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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Table of Content

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.

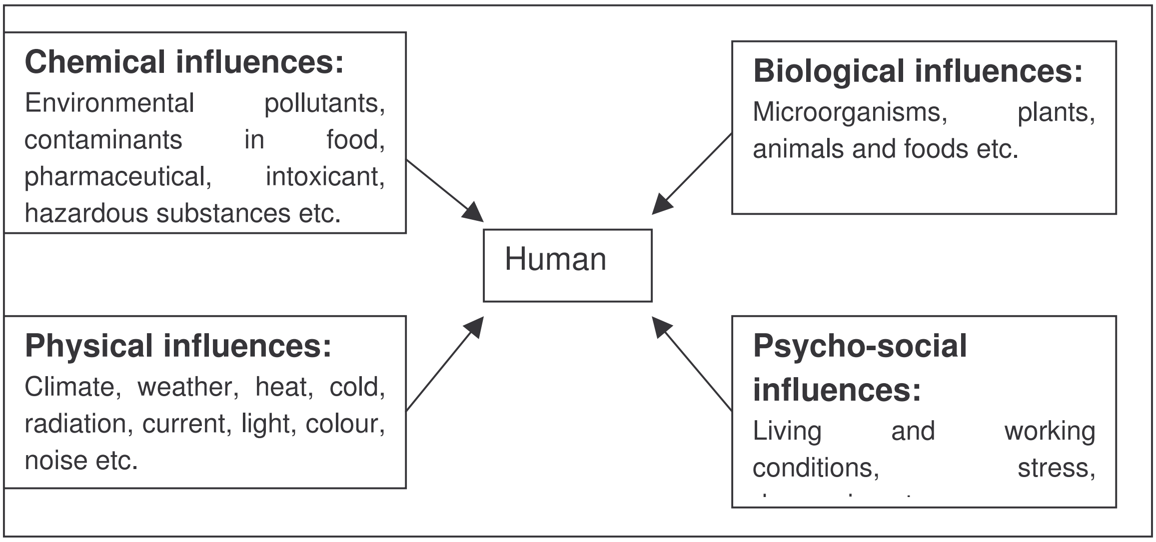


Figure 2: Environmental influences on human

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.

