

[f] This guideline limit can be increased to 41 egg/l if (i) conditions are hot and dry and surface irrigation is not used or (ii) if wastewater treatment is supplemented with anthelmintic chemotherapy campaigns in areas of wastewater reuse.

[g] In the case of fruit trees, irrigation should stop two weeks before fruit is picked, and no fruit should be picked off the ground. Spray/sprinkler irrigation should not be used.

Wastewater treatment technologies suitable for meeting the revised microbiological guidelines for agriculture include the use of waste stabilization ponds (WSP), wastewater storage and treatment reservoirs (WSTR), or conventional treatment processes. When using WSP, the revised guidelines usually require the use of 1 or more maturation ponds after the anaerobic and facultative ponds. Use of sequential batch-fed storage and treatment reservoirs can be designed to meet the guidelines for unrestricted and restricted irrigation. When conventional treatment processes are used secondary treatment, filtration and disinfection are often needed to meet the revised guidelines. The cost and difficulty in operating and maintaining conventional treatment plants to the level needed to meet the guidelines means that they are not recommended where WSP and WSTR can be used.

4. Regional Experiences in Formulating Guidelines

In most of the countries of the Mediterranean region, wastewater is widely reused at different extents within planned or unplanned systems. However, only few Mediterranean countries (such as Cyprus, Jordan, and Tunisia) have included water reuse in their water resources planning and have official policies calling for water reuse. Regarding the EM-Water countries, legal standards for wastewater reuse have only been adopted in Jordan and Turkey. The Palestinian Water Authority has developed guidelines for wastewater reuse, but these have not yet been enforced. In Lebanon, no specific guidelines for the reuse of wastewater have yet been developed, but are envisaged for the future. This delay can be explained by the fact that Lebanon is not as much suffering from water shortage as are other MEDA countries.

4.1 Tunisia (1989)

Irrigation with recycled wastewater is well established in Tunisia. The Tunisian government is pursuing wastewater reuse in agriculture as a strategic objective and is translating the objective into systematic practice. A wastewater reuse policy was launched at the beginning of the eighties.

Wastewater reuse in agriculture is regulated by the 1975 Water Code (law No. 75-16 of 31 March 1975), by the 1989 Decree No. 89-1047 (28 July 1989), by the Tunisian standard for the use of treated wastewater in agriculture (NT 106- 003 of 18 May 1989), by the list of crops than can be irrigated with treated wastewater (Decision of the Minister of Agriculture of 21 June 1994) and by the list of requirements for agricultural wastewater reuse projects (Decision of 28 September 1995). They prohibit the irrigation of vegetables that might be consumed raw. Therefore, most of the recycled wastewater is used to irrigate vineyards, citrus and other trees (olives, peaches, pears, apples, pomegranates, etc.), fodder crops (alfalfa, sorghum, etc), industrial crops (cotton, tobacco, sugar beet, etc), cereals, and golf courses (Tunis, Hammamet, Sousse, and Monastir). Some hotel gardens in Jerba and Zarzis are also irrigated with recycled wastewater.

In Tunisia, regulation of wastewater reuse in agriculture mainly relies on use restrictions. For instance, it has banned irrigation with wastewater (treated or untreated) for vegetables that are eaten uncooked. The same applies for heavily used pastures. These restrictions on allowed uses are supplemented by biological and chemical sum limit values (BOD5, COD, organic substances) and limit values for nematode eggs. Tunisia continues to permit wastewater irrigation for golf links, public parks, and the like, i.e. mainly for areas and crop types that pose little risk to consumers since the plants in question are not consumed or the crops do not come into direct contact with the wastewater used.

The 1989 decree stipulates that the use of recycled wastewater must be authorized by the Minister of Agriculture, in agreement with the Minister of Environment and Land Use Planning, and the Minister of Public Health. It sets out the precautions required to protect the health of farmers and consumers, and the environment. Monitoring the physical-chemical and biological quality of recycled wastewater and of the irrigated crops is planned: analyses of a set of physical-chemical parameters once a month, of trace elements once every 6 months, and of helminth eggs every two weeks on 24h composite samples, etc. In areas where sprinklers are used, buffer areas must be created. Direct grazing is prohibited on fields irrigated with wastewater.

Specifications determining the terms and general conditions of recycled wastewater reuse, such as the precautions that must be taken in order to prevent any contamination (workers, residential areas, consumers, etc.), have been published. The Ministries of Interior, Environment and Land Planning, Agriculture, Economy and Public Health are in charge of the implementation and enforcement of this decree. It is interesting to note that in Tunisia, the farmers pay for the treated wastewater they use to irrigate their fields.

However, in Tunisia, where the legal, technical, and political framework for reuse is relatively favorable, only 20% of treatment plant outflows are reused. The low motivation of farmers to reuse wastewater is in fact reported to be the main obstacle to increasing the current level of reused water. One of the most important reasons for this is the legal restriction concerning the use of wastewater to irrigate vegetables. Since vegetables are the most profitable and most easy-to-market crops in Tunisia, this legal restriction is sufficient to explain the slow rate of adoption by farmers.

4.2 Turkey (1991)

Water reuse was officially legitimized in 1991 through the regulation for irrigational wastewater reuse issued in by the Ministry of Environment. According to the "Water Pollution Control Regulations", in order to use treated wastewater in irrigation, a written permission from concerned government organisations must be obtained. A commission organized by the State Water Organisation, İller Bank and Agriculture Ministry and Environmental and Forest Ministry will decide whether the effluent can be used in irrigation or not.

The effluent quality criteria for irrigation according to the Turkish Water Pollution Control Regulations are given in the following tables. In general, the WHO standards have been adopted except the limits for the intestinal nematodes and the residual chlorine. Concerning the microbiological standards, the Turkish regulation seems unsufficient and needs to be revised according to the actual discussions (as mentioned before).

Boron concentrations are particularly important for Turkish conditions because Turkey is rich in terms of boron sources. Therefore water for irrigation is separately classified with respect to their boron concentrations which is not named expressively here.

Table 8: Maximum Concentrations of Toxic Elements in Effluents for Irrigation

Elements	**Max. Concentration (mg/l)**	**Elements**	**Max. Concentration (mg/l)**
Aluminium (Al)	5.0	Lead (Pb)	5.0
Arsenic (As)	0.1	Lithium (Li)	2.5
Beryllium (Be)	0.1	Manganese (Mn)	0.2
Cadmium (Cd)	0.01	Molybdenum (Mo)	0.01
Chromium (Cr)	0.1	Nickel (Ni)	0.2
Cobalt (Co)	0.05	Selenium (Se)	0.02
Copper (Cu)	0.2	Vanadium (V)	0.1
Fluorine (F)	1.0	Zinc (Zn)	2.0
Iron (Fe)	5.0		

Table 9: Effluent Quality Criteria for Irrigation

Effluent quality criteria	First class effluent (very good)	Second class effluent (good)	Third class effluent (usable)	Fourth class effluent (usable by care)	Fifth class effluent (can not be used)
$EC25 * 10^6$ (umhos/cm)	0.250	250-750	750-2000	2000-3000	>3000
Sodium percent (Na%)	<20	20-40	40-60	60-80	>80
Sodium absorption range	<10	10-18	18-26	<26	
Sodium carbonate residual					
meq/l	<1.25	1.25-2.5	>2.5	12-20	
mg/l	<66	66-133	>133	625-710	
Chloride (Cl)					
meq/l	0-4	4-7	7-12	12-20	>20
mg/l	0-142	142-249	249-426	626-710	>710
Sulfide (SO_4)					
meq/l	0-4	4-7	7-12	12-20	>20
mg/l	0-192	192-336	336-575	576-960	>960
Total salts mg/l	0-175	175-525	525-1400	1400-2100	>2100
Boron[1] concentration mg/l	0-0.5	0.5-1.12	1.12-2.0	2.0	-
NO_3 or NH^+_4	0-5	5-10	10-30	30-50	>50
Fecal coliforms (in 100 ml)	0-2	2-20	20-102	102-103	>103
BOD_5 (mg/l)	0-25	25-50	50-100	100-200	>200
Suspended solids mg/l	20	30	45	60	>100
pH	6.5-8.5	6.5-8.5	6.5-8.5	6-9	<6 or >9
Temperature ºC	30	30	35	40	>40

[1] With respect to Boron concentration there is even a more detailed classification of irrigation waters

4.3 Jordan (2002)

The key policy objectives of the Jordan water reuse management plan are to use reclaimed water, where practical, in exchange for present and future use of freshwater and to maximize the returns from reclaimed water resources. Therefore, the Government of Jordan has imposed that all new wastewater treatment projects must include feasibility aspects for wastewater reuse and has set standards for treated domestic wastewater effluent (Jordanian Standards JS 893/1995 revised in 2002).

Table 10: Allowable Limit for properties and criteria for reuse in irrigation

Allowable limits per end use				
Parameter	**Unit**	**Cooked Vegetables, Parks, Playgrounds and Sides of Roads within city limits**	**Fruit Trees, Sides of Roads outside city limits, and landscape**	**Field Crops, Industrial Crops and Forest Trees**
		A	B	C
Biological Oxygen Demand	mg/l	30	200	300
Chemical Oxygen Demand	mg/l	100	500	500
Dissolved Oxygen	mg/l	>2	-	-
Total suspended solids	mg/l	50	150	150
pH	unit	6-9	6-9	6-9
Turbidity	NTU	10	-	-
Nitrate	mg/l	30	45	45
Total Nitrogen	mg/l	45	70	70
Escherishia Coli	Most probable number or colony forming unit/ 100ml	100	1000	-
Intestinal Helminthes Eggs	Egg/l	< or =1	< or =1	< or =1

Standard: http://www.mwi.gov.jo/main%20topics/Standards/js893-master.htm

The Jordanian standards for wastewater reuse are based on reuse categories depending on crops/ areas to be irrigated. The standard prohibits using reclaimed water for irrigating vegetables that are eaten uncooked (raw). Further, it is prohibited to use sprinkler irrigation except for irrigating golf courses. In the latter case, irrigation should take place at night and sprinklers must be movable and not accessible for day use. When using reclaimed water for irrigating fruit trees, irrigation must be stopped two weeks prior to fruits harvesting and any falling fruits in contact with the soil must be removed.

In addition, the Jordanian standards provide values for a range of chemical wastewater components that are considered for guidance only. In case of exceeding these values, the end user must carry out scientific studies to verify the effect of that water on public health and the environment and suggest ways and means to prevent damage to either.

Table 11: Guidelines for Reuse in Irrigation

Fat And grease	FOG	mg/l	8
Phenol	Phenol	mg/l	<0.002
Detergent	MBAS	mg/l	100
Total Dissolved Solids	TDS	mg/l	1500
Total Phosphate	$T\text{-}PO_4$	mg/l	30
Chloride	Cl	mg/l	400
Sulfate	SO_4	mg/l	500
Bicarbonate	HCO_3	mg/l	400
Sodium	Na	mg/l	230
Magnesium	Mg	mg/l	100
Calcium	Ca	mg/l	230
Sodium Adsorption Ration	SAR	-	9
Aluminum	Al	mg/l	5
Arsenic	As	mg/l	0.1
Beryllium	Be	mg/l	0.1
Copper	Cu	mg/l	0.2
Fluoride	F	mg/l	1.5
Iron	Fe	mg/l	5.0
Lithium	Li	mg/l	2.5(0. 075 for citrus crops)
Manganese	Mn	mg/l	0.2
Molybdenum	Mo	mg/l	0.01
Nickel	Ni	mg/l	0.2
Lead	Pb	mg/l	5.0
Selenium	Se	mg/l	0.05
Cadmium	Cd	mg/l	0.01
Zinc	Zn	mg/l	5.0
Chrome	Cr	mg/l	0.1
Mercury	Hg	mg/l	0.002
Vanadium	V	mg/l	0.1
Cobalt	Co	mg/l	0.05
Boron	B	mg/l	1.0
Cyanide	CN	mg/l	0.01

4.4 Recommended for Gaza (2002)

Although reclaimed wastewater reuse for agriculture is increasingly being recognized as an essential component in the management strategy for water shortage in the neighboring countries, such practice is still not officially followed for agriculture in Gaza Strip. There is now a master plan introduced by donor countries to construct three new WWTPs in Gaza Strip to replace the existing ones by the year 2020. Most of the reclaimed wastewater produced from these plants would be suitably managed for use in irrigation.

Environmental Limit Values for reuse of wastewater have been prepared by the Palestinian Standards Institute and the Palestinian Water Authority. However, these limit values have not been enforced so far. The draft Palestinian standards include quality standards for reuse of treated wastewater depending on the crops and areas to be irrigated. They further stipulate that some best practices have to be adopted when reusing wastewater. These include:

- Irrigation has to be stopped two weeks before harvesting period when treated wastewater used for productive crops and field crops, for animal feeding crops before grazing and falling products or that close to the ground has to be excluded.
- Sprinkler irrigation is prohibited.
- Use of treated wastewater is forbidden for irrigation of all vegetables
- Closed pipes have to be used when wastewater transported in areas with high soil permeability, which can affect the aquifer or surface water, used for drinking.
- Dilution of treated water, to meet the requested quality by mixing with fresh water in the treatment plant is forbidden.

Table 12: Recommended Guidelines by the Palestinian Standards Institute for Treated Wastewater Characteristics according to different applications

Quality Parameter (mg/l except otherwise indicated)	Fodder Irrigation		Gardens, Playgrounds, Recreational	Industrial Crops	Groundwater Recharge	Seawater Outfall	Landscapes	Trees	
	Dry	Wet						Citrus	Olive
BOD_5	60	45	40	60	40	60	60	45	45
COD	200	150	150	200	150	200	200	150	150
DO	> 0.5	> 0.5	> 0.5	> 0.5	> 1.0	> 1.0	> 0.5	> 0.5	> 0.5
TDS	1500	1500	1200	1500	1500	-	1500	1500	500
TSS	50	40	30	50	50	60	50	40	40
pH	6 – 9	6 – 9	6 – 9	6 – 9	6 – 9	6 – 9	6 – 9	6 – 9	6 – 9
Color (PCU)	Free	Free	Free	Free	Free of colored matter	Free of colored matter	Free	Free	Free
FOG	5	5	5	5	0	10	5	5	5
Phenol	0.002	0.002	0.002	0.002	0.002	1	0.002	0.002	0.002
MBAS	15	15	15	15	5	25	15	15	15
NO_3-N	50	50	50	50	15	25	50	50	50
NH_4-N	-	-	50	-	10	5	-	-	-
O.Kj-N	50	50	50	50	10	10	50	50	50
PO_4-P	30	30	30	30	15	5	30	30	30
Cl	500	500	350	500	600	-	500	400	400
SO_4	500	500	500	500	1000	1000	500	500	500
Na	200	200	200	200	230	-	200	200	200
Mg	60	60	60	60	150	-	60	60	60
Ca	400	400	400	400	400	-	400	400	400
SAR	9	9	10	9	9	-	9	9	9
Residual Cl_2	-	-	-	-	-	-	-	-	-

Table 12 (continued):

Quality Parameter (mg/l except otherwise indicated)	**Fodder Irrigation**		**Gardens, Playgrounds, Recreational**	**Industrial Crops**	**Groundwater Recharge**	**Seawater Outfall**	**Landscapes**	**Trees**	
	Dry	**Wet**						**Citrus**	**Olive**
Al	5	5	5	5	1	5	5	5	5
Ar	0.1	0.1	0.1	0.1	0.05	0.05	0.01	0.01	0.01
Cu	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
F	1	1	1	1	1.5	-	1	1	1
Fe	5	5	5	5	2	2	5	5	5
Mn	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Ni	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Pb	1	1	0.1	1	0.1	0.1	1	1	1
Se	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Cd	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Zn	2.0	2.0	2.0	2.0	5.0	5.0	2.0	2.0	2.0
CN	0.05	0.05	0.05	0.05	0.1	0.1	0.05	0.05	0.05
Cr	0.1	0.1	0.1	0.1	0.05	0.5	0.1	0.1	0.1
Hg	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Co	0.05	0.05	0.05	0.05	0.05	1.0	0.05	0.05	0.05
B	0.7	0.7	0.7	0.7	1.0	2.0	0.7	0.7	0.7
FC (CFU/100 ml)	1000	1000	200	1000	1000	50000	1000	1000	1000
Pathogens	Free	Free	Free	Free	Free	Free	Free	Free	Free
Amoeba & Gardia (Cyst/L)	-	-	Free	-	Free	Free	-	-	-
Nematodes (Eggs/L)	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1

(-) Undefined

4.5 Recommended Mediterranean (2003)

Common guidelines on water reuse in all Mediterranean countries have been proposed by Bahri and Brissaud (2002). These guidelines have been developed under a project funded by UNEP/WHO and have been presented in various meetings. These are based on the consideration that: (a) an agricultural Mediterranean market is developing with large amounts of agricultural products (vegetables, fruits, etc) imported and exported among Europe and other Mediterranean countries; (b) tourism is an essential part of the economic activity of the region; its development might be jeopardized in the long term by disease outbreaks linked to wastewater mismanagement; (c) there is a growing concern of consumers about the food quality and health hazards; (d) unfair competition among farmers should be avoided. These guidelines have been prepared making a large use of the results of the recent assessment of the WHO guidelines by Blumenthal et al., (2000).

However, contemplating to set up Mediterranean guidelines raises three questions:

(a) how to derive health guidelines for water reuse, which would be applicable in many different settings of the Mediterranean Region, in economically less developed countries as well as in industrialized ones?
(b) can uniform water reuse guidelines be realistically enforced in every country of the region ?
(c) does the actual knowledge allow a definitive position regarding the limits to be set up?

In addition, it should be noticed that:

(a) populations of the North and South banks are both exposed to contamination of food and the environment,
(b) guidelines provide a reasonable health protection defined through either the concept of "no measurable excess risk of infection attributable to wastewater reuse" or an acceptable maximum annual risk, and
(c) guidelines are not unnecessarily too stringent, i.e. too costly with regard to the risk reduction.

As non potable reuse will long remain the goal of the large majority of the reuse projects, these draft guidelines for domestic water reuse for the Mediterranean Region are focused on the microbiological hazards. Four categories of recycled water uses are considered (see table 13):

Category I: urban and residential reuses, landscape and recreational impoundments.
Category II: unrestricted irrigation, landscape impoundments (contact with water not allowed), and industrial reuses.
Category III: restricted agricultural irrigation.

Category IV: irrigation with recycled water application systems or methods (drip, subsurface, etc) providing a high degree of protection against contamination and using water more efficiently.

Table 13: Proposed Mediterranean guidelines

	Quality criteria			
	Microbiological			
Water category	**Intestinal nematode (a) (No. eggs per liter)**	**FC or *E. coli* (b) (cfu/ 100 ml)**	**Physical-chemical SS (c)) (mg/L)**	**Wastewater treatment expected to meet the criteria**
Category I				
a) Residential reuse: private garden watering, toilet flushing, and vehicle washing. b) Urban reuse: irrigation of areas with free admittance (greenbelts, parks, golf courses, sport fields), street cleaning, fire-fighting, fountains, and other recreational places. c) Landscape and recreational impoundments: ponds, water bodies and streams for recreational purposes, where incidental contact is allowed (except for bathing purposes).	≤0.1(h)	≤200 (d)	≤10	Secondary treatment + filtration + disinfection
Category II				
a) Irrigation of vegetables (surface or sprinkler irrigated), green fodder and pasture for direct grazing, sprinkler-irrigated fruit trees b) Landscape impoundments: ponds, water bodies and ornamental streams, where public contact with water is not allowed. c) Industrial reuse (except for food industry).	≤0.1(h)	≤1000 (d)	≤20 ≤150 (f)	Secondary treatment or equivalent (g)+ filtration + disinfection or Secondary treatment or equivalent (g)+ either storage or well-designed series of maturation ponds or infiltration percolation

Table 12 (continued):

	Quality criteria			
	Microbiological			
Water category	**Intestinal nematode (a) (No. eggs per liter)**	**FC or *E. coli* (b) (cfu/ 100 ml**	**Physical-chemical SS (c)) (mg/L)**	**Wastewater treatment expected to meet the criteria**
Category III				
Irrigation of cereals and oleaginous seeds, fiber, & seed crops, dry fodder, green fodder without direct grazing, crops for canning industry, industrial crops, fruit trees (except sprinkler-irrigated)(e), plant nurseries, ornamental nurseries, wooden areas, green areas with no access to the public.	≤1	None required	≤35 ≤150 (f)	Secondary treatment or equivalent (g)+ a few days storage or Oxidation pond systems
Category IV				
a) Irrigation of vegetables (except tuber, roots, etc.) with surface and subsurface trickle systems (except micro-sprinklers) using practices (such as plastic mulching, support, etc.) guaranteeing absence of contact between reclaimed water and edible part of vegetables. b) Irrigation of crops in category III with trickle irrigation systems (such as drip, bubbler, micro-sprinkler and subsurface). c) Irrigation with surface trickle irrigation systems of greenbelts and green areas with no access to the public. d) Irrigation of parks, golf courses, sport fields with sub-surface irrigation systems.	None required	None required	Pretreatment as required by the irrigation technology, but not less than primary sedimentation	

The proposed Mediterranean guidelines are minimum requirements which should constitute the basis of water reuse regulations in every country of the region. Wealthy countries might wish higher protection. Due to late development of wastewater treatment in several countries, all of them cannot be expected to comply with the guidelines within the same delay. However, every country could commit itself to reach the guidelines within a delay depending on its current equipment and financial capacities.

5. Guiding questions

When wastewater reuse guidelines are formulated, the local conditions always have to be considered (existing treatment facilities, agricultural practices, hygienic standards, climate, etc.).

Please discuss the following questions **in the Forum**, important for the formulation of regional wastewater reuse guidelines in the Mediterranean.

- Is wastewater reuse already common practice in your country?
- Which are the main obstacles against wastewater reuse?
- What types of wastewater reuse are most relevant / mainly applied in your country?
- How is the wastewater usually treated before reuse?
- Which crops are mainly irrigated with reclaimed water?
- If wastewater reuse guidelines exist in your country, is the common practice inline with these guidelines, and how is the compliance monitored?
- For the policy for wastewater reuse in irrigation, there are two different possibilities:
    - (a) To choose different categories such as restricted or unrestricted irrigation, crops eaten raw or not, sport fields etc., with different water quality requirements. The control of the water quality is then more difficult and misuse not easy to discover.
    - (b) To have restrictive standards, so that the treated wastewater can be used for irrigation everywhere. If quality requirements are not stringent enough, irrigation methods should be prescribed, which don't produce aerosols, and irrigation with treated wastewater has to be stopped for a determined period before harvesting.
- Which option do you regard as more appropriate for the Mediterranean region?
- What parameters do you consider most important to be reflected / regulated in Mediterranean wastewater reuse guidelines?
- What standards are economically and administratively enforceable in your country?

6. References

This lesson mainly draws on four Country Studies (Jordan, Palestine, Lebanon and Turkey) compiled within the EMWater project and the following literature:

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Guidelines for Water Reuse International and Regional Experiences

Annika Kramer & Julika Post

Why Guidelines ?

- Reuse of water as resource in water scare regions is increasingly gaining importance
- Agricultural reuse of water can be related to health risks (farmers, consumers)
- Constituents of reclaimed water effect plant growth, crop yield, environment, soil conditions, irrigation infrastructure

⇨ Guidelines needed to reduce negative impacts and to boost reuse of valuable resource

Guidelines for water reuse in agriculture...

