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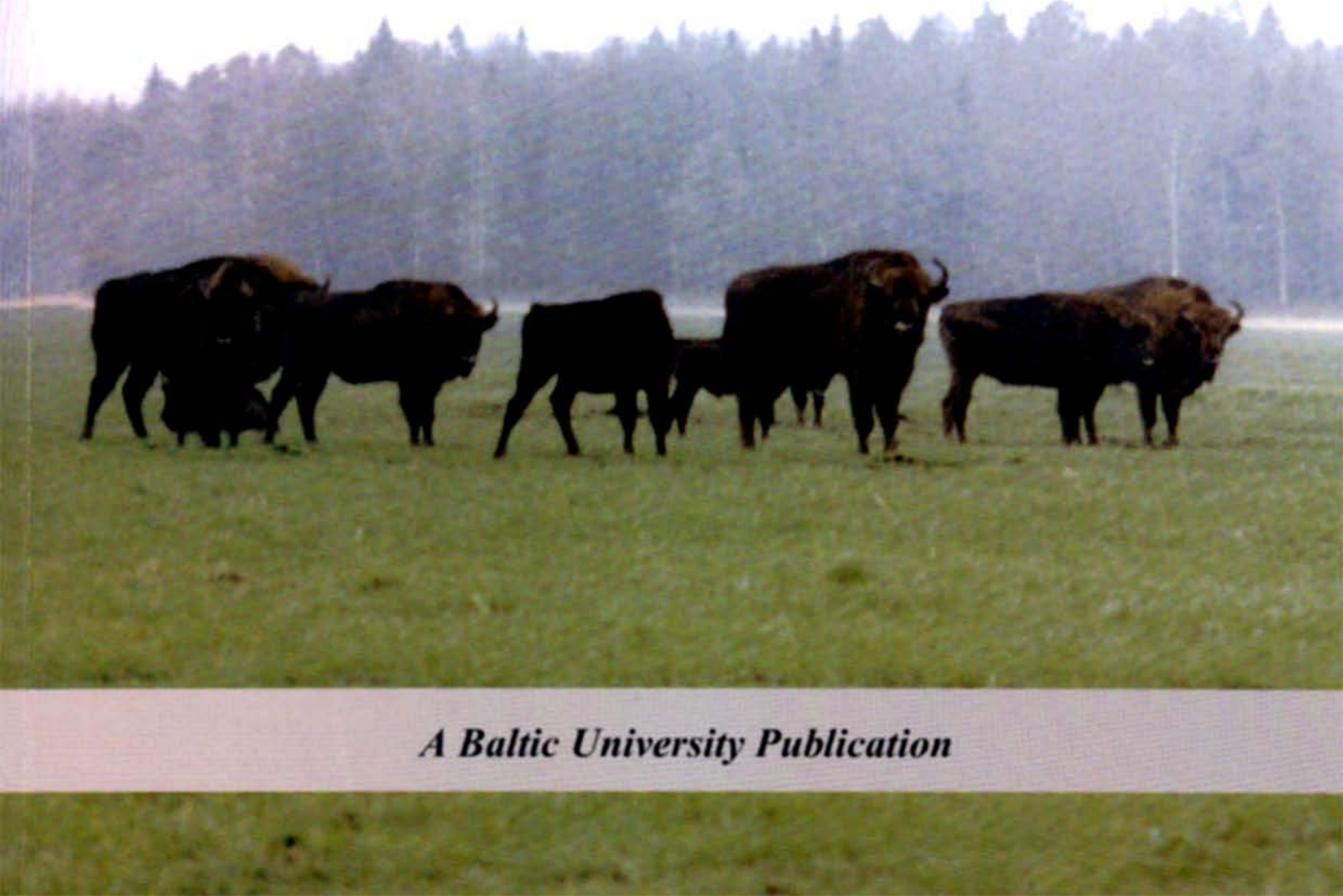
ENVIRONMENTAL SCIENCE



A Baltic University Publication

RESOURCE MANAGEMENT AND THE TECHNOLOGY OF CLEAN WATER

17

Water is life. Most life-forms live in water and life on land have developed various means to secure a constant supply of water. An adult person drinks about two litres per day, but needs much more when the food eaten is considered. In irrigation about 500 litre of water is used to produce one kg of bread, and a growing cow drinks about 50 litres of water for each litre of meat it produces in addition to the water it receives with its food. Indeed, provision of water is a most essential engineering task. (Photo: Inga-May Lehman Nådin.)

> *”A drop of rain fell on my hand*
> *condensed from Ganges and the Nile”*
>
> Wisława Szymborska
> From the poem "Water"

Water is a key resource in society. People have always settled where water is available in good quantity and quality. Safeguarding this key resource is still a first priority in our societies. Living close to water is also today a favourite choice as can be seen on any map of population density or distribution of cities. A healthy environment requires a well functioning management of water.

In the world as a whole bad quality water and too little water is a growing threat towards human health and well-being and is the most urgent environmental challenge. On a global scale lack of safe water causes about a third of all child mortality. It is the cause of wars, starvation, and failure of harvests. Growing populations in the mega-cities in the developing world constitutes an especially serious water problem.

In this perspective the Baltic Sea region has good access to water. Germany and Poland have a runoff of some 1,200 m^3 per person and year, a figure that is close to 20 times higher in the far north. On the consumption side, households today use some 200 litres per day, a figure that was only a few years ago considerably higher, and much higher in the countries in transition where water was not priced at all during the communist time. Likewise, industries are recently using water in a more economic way, as better technologies have developed during the last twenty years.

The largest threat towards healthy water is improper ways of getting rid of waste. At one time human sewage and food waste were too often emptied in the streets and in the nearest water course. Water downstream then became a carrier of diseases. Especially in the cities, the smell and sight was terrible as waste accumulated on the streets.

It was not until the late 19th century that infection of water by human sewage was properly understood and an acceptable system for management of sewage gradually developed. In the West such systems were installed on a major scale from the 1950s on. In Central and Eastern Europe improved and enlarged water works, sewage systems, and wastewater treatment plants have been a first priority after the systems change around 1990, and a very large share of environmental investments have been and still are devoted to aspects of water quality.

In this chapter the use and management of water are discussed. Water management is traditionally a task for engineers in the field of technology of hygiene. Today the scope of engineers has to be enlarged to include concepts of ecology and recycling.

In historical times very little was wasted. Sustainability requires that we return to this approach, and regard waste as a resource to be recycled. A weak point in water management is the recycling of nutrients. Sludge from wastewater treatment plants is a major source of phosphorus, a nutrient which should be returned to farmland, to close the phosphorus cycle. Considering all aspects of water and the nutrients it carries is part of sustainable water management.

Authors of this chapter
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RESOURCE MANAGEMENT AND THE TECHNOLOGY OF CLEAN WATER

WATER – A CRITICAL RESOURCE

WASTE DISPOSAL AND WATER POLLUTION

WASTEWATER TREATMENT PRACTICES

IMPLEMENTATION OF WATER AND WASTEWATER HANDLING PRACTICES

NEW DEVELOPMENTS

WATER – A CRITICAL RESOURCE

Water – a threatened human resource

Water dominates our planet and is basic to man's living conditions. Yet it is in many places a limited and threatened resource. The water we use, freshwater, constitutes only a small fraction, about 0.75%, of the total amount of water in the world. Most freshwater is underground, groundwater. The surface water in lakes and rivers is only about 1% of the freshwater, and it is very unevenly distributed. Due to the massive increase in human consumption of water and a steadily increasing pollution of fresh water sources, in particular rivers, the water situation is deteriorating in many parts of the world. In the developing world at least one-fifth of city dwellers and three-quarters of rural people lack access to reasonably safe supplies of water. Pollutants in fresh water is today an increasing threat against human health and welfare.