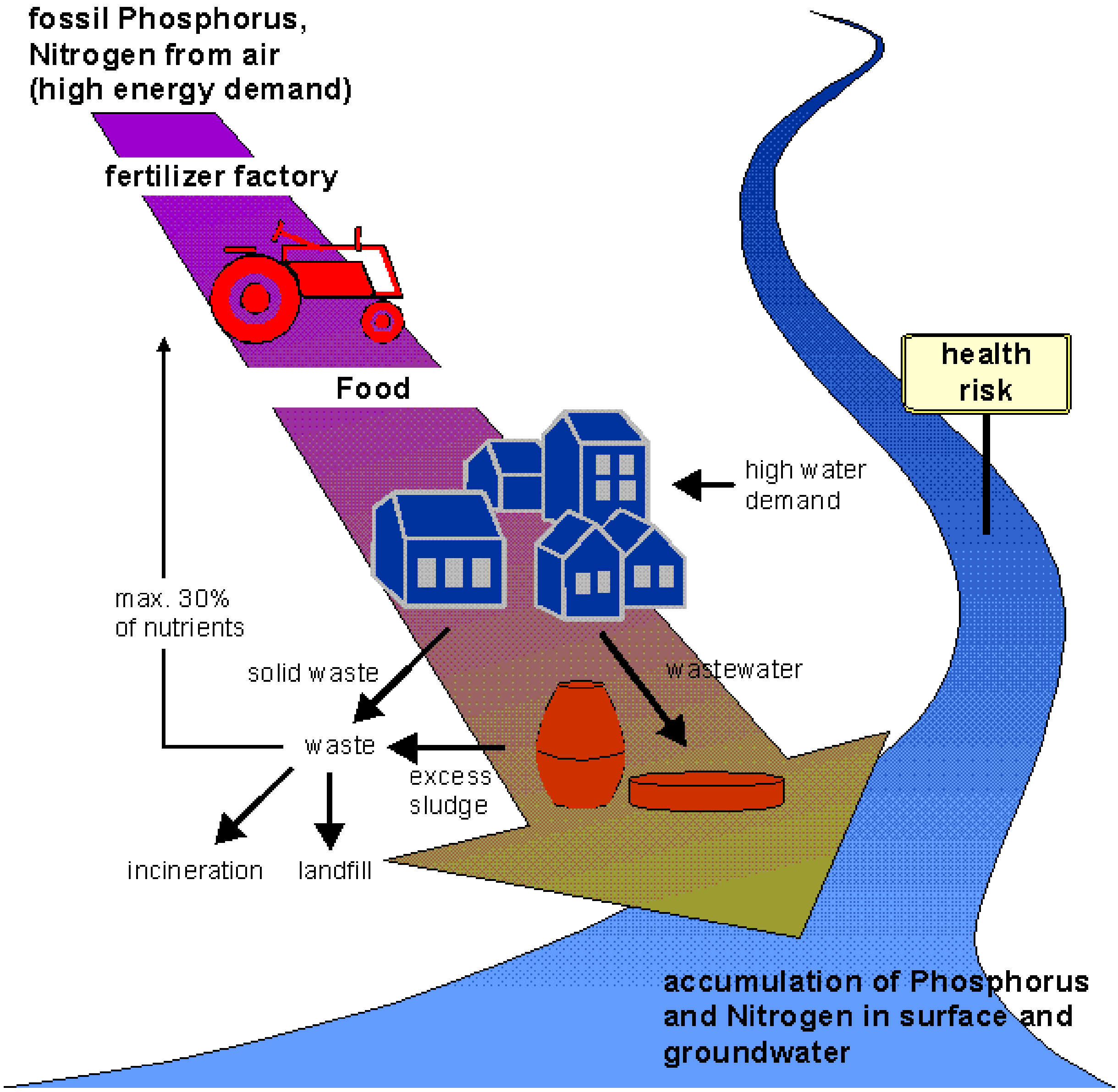


Figure 3: Conventional Sanitation System (source Otterwasser GmbH)