...focus on	• health and environmental protection
...define	• extent of required wwt • required water quality through limit values (bacteriological / physico-chemical) • irrigation method • control of areas and/or crops

Standards for safe reuse...

...need to be....

a) realistic in relation to local conditions (epidemiological, socio-cultural, technical, environmental factors)

b) affordable

c) Enforceable

⇨ If guidelines are set to strict and are therefore not affordable/enforceable, in worst case two options remain:

- no water reuse
- (illegal) reuse without applying guidelines

Parameters typically regulated in guidelines

(1) Microbiological parameters

(2) Physico-chemical parameters

(3) Other parameters: crop restriction, irrigation practices, human exposure control

⇨ to protect human and environmental health
⇨ to sustain long-term soil productivity
⇨ to maintain functioning of irrigation schemes

(1) Microbiological parameters

- Indicators for microbiological contamination
  ⇨limit values for
  - total coliforms
  - fecal coliforms

- Indicators for parasite contamination
  ⇨limit values for
  - helminth / nematodes eggs

(2) Physico-chemical parameters

- Limit values for
  - salinity
  - heavy metals
  - nutrients (N, P, K)
  - suspended solids
  - pH
  - and ohters

(3) Other parameters

- Specific requirements for wastewater treatment
- Crop restriction, e.g.:
  - no vegetables that can be eaten raw
  - no edible plant parts, etc.
- Restriction of irrigation practices, e.g.:
  - no spray/sprinkler irrigation
- Human exposure control and awareness
  - farm workers
  - their families
  - crop handlers
  - consumers of crops
  - people living close to irrigated areas

Different approaches – International experience

- Set strict limit values for microorganisms and chemicals
  (USA, California, Spain, etc.)
  ⇨ costly
- Crop restrictions + irrigation practices
  (many developing countries)
  ⇨ difficult to monitor / control
- Combination of use restrictions + easy-to-measure limit values for chem. and biol. sum parameters
  (Mexico, Tunisia, WHO a.o.)
  ⇨ comprehensive and pragmatic approach targeting minimum safety and conducive to promoting water reuse

WHO Guidelines
(1989, revised version expected end of 2005)

- focus on protection of human and public health
- 3 categories (A, B, C) defined by
  - reuse restriction
  - limit values for fecal coliforms, intestinal nematodes
  - type of wwt
- set the benchmark for the development of water reuse guidelines
- offer framework guidance to decision makers

⇨ goals should be modified according to local needs to be in line with the capabilities of the country in question

Mexican Guidelines (1996)

- designed to be achievable with the technology and resources available at present / near future
- 2 categories (restricted and unrestricted reuse) defined by
  - reuse restriction: restricted category excludes salad crops and vegetable eaten raw
  - limit values for fecal coliforms, helminth eggs
  - limit values for heavy metals, cyanides
- realistically policed by reducing the amount of monitoring required
- sufficient to protect “at-risk” groups

Mediterranean Recommendations
(proposed by Bahri and Brissaud, 2002)

- proposed for all Mediterranean countries
- minimum requirements to constitute the basis of water reuse regulations in every country in the region
- higher protection standards possibly for developed countries
- 4 categories of reuse (I-IV) defined by
  - reuse restriction
  - limit values for fecal coliforms, intestinal nematodes, suspended solids
  - type of wastewater treatment

Guiding Questions

When wastewater reuse guidelines are formulated, the specific local conditions have to be considered:

- What are the **specific needs** (for example typical crop types, irrigation systems, etc.)?
- What is the typical **wastewater composition**, what treatment is available?
- What are the **challenges** in enforcing water reuse guidelines?

Lesson D2

WASTEWATER REUSE TECHNOLOGIES

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Keywords
Disinfection, Membrane filtration, Slow sand filtration, Wastewater reuse, Wastewater reclamation, UV radiation

Table of content

Overview and summary

Wastewater is becoming an increasingly important source of water for reuse especially for irrigation purpose. The demands of growing communities for both food and water require the agricultural sector not only to increase food production but also to reduce its use of natural water resources. At the same time the amount of sewage is increasing. The reuse of wastewater primarly for irrigation can be a solution.

This lesson deals with the wastewater treatment technologies which are able to comply with the standards for water reuse. Usually the hygienic standard cannot be met by conventional treatment (even if it is highly efficient in removal of organics and nutrients) like activated sludge and secondary clarifier. Organic compounds and nutrients can be, contrary to conventional treatment goals, useful for irrigation because they have an additional fertilising effect on the fields.

The authors recommend therefore membrane filtration, reverse osmosis and UV radiation to disinfect the treated wastewater and to achieve the highest standard which can be used for almost all purposes. In case of reuse in restricted agriculture, other options are suitable like slow sand filtration or ponds with long residence time.

1. Introduction

1.1 Why thinking of wastewater reuse?

Considering the reuse of wastewater seems to be a silly idea itself because the term "wastewater" already contains the word "waste" which refers to something useless. But some important facts show that the question deserves its standing.

1.1.1 Lack of proper water and wastewater management

- 5 million people die due to water pollution problems every year. Additionally, about 20% of the world population have less than 20 litres of water per day and the world water consumption quadrupled in the last 50 years. During the next years, water demand will continually increase due to population growth (WBGU, 1999).
- 2 billion people are currently lacking access to sanitation and water; (WHO, http://www.euro.who.int/eprise/main/WHO/Progs/WSN/Home).
  Wastewater reuse can be a good option to improve this world wide situation.

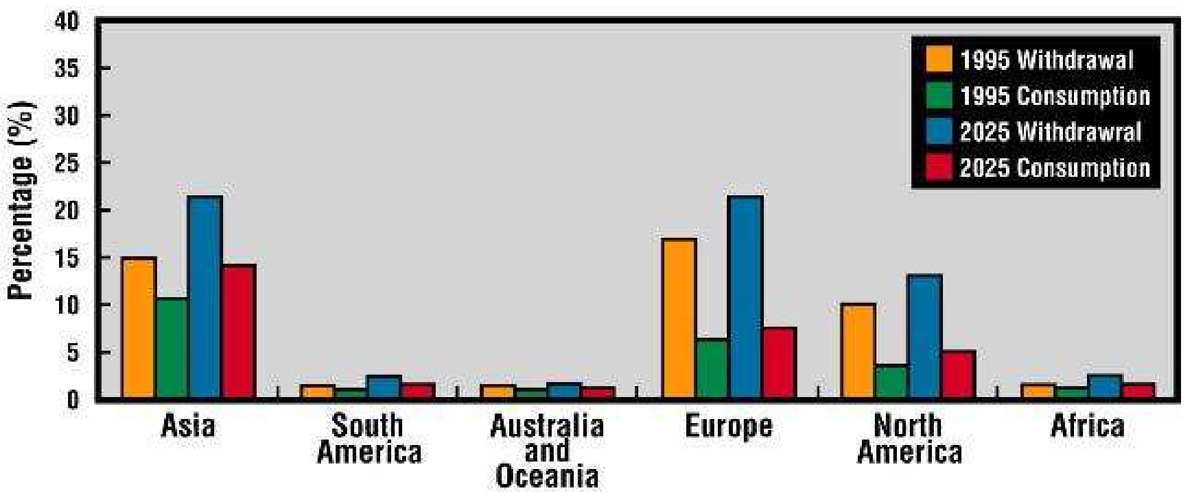

Figure 1: Water use and withdrawals (source: www.unesco.org)

1.1.2 Water imbalance management

The world is suffering the beginning of a "World water crisis". Many regions of the world are concerned and some are specifically endangered. The imbalance between water consumption through use and recharge of natural surface water (withdrawal) have sharply increased. The figure below shows clearly that Asia, Europe, and Northamerica already have this imbalance. It will increase in the coming decades, if nothing is done against it.

1.1.3 Presence of arid regions

Due to climate change or simply by men's activity like irrigation for agriculture, many regions have seen their availability of fresh water decreasing and even disappearing what led to new deserts, arid and semi-arid regions. The situation is particularly critical in the Middle East and North Africa where almost all conventional water resources have been exploited like in Saudi Arabia, the Arab Emirates, Oman, Qatar, Kuwait, Bahrain, Yemen, Jordan, Israel, Palestinian territories, and Libya *(Lazarova, 2001).*

1.1.4 Most of global water contains salt

The world only disposes 5% fresh water, 95% is sea water, rich of salt. Salt water cannot be used directly by plants and. They need fresh water for their survival. In regions where desalinated water is the main water source, activities like e.g. agriculture that utilises about 70% of global fresh water today, cannot be overcome with desalinated water. In such a case reuse of wastewater can be another option.

1.2 Planning issues

Wastewater reuse always comes along with public acceptance, environmental issues and investment costs. One should ensure that these basic requirements are fulfilled. Good understanding and clear definition of the whole procedure must be performed; it is necessary to do a preliminary study. This study must assess the effluent quality (water treatment and disposal needs), identify a potential reclaimed water market and set up an estimation of investment costs of the reclaiming procedure. The study must also provide insight into the viability of wastewater reuse and starting point for detailed planning. Table 1 summarises the major elements which need to be considered.

Table 1: Summary of major elements of wastewater reuse planning (Asano, 1998)

Planning phase	**Objective of planning**
Assess wastewater treatment and disposal needs	Evaluate quantity of wastewater available for reuse and disposal options
Assess water supply and demand	Evaluate dominant water use patterns
Analyse market for reclaimed water	Identify potential users of reclaimed water and associated water quantity and quality requirements
Conduct engineering and economic analyses	Determine treatment and distribution system requirements for potential users of reclaimed water
Develop implementation plan with financial analysis	Develop strategies, schedules and financial options for implementation of project

1.2.1 Market analysis

Once quality and quantity of reclaimed water are determined, a market analysis to identify its potential users has to be conducted. In particular water retailer records of the relevant zone are helpful. Potential users should be contacted and sites reusing effluent visited to detect eventual onsite problems or to define water systems modifications needed to accommodate the reuse. One should try to identify financial expectations of the users. These measures should be undertaken to gain the user confidence in the project and secure the market of reclaimed water.

1.2.2 Monetary analysis

When social, technical, and environmental concerns are considered in a reclaimed water project, the monetary aspect important for the realisation of the project has to be analysed. The economic analysis focuses on costs invested to construct and operate the reclaimed procedure, while the financial analysis is based on the market value of goods and services, including subsidies or monetary transfers (Asano, 1998).

Additionally, attention shall be given to maintenance aspects that will also create running costs.

For further information about financial aspects see lesson D3.

2. Overview of basic treatment technologies

The first step in wastewater treatment is usually a physical pretreatment.
The following biological treatment is the main efficient technology to degrade the majority of organic compounds, parts of the nutrients and to decrease the level of microbiological pollution. The most developed techniques at the level of urban treatment plants are intensive biological processes (removal of organics and nitrogen). Their principle is to enforce and concentrate the natural phenomena of organic and nutrient removal in a small space. They are especially appropriate and effective for high concentrated domestic wastewater and blackwater.

The following technologies are some examples of those used for an intensive treatment:

- Activated sludge plant / Sequencing batch reactor (SBR)
- Trickling filter
- Rotating biological contactors
- Anaerobic treatment systems

On the other hand there are extensive treatment techniques available which are less intensive processes close to nature, use very little energy and often much more space.

- Constructed wetlands (soil filter)
- Natural lagoon, stabilisation pond
- Slow sand filtration

2.1 Activated sludge plant / Sequencing batch reactor (SBR)

The activated sludge process is an aerobic (oxygen-rich), continuous-flow biological method for the treatment of domestic and biodegradable industrial wastewater, in which organic matter is utilized by microorganisms for life-sustaining processes, that is, for energy for reproduction, digestion, movement, etc. and as a food source to produce cell growth and more microorganisms. During these activities of utilization and degradation of organic materials, degradation products of carbon dioxide and water are also formed.

The activated sludge process is characterized by the suspension of microorganisms in the wastewater, a mixture referred to as the mixed liquor. Activated sludge is used as part of an overall treatment system, which includes primary treatment of the wastewater for the removal of particulate solids before the use of activated sludge as a secondary treatment process to remove suspended and dissolved organic solids.

The conventional activated sludge process consists of an aeration basin, with air as the oxygen source, where treatment is accomplished. Soluble (dissolved) organic materials are absorbed through the cell walls of the microorganisms and into the cells, where they are broken down and converted to more microorganisms, carbon dioxide, water, and energy. Insoluble (solid) particles are adsorbed on the cell walls, transformed to a soluble form by enzymes (biological catalysts) secreted by the microorganisms, and absorbed through the cell wall, where they are also digested and used by the microorganisms in their life-sustaining processes. The microorganisms that are responsible for the degradation of the organic materials are maintained in suspension by mixing induced by the aeration system.

The aeration basin is followed by a secondary clarifier (settling tank), where the flocs of microorganisms with their adsorbed organic materials settle out. A portion of the settled microorganisms, referred to as sludge, are recycled to the aeration basin to maintain an active population of microorganisms and an adequate supply of biological solids for the adsorption of organic materials. Excess sludge is wasted by being piped to separate sludge-handling processes. The liquids from the clarifier are transported to facilities for disinfection and final discharge to receiving waters, or to tertiary treatment units for further treatment.

Activated sludge processes are designed based on the mixed liquor suspended solids (MLSS) and the organic loading of the wastewater, as represented by the biochemical oxygen demand (BOD) or chemical oxygen demand (COD). The MLSS represents the quantity of microorganisms involved in the treatment of the organic materials in the aeration basin, while the organic loading determines the requirements for the design of the aeration system.

The sequencing batch reactor (SBR) is a fill-and draw activated sludge system for wastewater treatment. In this system, wastewater is added to a single "batch" reactor, treated to remove undesirable components, and then discharged. Equalization, aeration, and clarification can all be achieved using a single batch reactor, while the steps are performed after another. Aerobic decomposition, settling, and return occur in the same chamber. Air is bubbled through the liquid during the decomposition cycle. The bubbler shuts off, and the wastewater goes through a settling cycle (see figure 2). Once the bubbler turns back on, the tank re-enters the decomposition cycle, and settled bacteria mixes back into the aerobic environment. After settling of bacteria and solids, the treated effluent is discharged to the soil treatment system. Bacteria settle out more consistently in this kind of tank, but since it has more moving parts and requires a controller, it has more potential for mechanical and electrical failure.

To optimize the performance of the system, more batch reactors can be used in a predetermined sequence of operations. SBR systems have been successfully used to treat both municipal and industrial wastewater. They are uniquely suited for wastewater treatment applications characterized by low or intermittent flow conditions with low ground space demand, while conventional activated sludge technologies have a high demand on area.

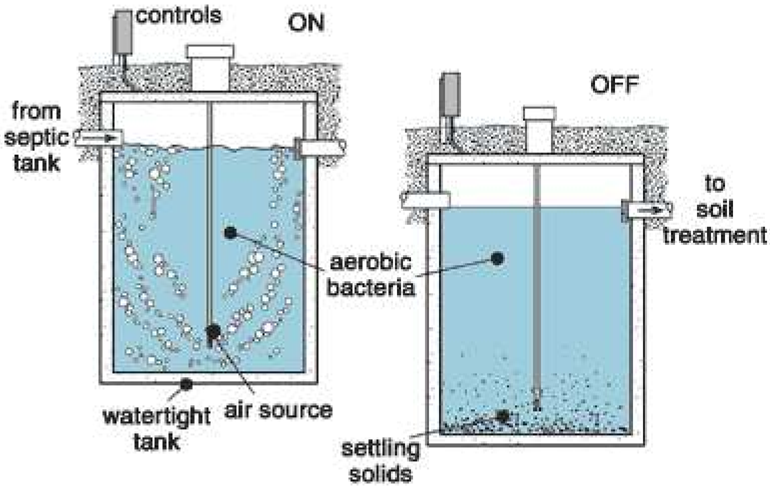

Figure 2: Sequencing batch reactor during aeration (left) and settling (right)- *(Source University of Minnesota)*

2.2 Trickling filter (TF)

A trickling filter (TF) is a wastewater treatment system that biodegrades organic matter and can also be used to achieve nitrification. The wastewater trickles through a circular bed of coarse stones or plastic material. A rotating distributor (a rotating pipe with several holes across it) evenly distributes the wastewater from above the bed. The microorganisms in the wastewater attach themselves to the bed (also known as the filter media), which is covered with bacteria (see figure 3). The bacteria break down the organic waste and remove pollutants from the wastewater.

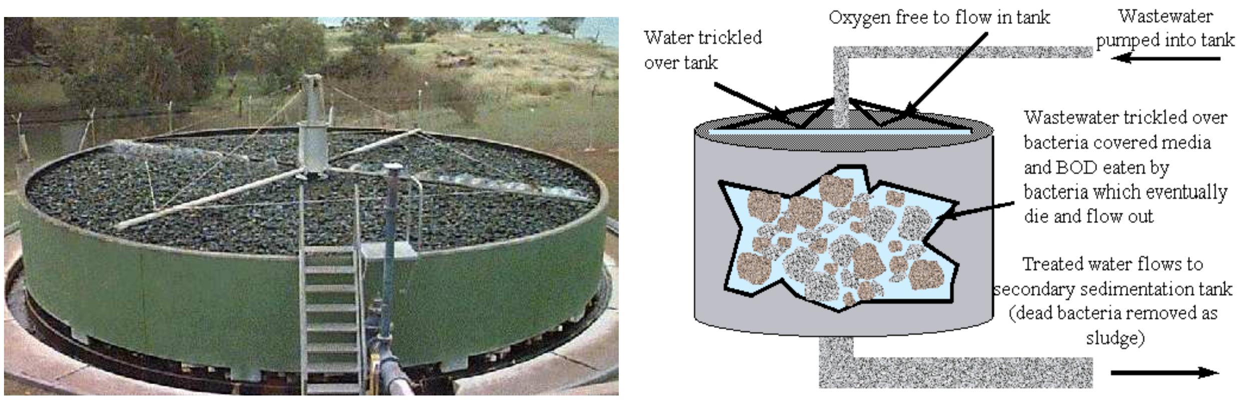

Figure 3: Trickling filter

When excess nutrients became a concern, it became necessary to adapt “conventional” sewage treatment systems to meet the increased oxygen demand placed on receiving waters by high ammonia nitrogen concentrations in wastewater effluents. TFs and other attached-growth processes proved to be well-suited for the removal of ammonia nitrogen by oxidizing it to nitrate nitrogen (nitrification).

2.3 Rotating biological contactors (RBC)

The Rotating Biological Contactor Process (RBC) consists of a series of discs attached to a common shaft. The discs are partially submerged in a trough of continuously flowing wastewater. As the discs rotate, a film of microorganisms growing on the discs consume oxygen from the air and substrate from the wastewater (see figure 4).

In this way, organic materials (substrate) are removed from the wastewater. The rotation of the RBC disks can be achieved by a motor and drive system on each shaft or by an air drive system with a coarse bubble diffuser at the bottom of the tank supplying air that is caught by the air cups attached to the disks. The rotation of the disks imparts a shear force to the biofilm, keeping its thickness relatively constant by removing the cells generated by consumption of the substrates. Rotation of the disks also serves to provide oxygen required for the growth of biomass and substrate degradation. A settling tank is normally required to remove the biomass from the effluent.

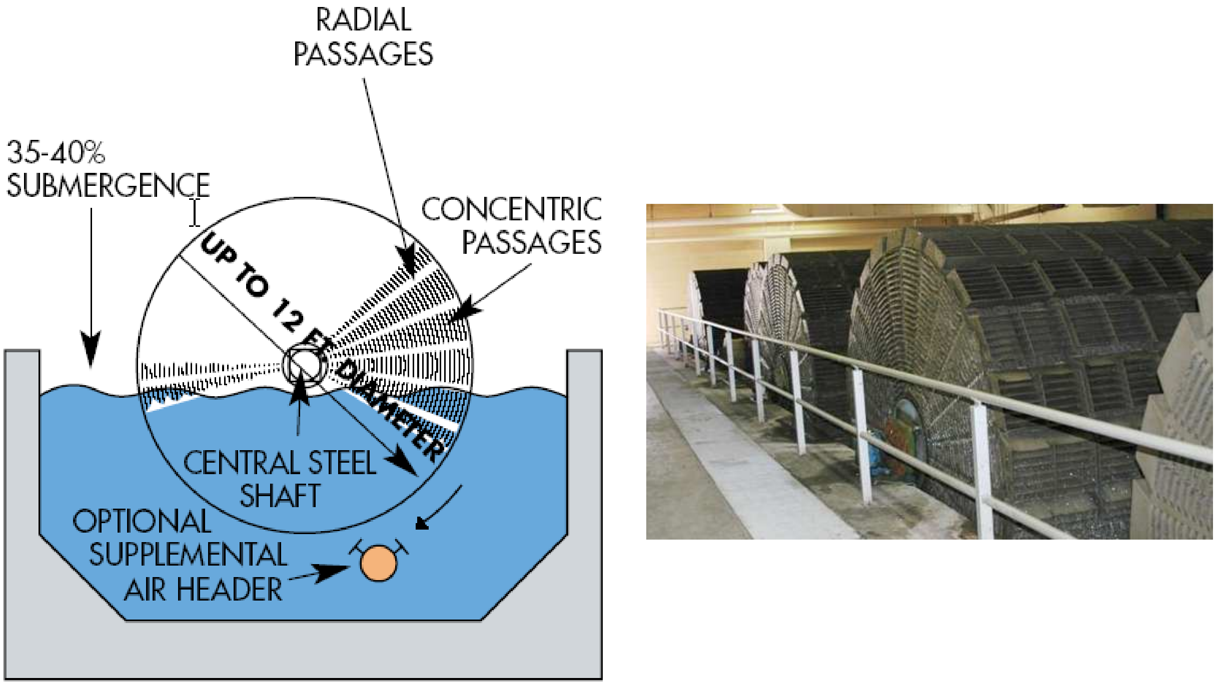

Figure 4: Conventional Rotating biological contactors system *(Source USFilter and ChevronTexaco)*

2.4 Anaerobic treatment systems

Different types of anaerobic treatment systems can be used as pretreatment devices for high-strength wastewater and some onsite pretreatment applications. Two examples are in shown in figure 5. Anaerobic treatment systems are widely used in hot climates. These systems can reduce high BOD and TSS to levels that can be readily treated by typical aerobic processes such as suspended and fixed growth aerobic units or recirculating/intermittent media filters. International literature contains numerous references to anaerobic treatment systems.