In the Baltic Sea basin the available amount of fresh water per capita is comparatively high. Annually the total fresh water runoff, that is the water available for consumption, is 450 km^3. Due to high precipitation and low evapotranspiration, i.e. loss of water through plants and from ground, the water resources are much greater in the northern and western part of the region. In addition the low population density in the north makes per capita water resources in the north very large, about 22,000 m^3 per person and year, while it is almost 20-fold less in Germany and Poland, where water often is e.g. a limiting factor in agriculture.

But not all water can be used for human needs. Most must be left in streams and rivers to safeguard ecosystems and much of it is far away from human settlements. In Sweden 3-4% of the total runoff is used for human consumption, which is a comfortable level. In Poland on the other hand some 18% of the runoff is used. This is close to the practical maximum.

While water access is not very limited, the problem is rather one of water quality. In the Baltic Sea region pollution has deteriorated water quality to the extent that in many places the water supply is critically threatened. St. Petersburg, the largest city in the region with some five million inhabitants, can illustrate this problem. The Neva River, passing through the city, carries some 70-75 km^3 per year of water from Lake Ladoga, itself polluted by e.g. several pulp and paper industries. The amounts retracted to the city from the river by the waterworks, by industries and by water for energy production, i.e. the total water consumption

Figure 17.1. Water in the Baltic region. In the northern and middle Baltic Sea region water is plentiful and clean and fresh, as in this stream. In the south, on the contrary, there is about 20-fold less water per person, and problems with pollution are much larger. (Photo: Inga-May Lehman Nådin.)

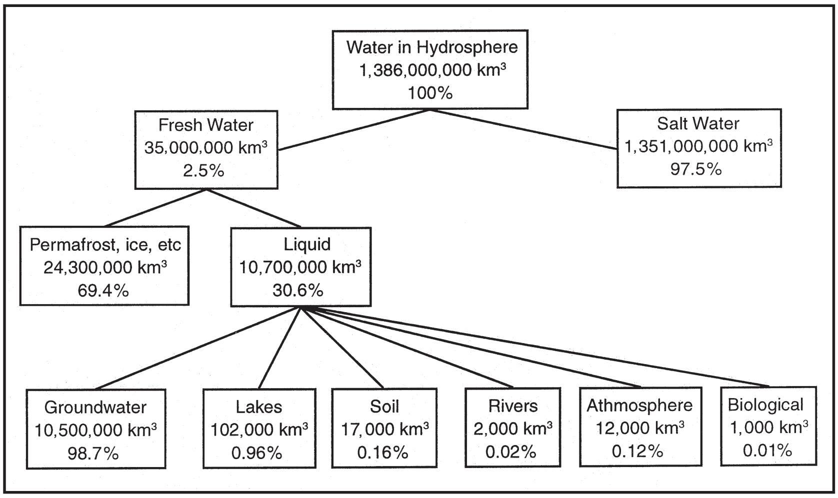
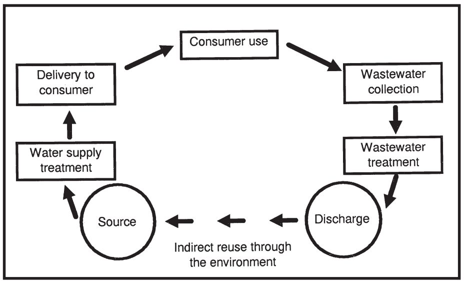


Figure 17.2. Water resources on Earth. Figures are in million km^3. (Source: Saiejs and van Berkel, 1995.)



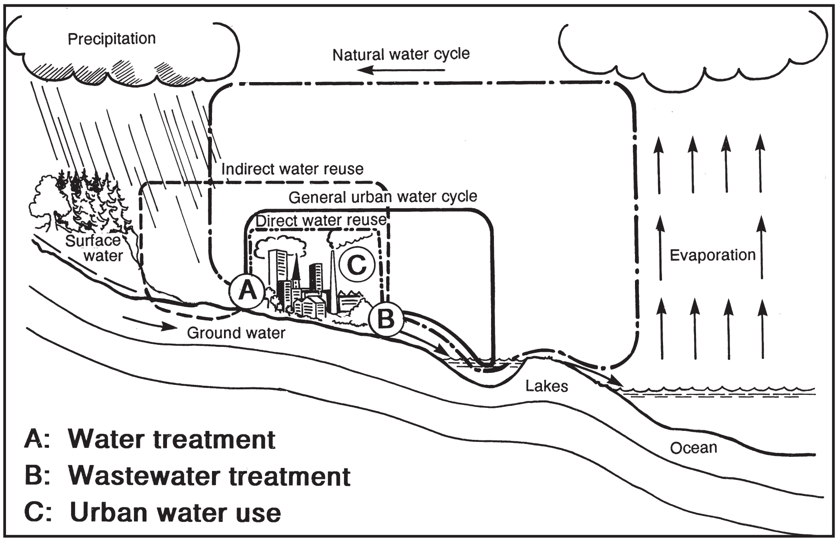


Figure 17.3. Water cycled. The water consumption cycle (top), and the natural water cycle with various forms of consumtion cycles (right).

in St. Petersburg, is 1.5 – 2.5%, of the total Neva discharge, or some 600 litres per day per person. In general the water delivered to households is not safe; boiling is required before it can be used for drinking. Of the water emitted to the river from the city only about two-thirds has passed through a wastewater treatment plant. This heavily pollutes the Gulf of Finland and the Baltic Sea. In the second largest city in the Baltic Sea region, Warsaw, the Wisla River is likewise serving the double purposes of being the source of fresh water for the city and the recipient of wastewater, before it empties into the Baltic Sea.

The situation has been much improved during the 1990s. Large investments have been made to improve the situation and in general all of the larger cities have all wastewater going to treatment plants. Riga is e.g. a good example where the treatment plants have been expanded, and since 2000 all wastewater goes to the enlarged treatment plant. Gdansk was awarded a prize in 1999 for good water management; tap water there is perfectly safe to drink. In St Petersburg large investments in the wastewater treatment plant began in 2002.

The water consumption cycle

In *the natural water cycle* (Figure 17.3) water evaporates from the surface of the Earth to the atmosphere where it forms clouds and returns to the land surface as precipitation; on land the water passes through ground water, to smaller streams and larger rivers to lakes and finally to the sea.

Man retracts water from groundwater (wells and springs) and surface water (rivers and lakes). After treatment in water works the water is transported to the consumers (population, industries, and general purposes, etc.). After consumer use the wastewater is collected, sometimes passed through a wastewater treatment plant, and discharged to the recipient, i.e. a river or a lake. This is *the water consumption cycle* (Figure 17.3). During this cycle various substances are added to the water as pollutants, making the wastewater potentially harmful to the environment and to human health.

In a situation with minimal human use of water, the fresh water used for human consumption is not affected by wastewater. The wastewater is indeed purified in the recipient by natural processes. Increases in water consumption, urbanisation and population growth, however, make it necessary to shorten the water cycles. The water used for water works contains a larger share of wastewater.

Several possibilities are available with indirect or direct reuse of wastewater. Still, intensified water use will increase the risk of accumulation of pollutants in water, and improved treatment methods must be used to counteract water

Table 17.1. Withdrawal of freshwater by sector in Sweden. (Ministry of Foreign Affairs and SEPA, 1998.)

Sector	Withdrawal, %
Industry	70
Households	16
Agriculture	5
Miscellaneous	9

quality deterioration. The examples of St. Petersburg and Warsaw illustrate the shortened water cycles found today in the Baltic Sea region. In the future, extremely short water cycles and direct reuse of wastewater may be necessary for many large cities.

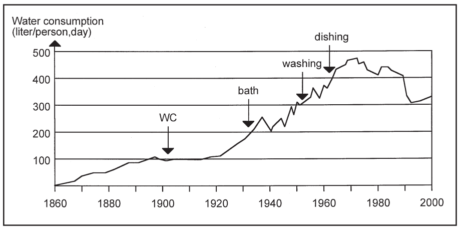


Figure 17.4. Water use in Stockholm between 1860 and 2000. (Cronström, 1986, updated by E. Levlin)

The use of water in society

A general trend in Europe is a decline in the withdrawal of freshwater especially for industrial use but also for households (data for Sweden is shown in Table 17.1.) Many water saving strategies have been introduced with the purpose to save freshwater resources, decrease discharges of wastewater, and facilitate recovery of chemicals and energy.