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

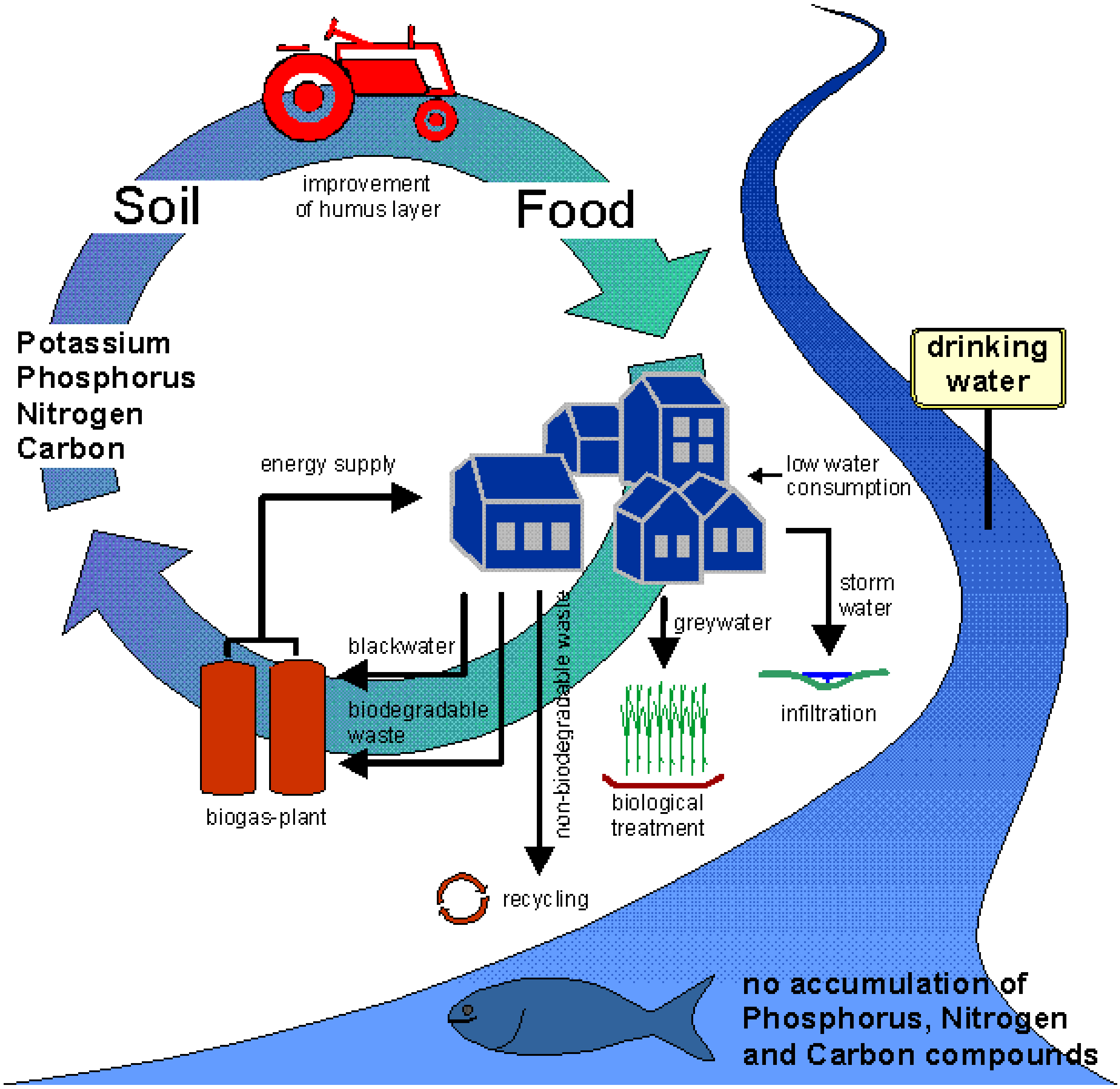


Figure 4: Sustainable Sanitation System (source Otterwasser GmbH)

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

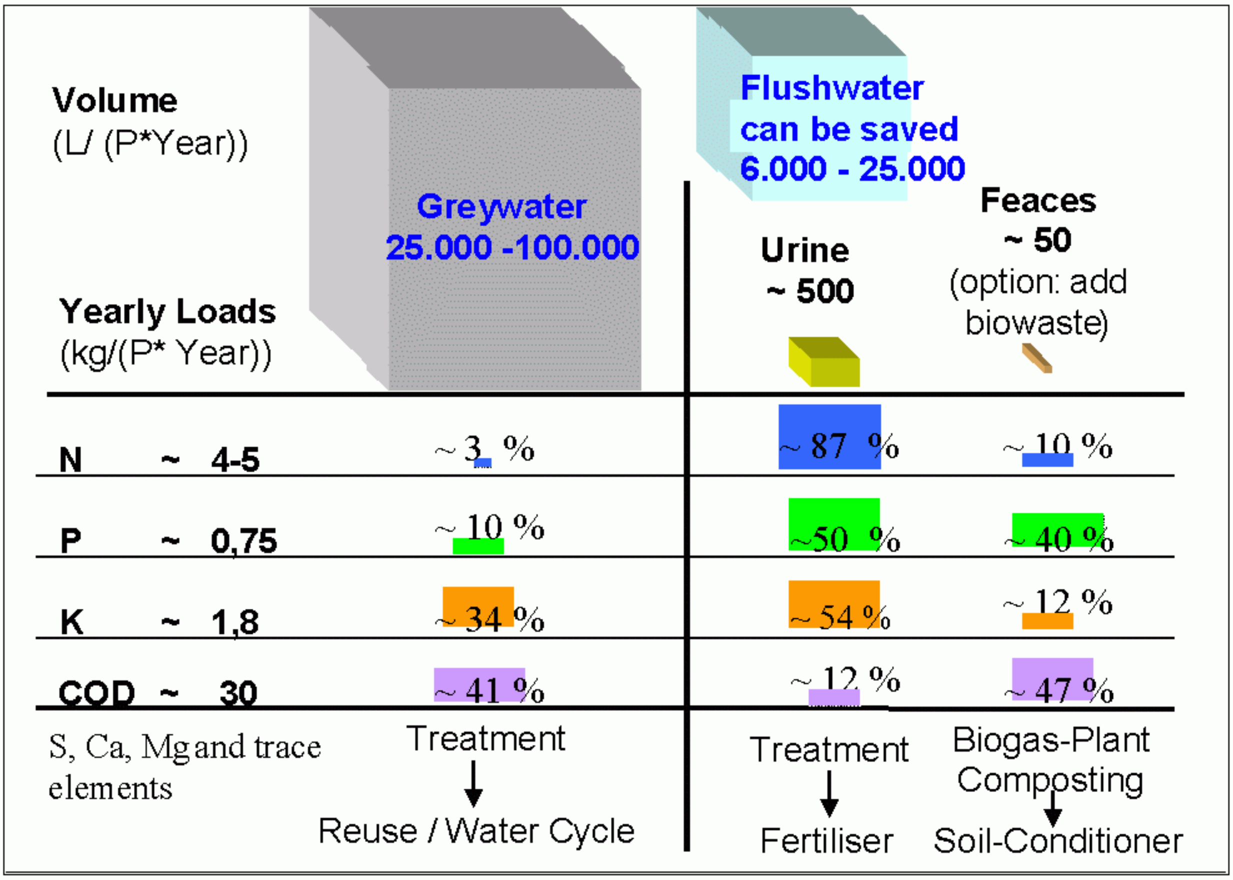
Different particular wastewater streams are forming the domestic wastewater (see figure 1). The wastewater originating from toilets is called black water and can be further divided into yellow water (urine with or without flush water) and brown water (toilet wastewater without urine). Additionally, grey 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.