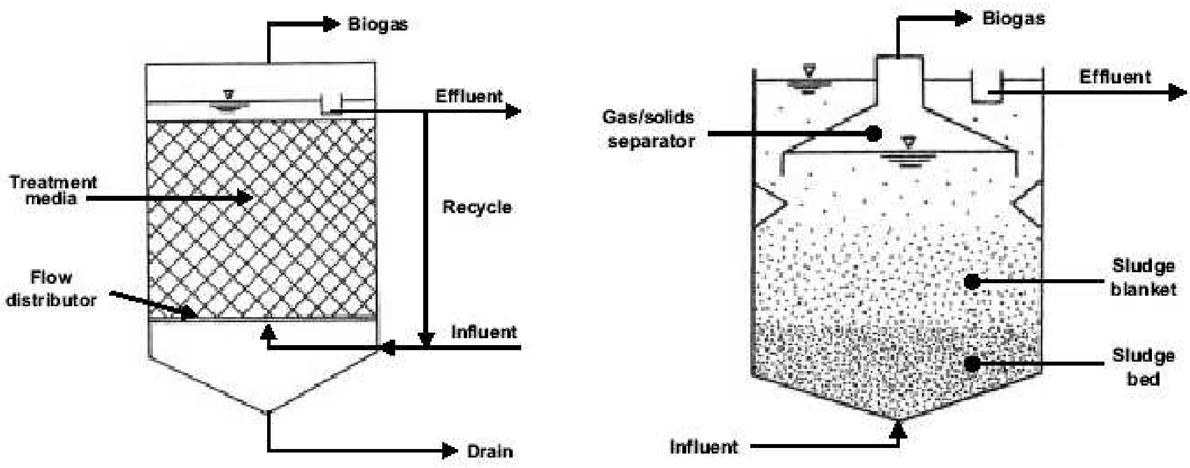

Figure 5: Two different types of Anaerobic treatment systems: Schematic of the upflow anaerobic filter process (left) an upflow anaerobic sludge blanket process

2.5 Constructed wetlands (soil filter)

Constructed wetlands are small artificial wastewater treatment systems consisting of one or more shallow treatment cells, with herbaceous vegetation that flourish in saturated or flooded cells. There are two basic types of constructed wetlands, Free Water Surface constructed wetlands (FWS) and Vegetated Submerged Bed constructed wetlands (VSB).

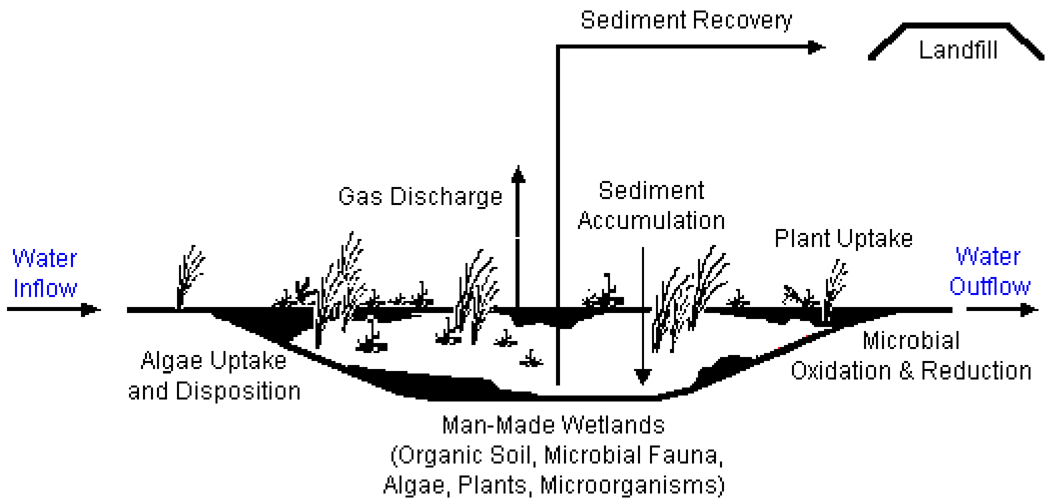

Figure 6: Constructed Wetlands

FWS wetlands have a combination of open water areas with some floating vegetation as well as emergent plants rooted in the soil bottom. They are usually more suitable to warmer climates, because biological decomposition rates are temperature dependent, decreasing with decreasing water temperature. In these systems wastewater is treated by the processes of sedimentation, filtration, digestion, oxidation, reduction, adsorption and precipitation.

VSB constructed wetlands, also known as subsurface flow wetlands, Consist of gravel soil beds planted with wetland vegetation. These systems have many of the same features of the FWS but are distinguished by their subsurface hydraulic grade. Unlike the FWS wetland, the wastewater stays beneath the surface, flows in contact with the roots and rhizomes of the plants and is invisible or unavailable to animals. VSB constructed wetlands are generally lower in cost and maintenance requirements than the FWS constructed wetlands.

2.6 Natural lagoon, stabilisation pond

Lagoon systems are shallow basins which hold the waste-water for several months to allow for the natural degradation of sewage. These systems take advantage of natural aeration and microorganisms in the wastewater to renovate sewage.

2.7 Membrane reactor

Membrane processes are primarily used for separations. As a unit operation they have several major attributes:

- They provide a well-defined, mass transfer surface area that is mostly independent of the operating conditions
- Their surface area provides selective transport of specific components between two phases
- Membrane process units are built of modules
- As devices, membrane modules typically provide high surface area per unit volume (the highest being for hollow fiber forms) and are relatively easy to operate
- The scale-up of membrane processes is usually linear with load

The selective separating layer in the module is what is typically called 'the membrane.' Currently membranes made from a broad spectrum of polymeric and inorganic compounds are commercially available.

There are many membrane processes or unit operations. They are differentiated primarily on the basis of the driving force for mass transfer through the membrane, the predominant transport mechanism, and the phases that are present. Each membrane unit operation has its own specific nomenclature, engineering characteristics, and concerns, but it is also possible that a given membrane module can be used for different membrane unit operations. Due to their very high capital, operation and maintenance costs, they are only suitable for special applications in wastewater treatment for developing countries. For application in wastewater treatment see Chapter 3.4.

2.8 Slow sand filtration

Slow sand filtration can be very effective to treat municipal treatment in a tertiary step. The application of slow sand filtration (SSF) is feasible on a biologically pre-treated wastewater. The mechanisms for water impurities removal are mechanical filtration, enhanced biological activity on surfaces and adsorption. These features make SSF very attractive for advanced treatment of effluents. The key parameters of the SSF are the depth of the sand filter and the effective size of the sand. The effective size of the sand is usually 0.15 – 0.4 mm and the depth between 0.6 to 1.0 m. The filter doesn't need to be backwashed regularly, it is easy to remove the first layer on the surface and to replace it with new material. The used material can be recycled or disposed. The SSF is able to remove significantly bacteria so that the effluent is almost hygienically safe.

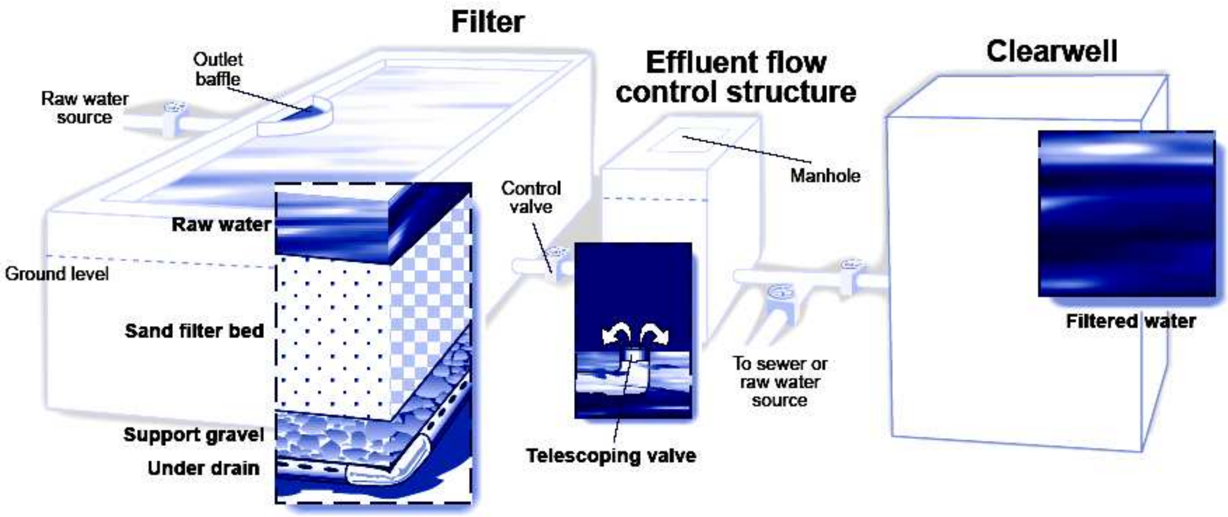

Figure 7: Slow sand filtration system (source: National Drinking Water Clearinghouse)

Table 2 gives an overview of the common technologies and their characteristics

Table 2: Wastewater technologies and their characteristics (Wendland, 2003)

Technology	Climate	Ground space demand	Energy costs	Capital and operation costs	Technical knowledge for operation and maintenance	Hygienic Quality in the effluent
Activate sludge plant (SBR)	Good biological activity in warm climate, evaporation in warm and dry climate	low	high	High capital costs, lower operation and maintenance costs	high	Elimination by factor 10-100
Trickling filter, rotation disc contactor	Independent, usually built in house	low	medium	High capital, operation and maintenance costs	medium	Elimination by factor 10-100
Anaerobic reactor	No evaporation problems, the warmer, the better the biological activity	medium	Energy recovery	High capital costs but energy recovery of biogas	high	Elimination by factor 10-100
Constructed Wetland	Transpiration depends on the type of plants	high	low	Low capital, operation and maintenance costs	medium	1 log elimination
Lagoons (aerated or natural)	High evaporation rate in dry climate	high	Low for natural, medium for aeration	Low capital, operation and maintenance costs	low	> 3 log elimination for long residence time
Membrane reactor	Evaporation in warm and dry climate	very low	very high	High capital, operation and maintenance costs	high	Hygienically safe (UF)
Slow sand filtration	Evaporation in warm and dry climate	medium	medium	Low capital, operation and maintenance costs	medium	Hygienically almost safe
UV, Chlorine Ozone	Needs building	low	high	Low capital, high operation and maintenance costs	high	Hygienically safe

The basic technologies applied in developed countries, primarily activated sludge process, are not able to meet common hygienic standard. The effluent of these plants contains still many pathogens which are usually highly diluted in the receiving waters so that they don´t harm. Only the filtration, physical and chemical technologies can meet the hygienic standards mostly required for water reuse.

3. Disinfection technologies

The regulation in many countries requires the disinfection of the treated water in order to protect farmers and consumers. The goal of disinfection is the removal, killing or inactivation of pathogens so that there is no danger for health any more. This means at least a reduction of 4-5 logs in municipal wastewater.

The conventional wastewater treatment with physical and biological technologies is not able to disinfect the wastewater efficiently. Since organic load and suspended solids have an negative impact on the disinfection rate, it is recommended to treat the wastewater biologically before disinfection.

Disinfection methods can generally be grouped in two types: physical and chemical methods. An overview is given in table 3.

Table 3: Disinfection efficiency of several technologies (Jacangelo & Trussell, 2001)

Disinfection Technology	Bacteria	Viruses	Protozoa	Total
Chlorine gas	+++	+++	+/-	++
Chloramine	+	-	--	-
Chlorine dioxide	++/+++	++/+++	+	++
Ozone	+++	+++	++/+++	++/+++
UV	++/+++	+	++	++
Ultrafiltration (<0.01 µm)	+++	+++	+++	+++

+++ very good, ++ good, -bad, --very bad

If all methods with chlorine are considered as one there are three common methods of disinfection in general: Chlorination, ozonation, and ultraviolet (UV) disinfection. Disinfection is considered to be the primary mechanism for the inactivation/destruction of pathogenic organisms to prevent the spread of waterborne diseases to downstream users and the environment. It is important that wastewater be adequately treated prior to disinfection in order for any disinfectant to be effective. All three disinfection methods can effectively meet the discharge permit requirements for treated wastewater. However, the advantages and disadvantages of each must be weighed when selecting a method of disinfection.

3.1 Chlorine disinfection

Chlorine, the most widely used disinfectant for municipal wastewater, destroys target organisms by oxidation of cellular material. It may be applied as chlorine gas, hypochlorite solutions, and other chlorine compounds in solid or liquid form.

Chlorination is a well-established technology. Presently, chlorine is more cost-effective than either UV or ozone disinfection (except when dechlorination is required and fire code requirements must be met). The chlorine residual that remains in the wastewater effluent can prolong disinfection even after initial treatment and can be measured to evaluate the effectiveness. Chlorine disinfection is also reliable and effective against a wide spectrum of pathogenic organisms and is effective in oxidizing certain organic and inorganic compounds including certain noxious odors.

But is has to be considered that the chlorine residual, even at low concentrations, is toxic to aquatic life and may require dechlorination. All forms of chlorine are highly corrosive and toxic. Thus, storage, shipping, and handling pose a risk, requiring increased safety regulations. In some cases Chlorine oxidizes organic matter in wastewater, creating more hazardous compounds. In all cases the level of total dissolved solids is increased in the treated effluent. Another problem in developing counries can be that some parasitic species have shown resistance to low doses of chlorine ans the long-term effects of discharging dechlorinated compounds into the environment are unknown.

***Table 4: Chlorine dosage ranges according to wastewater* type (Rowe & Abdel-Magib, 1995)**

Type of wastewater	**Dosage ranges (mg/l)**
Raw	6 – 40
Primary effluent	5 – 24
Secondary effluent	2 – 9
Filtered effluent	1 – 6

3.2 Ultraviolet disinfection system

An Ultraviolet (UV) disinfection system transfers energy from a mercury arc lamp to an organism's genetic material. When UV radiation penetrates the cell wall of an organism, it destroys the cell's ability to reproduce. UV radiation, generated by an electrical discharge through mercury vapor, penetrates the genetic material of microorganisms and retards their ability to reproduce. The effectiveness of a UV disinfection system depends on the characteristics of the wastewater, the intensity of UV radiation, the amount of time the microorganisms are exposed to the radiation, and the reactor configuration. For any one treatment plant, disinfection success is directly related to the concentration of colloidal and particulate constituents in the wastewater.

The main components of a UV disinfection system are mercury arc lamps, a reactor, and ballasts. The source of UV radiation is either the low-pressure or medium-pressure mercury arc lamp with low or high intensities.

Physical methods include *ultraviolet rays* (UV), a more than 100 years old technique. The wastewater must flow through a chamber where it is exposed to UV light at a wavelength of 200 to 310 nm. The inactivation of the pathogens takes place due to the absorption of UV via proteins and the cells are damaged irreversibly.

The advantages (Cornel & Weber, 2004), no unwanted by-products, good efficiency, the technology is easy to combine with other treatment options.

As disadvantages are known: Lack of depository effect, possible regrowth of pathogens, the wastewater must be free of suspended solids, the fouling on protection pipes an lack of practicable dosage measurement.

A very important issue with UV treatment is the fact that the wastewater must be very well treated and nearly free of turbidity and suspended solids which can be realised by high efficient biological treatment, best followed by a sand filtration step.

3.3 Ozonation

Like chlorine, ozone is a strong oxidizing agent. The ozonation (or ozonization) of compounds in water is a complex process. The mechanisms are very complicated, the parameters are many, but the possibilities of developing cost-effective treatment schemes for drinking water and waste water are large.

The ozonation can be applied as an alternative way of water purification capable of being used instead of conventional chlorination, in combination with chlorine, hydrogen peroxide and other oxidizing agents, as well as together with ultra-violet irradiation, ultrasound, sand, adsorption and on-exchange filtration. It is becoming traditional to use ozone at the end of process. For effective disinfection to be possible ozone concentration should be brought to 0.4-1mg/l and sustained like this within 4 minutes (Chichirova 1999). Thanks to its floculating effect ozone can be used for water pretreatment for converting permeates into colloidal form with subsequent precipitation on filters.

The advantage of ozonization is in the fact that ozone, besides being disinfectant, is able to discolor, eliminate the smells and flavors of water and, in general, make it more tasty. Ozone does not change natural properties of water. Ozone came into use as a disinfectant of potable water earlier, than chlorine. But it has not found the same wide application for water treatment techniques in developing countries because of shortage of electric power, as well as because chemical and physical properties of ozone aqueous solution are not sufficiently known yet.

3.4 Filtration

Disinfection due to filtration is already applied in the field of drinking water and landfill leachate treatment. The different types of membrane filtration are listed in table 5.

Table 5 Membrane technologies in wastewater treatment (MUNLV, 2003)

Membrane process	**Phase separation**	**Driving power (Pressure difference)**	**Application (Separation performance)**
Microfiltration	liquid / solid	0.1 – 3 bar	Suspended solids
Ultrafiltration	liquid / liquid	0.5 – 10 bar	Macro molecules, Bacteria, Viruses
Nanofiltration	liquid / liquid	2 – 40 bar	Organic molecules
Revers osmosis	liquid / liquid	5 – 70 (120) bar	All ions and molecules

In wastewater treatment micro and ultrafiltration is mainly applied for separation of suspended solids, respective disinfection. A porosity of less than 0.2 µm (ultrafiltration) is required to remove pathogens totally (ATV 1998). Although viruses may be even smaller, they are also removed because they are located on particles.

Membranes can be used as a separate final step after biological treatment or as integrated unit in an intensive technology like activated sludge reactor. The possible applications within the activated sludge process are shown in figure 8.

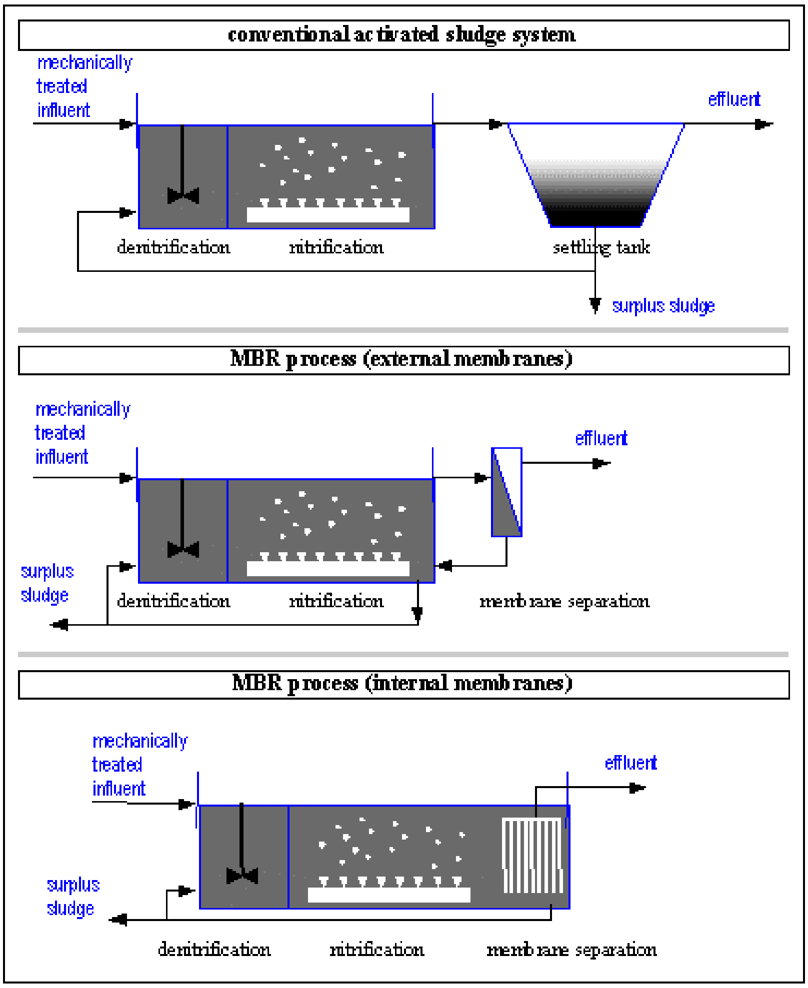

Figure 8: Implementation of membrane technologies in activated sludge systems

Firstly the filtration can be applied as last unit for tertiary treatment. Secondly the membrane bioreactor has been developed in the last years that is characterised by a combination of activated sludge process and membrane filtration. In this case, the filtration unit replaces the sedimentation unit. The activated sludge process can be operated with higher biomass concentrations than the conventional activated sludge process. Therefore the space needed for this technique is much smaller.

Advantages of filtration are the following:

- Pure physical treatment
- No chemical agents necessary
- No unwanted by-products
- Good efficiency
- Can be combined with activated sludge process (membrane bioreactor)

As disadvantages are known:

- High investment and running costs, especially energy demand
- Clogging due to fouling and biofouling on the membranes which requires the use of chemicals
- Membranes must be replaced from time to time

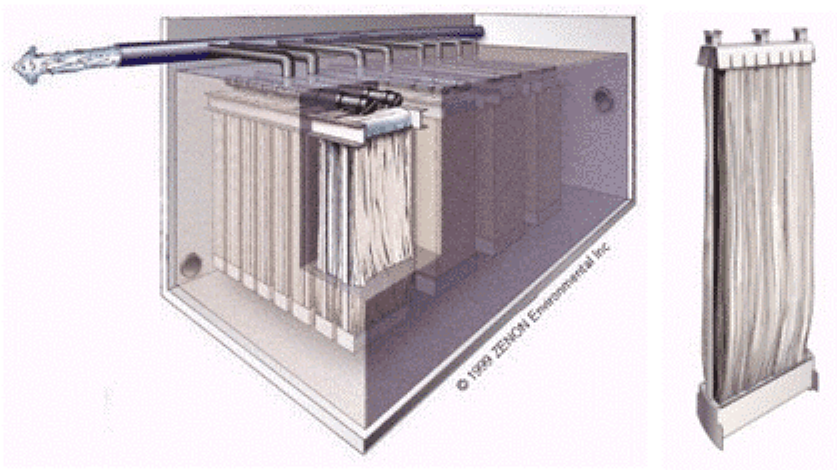

Figure 9: Membrane modules by Zeenon, Germany

Membranes represent a very promising technology that still needs development to cope with biofouling effects.

