

# Sewage Treatment, Sanitation and Water Supply Handbook



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## Chapter 1

# Sewage Treatment



The objective of sewage treatment is to produce a disposable effluent without causing harm to the surrounding environment and prevent pollution.

**Sewage treatment**, or **domestic wastewater treatment**, is the process of removing contaminants from wastewater and household sewage, both runoff (effluents) and domestic. It includes physical, chemical, and biological processes to remove physical, chemical and biological contaminants. Its objective is to produce an environmentally-safe fluid waste stream (or treated effluent) and a solid waste (or treated sludge) suitable for

disposal or reuse (usually as farm fertilizer). Using advanced technology it is now possible to re-use sewage effluent for drinking water, although Singapore is the only country to implement such technology on a production scale in its production of NEWater.

## ***Origins of sewage***

Sewage is created by residential, institutional, and commercial and industrial establishments and includes household waste liquid from toilets, baths, showers, kitchens, sinks and so forth that is disposed of via sewers. In many areas, sewage also includes liquid waste from industry and commerce. The separation and draining of household waste into greywater and blackwater is becoming more common in the developed world, with greywater being permitted to be used for watering plants or recycled for flushing toilets.

Sewage may include stormwater runoff. Sewerage systems capable of handling stormwater are known as combined systems. Combined sewer systems are usually avoided now because precipitation causes widely varying flows reducing sewage treatment plant efficiency. Combined sewers require much larger, more expensive, treatment facilities than sanitary sewers. Heavy storm runoff may overwhelm the sewage treatment system, causing a spill or overflow. Sanitary sewers are typically much smaller than combined sewers, and they are not designed to transport stormwater. Backups of raw sewage can occur if excessive Infiltration/Inflow is allowed into a sanitary sewer system.

Modern sewered developments tend to be provided with separate storm drain systems for rainwater. As rainfall travels over roofs and the ground, it may pick up various contaminants including soil particles and other sediment, heavy metals, organic compounds, animal waste, and oil and grease. Some jurisdictions require stormwater to receive some level of treatment before being discharged directly into waterways. Examples of treatment processes used for stormwater include retention basins, wetlands, buried vaults with various kinds of media filters, and vortex separators (to remove coarse solids).

## ***Process overview***

Sewage can be treated close to where it is created, a decentralised system, (in septic tanks, biofilters or aerobic treatment systems), or be collected and transported via a network of pipes and pump stations to a municipal treatment plant, a centralised system. Sewage collection and treatment is typically subject to local, state and federal regulations and standards. Industrial sources of wastewater often require specialized treatment processes.

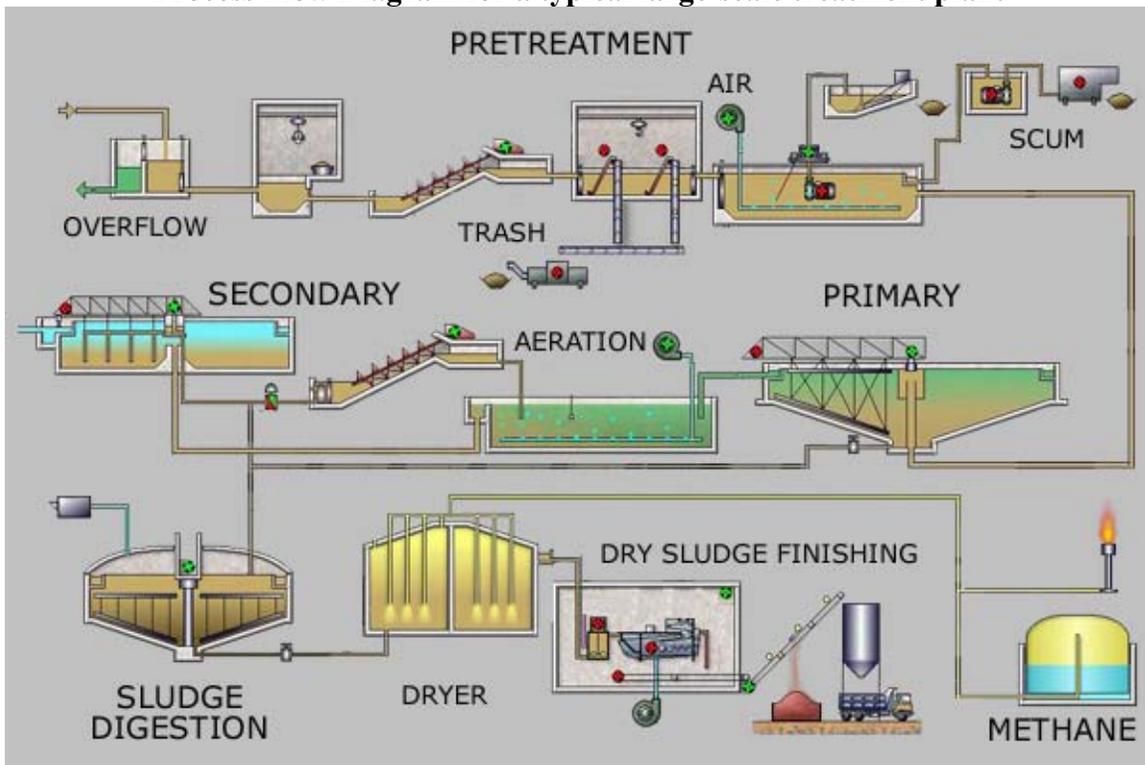
Sewage treatment generally involves three stages, called primary, secondary and tertiary treatment.

- *Primary treatment* consists of temporarily holding the sewage in a quiescent basin where heavy solids can settle to the bottom while oil, grease and lighter solids

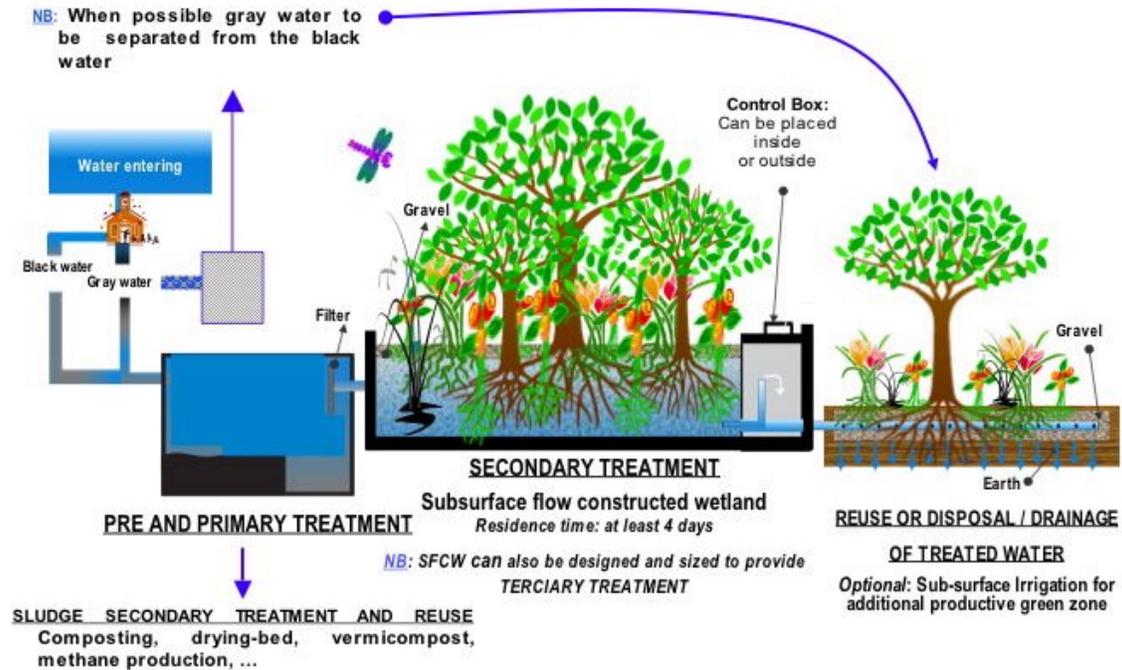
float to the surface. The settled and floating materials are removed and the remaining liquid may be discharged or subjected to secondary treatment.

- *Secondary treatment* removes dissolved and suspended biological matter. Secondary treatment is typically performed by indigenous, water-borne micro-organisms in a managed habitat. Secondary treatment may require a separation process to remove the micro-organisms from the treated water prior to discharge or tertiary treatment.
- *Tertiary treatment* is sometimes defined as anything more than primary and secondary treatment in order to allow rejection into a highly sensitive or fragile ecosystem (estuaries, low-flow rivers, coral reefs,...). Treated water is sometimes disinfected chemically or physically (for example, by lagoons and microfiltration) prior to discharge into a stream, river, bay, lagoon or wetland, or it can be used for the irrigation of a golf course, green way or park. If it is sufficiently clean, it can also be used for groundwater recharge or agricultural purposes.

**Process Flow Diagram for a typical large-scale treatment plant**



Process Flow Diagram for a typical treatment plant via Subsurface Flow Constructed Wetlands (SFCW)



## Pre-treatment

Pre-treatment removes materials that can be easily collected from the raw waste water before they damage or clog the pumps and skimmers of primary treatment clarifiers (trash, tree limbs, leaves, etc.).

## Screening

The influent sewage water is screened to remove all large objects like cans, rags, sticks, plastic packets etc. carried in the sewage stream. This is most commonly done with an automated mechanically raked bar screen in modern plants serving large populations, whilst in smaller or less modern plants a manually cleaned screen may be used. The raking action of a mechanical bar screen is typically paced according to the accumulation on the bar screens and/or flow rate. The solids are collected and later disposed in a landfill or incinerated. Bar screens or mesh screens of varying sizes may be used to optimize solids removal. If gross solids are not removed they become entrained in pipes and moving parts of the treatment plant and can cause substantial damage and inefficiency in the process.

## Grit removal

Pre-treatment may include a sand or grit channel or chamber where the velocity of the incoming wastewater is adjusted to allow the settlement of sand, grit, stones, and broken glass. These particles are removed because they may damage pumps and other

equipment. For small sanitary sewer systems, the grit chambers may not be necessary, but grit removal is desirable at larger plants.



An empty sedimentation tank at the treatment plant in Merchtem, Belgium.

## **Fat and grease removal**

In some larger plants, fat and grease is removed by passing the sewage through a small tank where skimmers collect the fat floating on the surface. Air blowers in the base of the tank may also be used to help recover the fat as a froth. In most plants however, fat and grease removal takes place in the primary settlement tank using mechanical surface skimmers.

## **Primary treatment**

In the primary sedimentation stage, sewage flows through large tanks, commonly called "primary clarifiers" or "primary sedimentation tanks." The tanks are used to settle sludge while grease and oils rise to the surface and are skimmed off. Primary settling tanks are usually equipped with mechanically driven scrapers that continually drive the collected sludge towards a hopper in the base of the tank where it is pumped to sludge treatment facilities.<sup>9-11</sup> Grease and oil from the floating material can sometimes be recovered for saponification.

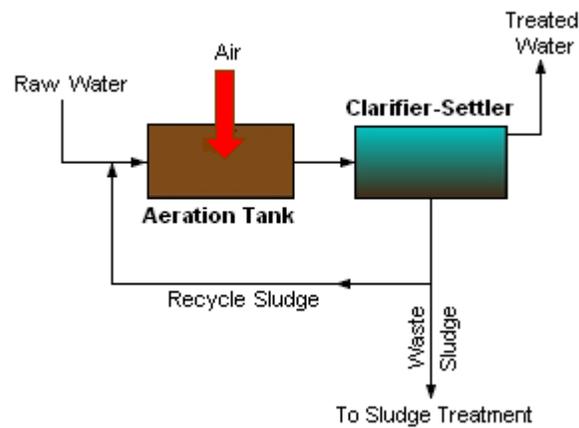
The dimensions of the tank should be designed to effect removal of a high percentage of the floatables and sludge. A typical sedimentation tank may remove from 60 to 65 percent of suspended solids, and from 30 to 35 percent of biochemical oxygen demand (BOD) from the sewage.

## Secondary treatment

**Secondary treatment** is designed to substantially degrade the biological content of the sewage which are derived from human waste, food waste, soaps and detergent. The majority of municipal plants treat the settled sewage liquor using aerobic biological processes. To be effective, the biota require both oxygen and food to live. The bacteria and protozoa consume biodegradable soluble organic contaminants (e.g. sugars, fats, organic short-chain carbon molecules, etc.) and bind much of the less soluble fractions into floc. Secondary treatment systems are classified as *fixed-film* or *suspended-growth* systems.

- **Fixed-film** or **attached growth** systems include trickling filters and rotating biological contactors, where the biomass grows on media and the sewage passes over its surface.
- **Suspended-growth** systems include activated sludge, where the biomass is mixed with the sewage and can be operated in a smaller space than fixed-film systems that treat the same amount of water. However, fixed-film systems are more able to cope with drastic changes in the amount of biological material and can provide higher removal rates for organic material and suspended solids than suspended growth systems.

Roughing filters are intended to treat particularly strong or variable organic loads, typically industrial, to allow them to then be treated by conventional secondary treatment processes. Characteristics include filters filled with media to which wastewater is applied. They are designed to allow high hydraulic loading and a high level of aeration. On larger installations, air is forced through the media using blowers. The resultant wastewater is usually within the normal range for conventional treatment processes.



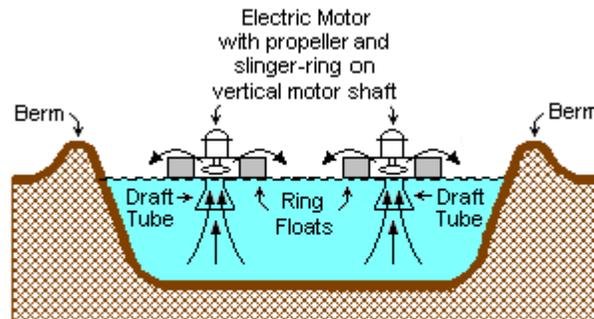
A generalized, schematic diagram of an activated sludge process.

A filter removes a small percentage of the suspended organic matter, while the majority of the organic matter undergoes a change of character, only due to the biological oxidation and nitrification taking place in the filter. With this aerobic oxidation and nitrification, the organic solids are converted into coagulated suspended mass, which is heavier and bulkier, and can settle to the bottom of a tank. The effluent of the filter is therefore passed through a sedimentation tank, called a secondary clarifier, secondary settling tank or humus tank.

## Activated sludge

In general, activated sludge plants encompass a variety of mechanisms and processes that use dissolved oxygen to promote the growth of biological floc that substantially removes organic material.

The process traps particulate material and can, under ideal conditions, convert ammonia to nitrite and nitrate and ultimately to nitrogen gas.



**A TYPICAL SURFACE – AERATED BASIN**

Note: The ring floats are tethered to posts on the berms.

A Typical Surface-Aerated Basin (using motor-driven floating aerators)

## Surface-aerated basins (Lagoons)

Many small municipal sewage systems in the United States (1 million gal./day or less) use aerated lagoons.

Most biological oxidation processes for treating industrial wastewaters have in common the use of oxygen (or air) and microbial action. Surface-aerated basins achieve 80 to 90 percent removal of BOD with retention times of 1 to 10 days. The basins may range in depth from 1.5 to 5.0 metres and use motor-driven aerators floating on the surface of the wastewater.

In an aerated basin system, the aerators provide two functions: they transfer air into the basins required by the biological oxidation reactions, and they provide the mixing required for dispersing the air and for contacting the reactants (that is, oxygen, wastewater and microbes). Typically, the floating surface aerators are rated to deliver the amount of air equivalent to 1.8 to 2.7 kg O<sub>2</sub>/kW·h. However, they do not provide as good

mixing as is normally achieved in activated sludge systems and therefore aerated basins do not achieve the same performance level as activated sludge units.

Biological oxidation processes are sensitive to temperature and, between 0 °C and 40 °C, the rate of biological reactions increase with temperature. Most surface aerated vessels operate at between 4 °C and 32 °C.

## **Constructed wetlands**

Constructed wetlands (can either be surface flow or subsurface flow, horizontal or vertical flow), include engineered reedbeds and belong to the family of phytoremediation and ecotechnologies; they provide a high degree of biological improvement and depending on design, act as a primary, secondary and sometimes tertiary treatment. One example is a small reedbed used to clean the drainage from the elephants' enclosure at Chester Zoo in England; numerous CWs are used to recycle the water of the city of Honfleur in France and numerous other towns in Europe, the US, Asia and Australia. They are known to be highly productive systems as they copy natural wetlands, called the "Kidneys of the earth" for their fundamental recycling capacity of the hydrological cycle in the biosphere. Robust and reliable, their treatment capacities improve as time goes by, at the opposite of conventional treatment plants whose machinery ages with time. They are being increasingly used, although adequate and experienced design are more fundamental than for other systems and space limitation may impede their use.

## **Filter beds (oxidizing beds)**

In older plants and those receiving variable loadings, trickling filter beds are used where the settled sewage liquor is spread onto the surface of a bed made up of coke (carbonized coal), limestone chips or specially fabricated plastic media. Such media must have large surface areas to support the biofilms that form. The liquor is typically distributed through perforated spray arms. The distributed liquor trickles through the bed and is collected in drains at the base. These drains also provide a source of air which percolates up through the bed, keeping it aerobic. Biological films of bacteria, protozoa and fungi form on the media's surfaces and eat or otherwise reduce the organic content. This biofilm is often grazed by insect larvae, snails, and worms which help maintain an optimal thickness. Overloading of beds increases the thickness of the film leading to clogging of the filter media and ponding on the surface. Recent advances in media and process microbiology design overcome many issues with Trickling filter designs.

## **Soil Bio-Technology**

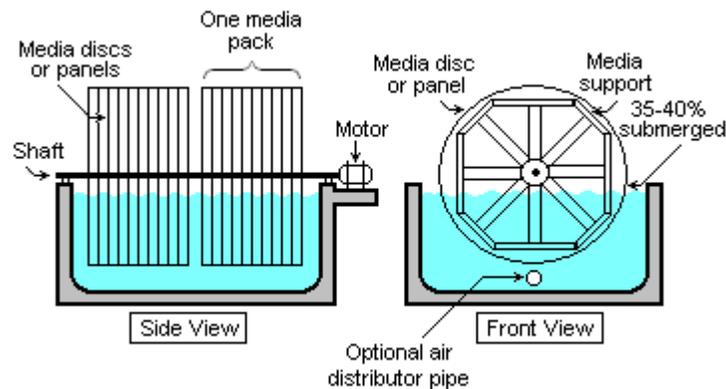
A new process called Soil Bio-Technology (SBT) developed at IIT Bombay has shown tremendous improvements in process efficiency enabling total water reuse, due to extremely low operating power requirements of less than 50 joules per kg of treated water. Typically SBT systems can achieve chemical oxygen demand (COD) levels less than 10 mg/L from sewage input of COD 400 mg/L. SBT plants exhibit high reductions in COD values and bacterial counts as a result of the very high microbial densities available in the media. Unlike conventional treatment plants, SBT plants produce

insignificant amounts of sludge, precluding the need for sludge disposal areas that are required by other technologies.

In the Indian context, conventional sewage treatment plants fall into systemic disrepair due to 1) high operating costs, 2) equipment corrosion due to methanogenesis and hydrogen sulphide, 3) non-reusability of treated water due to high COD ( $>30$  mg/L) and high fecal coliform ( $>3000$  NFU) counts, 4) lack of skilled operating personnel and 5) equipment replacement issues. Examples of such systemic failures has been documented by Sankat Mochan Foundation at the Ganges basin after a massive cleanup effort by the Indian government in 1986 by setting up sewage treatment plants under the Ganga Action Plan failed to improve river water quality.

## Biological aerated filters

Biological Aerated (or Anoxic) Filter (BAF) or Biofilters combine filtration with biological carbon reduction, nitrification or denitrification. BAF usually includes a reactor filled with a filter media. The media is either in suspension or supported by a gravel layer at the foot of the filter. The dual purpose of this media is to support highly active biomass that is attached to it and to filter suspended solids. Carbon reduction and ammonia conversion occurs in aerobic mode and sometime achieved in a single reactor while nitrate conversion occurs in anoxic mode. BAF is operated either in upflow or downflow configuration depending on design specified by manufacturer.



Schematic diagram of a typical rotating biological contactor (RBC). The treated effluent clarifier/settler is not included in the diagram.

## Rotating biological contactors

Rotating biological contactors (RBCs) are mechanical secondary treatment systems, which are robust and capable of withstanding surges in organic load. RBCs were first installed in Germany in 1960 and have since been developed and refined into a reliable operating unit. The rotating disks support the growth of bacteria and micro-organisms present in the sewage, which break down and stabilise organic pollutants. To be successful, micro-organisms need both oxygen to live and food to grow. Oxygen is obtained from the atmosphere as the disks rotate. As the micro-organisms grow, they build up on the media until they are sloughed off due to shear forces provided by the

rotating discs in the sewage. Effluent from the RBC is then passed through final clarifiers where the micro-organisms in suspension settle as a sludge. The sludge is withdrawn from the clarifier for further treatment.

A functionally similar biological filtering system has become popular as part of home aquarium filtration and purification. The aquarium water is drawn up out of the tank and then cascaded over a freely spinning corrugated fiber-mesh wheel before passing through a media filter and back into the aquarium. The spinning mesh wheel develops a biofilm coating of microorganisms that feed on the suspended wastes in the aquarium water and are also exposed to the atmosphere as the wheel rotates. This is especially good at removing waste urea and ammonia excreted into the aquarium water by the fish and other animals.

## **Membrane bioreactors**

Membrane bioreactors (MBR) combine activated sludge treatment with a membrane liquid-solid separation process. The membrane component uses low pressure microfiltration or ultra filtration membranes and eliminates the need for clarification and tertiary filtration. The membranes are typically immersed in the aeration tank; however, some applications utilize a separate membrane tank. One of the key benefits of an MBR system is that it effectively overcomes the limitations associated with poor settling of sludge in conventional activated sludge (CAS) processes. The technology permits bioreactor operation with considerably higher mixed liquor suspended solids (MLSS) concentration than CAS systems, which are limited by sludge settling. The process is typically operated at MLSS in the range of 8,000–12,000 mg/L, while CAS are operated in the range of 2,000–3,000 mg/L. The elevated biomass concentration in the MBR process allows for very effective removal of both soluble and particulate biodegradable materials at higher loading rates. Thus increased sludge retention times, usually exceeding 15 days, ensure complete nitrification even in extremely cold weather.

The cost of building and operating an MBR is usually higher than conventional wastewater treatment. Membrane filters can be blinded with grease or abraded by suspended grit and lack a clarifier's flexibility to pass peak flows. The technology has become increasingly popular for reliably pretreated waste streams and has gained wider acceptance where infiltration and inflow have been controlled, however, and the life-cycle costs have been steadily decreasing. The small footprint of MBR systems, and the high quality effluent produced, make them particularly useful for water reuse applications.

## Secondary sedimentation



Secondary Sedimentation tank at a rural treatment plant.

The final step in the secondary treatment stage is to settle out the biological floc or filter material through a secondary clarifier and to produce sewage water containing low levels of organic material and suspended matter.

## Tertiary treatment

The purpose of tertiary treatment is to provide a final treatment stage to raise the effluent quality before it is discharged to the receiving environment (sea, river, lake, ground, etc.). More than one tertiary treatment process may be used at any treatment plant. If disinfection is practiced, it is always the final process. It is also called "effluent polishing."

## Filtration

Sand filtration removes much of the residual suspended matter. Filtration over activated carbon, also called *carbon adsorption*, removes residual toxins.

## Lagooning



A sewage treatment plant and lagoon in Everett, Washington, United States.

Lagooning provides settlement and further biological improvement through storage in large man-made ponds or lagoons. These lagoons are highly aerobic and colonization by native macrophytes, especially reeds, is often encouraged. Small filter feeding invertebrates such as *Daphnia* and species of *Rotifera* greatly assist in treatment by removing fine particulates.

## Nutrient removal

Wastewater may contain high levels of the nutrients nitrogen and phosphorus. Excessive release to the environment can lead to a build up of nutrients, called eutrophication, which can in turn encourage the overgrowth of weeds, algae, and cyanobacteria (blue-green algae). This may cause an algal bloom, a rapid growth in the population of algae. The algae numbers are unsustainable and eventually most of them die. The decomposition of the algae by bacteria uses up so much of oxygen in the water that most or all of the animals die, which creates more organic matter for the bacteria to decompose. In addition to causing deoxygenation, some algal species produce toxins that contaminate drinking water supplies. Different treatment processes are required to remove nitrogen and phosphorus.

## Nitrogen removal

The removal of nitrogen is effected through the biological oxidation of nitrogen from ammonia to nitrate (nitrification), followed by denitrification, the reduction of nitrate to nitrogen gas. Nitrogen gas is released to the atmosphere and thus removed from the water.

Nitrification itself is a two-step aerobic process, each step facilitated by a different type of bacteria. The oxidation of ammonia ( $\text{NH}_3$ ) to nitrite ( $\text{NO}_2^-$ ) is most often facilitated by *Nitrosomonas* spp. (nitroso referring to the formation of a nitroso functional group). Nitrite oxidation to nitrate ( $\text{NO}_3^-$ ), though traditionally believed to be facilitated by *Nitrobacter* spp. (nitro referring the formation of a nitro functional group), is now known to be facilitated in the environment almost exclusively by *Nitrospira* spp.

Denitrification requires anoxic conditions to encourage the appropriate biological communities to form. It is facilitated by a wide diversity of bacteria. Sand filters, lagooning and reed beds can all be used to reduce nitrogen, but the activated sludge process (if designed well) can do the job the most easily. Since denitrification is the reduction of nitrate to dinitrogen gas, an electron donor is needed. This can be, depending on the wastewater, organic matter (from faeces), sulfide, or an added donor like methanol.

Sometimes the conversion of toxic ammonia to nitrate alone is referred to as tertiary treatment.

Many sewage treatment plants use axial flow pumps to transfer the nitrified mixed liquor from the aeration zone to the anoxic zone for denitrification. These pumps are often referred to as *Internal Mixed Liquor Recycle* (IMLR) pumps. The sludge in the anoxic tanks must be mixed well (mixture of recirculated mixed liquor, return activated sludge [RAS], and raw influent) by using submersible mixers in order to achieve the desired denitrification.

## Phosphorus removal

Phosphorus removal is important as it is a limiting nutrient for algae growth in many fresh water systems. It is also particularly important for water reuse systems where high phosphorus concentrations may lead to fouling of downstream equipment such as reverse osmosis.

Phosphorus can be removed biologically in a process called enhanced biological phosphorus removal. In this process, specific bacteria, called polyphosphate accumulating organisms (PAOs), are selectively enriched and accumulate large quantities of phosphorus within their cells (up to 20 percent of their mass). When the biomass enriched in these bacteria is separated from the treated water, these biosolids have a high fertilizer value.

Phosphorus removal can also be achieved by chemical precipitation, usually with salts of iron (e.g. ferric chloride), aluminum (e.g. alum), or lime. This may lead to excessive

sludge production as hydroxides precipitates and the added chemicals can be expensive. Chemical phosphorus removal requires significantly smaller equipment footprint than biological removal, is easier to operate and is often more reliable than biological phosphorus removal. Another method for phosphorus removal is to use granular laterite.

Once removed, phosphorus, in the form of a phosphate-rich sludge, may be stored in a land fill or resold for use in fertilizer.

## **Disinfection**

The purpose of disinfection in the treatment of waste water is to substantially reduce the number of microorganisms in the water to be discharged back into the environment. The effectiveness of disinfection depends on the quality of the water being treated (e.g., cloudiness, pH, etc.), the type of disinfection being used, the disinfectant dosage (concentration and time), and other environmental variables. Cloudy water will be treated less successfully, since solid matter can shield organisms, especially from ultraviolet light or if contact times are low. Generally, short contact times, low doses and high flows all militate against effective disinfection. Common methods of disinfection include ozone, chlorine, ultraviolet light, or sodium hypochlorite. Chloramine, which is used for drinking water, is not used in waste water treatment because of its persistence.

Chlorination remains the most common form of waste water disinfection in North America due to its low cost and long-term history of effectiveness. One disadvantage is that chlorination of residual organic material can generate chlorinated-organic compounds that may be carcinogenic or harmful to the environment. Residual chlorine or chloramines may also be capable of chlorinating organic material in the natural aquatic environment. Further, because residual chlorine is toxic to aquatic species, the treated effluent must also be chemically dechlorinated, adding to the complexity and cost of treatment.

Ultraviolet (UV) light can be used instead of chlorine, iodine, or other chemicals. Because no chemicals are used, the treated water has no adverse effect on organisms that later consume it, as may be the case with other methods. UV radiation causes damage to the genetic structure of bacteria, viruses, and other pathogens, making them incapable of reproduction. The key disadvantages of UV disinfection are the need for frequent lamp maintenance and replacement and the need for a highly treated effluent to ensure that the target microorganisms are not shielded from the UV radiation (i.e., any solids present in the treated effluent may protect microorganisms from the UV light). In the United Kingdom, UV light is becoming the most common means of disinfection because of the concerns about the impacts of chlorine in chlorinating residual organics in the wastewater and in chlorinating organics in the receiving water. Some sewage treatment systems in Canada and the US also use UV light for their effluent water disinfection.