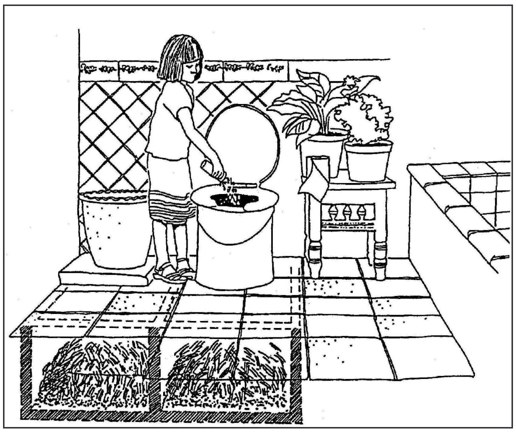


Figure 7: Double-vault toilet with urine diversion (Source: Esrey et al., 1998)

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.

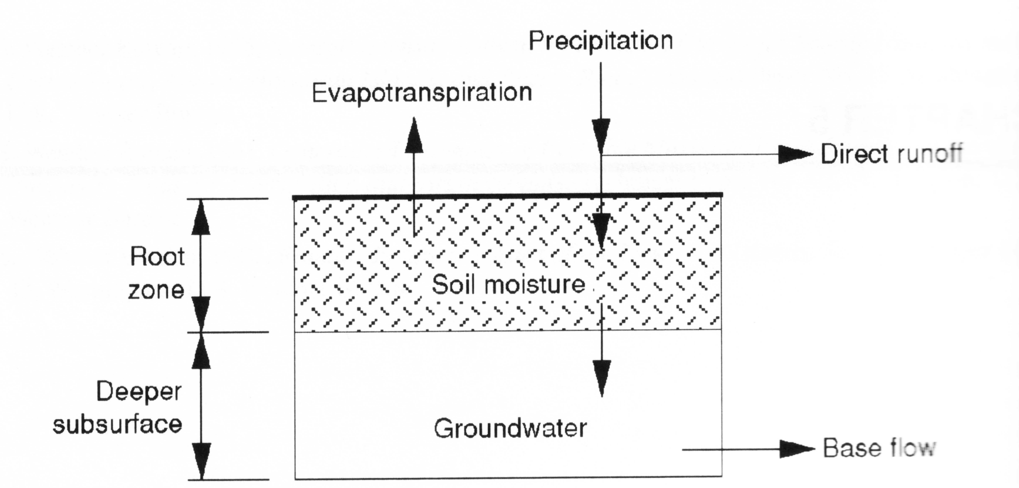


Figure 8: Water balance concept (Source: Ferguson, 1998)

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).

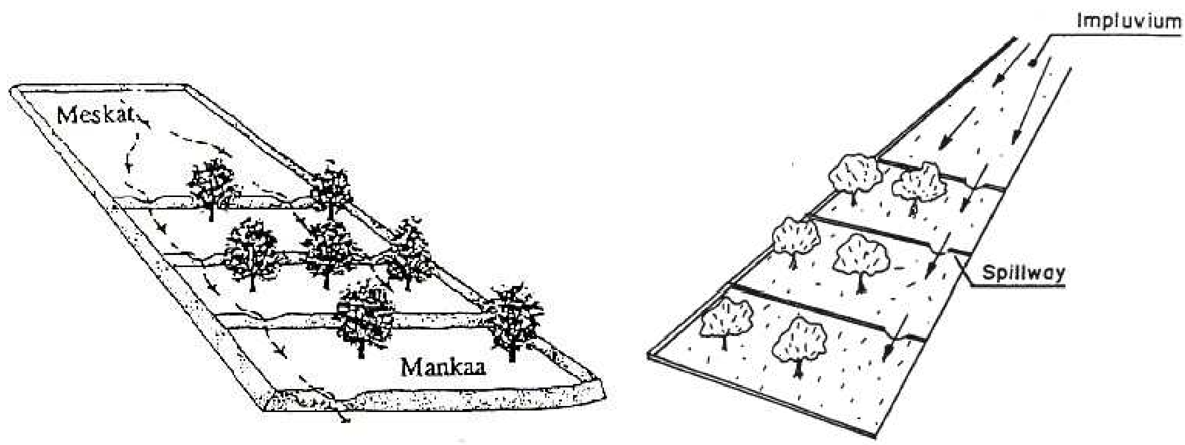


Figure 9: Meskat system (Source: Prinz, 1996 and Oueasser)

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.