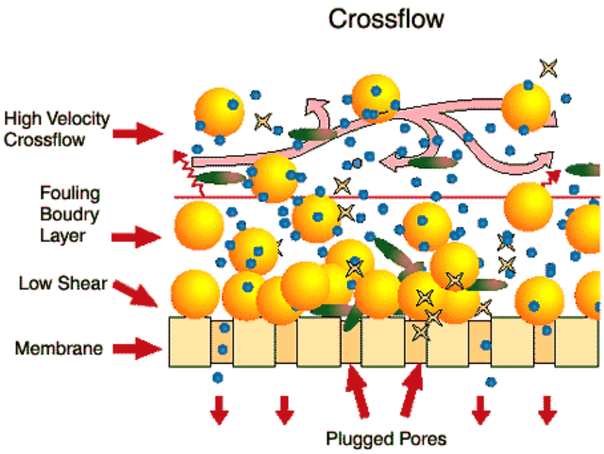

Figure 10: Cross flow filtration

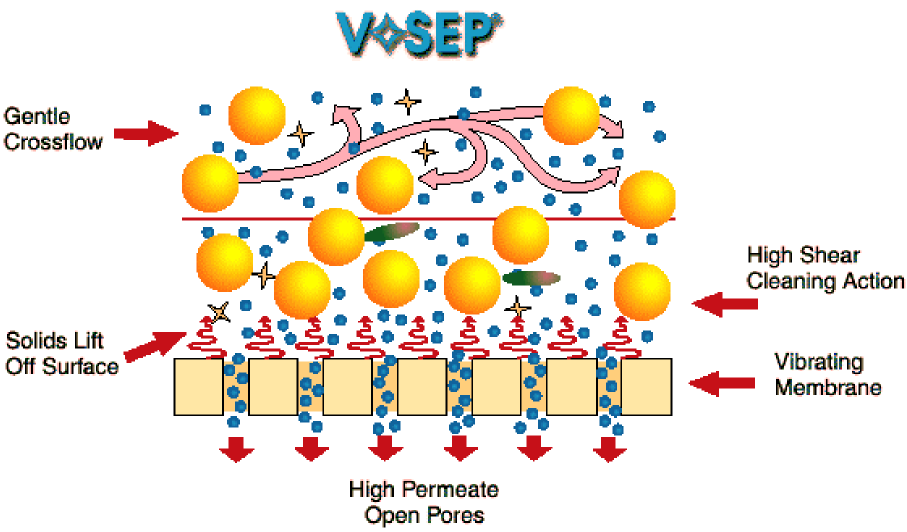

Figure 11: Vibrating membranes with cross flow filtration

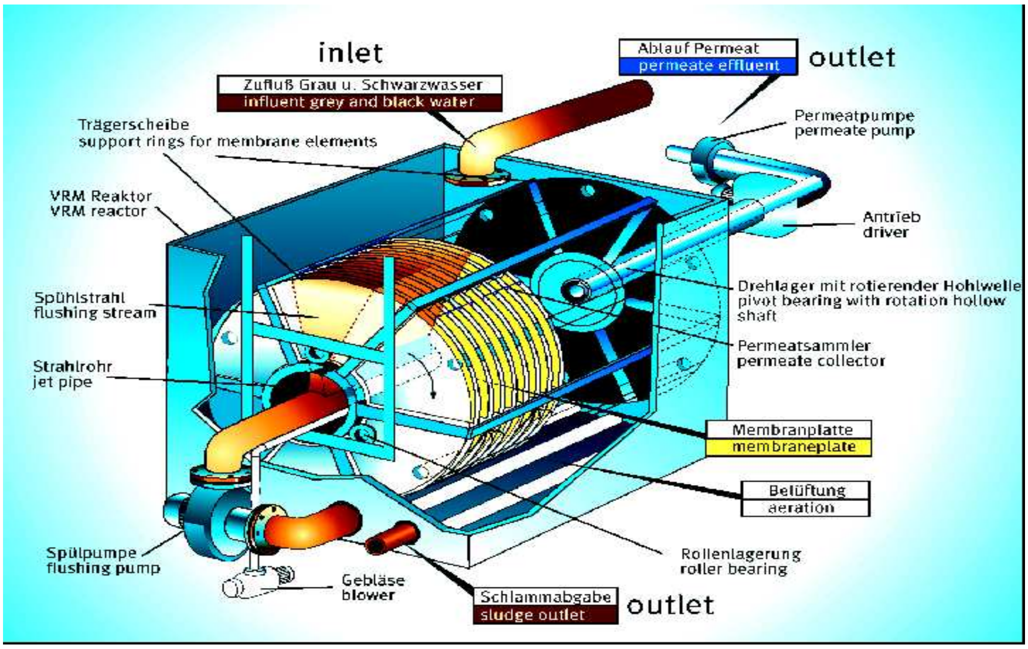

Figure 12: Vacuum rotation membrane by Huber, Germany

New technologies work with vibrating or rotating membranes to avoid fouling like shown in Figure 13 and 14.

Reverse osmosis is the best technology to produce clean water from wastewater since it removes even salts, heavy metals and pharmaceutical residues.

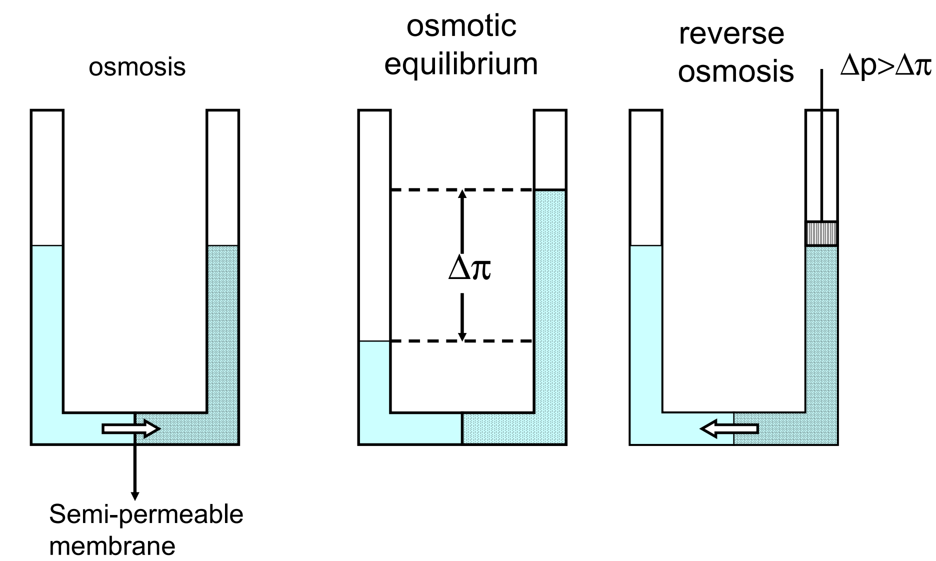

Figure 13: Principle of reverse osmosis

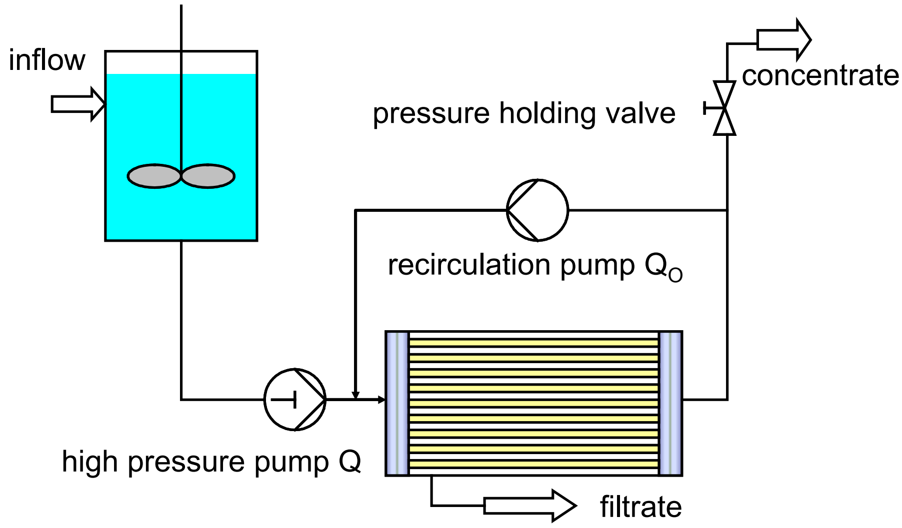

Figure 14: Treatment scheme of reverse osmosis

Like shown in Figure 14 a high driving power is needed for reverse osmosis, see also table 5. That is why it requires high energy costs. A practical example is presented in the next chapter.

4. Case studies

Many concepts for wastewater reuse are applied worldwide with different technologies and for different purposes. A good overview is given in van der Graaf et al (2005).
In this lesson two high tech water reuse plants are presented to illustrate the efficiency of water reuse.

4.1 Torreele Wastewater Treatment Plant, Belgium

In Torreele, a wastewater treatment plant with ultrafiltration as pre-treatment and reverse osmosis was realised in 2002 for aquifer recharge.

Problem
Seawater infiltration makes drinking water production difficult in the coastal area of Belgium. To combat this problem, The Belgian Intermunicipal Water Company of the Veurne Region (IWVA) wanted to design a plant that could produce water suitable for aquifer recharge.

Surface water is typically used to recharge the aquifers, but since these water sources tend to experience reduced flows during the summer months, an alternate supply of continuous high quality water was required to protect the aquifers from seawater infiltration and to reduce demand on potable surface water.

Solution
After extensive piloting, IWVA selected a system which included ZENON's ultrafiltration (UF) membranes in December 2000. This system's multi-barrier approach consisted of a ZeeWeed® system, followed by reverse osmosis (RO) and ultraviolet (UV) disinfection.

UF is the method of choice for RO pretreatment. When compared to conventional pretreatment, ZeeWeed® membranes remove suspended solids and colloidal material more reliably and with the use of fewer chemicals. The membrane is capable of handling solids spikes, and consistently produces an ideal RO feed typically yielding an SDI < 3. ZeeWeed® enables the RO system to operate with a higher sustainable flux, smaller system size, and lower cleaning frequency, thereby signifi cantly reducing operating and capital costs.

The new IWVA Station Torreele tertiary plant produces treated water equivalent to nearly 40 percent of the annual drinking water requirements for this area. The system also constantly meets the drinking water regulatory limits for parasites and salt.

Process Overview
The secondary effluent first passes through the headworks, consisting of a 1mm (0.04") mechanical screen. Once dosed with chlorine, the water is held in a reservoir, and then flows by gravity into the ZeeWeed® UF tanks. Filtration is achieved by drawing water to the inside of the membrane fiber using suction created by permeate pumps.

Permeate is then sent to an RO system, passes through a UV disinfection unit, and is pumped into the dune area. From there, the water seeps into the groundwater table over an open pond of approximately 2 hectares (20,000 m2).

The infiltration water is composed of 90 percent RO filtrate and 10 percent ZeeWeed® filtrate. This mixing is done to remineralize the RO filtration, so the salt content matches that of the natural dune water.

More information on http://www.iwva.be/docs/torreele_en.pdf.

4.2 NEWater, Singapore

In Singapore, 3 water reclamation plants were installed between 2002 and 2004 and they produce today a capacity of 92,000 m3/day for industrial use and groundwater recharge.

Problem
The primary objective of the initiative for the project NEWater was to determine the suitability of using treated wastewater as a source of raw water to supplement Singapore's water supply because of the increasing water demand and decreasing water resources in Singapore.

Solution and process overview
NEWater is the product from a multiple barrier water reclamation process. The first barrier is the conventional wastewater treatment process whereby the used water is treated to globally recognised standards in the Water Reclamation Plants.

The second barrier is the first stage of the NEWater production process known as Microfiltration (MF). In this process, the treated used water is passed through membranes to filter out and retained on the membrane surface suspended solids, colloidal particles, disease-causing bacteria, some viruses and protozoan cysts. The filtered water that goes through the membrane contains only dissolved salts and organic molecules.

The third barrier or the second stage of the NEWater production process is known as Reverse Osmosis (RO). In RO, a semi-permeable membrane is used. The semi-permeable membrane has very small pores which only allow very small molecules like water molecules to pass through. Consequently, undesirable contaminants such as bacteria, viruses, heavy metals, nitrate, chloride, sulphate, disinfection by-products, aromatic hydrocarbons, pesticides etc, cannot pass through the membrane. Hence, NEWater is RO water and is free from viruses and bacteria and contains very low levels of salts and organic matter.

At this stage, the water is already of a high grade water quality. The fourth barrier or third stage of the NEWater production process really acts as a further safety back-up to the RO. In this stage, ultraviolet or UV disinfection is used to ensure that all organisms are inactivated and the purity of the product water guaranteed.

With the addition of some alkaline chemicals to restore the acid-alkali or pH balance, the NEWater is now ready to be piped off to its wide range of applications.

Table 6: Water quality of NEWater in Singapore (http://www.pub.gov.sg/NEWater_files/newater_quality/index.html)

Water Quality Parameters	NEWater	USEPA /WHO Standards
A) Physical		
Turbidity (NTU)	<5	5 / 5
Colour (Hazen units)	<5	15 / 15
Conductivity (µS/cm)	<200	Not Specified(- / -)
pH Value	7.0 - 8.5	6.5-8.5 / -
Total Dissolved Solids (mg/L)	<100	500 / 1000
Total Organic Carbon (mg/L)	<0.5	- / -
Total Alkalinity (CaCO3) (mg/L)	<20	- / -
Total Hardness (CaCO3) (mg/L)	<20	Not available
B) Chemical (mg/l)		
Ammoniacal nitrogen (as N)	<1.0	- / 1.5
Chloride (Cl)	<20	250 / 250
Fluoride (F)	<0.5	4 / 1.5
Nitrate (NO3)	<15	- / -
Silica (SiO2)	<3	- / -
Sulphate (SO4)	<5	250 / 250
Residual Chlorine (Cl, Total)	<2	- / 5
Total Trihalomethanes (as mg/l)	<0.08	0.08 / -
C) Metals (mg/l)		
Aluminium	<0.1	0.05-0.2 / 0.2
Barium (Ba)	<0.1	2 / 0.7
Boron (B)	<0.5	- / 0.9
Calcium (Ca)	<20	- / -
Copper (Cu)	<0.05	1.3 / 2
Iron (Fe)	<0.04	0.3 / 0.3
Manganese (Mn)	<0.05	0.05 / 0.5
Sodium (Na)	<20	- / 200
Strontium (Sr)	<0.1	- / -
Zinc (Zn)	<0.1	5 / 3
D) Bacteriological		
Total Coliform Bacteria (Counts/100 ml)	Not detectable	Not detectable
Enterovirus	Not detectable	Not detectable

Please look for more information in

http://www.pub.gov.sg/NEWater_files/overview/index.html

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Impact of Wastewater Reuse on Plants

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Hamburg University of Technology

Important considerations

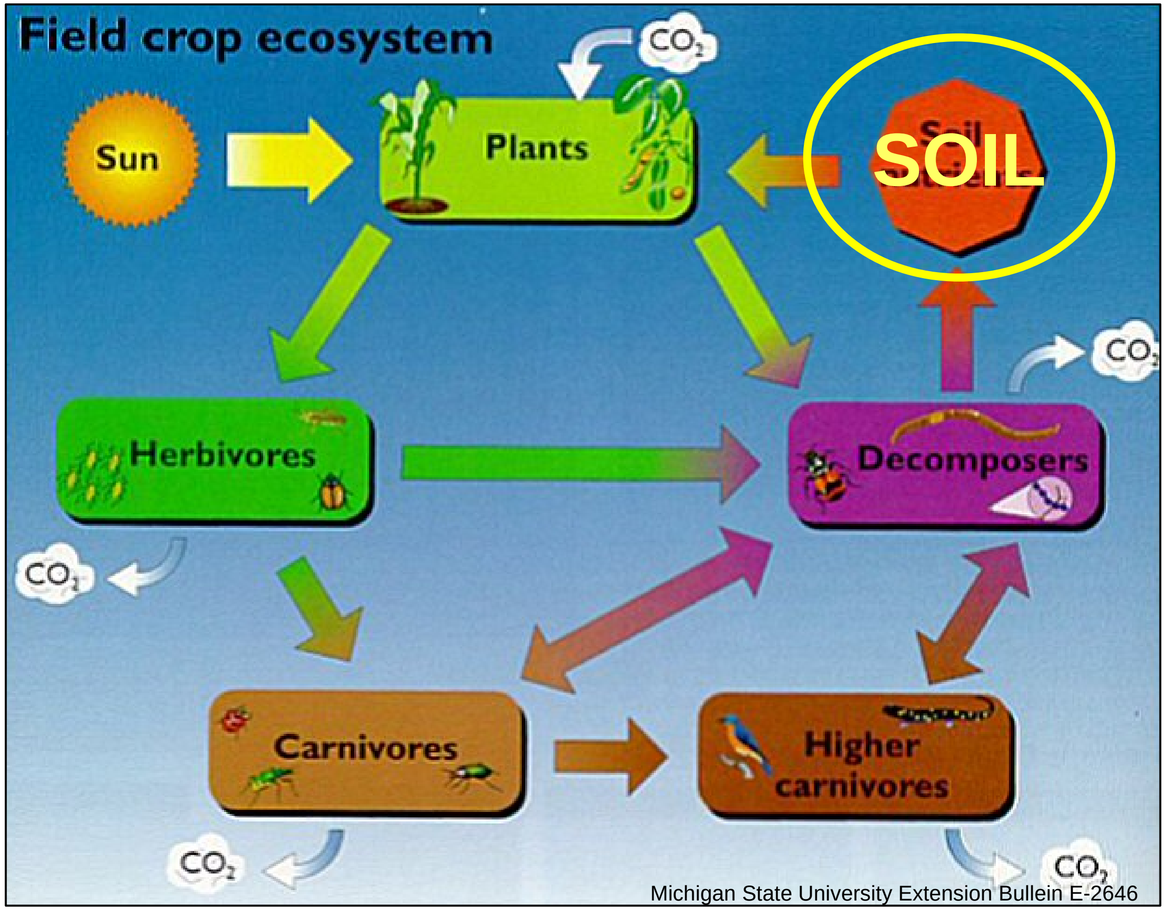
- Health aspects
- Socio-cultural acceptance & reluctance
- Legal aspects, institutional issues, restrictions on use
- Impact on plants, groundwater, environment, etc.
- Technology
- Economic aspects

Needs of Plants

- Soil
- Water
- Nutrients
- Gases (CO_2, O_2)
- Animals: microbial organisms
- Light

Ecosystem of agricultural fields

Plants are part of a complex ecosystem!



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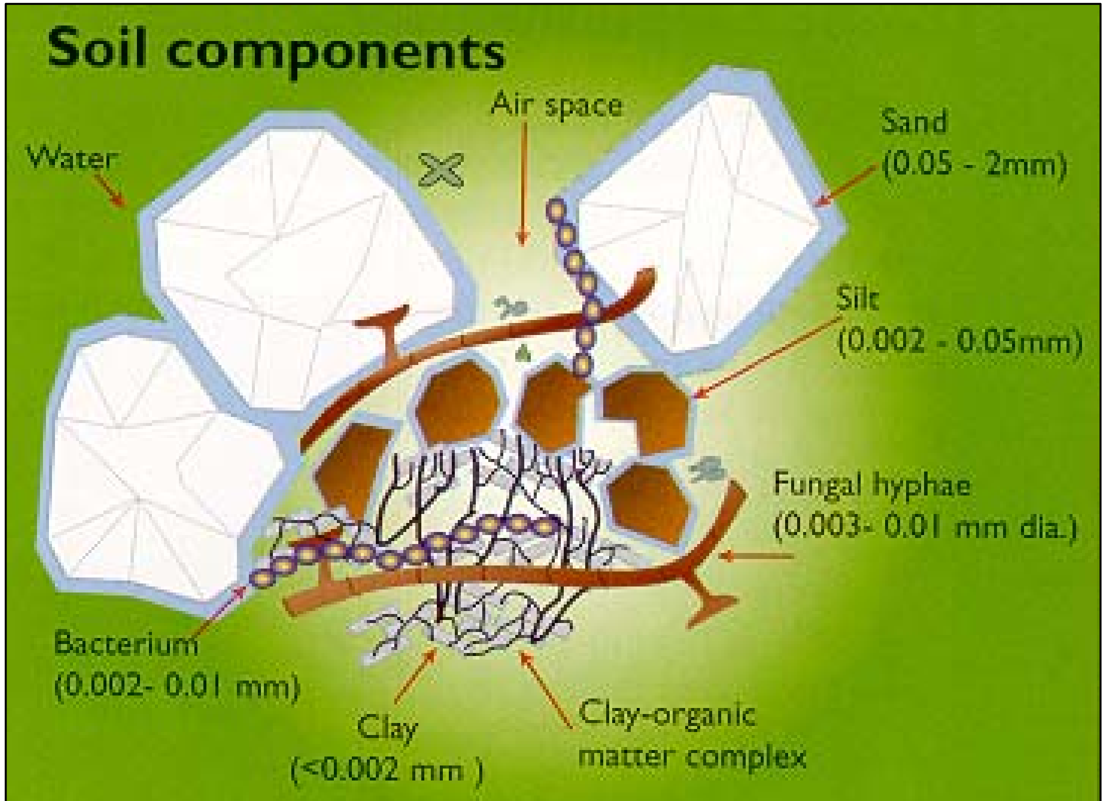
Subsystem: Soil



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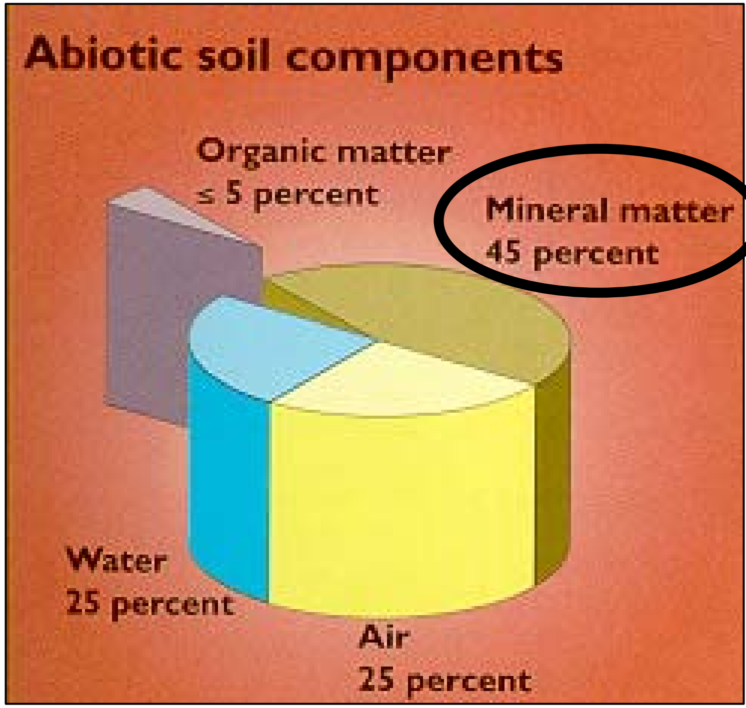
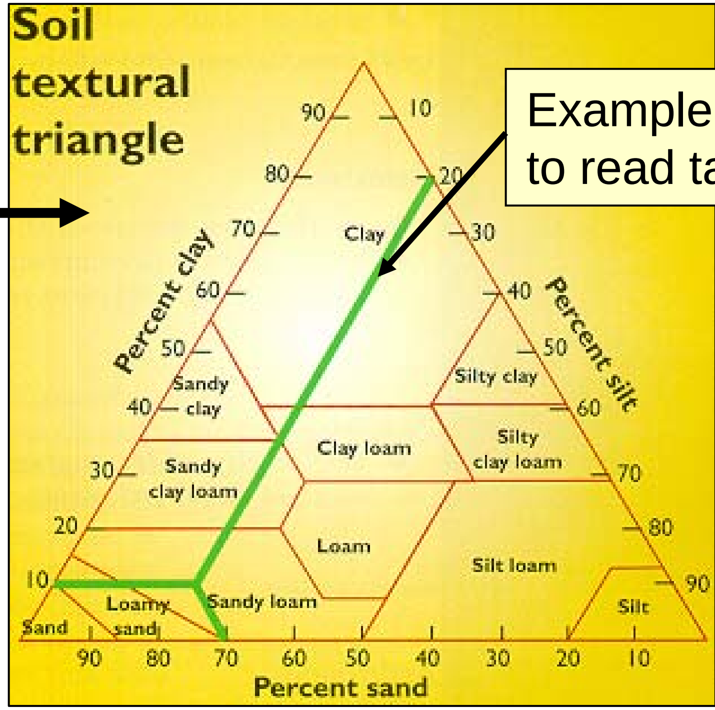
Components can be classified into:

- biotic
- abiotic

Subsystem: Soil

ABIOTIC





Example how to read table.