Ozone ( $O_3$ ) is generated by passing oxygen ( $O_2$ ) through a high voltage potential resulting in a third oxygen atom becoming attached and forming  $O_3$ . Ozone is very unstable and reactive and oxidizes most organic material it comes in contact with, thereby destroying many pathogenic microorganisms. Ozone is considered to be safer than chlorine because, unlike chlorine which has to be stored on site (highly poisonous in the

event of an accidental release), ozone is generated onsite as needed. Ozonation also produces fewer disinfection by-products than chlorination. A disadvantage of ozone disinfection is the high cost of the ozone generation equipment and the requirements for special operators.

## **Odour Control**

Odours emitted by sewage treatment are typically an indication of an anaerobic or "septic" condition. Early stages of processing will tend to produce smelly gases, with hydrogen sulfide being most common in generating complaints. Large process plants in urban areas will often treat the odours with carbon reactors, a contact media with bio-slimes, small doses of chlorine, or circulating fluids to biologically capture and metabolize the obnoxious gases. Other methods of odour control exist, including addition of iron salts, hydrogen peroxide, calcium nitrate, etc. to manage hydrogen sulfide levels.

## ***Package plants and batch reactors***

To use less space, treat difficult waste and intermittent flows, a number of designs of hybrid treatment plants have been produced. Such plants often combine at least two stages of the three main treatment stages into one combined stage. In the UK, where a large number of wastewater treatment plants serve small populations, package plants are a viable alternative to building a large structure for each process stage. In the US, package plants are typically used in rural areas, highway rest stops and trailer parks.

One type of system that combines secondary treatment and settlement is the sequencing batch reactor (SBR). Typically, activated sludge is mixed with raw incoming sewage, and then mixed and aerated. The settled sludge is run off and re-aerated before a proportion is returned to the headworks. SBR plants are now being deployed in many parts of the world.

The disadvantage of the SBR process is that it requires a precise control of timing, mixing and aeration. This precision is typically achieved with computer controls linked to sensors. Such a complex, fragile system is unsuited to places where controls may be unreliable, poorly maintained, or where the power supply may be intermittent. Extended aeration package plants use separate basins for aeration and settling, and are somewhat larger than SBR plants with reduced timing sensitivity.

Package plants may be referred to as *high charged* or *low charged*. This refers to the way the biological load is processed. In high charged systems, the biological stage is presented with a high organic load and the combined floc and organic material is then oxygenated for a few hours before being charged again with a new load. In the low charged system the biological stage contains a low organic load and is combined with flocculate for longer times.

## ***Sludge treatment and disposal***

The sludges accumulated in a wastewater treatment process must be treated and disposed of in a safe and effective manner. The purpose of digestion is to reduce the amount of

organic matter and the number of disease-causing microorganisms present in the solids. The most common treatment options include anaerobic digestion, aerobic digestion, and composting. Incineration is also used albeit to a much lesser degree.

Sludge treatment depends on the amount of solids generated and other site-specific conditions. Composting is most often applied to small-scale plants with aerobic digestion for mid sized operations, and anaerobic digestion for the larger-scale operations.

## **Anaerobic digestion**

Anaerobic digestion is a bacterial process that is carried out in the absence of oxygen. The process can either be *thermophilic* digestion, in which sludge is fermented in tanks at a temperature of 55°C, or *mesophilic*, at a temperature of around 36°C. Though allowing shorter retention time (and thus smaller tanks), thermophilic digestion is more expensive in terms of energy consumption for heating the sludge.

Anaerobic digestion is the most common (mesophilic) treatment of domestic sewage in septic tanks, which normally retain the sewage from one day to two days, reducing the BOD by about 35 to 40 percent. This reduction can be increased with a combination of anaerobic and aerobic treatment by installing *Aerobic Treatment Units* (ATUs) in the septic tank.

One major feature of anaerobic digestion is the production of biogas (with the most useful component being methane), which can be used in generators for electricity production and/or in boilers for heating purposes.

## **Aerobic digestion**

Aerobic digestion is a bacterial process occurring in the presence of oxygen. Under aerobic conditions, bacteria rapidly consume organic matter and convert it into carbon dioxide. The operating costs used to be characteristically much greater for aerobic digestion because of the energy used by the blowers, pumps and motors needed to add oxygen to the process.

Aerobic digestion can also be achieved by using diffuser systems or jet aerators to oxidize the sludge.

## **Composting**

Composting is also an aerobic process that involves mixing the sludge with sources of carbon such as sawdust, straw or wood chips. In the presence of oxygen, bacteria digest both the wastewater solids and the added carbon source and, in doing so, produce a large amount of heat.

## **Incineration**

Incineration of sludge is less common because of air emissions concerns and the supplemental fuel (typically natural gases or fuel oil) required to burn the low calorific

value sludge and vaporize residual water. Stepped multiple hearth incinerators with high residence time and fluidized bed incinerators are the most common systems used to combust wastewater sludge. Co-firing in municipal waste-to-energy plants is occasionally done, this option being less expensive assuming the facilities already exist for solid waste and there is no need for auxiliary fuel.

## **Sludge disposal**

When a liquid sludge is produced, further treatment may be required to make it suitable for final disposal. Typically, sludges are thickened (dewatered) to reduce the volumes transported off-site for disposal. There is no process which completely eliminates the need to dispose of biosolids. There is, however, an additional step some cities are taking to superheat sludge and convert it into small pelletized granules that are high in nitrogen and other organic materials. In New York City, for example, several sewage treatment plants have dewatering facilities that use large centrifuges along with the addition of chemicals such as polymer to further remove liquid from the sludge. The removed fluid, called centrate, is typically reintroduced into the wastewater process. The product which is left is called "cake" and that is picked up by companies which turn it into fertilizer pellets. This product is then sold to local farmers and turf farms as a soil amendment or fertilizer, reducing the amount of space required to dispose of sludge in landfills. Much sludge originating from commercial or industrial areas is contaminated with toxic materials that are released into the sewers from the industrial processes. Elevated concentrations of such materials may make the sludge unsuitable for agricultural use and it may then have to be incinerated or disposed of to landfill.

## ***Treatment in the receiving environment***



The outlet of a wastewater treating plant flows into a small river

Many processes in a wastewater treatment plant are designed to mimic the natural treatment processes that occur in the environment, whether that environment is a natural water body or the ground. If not overloaded, bacteria in the environment will consume organic contaminants, although this will reduce the levels of oxygen in the water and may significantly change the overall ecology of the receiving water. Native bacterial populations feed on the organic contaminants, and the numbers of disease-causing microorganisms are reduced by natural environmental conditions such as predation or exposure to ultraviolet radiation. Consequently, in cases where the receiving environment provides a high level of dilution, a high degree of wastewater treatment may not be required. However, recent evidence has demonstrated that very low levels of specific contaminants in wastewater, including hormones (from animal husbandry and residue from human hormonal contraception methods) and synthetic materials such as phthalates that mimic hormones in their action, can have an unpredictable adverse impact on the natural biota and potentially on humans if the water is re-used for drinking water. In the US and EU, uncontrolled discharges of wastewater to the environment are not permitted under law, and strict water quality requirements are to be met. A significant threat in the coming decades will be the increasing uncontrolled discharges of wastewater within rapidly developing countries.

## Effects on Biology

Sewage treatment plants can have multiple effects on nutrient levels in the water that the treated sewage flows into. These effects on nutrients can have large effects on the biological life in the water in contact with the effluent. Stabilization ponds (or treatment ponds) can include any of the following:

- Oxidation ponds, which are aerobic bodies of water usually 1–2 meters in depth that receive effluent from sedimentation tanks or other forms of primary treatment.
  - Dominated by algae
- Polishing ponds are similar to oxidation ponds but receive effluent from an oxidation pond or from a plant with an extended mechanical treatment.
  - Dominated by zooplankton
- Facultative lagoons, raw sewage lagoons, or sewage lagoons are ponds where sewage is added with no primary treatment other than coarse screening. These ponds provide effective treatment when the surface remains aerobic; although anaerobic conditions may develop near the layer of settled sludge on the bottom of the pond.
- Anaerobic lagoons are heavily loaded ponds.
  - Dominated by bacteria
- Sludge lagoons are aerobic ponds, usually 2–5 meters in depth, that receive anaerobically digested primary sludge, or activated secondary sludge under water.
  - Upper layers are dominated by algae

Phosphorous limitation is a possible result from sewage treatment and results in flagellate-dominated plankton, particularly in summer and fall.

At the same time a different study found high nutrient concentrations linked to sewage effluents. High nutrient concentration leads to high chlorophyll a concentrations, which is a proxy for primary production in marine environments. High primary production means high phytoplankton populations and most likely high zooplankton populations because zooplankton feed on phytoplankton. However, effluent released into marine systems also leads to greater population instability.

A study done in Britain found that the quality of effluent effected the planktonic life in the water in direct contact with the wastewater effluent. Turbid, low-quality effluents either did not contain ciliated protozoa or contained only a few species in small numbers. On the other hand, high-quality effluents contained a wide variety of ciliated protozoa in large numbers. Due to these findings, it seems unlikely that any particular component of

the industrial effluent has, by itself, any harmful effects on the protozoan populations of activated sludge plants.

The planktonic trends of high populations close to input of treated sewage is contrasted by the bacterial trend. In a study of *Aeromonas* spp. in increasing distance from a wastewater source, greater change in seasonal cycles was found the furthest from the effluent. This trend is so strong that the furthest location studied actually had an inversion of the *Aeromonas* spp. cycle in comparison to that of fecal coliforms. Since there is a main pattern in the cycles that occurred simultaneously at all stations it indicates seasonal factors (temperature, solar radiation, phytoplankton) control of the bacterial population. The effluent dominant species changes from *Aeromonas caviae* in winter to *Aeromonas sobria* in the spring and fall while the inflow dominant species is *Aeromonas caviae*, which is constant throughout the seasons.

### ***Sewage treatment in developing countries***

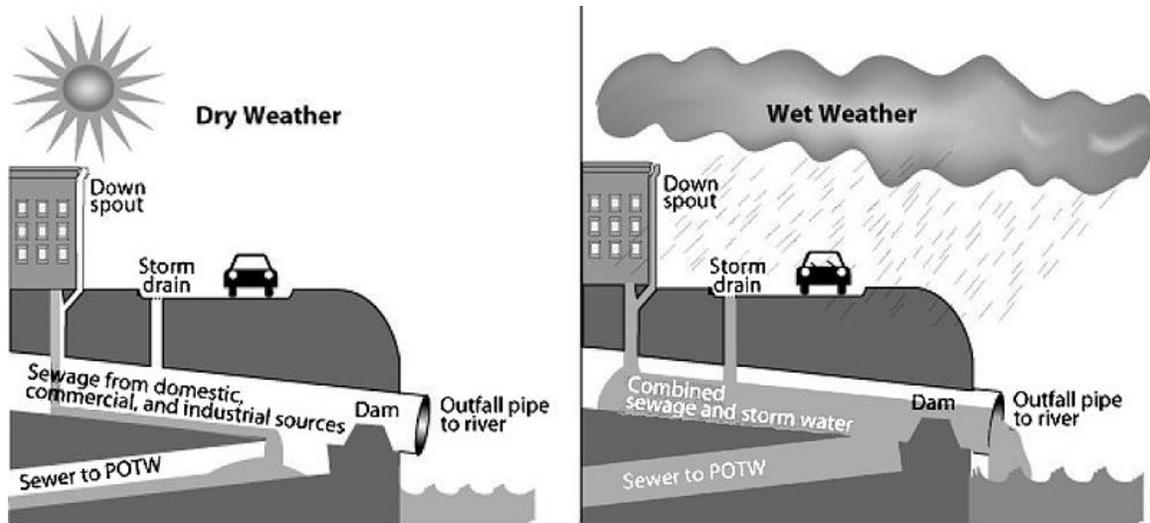
Few reliable figures on the share of the wastewater collected in sewers that is being treated in the world exist. In many developing countries the bulk of domestic and industrial wastewater is discharged without any treatment or after primary treatment only. In Latin America about 15% of collected wastewater passes through treatment plants (with varying levels of actual treatment). In Venezuela, a below average country in South America with respect to wastewater treatment, 97 percent of the country's sewage is discharged raw into the environment. In a relatively developed Middle Eastern country such as Iran, Tehran's majority of population has totally untreated sewage injected to the city's groundwater. However now the construction of major parts of the sewage system, collection and treatment, in Tehran is almost complete, and under development, due to be fully completed by the end of 2012.

In Israel, about 50 percent of agricultural water usage (total use was 1 billion cubic metres in 2008) is provided through reclaimed sewer water. Future plans call for increased use of treated sewer water as well as more desalination plants.

Most of sub-Saharan Africa is without wastewater treatment.

## Chapter 2

# Combined Sewer



**Combined Sewer System.** During dry weather (and small storms), all flows are handled by the publicly owned treatment works (POTW). During large storms, the relief structure allows some of the combined stormwater and sewage to be discharged untreated to an adjacent water body.

A **combined sewer** is a type of sewer system that collects sanitary sewage and stormwater runoff in a single pipe system. Combined sewers can cause serious water pollution problems due to combined sewer overflows, which are caused by large variations in flow between dry and wet weather. This type of sewer design is no longer used in building new communities, but many older cities continue to operate combined sewers.

### ***Design history***

The earliest covered sewers uncovered by archaeologists are in the regularly planned cities of the Indus Valley Civilization. In ancient Rome, the Cloaca Maxima, considered a marvel of engineering, disgorged into the Tiber. In ancient China, sewers existed in various cities such as Linzi. In medieval European cities, small natural waterways used

for carrying off wastewater were eventually covered over and functioned as sewers. London's River Fleet is such a system. Open drains along the center of some streets were known as 'kennels' (= canals, channels). The nineteenth century brick-vaulted sewer system of Paris (The Paris sewers) offers tours for tourists.

Most of these early sewers received significant amounts of draft animal dung in street runoff; but handling of human waste varied with location. Public latrines were built over the Cloaca Maxima, but chamber pot contents were prohibited from Paris sewers as recently as 1880. People wealthy enough to enjoy 19th century flush toilets often had the political power to allow them to drain into public sewers; and the practice became the norm as indoor plumbing became more common.

Many cities that installed sewage collection systems in the early 20th century, or earlier, used single-pipe systems that collect both sewage and urban runoff from streets and roofs. This type of collection system is referred to as a **combined sewer system** or a CSS. The cities' rationale when these systems were built was that it would be cheaper to build just a single system.<sup>8</sup> Most cities at that time did not have sewage treatment plants, so there was no perceived public health advantage in constructing a separate storm sewer system.<sup>p.2-3</sup> Combined sewer systems are found throughout the United States, but are most heavily concentrated in the Northeast and Great Lakes regions. State and local authorities have generally not allowed the construction of new CSSs since the first half of the 20th century.

When constructed, combined sewer systems were typically sized to carry three to five times the average dry weather flows.<sup>p.2-4</sup> As cities added sewage treatment plants, relief structures were installed in the collection system so that the flow could be discharged into a river or stream during large storm events when the capacity of the pipe exceeded the capacity of the wastewater treatment plant. By using these devices, called *regulators*, to discharge the excessive flow into a nearby water body, sewer backups in homes and streets are prevented.

In the UK, sewerage provision regulators (agencies) categorise all sewerage derived flooding as being one of two types: those due to hydraulic overloading and those due to all other causes. Although the media tends to focus on the former, 84% of sewerage derived flooding incidents (~26,000 per year) in England and Wales fall into the latter of these categories and ~90% of these are due to blockages. Considering the role of blockages is therefore a key research challenge; across the world they are probably the number one cause of losses in sewer serviceability (and hence flooding) in either dry or wet weather flow conditions.

## **Combined Sewer Overflows**

A **combined sewer overflow**, or CSO, is the discharge of wastewater and stormwater from a combined sewer system directly into a river, stream, lake or ocean. Overflow frequency and duration varies both from system to system, and from outfall to outfall, within a single combined sewer system. Some CSO outfalls discharge infrequently, while others activate every time it rains. During heavy rainfall when the stormwater exceeds the sanitary flow, the CSO is diluted.

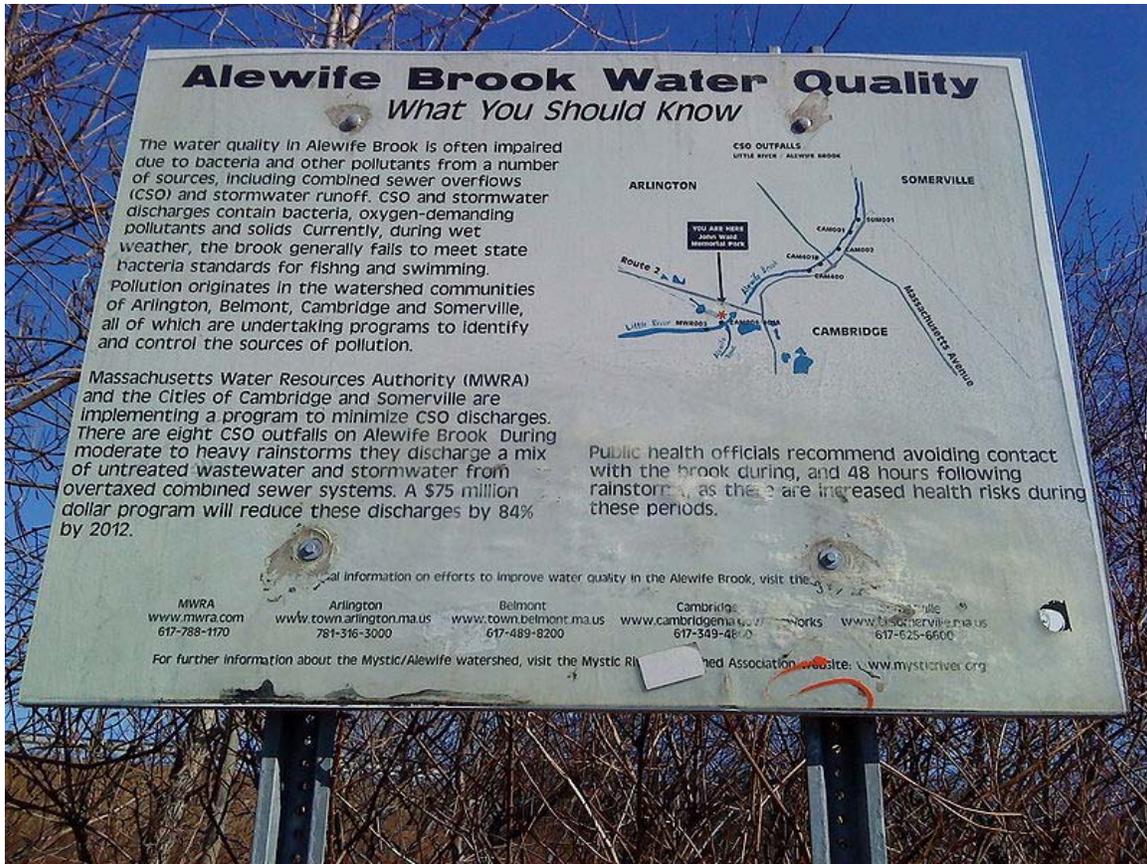
The storm water component contributes a significant amount of pollutants to CSO. Each storm is different in the quantity and type of pollutants it contributes. For example, storms that occur in late summer, when it has not rained for a while, have the most pollutants. Pollutants like oil, grease, fecal coliform from pet and wildlife waste, and pesticides get flushed into the sewer system. In cold weather areas, pollutants from cars, people and animals also accumulate on hard surfaces and grass during the winter and then are flushed into the sewer systems during heavy spring rains.

### ***Extent and Effects of CSOs in United States***

About 772 communities in the United States have combined sewer systems, serving about 40 million people. CSO discharges during heavy storms can cause serious water pollution problems in these communities. Pollutants from CSO discharges can include bacteria and other pathogens, toxic chemicals, and debris. The U.S. Environmental Protection Agency (EPA) issued a policy in 1994 requiring municipalities to make improvements to reduce or eliminate CSO-related pollution problems. In 2000 Congress amended the Clean Water Act to require the municipalities to comply with the EPA policy.

### ***Mitigation of CSO Impacts in United States***

Municipalities have been undertaking projects to mitigate CSO since the 1990s. For example, prior to 1990, the quantity of untreated combined sewage discharged annually to lakes, rivers and streams in southeast Michigan was estimated at more than 30 billion gallons per year. In 2005, with nearly US\$1 billion of a planned \$2.4 billion CSO investment put into operation, untreated discharges have been reduced by more than 20 billion gallons per year. This investment that has yielded a 67% reduction in CSO has included numerous sewer separation, CSO storage and treatment facilities and wastewater treatment plant improvements constructed by local and regional governments. Many other areas of the U.S. are undertaking similar projects to address CSO.



CSO signage at the Alewife Brook Reservation in Cambridge, MA.

## Sewer separation

Some U.S. cities have undertaken sewer separation projects—building a second piping system for all or part of the community. In many of these projects, cities have been able to separate only portions of their combined systems. High costs or physical limitations may preclude building a completely separate system. Washington, D.C. is separating its sewers in four small neighborhoods at a cost of \$11 million. (The project cost also includes improvements to the drinking water piping system.)

## CSO storage

Another solution is to build a CSO storage facility, such as a tunnel that can store flow from many sewer connections. Because a tunnel can share capacity among several outfalls, it can reduce the total volume of storage that must be provided for a specific number of outfalls. Storage tunnels store combined sewage but do not treat it. When the storm is over, the flows are pumped out of the tunnel and sent to a wastewater treatment plant.

## Expanding sewage treatment capacity

Some cities have expanded their basic sewage treatment capacity to handle some or all of the CSO volume. In 2002 the city of Toledo, Ohio, following litigation, agreed to double

its treatment capacity, and build a storage basin, to eliminate most overflows. The city also agreed to study ways to reduce stormwater flows into the sewer system.

## **Retention basins**

Retention treatment basins or large concrete tanks that store and treat combined sewage are another solution. These underground structures can range in storage and treatment capacity from 2 million to 120 million gallons of combined sewage. While each facility is unique, a typical facility operation is as follows. Flows from the overloaded sewers are pumped into a basin that is divided into compartments. The *first flush* compartment captures and stores flows with the highest level of pollutants from the first part of a storm. These pollutants include motor oil, sediment, road salt, and lawn chemicals (pesticides and fertilizers) that are picked up by the stormwater as it runs off roads and lawns. The flows from this compartment are stored and sent to the wastewater treatment plant when there is capacity in the interceptor sewer after the storm. The second compartment is a treatment or flow-through compartment. The flows are disinfected by injecting sodium hypochlorite, or bleach, as they enter this compartment. It then takes about 20 to 30 minutes for the flows to move to the end of the compartment. During this time, bacteria are killed and large solid materials settle out. At the end of the compartment, any remaining sanitary trash is skimmed off the top and the treated flows are discharged into the river or lake.

## **Screening and disinfection facilities**

Screening and disinfection facilities treat CSO without ever storing it. Called flow-through facilities, they use fine screens to remove solids and sanitary trash from the combined sewage. Flows are injected with sodium hypochlorite for disinfection and mixed as they travel through a series of fine screens to remove debris. The fine screens have openings that range in size from 4 to 6 mm, or a little less than ¼ inch. The flow is sent through the facility at a rate that provides enough time for the sodium hypochlorite to kill bacteria. All of the materials removed by the screens are then sent to the wastewater treatment plant through the interceptor sewer.

## **Reducing stormwater flows**

Communities may implement low impact development techniques to reduce flows of stormwater into the collection system. This includes:

- constructing new and renovated streets, parking lots and sidewalks with permeable paving and pervious concrete
- installing green roofs on buildings
- installing bioretention systems, also called rain gardens, in landscaped areas
- Rainwater harvesting equipment collects runoff from building roofs during wet weather for irrigating landscapes and gardens during dry weather
- Graywater collection and use on site reduces sewage discharges at all times

The 2004 EPA **Report to Congress** on CSO's provides a review of available technologies to mitigate CSO impacts.

## Chapter 3

# Sanitary Sewer



PVC Sanitary Sewer Installation. Sanitary sewers are sized to carry the amount of sewage generated by the collection area. Sanitary sewers are much smaller than combined sewers designed to also carry surface runoff. The few sanitary sewers large enough for a man to stand erect typically carry flows that would sweep him off his feet.



A manhole cover for a sanitary sewer access point



Interior photo of a large sanitary sewer from an access manhole

A **sanitary sewer** (also called a **foul sewer**) is a separate underground carriage system specifically for transporting sewage from houses and commercial buildings to treatment or disposal. Sanitary sewers serving industrial areas also carry industrial wastewater. The 'system of sewers' is called sewerage.

Sanitary sewers are operated separately and independently of storm drains, which carry the runoff of rain and other water which wash into city streets.<sup>:Ch.1</sup> Sewers carrying both sewage and stormwater together are called combined sewers.

### ***Nomenclature***

In the developed world, sewers are usually pipelines that begin with connecting pipes from buildings to one or more levels of larger underground trunk mains, which transport the sewage to sewage treatment facilities. Vertical pipes, called manholes, connect the mains to the surface. The manholes are used for access to the sewer pipes for inspection and maintenance, and as a means to vent sewer gases. They also facilitate vertical and horizontal angles in otherwise straight pipelines. Sewers are generally gravity powered, though pumps may be used if necessary. The most commonly used sanitary pipe is SDR-35 (standard dimension ratio), with smaller sized laterals interconnected within a larger sized main.

Pipes conveying sewage from an individual building to a common gravity sewer line are called laterals. Branch sewers typically run under streets receiving laterals from buildings along that street and discharge by gravity into trunk sewers at manholes. Larger cities may have sewers called interceptors receiving flow from multiple trunk sewers. A lift station is a gravity sewer sump with a pump to lift accumulated sewage to a higher elevation. The pump may discharge to another gravity sewer at that location or may discharge through a pressurized force main to some distant location.

## ***History***

As an outgrowth of the Industrial Revolution, many cities in Europe and North America grew in the 19th century, frequently leading to crowding and increasing concerns about public health. As part of a trend of municipal sanitation programs in the late 19th and 20th centuries, many cities constructed extensive sewer systems to help control outbreaks of disease such as typhoid and cholera. Initially these systems discharged sewage directly to surface waters without treatment. As pollution of water bodies became a concern, cities added sewage treatment plants to their systems.

## ***Maintenance***

All sewers deteriorate with age; but Infiltration/Inflow is a problem unique to sanitary sewers; since both combined sewers and storm drains are sized to carry these contributions. Holding infiltration to acceptable levels requires a higher standard of maintenance than necessary for structural integrity considerations of combined sewers. A comprehensive construction inspection program is required to prevent inappropriate connection of cellar, yard, and roof drains to sanitary sewers. The probability of inappropriate connections is higher where combined sewers and sanitary sewers are found in close proximity; because construction personnel may not recognize the difference. Many older cities still use combined sewers while adjacent suburbs were built with separate sanitary sewers.

## ***Simplified sewers***

Simplified sanitary sewers consist of small-diameter pipes (typically 100 mm or about 4 inches), often laid at fairly flat gradients (1 in 200). The investment cost for sanitary sewers can be about half the costs of conventional sewers. However, the requirements for operation and maintenance are usually higher. Simplified sewers are most common in Brazil and are also used in a number of other developing countries.

## Chapter 4

# Sludge



Sludge

**Sludge** refers to the residual, semi-solid material left from industrial wastewater, or sewage treatment processes. It can also refer to the settled suspension obtained from conventional drinking water treatment, and numerous other industrial processes. The term is also sometimes used as a generic term for solids separated from suspension in a liquid; this 'soupy' material usually contains significant quantities of 'interstitial' water (between the solid particles).

When fresh sewage or wastewater is added to a settling tank, approximately 50% of the suspended solid matter will settle out in an hour and a half. This collection of solids is known as raw sludge or primary solids and is said to be "fresh" before anaerobic processes become active. The sludge will become putrescent in a short time once anaerobic bacteria take over, and must be removed from the sedimentation tank before this happens.

This is accomplished in one of two ways. In an Imhoff tank, fresh sludge is passed through a slot to the lower story or digestion chamber where it is decomposed by anaerobic bacteria, resulting in liquefaction and reduced volume of the sludge. After digesting for an extended period, the result is called "digested" sludge and may be disposed of by drying and then landfilling. More commonly with domestic sewage, the fresh sludge is continuously extracted from the tank mechanically and passed to separate sludge digestion tanks that operate at higher temperatures than the lower story of the Imhoff tank and, as a result, digest much more rapidly and efficiently.

Excess solids from biological processes such as activated sludge may still be referred to as sludge, but the term biosolids, is more commonly used to refer to the material, particularly after further processing such as aerobic composting. Industrial wastewater solids are also referred to as sludge, whether generated from biological or physical-chemical processes. Surface water plants also generate sludge made up of solids removed from the raw water.

## ***Background and history***

Biosolids, the treated form of sewage sludge, have been in use in UK and European agriculture for more than 80 years, though there is increasing pressure to stop the practice of land application. In the 1990s there was pressure in some European countries to ban the use of sewage sludge as a fertilizer. Switzerland, Sweden, Austria, and others introduced a ban. Since the 1960s there has been cooperative activity with industry to reduce the inputs of persistent substances from factories. This has been very successful and, for example, the content of cadmium in sewage sludge in major European cities is now only 1% of what it was in 1970.