The use of water varies considerably between different parts of the world. On a global level irrigation and agriculture account for the largest share of water resources needed, about 65%, followed by industry, 24%, municipal needs, 7% and reservoirs, 4%. In the Baltic Sea region water for irrigation has a much smaller proportion of water use.

The availability of internally renewable water resources, i.e. the difference between total precipitation and the amount lost through evaporation, varies much between different countries around the Baltic Sea. Germany and Poland had for instance a per capita renewable water resource of 1,200-1,300 m^3/year in 1990, while the figure was about 21,000-22,000 m^3/year in Finland and Sweden. The per capita water use in all these countries varied between about 500 to 800 m^3/year in 1980. In 2001 this figure has decreased considerably.

Many countries are today dependent on the water flow from rivers coming from surrounding countries. If water resources are threatened this may lead to political conflicts.

Raw water for the production of *potable water* is obtained as surface water or ground water. In Sweden about 50% is obtained from surface water, and 25% from ground water. Another 25% consists of surface water treated through

Table 17.2. Drinking water consumers in Sweden 1994. During the 1990s only marginal changes have occurred. (Source: VAV, 1995.)

Users	Yearly use (Mm^3)	Per capita use (l/p/d)	Relative use (%)
Households	544	198	57
Industries	95	35	10
General services, etc.	95	35	10
Losses and own use	219	79	23
Total	**953**	**347**	**100**

Outlook
Box 17.1

Water – a key question for the global environment

Access to safe water is one of the most urgent issues in the world today. Lack of safe drinking water is a major cause of health problems in the developing world, causing about 30% of all child mortality or a staggering 25,000 deaths per day. Improved health is in turn necessary for improved living conditions.

Total water demand for one person

Irrigation in agriculture is world-wide the largest use of water, accounting for some 70% of the total volume. Water is most often the resource that limits production. Globally only 17% of all farmland is irrigated but 40% of all food is produced on this irrigated land. To produce the food needed for a balanced diet with meat for one person about 2,000 m^3 per year (5,000 litres per day) is used. Normally this is taken up naturally from groundwater or streams, but for irrigated areas it is withdrawn from rivers and lakes.

Water in cities

Water for cities is another key area. The water problem is serious in the growing mega-cities in Africa, Asia, and South America. It is aggrevated as people immigrate to the new urban areas that are not planned properly. Especially difficult problems occur in China. As population increases, wastewater is polluting the water to be used for human consumption. In many cases, sewage waste and water wells are close to each other, which causes propagation of disease.

Dry areas

Lack of water is an age old problem in arid and semiarid areas. Water scarcity is one component in several of the serious conflicts and wars in this part of the world. Water saving techniques are slowly being introduced to improve the situation.

International initiatives

The United Nation declared 1980-1990 the Decade for Safe Water and Sanitation. The Baltic Sea region contributes through the Stockholm International Water Institute, SIWI, with among other arrangements the annual water symposium in Stocholm in August, the annual World Water Prize, and several initiatives for the Baltic Sea basin. Water will be one of the key areas in the Johannesburg Summit on sustainable development in September 2002.

artificial infiltration into the ground. Similar figures apply for the other countries in the region.

Most water has to be purified before it can be used for potable purposes, i.e. human consumption. There is virtually no water that is impossible to purify to potable standards, but some raw waters are so bad as to merit rejection because of the risks and expense involved. The treatment of fresh water is made in water works and may include pre-treatment, mixing, coagulation, flocculation, sedimentation, filtration, and disinfection. Sometimes activated carbon is used to improve water quality.

Water consumption per person and day in urban areas increased in parallel with the standard of living. However, in some countries, like Sweden, a stagnation at about 380 litres per person and day occurred during the 1980s and up to the 1990s when it started to decrease. In 1994 some 350 litres per person and day was used in urban areas, some 200 litres in households and the rest in industries, and services and was lost in the system. Introduction of water-saving household equipment is the main reason for the decrease in Sweden, while water price is an important factor in Eastern Europe. Efficient water-saving equipment may decrease the household water consumtion down towards 100 litres per person and day. The use of municipal water in Sweden is summarized in Table 17.2. In rural areas water requirements were about 150-200 litres per person and day in the mid-1990s.

In the newly independent states pricing of water was introduced during the 1990s. This made a large difference as compared to communist times when water was a free resource and could be used without payment. Water consumption in Gdansk, Poland has, e.g. decreased during the 1990s from about 600 litres per capita and day in the late 1980s to about 130 litres per capita and day during 2000.

The main part, 57%, of drinking water consumption in Sweden is accounted for by households. The water is used for different purposes in a household (Table 17.3). Although only a small amount of water is used for food preparation and drinking, 10 litres or about 5-10%, this part sets the water quality standards.

Typically about 20% of the total amount of the produced water is lost by poor condition of the infrastructure (old pipes, bad connections, etc.). This figure can be substantially higher if control and maintenance of the infrastructure is not efficient.

Table 17.3. Typical household use of water in Sweden. (Source: VAV, 2000.)

Water use	Consumption (l/p/d)	Relative use (%)
Food and drink	10	5
Toilet flushing	40	20
Laundry	30	15
Dish washing	40	20
Personal hygiene	70	35
Miscellananeous	10	5
Total	**200**	**100**

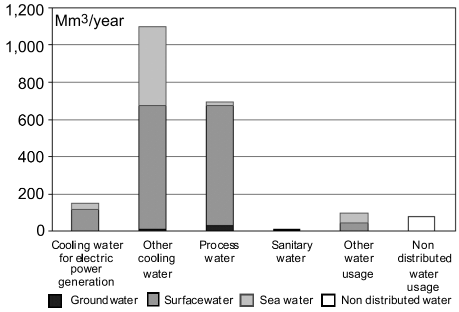


Figure 17.5. Industrial water use in Sweden in 2000. (Source: Statistics Sweden, SCB, 2002. See http://www.scb.se/statistik/mi0901/mi0901dia2.asp.)

WASTE DISPOSAL AND WATER POLLUTION

The origin of wastewater management

In areas with high population densities, waste, including wastewater and sewage, disposal must be organized by people, as it has been since earliest times. In the ancient cities of Jerusalem and Athens sewage was used for agriculture on farms. As recently as the second half of the nineteenth century, faecal matter was collected from 260,000 inhabitants in Nürnberg, Germany, and sent in vehicles to rural environments as manure.

A second means of waste disposal is the use of running water for the transportation of wastes. Sewers were installed in the ancient palace of Knossos at Crete and especially in classical Rome. The Roman cloacae served to carry off the sewage and rainwater together and emptied directly into the river, Tiber, thus polluting its waters, which were used not only for bathing but also for drinking purposes.

Figure 17.6. Without treatment. Originally wastewater went out to the streams without treaetment. It is still too common. (Photo: Pawel Migula.)

A sophisticated system that even predates these examples was found when excavating the 4,000 year old city of Mohenjo-Daro at the River Indus with about 40,000 inhabitants. The system included both wells for dumping and sewers for transportation of waste matter.

The two means of disposal can be seen as the roots of the modern practice of waste disposal, one oriented towards ecological solutions and one oriented towards technically intensified and controlled solutions. The know-how of waste disposal in the ancient world was lost in the following centuries. However, a systematic and scientific evaluation of wastewater handling started in England around the 1850s and was followed up by other countries in Europe, and in the USA and South Africa. The goals were the same as today:

- a prompt removal of sewage from the neighbourhood of dwellings,
- preventing the pollution of receiving waters by the utilisation of efficient methods of sewage disposal, and
- profitable disposal and use of sewage.