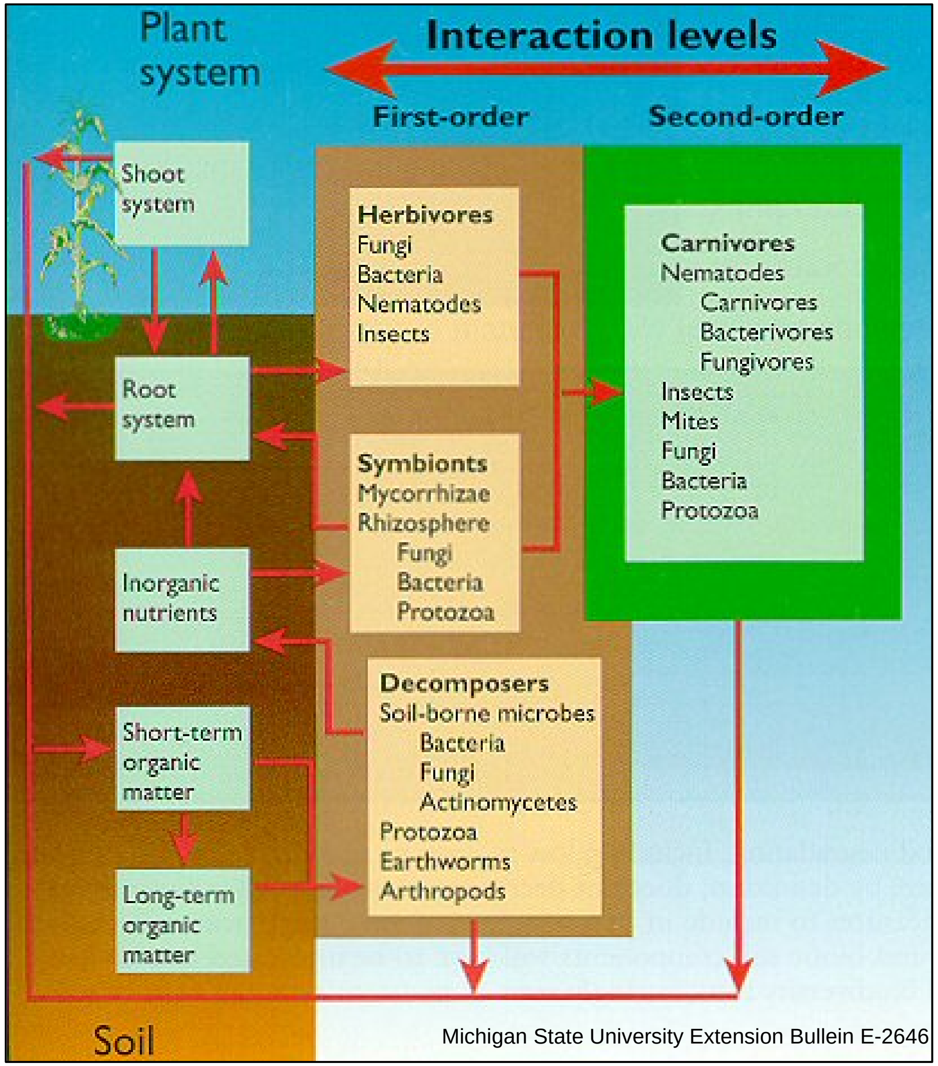
Michigan State University Extension Bullein E-2646

Subsystem: Soil

BIOTIC

- First order:
  - Herbivores
  - Symbionts
  - Decomposer
- Second order:
  - Carnivores

Soil-Plant Interactions



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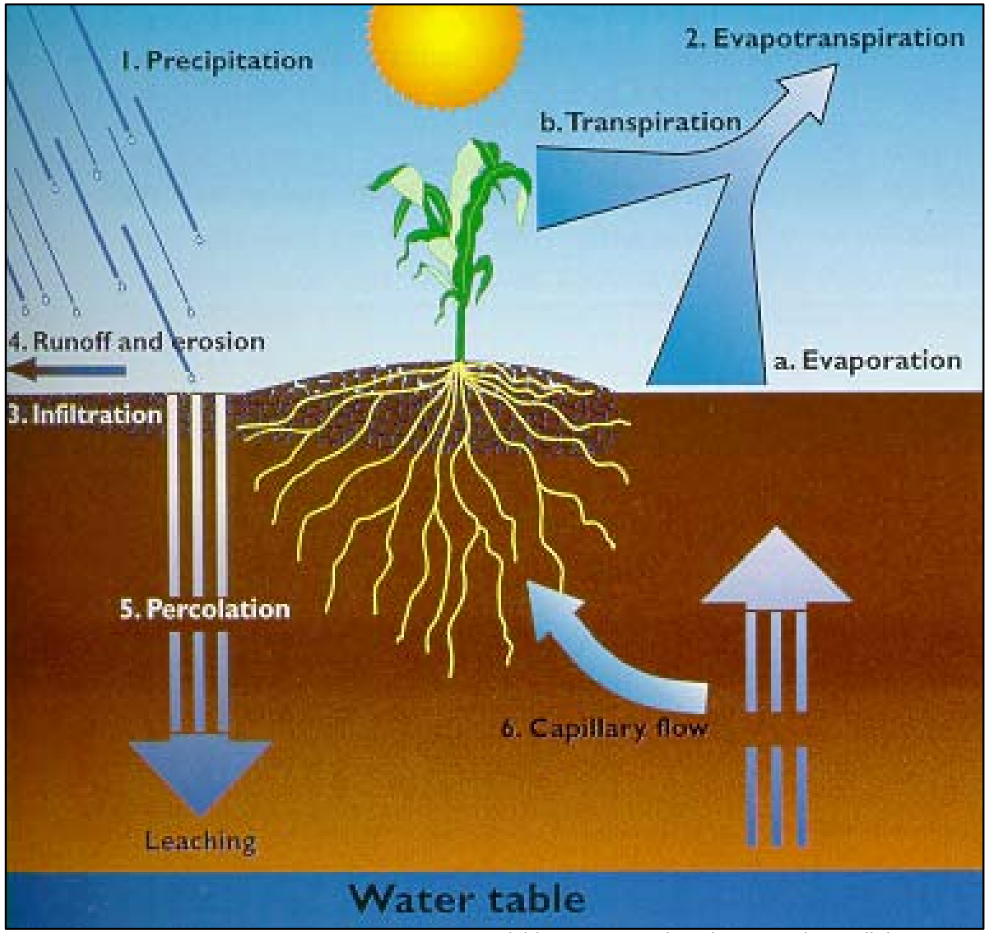
Subsystem: Water



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Nutrients

- Non-mineral nutrients:
  largest amount used, derived from CO_2 and H_2O
- Mineral nutrients:
  taken up from soil through roots:
  - Macronutrients
  - Micronutrients / trace elements

Nutrients

Plants need 16 essential nutrients:

- macro-nutrients

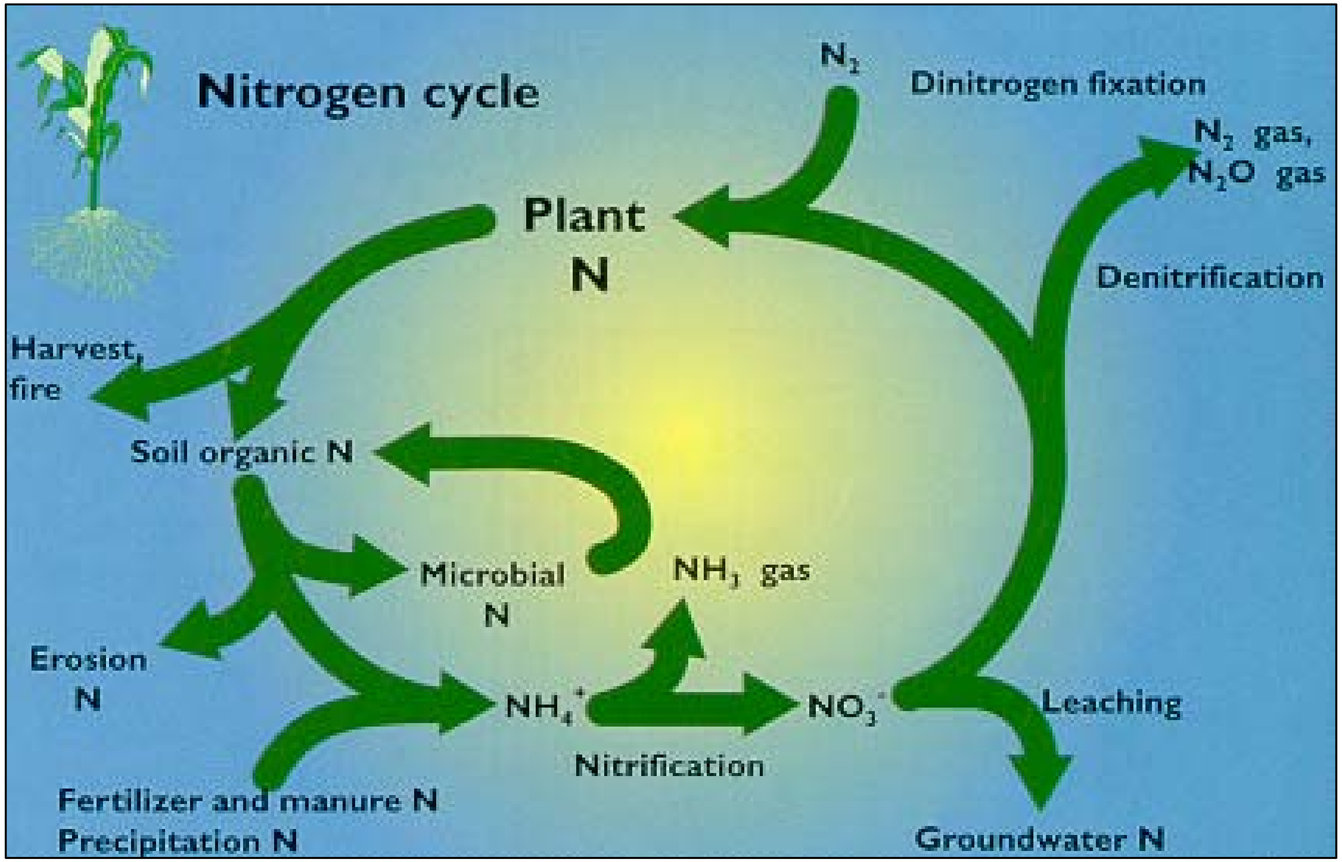
Most important to fertilise! **N P K**

Element:	Form of uptake:
H	Water (H_2O)
C	Carbon dioxide (CO_2), Hydrogen Carbonate (HCO_3^-)
O	Oxygen (O_2), Carbon dioxide (CO_2)
N	Nitrate (NO_3^-), Ammonia (NH_4^+), (NH_3, NO_x, N_2)
P	Phosphates ($H_2PO_4^-$, HPO_4^{2-})
S	Sulphate (SO_4^{2-}), (Sulphate dioxide (SO_2))
K	K^+
Mg	Mg^{2+}
Ca	Ca^{2+}

- micro-nutrients

Element:	Form of uptake:
B	Hydroboronoxides ($H_2BO_3^-$, ($B(OH)_4^-$), Boric acid (H_3BO_3))
Cl	Cl^-, (HCl)
Mn	Mn^{2+}
Fe	Fe^{2+}, Fe^{3+}
Cu	Cu^{2+}
Zn	Zn^{2+}
Mo	Molybdate (MoO_4^{2-})

Nitrogen



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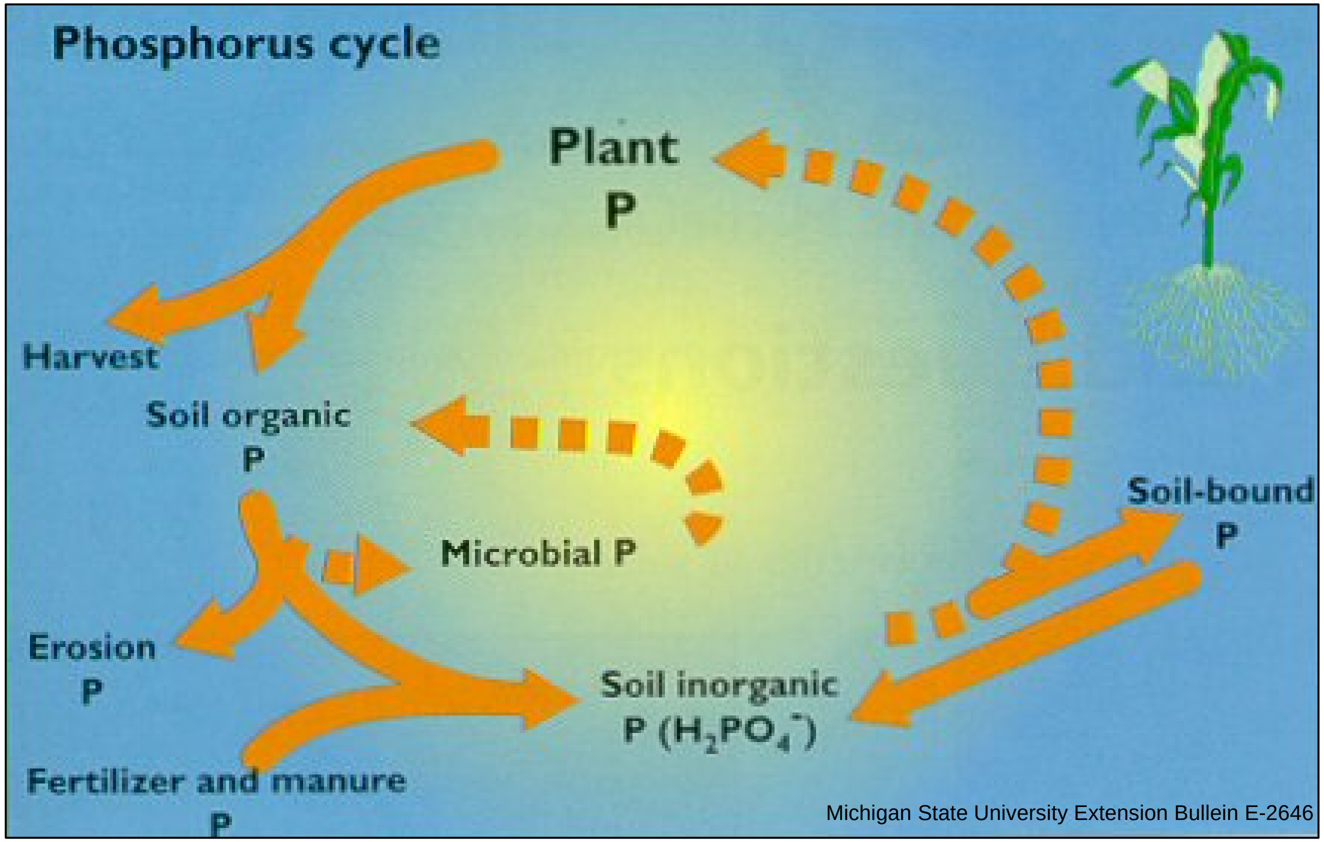
Phosphorus



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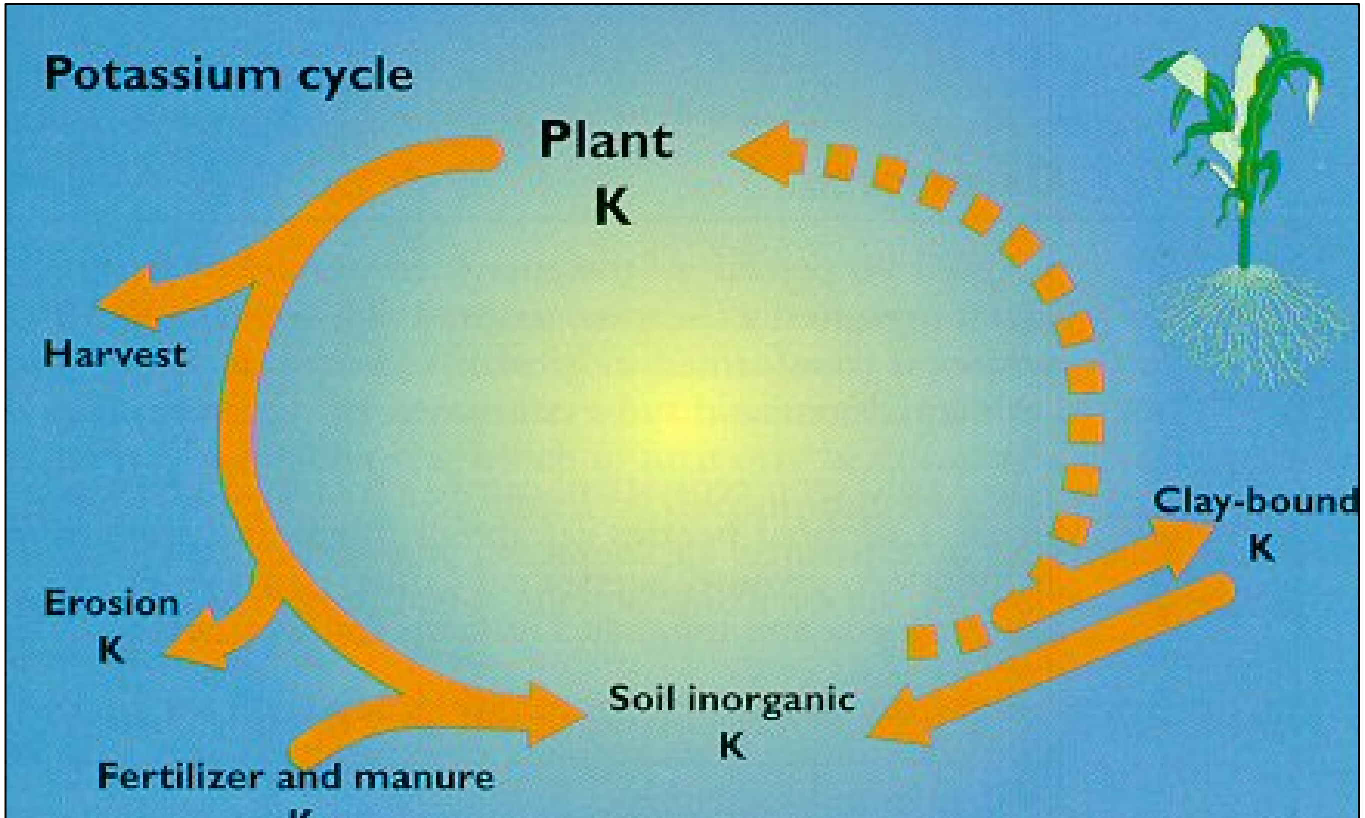
Potassium



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Needs covered by wastewater

- **Soil**
- **Water**
- **Nutrients**

Possible to cover with wastewater!

- Gases (CO_2, O_2)
- Animals: microbial organisms
- Light

Not covered but also not applied through humans.

Implementations

IMWI, 2004

Field irrigated with wastewater, Pakistan

IMWI, 2004

Watercourse carrying municipal effluents to fields near Haroonabad, Pakistan

Near East Region

- 14% of world area
- 10% of world population
- 3.5% of total precipitation
- 2.2% of annual internal renewable water resources

FAO, 2002

Deficiency level of renewable water resources is below 500m^3/capita*y.

Reuse in NER now

- Direct reuse
  - irrigation and fertilisation purposes in agriculture and landscape management
- Indirect reuse
  - recharge of groundwater aquifers (to control over-drafts and salt intrusion in coastal areas)

Situation NER

- WW treatment is seen as more and more important, in aspects of reuse as well
- Kuwait, Jordan, the Gulf States, Saudi Arabia, and Cyprus included ww as important water resource in their national strategies and action plans
- Large share of ww not treated
- Parts of it used uncontrolled (although for production of food crops eaten raw)

FAO, 2002

Situation NER

Country	WASTEWATER PRODUCTION (million m^3/y)		
	Produced wastewater	Treated wastewater	Reused wastewater
Cyprus	50	16	23
Iraq		425	
Jordan	300	69	58
Lebanon	350	4	2
Malta	32.8	9.3	6
Syria	825	550	550
Turkey	2840	100	50

FAO

Situation NER

Major limitations

- High costs for treatment and management of reclaimed water
- Unclear policies, institutional conflicts, lack of regulatory framework
- Additional training and capacity strengthening needed
- Sometimes limitations in man power

FAO, 2002

Fatwa

- ”Wastewater does not become pure by treatment or disinfection, while it becomes more than pure when it gets transfer from the liquid phase to the gaseous phase and back again to its liquidity status.”

Mufti of the Kingdom of Jordan (5/10/03)

- ”Reclaimed water can be used for ablution and drinking if it is sufficiently and appropriately treated to ensure good health.“

Council of Leading Islamic Scholars in Saudi Arabia (1978)

Fatwa

- ”Impure water could be purified by the modern filtering techniques that are the best and most efficient methods for purification. Therefore, this Council believes that such water will be totally pure and it may be used for ritual purification and drinking as long as there are no negative consequences on health. If drinking is to be avoided, it is merely for reasons of public health and safety, not due to any ramifications of Islamic law.”

Scholars Council of the Kingdom of Saudi Arabia States, 1978

Treatment

Degrees of conventional treatment:

- Preliminary: removal of coarse solids and other large fragments from raw wastewater.
- Primary: removal of settable organic & inorganic solids and floating materials.
- Secondary: removal of the residual organic and suspended solids.
- Tertiary and/or advanced: removals of specific constituents like nutrients and heavy metals. Disinfection is often used to reduce microbiological constituents.

Quality criteria for reuse

- Salinity
- Alkalinity (due to high Na concentrations)
- Specific ion toxicity (often Na, Cl, B)
- Trace metals / heavy metals
- Pathogens
- Nutrient content
- Others...

Salinity

Electrical Conductivity of irrigation water (dS/m and mg/l)*					
<2 **<1280**	**2-3** **1280-1920**	**3-4** **1920-2560**	**4-5** **2560-3200**	**5-7** **3200-4480**	**>7** **>4480**
Citrus, Apples, Peach, Grapes, Strawberry, Potato, Pepper, Carrot, Onion, Beans, Corn	Fig, Olives, Broccoli, Tomato, Cucumber, Cantaloupe, Watermelon, Spinach, Vetch, Sudan grass, Alfalfa	Sorghum, Groundnut, Rice, Beets, Tall fescue	Soybean, Date palm, Harding grass, Trefoil, Artichokes	Safflower, Wheat, Sugar beet, Rye grass, Barley grass, Bermuda grass, Sudax	Cotton, Barley, Wheat grass

*1dS/m = 640 mg/l

FAO, 2000

Salinity

To overcome the problem:

- Select crops with high tolerance
- Select salt tolerant crops with the ability to absorb high amounts of salts
- Irrigation system
- Scheduling of irrigation (amount and frequency are crucial)
- Leaching
- Soil polymers and/or other soil conditioners
- Drainage

Trace metals - Heavy metals

Essential trace metals for plants:

- Copper
- Manganese
- Molybdenum
- Nickel
- Zinc
- Iron

Trace metals - Heavy metals

Most important heavy metals regarding potential hazards and occurrence in contaminated soils:

- Arsenic
- Cadmium
- Copper
- Chromium
- Mercury
- Lead
- Zinc

Trace metals - Heavy metals

TRACE METAL = HEAVY METAL

Trace metals and heavy metals are often the same elements. It is just a **QUESTION OF AMOUNT** what they are for plants and the whole environment.

Trace metals - Heavy metals

"Question of amount" for plants depends of:

- Type of plant
- Growing stage
- Time of input
- Interval of inputs
- Used part
- etc.