European legislation on dangerous substances has eliminated the production and marketing of some substances that have been of historic concern such as persistent organic micropollutants. The European Commission has said repeatedly that the "Directive on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture" (86/278/EEC) has been very successful in that there have been no cases of adverse effect where it has been applied. The EC encourages the use of sewage sludge in agriculture because it conserves organic matter and completes

nutrient cycles. Recycling of phosphate is regarded as especially important because the phosphate industry predicts that at the current rate of extraction the economic reserves will be exhausted in 100 or at most 250 years.

Of general interest on this topic is the Swanson et al. (2004) brief history of sewage management in New York City [Swanson, R.L., M.L. Bortman, T.P. O'Connor, and H.M. Stanford. 2004. Science, policy and the management of sewage materials; The New York City experience. *Mar. Poll. Bull.* 49: 679-687]. Since 1884 when sewage was first treated the amount of sludge has increased along with population and treatment technology. At first the sludge was discharged directly along the banks of rivers surrounding the city, a bit later piped further into the rivers, and then further still out into the harbor. In 1924, to relieve a dismal condition in New York Harbor which actually putrefied in places as a result of decay of sewage, New York City began dumping sludge at sea at a location in the New York Bight called the 12-Mile Site. This was deemed a successful public health measure and not until the late 1960s was there any examination of its consequences to marine life or to humans. There was accumulation of sludge particles on the seafloor and consequent changes in the numbers and types of benthic organisms. In 1970 a large area around the site was closed to shellfishing. From then until 1986, the practice of dumping at the 12-Mile Site came under increasing pressure stemming from a series of untoward environmental crises in the New York Bight that were attributed partly to sludge dumping. In 1986, sludge dumping was moved still further seaward to a site over the deep ocean called the 106-Mile Site. Then, again in response to political pressure arising from events unrelated to ocean dumping, the practice ended entirely in 1992. Since 1992, New York City sludge has been applied to land (outside of New York state). That practice, now employed by two-thirds of the sewage treatment plants in the US, has been under continued scrutiny. The wider question is whether or not changes on the sea floor caused by the portion of sludge that settles are severe enough to justify the added operational cost and human health concerns of applying sludge to land. The cost versus benefit question is moot in the U.S. because ocean dumping of sludge is banned, but international treaty (London Dumping Convention) allows the practice so, on a global basis, as more and more sewage is treated, every sludge management option deserves practical consideration.

The term biosolids was formally created in 1991 by the Name Change Task Force of the Water Environment Federation (WEF), formerly known as the "Federation of Sewage Works Associations" to differentiate raw, untreated sewage sludge from treated and tested sewage sludge that can legally be utilized as soil amendment and fertilizer. The Federation newsletter published a request for alternative names. Members sent in over 250 suggestions, including "all growth," "purenutri," "biolife," "bioslurp," "black gold," "geoslime," "sca-doo," "the end product," "humanure," "hu-doo," "organic residuals," "bioresidue," "urban biomass," "powergro," "organite," "recyclite," "nutri-cake" and "ROSE," short for "recycling of solids environmentally." In June 1991, the Name Change Task Force finally settled on "biosolids," which it defined as the "nutrient-rich, organic byproduct of the nation's wastewater treatment process."

The legal term for biosolids by law is sludge. Treatment processes do not remove cancer causing agents. According to the 1995 *Plain English Guide to the Part 503 Risk*

*Assessment*, There was never a risk assessment for the cancer causing agents or heavy metals found in sludge.

## **Treatment process**

Sewage sludge is produced from the treatment of wastewater and consists of two basic forms — raw primary sludge (basically faecal material) and secondary sludge (a living ‘culture’ of organisms that help remove contaminants from wastewater before it is returned to rivers or the sea). The sludge is transformed into biosolids using a number of complex treatments such as digestion, thickening, dewatering, drying, and lime/alkaline stabilisation. Some treatment processes such as composting and alkaline stabilization involve significant amendments may dilute contaminant concentrations; depending on the process and the contaminant in question, treatment may decrease or in some cases increase the bioavailability and/or solubility of contaminants. In general, the more effectively a wastewater stream is treated, the greater the resulting concentration of contaminants into the product sludge.

## **Biosolids**

**Biosolids**, also referred to as treated sludge, is a term used by the waste water industry to denote the byproduct of domestic and commercial sewage and wastewater treatment. These residuals are further treated to reduce pathogens and vector attraction by any of a number of approved methods. Toxic chemicals such as PCBs, dioxin, and brominated flame retardants, may remain in treated sludge. One of the main concerns in the treated sludge is the concentrated metals content; certain metals are regulated while others are not. Leaching methods can be used to reduce the metal content and meet the regulatory limit. The U.S. divides biosolids into two grades: Class B sewage sludge, and Class A treated sewage sludge. Class A sludge has been treated to reduce bacteria prior to application to land; Class B sludge has not.

Depending on their level of treatment and resultant pollutant content, biosolids can be used in regulated applications for non-food agriculture, food agriculture, or distribution for unlimited use. Treated biosolids can be produced in cake, granular, pellet or liquid form and are spread over land before being incorporated into the soil or injected directly into the soil by specialist contractors. It used to be common practice to dump sewage sludge into the ocean, however, this practice has stopped in many nations due environmental concerns as well to domestic and international laws and treaties. In particular, after the 1991 Congressional ban on ocean dumping, the U.S. Environmental Protection Agency (EPA) instituted a policy of digested sludge reuse on agricultural land. The EPA promoted this policy by presenting it as recycling and rechristening sewage sludge as "biosolids", as they are solids produced by biological activities.

A 2004 survey of 48 individuals near affected sites found that most reported irritation symptoms, about half reported an infection within a month of the application, and about a fourth were affected by *Staphylococcus aureus*, including two deaths. The number of reported *S. aureus* infections was 25 times as high as in hospitalized patients, a high-risk group. The authors point out that regulations call for protective gear when handling Class

B biosolids and that similar protections could be considered for residents in nearby areas given the wind conditions.

Khuder, Milz, Bisesi, Vincent, McNulty, and Czajkowski (as cited by Harrison and McBride of the Cornell Waste Management Institute in *Case for Caution Revisited: Health and Environmental Impacts of Application of Sewage Sludges to Agricultural Land*) conducted a health survey of persons living in close proximity to sludged land. A sample of 437 people exposed to sludge (living within 1-mile (1.6 km) of sludged land) - and using a control group of 176 people not exposed to sludge (not living within 1-mile (1.6 km) of sludged land) reported the following:

"Results revealed that some reported health-related symptoms were statistically significantly elevated among the exposed residents, including excessive secretion of tears, abdominal bloating, jaundice, skin ulcer, dehydration, weight loss, and general weakness. The frequency of reported occurrence of bronchitis, upper respiratory infection, and giardiasis were also statistically significantly elevated. The findings suggest an increased risk for certain respiratory, gastrointestinal, and other diseases among residents living near farm fields on which the use of biosolids was permitted."

—Khuder, et al., *Health Survey of Residents Living near Farm Fields Permitted to Receive Biosolids*

Although correlation does not imply causation, such extensive correlations may lead reasonable people to conclude that precaution is necessary in dealing with sludge and sludged farmlands.

Harrison and Oakes suggest that, in particular, "until investigations are carried out that answer these questions (...about the safety of Class B sludge...), land application of Class B sludges should be viewed as a practice that subjects neighbors and workers to substantial risk of disease." They further suggest that even Class A treated sludge may have chemical contaminants (including heavy metals, such as lead) or endotoxins present, and a precautionary approach may be justified on this basis, though the vast majority of incidents reported by Lewis, et al. have been correlated with exposure to Class B untreated sludge and not Class A treated sludge.

The EPA has recently (as of 2009) released the Targeted National Sewage Sludge Study, which reports on the level of metals, chemicals, hormones, and other materials present in a statistical sample of sewage sludges. Some highlights include:

- Silver is present to the degree of 20 mg/kg of sludge, on average, a near economically recoverable level, while some sludges of *exceptionally high quality* have up to 200 milligrams of silver per kilogram of sludge; one outlier demonstrated a silver lode of 800–900 mg per kg of sludge. It is unknown whether mineral speculators have yet invested in the sludge stocks of the United States.
- Barium is present at the rate of 500 mg/kg, while manganese is present at the rate of 1 g/kg sludge.

- High levels of sterols and other hormones have been detected, with averages in the range of up to 1,000,000 µg/kg sludge.
- Lead, arsenic, chromium, and cadmium are estimated by the EPA to be present in detectable quantities in 100% of national sewage sludges in the US, while thallium is only estimated to be present in 94.1% of sludges.

Recent studies (2010) have indicated that pharmaceuticals and personal care products, which often adsorb to sludge during wastewater treatment, can persist in agricultural soils following biosolid application. Some of these chemicals, including potential endocrine disruptor Triclosan, can also travel through the soil column and leach into agricultural tile drainage at detectable levels. Other studies, however, have shown that these chemicals remain adsorbed to surface soil particles, making them more susceptible to surface erosion than infiltration. These studies are also mixed in their findings regarding the persistence of chemicals such as triclosan, triclocarban, and other pharmaceuticals. The impact of this persistence in soils is unknown, but the link to human and land animal health is likely tied to the capacity for plants to absorb and accumulate these chemicals in their consumed tissues. Studies of this kind are in early stages, but evidence of root uptake and translocation to leaves did occur for both triclosan and triclocarban in soybeans. This effect was not present in corn when tested in a different study.

For produce to be USDA-certified organic, sludge (biosolids) cannot be used.

A PhD thesis studying the addition of sludge to neutralize soil acidity concluded that the practice was not recommended if large amounts are used because the sludge produces acids when it oxidizes.

## **United States**

According to the United States Environmental Protection Agency (EPA), biosolids that meet treatment and pollutant content criteria of Part 503.13 "can be safely recycled and applied as fertilizer to sustainably improve and maintain productive soils and stimulate plant growth." However, they can not be disposed of in a sludge only landfill under Part 503.23 because of high chromium levels and boundary restrictions. After the 1991 Congressional ban on ocean dumping, the US EPA promulgated regulations - 40 CFR Part 503 - that continued to allow the use of biosolids on land as fertilizers and soil amendments which had been previously allowed under Part 257. The EPA promoted biosolids recycling throughout the 1990s. The EPA's Part 503 regulations were developed with input from university, EPA, and USDA researchers from around the country and involved an extensive review of the scientific literature and the largest risk assessment the agency had conducted to that time. However, there was no risk assess for pathogens or chemicals and heavy metals were not considered to be cancer causing agents. The Part 503 regulations became effective in 1993.

United States municipal wastewater treatment plants in 1997 produced about 7.7 million dry tons of biosolids, and about 6.8 million dry tons in 1998 according to sources relying on EPA estimates. As of 2002, about 60% of all biosolids were applied to land as a soil amendment and fertilizer for growing crops. Biosolids that meet the Class B pathogen treatment and pollutant criteria, in accordance with the EPA "Standards for the use or

disposal of sewage sludge" (40 CFR Part 503), can be land applied with formal site restrictions and strict record keeping. Biosolids that meet Class A pathogen reduction requirements or equivalent treatment by a "Process to Further Reduce Pathogens" (PFRP) have the least restrictions on use. PFRPs include pasteurization, heat drying, thermophilic composting (aerobic digestion, most common method), and beta or gamma ray irradiation. Processes to reduce pathogens have no effect on heavy metals and may or may not have effects on the levels of other trace pollutants in biosolids. Treatment processes that involve significant amendments such as composting and alkaline stabilization may dilute total trace metals concentrations, but, depending on the process and the element in question, may decrease or in some cases increase the bioavailability and/or solubility of trace elements.

Often thought to consist of only "human waste", treated sewage sludge or "biosolids" contain any contaminants from sewage that are not broken down in the treatment process, or which do not remain with the water effluent leaving the treatment plant. The most commonly detected trace contaminants of concern are heavy metals (arsenic, cadmium, copper, etc., some of which are also critical plant micronutrients), and toxic chemicals (e.g. plasticizers, PDBEs, and others generated by human activities, including personal care products and medicines). Synthetic fibers from fabrics persist in biosolids as well as in biosolids-treated soils and may thus serve as an indicator of past biosolids application. Pathogens are not a significant health issue if biosolids are properly treated and site-specific management practices are followed; there is generally a greater concern for products that have been fertilized with un-treated animal wastes and which may be eaten raw.

The National Research Council published "Biosolids Applied to Land: Advancing Standards and Practices" in July 2002. The NRC concluded that while there is no documented scientific evidence that sewage sludge regulations have failed to protect public health, there is persistent uncertainty on possible adverse health effects. The NRC noted that further research is needed and made about 60 recommendations for addressing public health concerns, scientific uncertainties, and data gaps in the science underlying the sewage sludge standards. EPA responded with a commitment to conduct research addressing the NRC recommendations.

The EPA Office of the Inspector General (OIG) completed two assessments in 2000 and 2002 of the EPA sewage sludge program. The follow-up report in 2002 documented that "the EPA cannot assure the public that current land application practices are protective of human health and the environment." The report also documented that there had been an almost 100% reduction in EPA enforcement resources since the earlier assessment. This is probably the greatest issue with the practice: under both the federal program operated by the EPA and those of the several states, there is limited inspection and oversight by agencies charged with regulating these practices. To some degree, this lack of oversight is a function of the perceived (by the regulatory agencies) benign nature of the practice. However, a greater underlying issue is funding. Few states and the US EPA have the discretionary funds necessary to establish and implement a full enforcement program for biosolids. To do so would require substantial spending that most legislatures are unwilling to support. Some states and companies involved in biosolids management have willingly agreed to use a "fee" per unit of biosolids managed to help fund such programs,

and generally, where such programs are in place, biosolids land application proceeds without incident, however these fees are seldom sufficient to fully fund a rigorous inspection program.

A cautionary approach to land application of biosolids has been advocated by some for regions where soils have lower capacities for toxics sorption or due to the presence of unknowns in sewage biosolids. In 2007 the Northeast Regional Multi-State Research Committee (NEC 1001) issued conservative guidelines tailored to the soils and conditions typical of the northeastern US.

### ***Alternative pathways for sludge reuse***

Feridun of the United Sludge Free Alliance suggests that sludge can be recycled in a variety of ways that are both environmentally beneficial and sustainable, and which do not involve application of biologically active materials to croplands that humans live close to. These include using anaerobic digestion to produce biogas, pyrolysis of the sludge to create syngas and potentially biochar, or incineration in a waste-to-energy facility for direct production of electricity and steam for district heating or industrial uses. Synergies from these processes include a far lower, controlled level of methane release (an extremely potent greenhouse gas) to the atmosphere from the pyrolyzed/digested/combusted sludge rather than the uncontrolled release of methane from untreated sludge. If methane is captured rather than allowed to outgas, it can be used for fuel, closing the carbon cycle. Thermal or anaerobic processes greatly reduce the volume of the sludge, as well as achieve remediation the biological concerns. Direct waste-to-energy incineration systems require multi-step cleaning of the exhaust gas, to ensure no hazardous substances are released. In addition, the ash produced by incineration is difficult to use without subsequent treatment due to its high heavy metal content; solutions to this include leaching of the ashes to remove heavy metals followed by reuse of the ash as aggregate for concrete, or if biochar is used, the heavy metals may be fixed in place by the char structure. An other way to use dried sewage sludge as a energy resource is to burn it together with coal in coal-fired power stations. This is considered as biomass co-firing, which allows to produce the same amount of electricity with less carbon-dioxide emissions.

## Chapter 5

# Wastewater

**Wastewater** is any water that has been adversely affected in quality by anthropogenic influence. It comprises liquid waste discharged by domestic residences, commercial properties, industry, and/or agriculture and can encompass a wide range of potential contaminants and concentrations. In the most common usage, it refers to the municipal wastewater that contains a broad spectrum of contaminants resulting from the mixing of wastewaters from different sources.

**Sewage** is correctly the subset of wastewater that is contaminated with feces or urine, but is often used to mean any waste water. "Sewage" includes domestic, municipal, or industrial liquid waste products disposed of, usually via a pipe or sewer or similar structure, sometimes in a cesspool emptier.

The physical infrastructure, including pipes, pumps, screens, channels etc. used to convey sewage from its origin to the point of eventual treatment or disposal is termed sewerage.

### *Origin*

Wastewater or sewage can come from (text in brackets indicates likely inclusions or contaminants):

- Human waste (faeces, used toilet paper or wipes, urine, or other bodily fluids), also known as blackwater, usually from lavatories;
- Cesspit leakage;
- Septic tank discharge;
- Sewage treatment plant discharge;
- Washing water (personal, clothes, floors, dishes, etc.), also known as greywater or sullage;
- Rainfall collected on roofs, yards, hard-standings, etc. (generally clean with traces of oils and fuel);
- Groundwater infiltrated into sewage;
- Surplus manufactured liquids from domestic sources (drinks, cooking oil, pesticides, lubricating oil, paint, cleaning liquids, etc.);

- Urban rainfall runoff from roads, car parks, roofs, sidewalks, or pavements (contains oils, animal faeces, litter, fuel or rubber residues, metals from vehicle exhausts, etc.);
- Seawater ingress (high volumes of salt and micro-biota);
- Direct ingress of river water (high volumes of micro-biota);
- Direct ingress of manmade liquids (illegal disposal of pesticides, used oils, etc.);
- Highway drainage (oil, de-icing agents, rubber residues);
- Storm drains (almost anything, including cars, shopping trolleys, trees, cattle, etc.);
- Blackwater (surface water contaminated by sewage);
- Industrial waste
- industrial site drainage (silt, sand, alkali, oil, chemical residues);
  - Industrial cooling waters (biocides, heat, slimes, silt);
  - Industrial process waters;
  - Organic or bio-degradable waste, including waste from abattoirs, creameries, and ice cream manufacture;
  - Organic or non bio-degradable/difficult-to-treat waste (pharmaceutical or pesticide manufacturing);
  - extreme pH waste (from acid/alkali manufacturing, metal plating);
  - Toxic waste (metal plating, cyanide production, pesticide manufacturing, etc.);
  - Solids and Emulsions (paper manufacturing, foodstuffs, lubricating and hydraulic oil manufacturing, etc.);
  - agricultural drainage, direct and diffuse.

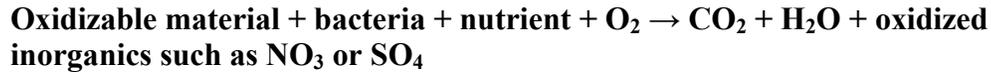
## ***Wastewater constituents***

The composition of wastewater varies widely. This is a partial list of what it may contain:

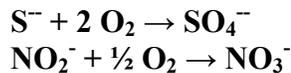
- Water (> 95%) which is often added during flushing to carry waste down a drain;
- Pathogens such as bacteria, viruses, prions and parasitic worms;
- Non-pathogenic bacteria;
- Organic particles such as feces, hairs, food, vomit, paper fibers, plant material, humus, etc.;
- Soluble organic material such as urea, fruit sugars, soluble proteins, drugs, pharmaceuticals, etc.;
- Inorganic particles such as sand, grit, metal particles, ceramics, etc.;
- Soluble inorganic material such as ammonia, road-salt, sea-salt, cyanide, hydrogen sulfide, thiocyanates, thiosulfates, etc.;
- Animals such as protozoa, insects, arthropods, small fish, etc.;
- Macro-solids such as sanitary napkins, nappies/diapers, condoms, needles, children's toys, dead animals or plants, etc.;
- Gases such as hydrogen sulfide, carbon dioxide, methane, etc.;
- Emulsions such as paints, adhesives, mayonnaise, hair colorants, emulsified oils, etc.;
- Toxins such as pesticides, poisons, herbicides, etc.
- Pharmaceuticals and other hormones.

## ***Wastewater quality indicators***

Any oxidizable material present in a natural waterway or in an industrial wastewater will be oxidized both by biochemical (bacterial) or chemical processes. The result is that the oxygen content of the water will be decreased. Basically, the reaction for biochemical oxidation may be written as:



Oxygen consumption by reducing chemicals such as sulfides and nitrites is typified as follows:



Since all natural waterways contain bacteria and nutrients, almost any waste compounds introduced into such waterways will initiate biochemical reactions (such as shown above). Those biochemical reactions create what is measured in the laboratory as the Biochemical oxygen demand (BOD). Such chemicals are also liable to be broken down using strong oxidizing agents and these chemical reactions create what is measured in the laboratory as the Chemical oxygen demand (COD). Both the BOD and COD tests are a measure of the relative oxygen-depletion effect of a waste contaminant. Both have been widely adopted as a measure of pollution effect. The BOD test measures the oxygen demand of biodegradable pollutants whereas the COD test measures the oxygen demand of oxidizable pollutants.

The so-called 5-day BOD measures the amount of oxygen consumed by biochemical oxidation of waste contaminants in a 5-day period. The total amount of oxygen consumed when the biochemical reaction is allowed to proceed to completion is called the Ultimate BOD. Because the Ultimate BOD is so time consuming, the 5-day BOD has been almost universally adopted as a measure of relative pollution effect.

There are also many different COD tests of which the 4-hour COD is probably the most common.

There is no generalized correlation between the 5-day BOD and the ultimate BOD. Similarly there is no generalized correlation between BOD and COD. It is possible to develop such correlations for a specific waste contaminants in a specific waste water stream but such correlations cannot be generalized for use with any other waste contaminants or waste water streams. This is because the composition of any waste water stream is different. As an example and effluent consisting of a solution of simple sugars that might discharge from a confectionery factory is likely to have organic components that degrade very quickly. In such a case the 5 day BOD and the ultimate BOD would be very similar. I.e there would be very little organic material left after 5 days. However a final effluent of a sewage treatment works serving a large industrialised area might have a discharge where the ultimate BOD was much greater than the 5 day BOD because much

of the easily degraded material would have been removed in the sewage treatment process and many industrial processes discharge difficult to degrade organic molecules.

The laboratory test procedures for the determining the above oxygen demands are detailed in many standard texts. American versions include the "Standard Methods For the Examination Of Water and Wastewater"

### ***Sewage disposal***



Industrial wastewater effluent with neutralized pH from tailing runoff. Taken in Peru.

In some urban areas, sewage is carried separately in sanitary sewers and runoff from streets is carried in storm drains. Access to either of these is typically through a manhole. During high precipitation periods a sanitary sewer overflow can occur, forcing untreated sewage to flow back into the environment. This can pose a serious threat to public health and the surrounding environment.

Sewage may drain directly into major watersheds with minimal or no treatment. When untreated, sewage can have serious impacts on the quality of an environment and on the health of people. Pathogens can cause a variety of illnesses. Some chemicals pose risks even at very low concentrations and can remain a threat for long periods of time because of bioaccumulation in animal or human tissue.

## ***Treatment***

There are numerous processes that can be used to clean up waste waters depending on the type and extent of contamination. Most wastewater is treated in industrial-scale wastewater treatment plants (WWTPs) which may include physical, chemical and biological treatment processes. However, the use of septic tanks and other On-Site Sewage Facilities (OSSF) is widespread in rural areas, serving up to one quarter of the homes in the U.S . The most important aerobic treatment system is the activated sludge process, based on the maintenance and recirculation of a complex biomass composed by micro-organisms able to absorb and adsorb the organic matter carried in the wastewater. Anaerobic processes are widely applied in the treatment of industrial wastewaters and biological sludge. Some wastewater may be highly treated and reused as reclaimed water. For some waste waters ecological approaches using reed bed systems such as constructed wetlands may be appropriate. Modern systems include tertiary treatment by micro filtration or synthetic membranes. After membrane filtration, the treated wastewater is indistinguishable from waters of natural origin of drinking quality. Nitrates can be removed from wastewater by microbial denitrification, for which a small amount of methanol is typically added to provide the bacteria with a source of carbon. Ozone Waste Water Treatment is also growing in popularity, and requires the use of an ozone generator, which decontaminates the water as Ozone bubbles percolate through the tank.

Disposal of wastewaters from an industrial plant is a difficult and costly problem. Most petroleum refineries, chemical and petrochemical plants have onsite facilities to treat their wastewaters so that the pollutant concentrations in the treated wastewater comply with the local and/or national regulations regarding disposal of wastewaters into community treatment plants or into rivers, lakes or oceans. Other Industrial processes that produce a lot of waste-waters such as paper and pulp production has created environmental concern leading to development of processes to recycle water use within plants before they have to be cleaned and disposed of.

## ***Reuse***

Treated wastewater can be reused as drinking water, in industry (cooling towers), in artificial recharge of aquifers, in agriculture (70% of Israel's irrigated agriculture is based on highly purified wastewater) and in the rehabilitation of natural ecosystems (Florida's Everglades).

## ***Algal fuel***

Woods Hole Oceanographic Institution and Harbor Branch Oceanographic Institution, following the conclusions of the USDOE's Aquatic Species Program, use wastewater for breeding algae. The wastewater from domestic and industrial sources contain rich organic compounds, which accelerate the growth of algae. This algae can be used to produce algal fuels

Algaewheel, based in Indianapolis, Indiana, presented a proposal to build a new wastewater treatment facility in Cedar Lake, Indiana that uses algae to treat municipal wastewater and uses the sludge byproduct to produce biofuel.

## ***Etymology***

The words "sewage" and "sewer" came from Old French *essouier* = "to drain", which came from Latin *exaquāre*. Their formal Latin antecedents are *exaquāticum* and *exaquārium*.

## ***Legislation***

### **European Union**

Council Directive 91/271/EEC on Urban Waste Water Treatment was adopted on 21 May 1991 , amended by the Commission Directive 98/15/EC . Commission Decision 93/481/EEC defines the information that Member States should provide the Commission on the state of implementation of the Directive.

## Chapter 6

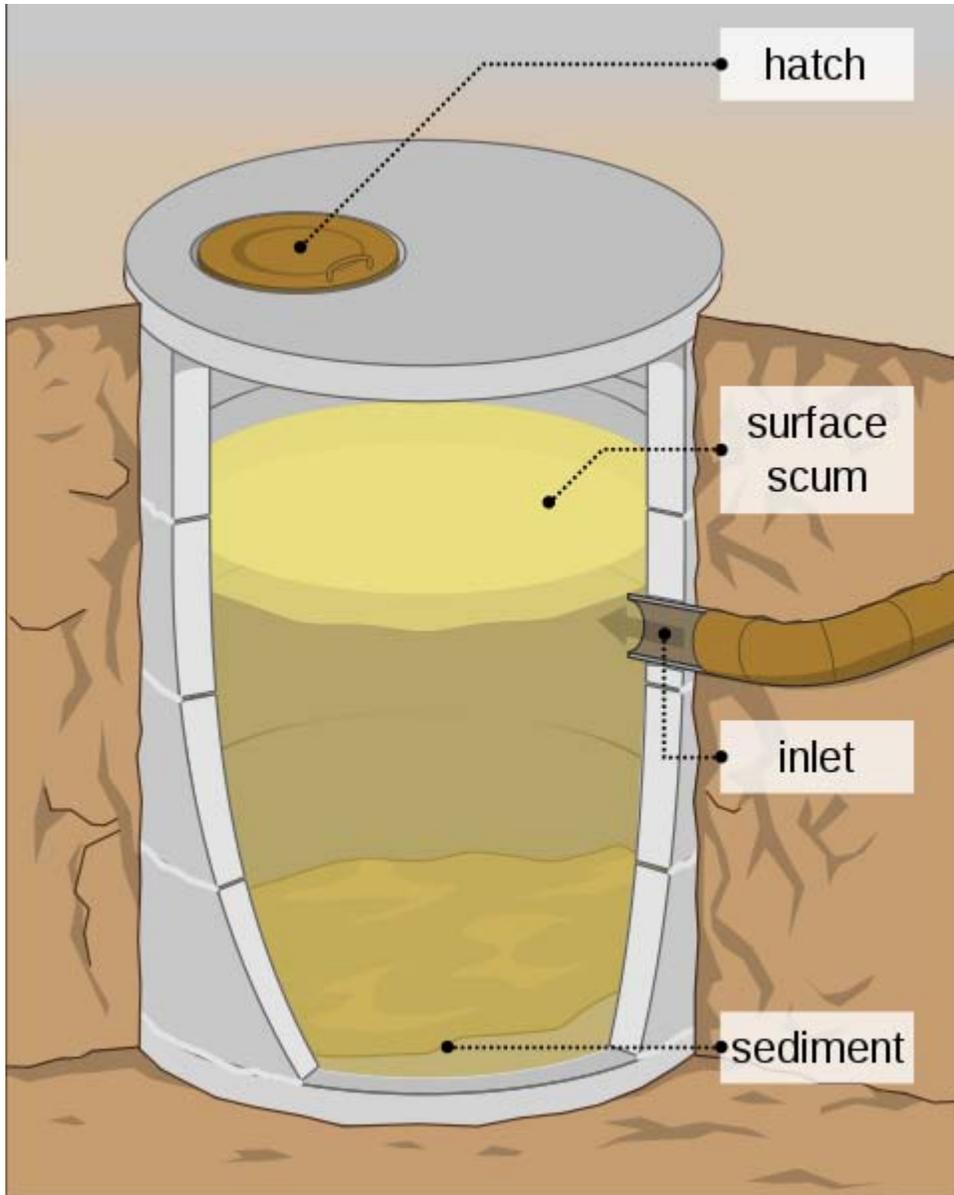
# Septic Tank



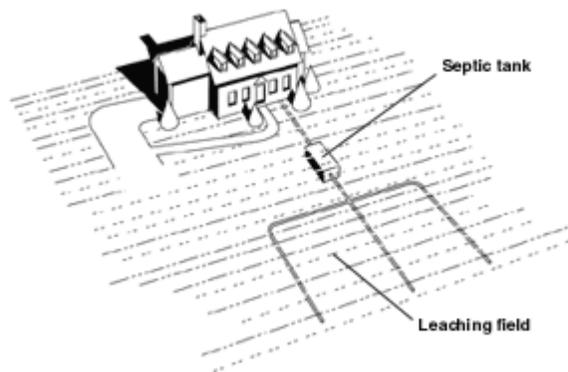
A septic tank before installation



The same tank partially installed in the ground



Septic tank scheme



Septic tank and septic drain field

A **septic tank** is a key component of the **septic system**, a small scale sewage treatment system common in areas with no connection to main sewage pipes provided by local governments or private corporations. (Other components, typically mandated and/or restricted by local governments, optionally include pumps, alarms, sand filters, and clarified liquid effluent disposal means such as a septic drain field, ponds, natural stone fibre filter plants or peat moss beds.) Septic systems are a type of On-Site Sewage Facility (OSSF). In North America approximately 25% of the population relies on septic tanks; this can include suburbs and small towns as well as rural areas (Indianapolis is an example of a large city where many of the city's neighborhoods are still on separate septic systems). In Europe they are generally limited to rural areas only.