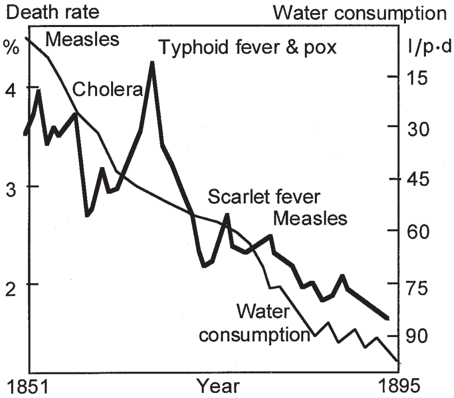


Figure 17.7. Waterborne diseases. As consumption from the water network in Stockholm (right axis - note the reverse scale - and thinner line) increased during the 19th century the death rate (left axis, thicker line) decreased in parallel, pointing to the role of water as disease carrier. (Source: Cronström, 1986.)

Water-borne diseases

The linkage between water pollution and water-borne diseases were suspected from death registers as early as the 19th century. In 1854 an English physician, John Snow, clearly traced the outbreak of cholera epidemics in London back to the Thames river, which was grossly polluted with raw sewage. Although the role of water-borne diseases thus was recognised early, dirty water is still the world's major cause of disease. More than a third of the world's population does not have safe drinking water. Water-borne diseases cause an average of 25,000 deaths per day.

To control water-borne diseases, it is necessary to separate sewage from the drinking water supply. This is illustrated by the close relationship between the decrease in death rate from water-borne diseases and the increase of water consumption from the water net for Stockholm over a long period during the 19th century (Figure 17.7). During this time the separation of sewage and drinking water was not efficient. Water-borne diseases are still a problem in some areas in the Baltic Sea region and the boiling of water before human consumption is recommended in many cities. On a few occasions when, by technical error in some city, the wastewater leaks directly into the drinking water net for households, large groups of people have been reported to become severely ill.

Irrigation using sewage, or sludge disposal on agricultural land, may also result in water-borne diseases. After the second world war, 90-100% of the population was infected by worms in certain cities in Germany, probably due to irrigation of crops with sewage.

Today in the Baltic Sea a similar situation has occurred when insufficiently treated or untreated wastewater is discharged directly into coastal areas used for recreation. Thus e.g. the beaches in Gdansk Bay, Riga Bay and along the Estonian coast were in the early 1990s closed due to bacterial contamination for several years. In other places around the Baltic Sea, beaches, e.g. on the east coast of Gotland, have been closed during summer, in particular during the month of August, because of intense algal blooms caused by eutrophication. High concentrations of blue-green algae produce a toxin that is harmful to man and even might kill, for example, dogs that drink the water.

Wastewater management and marine pollution

In the early 1960s the guiding principles for the necessary treatment efficiency were mainly self-purification and the assimilatory capacity of the local recipient. Dilution of pollutants was an important goal expressed in the slogan "the solution for pollution is dilution." Technically the dilution method of sewage disposal can be accomplished by transport of untreated or only partially treated wastewater to a

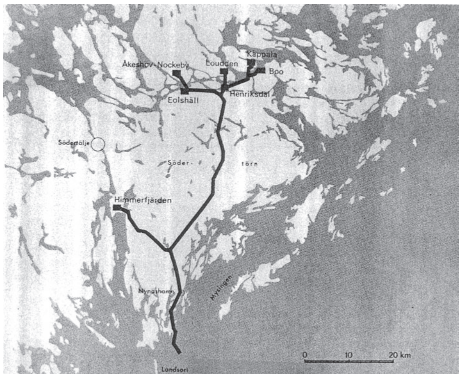


Figure 17.8. A map from a 1969 proposal to lead all wastewater from Stockholm to an outfall in the Baltic Sea - without treatment - illustrates the earlier belief that the sea could adsorb and even benefit from huge volumes of wastewater. The plan was never carried out. (Source: Cronström, 1986.)

Case
Box 17.2

A history of wastewater treatment in Sweden

Providing safe drinking water

Virulent epidemics were common in the mid-19th century and were the main reason for the introduction of water treatment in Sweden. Slow sand filtration was installed in Stockholm in 1861 and somewhat later in several other cities. In Gothenburg surface water was infiltrated into the ground in 1898. Chemical precipitation of surface water followed by rapid sand filtration has been used since the beginning of the 1920s.

First wastewater treatment plants

The first sewage purification plant with biological treatment was built for the town of Skara in 1897, but the big projects did not start until the 1930s. Stockholm, for instance, acquired its first purification plant in 1930. Most of these plants were limited to primary treatment. After an epidemic of salmonellosis in a Swedish city in the mid-1950s, building of biological treatment plants increased rapidly, with about 10 plants in operation in 1950 and more than 1,100 in 1975. The introduction of synthetic detergents in the mid-1950s accelerated eutrophication and at the end of the 1950s limnologists began to warn about the deterioration of the water quality in lakes and coastal areas.

The first Swedish chemical treatment plant (at Åker) was completed in 1961. Since the 1970s in Sweden, the installation of municipal wastewater treatment plants with chemical precipitation expanded very quickly.

Addressing new problems

The history of wastewater management has been characterized by the regular perception and occurrence of new severe water problems and the need for development of successively more advanced wastewater treatment systems. The successful combatment of water-borne diseases was the starting point for the development of water treatment plants and water distribution and sewer systems. The need for an efficient wastewater handling system for the protection of the environment has since then been underestimated. The early disposal philosophy stating that "the solution for pollution is dilution" could be justified for certain pollutants such as biodegradable organic substances discharged to a large recipient. However, effects on the Baltic Sea of discharges of toxic substances and nutrients clearly show the limitations of the dilution method.

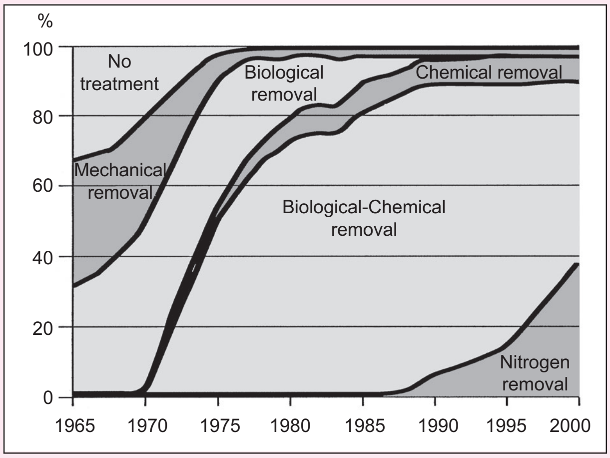


Figure 17.9. A history of municipal wastewater treatment in Sweden (Source. Ministry of Foreign Affairs and SEPA, 1998.)

Results - better water

The installation of biological and chemical wastewater treatment plants have in general led to significant improvements in recipient water quality. For example, the supply of phosphorus to the Stockholm inner archipelago has decreased rapidly since 1970 due to the installation of chemical precipitation at wastewater treatment plants. This has resulted in a corresponding decrease of chlorophyll-a in the 0-2 m layer. Large parts of Lake Mälaren, the second largest lake in Sweden, have shown improved conditions, due to which open air swimming has once again become possible in the central parts of the city of Stockholm. Source control and internal treatment have resulted in lowered contents of heavy metals in effluents from treatment plants.

The Baltic Sea region

A collection of articles on the historical developments in wastewater treatment and the conditions in the neighbouring areas of the Baltic Sea is available in *Ambio* Vol. 30, No 4-5, August 2001. The situation in Helsinki, Vaasa, Stockholm, Oslo, Malmö, Gdansk, and several Lithuanian and Latvian cities are described over a period from Medieval times (Gdansk), 1850-1911 (Malmö), over the entire 20th Century and today (Riga).

Table 17.4. Developments in Swedish water and wastewater handling systems.