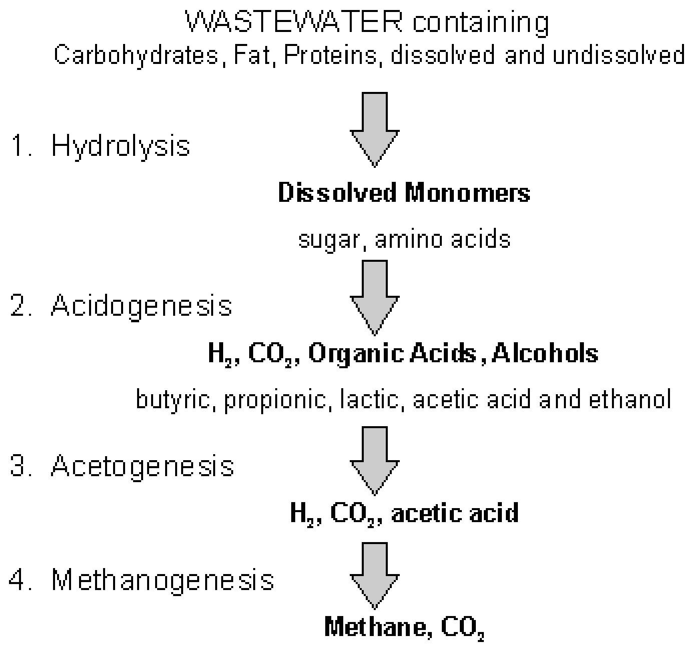


Figure 10: Anaerobic Microbiology

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.

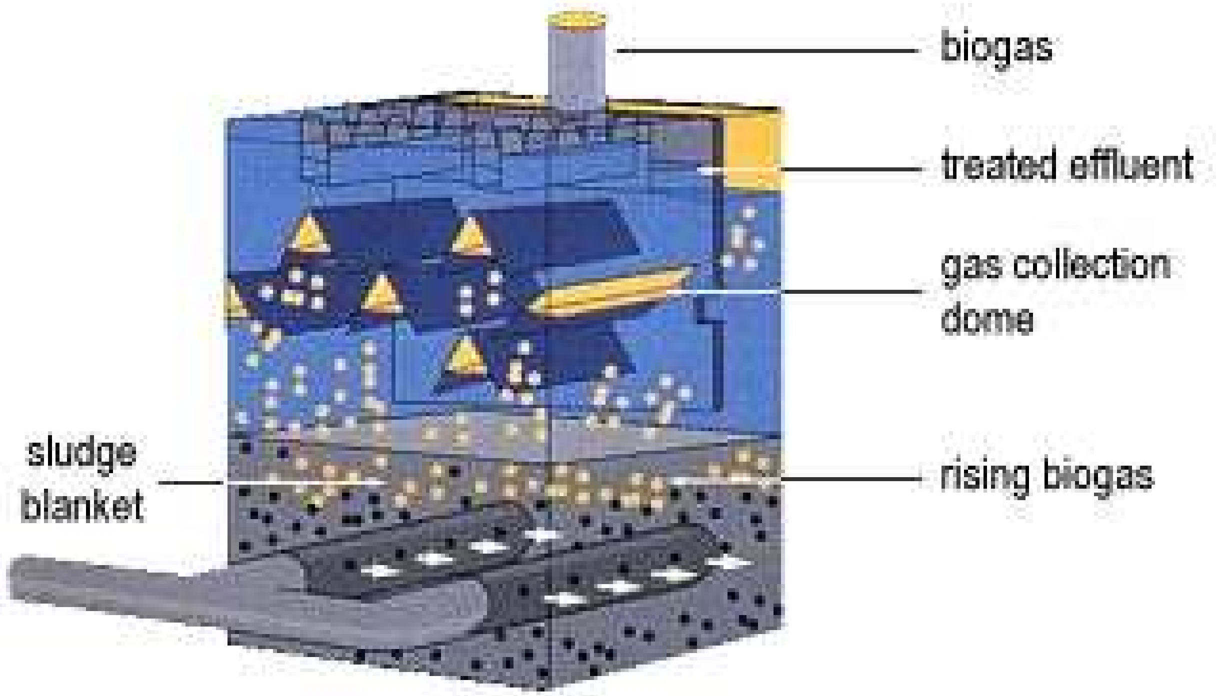


Figure 11: Schematic diagram of the UASB reactor

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.