The term "septic" refers to the anaerobic bacterial environment that develops in the tank and which decomposes or mineralizes the waste discharged into the tank. Septic tanks can be coupled with other on-site wastewater treatment units such as biofilters or aerobic systems involving artificial forced aeration.

Periodic preventive maintenance is required to remove the irreducible solids which settle and gradually fill the tank, reducing its efficiency. In most jurisdictions this maintenance is required by law, yet often not enforced. Those who ignore the requirement will eventually be faced with extremely costly repairs when solids escape the tank and destroy the clarified liquid effluent disposal means. A properly maintained system, on the other hand, can last for decades and possibly a lifetime.

## ***Description***

A septic tank generally consists of a tank (or sometimes more than one tank) of between 4000 - 7500 litres (1,000 and 2,000 gallons) in size connected to an inlet wastewater pipe at one end and a septic drain field at the other. These pipe connections are generally made via a T pipe which allows liquid entry and exit without disturbing any crust on the surface. Today the design of the tank usually incorporates two chambers (each of which is equipped with a manhole cover) which are separated by means of a dividing wall which has openings located about midway between the floor and roof of the tank.

Wastewater enters the first chamber of the tank, allowing solids to settle and scum to float. The settled solids are anaerobically digested, reducing the volume of solids. The liquid component flows through the dividing wall into the second chamber where further settlement takes place, with the excess liquid then draining in a relatively clear condition from the outlet into the leach field, also referred to as a drain field or seepage field, depending upon locality.

The remaining impurities are trapped and eliminated in the soil, with the excess water eliminated through percolation into the soil (eventually returning to the groundwater), through evaporation, and by uptake through the root system of plants and eventual transpiration. A piping network, often laid in a stone filled trench, distributes the wastewater throughout the field with multiple drainage holes in the network. The size of the leach field is proportional to the volume of wastewater and inversely proportional to the porosity of the drainage field. The entire septic system can operate by gravity alone, or where topographic considerations require, with inclusion of a lift pump. Certain septic

tank designs include siphons or other methods of increasing the volume and velocity of outflow to the drainage field. This helps to load all portions of the drainage pipe more evenly and extends the drainage field life by preventing premature clogging.

An Imhoff tank is a two-stage septic system where the sludge is digested in a separate tank. This avoids mixing digested sludge with incoming sewage. Also, some septic tank designs have a second stage where the effluent from the anaerobic first stage is aerated before it drains into the seepage field.

Waste that is not decomposed by the anaerobic digestion eventually has to be removed from the septic tank, or else the septic tank fills up and undecomposed wastewater discharges directly to the drainage field. Not only is this bad for the environment, but if the sludge overflows the septic tank into the leach field, it may clog the leach field piping or decrease the soil porosity itself, requiring expensive repairs.

How often the septic tank has to be emptied depends on the volume of the tank relative to the input of solids, the amount of indigestible solids and the ambient temperature (as anaerobic digestion occurs more efficiently at higher temperatures). The required frequency varies greatly depending on jurisdiction, usage, and system characteristics. Some health authorities require tanks to be emptied at prescribed intervals, while others leave it up to the determination of the inspector. Some systems require pumping every few years or sooner, while others may be able to go 10–20 years between pumpings. Contrary to what many believe, there is no "rule of thumb" for how often tanks should be emptied. An older system with an undersized tank that is being used by a large family will require much more frequent pumping than a new system used by only a few people. Anaerobic decomposition is rapidly re-started when the tank re-fills.

A properly designed and normally operating septic system is odour free and, besides periodic inspection and pumping of the septic tank, should last for decades with no maintenance.

A well designed and maintained concrete, fibreglass or plastic tank should last about 50 years.

### ***Potential problems***

- Excessive dumping of cooking oils and grease can cause the inlet drains to block. Oils and grease are often difficult to degrade and can cause odour problems and difficulties with the periodic emptying.
- Flushing non-biodegradable items such as cigarette butts and hygiene products such as sanitary towels and cotton buds will rapidly fill or clog a septic tank; these materials should not be disposed of in this way.
- The use of garbage disposers for disposal of waste food can cause a rapid overload of the system and early failure.
- Certain chemicals may damage the working of a septic tank, especially pesticides, herbicides, materials with high concentrations of bleach or caustic soda (lye) or any other inorganic materials such as paints or solvents.

- Roots from trees and shrubbery growing above the tank or the drainfield may clog and/or rupture them.
- Playgrounds and storage buildings may cause damage to a tank and the drainage field. In addition, covering the drainage field with an impervious surface, such as a driveway or parking area, will seriously affect its efficiency and possibly damage the tank and absorption system.
- Unsupervised septic tanks may cause serious injury or death to children playing nearby.
- Excessive water entering the system will overload it and cause it to fail. Checking for plumbing leaks and practicing water conservation will help the system's operation.
- Very high rainfall, rapid snow-melt, and flooding from rivers or the sea can all prevent a drain field from operating and can cause flow to backup and stop normal operation of the tank
- Over time biofilms develop on the pipes of the drainage field which can lead to blockage. Such a failure can be referred to as "Biomat failure".
- Septic tanks by themselves are ineffective at removing nitrogen compounds that can potentially cause algal blooms in receiving waters; this can be remedied by using a nitrogen-reducing technology, or by simply ensuring that the leach field is properly sited to prevent direct entry of effluent into bodies of water.
- Historically at least, not all varieties of toilet paper were suitable for disposal in a septic tank as they did not deteriorate sufficiently (or, at least at some points in history, some toilet paper was specifically marked as suitable for use in septic systems and some was not).

## ***Environmental issues***

Some pollutants, especially sulfates, under the anaerobic conditions of septic tanks, are reduced to hydrogen sulfide, a pungent and toxic gas. Likewise, methane, a potent greenhouse gas is another by-product. Nitrates and organic nitrogen compounds are reduced to ammonia. Because of the anaerobic conditions, fermentation processes take place, which ultimately generate carbon dioxide and methane.

The fermentation processes cause the contents of a septic tank to be anaerobic with a low redox potential, which keeps phosphate in a soluble and thus mobilized form. Because phosphate can be the limiting nutrient for plant growth in many ecosystems, the discharge from a septic tank into the environment can trigger prolific plant growth including algal blooms which can also include blooms of potentially toxic cyanobacteria.

Soil capacity to retain phosphorus is large compared with the load through a normal residential septic tank. An exception occurs when septic drain fields are located in sandy or coarser soils on property adjoining a water body. Because of limited particle surface area, these soils can become saturated with phosphate. Phosphate will progress beyond the treatment area, posing a threat of eutrophication to surface waters.

In areas with high population density, groundwater pollution levels often exceed acceptable limits. Some small towns are facing the costs of building very expensive

centralized wastewater treatment systems because of this problem, owing to the high cost of extended collection systems.

To slow development, building moratoriums and limits on the subdivision of property are often imposed. Ensuring existing septic tanks are functioning properly can also be helpful for a limited time, but becomes less effective as a primary remediation strategy as population density increases.

Trees in the vicinity of a concrete septic tank have the potential to penetrate the tank as the system ages and the concrete begins to develop cracks and small leaks. Tree roots can cause serious flow problems due to plugging and blockage of drain pipes, but the trees themselves tend to grow extremely vigorously due to the continuous influx of nutrients into the septic system.

## Chapter 7

# Activated Sludge

**Activated sludge** is a process for treating sewage and industrial wastewaters using air and a biological floc composed of bacteria and protozoans.

### ***Purpose***

In a sewage (or industrial wastewater) treatment plant, the activated sludge process can be used for one or several of the following purposes:

- oxidizing carbonaceous matter: biological matter.
- oxidizing nitrogenous matter: mainly ammonium and nitrogen in biological materials.
- removing phosphate.
- driving off entrained gases carbon dioxide, ammonia, nitrogen, etc.
- generating a biological floc that is easy to settle.
- generating a liquor that is low in dissolved or suspended material.

### ***The process***

The process involves air or oxygen being introduced into a mixture of primary treated or screened sewage or industrial wastewater (called wastewater from now on) combined with organisms to develop a biological floc which reduces the organic content of the sewage. This material, which in healthy sludge is a brown floc, is largely composed of saprotrophic bacteria but also has an important protozoan flora mainly composed of amoebae, Spirotrichs, Peritrichs including Vorticellids and a range of other filter feeding species. Other important constituents include motile and sedentary Rotifers. In poorly managed activated sludge, a range of mucilaginous filamentous bacteria can develop including *Sphaerotilus natans* which produces a sludge that is difficult to settle and can result in the sludge blanket decanting over the weirs in the settlement tank to severely contaminate the final effluent quality. This material is often described as sewage fungus but true fungal communities are relatively uncommon.

The combination of wastewater and biological mass is commonly known as **mixed liquor**. In all activated sludge plants, once the wastewater has received sufficient

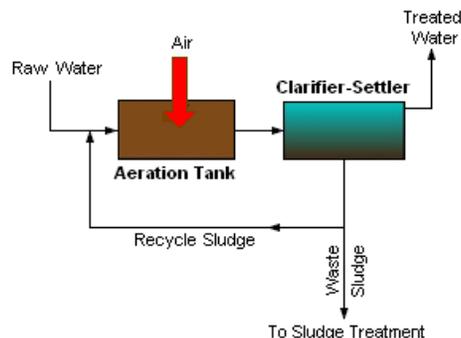
treatment, excess mixed liquor is discharged into settling tanks and the treated supernatant is run off to undergo further treatment before discharge. Part of the settled material, the sludge, is returned to the head of the aeration system to re-seed the new wastewater entering the tank. This fraction of the floc is called **return activated sludge** (R.A.S.). Excess sludge is called **surplus activated sludge**(S.A.S.) or **waste activated sludge**(W.A.S). S.A.S is removed from the treatment process to keep the ratio of biomass to food supplied in the wastewater in balance. S.A.S is stored in sludge tanks and is further treated by digestion, either under anaerobic or aerobic conditions prior to disposal.

Many sewage treatment plants use axial flow pumps to transfer nitrified mixed liquor from the aeration zone to the anoxic zone for denitrification. These pumps are often referred to as **internal mixed liquor recycle pumps** (IMLR pumps). The raw sewage, the RAS, and the nitrified mixed liquor are mixed by submersible mixers in the anoxic zones in order to achieve denitrification.

**Activated sludge** is also the name given to the active biological material produced by activated sludge plants.

## History

The activated sludge process was discovered in 1913 in the UK by two engineers, Edward Ardern and W.T. Lockett, conducting research for the Manchester Corporation Rivers Department at Davyhulme Sewage Works. Experiments on treating sewage in a draw-and-fill reactor (the precursor to today's sequencing batch reactor) produced a highly treated effluent. Believing that the sludge had been activated (in a similar manner to activated carbon) the process was named *activated sludge*. Not until much later was it realized that what had actually occurred was a means to concentrate biological organisms, decoupling the liquid retention time (ideally, low, for a compact treatment system) from the solids retention time (ideally, fairly high, for an effluent low in BOD<sub>5</sub> and ammonia.)



A generalized, schematic diagram of an activated sludge process.

## Arrangement

The general arrangement of an activated sludge process for removing carbonaceous pollution includes the following items:

- Aeration tank where air (or oxygen) is injected in the mixed liquor.
- Settling tank (usually referred to as "final clarifier" or "secondary settling tank") to allow the biological flocs to settle, thus separating the biological sludge from the clear treated water.

Treatment of nitrogenous matter or phosphate involves additional steps where the mixed liquor is left in anoxic condition (meaning that there is no residual dissolved oxygen).

## *Types of plants*



Activated sludge system in China

There are a variety of types of activated sludge plants. These include:

### **Package plants**

There are a wide range of other types of plants, often serving small communities or industrial plants that may use hybrid treatment processes often involving the use of aerobic sludge to treat the incoming sewage. In such plants the primary settlement stage of treatment may be omitted. In these plants, a biotic floc is created which provides the required substrate.

Package plants are commonly variants of extended aeration, to promote the 'fit & forget' approach required for small communities without dedicated operational staff. There are various standards to assist with their design.

### **Oxidation ditch**

In some areas, where more land is available, sewage is treated in large round or oval ditches with one or more horizontal aerators typically called brush or disc aerators which drive the mixed liquor around the ditch and provide aeration. These are oxidation ditches, often referred to by manufacturer's trade names such as Pasveer, Orbal, or Carrousel. They have the advantage that they are relatively easy to maintain and are resilient to shock loads that often occur in smaller communities (i.e. at breakfast time and in the evening).

Oxidation ditches are installed commonly as 'fit & forget' technology, with typical design parameters of a hydraulic retention time of 24 - 48 hours, and a sludge age of 12 - 20 days. This compares with nitrifying activated sludge plants having a retention time of 8 hours, and a sludge age of 8 - 12 days.

### **Deep Shaft**

Where land is in short supply sewage may be treated by injection of oxygen into a pressured return sludge stream which is injected into the base of a deep columnar tank buried in the ground. Such shafts may be up to 100 metres deep and are filled with sewage liquor. As the sewage rises the oxygen forced into solution by the pressure at the base of the shaft breaks out as molecular oxygen providing a highly efficient source of oxygen for the activated sludge biota. The rising oxygen and injected return sludge provide the physical mechanism for mixing of the sewage and sludge. Mixed sludge and sewage is decanted at the surface and separated into supernatant and sludge components. The efficiency of deep shaft treatment can be high.

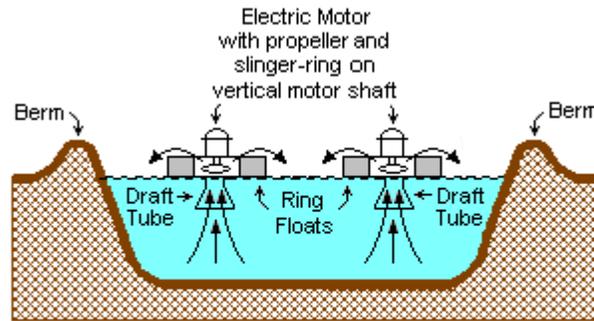
Surface aerators are commonly quoted as having an aeration efficiency of 0.5 - 1.5 kg O<sub>2</sub>/kWh, diffused aeration as 1.5 - 2.5 kg O<sub>2</sub>/KWh. Deep Shaft claims 5 - 8 kg O<sub>2</sub>/kWh.

However, the costs of construction are high. Deep Shaft has seen greatest uptake in Japan, because of the land area issues. Deep Shaft was developed by ICI, as a spin-off from their Pruteen process. In the UK it is found at three sites: Tilbury, Anglian water, treating a wastewater with a high industrial contribution; Southport, United Utilities,

because of land space issues; and Billingham, ICI, again treating industrial effluent, and built (after the Tilbury shafts) by ICI to help the agent sell more.

DeepShaft is a patented, licensed, process. The licensee has changed several times and, currently (2007), it is Aker Kvaerner Engineering Services.

## Surface-aerated Basins/Lagoons



**A TYPICAL SURFACE – AERATED BASIN**

Note: The ring floats are tethered to posts on the berms.

### A Typical Surface-Aerated Basing (using motor-driven floating aerators)

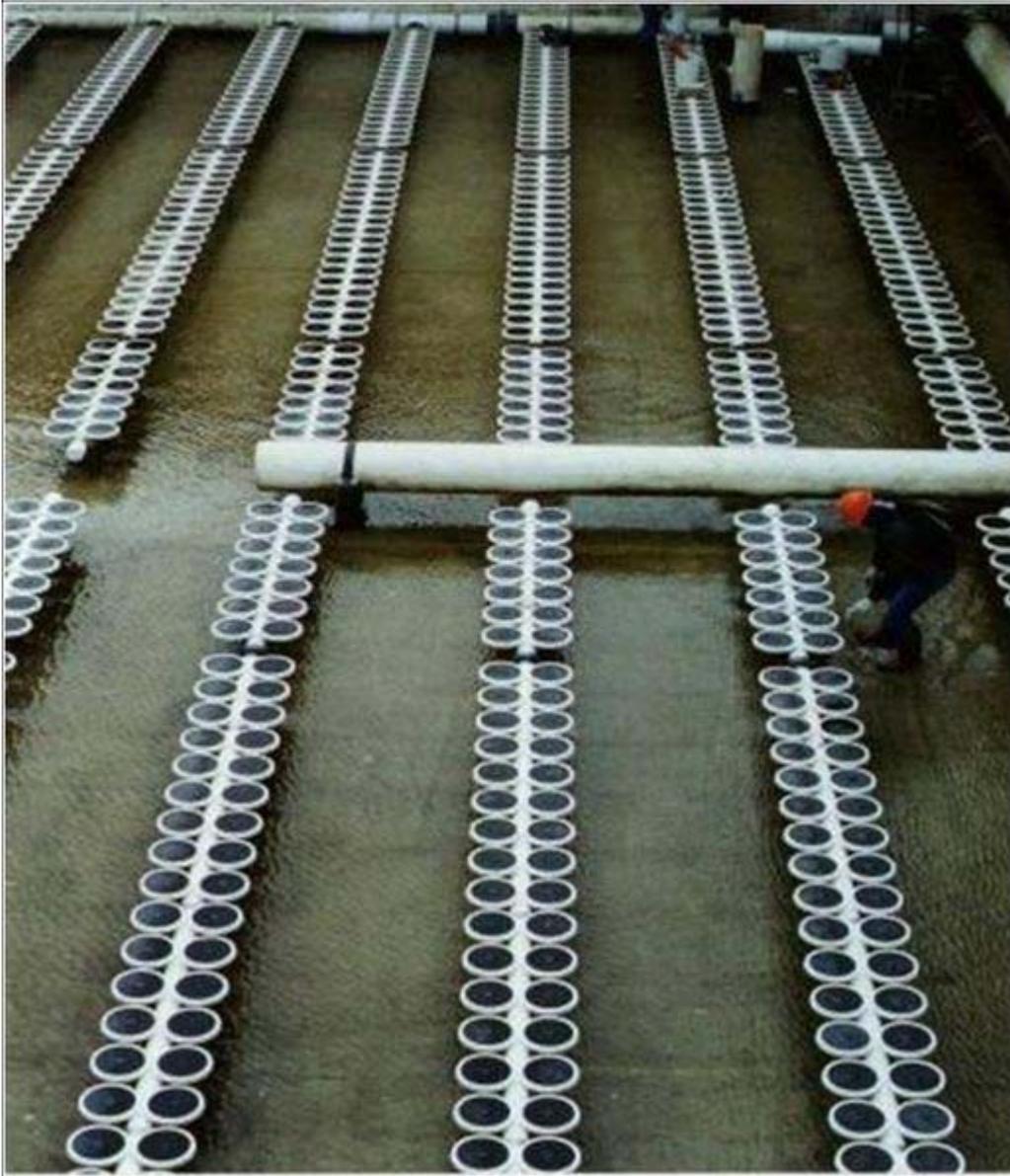
Most biological oxidation processes for treating industrial wastewaters have in common the use of oxygen (or air) and microbial action. Surface-aerated basins achieve 80 to 90% removal of BOD with retention times of 1 to 10 days. The basins may range in depth from 1.5 to 5.0 metres and utilize motor-driven aerators floating on the surface of the wastewater.

In an aerated basin system, the aerators provide two functions: they transfer air into the basins required by the biological oxidation reactions, and they provide the mixing required for dispersing the air and for contacting the reactants (that is, oxygen, wastewater and microbes). Typically, the floating surface aerators are rated to deliver the amount of air equivalent to 1.8 to 2.7 kg O<sub>2</sub>/kWh. However, they do not provide as good mixing as is normally achieved in activated sludge systems and therefore aerated basins do not achieve the same performance level as activated sludge units.

Biological oxidation processes are sensitive to temperature and, between 0 °C and 40 °C, the rate of biological reactions increase with temperature. Most surface aerated vessels operate at between 4 °C and 32 °C.

## ***Aeration methods***

### **Diffused Aeration**



Fine bubble membrane diffusers in an aeration tank

Sewage liquor is run into deep tanks with diffuser grid aeration systems that are attached to the floor. These are like the diffused airstone used in tropical fish tanks but on a much larger scale. Air is pumped through the blocks and the curtain of bubbles formed both oxygenates the liquor and also provide the necessary mixing action. Where capacity is limited or the sewage is unusually strong or difficult to treat, oxygen may be used instead of air. Typically, the air is generated by some type of blower or compressor.

## **Jet Aerators**

A jet aerator works through aspirating technology and thus does not require any external air source (i.e. compressor), except for the surrounding atmosphere. Jet aerators can be installed either as submersible units or piped through the tank wall using an external dry-installed chopper pump to feed the aspirating ejector(s).

## **Surface aerators (cones)**

Vertically mounted tubes of up to 1 metre diameter extending from just above the base of a deep concrete tank to just below the surface of the sewage liquor. A typical shaft might be 10 metres high. At the surface end the tube is formed into a cone with helical vanes attached to the inner surface. When the tube is rotated, the vanes spin liquor up and out of the cones drawing new sewage liquor from the base of the tank. In many works each cone is located in a separate cell that can be isolated from the remaining cells if required for maintenance. Some works may have two cones to a cell and some large works may have 4 cones per cell.

## Chapter 8

# Sewage



A preserved medieval waste pipe in Stockholm Old Town used to guide sewage onto the street where rain eventually would carry it away.

**Sewage** is water-carried wastes, in either solution or suspension, that is intended to flow away from a community. Also known as wastewater flows, sewage is the used water supply of the community. It is more than 99.9% pure water and is characterized by its volume or rate of flow, its physical condition, its chemical constituents, and the

bacteriological organisms that it contains. Depending on their origin, wastewater can be classed as sanitary, commercial, industrial, agricultural or surface runoff.

The spent water from residences and institutions, carrying body wastes, washing water, food preparation wastes, laundry wastes, and other waste products of normal living, are classed as domestic or sanitary sewage. Liquid-carried wastes from stores and service establishments serving the immediate community, termed commercial wastes, are included in the sanitary or domestic sewage category if their characteristics are similar to household flows. Wastes that result from an industrial process or the production or manufacture of goods are classed as industrial wastes. Their flows and strengths are usually more varied, intense, and concentrated than those of sanitary sewage. Surface runoff, also known as storm flow or overland flow, is that portion of precipitation that runs rapidly over the ground surface to a defined channel. Precipitation absorbs gases and particulates from the atmosphere, dissolves and leaches materials from vegetation and soil, suspends matter from the land, washes spills and debris from urban streets and highways, and carries all these pollutants as wastes in its flow to a collection point.

Wastewater from all of these sources may carry pathogenic organisms that can transmit disease to humans and other animals; contain organic matter that can cause odor and nuisance problems; hold nutrients that may cause eutrophication of receiving water bodies; and can lead to ecotoxicity. Proper collection and safe, nuisance-free disposal of the liquid wastes of a community are legally recognized as a necessity in an urbanized, industrialized society

"Sewage" and "Sewerage" may be used interchangeably in the USA but elsewhere they retain separate and different meanings - sewage being the liquid material and sewerage being the pipes, pumps and infrastructure through which sewage flows.

### ***Etymology***

- The words 'sewage' and 'sewer' come from Old French *seuwiere* or from Anglo-Norman *sewere* or from Anglo-French *assewer*, *essiver* meaning "(channel) to drain the overflow from a fish pond" or "to drain" and ultimately from Vulgar Latin \**exaquaticum* and \**exaquarium*, from the verb \**exaquare* = "to drain", from Latin *ex-* 'out of' + *aqua* 'water'.

### ***Sewage services***

#### **Collection and disposal**

A system of sewer pipes (sewers) collects sewage and takes it for treatment or disposal. The system of sewers is called *sewerage* or *sewerage system* in British English and *sewage system* in American English. Where a main sewerage system has not been provided, sewage may be collected from homes by pipes into septic tanks or cesspits, where it may be treated or collected in vehicles and taken for treatment or disposal. Properly functioning septic tanks require emptying every 2–5 years depending on the load of the system.

Sewage and waste water is also disposed of to rivers, streams and the sea in many parts of the world. Doing so can lead to serious pollution of the receiving water. This is common in third world countries and may still occur in some developed countries, where septic tank systems are too expensive.

## **Treatment**

Sewage treatment is the process of removing the contaminants from sewage to produce liquid and solid (sludge) suitable for discharge to the environment or for reuse. It is a form of waste management. A septic tank or other on-site wastewater treatment system such as biofilters can be used to treat sewage close to where it is created.

Sewage water is a complex matrix, with many distinctive chemical characteristics. These include high concentrations of ammonium, nitrate, phosphorus, high conductivity (due to high dissolved solids), high alkalinity, with pH typically ranging between 7 and 8. Trihalomethanes are also likely to be present as a result of past disinfection.

In developed countries sewage collection and treatment is typically subject to local, state and federal regulations and standards.

## **Conversion to fertiliser**

Sewage sludge can be collected through a sludge processing plant that automatically heats the matter and conveys it into fertiliser pellets (hereby removing possible contamination by chemical detergents, ...) This approach allows to eliminate seawater pollution by conveying the water directly to the sea without treatment (a practice which is still common in developing countries, despite environmental regulation). Sludge plants are useful in areas that have already set-up a sewage-system, but not in areas without such a system, as composting toilets are more efficient and do not require sewage pipes (which break over time).

## **Electricity**

Power can also be obtained from sewage water. The technique uses Microbial fuel cells.

## Chapter 9

# Vacuum Sewerage

A vacuum sewer system uses the differential pressure between atmospheric pressure and a partial vacuum maintained in the piping network and vacuum station collection vessel. This differential pressure allows a central vacuum station to collect the wastewater of several thousand individual homes, depending on terrain and the local situation. Vacuum sewers take advantage of available natural slope in the terrain and are most economical in flat sandy soils with high ground water.

Vacuum sewers were first installed in Europe in 1882 but until the last 30 years it had been relegated to a niche market. The first who has applied the negative pressure drainage (so called vacuum sewerage) was the Dutch engineer Liernur in the second half of the 19th century. It was only used on ships, trains and airplanes for a long time. Technical implementations of **vacuum sewerage** systems were started after 1959 in Sweden by Joel Liljendahl and afterwards brought onto the market by Electrolux. Nowadays several system suppliers offer a wide range of products for many applications.

### ***Introduction***

1.Collection chambers and vacuum valve units 2.Vacuum sewer lines 3.Central vacuum station Vacuum technology is based on differential air pressure. Rotary vane vacuum pumps generate an operation pressure of -0.4 to -0.6 bar at the vacuum station, which is also the only element of the vacuum sewerage system that must be supplied with electricity. Interface valves that are installed inside the collection chambers work pneumatically. Any sewage flows by means of gravity into each house's collection sump. After a certain fill level inside this sump is reached, the interface valve will open. The impulse to open the valve is usually transferred by a pneumatically (pneumatic pressure created by fill level) controlled controller unit. No electricity is needed to open or close the valve. The according energy is provided by the vacuum itself. While the valve is open, the resulting differential pressure between atmosphere and vacuum becomes the driving force and transports the wastewater towards the vacuum station. Besides these collection chambers, no other manholes, neither for changes in direction, nor for inspection or connection of branch lines, are necessary. High flow rates keep the system free of any blockages or sedimentation.

Vacuum sewer systems are considered to be free of ex- and infiltration which allows the usage even in water protection areas. For this reason, vacuum sewer lines may even be laid in the same trench as potable water lines (depending on local guidelines). The system supplier should certify his product to be used in that way. To achieve the condition of an infiltration-free system and therefore allowing to reduce the waste water amounts that need to be treated, water tight (PE material or similar) collection chambers should be used. Valve and collection sump (waste water) preferably should be physically separated (different chambers) in order to protect service personal against direct contact with waste water and to ensure longer life cycles (waste water is considered to be corrosive).