Time period	Driving forces in society (examples)	Effects on environment	Remedies
Before 1930	Population growth and urbanization	Contamination of local water sources, and spread of waterborne diseases	Supply of water from an uncontaminated water source
1930 - 1990	Increasing standards in houses (WC, bath etc), increased use of different products and rapid growth in the economy	Impairment of the environment due to discharges of different substances, although compensated by different remedies	Gradual building of water and wastewater handling infrastructure including different treatment steps for efficient control of industrial discharges
1990 -	Increased awareness of environmental issues and its relation to life style	Improved environmental quality especially on a local scale due to decreases of discharges	Development of Agenda 21, multidisciplinary approaches to problemsolutions, and use of international environmental standards such as EMAS and ISO 14001

Figure 17.10. From this pipe 70% of the wastewater from the city of Kaunas, Lithuania, in the early 1990s, came out in the river untreated. The situation was similar in most cities in central and eastern Europe. Kaunas, Lithuania's second largest city, has more than 400.000 inhabitants. The wastewater treamtment plant is now expanded, with financing from among others the Swedish International Development and cooperation Agency. (Photo: Victor Brott, courtesy of Sida.)

large recipient, or use of submarine outfalls. A 1969 plan, which was not executed, for a regional wastewater system for the Stockholm area with a submarine outfall into the Baltic Sea, illustrates earlier overestimations of the self-purification and assimilatory capacity of marine environments (Figure 17.8).

Today the deterioration of water quality in marine environments with respect to eutrophication and toxic pollutants has shown the need for improved wastewater management. Treatment goals should not only satisfy water quality in local recipients but also consider the effects on marine water quality. This leads to the need to develop improved operational modes, expansion of existing treatment plants and the development of new treatment and management methods. In general the need for efficient treatment of wastewater has been underestimated during the last century. Problems concerning water quality have been identified in chronological order (Figure 17.11), and some decades afterwards in each case treatment methods have been implemented to solve the pollution problems.

Special focus is today directed towards:

- advanced wastewater treatment methods including nutrient removal,
- possible use of local and ecological methods, and
- changes in use of chemicals, production technology, recirculation, etc. ("clean technology").

Developments of wastewater treatment systems have been much influenced by developments in society. Different driving forces have changed priorities from a focus on hygienic aspects as a starting point via gradual improvements of treatment methods to a focus more related to – in addition to earlier requirements – recycling of resources, energy savings and recovery, public participation and interactions with other sectors in society. Developments of water and wastewater handling systems are illustrated in Table 17.4.

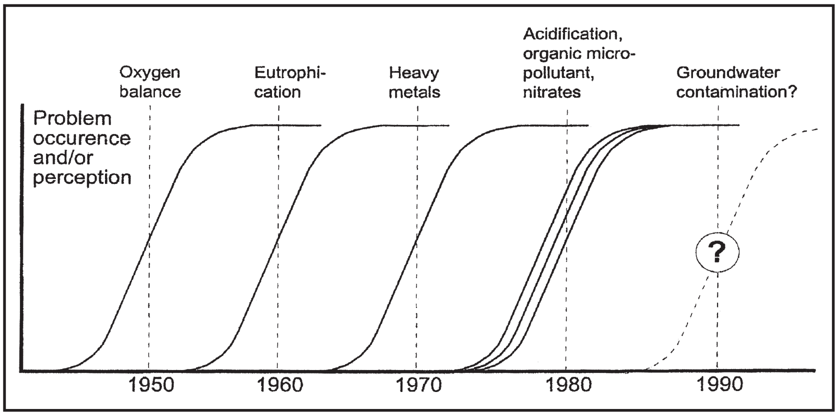


Figure 17.11. Historical identification of water pollution problems in Europe. (Source: Somlyody et al., updated 1992.)

WASTEWATER TREATMENT PRACTICES

Wastewater management

The history of pathogens in European waters is a classic example of the appearance, recognition and control of a water problem. However, new freshwater quality problems occurred and were identified throughout history in Europe (Figure 17.11). Especially problems concerning oxygen balance, eutrophication, heavy metals, and organic micropollutants can be related to wastewater management, although other pollutant sources may have a large or even dominating role.

During the 1960s it became apparent that removal of organic matter from sewage effluents decreased the need for primary oxygen for biodegradation, but did not prevent algal blooms and their consequences in lakes and reservoirs. Algal growth had been stimulated by phosphorus and nitrogen in wastewater effluents. In addition the introduction of phosphate-containing synthetic detergents in the 1950s significantly increased the phosphorus load to the recipients.

Phosphorus was normally considered to be the rate-limiting factor for algal growth. The control method for the reduction of phosphorus was mainly chemical precipitation, although some measures were also taken to diminish the phosphate content in the detergents. Later on special methods were developed for biological phosphorus removal.

A person drinks about two litres of water a day. Most of this water is used to transport waste products, mainly nitrogen and phosphate, out of the body, which happens when we urinate and sweat. In this perspective, the use of water for flushing the toilet is not so disparate after all. Only birds are able to get around this, by producing solid nitrogen waste, uric acid, and thus needing to drink much less water to become less heavy and fly more easily.

During the 1970s much interest was focused on the environmental effects caused by the production of a growing number of chemicals. Industrial production caused the discharge of for instance heavy metals, synthetic chemicals and organic micropollutants. Many treatment methods were developed to remove the pollutants. However, disposal problems of the toxic substances have led to other control methods than external treatment such as bans on certain chemicals, source control, new production technologies and internal recirculation and treatment of process streams. This type of pollution control is often called “clean technology”.

Collection and transport systems

Early use of sewers had the purpose of removing rainfall without causing inconvenience or flooding. As water supplies developed and the use of indoor toilets increased, the need for transporting wastewater, called sanitary wastes, became obvious. In London it was illegal to discharge human excreta into sewers

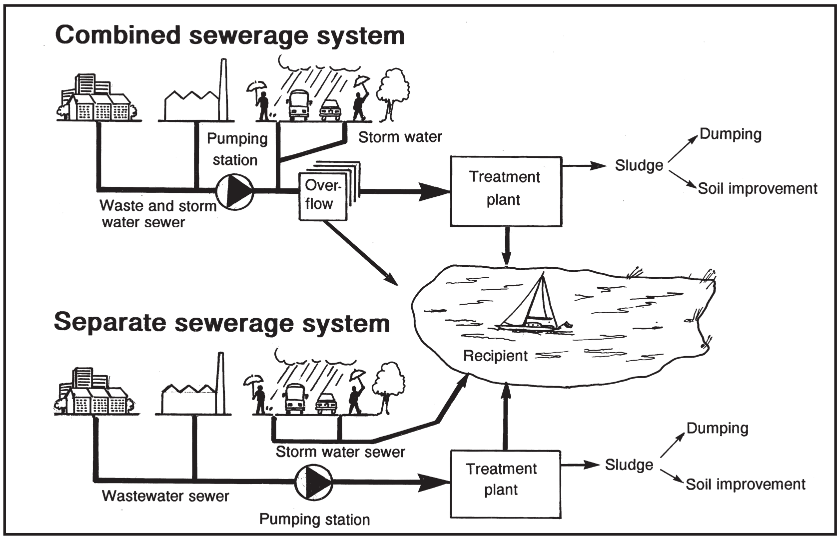


Figure 17.12. Two types of wastewater collection systems, sewerages. **Top**. The combined system, where stormwater and wastewater are collected in a single sewerage system. **Bottom**. The two systems are separate.

before 1815. Afterwards it became permissible to drain houses into sewers, and in 1847 it was made compulsory.

Sewers are classified into systems according to the purpose for which they are constructed. Two basic types of collection systems exist (Figure 17.12):

- The combined system in which sanitary wastes and storm water, i.e. surface water collected in an area after rain or snow, is discharged to one system of sewers which lead to the wastewater treatment plant or point of outfall.
- The separate system, in which the sanitary wastes is carried by an individual system of sewers to the wastewater treatment plant or point of outfall, while surface water is carried away by a number of local systems, discharging at various points into natural watercourses.