Trace metals - heavy metals

Recommended limits for trace elements in reclaimed water use for irrigation:

Constituent	Long-term use (mg/l)[b]	Short-term use (mg/l)[c]
Arsenic	0.10	2.0
Cadmium	0.01	0.05
Copper	0.2	5.0
Iron	5.0	20.0
Lead	5.0	10.0
Manganese	0.2	10.0
Molybdenum	0.01	0.05
Nickel	0.2	2.0
Zinc	2.0	10.0

[a] For water used continuously on all soils

FAO, 2000

[b] For water used for a period of up to 20 years on fine - textured neutral or alkaline soils

TM/HM - Situation NER

In general, heavy metals and trace elements should not be considered as pressing or serious problem in NER for two main reasons:

- The concentration of heavy metals in municipal wastewater is low due to low heavy industry activities.
- The soils of NER have mostly high $CaCO_3$ rates and pH above 7, which inactivate the heavy metals and reduce their mobility and availability to crops. HM become unavailable.

TM/HM - Situation NER

Therefore:

- HM in treated wastewater under calcareous soil conditions is not considered as problem and no particular management is required.
- Under acid conditions (just few cases) HM could be a problem and measures are recommended.

TM/HM - Situation NER

Recommended measures:

- Liming (use of calcium carbonate). In this way soil pH is increased and thus solubility of HMs is reduced.
- Avoid using acid fertilizers.
- Select crops tolerant to certain HMs.
- Select crops having no bio-magnification characteristics → accumulation of certain heavy metals by specific crops and/or parts of the crop.

Link: ww - plants

Nutrient contents

	Total N	P	K
Faeces	5-7	3-5.4	1-2.5
Urine	15-19	2.5-5	3-4.5
Nightsoil	10.4-13	2.7-5	2-3.5
Cow manure	0.3-2	0.1-0.7	0.3-1.2
Pig manure	4-6	3-4	2-3
Plant residues	1-11	0.5-2.8	1-11

IMT, NLH

Pathogens of main concern

- Bacteria: Coliforms: Echerichia, Balmonella, Klebsiella, Enterococcus, Citrobacter
- Virus: Poliovirus, Hapatitis A and E, Norwalk virus, Rotavirus, Echovirus
- Protozoa: Cryptosporidium parvum, Giardia lamblia, Entamoeba histolytica, Cyclospora cayetanensis, Gnathostoma spinigerum

Pathogens

This leads to the following illnesses:

- Hepatitis
- Typhoid
- Dysentery
- Cholera
- Cryptosporidiosis
- Giardiasis
- Malnutrition
- Death...

Pathogen removal during sewage treatment

		Enteric virus	Salmonella	Giardia	Cryptosporidium
Concentration in raw sewerage*		10^5-10^6	10^3-10^5	10^4-10^5	10^2-10^5
Infectious dose*		1-10^1	10^1-10^8	< 20	1-10^1
Primary treatment[a]	% removal	50-98.3	95.8-99.8	27-64	0.7
	No. remaining/l	1700-500000	160-3360	72000-146000	
Secondary treatment[b]	% removal	53-99.92	98.65-99.996	45-96.7	
	No. remaining/l	80-470000	3-1075	6480-109500	
Secondary treatment[c]	% removal	99.983-99.9999998	99.99-99.999999995	98.5-99.99995	2.7[d]
	No. remaining/l	0.007-170	0.000004-7	0.099-2.951	

* number per litre.

[a] Primary sedimentation and disinfection.

[b] Primary sedimentation, trickling filter or activated sludge, and disinfection.

[c] Primary sedimentation, trickling filter or activated sludge, disinfection, coagulation, filtration, and disinfection.

[d] Filtration only.

Data from Crook (1998), Yates (1994), Robertson et al. (1995), Enriquez et al. (1995), Modore et al. (1987), Feachem et al. (1983)

Pathogen removal

Two main steps:

- Come into contact with surfaces
- Interact with those surfaces

Pathogen removal

Come into contact with surfaces through:

- Diffusion:< 2 microns
- Sedimentation: 2-10 microns
- Physical straining: > 10 microns

Pathogen removal

Interact with those surfaces:

- Sorption: Bonding-ionic/covalent, precipitation-hydroxyl formation, bridging-biopolymers, polysaccharides, etc.
- Coagulation: Electrostatic forces, Van der Waals forces, hydrophobic forces

Pathogen survival

Type of Pathogen	Survival time in days			
	In faeces, nightsoil and sludge	In fresh water and sewage	In the soil	On crops
Viruses *Enteroviruses*	< 100 (< 20)	< 120 (< 50)	< 100 (<20)	< 60 (<15)
Bacteria Faecal Coliforms	< 90 (<50)	< 60(< 30)	< 70 (< 20)	< 30 (< 15)
Salmonella spp.	< 60 (< 30)	< 60 (< 30)	< 70 (< 20)	< 30 (<15)
Shigella spp.	< 30 (<10)	< 30 (< 10)	-	< 10 (< 5)
Vibrio cholerae	< 30 (< 5)	< 30 (< 10)	< 20 (< 10)	< 5 (< 2)
Protozoa *Entamoeba histolytica cysts*	< 30 (< 15)	< 30 (< 15)	< 20 (< 10)	< 10 (< 2)
Helminths *Ascaris lumbricoides eggs*	Many months	Many months	Many months	< 60 (< 30)

Figures in brackets show the usual survival time.

Mara and Cairncross, 1988

Nutrients

- Suspended solids,
- Colloidal solids,
- Dissolved solids:

1. Are present in wastewater
2. Contain macro- and micro-nutrients, which are essential for crop nutrition.

Nutrients

One problem can be that the nutrient content of ww exceeds plant needs and thus:

- pose a potential source for groundwater pollution.
- cause excessive vegetative growth.
- plants mature delayed or uneven.
- reduce quality of the irrigated crops.

Calculation of nutrients present in the treated effluent as part of the overall fertilisation program is necessary.

In this respect wastewater analysis is required at least once at the beginning of the growing season.

Nutrients

Fertilisation potential through wastewater:

	N	P	K
Nutrient concentration (mg/l)	40	10	30
Yearly nutrients (kg/ha) added through application of 10000m^3 water/ha	400	100	300

FAO, 2000

These application rates supply sufficient or even more of N required by agricultural crops and also most of P and K.

Nutrient uptake

Fertiliser uptake in % as influenced by the irrigation system:

Irrigation system*	Nitrogen	Phosphorus	Potassium
Furrow	40 – 60	10 – 20	60 – 75
Sprinkler	60 – 70	15 – 25	70 – 80
Microirrigation	75 - 85	25 - 35	80 - 90

*The values refer to good designed and operated irrigation systems

FAO, RNEA, 1992

Nutrient uptake

Nutrients required by selected crops for canopy formation and fruit production

Crop	N	P	K	P_2O_5	K_2O
Tomato					
Canopy (kg/ha)	95	12	108	27	130
Fruits (kg/ton)	1.80	0.17	3.13	0.38	3.75
Eggplant					
Canopy (kg/ha)	105	13	113	30	135
Fruits (kg/ton)	1.96	0.17	3.2	0.40	3.8
Lettuce (kg/ha)	115	14	160	32	192
Banana					
Canopy (kg/ha)	250	26	800	60	1000
Fruits (kg/ton)	2.0	0.22	5.0	0.5	6.0
Citrus					
Canopy (kg/ha)	85	8	90	18	108
Fruits (kg/ton)	1.44	0.19	1.53	0.44	1.84

FAO, Papadopoulos, 2000

Others

- Clogging of sprinkler, mini-sprinkler and drip irrigation systems. The most serious problems occur with drip systems. Filtration is required → more attendance needed!
- Plugging through slimes, bacteria, algae, and suspended solids etc. in the sprinkler head, emitter orifice or supply line.

Biological quality criteria

This criteria is generally expressed in the guidelines of WHO (World Health Organisation).

The WHO divides into 3 categories of different reuse conditions:

- A: Irrigation of crops likely to be eaten uncooked, sports fields, public parks.
- B: Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees.
- C: Localised irrigation of crops in category B if exposure of workers and the public does not occur.

Biological quality criteria

Category	Person / group exposed	Nematodes (eggs/kg)	Fecal coliforms (No/100g)
A	Workers, Consumers, Public	≤ 1	≤ 1000
B	Workers	≤ 1	No standard recommended.
C	None	Not relevant.	Not relevant.

WHO, 1989

WHO guidelines

- need right balance between maximising public health benefits and still allowing for the beneficial use of scarce resources
- need to be adapted to the local social, economic and environmental conditions
- should be co-implemented with other health interventions: hygiene promotion, provision of adequate drinking water and sanitation, other primary health-care measures

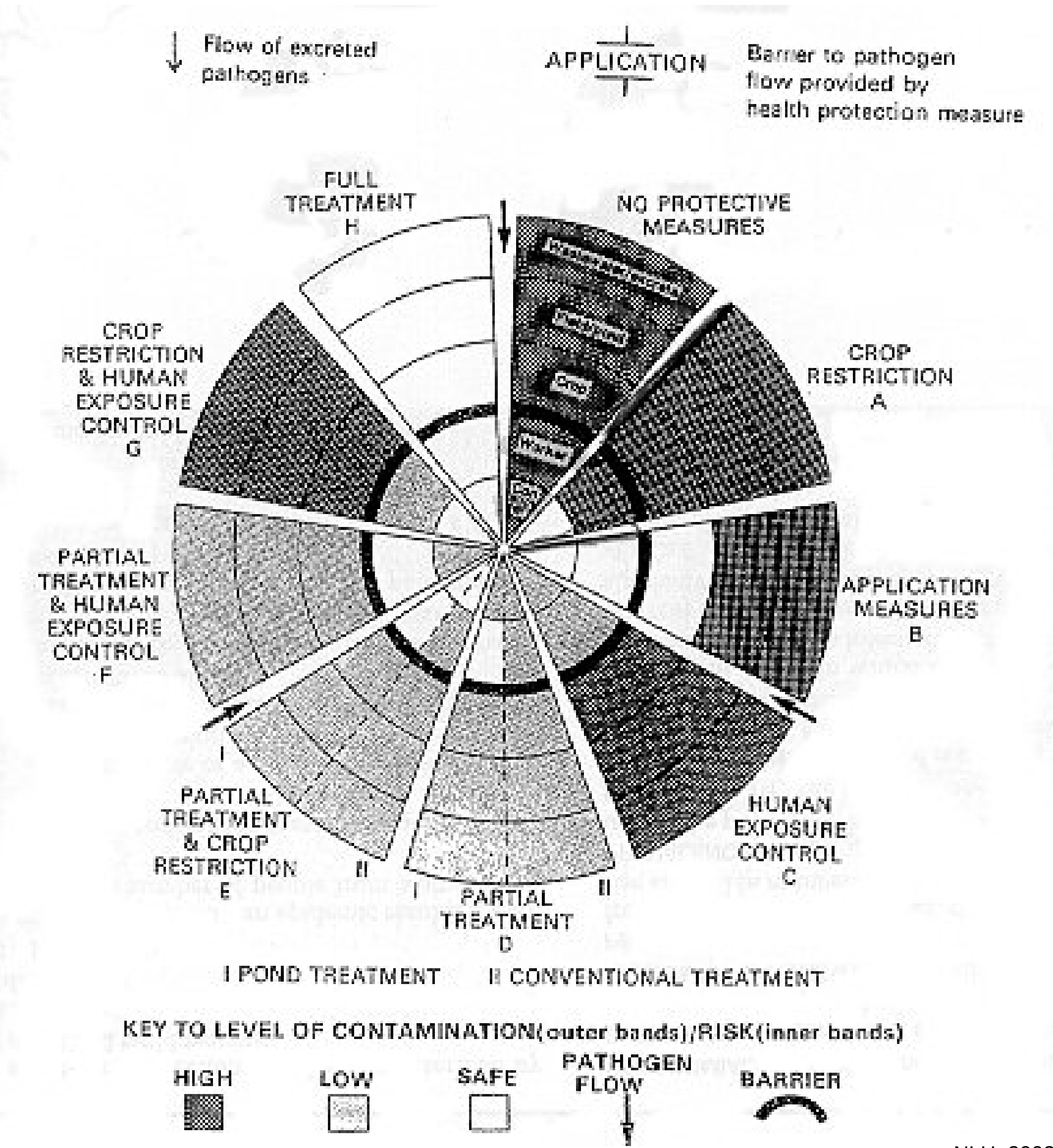
WHO guidelines

- Were published in 1989.
- Are currently under revision with expected publication in 2004.
  - 2nd edition, Vol. 1 and 2
  - technical report, 2nd edition
- Online available: http://www.who.int/water_sanitation_health/wastewater/en/
  - Executive summary of the 1989 guidelines
  - Analysis of wastewater for use in agriculture
- Full guidelines can be ordered via WHO homepage.

Risk assess-ment

Explanation circles (out → in):

- wastewater/excreta
- field/pond
- crop
- worker
- consumer



NLH, 2003

Risk assessment

IMWI, 2004

Wastewater pumping station near Hanoi

People bathing and washing in the Ganges, India.

Earth Island Institute, 2004

IMWI, 2004

A farmer wades through a homemade diversion canal, which carries wastewater to his fields, Pakistan

Risk assessment

Differentiation between actual and potential risks!

An actual risk only exists, when all of these conditions are fulfilled:

- Either an infectious dose exists or pathogens multiplies to this dose.
- The infective dose reaches the human host.
- The host becomes infected.
- The infection causes disease or further transmission.

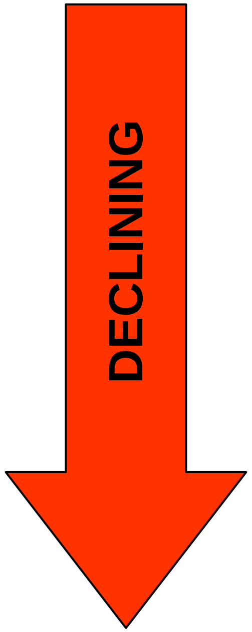
Risk assessment

Risk assessment process:

- 1. Hazard identification
- 2. Exposure assessment
- 3. Dose-Response assessment
- 4. Risk characterisation

Risk

Declining potential to transmit pathogens irrespectively of irrigation method and wastewater quality used:



Vegetables eaten raw

Vegetables eaten cooked

Ornamentals raised for sale

Trees producing fruits (eaten raw without peeling)

Lawns in amenity areas of unlimited access to public

Trees producing fruits eaten raw after peeling

Table grapes

Lawns and other trees in amenity areas of limited access

Fodder crops

Trees producing nuts and other similar trees

Industrial crops

Irrigation systems

1. Surface methods → traditional

- Flood irrigation (by border or basin), wetting almost all the land surface
- Hose-basin irrigation. The water is delivered by hose
- Furrow irrigation, wetting only part of the ground surface.

Irrigation

USGS, 2004

Traditional spray irrigation

Farmland in USA being irrigated by a large spray-irrigation system

USGS, 2004

Irrigation systems

2. Pressurised irrigation methods

- Sprinklers: sprinklers of high capacity, ordinary mini-sprinklers, and sprayers.
- Drip: point or localised irrigation system.
- Subsurface irrigation: yet used with wastewater, may provide the best health protection.
- Bubbler irrigation: localised irrigation technique with regulated flow.

Irrigation

Aquatechnik, 2004

Sprinkler

Aquatechnik, 2004

Drip

Microsprinkler implemented for vegetables

Hammer, 2003

Irrigation systems

Factors influencing choice of system:

- Foliar wetting and consequent leaf damage resulting in poor yield
- Salt accumulation in the root zone with repeated applications
- Ability to maintain high soil-water potential
- Suitability to handle brackish water without significant yield loss
- Economic aspects (investment costs, running costs...)
- Maintenance and operation
- etc.

Irrigation systems

Due to the facts mentioned, to stay within the WHO guidelines, and to keep risks low:

Not every crop can be irrigated with every irrigation system
(and every type of wastewater)!

Irrigation of fruit trees

Before and after

Guayaba plantation in Cuba.

Irrigation of flowers

Hammer, 2003

Hammer, 2003

Hammer, 2003

Control measures

- Wastewater reuse guidelines
  - national
  - WHO
  - Fatwa for reclaimed water
- Monitoring and control of wastewater quality
- Control of storage, transport, and distribution facilities
- Control of crops
- Control of workers

EFFICIENT MANAGEMENT OF WASTEWATER

Lesson D3

ECONOMIC INSTRUMENTS IN WASTEWATER MANAGEMENT

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Keywords
Cost Recovery, Demand Side Management, Polluter Pays Principle, Pollution Charges, Subsidies, Tariff Systems, Water Pricing

Table of content

Overview and summary

Economic instruments, such as water tariffs or pollution charges, are an important complement to technical, regulatory, and institutional tools to achieve a sustainable and efficient management of wastewater. Economic instruments use market-based, mostly monetary, measures with the objective to raise revenue to help finance wastewater services, to provide incentives to use water efficiently and carefully, to provide disincentives for the anti-social release of polluted wastewater, to make the polluter pay for the environmental damage done, and to raise awareness on the environmental and societal costs of water use and wastewater discharge. The most common economic instruments used in wastewater management are the pricing of wastewater services and levying of charges for wastewater discharge into the environment. In this lesson, different economic instruments used in wastewater management will be presented. Special emphasis will be given to the various tariff structures that are used to levy wastewater service fees. Tariffs determine the level of revenues that service providers receive from users. They are designed for different purposes, and often contain some elements to address poverty.

1. Introduction

In order to be sustainable, wastewater management does not only have to provide for the protection of human health and environmental, but also has to do this in a manner that is economically and socially feasible in the long-term. Economic instruments, such as service fees and effluent charges can complement the use of institutional, regulatory, and technical tools to foster sustainability in wastewater management.

A basic principle of economic instruments used in environmental management is the "polluter pays principle". This principle states that anyone whose actions pollute or adversely affect the environment should pay the cost for remedial action. Consequently, activities which are less damaging will incur a lesser cost, and therefore be more economically justifiable. Linked with this principle is also the demand for full recovery of the costs linked to the provision of sanitation services and wastewater management through water users and wastewater dischargers. As explained in lesson D1 supply of wastewater management services is linked with a variety of costs. These costs include investment costs as well as operation and maintenance costs for wastewater treatment facilities and sewerage networks. Furthermore, costs accrue from pollution of surface waters in consequence of discharge of treated (or untreated) wastewater.

The use of economic instruments can help to cover the costs related to wastewater management and provide incentives for the pollution prevention. The following chapter provides an overview on economic instruments used in wastewater management and focuses on the different options for wastewater service fees.

2. Economic instruments in wastewater management

2.1 Objectives

2.1.1 Raise revenues and recover costs

The most obvious reason for using economic instruments, such as wastewater service fees or effluent charges, in wastewater management is the aim to raise revenue for financing service infrastructure or remedial actions for environmental damage. For recovery of costs of sanitation services, the polluter pays principle requires that not only the investment and operational costs of a treatment plant have to be covered, but also the costs that arise from the environmental damage linked with discharge of (treated) wastewater into surface waters.

2.1.2 Set incentives for water conservation and pollution prevention

Another objective of economic instruments is to provide an economic incentive for water users to use water carefully, efficiently, and safely in order to save water resources and prevent pollution. If discharge of wastewater into the sewerage system or the environment is linked with increasing wastewater bills, people might change their behaviour or industrial processes in order to produce less wastewater to save costs. Economic instruments can therefore contribute significantly to demand side management in water management.

2.1.3 Awareness raising and economic efficiency

Economic instruments can also be introduced in order to raise awareness on the relationship between water use and resulting environmental and/or social impacts. In order to attain economic efficiency, prices for wastewater discharge would have to reflect to consumers all the financial, environmental, and other costs that their decision to use water (and produce wastewater) imposes on the rest of the system and the economy.

2.2 Mechanisms

Various economic instruments are being applied in wastewater management with the aim to pursue one or more of the above mentioned objectives:

***Pollution charges*:** In many countries charges are imposed for discharge of treated and untreated wastewater into the environment. These charges are mostly levied upon discharge of effluents from treatment plants and industry.

Fees for wastewater services / user charges: Fees or user charges are directly charged to users of wastewater services upon connection to and discharge of wastewater into the sewerage system. For households, volume of discharged wastewater is directly related to the consumption of potable water. Consequently, the fee is usually collected as a surcharge on the water consumption bill. Different regulations could be considered if large amounts of potable water are used for other purposes like irrigating the garden.

As user charges and effluent charges are the most common economic instruments used in wastewater management, these will be further explained in the following chapters. Other economic instruments in wastewater management include:

Indirect local taxes: Local governments may impose indirect taxes to generate revenue directly for the financing of wastewater systems. For example, authorities may recover sewerage investments through surcharges on property taxes. In general, these are levied only on properties with access to the sewer system, in which case the surcharge is actually a variant of the user charge. The limitation of this surcharge is that it depends on the performance of the property tax system, which is usually not (well) developed in low-income countries. In many countries, the money collected from wastewater discharge is not always earmarked for water infrastructure. It normally goes in to the national treasury, and then may be used for other services.

Discharge permits: Discharge permits may also be a tool for controlling pollution and raising revenue. In this approach, a responsible authority sets maximum limits on the total allowable emissions of a pollutant to a sewer or to the surface water. According to this limit discharge permits are issued. In the discharge permit, the charges or levies can be incorporated for cost recovery purposes. Tradable discharge permits can give polluters more flexibility in investment and operation of wastewater management systems.

3. Pollution charges

According to the polluter pays principle, wastewater dischargers should be charged for the environmental and social costs that result from disposing wastewater - such as downstream impacts of sewage discharges. Therefore, pollution charges are often levied by local or national governments on the discharge of water into the environment, i.e. mostly into surface waters. They are usually imposed on operators of treatment plants and industrial dischargers. The charges are generally calculated based on actual quantities and/or pollution loads of the effluent. There is a variety of charging systems into place to determine the pollution charges on wastewater discharge. For treatment plants the pollution charge is often calculated based on the number of inhabitants served by the plant. Further on, charges are calculated based on specific chemical, biological and biochemical parameters determining the pollution load, such as content of phosphorus, nitrogen, biological oxygen demand, heavy metals, etc. Pollution charges are therefore of special interests for industries who discharge wastewater of high pollution loads into sewer systems or directly into nature. High pollution charges will encourage reduction in effluents produced or in-house treatment by industry.

3.1 Pollution Charges in Germany

In Germany, for example, the Effluent Charges Act (Abwasserabgabengesetz, AbwAG) serves to implement the polluter pays principle. Corresponding to the Act, dischargers of wastewater must bear at least a portion of the cost of using the environmental resource water by paying for the point source discharge of (treated) wastewater into a water body. Generally, the payment of effluent charges in no way exempts one from the responsibility of treating wastewater. The charge is calculated according to the amount and harmfulness of the discharged substances, measured in pollution units (Schadeinheiten SE) and is intended to create financial incentives for reducing waste water emissions as far as possible. The effluent charge is paid to the states and these funds are tied to measures for conserving water bodies. The charge per pollutant unit per year has been raised, in several steps, from DM 12 (ca. EUR 6) in 1981 to DM 70 (ca. EUR 35) since January 1, 1997. The table below gives an overview on how pollution units are calculated.