In order to ensure reliable transport, the vacuum sewer line is laid in a saw-tooth (length-) profile, which will be referred to more precisely afterwards. The whole vacuum sewers are filled with air at a pressure of -0.4 to -0.6 bar. The most important aspect for a reliable operation is the air-to-liquid ratio. When a system is well designed, the sewers contain only very small amounts of sewage. The air-to-liquid ratio is usually maintained by "intelligent" controller units or valves that adjust their opening times according to the pressure in the system.

Considering that the vacuum idea relies on external energy for the transport of fluids, sewers can be laid in flat terrain and up to certain limits may also be counter-sloped. The saw-tooth profile keeps sewer lines shallow, lifts minimise trench depth (approx. 1.0 – 1.2 m). In this depth, expensive trenching, as it is the case for gravity sewers with the necessity to install continuously falling slopes of at least 0.5 - 1.0%, is avoided. Lifting stations are not required.

Once arrived in the vacuum collection tank at the vacuum station, the wastewater is pumped to the discharge point, which could be a gravity sewer or the treatment station directly. As the dwell time of the wastewater inside the system is very short and the wastewater is continuously mixed with air, the sewage is kept fresh and any fouling inside the system is avoided (less H<sub>2</sub>S).

## **Advantages**

Closed, pneumatically controlled system with a central vacuum station. Electrical energy is only needed at this central station No sedimentation due to self-cleansing high velocities spooling and maintenance of the sewer lines is not necessary Manholes are not required Usually only a single vacuum pump station is required rather than multiple stations found in gravity and low pressure networks. This frees up land , reduces energy costs and reduces operational costs. Capital costs can be reduced by up to 50% due to simple trenching at shallow depths, close to surface Flexibility of piping, obstacles (as open channels) can be over- or underpassed reduced installation time Small diameter sewer pipes of HDPE, PVC materials; savings of material costs Aeration of sewage, less development of H<sub>2</sub>S, with its dangers for workers, inhabitants, as well as corrosion of the pipes may be avoided; No infiltration, less hydraulic load at treatment station and discharge sewers absolutely no leakages (vacuum avoids exfiltration) Sewers may be laid in the same trench with other mains, also with potable water or storm-water, as well as in water protection areas Lower cost to maintain in the long term due to shallow trenching and easy identification of problems In combination of vacuum toilets it creates

concentrated waste streams, which makes it feasible to use different waste water treatment techniques, like anaerobic treatment

## **Application Fields**

Vacuum sewer systems becomes more and more the preferred system in the case of particular circumstances:

Especially difficult situations as ribbon, peripheral settlements on flat terrain with high specific conduit lengths of longer than 4 metres per inhabitant are predestined for the application of vacuum sewerage systems. In the case of sparse population density the influence of the costs for the collection chambers and vacuum stations are less important in comparison to the costs of long and deep sewers on gravity. Missing incline of the ground, unfavourable soil (rocky or swampy grounds) and high groundwater table (with the necessity of dewatering trenches) lead to enormous investment costs in regards to gravity sewerage systems. On the contrary vacuum sewers that are small in diameter can be laid close to the surface in small trenches. Vacuum sewers can pass through water protection areas and areas with sensitive high ground water tables, because there is no danger of spoiling groundwater resources (vacuum sewers have a high leak tightness due to their material; moreover the vacuum itself does not allow exfiltration). Vacuum systems has also been applied to collect toxic wastewater. Vacuum systems are seen as a priority in many environmentally sensitive areas such as the Couran Cove Eco Resort close to the Barrier Reef in Australia. In seasonal settlements (recreation areas, camping sites etc.) with conventional gravity sewer systems, sedimentation problems can easily occur as automatic spooling from the daily waste water does not take place. High flow velocities within vacuum sewers prevent such sedimentation problems. The Formula 1 race tracks in Shanghai and Abu Dhabi are using a vacuum sewer system for that reason. Even in old narrow and historical villages, the use of vacuum sewer systems becomes more and more important due to a fast (traffic, tourism), cost-effective and flexible installation. Good examples and references can be found in France, such as the village of Flavigny, in Oman at the township of Khasab and Al Seeb. Lack of water in many countries and drastic water savings measures have led to difficulties with aging gravity networks with solids blocking in the pipes. Neither the lack of water nor solids affect resp. occur in vacuum sewer systems. That's why this technology becomes interesting for such kind of applications. As PE or PVC pipes are used, no solids from ageing pipes will enter the system. All other solid are kept out at the collection chambers. vacuum sewer systems don't have any manholes to dump big solids into the system.

## **Collection chambers / vacuum valves**

Raw sewage flows by gravity from one or more lots into a sealed collection sump. A vacuum interface valve is installed, which is controlled and operated pneumatically without electricity. When a certain amount of sewage has accumulated the controller opens the valve. It is important to understand that the valve shall open only, if the low pressure inside the vacuum sewer line is strong enough to ensure reliable transport. A minimum value of 0.15 bar for the existing low pressure in the adjacent vacuum line.

When the valve opens, between 20 and 40 l (depending on adjustment and valve) portions of effluent are sucked into the sewer line. Air entering via the incoming gravity line or air vent will be sucked into the sewer line due to the pressure difference to push the sewage. The interface valve will close again after a few seconds. The exact time should have an option to be adjusted and must be long enough to make sure that enough air can enter in order to push the sewage efficiently. This depends on the negative pressure conditions: Generally, the volume of air-stream should be lessened as far as possible, so that the pumps do not have to work unnecessarily. On the other hand minimum ratios of air-to-liquid should be guaranteed to have reliable transporting conditions. Usually the systems work with air-liquid ratios of about 4:1 to 15:1. Vacuum Technology is very reliable and tested technology when the right equipment is used. The restricting minimum diameter of the system should prevent the interface valves and the vacuum sewers from clogging. So, the connection from the sump to the interface valve should have a diameter of 75mm so that no blockage point is created. Usually, larger particles do not arrive in the sump, even though it still can occur. Large particles can be easily removed from the sump by an operator if required. But generally anything that can fit down a house service line should be able to enter the vacuum system and then the vacuum pump station without blockage.

## **Vacuum Lines / Description of Hydropneumatic Transport**

Flow situations in vacuum sewers cannot be simply described with hydraulic laws. Instead of it a two-phases-flow transport has to be considered (e.g. hydropneumatical). Conveyance takes place by means of a two-phase regime, air (compressible) and effluent. Because of this the continuity equation becomes very complicated.

As it was mentioned before, the main characteristic of vacuum sewerage is the necessity to lay the sewers in the form of a distinct saw-tooth or stepped profile. An effective transport of sewage can only be guaranteed, if the hydraulic losses are agreed to by an approved supplier.

Doses of sewage enter the vacuum line from the collection chambers. As sewage arrive at a low point of the sewer line, sewage is collected there, - until valves upstream open and arriving air will increase the pressure gradient again. Air moving at high velocity into the direction of the vacuum station will exert a strong impulse on the developing sewage.

In this way sewage will be shifted with almost the same velocity over the next peak down the line. The transport of sewage will continue along the sewer line as far as the pressure gradient remains. In a horizontally laid pipe air would stream over water without moving it further.

High flow velocities in the low points of up to 5 m/s avoid any kind of sedimentation, since during the starting movement this kind of flushing effect would take away all hypothetical deposits. Sedimentation problems have never been reported for vacuum sewerage systems.

Prevailing diameters in vacuum sewers are in range of DN 80 and DN 315 (inner diameter). Usually PEHD or PVC pipes are applied in vacuum systems due to their low

costs of installation and flexibility. Vacuum sewers have to be absolutely tight. Therefore, DIN EN 1091 requires a thickness of at least PN 10. Leakages do not appear in vacuum systems due to an absolute tightness of installations (each construction company is easily able to install vacuum pipes).

## **Vacuum Station**

The vacuum collection station is the only place of the complete system, where energy is required! The vacuum station consists of rotary vane vacuum pumps (generate vacuum in the sewer lines), a collection tank, and duplicated sewage pumps (duty/standby) that discharge sewage away from the collection tanks to a wastewater treatment facility. The vacuum pumps maintain a negative pressure inside the collection tank in a range of -0.4 to -0.6 bar (adjustable). When the negative pressure inside the system falls under a certain limit the vacuum pumps will start working. Vacuum pumps run only for a few hours a day and do not need to run continuously since the vacuum interface valves at collection pits are normally closed.

Collection tanks are mostly made of steel and not of stainless steel (risk of local chemical element corrosion). In choosing tank materials, water tightness has a high priority, subsequently all joints should be sealed. Vacuum tanks are sized according to flow rates and vacuum suction capacity with typical volumes ranging from 5 to 12 m<sup>3</sup>. About 75% of the tank's volume will be required as a vacuum reservoir. With this vacuum reserve the vacuum pumps shall be prevented from too high a starting rate, which is normally limited to 10-15 starts per hour (worst case).

## **Design**

Planning a vacuum sewerage system seems to be initially a question of design. There is never only one solution at sewer networks in general, but vacuum systems can be designed in many different ways (e.g. connected area, location of the vacuum station, choice of the length profile etc.). A good design needs a perfect overall picture on all the system's parameters! Some suppliers of vacuum system components help seriously during the design with their assistance. The use of such experienced help is recommendable and preferable.

In the guidelines mentioned above the control of the following parameters is demanded:

- air-liquid ratio (depending from distances and population density)
- energetic loss (derived from the maximum trunk length in between the vacuum station and the furthest interface valve as well as from geodetic steps due to topography)
- network-length (sum of all trunks leading together)
- flow-rate
- vacuum reserve volume (considering also the sewer network)
- maximum tolerable distances in between air inlets (interface valves).

The most significant step in designing a vacuum sewerage system is the choice of a good pipe-routing. System boundaries such as maximum trunk length and additional elevations

of the pipe length-profile do not have to be surpassed. As this kind of work requires iterations, design-diagrams have been developed. The maximum trunk length is restricted to 4000 m in absolutely flat terrain. A longer distance can be handled must be done in consultation with a system supplier.

While the norms do not give sufficient information about checking and dimensioning of design parameters, it shall be emphasised, that vacuum sewerage systems could become remarkably larger than the norms show it!

### ***Hints about Operation***

Unjustified prejudices against “new” technologies still prevail. Highly assumed maintenance/operational costs are the main obstacle against further expansion of vacuum sewerage systems on the market. Problems, especially at collection chambers, and frequent system break-downs (drowning) were the birth labour of first vacuum sewerage systems. Nowadays, vacuum systems are reliable when their design is based on special knowledge of professional companies.

Vacuum stations should be visited at least once a week to carry out a visual inspection. Experiences have shown that a well-designed vacuum station will not need more than one visible control and short check once a week (similar to a pumping system). Operating hours and power consumption of the pumps should be checked regularly. Mechanical and electrical maintenance, cleaning of the vacuum tank, briefly a total check of the vacuum station, should at least be done once a year (oil-change and filter change of the vacuum pumps).

### ***Conclusion***

Highly estimated operation costs and fear of malfunction have been the main prejudices and obstacles in the past against an expanded use of vacuum sewers. For an unprejudiced choice of a sewerage concept, it is necessary not to overestimate operational costs of alternative wastewater collection systems. Further, more difficult conditions during construction have to be considered for conventional gravity sewerage! When a vacuum sewerage system is well designed, operational reliability will be guaranteed.

Vacuum sewerage seems to become more and more important as capital costs could be reduced remarkably. Good references from communities seem to show satisfaction. Especially in cases of sparse population density, flat terrain, and high specific costs of pipe-laying, alternative sewerage systems could become much more economic, also in the long run.

It is significant not to over-estimate the operation costs of alternative wastewater collection systems, in comparison with the costs of a conventional gravity system (which constitutes work under more difficult conditions). When a vacuum sewerage system is duly designed and built, its operational reliability is guaranteed.

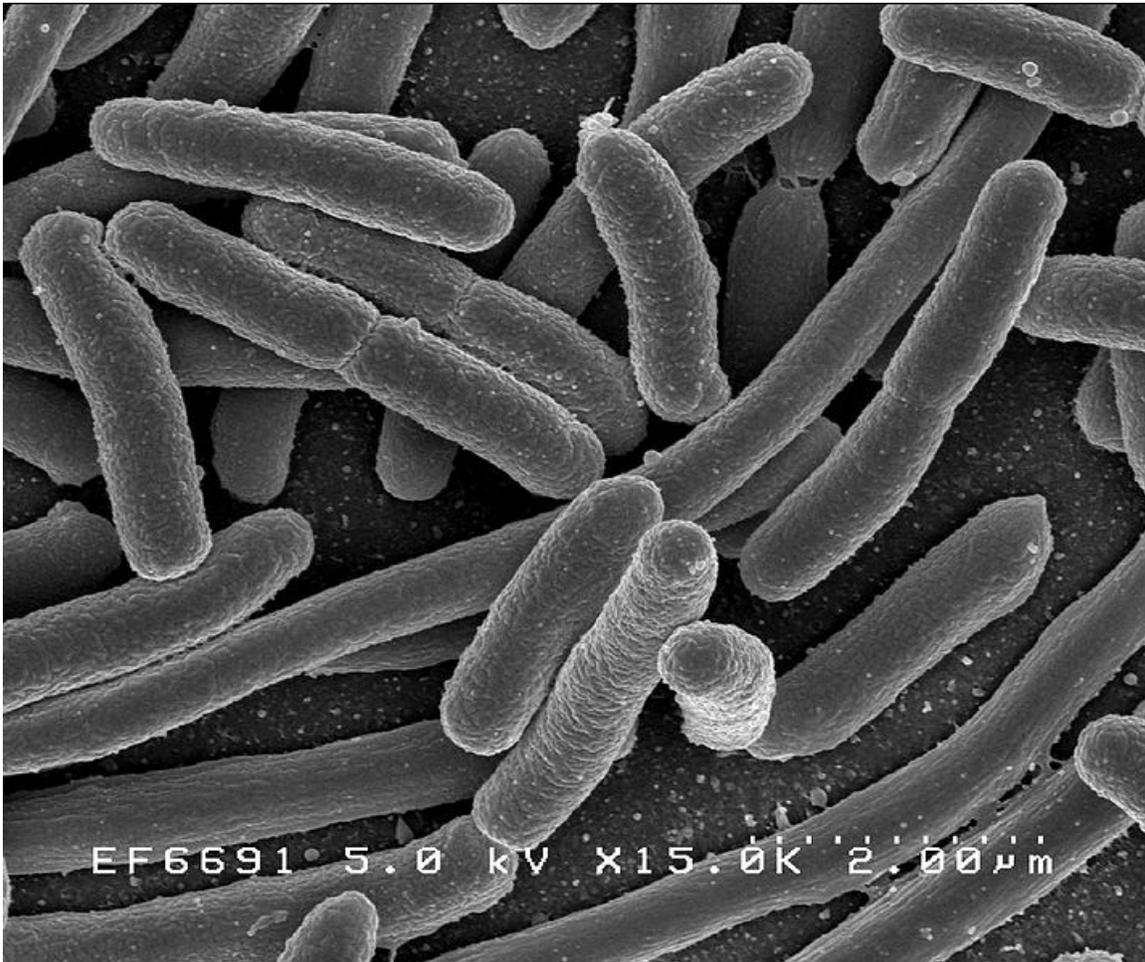
As engineers and municipal officials become acquainted with the advantages of vacuum sewers, the use of this technology will probably expand more and more worldwide.

It is hoped that the use of alternative sewerage concepts will allow designers and regulators to find ways of keeping project costs at a minimum.

Frequently, a combination of different alternative systems together as well as conventional sections will become the most feasible and the most reliable solution for the collection of wastewater.

## Chapter 10

# Sanitation



E. coli bacteria under magnification

**Sanitation** is the hygienic means of promoting health through prevention of human contact with the hazards of wastes. Hazards can be either physical, microbiological, biological or chemical agents of disease. Wastes that can cause health problems are human and animal feces, solid wastes, domestic wastewater (sewage, sullage, greywater),

industrial wastes, and agricultural wastes. Hygienic means of prevention can be by using engineering solutions (e.g. sewerage and wastewater treatment), simple technologies (e.g. latrines, septic tanks), or even by personal hygiene practices (e.g. simple handwashing with soap).

The World Health Organization states that:

"Sanitation generally refers to the provision of facilities and services for the safe disposal of human urine and faeces. Inadequate sanitation is a major cause of disease world-wide and improving sanitation is known to have a significant beneficial impact on health both in households and across communities. The word 'sanitation' also refers to the maintenance of hygienic conditions, through services such as garbage collection and wastewater disposal.

The term "**sanitation**" can be applied to a specific aspect, concept, location, or strategy, such as:

- **Basic sanitation** - refers to the management of human feces at the household level. This terminology is the indicator used to describe the target of the Millennium Development Goal on sanitation.
- **On-site sanitation** - the collection and treatment of waste is done where it is deposited. Examples are the use of pit latrines, septic tanks, and imhoff tanks.
- **Food sanitation** - refers to the hygienic measures for ensuring food safety.
- **Environmental sanitation** - the control of environmental factors that form links in disease transmission. Subsets of this category are solid waste management, water and wastewater treatment, industrial waste treatment and noise and pollution control.
- **Ecological sanitation** - a concept and an approach of recycling to nature the nutrients from human and animal wastes.

## ***History***

The earliest evidence of urban sanitation was seen in Harappa, Mohenjo-daro and the recently discovered Rakhigarhi of Indus Valley civilization. This urban plan included the world's first urban sanitation systems. Within the city, individual homes or groups of homes obtained water from wells. From a room that appears to have been set aside for bathing, waste water was directed to covered drains, which lined the major streets. Houses opened only to inner courtyards and smaller pole.

Roman cities and Roman villas had elements of sanitation systems, delivering water in the streets of towns such as Pompeii, and building stone and wooden drains to collect and remove wastewater from populated areas - see for instance the Cloaca Maxima into the River Tiber in Rome. But there is little record of other sanitation in most of Europe until the High Middle Ages. Unsanitary conditions and overcrowding were widespread throughout Europe and Asia during the Middle Ages, resulting periodically in cataclysmic pandemics such as the Plague of Justinian (541-42) and the Black Death (1347-1351), which killed tens of millions of people and radically altered societies.

Very high infant and child mortality prevailed in Europe throughout medieval times, due not only to deficiencies in sanitation but to insufficient food for a population which had expanded faster than agriculture. This was further complicated by frequent warfare and exploitation of civilians by brutal rulers. Life for the average person at this time was indeed 'nasty, brutish and short.

The word Sanitation is also now used in pop culture. It is used as a substitution of "yo" and means a smelly person.

## ***Wastewater sanitation***

### **Wastewater collection**

The standard sanitation technology in urban areas is the collection of wastewater in sewers, its treatment in wastewater treatment plants for reuse or disposal in rivers, lakes or the sea. Sewers are either combined with storm drains or separated from them as sanitary sewers. Combined sewers are usually found in the central, older parts or urban areas. Heavy rainfall and inadequate maintenance can lead to combined sewer overflows or sanitary sewer overflows, i.e. more or less diluted raw sewage being discharged into the environment. Industries often discharge wastewater into municipal sewers, which can complicate wastewater treatment unless industries pre-treat their discharges.

The high investment cost of conventional wastewater collection systems are difficult to afford for many developing countries. Some countries have therefore promoted alternative wastewater collection systems such as condominial sewerage, which uses smaller diameter pipes at lower depth with different network layouts from conventional sewerage.

## Wastewater treatment



Sewage treatment plant, Australia.

In developed countries treatment of municipal wastewater is now widespread, but not yet universal. In developing countries most wastewater is still discharged untreated into the environment. For example, in Latin America only about 15% of collected sewerage is being treated.

## Reuse of wastewater

The reuse of untreated wastewater in irrigated agriculture is common in developing countries. The reuse of treated wastewater in landscaping (esp. on golf courses), irrigated agriculture and for industrial use is becoming increasingly widespread.

In many peri-urban and rural areas households are not connected to sewers. They discharge their wastewater into septic tanks or other types of on-site sanitation.

## Ecological sanitation

Ecological sanitation is sometimes presented as a radical alternative to conventional sanitation systems. Ecological sanitation is based on composting or vermicomposting toilets where an extra separation of urine and feces at the source for sanitization and recycling has been done. It thus eliminates the creation of blackwater and eliminates fecal pathogens from any still present wastewater (urine). If ecological sanitation is practiced municipal wastewater consists only of greywater, which can be recycled for gardening. However, in most cases greywater continues to be discharged to sewers.

## **Sanitation and public health**

The importance of waste isolation lies in an effort to prevent water and sanitation related diseases, which afflicts both developed countries as well as developing countries to differing degrees. It is estimated that up to 5 million people die each year from preventable water-borne disease, as a result of inadequate sanitation and hygiene practices. The affects of sanitation have also had a large impact on society. Published in *Griffins Public Sanitation* proven studies show that higher sanitation produces more attractiveness.

## **Global access to improved sanitation**

The Joint Monitoring Program for water and sanitation of WHO and UNICEF has defined improved sanitation as

- connection to a public sewer
- connection to a septic system
- pour-flush latrine
- simple pit latrine
- ventilated improved pit latrine

According to that definition, 62% of the world's population has access to improved sanitation in 2008, up 8% since 1990. Only slightly more than half of them or 31% of the world population lived in houses connected to a sewer. Overall, 2.5 billion people lack access to improved sanitation and thus must resort to open defecation or other unsanitary forms of defecation, such as public latrines or open pit latrines. This includes 1.2 billion people who have access to no facilities at all. This outcome presents substantial public health risks as the waste could contaminate drinking water and cause life threatening forms of diarrhea to infants. Improved sanitation, including hand washing and water purification, could save the lives of 1.5 million children who suffer from diarrheal diseases each year.

In developed countries, where less than 20% of the world population lives, 99% of the population has access to improved sanitation and 81% were connected to sewers.

## ***Solid waste disposal***



Hiriya Landfill, Israel.

Disposal of solid waste is most commonly conducted in landfills, but incineration, recycling, composting and conversion to biofuels are also avenues. In the case of landfills, advanced countries typically have rigid protocols for daily cover with topsoil, where underdeveloped countries customarily rely upon less stringent protocols. The importance of daily cover lies in the reduction of vector contact and spreading of pathogens. Daily cover also minimises odor emissions and reduces windblown litter. Likewise, developed countries typically have requirements for perimeter sealing of the landfill with clay-type soils to minimize migration of leachate that could contaminate groundwater (and hence jeopardize some drinking water supplies).

For incineration options, the release of air pollutants, including certain toxic components is an attendant adverse outcome. Recycling and biofuel conversion are the sustainable options that generally have superior life cycle costs, particularly when total ecological consequences are considered. Composting value will ultimately be limited by the market demand for compost product.

## ***Sanitation in the developing world***

The United Nations Millennium Development Goals (MDGs) include a target to reduce by half the proportion of people without access to basic sanitation by 2015. In December 2006, the United Nations General Assembly declared 2008 'The International Year of Sanitation', in recognition of the slow progress being made towards the MDGs sanitation target. The year aims to develop awareness and action to meet the target. Particular concerns are:

- Removing the stigma around sanitation, so that the importance of sanitation can be more easily and publicly discussed.
- Highlighting the poverty reduction, health and other benefits that flow from better hygiene, household sanitation arrangements and wastewater treatment.

Research from the Overseas Development Institute suggests that sanitation and hygiene promotion needs to be better 'mainstreamed' in development, if the MDG on sanitation is to be met. At present, promotion of sanitation and hygiene is mainly carried out through water institutions. The research argues that there are, in fact, many institutions that should carry out activities to develop better sanitation and hygiene in developing countries. For example, educational institutions can teach on hygiene, and health institutions can dedicate resources to preventative works (to avoid, for example, outbreaks of cholera).

The Institute of Development Studies (IDS) coordinated research programme on Community-led Total Sanitation (CLTS) is a radically different approach to rural sanitation in developing countries and has shown promising successes where traditional rural sanitation programmes have failed. CLTS is an unsubsidized approach to rural sanitation that facilitates communities to recognize the problem of open defecation and take collective action to clean up and become 'open defecation free'. It uses community-led methods such as participatory mapping and analysing pathways between feces and mouth as a means of galvanizing communities into action. An IDS 'In Focus' Policy Brief suggests that in many countries the Millennium development goal for sanitation is off track and asks how CLTS can be adopted and spread on a large scale in the many countries and regions where open defecation still prevails.

### ***Sanitation in the food industry***



Modern restaurant food preparation area.

Sanitation within the food industry means to the adequate treatment of food-contact surfaces by a process that is effective in destroying vegetative cells of microorganisms of public health significance, and in substantially reducing numbers of other undesirable microorganisms, but without adversely affecting the product or its safety for the consumer (U.S. Food and Drug Administration, Code of Federal Regulations, 21CFR110, USA). Sanitation Standard Operating Procedures are indispensable for food industries in US, which are regulated by 9 CFR part 416 in conjunction with 21 CFR part 178.1010. Similarly in Japan, food hygiene has to be reached through the compliance of Food Sanitation Law.

Additionally, in the food and Biopharmaceutical industries, the term sanitary equipment means equipment that is fully cleanable using Clean-in-place (CIP), and Sterilization in place (SIP) procedures: that is fully drainable from cleaning solutions and other liquids. The design should have a minimum amount of deadleg or areas where the turbulence

during cleaning is not enough to remove product deposits. In general, to improve cleanability, this equipment is made from Stainless Steel 316L, (an alloy containing small amounts of molybdenum). The surface is usually electropolished to an effective surface roughness of less than 0.5 micrometre, to reduce the possibility of bacterial adhesion to the surface.

## Chapter 11

# Sewage Sludge Treatment

**Sewage sludge treatment** described the processes used to manage and dispose of the sludges produced during sewage treatment.

### ***Sources of sludge***

Coarse primary solids and secondary biosolids accumulated in a wastewater treatment process must be treated and disposed of in a safe and effective manner. This material may be inadvertently contaminated with toxic organic and inorganic compounds (e.g. heavy metals).

### ***Digestion***

Many sludges are treated using a variety of digestion techniques, the purpose of which is to reduce the amount of organic matter and the number of disease-causing microorganisms present in the solids. The most common treatment options include anaerobic digestion, aerobic digestion, and composting.

### **Anaerobic digestion**

Anaerobic digestion is a bacterial process that is carried out in the absence of oxygen. The process can either be *thermophilic* digestion in which sludge is fermented in tanks at a temperature of 55°C or *mesophilic*, at a temperature of around 36°C. Though allowing shorter retention time, thus smaller tanks, thermophilic digestion is more expensive in terms of energy consumption for heating the sludge.

Anaerobic digestion generates biogas with a high proportion of methane that may be used to both heat the tank and run engines or microturbines for other on-site processes. In large treatment plants sufficient energy can be generated in this way to produce more electricity than the machines require. The methane generation is a key advantage of the anaerobic process. Its key disadvantage is the long time required for the process (up to 30 days) and the high capital cost.

Under laboratory conditions it is possible to directly generate useful amounts of electricity from organic sludge using naturally occurring electrochemically active

bacteria. Potentially, this technique could lead to an ecologically positive form of power generation, but in order to be effective such a microbial fuel cell must maximize the contact area between the effluent and the bacteria-coated anode surface, which could severely hamper throughput.

## **Aerobic digestion**

Aerobic digestion is a bacterial process occurring in the presence of oxygen. Under aerobic conditions, bacteria rapidly consume organic matter and convert it into carbon dioxide. Once there is a lack of organic matter, bacteria die and are used as food by other bacteria. This stage of the process is known as *endogenous respiration*. Solids reduction occurs in this phase. Because the aerobic digestion occurs much faster than anaerobic digestion, the capital costs of aerobic digestion are lower. However, the operating costs are characteristically much greater for aerobic digestion because of energy costs for aeration needed to add oxygen to the process.

## **Composting**

Composting is also an aerobic process that involves mixing the wastewater solids with sources of carbon such as sawdust, straw or wood chips. In the presence of oxygen, bacteria digest both the wastewater solids and the added carbon source and, in doing so, produce a large amount of heat.

Both anaerobic and aerobic digestion processes can result in the destruction of disease-causing microorganisms and parasites to a sufficient level to allow the resulting digested solids to be safely applied to land used as a soil amendment material (with similar benefits to peat) or used for agriculture as a fertilizer provided that levels of toxic constituents are sufficiently low.

The largest composting site in the world that also processes sewage is the Edmonton Composting Facility, in Edmonton, Canada.

## ***Thermal depolymerization***

Thermal depolymerization uses hydrous pyrolysis to convert reduced complex organics to oil. The preacerated, grit-reduced sludge is heated to 250C and compressed to 40 MPa. The hydrogen in the water inserts itself between chemical bonds in natural polymers such as fats, proteins and cellulose. The oxygen of the water combines with carbon, hydrogen and metals. The result is oil, light combustible gases such as methane, propane and butane, water with soluble salts, carbon dioxide, and a small residue of inert insoluble material that resembles powdered rock and char. All organisms and many organic toxins are destroyed. Inorganic salts such as nitrates and phosphates remain in the water after treatment at sufficiently high levels that further treatment is required.

The energy from decompressing the material is recovered, and the process heat and pressure is usually powered from the light combustible gases. The oil is usually treated further to make a refined useful light grade of oil, such as no. 2 diesel and no. 4 heating oil, and then sold.