New cities or more recently built parts of older cities almost all have separate sewers for *sanitary wastes* and *stormwater*. Different hydraulic problems with the combined system include flooding of basements, overflow of untreated combined sewage to receiving water and shock loading of wastewater treatment plants. The severity of the hydraulic problems is related to rain intensity, rain duration and the construction of the system.

Sanitary waste can also have a double system, however. Toilet water, called *black water*, is much more polluted and of much smaller volumes than the so-called *grey water* arising from laundry, kitchen, personal hygiene, etc. Some research has focused on the separation of these different wastewater streams in households. The separation would facilitate nitrogen removal because of the fact that the main nitrogen source to municipal wastewater treatment plants is toilet water. Separate sewers for black and grey water are however very rare. As a further step special toilets are today available that separate urine from faeces. Urine stored in a tank can be used as a fertiliser with a low content of pathogens.

Industries discharge their wastewater into the combined or separate system. These wastes may be toxic or may accumulate in the sludge at the treatment plant. Pre-treatment of industrial wastewater is therefore often necessary. In contrast to the situation in households, separation of wastewater streams in modern industries is common practice. It facilitates recycling of water and materials and internal treatment processes.

Stormwater as a rule is led directly to a nearby water area without any intervening purification. The pollution contents of stormwater depends on factors such as air pollution, the nature of precipitation, and traffic density. Local handling is normally the best solution for storm water with a low concentration of pollutants. Different methods include natural systems with local infiltration and run-off to open ditches, i.e. a separate system.

On-site, that is *local, wastewater disposal systems* for a single or a few houses, typically on the countryside, have often been regarded as temporary solutions until sewers are built. But solutions to wastewater problems in urban areas are often not suitable for rural communities due to the need of extensive maintenance. If on-site wastewater disposal systems are constructed properly and do not need frequent maintenance, they provide reliable and efficient means of wastewater treatment and disposal at relatively low cost. Soil provides an effective medium for treating domestic wastewater.

A typical on-site treatment system may consist of a septic tank for removal and storage of solids, followed by infiltration-percolation in soil, where organic matter and phosphorus are reduced. Also, nitrogen can be successfully removed by modification of the design of the infiltration systems.

How nature handles wastewater

Wastewater discharged into an ecosystem will normally be transformed by self-purification. The processes taking place in these natural systems have been

Monitoring of water

Water quality is carefully monitored in more or less automated systems. Thus outgoing water to the network of households in a city is normally controlled, either on-line or by sampling, to see that not the set quality parameters are passed. In addition the bacterial count of outgoing water is an important measure to be checked regularly for health reasons.

Water leaving waste water treatment plants are also monitored on a regular basis. Thus outgoing water quality in Fyris river outside Uppsala is available on internet for any one interested, giving data for phosphorus and nitrogen.

The quality of water on all public beaches is monitored according to European Union regulation on a regular basis within all countries in the Union.

Figure 17.13. Natural wastewater cleaning. Small streams clean wastewater efficiently by producing biomass, by nitrification and denitrification, and binding of phosphorous to bottom sediments. (Photo: Lars Rydén.)

discussed for about a century and form the basis for the concept of ecological water management. Many of the processes are used or mimicked in wastewater treatment plants. Below we will briefly mention some of them and their relevance for treatment plants.

Biological processes are the most important. Organic substances constitute the substrate for microorganisms and are oxidized and transformed into biomass when these organisms grow and are thus incorporated into food chains in the ecosystems. Also, nitrogen and phosphorus-containing compounds are important nutrients for the growth of microorganisms, algae and plants. These biological processes occur for instance in oxidation ponds in treatment plants.

Chemical reactions with the dissolution or precipitation of different substances occur as natural processes in self-purification. E.g. ferrous iron is released from bottom sediments under anaerobic, oxygen-free, conditions. In oxygenic condition closer to the surface it is oxidized to ferric iron and might as such combine with phosphate. The ferric phosphate forms flocs which settle to the bottom sediment. Also in treatment plants ferric iron is utilised to precipitate phosphate.

Light, and even more so ultraviolet light, has an important role in the degradation of chemicals in nature. In particular certain organic micropollutants are oxidized by light.

Physical separation processes such as adsorption and filtering have an important role. Many pollutants adsorb to particles in soil and sediments in nature. Thus both lipid-soluble aromatic hydrocarbons and heavy metals are found on particles that sediment to bottom of lakes, rivers and the coastal areas of the sea. Adsorption processes are also used in treatment plants, e.g. in ion exchange. Filtering of water is used by many animals, e.g. mussels, although it must be emphasized that mussels do not remove the substances filtered. They only use nutrients for their own growth. Filtering employed in membrane processes in treatment plants remove a pollutant that finally is recovered somewhere else, where it has to be dealt with.

Self-purification requires large volumes and is slow as illustrated by the deterioration of the water quality of the Baltic Sea itself. Natural treatment systems constructed by man, such as oxidation ponds, wetlands, and land based treatment, are designed for a higher metabolic rate and for a better control of the processes than in the recipient. However, these also require large areas and long residence times and are thus limited in their use for wastewater treatment.

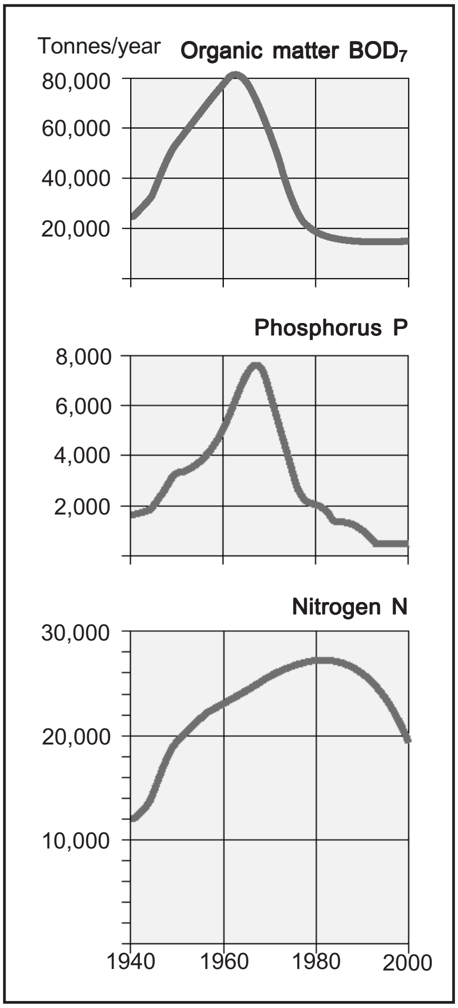


Figure 17.14. Impact on the recipient by discharges from municipal wastewater treatment plants in Sweden. The removal of organic matter, phosphorus and last nitrogen in the treatment plants over the period 1940 to 2000. (Source: Ministry of Foreign Affairs and SEPA, 1998).

Engineering tasks

Several different approaches have been used in managing wastewater problems. The main principles are:

- Separation of waste and waters and waste minimization, forming the basis of so-called clean technology.
- Treatment of wastewater by use of technical methods.
- Efficient use of the natural assimilative capacity, forming the basis for the ecological engineering approach.
- Methods to improve the assimilative capacities of the receiving waters, such as aeration, liming, addition of nitrates to bottom sediments, addition of chemical precipitation agents, removal of sediments, etc.

The different technical methods in wastewater treatment focus on the possibilities of intensifying biological, chemical or physical separation processes in order to diminish space and residence time. These methods have in general been used in urban areas with high population densities, where the natural processes are not effective enough for handling the wastewater.

The linkage between wastewater pollutants and water quality in the recipient is illustrated in Figure 17.14. Here we will deal with the technical methods, while the ecological approaches and clean technology are treated later.