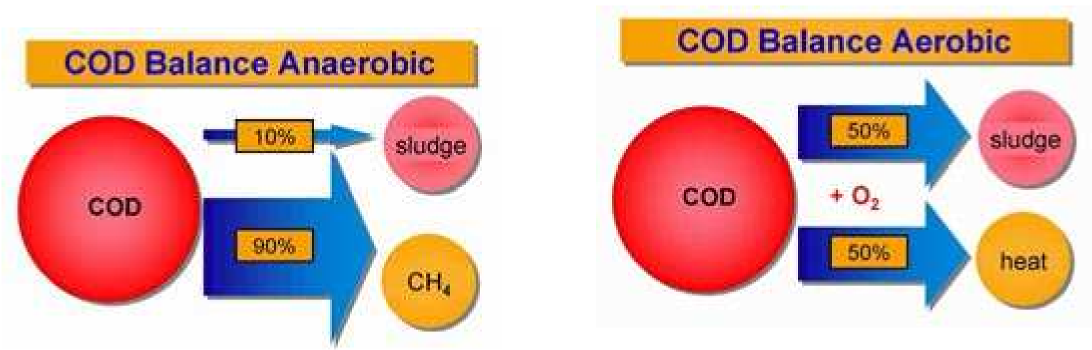


Figure 12. Comparison of the COD balance during anaerobic and aerobic treatment of wastewater containing organic pollution

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.

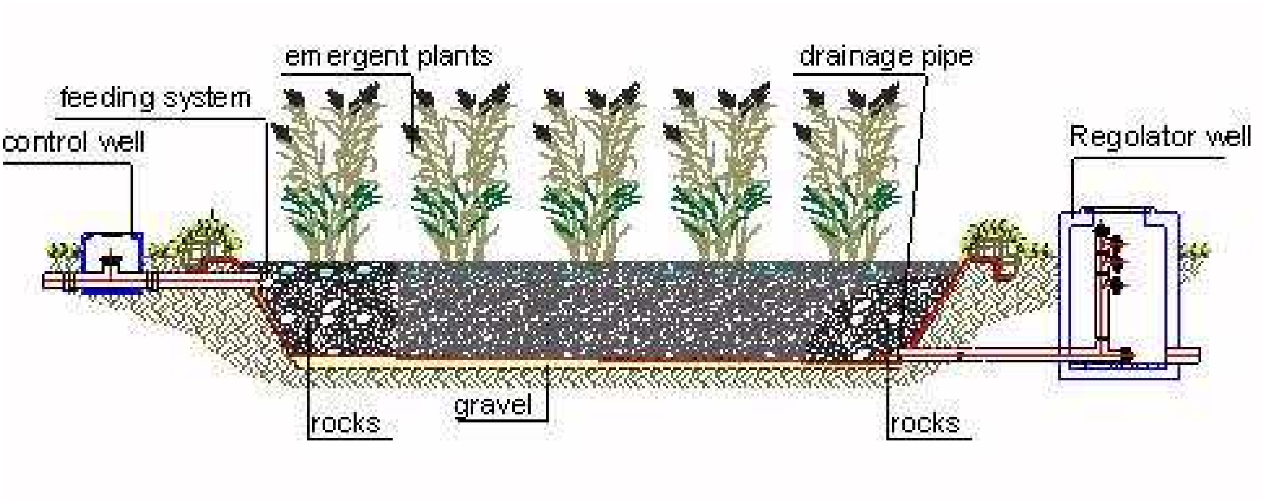


Figure 14: Detailed schematic of a horizontal flow system (HSF)

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.