The choice of a wastewater solid treatment method depends on the amount of solids generated and other site-specific conditions. However, in general, composting is most often applied to smaller-scale applications followed by aerobic digestion and then lastly anaerobic digestion for the larger-scale municipal applications.

### ***Sludge disposal***

When a liquid sludge is produced, further treatment may be required to make it suitable for final disposal. Typically, sludges are thickened (dewatered) to reduce the volumes transported off-site for disposal. Processes for reducing water content include lagooning in drying beds to produce a cake that can be applied to land or incinerated; pressing, where sludge is mechanically filtered, often through cloth screens to produce a firm cake; and centrifugation where the sludge is thickened by centrifugally separating the solid and liquid. Sludges can be disposed of by liquid injection to land or by disposal in a landfill. There are concerns about sludge incineration because of air pollutants in the emissions, along with the high cost of supplemental fuel, making this a less attractive and less commonly constructed means of sludge treatment and disposal. There is no process which completely eliminates the requirements for disposal of biosolids.

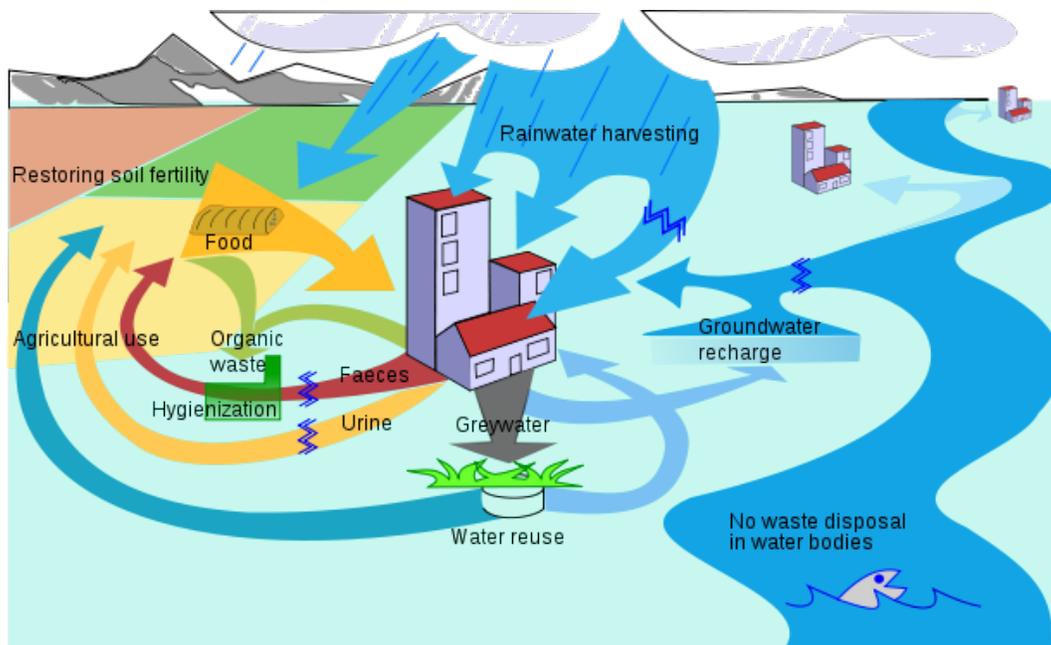
In South Australia, after centrifugation, the sludge is then completely dried by sunlight. The nutrient rich biosolids are then provided to farmers free-of-charge to use as a natural fertiliser. This method has reduced the amount of landfill generated by the process each year.

In the very large metropolitan areas of southern California inland communities return sewage sludge to the sewer system of communities at lower elevations to be reprocessed at a few very large treatment plants on the Pacific coast. This reduces the required size of interceptor sewers and allows local recycling of treated waste-water while retaining the economy of a single sludge processing facility.

## Chapter 12

# Ecological Sanitation

**Ecological sanitation**, also known as **ecosan** or **eco-san**, is a sanitation process that uses human blackwater and sometimes immediately eliminates fecal pathogens from any still present wastewater (urine) at the source. The objectives are to offer economically and ecologically sustainable and culturally acceptable systems that aim to close the natural nutrient and water cycle.



### ***Introduction to ecological sanitation***

Ecological sanitation (ecosan) offers a new philosophy of dealing with what is presently regarded as waste and wastewater. Ecosan is based on the systematic implementation of reuse and recycling of nutrients and water as a hygienically safe, closed-loop and holistic alternative to conventional sanitation solutions. Ecosan systems enable the recovery of nutrients from human faeces and urine for the benefit of agriculture, thus helping to preserve soil fertility, assure food security for future generations, minimize water pollution and recover bioenergy. They ensure that water is used economically and is recycled in a safe way to the greatest possible extent for purposes such as irrigation or groundwater recharge.

The main objectives of ecological sanitation are:

- To reduce the health risks related to sanitation, contaminated water and waste
- To prevent the pollution of surface and ground water
- To prevent the degradation of soil fertility
- To optimise the management of nutrients and water resources.

### ***History of reuse-oriented sanitation approaches***

In a very broad sense the recovery and use of urine and feces has been practiced over millennia by almost all cultures. The uses were not limited to agricultural production (although for modern application this may be of most relevance), like the Romans who were well aware of the disinfecting attributes of urine and also used it for washing clothing.

The most widely known example of the diligent collection and use of human excreta in agriculture is China. Reportedly, the Chinese were aware of the benefits of using excreta in crop production before 500 B.C., enabling them to sustain more people at a higher density than any other system of agriculture. The value of “night soil” as a fertilizer was clearly recognized with well developed systems in place to enable the collection of excreta from cities and its transportation to fields.

Elaborate systems were developed in urban centers of Yemen enabling the separation of urine and excreta even in multi-story buildings. Feces were collected from toilets via vertical drop shafts, while urine did not enter the shaft but passed instead along a channel leading through the wall to the outside where it evaporated. Here, feces were not used in agriculture but were dried and burnt as fuel.

In Mexico and Peru, both the Aztec and Inca cultures collected human excreta for agricultural use. In Peru, the Incas had a high regard for excreta as a fertilizer, which was stored, dried and pulverized to be utilized when planting maize.

In the Middle Ages, the use of excreta and greywater was the norm. European cities were rapidly urbanizing and sanitation was becoming an increasingly serious problem, whilst at the same time the cities themselves were becoming an increasingly important source of agricultural nutrients. The practice of using the nutrients in excreta and wastewater for agriculture therefore continued in Europe into the middle of the 19th Century. Farmers, recognizing the value of excreta, were eager to get these fertilizers to increase production and urban sanitation benefited.

The increasing number of research and demonstration projects for excreta reuse carried out in Sweden from the 1980s to the early 21st century aimed at developing hygienically safe closed loop sanitation systems. Similar lines of research began elsewhere, for example in Zimbabwe, in the Netherlands, Norway and Germany. These closed-loop sanitation systems became popular under the name “ecosan”, “dewats”, “desar”, and

other abbreviations. They placed their emphasis on the hygienisation of the contaminated flow streams, and shifted the concept from waste disposal to resource conservation and safe reuse.

## ***Concepts of ecological sanitation***

Ecological sanitation (Ecosan) is a new holistic paradigm in sanitation, which is based on an overall view of material flows as part of an ecologically and economically sustainable wastewater management system tailored to the needs of the users and to the respective local conditions. It does not favour a specific sanitation technology, but is rather a new philosophy in handling substances that have so far been seen simply as wastewater and water-carried waste for disposal.

According to Esrey et al. (2003) ecological sanitation can be defined as a system that:

- Prevents disease and promotes health
- Protects the environment and conserves water
- Recovers and recycles nutrients and organic matter

Ecosan offers a flexible framework, where centralised elements can be combined with decentralised ones, waterborne with dry sanitation, high-tech with low-tech, etc. By considering a much larger range of options, optimal and economic solutions can be developed for each particular situation.

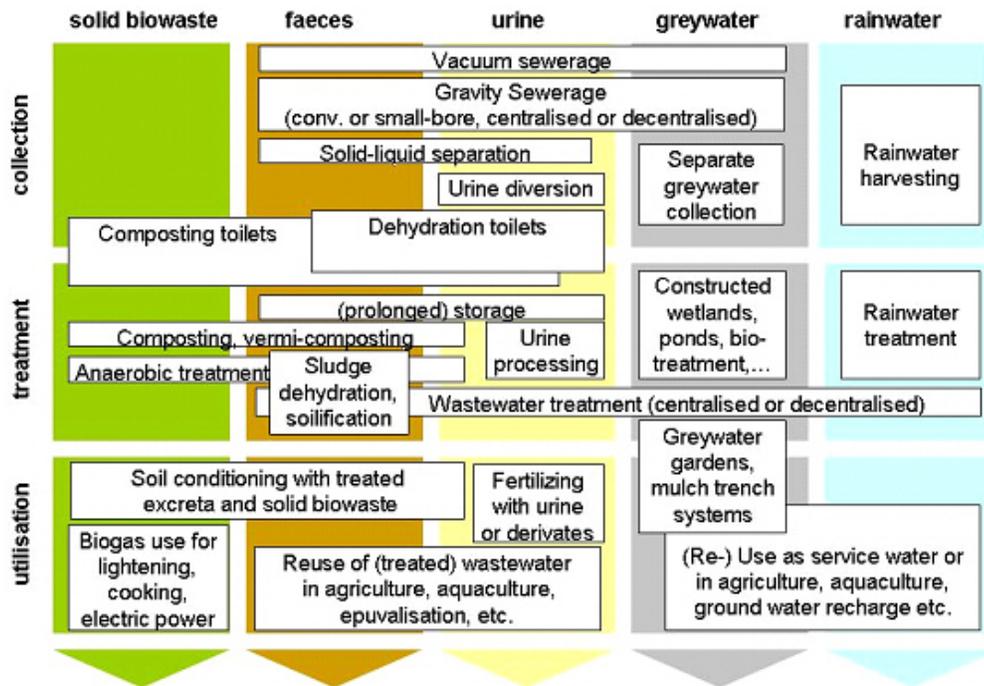
Thus, the most important advantages of ecological sanitation systems are:

- Improvement of health by minimising the introduction of pathogens from human excreta into the water cycle
- Promotion of safe, hygienic recovery and use of nutrients, organics, trace elements, water and energy
- Preservation of soil fertility
- Contribution to the conservation of resources through lower water consumption, substitution of mineral fertiliser and minimisation of water pollution
- Improvement of agricultural productivity and food security
- Preference for modular, decentralised partial-flow systems for more appropriate cost-efficient solutions adapted to the local situation
- Promotion of a holistic, interdisciplinary approach
- Material flow cycle instead of disposal of valuable resources

## ***Technologies of ecosan systems***

Determining ecosan systems as ecological sanitation is not easy, for it is not just one specific technology, but a new approach based on an ecosystem-oriented view of material flows.

The following diagram gives an overview of the different collection, treatment and reuse possibilities of the five flow streams considered in ecological sanitation systems:



## Project examples

Examples of ecosan projects can be found among others in the collection of project data sheets of [gtz ecosan](#) or on the Enhanced Global Map of ecosan activities by [EcoSanRes](#). In the following some examples are given that underline the diversity of ecosan projects:

### Guangxi province, China - large-scale project of urine diverting dehydration toilets

The dissemination programme of ecological dry toilets for Hsinchu County, Guangxi province, one of the poorest provinces in China, started in 1997 with support of UNICEF, SIDA and the Red Cross and has been expanded to 17 provinces until the year 2003. By this year, the scale of the project had increased to approximately 685,000 toilet units – today more than one million double vault urine diversion dehydration toilets (UDDTs) are installed in rural areas of China.

In UDDTs, urine and faeces are collected separately: The urine is collected in the front and lead by a plastic pipe to a storage canister from where it can be used as a fertilizer in agriculture, the faeces fall at the back in one of two ventilated storage chambers and are covered with ash for better dehydration. After about one year of storage the dried material can be removed and used as a soil conditioner in agriculture.

**KfW, Frankfurt, Germany - vacuum toilets + greywater treatment** The sanitation concept of the modern office building “Ostarkarde” of the KfW Bankengruppe in Frankfurt is based on a separate excreta and greywater collection. While urine and faeces are collected via vacuum toilets and a vacuum sewerage using much less water for flushing, the greywater from hand washing and kitchen is collected and treated separately in a compact activated sludge reactor combined with membrane filtration. The treated greywater is then reused for toilet flushing and cleaning water. The amount of greywater

can be reduced by 76% by this cost-efficient system which could be one of the prior choices for sanitation systems of newly constructed office buildings.

**Tanum Municipality** in Sweden has introduced urine separation toilets to recover phosphorus.

### ***Arguments for the use of ecological sanitation***

Often, water used in flush toilets is of drinking quality. Only 1% of global water is drinkable, therefore, it is a precious resource. Water fit to be drunk is being used for other purposes that can use lesser quality water, such as toilets.

Mixing feces and urine makes treatment difficult. All waste water treatment plants use some natural/biological processes, but nature does not normally have this waste water, so there are no microbes that can deal with this mix. In order to treat waste, treatment plants have to do this in stages. Each stage treats a different component of the mix by creating the right environment for microbes to do their work (aerobic, anaerobic, anoxic and the right pH). This is costly and requires energy.

A mix of domestic and industrial effluent in water cannot be treated properly, for heavy metals and other pollutants make this water unsuitable for reuse. This is normally discharged into the ground or water bodies.

Because of the complexity of the treatment process, treatment plants tend to be large. This requires costly infrastructure to build and maintain it, often out of the reach of poorer communities.

John Jeavons argues that "Each person's urine and manure contain approximately enough nutrients to produce enough food to feed that person." Urea is the major component of urine, yet we produce vast quantities of urea by using fossil fuels. By properly managing urine, treatment costs as well as fertilizer costs can be reduced. Feces also contains recognized nutrients, and could be used for modern agriculture, as micronutrient deficiency is a significant problem.

## Chapter 13

# Sewage Collection and Disposal



Deer Island Waste Water Treatment Plant serving Boston, Massachusetts, and vicinity.

**Sewage collection and disposal** systems transport sewage through cities and other inhabited areas to sewage treatment plants to protect public health and prevent disease. Sewage is treated to control water pollution before discharge to surface waters.

### ***Collection***

A sewage system may convey the wastewater by gravity to a sewage treatment plant. Where pipeline excavation is difficult because of rock or there is limited topographic relief (i.e., due to flat terrain), gravity collection systems may not be practical and the sewage must be pumped through a pipeline to the treatment plant. In low-lying

communities, wastewater may be conveyed by vacuum. Pipelines range in size from pipes of six inches (150 mm) in diameter to concrete-lined tunnels of up to thirty feet (10 m) in diameter.

Community sewage can also be collected by an effluent sewer system, also known as a STEP system (Septic Tank Effluent Pumping). At each home, a buried collection tank is used to separate solids from the liquid effluent portion. Only the liquid portion is then pumped through small diameter pipe (typically 1.5" to 4") to downstream treatment. Because the wastestream is pressurized, the pipes can be laid just below the ground surface along the land's contour.

Sewage can also be collected by low pressure pumps and vacuum systems. A low pressure system uses a small grinder pump located at each point of connection, typically a house or business. Vacuum sewer systems use differential atmospheric pressure to move the liquid to a central vacuum station. Typically a vacuum sewer station can service approximately 1,200 homes before it becomes more cost-effective to build another station.

### ***Design and analysis of collection systems***

Design and sizing of sewage collection systems considers population served, commercial and industrial flows, flow peaking characteristics and wet weather flows. Combined sewer systems are designed to transport both stormwater runoff and sewage in the same pipe. Besides the projected sewage flow, the size and characteristics of the watershed are the overriding design considerations for combined sewers. Often, combined sewers can not handle the volume of runoff, resulting in combined sewer overflows and causing water pollution problems in nearby water bodies.

Separate sanitary sewer systems are designed to transport sewage alone. In communities served by separate sanitary sewers, another pipe system is constructed to convey stormwater runoff directly to surface waters. Most municipal sewer systems constructed today are separate sewer systems.

Although separate sewer systems are intended to transport only sewage, all sewer systems have some degree of inflow and infiltration of surface water and groundwater, which can lead to sanitary sewer overflows. Inflow and infiltration is highly affected by antecedent moisture conditions, which also represents an important design consideration in these systems.

A **sewer bed** is a piece of land typically used by a municipality for the dumping of raw sewage. Usually raw sewage was brought by truck or drawn by horses to be dumped, but the practice stopped back in the 1940s.

### ***Historical sewage conveyance and disposal***

The historical focus of sewage treatment was on conveyance of raw sewage to a natural body of water, e.g. a river or ocean, where it would be satisfactorily diluted and

dissipated. Early human habitations were often built next to water sources. Rivers could double as a crude form of natural sewage disposal.

According to Teresi (2002):

The Indus architects designed sewage disposal systems on a large scale, building networks of brick effluent drains following the lines of the streets. The drains were seven to ten feet wide, cut at two feet below ground level with U-shaped bottoms lined with loose brick easily taken up for cleaning. At the intersection of two drains, the sewage planners installed cesspools with steps leading down into them, for periodic cleaning. By 2700 B.C., these cities had standardized earthenware plumbing pipes with broad flanges for easy joining with asphalt to stop leaks.

### **Ancient systems**

The first sanitation system has been found at the prehistoric Middle East, in south-east of Iran near Zabol In Burnt City (Shahre soukhteh) areas. The first time an inverted siphon system was used, along with glass covered clay pipes, was in the palaces of Crete, Greece. It is still in working condition, after about 3000 years.

Higher population densities required more complex sewer collection and conveyance systems to maintain (somewhat) sanitary conditions in crowded cities. The ancient cities of Harappa and Mohenjo-daro of the Indus Valley civilization constructed complex networks of brick-lined sewage drains from around 2600 BC and also had outdoor flush toilets connected to this network.

The urban areas of the Indus Valley civilization provided public and private baths, sewage was disposed through underground drains built with precisely laid bricks, and a sophisticated water management system with numerous reservoirs was established. In the drainage systems, drains from houses were connected to wider public drains.

Ancient Minoan civilization had stone sewers that were periodically flushed with clean water.

Roman towns and garrisons in the United Kingdom between 46 BC and 400 AD had complex sewer networks sometimes constructed out of hollowed out Elm logs which were shaped so that they butted together with the down-stream pipe providing a socket for the upstream pipe.

A significant development was the construction of a network of sewers to collect waste water, which began from the Indus Valley civilization. In some cities, including Rome, Istanbul (Constantinople) and Fustat, networked ancient sewer systems continue to function today as collection systems for those cities' modernized sewer systems. Instead of flowing to a river or the sea, the pipes have been re-routed to modern sewer treatment facilities.

## **16th century**

The system then remained with not much progress until the 16th century, where, in England, Sir John Harington invented a device for Queen Elizabeth (his godmother) that released wastes into cesspools.

However, many cities had no sewers and relied on nearby rivers or occasional rain to wash away sewage. In some cities, waste water simply ran down the streets, which had stepping stones to keep pedestrians out of the muck, and eventually drained as runoff into the local watershed. This was enough in early cities with few occupants but the growth of cities quickly overpolluted streets and became a constant source of disease. Even as recently as the late 19th century sewerage systems in parts of the highly industrialised United Kingdom were so inadequate that water-borne diseases such as cholera and typhoid were still common. In Merthyr Tydfil, a large town in South Wales, most houses discharged their sewage to individual cess-pits which persistently overflowed causing the pavements to be awash with foul sewage.

## **Industrial Revolution era**

As an outgrowth of the Industrial Revolution, many cities in Europe and North America grew in the 19th century, frequently leading to crowding and increasing concerns about public health. As part of a trend of municipal sanitation programs in the late 19th and 20th centuries, many cities constructed extensive sewer systems to help control outbreaks of disease. Initially these systems discharged sewage directly to surface waters without treatment. The first comprehensive sewer system was built in Hamburg, Germany in the mid-19th century. The first such systems in the United States were built in the late 1850s in Chicago and Brooklyn.

As pollution of water bodies became a concern, cities attempted to treat the sewage before discharge. Early techniques involved land application of sewage on agricultural land. In the late 19th century some cities began to add chemical treatment and sedimentation systems to their sewers. In the United States, the first sewage treatment plant using chemical precipitation was built in Worcester, Massachusetts in 1890.

## Chapter 14

# Micro Credit for Water Supply and Sanitation

**Micro credit for water supply and sanitation** is an innovative application of micro credit to provide loans to small enterprises and households in order to increase access to an improved water source and sanitation in developing countries. While most investments in water supply and sanitation infrastructure are financed by the public sector, current investment levels are insufficient to achieve universal access or, at the minimum, to reach the Millennium Development Goals related to water supply and sanitation. Commercial credit to public utilities is limited by low tariffs and insufficient cost recovery. Micro credits are a complementary or alternative approach to allow the poor to gain access to water supply and sanitation. Funding is either provided to small-scale independent water providers who generate an income stream from selling water or to households in order to finance house connections, plumbing installations in their houses, or various forms of on-site sanitation such as septic tanks or latrines. While they have become increasingly common, many microfinance institutions still have only limited experience with financing investments in water supply and sanitation. While there have been many pilot projects in both urban and rural areas, just a small number have actually been scaled up.

### ***Classification***

According to an extensive study of microfinance in water supply and sanitation, there are three types of microcredit products in the water sector across urban and rural areas:

1. Retail loans aiming to improve access to water supply and sanitation at household level,
2. Loans for small and medium enterprises receiving micro credits for small water supply investments and
3. Loans for urban services upgrading and shared facilities in low income areas.

### **Retail loans for household water and sanitation**

Retail loans for water and sanitation facilities are being offered to individuals by some large and commonly known microfinance institutions such as the Grameen Bank and the Vietnam Bank for Social Policies in South East Asia. In general, these credits are used to finance such things as bathrooms, toilets or water purifiers and range from 30 to 250 USD with a tenure generally less than three years. Although the potential market size is considered as huge in both rural and urban areas and some of these water and sanitation

schemes have achieved a significant scale, compared to the microfinance institution's overall size and scope, they still play a minor role.

In 1999, all microfinance institutions in Bangladesh and more recent in Vietnam had reached only about 9 percent and 2.4 percent of rural households respectively. In both countries, the water and sanitation portfolio amounts to less than two percent of the microfinance institution's portfolio in total. However, borrowers for water supply and sanitation comprised 30 percent of total borrowers for Grameen Bank and 10 percent of total borrowers from Vietnam Bank for Social Policies.

Complementary to targeted micro credits, general purpose loans are increasingly gaining weight, as they are used for water and sanitation activities in India and a number of African countries (e.g. Benin, Zambia, and Uganda). For instance, the water and sanitation portfolio of the Indian microfinance institution SEWA Bank comprised 15 percent of all loans provided in the city of Ahmedabad over a period of five years.

Development aid institutions particularly focused on establishing linkage with local microfinance institutions. USAID for instance, has been actively involved by assisting microfinance institutions in designing micro credit products for the water supply sector in Indonesia.

#### **Indonesia: Expanding customer base through cooperation**

In 2006, the Bank Rakyat Indonesia signed a Memorandum of Understanding with the water utility PDAM Tanah to initiate water connections schemes on the basis of micro credits creating a win-win situation. The joint venture with technical support of the USAID Environmental Services Program is planned to be extended to other regions. By 2009, the involved institutions intend to have provided 10,000 households with water connections. According to Metha, the effort has resulted in benefits for the utility, the microfinance institution and for the customers who gained access to water supply. The utility benefited from the expanded customer base and additional water sales as it has helped to reduce its average costs by 42 percent over a period of three years and to reduce its non-revenue water ratio from a percentage of 56,5 in 2002 to 36 percent at the end of 2004. Furthermore, the impact assessment report of both institutions conclude, that the financial cooperation could be extended to finance PDAMS's need for additional banking services.

#### **Vietnam: Sanitation Revolving Fund managed by the Women's Union**

In 1999, the World Bank in cooperation with the governments of Australia, Finland and Denmark supported the creation of a Sanitation Revolving Fund with an initial working capital of USD 3 million. The project was carried out in the cities of Danang, Haiphong and Quang Ninh. The overall aim was to provide small loans (USD 145) to low-income and poor households for targeted sanitation investments such as septic tanks, urine diverting/composting latrines or sewer connections. Households willing to participate needed to join a savings and credit group of 12 to 20 people. Members of those groups were required to live near to each other to ensure community control. The loans had a catalyst effect for household investment. With loans covering approximately two thirds of investment costs, households had to find complementary sources of finance (from family and friends). In contrast to a centralized, supply-driven approach, where government

institutions design a project with little community consultation and no capacity building for the community, this approach was strictly demand driven and thus required the Sanitation Revolving Fund to develop awareness raising campaigns for sanitation. Managed by the microfinance-experienced Women's Union of Vietnam, the Sanitation Revolving Fund gave 200.000 households the opportunity to finance and build sanitation facilities over a period of seven years. With a leverage effect of up to 25 times the amount of public spending on household investment and repayment rates of almost 100 percent, the fund is seen as a best practice example by its financiers and thus considered to be scaled up with further support of the World Bank and the Vietnam Bank for Social Policies.

### **Small and medium enterprise (SME) loans for water and sanitation**

SME-type loans are used for investments by community groups, for private providers in greenfield contexts or for rehabilitation measures of water supply and sanitation. Supplied by mature microfinance institutions, these loans are seen as suitable for other suppliers in the value chain such as pit latrine emptiers and tanker suppliers. With the right frame conditions such as solid a policy environment and clear institutional relationships, there is a market potential for small-scale water supply projects.

In comparison to retail loans on the household level, the experience with loan products for SME is fairly limited. These loan programs remain mostly at pilot level. However, the design of some recent projects using micro credits for community-based service providers in some African countries (such as those of the K-Rep Bank in Kenya and Togo) shows a sustainable expansion potential. In the case of Kenya's K-Rep Bank, the Water and Sanitation Program, which facilitated the project, is already exploring a countrywide scaling up.

#### **Kenya: K-Rep Bank finances community water projects**

Kenya has numerous community-managed small water enterprises. The financial and institutional frame conditions are enhancing the provision of commercial finance. The water and sanitation program in Africa has launched an initiative to use micro credits for the local water and sanitation sector. As part of this initiative, the commercial microfinance bank K-Rep provides loans to 21 community-managed water projects. The Global Partnership on Output-based Aid supports the programme by providing partial subsidies. Every project is pre-financed with a loan up to 80 percent of the project costs (in average USD 80.000). After an independent verification process, certifying a successful completion, a part of the loan is refinanced by a 40 percent Global Partnership on Output-based Aid subsidy. The remaining loan repayments have to be generated from water revenues. In Addition, technical management assistance grants are provided to assist with the project development and to enable the development of market based Business Development Services sector for small water projects. The assistance for further 21 projects have been approved by the Global Partnership on Output-based Aid and the European Union Water Facilities.

#### **Togo: Micro credits for the productive use of rainwater-harvesting tanks and shallow boreholes**

In Togo, CREPA (Centre Regional pour l'Eau Potable et L'Assainissement à Faible

Côt) was encouraging the liberalisation of water services in 2001. As a consequence, six domestic micro finance institutions were preparing micro credit scheme for a shallow borehole (3000 USD) or rainwater-harvesting tank (1000 USD) for at least two households from a certain area. The loans are originally dedicated to households, which act as small private provider selling water in bulk or in buckets. However the funds are directly disbursed to the private (drilling) companies. In the period from 2001 to 2006, roughly 1200 water points were built and are hence used for small business activities by the households participated in that programme.

### **Loans for urban services upgrading and shared facilities in low income areas**

According to UN-Habitat, by 2020 the number people living in the urban slums of developing countries without adequate WSS services will increase to about 1.4 billion. In this scenario, micro credits could be used as an instrument to finance the upgrade or building of shared facilities in “slum areas”.

## Chapter 15

# Water Supply and Sanitation in Ethiopia

Access to **water supply and sanitation in Ethiopia** is one of the lowest in the world. While access has increased substantially with funding from external aid, much still remains to be done to achieve the Millennium Development Goal of halving the share of people without access to water and sanitation by 2015, to improve sustainability and to improve service quality.

Some factors inhibiting the achievement of these goals are the limited capacity of water bureaus in the country's nine regions and water desks in the 550 woredas; insufficient cost recovery for proper operation and maintenance; and different policies and procedures used by various donors, notwithstanding the Paris declaration on aid effectiveness.

In 2001 the government adopted a water and sanitation strategy that called for more decentralized decision-making; promoting the involvement of all stakeholders, including the private sector; increasing levels of cost recovery; as well as integrating water supply, sanitation and hygiene promotion activities. Implementation of the policy apparently is uneven. In 2005 the government announced highly ambitious targets to increase coverage in its Plan for Accelerated Sustained Development and to End Poverty (PADEP) for 2010. The investment needed to achieve the goal is about US\$ 300 million per year, compared to actual investments of US\$ 39 million in 2001-2002. While donors have committed substantial funds to the sector, effectively spending the money and to ensure the proper operation and maintenance of infrastructure built with these funds remain a challenge.

### ***Water resources and use***

Ethiopia has 12 river basins with an annual runoff volume of 122 billion m<sup>3</sup> of water and an estimated 2.6 - 6.5 billion m<sup>3</sup> of ground water potential. This corresponds to an average of 1575 m<sup>3</sup> of physically available water per person per year, a relatively large volume. However, due to large spatial and temporal variations in rainfall and lack of storage, water is often not available where and when needed. Only about 3% of water resources are used, of which only about 11% (0.3% of the total) is used for domestic water supply.