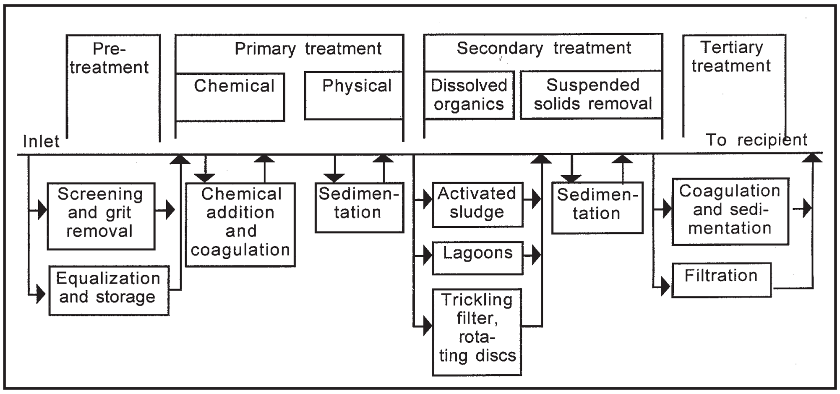


Figure 17.15. Wastewater treatment technology. Wastewater treatment is here shown as a sequence of pre-treatment, and primary, secondary, and tertiary treatment (above). It may also be seen as consisting of chemical, physical, and biological steps (below).

The problems arising when designing a technical solution are for instance the construction costs, the consumption of chemicals and energy to run the treatment plant, and the safe and ecologically sound disposal of sludge produced. A typical system for wastewater handling is shown in Figure 17.15. In order to manage the wastewater system, several engineering tasks must be performed concerning the source of wastewater generation, source control, collection and transmission, pumping, treatment, and disposal and reuse (Table 17.5).

The objective of wastewater treatment is to reduce the concentration of different pollutants to a level where discharge of the effluent will not adversely affect the environment. Treatment methods may be classified as physical, chemical, and biological:

1. *Physical* in which change is brought about through application of physical forces like screening, mixing, sedimentation, and filtration.
2. *Chemical* in which removal or treatment of contaminants is brought about by the addition of chemicals or by chemical reactions like chemical precipitation and disinfection by chlorine or ozone.
3. *Biological* in which the removal of contaminants is brought about by biological means such as the activated sludge process.

Different unit operations, processes and treatment systems may be used to remove a certain contaminant in wastewater. The treatment processes can be combined to form process trains, i.e. treatment schemes in which the influent wastewater is treated to a specified water quality. For stringent requirements it is necessary to combine several treatment processes.

An advanced treatment system for municipal wastewater with a technically oriented process scheme is shown in Figure 17.15. The six main steps are:

1. *Pre-treatment* in order to remove coarse particles and sand.
2. *Physical (often called mechanical or primary)* treatment by sedimentation for the removal of suspended solids. The treatment efficiency may be improved by the addition of precipitation chemicals.
3. *Biological treatment (often called secondary treatment)* for the removal of organic substances. By modification of the biological treatment processes it is possible to obtain removal of nitrogen and/or phosphorus.
4. *Complementary treatment* (often called polishing or tertiary treatment) by use of a chemical precipitation step or a filtration step. Other complementary treatment methods could for instance be activated carbon, ion exchange, reverse osmosis and the use of wetland or land treatment.
5. *Sludge treatment* with the purpose to reduce the sludge volume and stabilize the sludge.
6. *Sludge disposal*.

Some of these steps are discussed below.

Table 17.5. Major elements of wastewater management systems and associated engineering tasks. (Source: Tchobanoglous, 1981.)

Element	Engineering task
Source of generation	Estimation of the quantities of wastewater, evaluation of techniques for wastewater reduction, and determination of wastewater characteristics.
Source control	Design of on-site systems to provide partial treatment of the wastewater before it is discharged to collection systems (principally involves industrial dischargers).
Collection and transmission	Design of sewers used to collect wastewater from the various sources of generation and to transport it to treatment facilities or to other locations for processing.
Pumping	Design of pumping stations and force mains to lift and transport wastewater.
Treatment (wastewater and sludge)	Selection, analysis, and design of treatment operations and processes to meet specified treatment objectives related to the removal of wastewater contaminants of concern.
Disposal and reuse	Design of facilities used for the disposal and reuse of treated effluent in the aquatic and land environment, and the disposal and resuse of sludge on land.

Figure 17.16. Himmerfjärden wastewater treatment plant. This plant located in the south-western part of Stockholm region receives wastewater from nearly 250,000 people. It is today highly automated. (Photo: Józef Trela.)

Wastewater treatment steps

Biological treatment. There are several objectives of the biological treatment of wastewater:

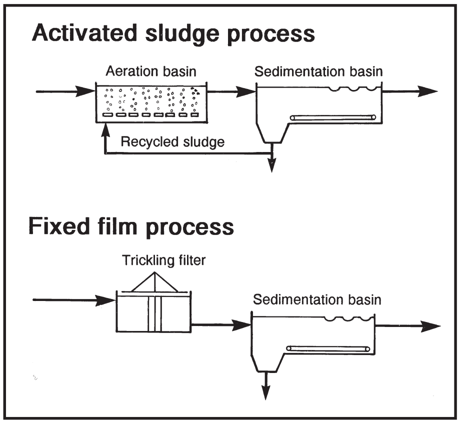
- Degradation of organic material to carbon dioxide or methane.
- Removal of nutrients (nitrogen and phosphorus).
- Coagulation of colloidal solids into flocs.
- Transfer of metal ions and microorganic pollutants from the water phase to the sludge.

Biological treatment is both an oxidation-reduction process and a separation process. If toxic substances are transferred into the sludge phase or stripped off to the gas phase, further treatment of these phases may be necessary.

Biological treatment processes can be classified in a number of ways such as aerobic (presence of oxygen) and anaerobic (absence of oxygen) processes, and on the basis of the type of reactor used for the biological processes. The activated sludge process and oxidation ponds are examples of suspended growth reactors in which microorganisms are maintained in suspension within the liquid. In fixed film reactors microorganisms are attached to some inert medium, such as rocks or especially designed ceramic or plastic materials. Examples of fixed film reactors are trickling filters, rotating discs and fluidised beds. Process schemes are shown in Figure 17.17 of the activated sludge process and trickling filters.

The activated sludge process. The activated sludge process was developed around 1914 for the removal of oxygen-consuming substances. Many modifications have been developed during the last few years, and today the process is an important alternative for nutrient removal. When removing the organic material part of the organic material is oxidized to carbon dioxide and water and part of the organic material is removed as an excess sludge, which must be further treated. The function of trickling filters and rotating disks is similar to the activated sludge process. Fixed film reactors are used for nitrogen removal but are at present not used for biological phosphorus removal. Both suspended growth and fixed film reactors are used for anaerobic treatment of organic wastes with a high concentration. The obtained methane gas may be used for energy production.

Figure 17.17. Biological treatment of wastewater. Top. Simplified diagram of the activated sludge process. **Bottom**. The fixed film process.



Chemical treatment. Chemical precipitation is a widely used process for the removal of for instance:

- Phosphates by the addition of iron salts and aluminium salts or lime.
- Metals by the addition of hydroxide, carbonate or sulphide.
- Colloids and colour.