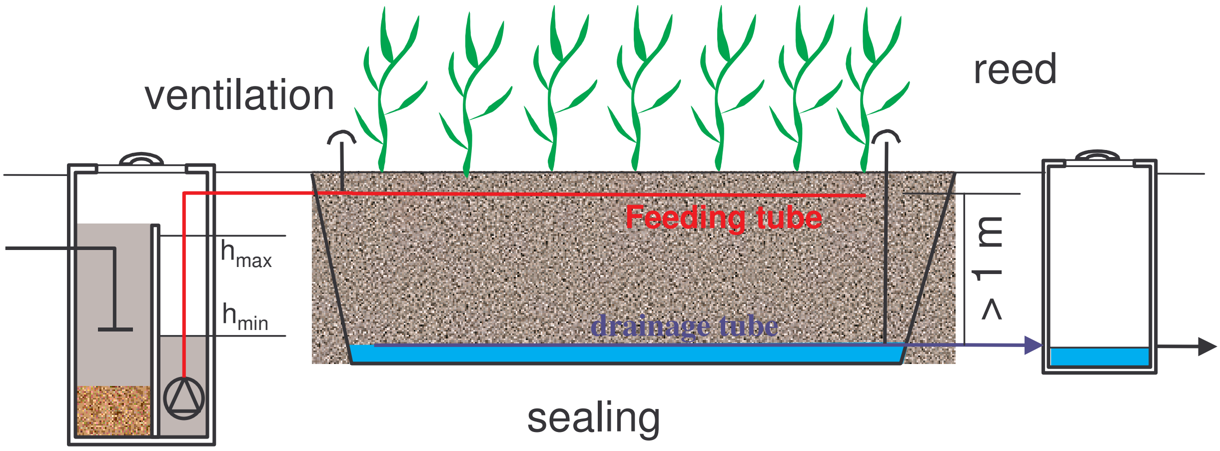


Figure 15: Detailed schematic of an unsaturated vertical flow system (VSF)

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.

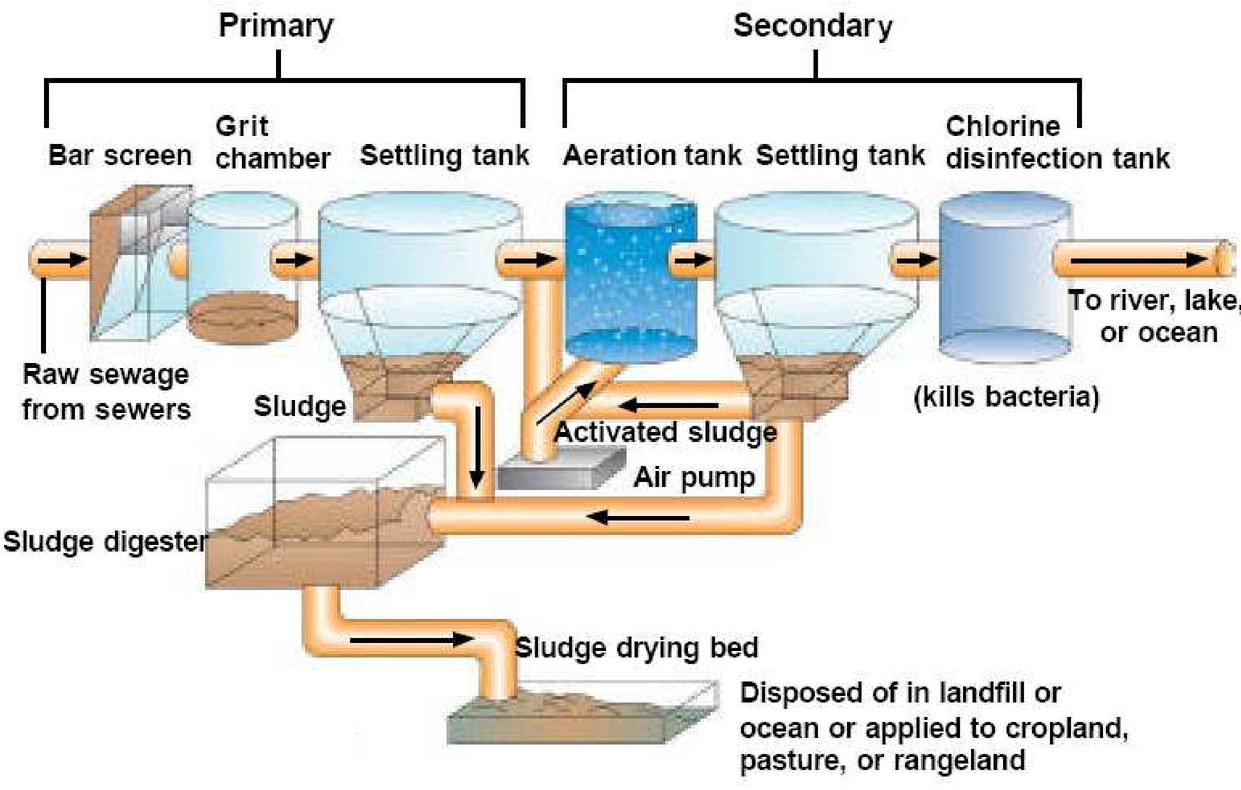


Figure 16: Wastewater treatment plant (Queens University 2004)

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.