The capital Addis Abeba's main source of drinking water is the Gafsara dam built during the Italian occupation and rehabilitated in 2009. Wells and another dam complement the supply. The city of Dire Dawa is supplied exclusively from groundwater which is highly polluted. The situation is most dramatic in Harar where "a steady decrease of the level of Lake Alemaya has resulted in the complete closure of the treatment plant". Due to supply shortfall water vendors sell untreated water with extremely high prices. The lake dries up because of local climate change, changes in land use in its basin and increased irrigation of Khat, a mild drug that is being grown for local consumption and export. A pipeline is expected to bring water over a distance of 75 km from a well field near Dire Dawa to Harar.

The great majority of the rural community water supply relies on groundwater through shallow wells, deep wells and springs. People who have no access to improved supply usually obtain water from rivers, unprotected springs and hand-dug wells. Rainwater harvesting is also common.

## **Access**

According to data from the Joint Monitoring Programme for Water Supply and Sanitation of WHO and UNICEF, which are in turn based on data from various national surveys including the 2005 Ethiopia Demographic and Health Survey (DHS), access to an improved water source and improved sanitation was estimated as follows in 2008:

- 38% for improved water supply (98% for urban areas and 26% for rural areas)
- 12% for improved sanitation (29% in urban areas, 8% in rural areas)

In 1990 access to improved water supply was estimated at only 17%, and access to improved sanitation was estimated at only 4%. There thus has been a significant increase in access for water supply and sanitation, which spans both urban and rural areas.

In communities that lack access to an improved water source, women bear the brunt of the burden of collecting water. For example, according to an article by Tina Rosenberg for National Geographic, in the mountain-top village Foro in the Konso district of southwestern Ethiopia women make three to five round trips per day to fetch dirty water from the Koiro river. Each roundtrip lasts two to three hours and water is carried in "50-pound jerrycans".

## **Service quality**

Rationing and service interruptions are frequent. There are no wastewater treatment plants in Ethiopia, so all wastewater collected in sewers is discharged without any treatment to the environment.

## ***Responsibility for water supply and sanitation***

In order to understand responsibilities in the sector it is necessary to provide a brief overview of local government in Ethiopia. Ethiopia is a federal state consisting of the following subdivisions:

- nine ethnically based regions or Kililoch with a population between 200,000 and 25 million each;
- 68 Zones with a population between 100,000 and a few million each;
- 550 Woredas or districts, with a population between 10,000 and more than 300,000 each;
- A large number of Kebeles, which constitute the smallest administrative units in Ethiopia.

In addition to the nine regions there are two “chartered cities”, (Addis Ababa and Dire Dawa), where the lower-level administrative units mentioned above do not exist. There is wide disparity in development and institutional capacity between regions and also within regions. The Amhara, Oromia, Tigray regions as well as the small Harari region are relatively developed. About 70% of Ethiopians live in these four regions. The Southern Nations, where about 20% of the population lives, is very heterogenous. In the more pastoralist and remote “emerging” regions Somali, Afar, Gambella and Benishangul-Gumuz, where about 10% of the population lives, capacity tends to be lowest.

## **Policy and regulation**

There are strong national water supply and sanitation policies and key agencies have clear roles and strategies. National policies are set by the Ministry of Water Resources (MWR) for water supply and by the Ministry of Health for sanitation. In October 2006 a Memorandum of Understanding has been signed by both Ministries, as well as by the Ministry of the Environment, to clearly define the roles and responsibilities of each Ministry. Regional Water Bureaus and Woreda Water Desks are in charge of investment planning, monitoring and technical assistance to service providers. Their capacity to fulfill these tasks is sometimes limited.

## **Water supply**

Formally the MWR's mandate covers only water resources management and it has no legal mandate concerning drinking water supply. Nevertheless, de facto it is the entity in charge of setting policies for water supply and to channel donor funds in the sector to local government entities. MWR has 737 employees in eight departments and 10 "services". One of the eight departments is the Water Supply and Sewerage Department. Since 2006 Asfaw Dingamo is the Minister of Water Resources.

In 2001 the government adopted a National Water Strategy prepared by the MWR. The overall strategy includes a water resources strategy, a hydropower development strategy, a water supply and sanitation strategy, and an irrigation strategy.

Concerning water supply and sanitation, the strategy aims at:

- More decentralized decision-making
- Promoting the involvement of all stakeholders, including the private sector
- Increasing levels of cost recovery
- Integrating water supply, sanitation and hygiene promotion activities.

The strategy document does not include a diagnostic of the current situation. The water and sanitation part of the strategy alone includes 44 recommendations concerning technical, institutional, capacity building, social, economic and environmental issues. There is no prioritization between the recommendations and the strategy does not establish mechanisms to monitor the implementation of the strategy.

## **Sanitation**

The Ministry of Health is in charge of policies related to sanitation and hygiene promotion. It has adopted a Sanitation and Hygiene Promotion Strategy. De facto sewers in urban areas are under the responsibility of the MWR, while the promotion of on-site sanitation is the responsibility of the Ministry of Health. The Sanitation and Hygiene Promotion Strategy has re-focused government resources on the promotion of pro-poor, low-cost practices.

## **Service provision**

In the capital the Addis Ababa Water and Sewer Authority provides water and sewer services. In other cities and small towns Town Water Boards are responsible for service provision. They are expected to contract out service provision to private operators. In rural areas community water and sanitation committees operate water systems and promote sanitation. Not all the local committees are registered, which is a prerequisite to open a bank account to hold funds collected from users. Local committees are supported by Woreda Water Desks.

## **Other**

Regional water resources development bureaus play an important role in planning investments at the regional level and in capacity building.

The Ethiopian Social Rehabilitation and Development Fund (ERSDF) – a Social Fund established in 1996 - is also an important actor, especially in rural areas. It has financed almost 2,000 rural water projects serving about 2.5 million people. However, the government has decided to phase out the ERSDF and to re-deploy its staff to other institutions.

## ***History and recent developments***

Until 1995 the national government had been responsible for centrally planning and implementing water and sanitation projects. Under the 1995 constitution Ethiopia became a federal state, which implied the decentralization of many functions to lower levels of government. This process has now been under way for more than a decade, but decentralization has been hampered by the limited capacity of local government to carry out its new responsibilities.

Also in 1995, a Ministry of Water Resources was created, taking over many of the responsibilities of the water resources department of the former Ministry of Public Works.

In 1999 the government adopted a National Water Resources Management Policy, which was followed by the establishment of a Water Resources Development Fund (2002) and a Water Sector Development Program. The latter includes a water supply and sewerage development program (nota bene the focus on sewerage and thus the absence of on-site sanitation from the program).

The government's Plan for Accelerated Sustained Development and to End Poverty (PADEP), covering the period 2005-2010, aimed at increasing access to an improved water source to 84% and access to improved sanitation to 80% by 2010. These ambitious targets go well beyond the water and sanitation targets of the Millennium Development Goals, which aim at halving the share of people without access by 2015. Since in 2008 access to an improved water source was 38% and to improved sanitation 12% it seems that these targets cannot be met.

## ***Tariffs and cost recovery***

On average cost recovery is too low to recover operating costs, not to speak of providing adequate maintenance of facilities. Recurrent expenditures - estimated at US\$ 29 million in 2001-02 - were financed primarily through user charges (64%), as well as by subsidies from the regional governments (31%) and the federal government (5%). Despite this overall bleak picture, a few service providers recover all operating costs and generate a modest cash surplus.

The National Water Resources Management Policy aims at full cost recovery for urban systems and recovery of operation and maintenance costs for rural systems. It is not clear if progress has been made to achieve this ambitious objective since the policy was adopted.

## ***Investment and financing***

### **Investment**

There are no reliable estimates of actual investment levels in the sector, and available estimates vary greatly. A detailed estimate of investment and financial flows in the Ethiopian water sector was carried out by the World Bank's Water and Sanitation Program (WSP) for the financial year 2001-02. It estimated total sector investments at US\$ 39 million or less than half a dollar per capita, being one of the lowest recorded sector investment levels in the world.

The government estimates that annual investments in the 2006-2015 period will reach about US\$ 100 million per year, or about two and a half times their level in 2001-2002. This projection is based on funding commitments made by donors and the government. It thus does not take into account bottlenecks in implementation due to limited capacities or other potential pitfalls. The World Bank projects the 2008 investment level at US\$ 100 million, including resources from a 5-year US\$ 100 million World Bank loan for urban water supply and sanitation approved in 2007.

The World Bank has estimated that the annual cost of achieving the government's targets to increase coverage until 2010 are about US\$ 400 million "in the first few years" and falling to US\$ 200 million "in later years". A detailed estimate by the government as part of its MDG Needs Assessment Report estimated investment needs at US\$ 297 million per year for the period 2006-2015, roughly in line with the World Bank estimate.

### **Financing**

**Sources.** According to the WSP estimate quoted above, in 2001-2002 only 9% of sector investments were funded by the federal budget, 55% through the regional budget, 33% off-budget by NGOs, 2% by the ERSDF and 1% by other sources. This estimate does not include community in-kind contributions, which are high for rural water supply and sanitation. A high but unknown share of the federal budget and probably also of the Woreda budget devoted to the sector is funded by donors. Concerning projected investments for 2006–2015, it is estimated that 12% (US\$ 12 million) will be funded by the government with its own resources, 15% (US\$ 16 million) by communities and 73% (US\$ 75 million) by donors. It is not clear if this estimate includes off-budget support by NGOs. Because of the different categories used, a comparison between the historical and projected sources of financing is not possible.

**Processes.** The financing system has evolved in line with the policy of decentralization. Thus, for example, the country's 550 Woredas now receive block grants from the central government and then can decide autonomously how to use these grants within broad criteria set by the Water Resources Development Fund (WRDF). The WRDF is administered by a Board that is responsible to the MWR and is funded through budgetary allocations and donor funds.

## ***External cooperation***

Donors finance numerous projects in water supply and sanitation in Ethiopia – some through the Federal Government and some directly to regions, towns and communities. The donors have established a technical working group (TWG) on water as part of a core donor group called the Development Assistance Group. A Multi-Stakeholder Forum is also supported through the European Union Water Initiative. Despite improved coordination, donors still use different implementation arrangements. As a result, according to the World Bank, transaction cost are high.

Important donors in the sector are the African Development Bank, CIDA, the British DFID, the EU, FINIDA, AFD from France, Germany (through GTZ and KfW), JICA, the Netherlands, UNDP, UNICEF and the World Bank. There are also about 500 local and foreign NGOs, many of which are active in water supply and sanitation.

The African Development Bank provided a US\$64 million grant for rural water supply and sanitation approved in 2005

WaterAid is engaged in Ethiopia since 1983. It works closely with established local non governmental organisations (NGOs). In Oromia Region, water projects tend to be spring-fed gravity schemes, some of which are very large, providing water for tens of thousands of people. In Southern Nations, Nationalities, and People's Region schemes have included deep boreholes as water is sometimes only found below 200 metres. For example, in the village of Orbesho residents - mainly women - built themselves an access road to allow drilling equipment to be brought in, dug trenches for pipes and collected stones for structures. In Amhara and Tigray the main technologies have been hand-dug wells and spring development. In Benishangul-Gumuz rope pumps are also used. In sanitation, WaterAid supports the construction and use of latrines. Hygiene education has increasingly focused on the close links between proper handwashing at critical times, like before eating and after going to the toilet, and improved health. In all cases WaterAid works closely with communities from the start. Particular attention is now being paid to engaging women. Since 1998 WaterAid has also been engaged in the slum areas of Addis Ababa. Projects include establishing communal water points linked to the city's piped systems, as well as shower and latrine blocks.

The World Bank provided a US\$ 100 million credit/grant for urban water supply and sanitation approved in 2007. and a US\$ 100 million credit for water supply and sanitation in 2004. In March 2010, the World Bank approved additional financing of US\$ 80 million for the 2004 water supply and sanitation project. According to the World Bank, until 2010 the original project had financed the construction of 1288 hand dug wells, 835 protected springs, 576 shallow wells, 99 deep wells, 75 rural piped systems and 35 rainwater harvesting, as well as conducting hygiene and sanitation promotion. In rural areas alone, according to the World Bank the project facilitated access to clean water and improved sanitation facilities to about 1.4 million people. In urban areas, the project provided "immediate service improvement" in 87 towns which benefited about 143,000 people.

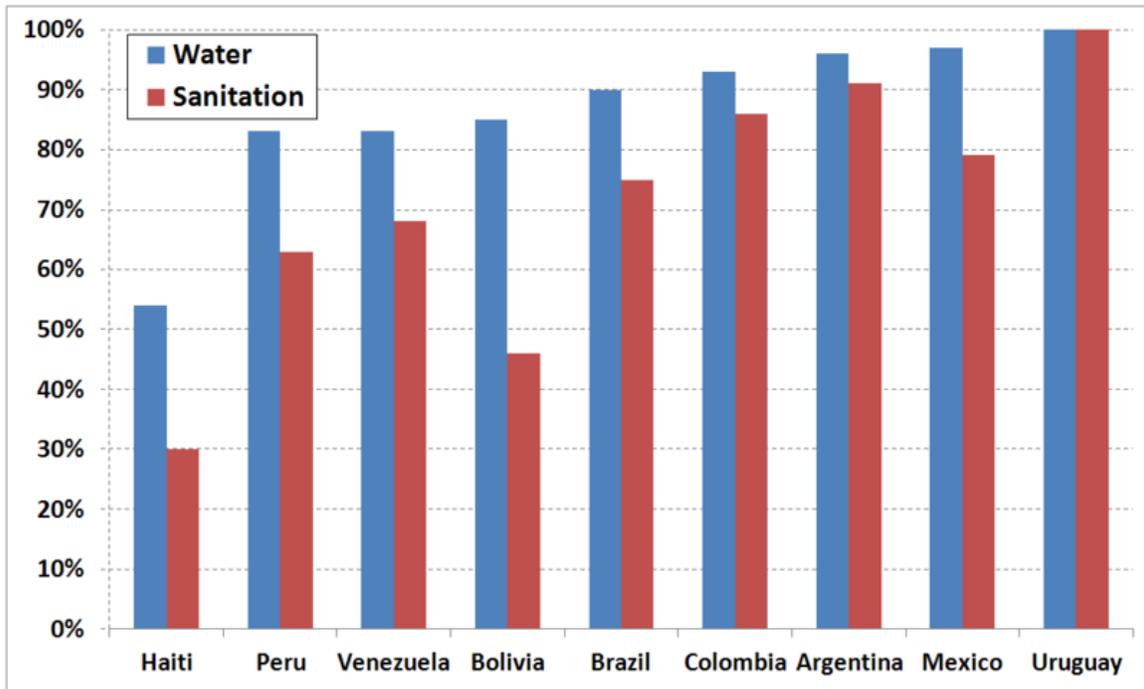
## Chapter 16

# Water Supply and Sanitation in Latin America

**Water supply and sanitation in Latin America** is characterized by insufficient access and in many cases by poor service quality, with detrimental impacts on public health. Water and sanitation services are provided by a vast array of mostly local service providers under an often fragmented policy and regulatory framework. Financing of water and sanitation remains a serious challenge.



## Access



Water and Sanitation Coverage (broad definition) in selected Latin American countries in 2004. Source: World Health Organization (WHO)/UNICEF (2006): Meeting the MDG drinking water and sanitation target : the urban and rural challenge of the decade.

Access to water and sanitation remains insufficient, in particular in rural areas and for the poor. It also differs substantially among and within countries. According to the Joint Monitoring Program of the World Health Organization and UNICEF, in 2004 the share of population which was connected to an improved water source varied from 54% in Haiti to 100% in Uruguay. All together, 50 million people or 9% of the population of Latin America and the Caribbean did not have access to improved water supply, and 125 million or 23% did not have access to improved sanitation. Increasing access remains a challenge, in particular given the poor financial health of service providers and fiscal constraints on behalf of central and local governments.

As far as sanitation is concerned, only 51% of the population has access to sewers. Only an estimated 15% of the collected wastewater finds its way into wastewater treatment plants, which often are not properly functioning. 26% of the population has access to forms of sanitation other than sewers, including septic tanks and various types of latrines., a level that is about as high as in the United States and almost twice as high as in Central Europe. The highest water use can be found in some utilities in Chile and Argentina, where water resources are abundant and water use is almost 500 liter/capita/day. The lowest water use is in Aguas de Illimani serving La Paz, the capital of Bolivia, with less than 50 liter/capita/day. In rural areas water use is sometimes even lower than this level.

## ***Quality of service***

Even for those having access to water supply, poor quality of service is often experienced, in the form of intermittent supply, low pressure and poor drinking water quality. However, differences in service quality between countries and between cities in Latin America are vast, and some service providers achieve a quality of service on par with developed countries.

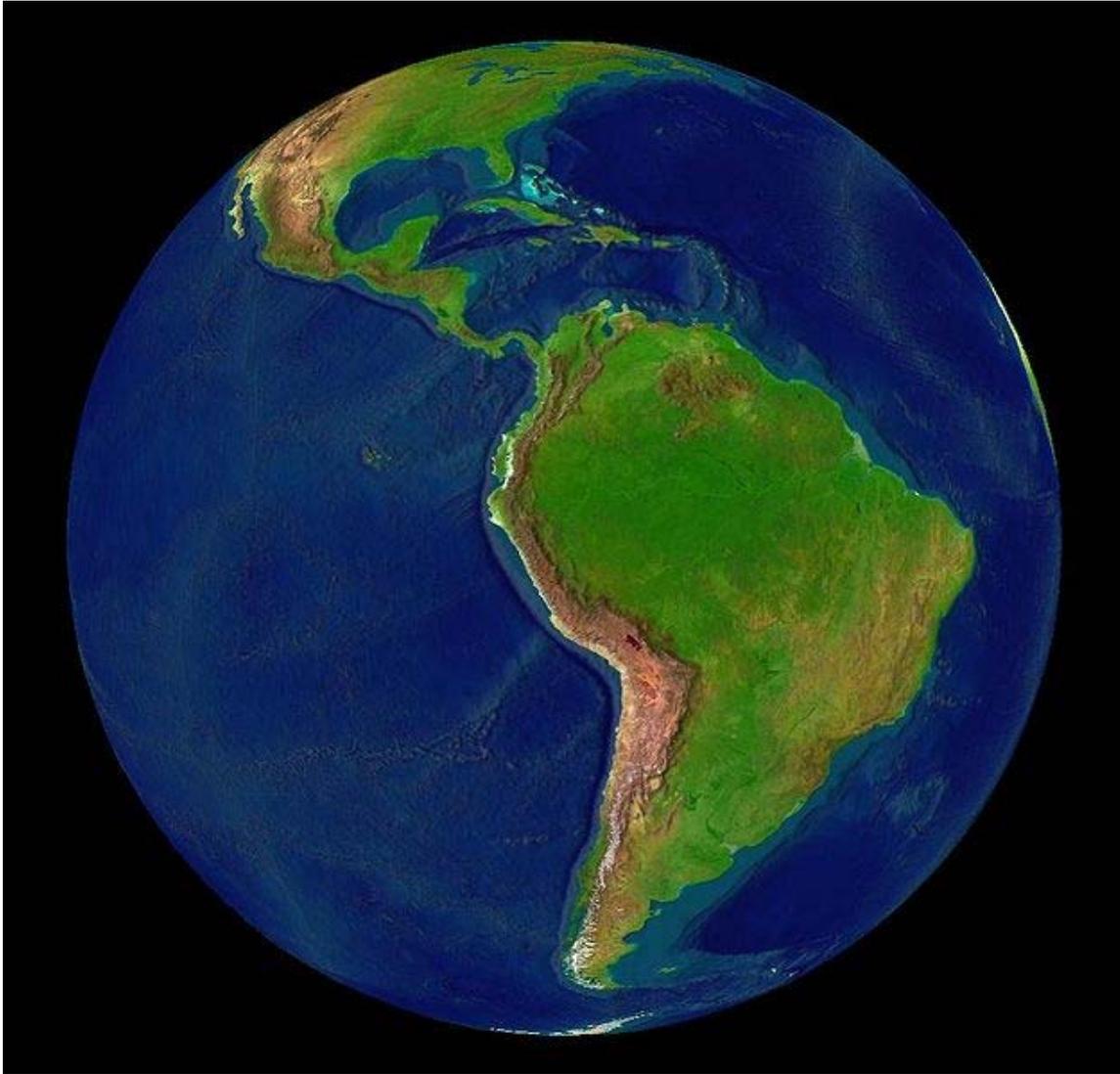
## ***Institutional responsibility***

### **Service provision**

Responsibility for water supply and sewerage service provision in Latin American countries is vested either in municipalities, or in regional or national companies. Municipalities are in charge of water and sanitation service provision in Brazil, Colombia, Ecuador, Guatemala, Mexico and Peru. In some countries, such as in Colombia and Mexico, municipalities took over this responsibility from national service providers during the decentralization of the 1980s. Subsequently, especially the larger municipalities have often created specialized municipal (and sometimes inter-municipal) public utilities, whose finances are kept separate from the city's finances. While in most cases the companies are public, in a few notable cases they are mixed or private companies operating under concession, lease or management contracts. Chile and Venezuela are examples of countries that have created regional water companies; however, in the case of Venezuela, the United Nations reports that Venezuela remains one of the poorest in water service provision in this region. State-level regional water companies also exist in all 26 states of Brazil, where they provide services on behalf of some (but not all) municipalities in each state. National public water and sewer companies, which have for the most part been created in the 1960s and 1970s, still exist in Costa Rica, the Dominican Republic, El Salvador, Haiti, Panama, Paraguay and Uruguay. About 90% of urban water and sanitation services in Latin America are provided by public entities. Many private concession contracts signed during the 1990s in Latin America have been either renegotiated or cancelled. The most notable cancellations include the concession for Aguas Argentinas in Buenos Aires, Argentina, and the concessions for Cochabamba and La Paz, Bolivia. Private and mixed companies, however, continue to provide services in many cities of Colombia, in most of Chile, some Brazilian cities, and in Guayaquil, Ecuador.

In rural areas, the provision of water services is usually the responsibility of community organizations (Juntas de Agua). While the infrastructure is funded primarily by transfers from the national governments, typically community labor and sometimes cash contributions are mobilized. When communities are associated in the choice of service level and other key choices, this instills a sense of ownership that makes it more likely that communities will maintain the infrastructure.

## Policy and regulation



A terrain map of Latin America

At the level of national governments, responsibility for policies in water and sanitation is typically fragmented between various Ministries, making the development of coherent policies in areas such as transfers to local service providers a challenging undertaking. The economic regulation of service providers is sometimes entrusted to Ministries and sometimes to autonomous regulatory agencies. These agencies sometimes cover only water and sanitation or multiple infrastructure sectors; they can be either at the national (as in Chile, Colombia and Peru) or at the state level (as in Argentina and in some states of Mexico). Their functions vary and may include tariff approvals, monitoring of service quality and handling of complaints. Environmental regulation is entrusted to environmental agencies and the regulation of drinking water quality to Ministries of Health.

## **Supporting community organizations**

Supporting the numerous community organizations that provide water and sanitation services in Latin America - mainly in rural areas - is a key public function that is often underestimated and neglected. Responsibility for this function, if it is defined at all, can be assigned to a government Ministry and its regional branches, a Social Fund or municipalities. Often NGOs also carry out this function, either on their own initiative and with their own resources, or under contract by the government.

In Honduras support to community organizations (Juntas de Agua) is entrusted to the Social Fund FHIS, in cooperation with a national agency for technical assistance in water and sanitation (SANAA). In El Salvador it is done by the Social Fund FISDL and various NGOs. In Peru it is carried out through NGOs and municipalities with the support of a national program (PRONASAR) implemented by the Ministry of Housing. In Paraguay it is the responsibility of a national agency in charge of promoting specifically water supply and sanitation in rural areas and small towns (SENASA). In Ecuador it is carried out under a national program (PRAGUAS) by consultants working for the Ministry of Housing. In Panama such support is provided by the Ministry of Health. In Haiti such support is provided by NGOs, some of which are under contract with the national urban water agency SNEP and its specialized unit for rural areas. There thus is a wide variety of institutional arrangements to support community organizations, so that one cannot speak of a uniform model for such support in Latin America.

## ***Financial aspects***

### **Tariffs**

According to a 2006 World Bank study average water tariffs in Latin America are the highest of any region of the developing world. Tariffs are about four times higher than in South Asia, three times higher than in Eastern Europe and Central Asia and almost twice as high as in East Asia. However, tariffs are less than half as high as in OECD countries. Based on a sample of 23 major cities in Latin America the average residential water tariff for a monthly consumption of 15 cubic meter was US\$0.41, equivalent to a monthly bill of only about US\$6.

### **Cost recovery**

It appears that most utilities in Latin America recover more than their operating costs and thus generate surpluses to self-finance a portion of their investments. The average recovery coefficient of operating costs among a sample of 48 private and public utilities from 8 countries was 1.64. The highest coefficients of more than 2 can be found in utilities in Chile, as well as in Pereira and Manizales in Colombia.

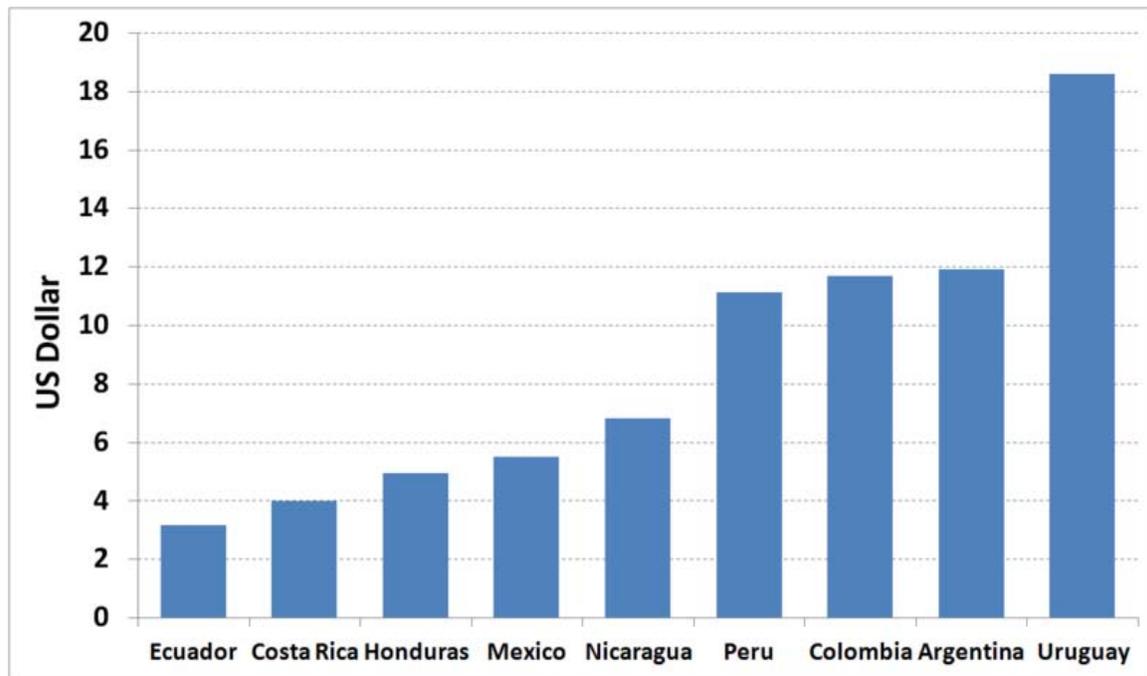
Despite the ostensibly high levels of tariffs and cost recovery estimated based on the sample of utilities analyzed, utilities do not generate sufficient revenue to finance a substantial share of their investments internally, or to be credit-worthy enough to mobilize commercial, long-term credit. The reasons include low levels of operational

efficiency, as detailed further below, poor recovery of bills, poor procurement practices and political corruption.

## **Affordability**

There are few studies on the affordability of water and sewer bills in Latin America. The Pan-American Health Organization (PAHO) analyzed multi-purpose household surveys conducted between 1995 and 1999 in 10 countries to assess the share of household income spent on water supply services. These data show that the expenditures on water vary between 0.4% of total expenditures in rural Panama to 3.0% in Kingston, Jamaica. For the households in the poorest income decile expenditures on water are higher, varying from 0.6% in rural Panama to 6.5% in Kingston, Jamaica. However, these figures have to be interpreted with caution. First, it is not clear how water expenditures were defined in the surveys. It seems that in some cases expenditures to buy bottled water and water from tankers were included, while in other cases they were excluded. Second, the sample includes both households with and without access to piped water systems. Therefore, especially in rural areas where coverage tends to be low, the shares are only a poor indication on the affordability of water bills. Third, it is not explicit if sewer bills are included in the analysis, although this is most likely the case, since sewer bills are always a surcharge on the water bill and are thus perceived by most households as part of their water expenditures.

## Investment



Annual investment per capita in several Latin American countries in water supply and sanitation (1997-2003 average) in constant US Dollars of 2006

The level of investment in water supply and sanitation in Latin America is tentatively estimated at 0.12% of GDP in the 1990s. A large share of these investments is needed to maintain and rehabilitate existing infrastructure. However, the World Bank has estimated that the investments needed to increase access to achieve the Millennium Development Goals (MDGs) in water and sanitation in Latin America by itself is 0.12% of GDP, not taking into account maintenance and rehabilitation. It can thus be concluded that, on average, a significant increase in investments is needed to achieve the MDGs.