Table 1: Contaminants and pollution units (Schadeinheit, SE)* according to the Effluent Charges Act (AbWAG)

Rated contaminants and contaminant groups	Measurements constituting one pollution unit
Oxidizable substances in chemical oxygen demand (COD)	50 Kilograms Oxygen
Phosphorus	3 Kilograms
Nitrogen	25 Kilograms
Halogen compounds as adsorbable organic halogen compounds (AOX)	2 Kilograms Halogen as organic chlorine
Metals and their compounds:	*In grams metal:*
Mercury	20 grams
Cadmium	100 grams
Chromium	500 grams
Nickel	500 grams
Lead	500 grams
Copper	1000 grams
Toxicity to fish	3000 cubic meters of wastewater divided by the dilution factor GF, by which wastewater is no longer toxic to fish

** "One SE corresponds roughly to the harm caused by the raw waste water produced by one inhabitant in one year (inhabitant equivalence)."*

4. Pricing of wastewater services

Utility services of all types have been, and continue to be, subsidised in many parts of the world. But experience shows that widespread subsidies lead to overuse of water resources, discharge of contaminated wastewater, and subsequent environmental problems. User fees that recover the cost of delivering services, such as wastewater treatment, are an essential part of the solution to this problem. It is generally agreed and widely accepted that users should, in most cases, pay for recurring operation and maintenance costs, while there are varying opinions about whether users should pay for capital costs, too, and if so, what percentage is reasonable, and how might it be paid (cash, sweat equity, smaller payments over time coinciding with crop or livestock market season, etc.). However, full cost recovery from water (see figure 1) users is not feasible or even desirable in all situations, for example for wastewater systems where the majority of users are poor.

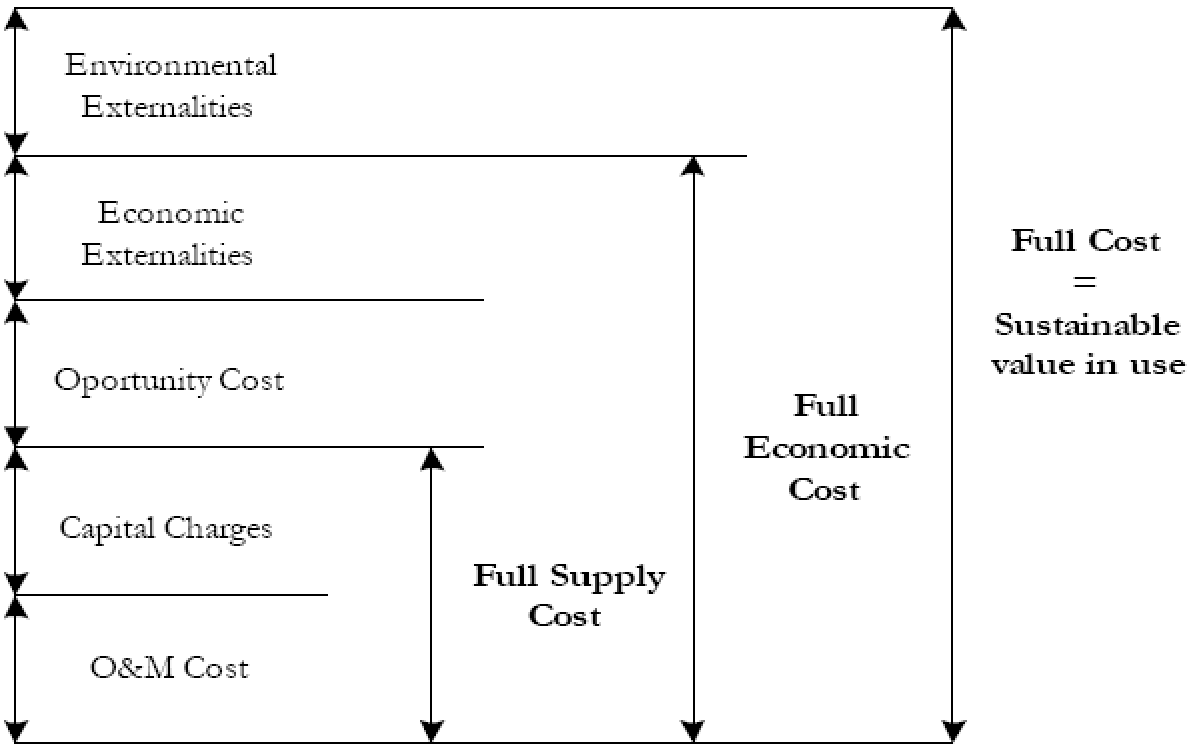

Figure 1: General principles of full cost of water (Source Klawitter 2004)

4.1 Requirements for setting wastewater service fees

When setting prices for wastewater services a range of aspects has to be considered as the goals pursued with setting prices for wastewater services are varied. They can be set either at the service provider level or by national (or local) government.

As mentioned above, one of the major aims is to **recover the costs** of service provision and sometimes also the costs resulting from environmental impact caused by wastewater discharge. The traditional approach to cost recovery considers only the financial costs of a project or programme, such as operations and maintenance (O&M) costs, capital costs and possibly investments for future growth and rehabilitation (which includes accounting for depreciation of assets over time). A wider economic perspective considers, in addition to the financial costs, opportunity and environmental costs (and benefits) to society. These include for example the costs of impacts on environment due to insufficient wastewater treatment and public health costs due to insufficient wastewater treatment. National policy then dictates whether part or all of these costs should be recovered from water users and wastewater dischargers. At a minimum, full supply costs should be recovered in order to ensure sustainability of investment and the viability of service providers. Moreover, the revenue stream should be relatively stable and not cause cash flow or financing difficulties for the utility.

The aims of wastewater charges further include the intention to send appropriate **price signals to users** about the relationship between water use and treatment costs or environmental damage, respectively, in the case of no or insufficient treatment. Price should therefore be high enough to set an **incentive to prevent pollution**, i.e. to discharge less or better treated wastewater.

Further on, some other aspects also need to be considered when setting prices for wastewater services:

- ***Affordability:*** Prices should make access to sanitation affordable for different income groups as lack of sanitation services has major impacts on human and environmental health resulting in negative effects for all members of a society. The price should, therefore, not be too high to drive consumers to unsafe alternatives of wastewater discharge.

- ***Fairness and equity:*** The demand for equity implicates that those who produce more wastewater or wastewater with a higher pollution load also pay more for sewerage and treatment. This usually means that water dischargers pay wastewater bills that are proportionate to the costs they impose on the utility. This would also be in line with the "polluter pays principle". Fairness, however, might require that the wastewater bill does not account for a disproportional large share of a household's total income.

- ***Transparency and feasibility*:** Complete fulfilment of all of the above mentioned objectives of wastewater charges would imply relatively complex tariff systems as well as intricate monitoring mechanisms (including installation, maintenance and reading of different meters). Administrative expenses for billing and monitoring payment should however be kept financially feasible. When designing tariffs (see below) it should be kept in mind that these should also be easy to explain, understand and implement.

Some of theses objectives, however, might conflict with each other. For example the affordability for poor could require low prices, which do not provide for full cost recovery, or measuring of pollution loads in wastewater might not be administratively feasible.

4.2 Tariff design options

In order to balance the varied objectives of wastewater charges, different tariff systems have been developed. A tariff is a system of procedures and elements which determines the customer's total water/ wastewater bill. Any part of that bill can be called a charge, measured in

- money per time (e.g. per month) or
- money per volume or
- money per unit pollution load.

Most tariffs are a combination of elements dependent on consumption or other factors. Usually a connection charge is further put on a customer who joins the public water supply and/ or sanitation systems.

Since water use is easier to observe or meter than is wastewater discharge and the volume of wastewater produced is related to the amount of water supplied, the cost of wastewater treatment is often included in water supply rates or tariffs.
There are different types of tariff systems that can mainly be divided into fixed charges, volumetric charges, and combinations of the both.

- Fixed Charge Tariff
- Constant Volumetric Tariff
- Increasing volumetric tariff
- Block Tariffs
- Two-part tariff (fixed + volumetric)

(Constant Volumetric Tariff, Increasing volumetric tariff, Block Tariffs: Volumetric charges)

4.2.1 Fixed Charge Tariff

Under a fixed charge tariff structure, consumers pay a certain amount independent of quantity and quality of wastewater produced. In the absence of metering, fixed charges are the only possible tariff structure. This can be the case for example in multi-story apartment buildings where the different renters do not have metered connections to the sewerage systems. The fixed charge itself can vary across households or discharger classes depending on their characteristics. For example there can be different fixed tariffs based on different types of dischargers (industry, agriculture, households, etc.), on property values (size of floor space), number of people living or working in the connected building. Another common approach is to charge different monthly fees depending on pipes' diameters used to connect the customer to the sewerage or distribution system.

The benefits of the fixed charge tariff system lie in its simplicity; however it does not provide any incentives for water conservation and pollution prevention. An Example for a differentiated fixed charge tariff is given in the textbox below.

4.2.1.1 Fixed Charge Tariff in Uganda

In Uganda in 1995, tariffs were set by the National Water and Sewerage Corporation, which had a monopoly over service provision at that time. Water charges included all operations and maintenance costs, depreciation and capital costs and also social equity. As of April 1995, un-metered residential consumers paid flat rates that were based on the number of taps. The table below demonstrates the difference between metered and unmetered connections.

Table 2: Fixed Charge Tariff in Uganda

In Ugandan Shillings: US$1 = 1,050 shillings (1996)

Number of Taps	Amount Shillings
1 Tap	3,696
2-4 Taps	11,088
5-8 Taps	18,480
Over 8 Taps	27,720
Metered (per m3)	616

Source: IRC 2003

4.2.2 Volumetric Tariffs

In contrary to the fixed charge tariff, all of the following tariff systems base the customers wastewater bills on the amount of water used (consumption based charges) or the amount and quality of wastewater produced (effluent charges). All volumetric charges require that the consumer has a metered connection and that this meter works reliably and is read on a periodic basis. As domestic wastewater does usually not vary significantly in pollution load, it is rather uncommon to bill domestic wastewater services dependent on effluent quality. For industrial wastewater, however, pollution load differs widely and is usually considered in their wastewater bill.

4.2.2.1 Constant Volumetric Tariff

In a constant or uniform volumetric tariff, all the users pay the same price per unit of wastewater discharged - independently of the total volume of water used or discharged by the consumer. A constant volumetric charge has the advantage of being easy for the customer to understand.

4.2.2.2 Increasing linear volumetric tariff

In this tariff structure, the price per unit of water discharged increases continuously as the total amount of water used or discharged by the customer increases. Although this tariff is rarely used it is interesting as it illustrates and sends a signal to the consumer that increased water use implicates increased marginal costs.

4.2.2.3 Block Tariffs

Under a block tariff scheme, users step-wisely pay different charges for different consumption levels. With an *increasing* block tariff, the rate per unit of water increases as the total volume of consumption/ discharge increases. Higher rates are set for higher levels of use. Consumers face a low per unit charge up to a specified quantity (or block) and then for any water consumed/ discharged in addition to this amount, they pay a higher price up to the limit of the second block, and so on. An example for an increasing block tariff is given in the textbox below. The main aim of increasing block tariffs is to set an incentive to use less water. Sometimes these tariffs are also called lifeline tariffs or social block tariffs when they aim to address the needs of the poor by providing a basic level of consumption/ sanitation (for example, using the WHO guidelines of 20 litres per day for basic needs) either for free or at very low cost. The marginal costs of providing the service have then to be covered by confronting customers in the highest price block with the marginal cost prices. In many cities, however, the increasing block tariff fails to reach its objective to address the needs of the poor, because the poor often have large families or more than one family shares a connection. This results in high volumetric uses/ discharges at one connection and consequently higher prices.
Block tariffs can also be designed as *decreasing* block tariffs. With these tariffs, on the other hand, consumers face a high volumetric charge up to the specified quantity of the first block, and then for any water consumed/ discharged in addition, they pay less. The idea is to reflect the fact that large consumers often impose lower average costs on the system. However, these tariffs are ever less applied because there is a growing interest in promoting water conservation.

4.2.2.4 Increasing block tariff

In Botswana, the Ministry of Mineral Resources and Water Affairs has been responsible for national water policy since 1993. A pricing system was implemented based on principles of equity, efficiency and cost recovery. Water from standpipes was supplied free, and households with private connections were provided with a lifeline-type tariff for the first 5 m^3 consumed. Ranges for consumption were grouped according to bands (blocks) – the table below shows the ranges of consumption and tariffs charged.

Table 3: Increasing block tariff in Botswana

Band	Use per month (m^3)	Tariff (US$ per m^3)
1	0-5	0.16
2	6-20	0.32
3	21-40	0.79
4	>40	1.54

Source: IRC 200

4.2.3 Two-part tariffs

While all of the above mentioned tariffs consist of only one charge, fixed or volumetric, another possibility is to combine them in a two-part tariff. A two-part water or wastewater tariff usually consists of

- a fixed monthly service charge plus
- a volumetric charge that is based on the actual consumption/ discharge.

There are many variations in the way these two components can be put together. For example, the volumetric charge can be a constant volumetric, a linear increasing or block tariff. In many cases, the fixed charge is rather low and serves as a means to recover the fixed administrative costs of service providing that are unrelated to the amount of water consumed/ discharged (such as costs for meter reading, billing, etc.). They can also be used to recover the investment costs of the utility. The revenues from the volumetric part of the tariff are then meant to cover the operational costs related with provision of the wastewater service.

4.2.4 Seasonal and Zonal Tariffs

Another option, though very rarely adopted, to structure tariffs for water and wastewater services are seasonal and zonal tariffs. These tariffs try to reflect the potential differences in costs that accrue with service providing in different seasons or local areas. For example, in the dry season, when rivers carry less water they can probably only receive less or better treated wastewater. Similarly, zonal tariff could reflect the higher costs linked with service in remote or extremely dry areas.

Local differences in costs incurring with water supply service are, for example, also reflected in the different prices (fixed charge tariffs) for water services in Lebanon and Palestine, as described in the textbox below.

4.3 Examples of Water Pricing in the MEDA Region

4.3.1 Water Pricing in Lebanon

The regional water authorities are empowered to set and collect water tariffs for domestic and agricultural use. Subscription fees for domestic water supply vary among the water boards. During the year 2001, tariffs ranged from US$ 44 per year to US$ 153 per year for a 1 m^3/day gauge subscription. Differences are partly due to water availability and distribution costs as gravity distribution is cheapest, while distribution by pumping is far more expensive. In Beirut and the Metn area, where water tariffs are highest, water is conveyed long distances and/or pumped from deep wells. In Bsharre and Dinniyeh, where water tariffs are lowest, water is available from springs and delivered by gravity.

Most households incur additional expenses to meet their water consumption. Assuming households with a 1 m^3/day gauge subscription actually receive and consume this amount of water per day; such households would be paying the equivalent of US$ 0.12-0.42 per m^3 of water. In fact, most households end up paying much more on a per cubic meter basis for two main reasons:

- Frequent and periodic water shortages (some areas report receiving water only a few hours per day) and
- Need to buy water from private haulers, at costs typically around US$ 5-10 per m^3.

As long as water meters are not installed, the price of water will remain unaffected by actual water consumption and people will pay the same amount regardless of the quantity of water actually delivered/ consumed. Users have no incentives to conserve water and wastage is much more common.

4.3.2 Water pricing in Palestine

The Municipalities and regional water authorities set and collect water tariffs for domestic use. Water fees for domestic water supply vary considerably among different localities. Tariffs ranged from US$ 0.15-0.2 to US$ 1.0-1.2. Differences are partly due to the level of services, water availability and distribution costs. In Dura and Ramallah area for example where water tariffs are highest, water is conveyed long distances and/or pumped from deep wells. In Qalqiliya and Jericho, where water tariffs are lowest, water is available in shallow wells (Qalqiliya) and/or springs (Jericho) at low pumping cost.

Some localities in the North and due to frequent and periodic water shortages (some areas report receiving water only a few hours per day) purchase water by tankers. Such localities are paying US$ 5/m3 of the additional purchased water. In some localities also water meters are not installed and the price of water remains unaffected by actual water consumption.

4.3.3 Water Pricing in Turkey

Water pricing activities of Irrigation Districts in Turkey are parallel to that of other organizations. The specific aspects for water pricing in Irrigation Districts can be gathered under the following topics:

1. The expenditures of that year to be determined by an estimated budget before the irrigation season.
2. The application of the tariff according to defined conditions to be based on qualifications of the scheme (under the responsibility of each organization) and region.
3. Making the collection in the same year and deterrence of applied penalties to recover charges, which can not be collected.

Water user organizations have to work with a balanced budget from the standpoint of revenues and expenditures. Therefore they have to determine expenditures of that year for the scheme under their responsibility and form a budget to recover these expenditures. Each association determines its own expenditure budget, which includes all kinds of expenditures necessary for maintenance of schemes and for irrigation management at the beginning of the fiscal year. In this budget, investments for irrigation schemes (machinery, equipment, and construction of new schemes, renewing of schemes) are also included. However, the capital investment cost is not included in O & M charges. Each association determines its would-be irrigable area and crop types using water user information forms and many other methods. Tariff studies prepared using estimated budget and potential irrigation figures, show differences among the water users organizations. Each association uses different methods depending on qualifications of its own scheme and region. These methods can be cited as follows:

Area based
a) Crop based (TL/da) (TL is Turkish Lira)
b) Fixed charge (TL/da)
c) Crop based depending on irrigation times (TL/da)
d) Fixed charge depending on irrigation times (TL/da)

Volumetric
a) Based on water amount consumed (TL/m3)
b) Based on water consumed hourly (TL/m3)

Water Users Organizations use mostly the “area and crop based” tariff method. This type is used mostly in gravity irrigation schemes. In pumped irrigation schemes, the volumetric method is used.

Factors which are taken into account when water user organizations choose a tariff method are:

- method should be easy and practical
- lack of data for calculations
- water charge per unit area is intended to be low.

For more details see the Turkey Country Report 2003

4.3.4 Water Pricing in Cyprus

The Water tariffs methodology used in calculating the required water tariffs for the agricultural and households sectors is described in the Loan Agreements with the World Bank (IBRD) (Government Printing Office 1988) and the Kuwait Fund (KFAED) for the financing of the Southern Conveyor Project, the largest water resources project in Cyprus. The water tariff for agriculture is calculated using the “Present Worth Value” method while for the households sector the “Balanced Budget” method is used.

For more details see:
http://www.uni-muenster.de/imperia/md/content/zufo/binder9.pdf

4.4 Conclusion

The following figures demonstrate the different prices and monthly bills for water/ wastewater services resulting from different single-part tariff structures (assuming that wastewater bills are calculated based on water consumption).

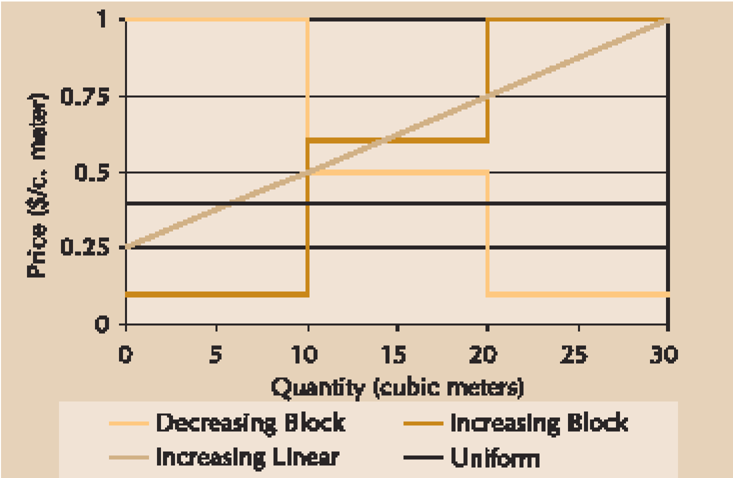

Figure 2: Price of water versus the quality of water used for selected tariff structures *(Source: WSP 2002)*

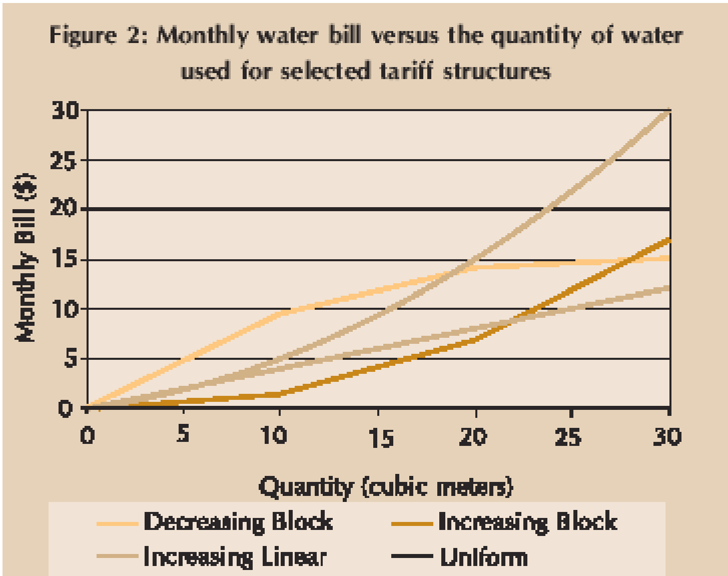

Figure 3: Monthly water bill versus the quality of water used for selected tariff structures *(Source: WSP 2002)*

Tariffs can be designed and prices set by the service provider or the local or national government. There is no consensus on which tariff structure best balances the objectives of the utility, consumers and society. Tariff design that contributes to the achievement of one objective may be detrimental to the achievement of another. In order to resolve this conflict, policy makers need to decide which objective has the highest priority and, where possible, use more than one instrument. Moreover, performance does not only depend on the choice of tariff structure but also on the level the tariff is set. Therefore setting of tariffs is very much a political process and often implicates controversy. The following table gives an overview on the advantages and disadvantages of different tariff structures.

Table 2: Summary of performance of alternative tariff structures against design objectives *(Source: WSP 2002)*

Tariff Structure	Objectives			
	Cost Recovery	Economic Efficiency	Equity	Affordability
Fixed Charge	***Adequate*** Provides stable cash flow if set at appropriate level, but utility may be vulnerable to resale of water and spiraling consumption.	***Poor*** Does not send a message about the cost of use of additional water.	***Poor*** People who use large quantities of water pay the same as those who use little.	***Adequate*** If differentiated by ability to pay, but households are unable to reduce their bills by economizing on water use.
Uniform Volumetric Charge	***Good*** If set at appropriate level, moreover revenues adjust automatically to changing consumption.	***Good*** If set at or near marginal cost of water.	***Good*** People pay according to how much they actually use.	***Good*** Can be differentiated by ability to pay, and people can limit their bills by reducing consumption.
Increasing Block Tariff	***Good*** But only if the size and height of the blocks are well designed.	***Poor*** Typically little water is actually sold at marginal cost.	***Poor*** People do not pay according to the costs their water use imposes on the utility.	***Poor*** Penalizes poor families with large households and/or shared connections.
Decreasing Block Tariff	***Good*** But only if the size and height of the blocks are well designed.	***Poor*** Typically little water is actually sold at marginal cost.	***Poor*** People do not pay according to the costs their water use imposes on the utility.	***Poor*** Penalizes poor families with low levels of consumption.

Historically, user fees are set (after technical analyses) without the involvement of those affected. However, **willingness to pay** is not a fixed item that experts can extract from historical data, but a complicated set of preferences and concerns that are only fully sorted out during a participatory process. Participation in setting charge rates can increase willingness to pay, because of an improved understanding of the benefits of wastewater treatment or an increased confidence that services will actually be delivered.