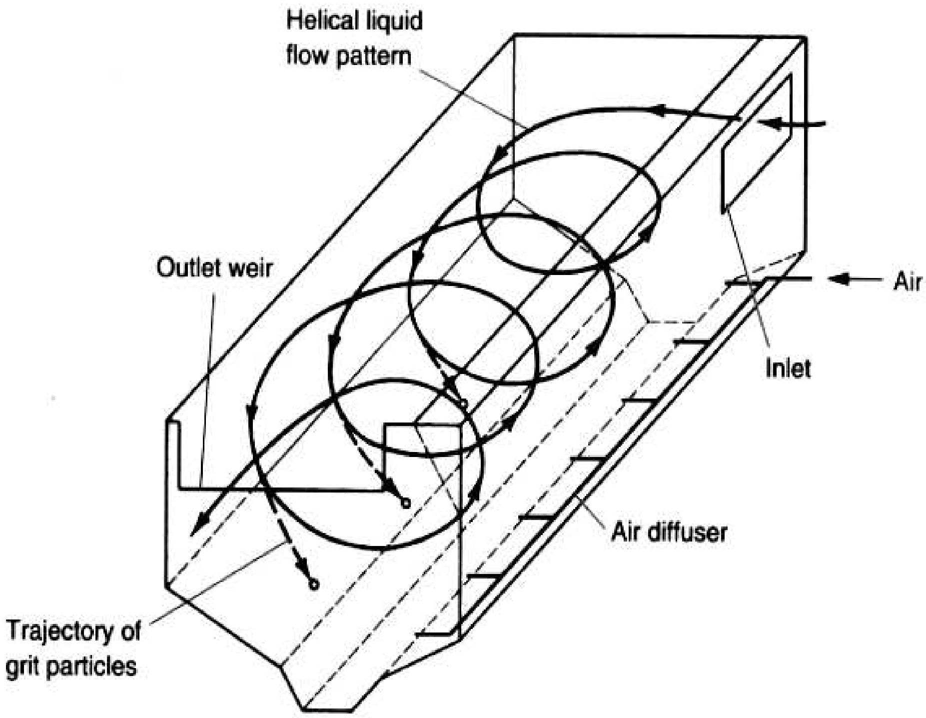


Figure 17: Aerated grit chamber (Crites and Tchobanoglous, 1998)

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.

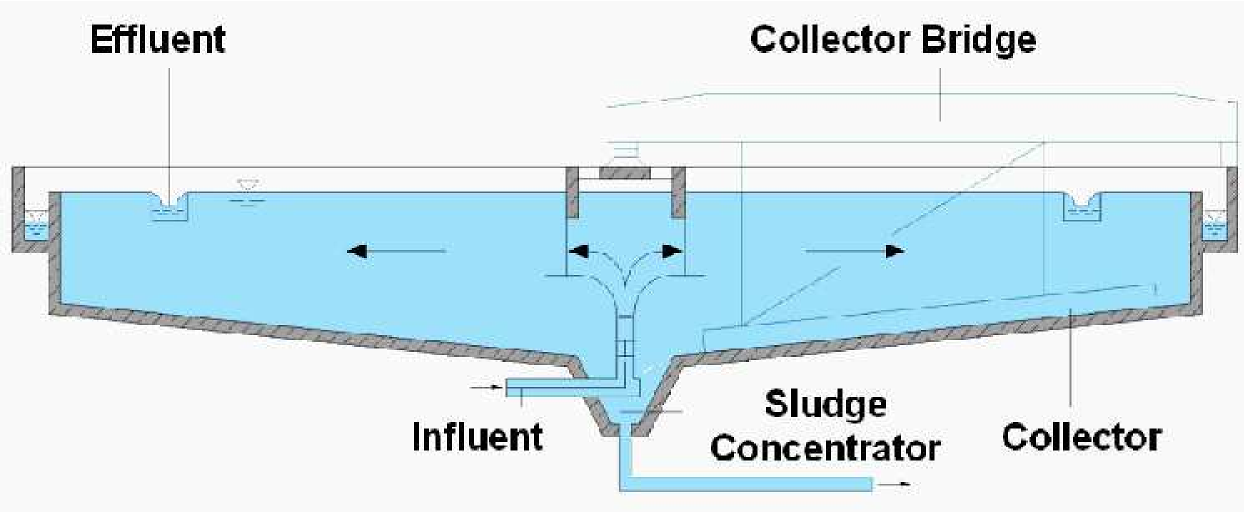


Figure 18: Example for a circular sedimentation tank (Source: Universität Stuttgart)

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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