## Financing

The modalities of financing water and sanitation infrastructure differ substantially between countries. Some countries that have reached higher levels of cost recovery, such as Chile and some utilities in Brazil and Mexico, rely on commercial credit financing. However, the vast majority of utilities relies on transfers from national governments. These can take various forms: In Colombia municipalities are legally entitled to receive transfers calculated through a formula based on their costs and poverty levels; in Mexico municipalities can apply for matching federal grants provided they fulfill certain conditions that vary by program; in Ecuador municipalities receive transfers based on a formula that takes into account their choice of management model and improvements in cost recovery; and in other countries utilities simply receive transfers that can vary from one year to the other without any conditions. The level of transfers from national governments is highly variable and often far from sufficient to increase coverage and improve service quality. Some countries pass loans from international financial institutions on to utilities in the form of credits. However, these international loans only account for a relatively small share of water and sanitation financing in Latin America.

## ***Efficiency***

There are wide differences in the operational efficiency among urban water and sanitation utilities in Latin America. The two most common measures of operation efficiency are labor productivity and non-revenue water (water losses). In terms of labor productivity, the most productive utilities have less than 2 employees per 1000 connections. They include EPM in Colombia, SEDAPAL in Lima, Aguas del Valle in Chile's 4th region, as well as Aguas de Formosa and Aguas de Salta in Argentina. The utility with the lowest labor productivity in the sample is EPSEL from the Lambayeque Region in Peru with more than 15 employees per 1000 connections. The average of the sample is about 5 employees per 1000 connections.

Concerning non-revenue water, the average of Latin American utilities in the sample considered is 40% and thus much higher than estimates of efficient levels, which vary between 15 and 25%. The highest level (73%) is registered by Interagua, the utility serving Guayaquil in Ecuador. The lowest level of any larger utility with a high share of household metering, which is a precondition to accurately measure non-revenue water, is registered in Aguas Cordillera in Chile with 20%.

## ***Strategy to improve services***

The Millennium Development Goals (MDG) aim at halving, by 2015, the proportion of people without sustainable access to safe drinking water and adequate sanitation, from a base year of 1990. According to a 2006 World Bank brief, this is achievable for some countries in Latin America and the Caribbean, while it represents a mammoth task for others. According to the World Bank even those countries on track to achieve the MDG targets face tremendous challenges in improving service quality, in particular to attain continuity of supply and to increase wastewater treatment. To meet these challenges Latin American and Caribbean countries, according to the World Bank, would have to advance on several fronts, including:

- **Improving the efficiency of service providers** to allow them to generate more internal resources to cover costs and fund investment. This includes better collection of bills, reduction of administrative losses (clandestine connections, under-metering) and physical losses, better procurement practices, the use of low-cost technologies and a reduction of overstaffing.
- **Increasing investments in water and sanitation** from the current low level of 0.15 percent of GDP. Investment needs are estimated to exceed 0.2 percent of GDP.
- **Introducing innovative mechanisms for commercial financing.** This includes tapping domestic capital markets where feasible and the judicious use of guarantees and guarantee facilities, while managing contingent liabilities prudently.
- **Targeting subsidies better and improving cost recovery.** Implicit and explicit subsidies through low tariffs mostly benefit the better-off. Increasing tariffs is often a necessity. But in order to make this more equitable, such measures would have to be complemented by actions to enhance collection efficiency, reduce the

- incidence of illegal connections, increase the share of metered connections, revise tariff structures and introduce means-tested subsidies where feasible.
- **Expanding access to water and sanitation services, especially to the poor**, while ensuring that these services are accessible, efficient, and sustainable. Low-cost technologies such as condominal sewers can play an important role in that respect, as can legalizing land tenure and finding innovative ways to provide services to those without land titles.
  - **Improving service quality**. Without continuous supply, reliably good drinking water quality, and the prevention of sewer overflows, health is endangered and – especially if customer service is poor and billing complaints not resolved swiftly – it is difficult to justify a higher degree of cost recovery.
  - **Strengthening the capacity of service providers**. This is essential, especially given the high turnover of senior staff in municipal utilities as a result of frequent changes in municipal governments. It is important to make municipal service providers more autonomous, to insulate them as much as possible from political influence, and to provide training and a career path for utility employees.
  - **Redefining the role of the private sector in service provision**. Private sector participation in water and sanitation in Latin America and the Caribbean has had mixed results. Some international operators have lost interest in the sector, sometimes citing governments' failure to abide by contracts. However, local private operators continue to play a major role in the sector, helping to improve efficiency and service quality, especially if state supervision is adequate.
  - **Strengthening information systems and impact evaluations**. Utilities often have only very limited information available on the quality of their services and their assets. Regulators and governments often have even less, and there are frequently only rudimentary data available on how projects and programs have influenced coverage and service quality. The strengthening of local and national information systems and impact evaluations is therefore a priority for the region.
  - **Improving regulatory frameworks**. A regulatory framework that ensures that the interests of both the consumer and the investor are adequately represented is essential. However, experience with utility regulation in the region is sobering, given the limited autonomy and resources of many regulators, as well as the limited ability of many service providers to fulfill norms set by regulators.

## Chapter 17

# Water Supply and Sanitation in Argentina

### Water supply and sanitation in Argentina



#### Data

<b>Water coverage (broad definition)</b>	96%
<b>Sanitation coverage (broad definition)</b>	91%
<b>Continuity of supply</b>	Mostly continuous
<b>Average urban water and sanitation tariff (US\$/m<sup>3</sup>)</b>	0.48 (water) and 0.31 (sewerage) in 2000
<b>Share of household metering</b>	Low

#### Institutions

<b>Decentralization to municipalities</b>	Substantial, since 1980
<b>Water and sanitation regulator</b>	At provincial level
<b>Responsibility for policy setting</b>	Ministry of Public Works
<b>Number of urban service providers</b>	1,650

**Water supply and sanitation in Argentina** is characterized by relatively low tariffs, mostly reasonable service quality, low levels of metering and high levels of consumption for those with access to services. At the same time, according to the WHO, 21% of the total population remains without access to house connections and 52% of the urban population do not have access to sewerage. The responsibility for operating and maintaining water and sanitation services rests with 19 provincial water and sewer companies, more than 100 municipalities and more than 950 cooperatives, the latter operating primarily in small towns. Among the largest water and sewer companies are Agua y Saneamientos Argentinos (AYSA) and Aguas Bonarenses S.A. (ABSA), both operating in Greater Buenos Aires, Aguas Provinciales de Santa Fe, and Aguas Cordobesas SA, all of them now publicly owned. In 2008 there were still a few private concessions, such as Aguas de Salta SA, which is majority-owned by Argentinean investors, and Obras Sanitarias de Mendoza (OSM).

Most service providers barely recover operation and maintenance costs and have no capacity to self-finance investments. While private operators were able to achieve higher levels of cost recovery, since the Argentine financial crisis in 2002 tariffs have been frozen and the self-financing capacity of utilities has disappeared. Roughly two-thirds of provincial water and sanitation spending since 2002 has come from general transfers from the federal government, the remainder coming from various national programs directed specifically to the sector.

Services are regulated by the 23 Provinces, in the case of 14 through regulatory agencies that have some limited autonomy from the government. Overall, however, responsibilities are not always clearly defined, and institutions are often weak, subject to political interference and lacking enforcement powers. The various national institutions with policy-setting responsibilities in the sector are not always well coordinated. There is no coherent national policy in terms of sector financing, subsidies, tariffs and service standards. The federal structure of the country and the dispersion of sector responsibilities between and within various levels of government make the development of a coherent sector policy all the more difficult.

Between 1991 and 1999, as part of one of the world's largest privatization programs covering a range of sectors, water and sanitation concessions with the private sector were signed covering 28% of the country's municipalities and 60% of the population. The highest profile concession was signed in 1993 with a consortium led by the French firm Suez for the central parts of Greater Buenos Aires. After the 2001 economic crisis, many concessions were renegotiated. Many were terminated, as it was the case in Buenos Aires in 2006.

The impact of private sector participation in water and sanitation is a controversial topic. While the public perception of the mostly international concessionaires is overwhelmingly negative in Argentina, some studies show positive impacts. For example, a 2002 study assessed the impact of privatization on child mortality based on household survey data, finding that child mortality fell 5 to 7 percent more in areas that privatized compared to those that remained under public or cooperative management. The authors estimate that the main reason is the massive expansion of access to water. According to Suez, the private concession in Buenos Aires extended access to water to

2 million people and access to sanitation to 1 million people, despite a freeze in tariffs imposed by the government in 2001 in violation of the concession agreement. The government argues that the concessionaire did not fully comply with its obligations concerning expansion and quality, saying that the supplied water had high levels of nitrate, pressure obligations were not kept and scheduled works were not carried out.

## Access

Argentina has achieved very high levels of access to an improved water source in urban areas (98%), using a broad definition of access. However, coverage using a narrower definition of access (house connections) is much lower at 83%, since many users still only have access through public standpipes. Also, access in rural areas remains relatively low for a country of Argentina's level of development (80% using a broad definition, 45% for house connections).

Access to improved sanitation, using a broad definition of access including septic tanks and improved latrines, is high at 91%. However, access to sewerage is only 44%.

		<b>Urban (90% of the population)</b>	<b>Rural (10% of the population)</b>	<b>Total</b>
Water	Broad definition	98%	80%	96%
	House connections	83%	45%	79%
Sanitation	Broad definition	92%	83%	91%
	Sewerage	48%	5%	44%

*Source:* Joint Monitoring Program WHO/UNICEF(JMP/2006). Data for water and sanitation based on the Census (2001).

According to a study by the *Centro de Implementación de Políticas Públicas para la Equidad y el Crecimiento* (CIPPEC) or Center for Implementation of Public Policies for Equity and Growth, the increase of coverage between 1991 and 2001 was lower in the poorest provinces.

## Service quality



Map of Argentina. *Source:* CIA

There are apparently no comprehensive data on water and sanitation water quality in Argentina. In urban areas, service generally is continuous and of potable quality. However, water rationing occurs in some cities during the summer months, and drinking water quality is sometimes sub-standard.

In Buenos Aires, in 2008 there were two water treatment plants and a new one was about to begin.

Concerning sanitation, existing sewage collection systems are insufficient to handle the increasing flows as a growing number of households connect to the sewer systems, leading to frequent sewer overflows.

The level of wastewater treatment varies among the Argentinean regions. According to the Pan American Health Organization, at the national level 10% of the collected wastewater was being treated in 2000. Whereas in many regional capitals, such as Mendoza, Córdoba, Tucumán, Neuquén, Jujuy, Salta and San Juan, most of the wastewater was treated, in the two largest urban areas of the country, Buenos Aires and Rosario, there was practically no treatment at all, resulting in serious environmental problems. However, in 2008 a bidding process was launched to build a wastewater treatment plant in Buenos Aires.

### ***History and recent developments***

From 1880 until 1980, the national utility *Obras Sanitarias de la Nación* (OSN) was in charge of providing water and sewer services in the main cities, while in smaller cities it was the responsibility of provincial governments, municipalities and cooperatives.

In 1980 the military government under Jorge Rafael Videla decentralized the provision of water and sanitation services in the main cities served by OSN, except for the metropolitan area of Buenos Aires where OSN continued to provide services. In other cities OSN transferred its responsibilities to provincial governments. Each province chose its model of service provision (municipal, public enterprises, cooperatives or others).

Between 1991 and 1999 under the government of Carlos Menem, as part of one of the worlds largest privatization programs covering a range of sectors, water and sanitation concessions with the private sector were signed in 28% of the country's municipalities covering 60% of the population. The highest profile concession was signed in 1993 with a consortium led by the French firm Suez for the metropolitan area of Buenos Aires. After the 2001 economic crisis, under the government of Nestor Kirchner, many concessions were renegotiated. Some were even terminated and the responsibility for service provision reverted to public entities, as it was the case in Buenos Aires where the newly created public enterprise *Agua y Saneamientos Argentinos* took over the responsibility for service provision in 2006. At the beginning of 2008, the government of the Province of Mendoza announced that it is interested in increasing its control of the provincial water utility *Obras Sanitarias de Mendoza*, of which it owns 20%, buying another 20% from Saur International.

### **Impact of private sector participation**

So far there has been no comprehensive, objective assessment of the impact of private sector participation in water supply and sanitation in Argentina. However, there has been some partial evidence. For example, a 2002 study assessed the impact of privatization on child mortality based on household survey data, finding that in the 1991-1997 period child mortality fell 5 to 7 percent more in areas that privatized compared to those that remained under public or cooperative management. It also found that the effect was largest in poorest areas (24%). The authors estimate that the main reason is the massive expansion of access to water, which was concentrated in poorer areas that did not receive services before private sector participation was introduced.

## The Buenos Aires concession

The largest and best-known case of private sector participation in the Argentine water and sanitation sector was the Buenos Aires concession, signed in 1993 and revoked in 2006. Its impact remains controversial and in early 2008 an arbitration case was still pending with the International Center for Settlement of Investment Disputes (ICSID) of the World Bank Group.

Critics argue that the concessionaire failed to achieve the targets set under the concession contract. When the government rescinded the concession in March 2006, it argued that Aguas Argentinas did not comply with obligations concerning expansion and quality. According to the government, the supplied water had high levels of nitrate, pressure obligations were not kept and scheduled waterworks were not executed by the concessionaire. On the other hand, proponents of private participation state that a freeze in tariffs at the time of the devaluation of the Peso during the Argentinean economic crisis in 2001 substantially reduced the real value of tariff revenues and thus made it difficult to achieve the original targets.

One factor which may have caused the cancellation of the concession contract was the precipitate preparation. Alcazar et al. list some features of the concession which indicate an overhasty process:

1. The regulatory agency ETOSS (*Ente Tripartito de Obras de Servicios de Saneamiento*, Tripartite Entity for Sanitary Services) lacked experience, since it was founded quickly as part of the concession process.
2. The available information in the concession contract about the state of the existing infrastructure was so poor, that the Argentinean government denied taking responsibility for it. This lack of information could have let the bidder to accept the contract in the expectation of future renegotiation.
3. Instead of creating a new and more transparent tariff system, the old one was adopted from OSN.

In addition, the inexperienced regulatory agency was repeatedly bypassed when decisions were taken, for example in the renegotiation of the contract in 1997. In that way, ETOSS was further weakened. The concession contract authorized Aguas Argentinas to demand dollars at the old 1:1 exchange rate after the peso devaluation. Solanes points out that without this practice companies may seek financing in local capital markets to avoid currency fluctuations. He also argues that the needs of the poor were not addressed in the concession. No subsidies were provided for the poor and the tariff system did not encourage expansion of coverage to poor areas, since new connections were often unaffordable and new users also had to pay the costs of expanding the network.

The concessionaire did invest much more than its public predecessor and achieved substantial increases in access to water and sewerage. According to the Argentinean economist Sebastian Galiani, the public company OSN had invested only US\$25m per year between 1983 and 1993, while the private concessionaire Aguas Argentinas increased investments to around US\$200 m per year between 1993 and 2000.

According to Suez, during the 13 year-duration of its concession it extended access to water to 2 million people and access to sanitation to 1 million people, despite the economic crisis. Between 2003 and 2005 alone about 100,000 inhabitants of poor neighborhoods and slums are said to have been connected through a "participatory management model" piloted by Aguas Argentinas. Aspects of the model have been adopted by the government to extend services to another 400,000 people in La Matanza in the province of Buenos Aires in the project "Water plus work" ("Aguas más trabajo").

### **An example of local private sector participation: Salta**

The government of Salta Province initiated the reform of its water sector in 1996. At the same time many other Argentinean provinces and municipalities brought in the private sector to improve water and sanitation services. While Salta also followed this approach, the process differed somewhat from the one in many other parts of Argentina. First, the provincial government conducted a series of meetings with municipalities and user organizations to discuss the benefits and risks of the concession before it was bid out. This process of consultations was continued by the private concessionaire after the contract was awarded. Second, the government decided from the onset that water and sanitation services in the poor province could not be financed entirely through tariff revenues. It thus decided to finance much of the investments to be undertaken by the private concessionaire with public grants, in addition to providing consumption subsidies. Third, the regulatory agency allowed the concessionaire to provide services at a lower standard in remote or isolated areas that were deemed unprofitable at conventional service standards. Fourth, the provincial regulatory agency granted tariff increases before and even after the 2001 economic crisis. These tariff increases were lower than it would have been necessary without subsidies or flexible service standards. And fifth, the government "ignored the traditional paradigm of only permitting companies with significant previous experience in water supply and sanitation to compete in the bidding process". This provision had favored a few large multinational water firms in other bidding processes. In Salta, however, the bid was won by the Argentinean construction, power and toll road enterprise MECON S.A. which signed a technical assistance contract with the Brazilian Paraná State public utility SANEPAR.

The private concession led to a substantial increase in access to water and sanitation from the time of concession award in 1999 to 2005. It also provided a significant decrease in service interruptions and improved customer service. 13 more municipalities joined the concession contract after it had been signed in order to share in its benefits, bringing the total number of municipalities served by the concessionaire to 56.

While most other private water concessions in Argentina were rescinded in the years after the 2001 economic crisis, the Salta concession has been upheld until 2009 despite a number of problems. In February 2008 the regulatory agency initiated penal proceedings against the concessionaire because one of its wastewater treatment plants discharging to the Arenales River was not functioning. In June 2008 the company was accused of not having complied with contractual targets for the installation of meters, water pressure, continuity of supply, drinking water quality norms, and of applying excessive interests on late payments. In May 2009 Juan Manuel Urtubey, governor of the Province, terminated the concession contract because of non-compliance and created a transition unit to

provide services until a state company would be created whose shares would be held by the Province (90%) and workers (10%).

## ***Responsibility for water supply and sanitation***

### **Policy and regulation**

Provinces have responsibility for setting rules and policies in the sector for their area. Institutions are weak, subject to political interference and lacking in enforcement powers. 14 out of 23 provinces have regulatory bodies, but they often have limited capacity and unclear institutional responsibilities. In most cases, they act as supervisors of private concession contracts, not covering public and cooperative service providers. This autonomy of provinces resulted in a highly heterogeneous system of water supply and sanitation. Moreover, it hinders to create an overview of the situation at the national level.

Despite recent progress in clarifying responsibilities, the institutional framework at the national level still lacks coherence and coordination among federal actors is weak. The Ministry of Public Works proposes sector policies to the Ministry of Federal Planning, Public Investment and Services which approves them. Within this policy framework the National Agency for Water and Sanitation Works (ENOHSA), a decentralized agency under the Ministry of Public Works, provides financing and technical assistance to service providers. As an advisor to the Ministry of Public Works it de facto influences sector policies. Recently ENOHSA has been also given the faculty to directly execute infrastructure works. There has been some confusion between its position as conceding power (in the Buenos Aires concession) and as policy-maker for the overall sector. There is no coherent national policy in terms of sector financing, subsidies, tariffs and service standards. Nor is there a sector law for water and sanitation. The federal structure of the country and the dispersion of sector responsibilities between and within various levels of government make the development of a coherent sector policy all the more difficult.

### **Service provision**

Provision of water and sanitation supply in Argentina is organized on a municipal or provincial basis by around 1,650 public, cooperative and private entities of various forms. 14 service providers are provincial (Argentina has 23 provinces), but do not necessarily serve the entire province. Some are multi-municipal, some serve a single municipality and others parts of a municipality. There are at least 990 mostly smaller cooperative service providers in Argentina, making Argentina the country in Latin America where this form of service provision is most prevalent.

## Financial aspects

### Tariffs



### Bills of Aguas y Saneamientos Argentinos

In 2000, the Argentinean water and sanitation tariff levels were high, given the low quality of services. According to the Panamerican Health Organization (PAHO), the mean tariff for water and sanitation was US\$ 0.79 per m<sup>3</sup>. There are two different tariff systems. The first method is based on the former OSN tariff system. It estimates the consumption of each user according to characteristics such as dwelling size, location of residence and type of dwelling. The second tariff system contains a fixed charge and a variable part which is based on metered consumption. This latter method was made possible by the extensive introduction of water metering, which was included in many concession contracts in the 1990s. The average household expenditure for water supply and sanitation in 2002 was 2.6%, ranging from 2.1% in the highest (wealthiest) quintile to 3.5% in the lowest (poorest) one.

### Cost recovery

Most service providers barely recover operation and maintenance costs and have no capacity to self-finance investments. While private operators were able to achieve higher levels of cost recovery and to substantially expand services before the crisis, since 2002 their tariffs have been frozen and their self-financing capacity has disappeared. Service providers thus are almost entirely dependent on federal transfers for investment financing. Roughly two-thirds of provincial water and sanitation spending over the period has come from general transfers from the federal government, the remainder coming from various programs directed specifically to the sector, including for flood protection and water resources management.

When the linkage of the Argentinean peso to the US-Dollar was abandoned due to a serious economic crisis in 2002, the tariffs did not increase but converted 1 to 1 to the devalued peso, resulting in various contract renegotiations. This decision worsened the financial situation of the suppliers. The lack of financial resources results in problems concerning even in maintaining the supply system.

Cutting off water services for non-payment is prohibited in Argentina based on a common interpretation of the constitution.

## ***External support***

### **Inter-American Development Bank**

- AR-L1015 : Water Infrastructure: Northern Provinces Development

Approved on January 31, 2007 in the amount of US\$240 million, the loan will address specific problems of irrigation, drainage, as well as low access to water and sanitation in the northern provinces of: Jujuy, Catamarca, Santiago del Estero, Tucumán, and Chaco.

- AR-L1034 : PEF:AR-L1031 Potable Water and Sanitation Program

Approved on September 25, 2006 in the amount of US\$ 180,000,000, the program will partly finance water and/or sewerage systems for communities up to 50,000 in Argentina.

### **World Bank**

- Infrastructure Project for the Province of Buenos Aires (APL2)

The US\$270 million loan was approved on June 28, 2007, and finances 40% sewerage and 16% flood protection for the highly vulnerable and low-income communities in the Province of Buenos Aires.

- Basic Municipal Services Project

The US\$175 million loan approved on April 3, 2006, finances water (27%), sanitation (27%), and sewerage (14%) projects in Argentina.

- Urban Flood Prevention and Drainage APL1

The US\$190 million loan approved on May 18, 2006, finances flood protection (94%) as well as general water and sanitation sector (2%) in the city of Buenos Aires through the protection of the city's critical infrastructure and the introduction of risk management into the Government investment program.

- Infrastructure Project for the Province of Buenos Aires (APL1)

The US\$267 million loan approved on February 15, 2006, finances infrastructure services in sewerage (30%) and flood protection (5%) in the Province of Buenos Aires.

## Chapter 18

# Water Supply and Sanitation in Mendoza

The debate about **water supply and sanitation in Mendoza** has been dominated by the controversial private concession for the provincial water company OSM granted in 1998 to a consortium led by Enron. While the concession improved water and sanitation services, it failed to meet all its specified targets. After the collapse of Enron the concession was overtaken by Argentine investors.

Besides OSM water services in the province are provided by the three municipalities of Maipu, Lujan and Tupungatu and 174 small not-for-profit operators.

With 1.6 million inhabitants the province of Mendoza is the 5th most populous province of Argentina. The province has an arid climate and its water supply depends on rivers fed by glaciers from the Andes.

### *History*

#### **Sector reform (1993-1998)**

In 1993, in response to poor service quality, the provincial Parliament passed a law (Law 6044) with the objective of restructuring the province's water and sanitation sector, introducing a private concession for the provincially-owned company Obras Sanitarias de Mendoza (OSM) and creating a regulatory agency for the sector.

In the same year the provincial government also first submitted a draft law to Parliament to pursue a policy of installing water meters and volumetric billing. More than 120,000 meters were installed in the following five years. However, that law was never passed. Meters were thus not read and fell into disrepair, while bills continued to be issued on a lump sum basis independently of consumption.

Moreover, a culture of non-payment reigned. According to a survey by the newspaper Los Andes, in 1999 one quarter of water users did not pay their water bills.

## **Early years of the concession (1998-2001)**

In 1998 the provincial government launched a bid for a concession for OSM, which was won by a US-French-Argentine consortium led by Enron. OSM's capital was thus held by the following entities:

- 50% by the Enron-led consortium Inversores del Aconcagua
- 20% by an operating company called Aguas de Mendoza
- 20% were kept by the provincial government
- 10% by the company's employees.

Inversora del Aconcagua initially consisted of the US firm Enron (57.5 %), the French firm SAUR International (17.5%), Italgas (5%) and Argentine investors (20%). Aguas de Mendoza is fully owned by SAUR International.

The concession contract was signed for the unusually long duration of 99 years. Investment commitments were US\$ 89million over 25 years.

Tariffs were supposed to remain stable for the first five years of the contract. However, there was a 37% increase after the renegotiation of the concession in 2003.

## **The concession after the economic crisis (2001 onwards)**

After the economic crisis of 2001 and the devaluation of the Peso a number of problems became apparent:

- Tariffs were frozen in 2002 by a national emergency decree, in contradiction of tariff increases stipulated in the concession contract. As a result, revenues were insufficient to recover increasing costs;
- There were delays in the execution of works;
- There were problems of bacteriological pollution of drinking water;
- Low water pressure (40% of users do not receive water below minimum pressure);
- Insufficient attention to user complaints;
- Reduction of environmental targets.

In 2002 a process was initiated to renegotiate the concession contract. When Enron went bankrupt in 2003 its part of the shares was initially taken over by its own subsidiary Azurix. In 2004 the shares of OSM were worth only one fifth of their value in 1998. In the same year South Water Argentina SA of the Sielecki Group took over 32% of the shares of OSM from Enron after the latter went bankrupt.

According to Susana Yelich, director of the consumer group Prodelco, service provision in 2004 was much better than at the time when OSM had been publicly managed. Nevertheless, many consumers were dissatisfied with the services they received and more than 120 law suits were initiated against the private operator.

At the beginning of 2008, the provincial government announced that it is interested in increasing its control of OSM, of which it owns 20%, buying another 20% from Saur International.

## ***Responsibility for water supply and sanitation***

### **Policy and regulation**

Sector policy is the responsibility of the provincial governor, assisted by the provincial Minister of Public Works and the Environment.

Economic regulation is the responsibility of a regulatory agency, the Ente Provincial de Aguas y Saneamiento (EPAS), under the Ministry of Public Works and Environment. It was created in 1995 on the basis of Law 6044 of 1993. EPAS remained a weak agency and, as a technical agency with limited autonomy. It was unable to fulfill its role of regulating the concession contract which included both technical and political elements. The regulator has been highly critical of the private concession, requesting it in 2003 to be cancelled due to non-respect of the contractual agreements.

### **Service provision**

There are three categories of service providers in the province of Mendoza:

- OSM with more than 320,000 water and sewer connections
- The three municipalities of Maipu, Lujan and Tupungatu with more than 100,000 water and sewer connections
- 174 small operators, such as cooperatives and neighborhood associations, with more than 38,000 connections.

## ***Financial aspects***

### **Tariffs**

In 1998 tariffs of OSM were 30 Pesos (US\$ 30) every two months, much more than the national average of 18 Pesos (US\$ 18). The average tariff level in 2004 was 60 pesos (US\$ 20) for water and sewerage for a period of two months, compared to only 15 pesos (US\$ 5) in the case of Buenos Aires. Because of the massive devaluation of the Argentine peso the dollar value of tariffs decreased in this period, although the Peso value of tariffs had doubled in Mendoza.

Note: Tariff data for municipalities and cooperatives are missing.

## **Sector finances**

It is a matter of controversy whether OSM made profits from its concession. In five years OSM paid only 1 million Pesos of dividends. In 2002 and 2003 OSM showed losses of 43 and 17 million Pesos respectively. However, according to the regulatory agency its rate of return was 13%.

Annual fees from the concession were intended to finance the construction of the Potrerillos levee on the Mendoza River, the largest hydraulic infrastructure ever built in the Province. The fees were supposed to be paid by the concessionaire to the Provincial Irrigation Department. However, due to the various problems that afflicted the concession that fee has never been paid. Until 2002 a debt of more than 4 million Pesos had been accumulated.

A list of 26,000 needy users (*carenciados*) was established in 2003, for whom the provincial government would pay 40-75% of the water bill. However, not all those on the list were truly needy, since the establishment of the list was influenced by clientelism. Despite requests by the concessionaire, the list has never been updated until 2004. Furthermore, the provincial government has only partially met its payment obligations towards OSM on behalf of the needy users, having accumulated a debt of 13 million Pesos towards OSM by 2000. On the other hand, OSM has not paid taxes, the concession fee and fines imposed on it by the regulator for not having met its investment obligations, equivalent to 13 million Pesos as well.

## ***Media and the water and sanitation sector***

Among the province's two main newspapers, Los Andes was highly critical of the concession and of privatization in general. The newspaper Uno was much less critical, which may be explained by the fact that its owner, Daniel Vila, was also a co-owner of OSM through Inversores del Aconcagua. In general the concession contract received negative media coverage, with the media giving ample space to the criticism voiced by politicians, consumer associations and the regulator.