4.5 Subsidies

Some of the failures of tariff systems, especially in providing affordable services for the poor while recovering costs, can be compensated by subsidies. It is generally agreed that in poor areas of middle and low income countries, subsidies are necessary to cover basic amounts of water usage and basic levels of sanitation service for poor customers. Sanitation services may be more natural candidates for subsidies than water services, as the willingness to pay for such services is often lower than for water services, and the wider social benefit in terms of both public health and surface water quality provide an economic rationale for subsidisation.

There are different types of subsidies that achieve different purposes. Government subsidies can for example either be paid directly to the customer (demand side subsidies) or to the utility (supply side subsidies). If government finance is not an option cross subsidies can be used, where some groups of customers are charged more than the true costs of service provision, and this surplus is used to cover less expensive service provision to poorer groups (as in block tariff systems). Another possibility is to apply a uniform surcharge, of say one or two percent, on all customers' bills and use these resources to finance any subsidies deemed necessary. Some types of subsidies might be better than others, depending on the type of project, tariff structures, and other preconditions.

However, research has shown that subsidies should rather be used to promote access to basic water and sanitation services rather than providing ongoing support for consumption. One of the reasons for this is that it is often the initial, relatively high cost of getting connected to the network that prevents poor people to benefit from water or wastewater services. Their willingness and ability to pay for the regular service fees are usually much higher.

5. Effects of water pricing policies

5.1 Direct effects

First of all water tariffs and charges convey a signal to water users on the value of water. As long as water and waste water treatment do not cost anything or the price is negligibly low or charges are included into general taxes, the notion of water as a public good that must be accessible to everybody in whatever amount one may want to use will persist. But if the water user can see that for example using freshwater for gardening in summer makes the bill go up significantly he will start reconsidering whether a fresh-green lawn is really a must during the hottest summer months. While the freshwater for gardening is not the main problem of developing countries, the principles of consumers' state are comparable.

This change in consumers' state of mind is urgently needed, as water is unfortunately scarce, environmentally damaged and is not economically cheap. Explicitly, incentives for water conservation are given by metering, volumetric charges, increasing block-tariffs and a move towards Full Cost Recovery as these instruments lead to a better reflection of marginal costs in water prices. The same is true for pollution charges. The reduction of discharges of polluting substances is rewarded by lower prices. If these charges are increased, pollution damage is reduced and/or those who are harmed by discharges are compensated.

Minimum charges, significant fixed elements, flat fee tariffs and prices below cost recovery on the other hand may prevent water users from getting a signal on the value of water. Also the coverage of water costs through general taxation revenues (as is the case i.e. in Ireland) and charging of irrigation water per surface (as is practised in i.e. the southern countries of the EU) act as disincentives. They water down the conservation message pricing can convey because unnecessary consumption is not reflected in the water bill. Such methods can even promote high consumption. This is like having paid for a huge ‘all you can eat’ buffet and then only eating a slice of dry bread. Hardly anybody would do that but everybody would try to get as much food as possible for his money. For example the calculation of prices for irrigation water in Spain in proportion to the hectares irrigated together with the very low prices paid acts as a disincentive for any improvement in efficiency, such as for example the installation of new irrigation technology which is of course linked to investment. But what is astounding is the fact that big changes in the way farmers produce their crops may not even be necessary to reach a certain gain in efficiency. Considerable amounts of irrigation water are lost due to evaporation because of the time of day chosen for irrigation. There is thus a waste of water occurring just because water users are not aware of the fact that water has a value. This waste would immediately stop after the introduction of a feasible price for irrigation water because only minor changes in management and technology would be necessary to reach a big change for the environment. Nothing would even have to change for the farmers or for society. Apparently it is thus possible for farmers to react to the introduction of a comprehensive pricing scheme with a reduction in water demand without even changing their crop patterns or production method left alone giving up their business. Just by increasing efficiency and avoiding leakage they can keep their water bills from going up. This valuable opportunity for water saving without farreaching changes in the existing system should not be squandered.

Domestic water consumption can also be directed in the right way by water pricing schemes. For the CEEC countries considerable increases in real prices are reported after dramatic reductions of subsidies and this is proven to have significant effects on domestic per capita water consumption. For example in Hungary consumption has fallen between 1986 and 1997 from 154 lhd to 102 lhd (lhd= litre per head per day) after large real price increases. Available data also shows that domestic water consumption decreases after introduction of metering. However a certain threshold can be determined up to which price increases do not affect consumption levels. The best responsiveness of household water demand is reported for 'peakpricing' practises, meaning that there are temporal variations in the price, according for example to general higher consumption in the summer. Unfortunately this possibility is hardly ever used. There are reported cases though, such as in New York where the imposition of a premium summer seasonal tariff was able to reduce the peak day ratio by 14 %. (Roth 2001)

5.2 Indirect effects

Indirect effects of water pricing are primarily secondary effects resulting for example from demand responses of users to water prices. This can be for instance the conservation of wetlands or the possibility to avoid the construction of new infrastructure. The considerations can be divided into three aspects dealing with society, economy and the environment.

5.2.1 Indirect effects on society

As already mentioned above, the attempt to create a cost covering water price might lead to equity problems. As man needs a certain volume of water for sheer survival, the increase of water prices above a certain level can mean severe hardship for the less well-off. Nonetheless a really adequate pricing policy can solve these possible problems, as it will combine the achievement of environmental objectives with an increase in social equity. Regional differences in the water price due to the internalisation of environmental externalities represent another inequality. Thus equity can be affected by Full Cost Recovery pricing, but this is not really a problem of the principle itself but more of the way of its implementation.

Another possible negative effect of water pricing on society is, that as water prices rise, certain enterprises (industrial as well as agricultural) especially smaller ones might face profitability problems. While bigger firms can even out losses by installing technology to save water or avoid polluting effluents. Especially in the agricultural sector this can cause high losses to society as smaller farms are often family owned which gives them considerable social value.

Even if jobs would be lost due to profitability problems as described above, the rising demand for water saving technology will drive innovation and the creation of new jobs.

This might not be an immediate solution for rural areas. In the long run it might solve the problem though.

Furthermore the social costs accruing generally from end-of pipe solutions for pollution problems have to be considered. The investment necessary for the construction of waste water treatment plants and canalisation burdens society with costs that could be reduced if pollution would be met at the source.

5.2.2 Indirect effects on the economy

The resource water is often used inefficiently, which, as outlined above, constitutes a loss to society. Progressive water pricing policy however leads to the best allocation of the existing supply-volume. Thus it assures the best possible social welfare. Economical water users have to make sure they do not waste any water or create more than minimal pollution, as they would otherwise face high costs. Thus for example factories and irrigators have to find ways to modernise their equipment. Innovation in the branches making the necessary technology available will be a consequence and will involve the creation of new jobs if such technologies ar not only imported.

5.2.3 Indirect effects on the environment

The described efforts for more efficient water use will put an end to the over-exploitation of aquifers and the entailed destruction of wetlands. Problems of eutrophication and pollution with hazardous substances could be addressed preventively. The turn from end-of-pipe solutions to preventive and production integrated measures would bring about a whole range of possible positive effects on the environment. As less water would be used, less infrastructure for water supply would be needed. Furthermore there would no longer be a necessity for water transfers from one region to another due to excessive water use in certain areas, mainly for irrigation purposes.

Nevertheless it has to be mentioned, that not every effective solution in one region can be transferred or copied to another region without adapting it to the specific regional situation!

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Economic Instruments in Wastewater Management

Annika Kramer

Economic Instruments in Wastewater Management

Objectives

1. Raise revenues and recover costs
2. Set incentives for water conservation and pollution prevention
3. Awareness raising and economic efficiency

Economic Instruments in Wastewater Management

Mechanisms

- Pollution charges
  - For discharge of untreated wastewater into the environment
- Fees for wastewater services/ user charges
  - For connection to and discharge of wastewater into the sewerage system

Other economic instruments:

- Indirect local taxes
- Discharge permits

Pollution Charges

- Charged for the environmental and social costs that result from disposing wastewater
- Usually imposed on operators of treatment plants and industrial dischargers
- Charges are generally calculated based on actual quantities and/or pollution loads of the effluent

Pollution Charges in Germany

- Effluent Charges Act (Abwasserabgabengesetz, AbwAG) implements polluter pays principle
- Calculation of charge:
  amount and harmfulness of discharged substances
  → pollution units (Schadeinheiten SE)
- Goal: create financial incentives for reducing waste water emissions
- Effluent charge is paid to states
  → spent on measures for conserving water bodies

Pollution Charges in Germany - Contaminants and pollution units/ Effluent Charges Act (AbWAG)

Rated contaminants and contaminant groups	**Measurements constituting one pollution unit**
Oxidizable substances in chemical oxygen demand (COD)	50 Kilograms Oxygen
Phosphorus	3 Kilograms
Nitrogen	25 Kilograms
Halogen compounds as adsorbable organic halogen compounds (AOX)	2 Kilograms Halogen as organic chlorine
Metals and their compounds:	*In grams metal:*
Mercury	20 grams
Cadmium	100 grams
Chromium	500 grams
Nickel	500 grams
Lead	500 grams
Copper	1000 grams
Toxicity to fish	3000 cubic meters of wastewater divided by the dilution factor GF, by which wastewater is no longer toxic to fish

Pricing of Wastewater Services - Requirements for setting wastewater service fees

Recover the costs

- Traditional approach:
  only financial costs of a project/ programme are recovered
  → operations and maintenance (O&M) costs, capital costs and possibly investments for future growth
- Wider economic perspective:
  includes opportunity and environmental costs (and benefits)
- whether part or all of these costs should be recovered from water users/ wastewater dischargers is a political decision

Price signals to users

- Relationship between water use and treatment costs or environmental damage
  → price should be high enough to set incentive to prevent pollution

Pricing of Wastewater Services – Requirements for setting wastewater service fees

Affordability

- Prices not too high to make access to sanitation affordable for everybody

Fairness and equity

- Fairness = wastewater bill not disproportional large share of a household's total income
- Equity = Polluter pays principle

Transparency and feasibility

- Easy to explain, understand and implement
- Financially feasible

→ Some objectives might conflict with each other, e.g.: Affordability - Recovery

Pricing of Wastewater Services – Tariff design options

Tariff = system of procedures and elements which determines the customer‘s total water/ wastewater bill

Charge = any part of water/ wastewater bill measured in

- Money per time (e.g. per month) or
- Money per volume or
- Money per unit pollution load.

Different types of tariff systems:

- Fixed Charge Tariff
- Constant Volumetric Tariff
- Increasing volumetric tariff
- Block Tariffs
- Two-part tariff (fixed + volumetric)

(Constant Volumetric Tariff, Increasing volumetric tariff, Block Tariffs: } Volumetric charges)

Pricing of Wastewater Services – Tariff design options

Fixed Charge Tariff

- Consumers pay a certain amount independent of quantity and quality of wastewater produced
- Fixed charges can vary across households or discharger classes → depending on their characteristics:
  - different types of dischargers (industry, agriculture, households, etc.
  - property values (size of floor space)
  - number of people living or working in the connected building
  - different monthly fees depending on pipes' diameters used to connect the customer to the sewerage or distribution system

→ **Benefit**: Simplicity, no metering necessary

But: no incentives for water conservation/ pollution prevention

Pricing of Wastewater Services – Tariff design options

Fixed Charge Tariff in Uganda (set 1995)

- Water charges aim: recovering operations and maintenance costs, depreciation and capital costs,
  while providing for social equity
- Un-metered residential consumers paid flat rates
  → based on number of taps

Difference between metered and unmetered connections:

Number of Taps	Amount Shillings
1 Tap	3,696
2-4 Taps	11,088
5-8 Taps	18,480
Over 8 Taps	27,720
Metered (per m^3)	616

US$ 1 = 1,000 shillings (1996)

Pricing of Wastewater Services – Tariff design options

Volumetric Tariffs

Base customers wastewater bills on

- amount of water used → consumption based charges
- amount and quality of wastewater produced → effluent charges

Require that

- Consumer has a metered connection
- Meter works reliably
- Meter is read on a periodic basis

Domestic wastewater → uncommon to bill services on effluent quality

Industrial wastewater → pollution load differs widely and is usually considered in wastewater bill

Pricing of Wastewater Services – Tariff design options

Volumetric Tariffs

- Constant Volumetric Tariff

  → All users pay same price per unit of wastewater discharged

- Increasing Linear Volumetric Tariff

  → Price per unit of water discharged increases continously as total amount of water used/ discharged by customer increases

- Block Tariffs

  → Users step-wisely pay different charges for different consumption levels

Pricing of Wastewater Services – Tariff design options

Two-part tariff

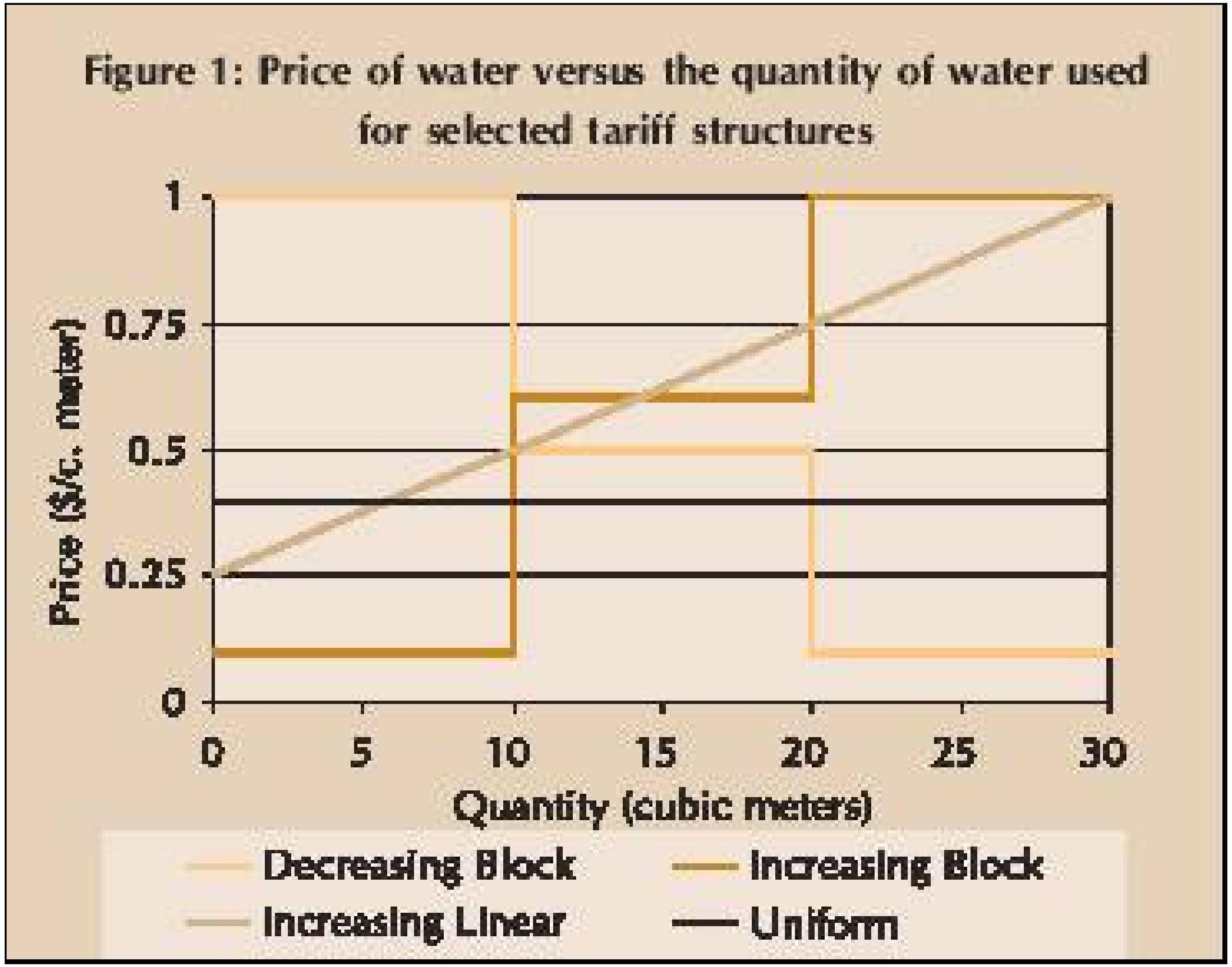
Usually consists of

(1) A *fixed* monthly service charge plus

(2) A *volumetric* charge that is based on the actual consumption/ discharge

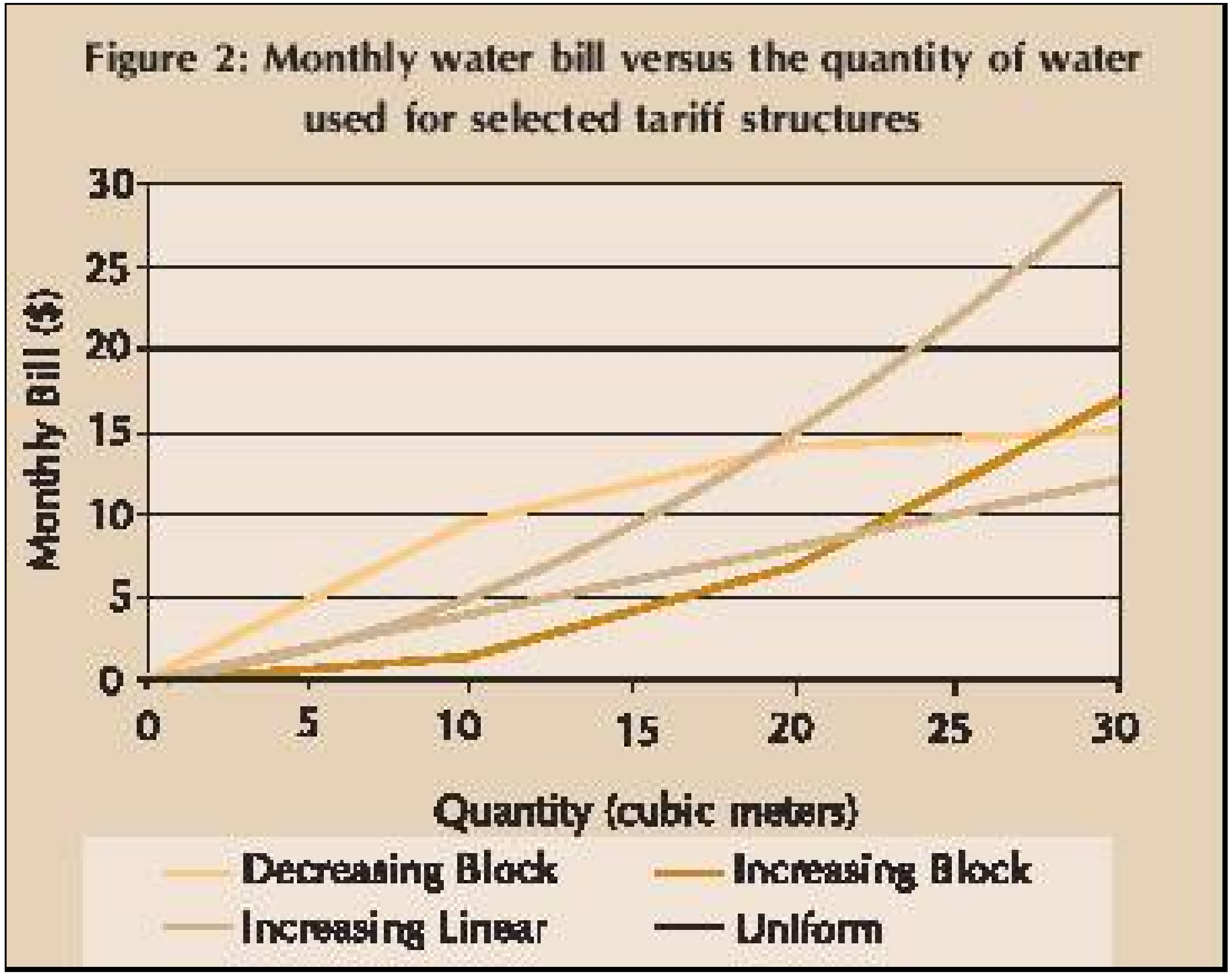
→ Many variations to put components together

Pricing of Wastewater Services – Tariff design options



Source: WSP 2002

Pricing of Wastewater Services – Tariff design options



Source: WSP 2002

Performance of tariffs against design objectives

Tariff Structure	Cost Recovery	Objectives: Economic Efficiency	Equity	Affordability
Fixed Charge	***Adequate*** Provides stable cash flow if set at appropriate level, but utility may be vulnerable to resale of water and spiraling consumption.	***Poor*** Does not send a message about the cost of use of additional water.	***Poor*** People who use large quantities of water pay the same as those who use little.	***Adequate*** If differentiated by ability to pay, but households are unable to reduce their bills by economizing on water use.
Uniform Volumetric Charge	***Good*** If set at appropriate level, moreover revenues adjust automatically to changing consumption.	***Good*** If set at or near marginal cost of water.	***Good*** People pay according to how much they actually use.	***Good*** Can be differentiated by ability to pay, and people can limit their bills by reducing consumption.
Increasing Block Tariff	***Good*** But only if the size and height of the blocks are well designed.	***Poor*** Typically little water is actually sold at marginal cost.	***Poor*** People do not pay according to the costs their water use imposes on the utility.	***Poor*** Penalizes poor families with large households and/or shared connections.
Decreasing Block Tariff	***Good*** But only if the size and height of the blocks are well designed.	***Poor*** Typically little water is actually sold at marginal cost.	***Poor*** People do not pay according to the costs their water use imposes on the utility.	***Poor*** Penalizes poor families with low levels of consumption.

Source: WSP 2002

Pricing of Wastewater Services – Tariff design options

Examples of Water Pricing in the MEDA Region

Lebanon

- Regional water authorities set and collect water tariffs for domestic and agricultural use
- Subscripition fees for domestic water supply vary among water boards

  → differences due to water availability and distribution costs

Pricing of Wastewater Services – Tariff design options

Examples of Water Pricing in the MEDA Region

Lebanon

- Most households: additional expenses for water consumption because
  - Frequent and periodic water shortages
  - Need to buy water from private haulers
- No installed water meters

  → price of water not affected by actual water consumption
- Users have no incentives to conserve water
  → wastage is common

Pricing of Wastewater Services – Tariff design options

Examples of Water Pricing in the MEDA Region

Palestine

- Municipalities and regional water authorities set and collect water tariffs for domestic use
- Water fees for domestic water supply vary among different localities → differences due to level of services, water availabilty and distribution costs
- Some localities: no installed water meters → price of water not affected by actual water consumption
- Users have no incentives to conserve water → wastage is much more common

Pricing of Wastewater Services – Subsidies

In poor areas of middle and low income countries:

- Subsidies are necessary to cover basic amounts of water usage and basic levels of sanitation service
- Different types of subsidies achieve different purposes:

  Government subsidies:

  - demand side subsidies → paid to the customer
  - Supply side subsidies → paid to the supplier

  Cross subsidies:

  - Some groups of customers are charged more – surplus is used to cover less expensive service provision to poorer groups

  Uniform surcharge on all customers' bills:

  - Use these resources to finance