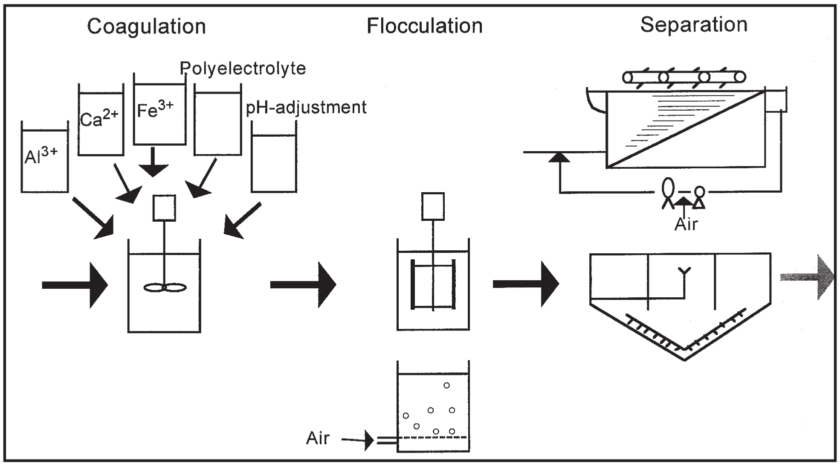


Figure 17.18. Chemical treatment of wastewater. The process includes coagulation, flocculation, and floc separation.

Wastewater treatment by chemical precipitation involves mixing, flocculation, separation and sludge handling (Figure 17.18).

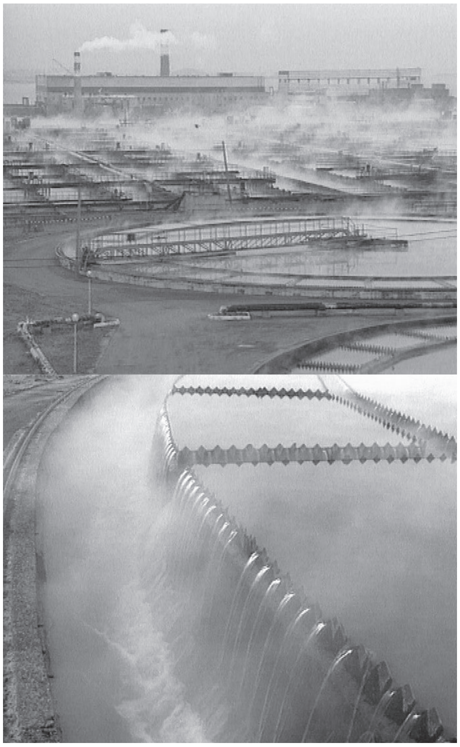
Another important technology in chemical treatment is the use of strong oxidizing agents (i.e. chlorine, ozone, permanganate, hydrogen peroxide, etc.), sometimes in combination with heat or radiation. The purpose might be disinfection, chemical oxidation of organic compounds to carbon dioxide and water or to smaller molecules that are biodegradable or easier to adsorb on activated carbon. This technology is of special interest in wastewater reuse and in destruction of organic micropollutants in industrial wastewaters.

Sludge handling

A variety of physical, chemical, and biological methods are applicable to sludge treatment. A flow sheet for sludge treatment is shown in Figure 17.20. The general purpose of sludge treatment is to reduce the sludge volume by thickening and dewatering and in some cases by drying or incineration. In order to facilitate dewatering, the sludge is conditioned by chemicals (normally polyelectrolytes). Conditioning may also be done by heat treatment or freezing although these methods are seldom used. The sludge can be stabilised by different methods:

- Biological stabilisation by use of anaerobic or aerobic digestion or composting.
- Chemical stabilisation by the addition of lime.
- Thermal stabilisation by use of heat drying, wet oxidation or incineration.

Figure 17.19. Treatment of wastewater. Top Biological treatment in activated sludge process (aerated tanks in background) with separation in sedimentation tanks. Bottom Effluent from sedimentation tanks. (Photo: from video Uldis Cekulis.)



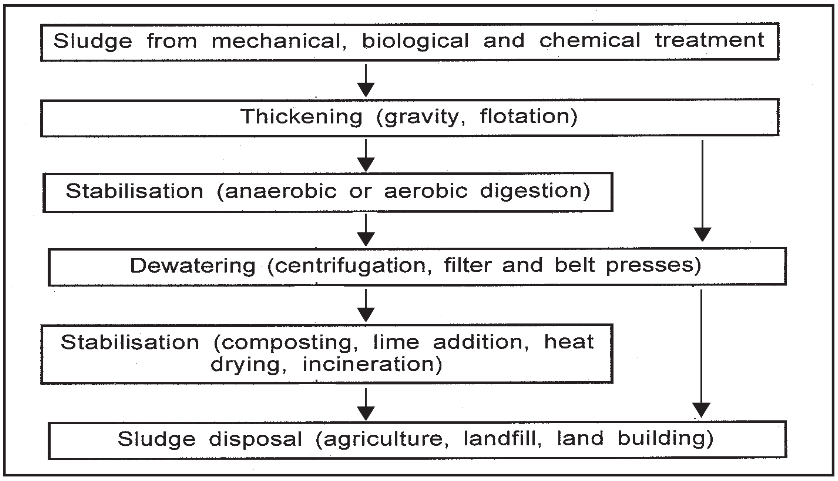


Figure 17.20. Sludge methods. Handling of the sludge produced in wastewater treatment.

Figure 17.21. Sludge deposition. Sludge was traditionally deposited on landfills, which is a waste of the nutrients in the sludge. Sludge landfilling, as here, will be restricted by law in future EU directives. (Photo: Lars Rydén.)

The purpose of stabilisation is to obtain a sludge which will not change with time and with a reduced odour and pathogen content. In anaerobic digestion methane gas is produced. The methane is valuable as household gas or elsewhere in energy production. The compost might be added to soils to improve soil quality in gardens and in fields.

Final disposal for the sludge usually involves some form of land disposal such as spreading on land, lagooning and landfilling. Final disposal for the sludge is today a critical problem in many countries. An important resource in the sludge is nutrients which can be utilised through using sludge as fertiliser in agriculture. Agricultural use is regarded as the best alternative if the pollutants in the sludge do not exceed values set by regulations and guidelines. The policy is to regard sludge as a resource that should be recirculated. The use of sludge in agriculture has often, however, not been accepted from the food industry, certain interest organisations, and part of the public even if the sludge quality is better than the stringent requirements from the authorities. Many metals accumulate to high concentrations in the surface layer of soil treated with sewage sludge.

Source control of pollutants to the sewer net has a key role for the sludge quality. Swedish municipalities may introduce restrictions on what substances may be supplied to the sewer net, for example limiting values or prohibition of certain substances. These restrictions are valid both for connected industries and households. For instance, the metal content in sewage sludge has been decreasing due to less use of certain metals in society. Examples include a change to unleaded gasoline, a stop in use of mercury thermometers, and ban on cadmium in paints and in finishing.

Landfill of sludge will probably be restricted considerably in the future. In several countries (as Germany) only sludge with a low percentage content of organics will be allowed for land deposit. Land deposit of sludge can contribute to diffusive spread of e.g. phosphorus and metals due to leakage and emission of e.g. methane gas (a greenhouse gas), methylated metal compounds (such as methylated mercury) and odours. In order to reduce landfill deposit of sludge a fee must be paid in certain countries. The use of sludge for land building, restoration of land and use for covering of landfills may be limited in the future due to lack of land and possible negative environmental effects. Disposal of organic sludges and wastes on landfill will not be allowed in Sweden after year 2005.

Incineration has gained interest as a method for final handling of sewage sludge, but it is not a good solution. The investment and operational costs are rather high and they may simply be disallowed for environmental reasons. Therefore, attention

Table 17.6. Metals in sludge from Swedish municipal wastewater treatment plants. **Total amounts.** Values in tonnes. (Source: Statistics Sweden and SEPA. http://www.environ.se/dokument/teknik/teknik.htm.)

Metal	1987	1995	1998
Mercury	0.34	0.31	0.25
Cadmium	0.34	0.35	0.28
Nickel	4	4	4
Chromium	10	8	8
Lead	12	10	8
Copper	43	90	91
Zinc	108	125	124

Table 17.7. Use of sludge from municipal wastewater treatment plants in Sweden 1995 and 1998. (Source: Statistics Sweden, 1997, 1999 ; http://www.environ.se/dokument/teknik/teknik.ht.)

Use	1995	1998
Agriculture	30%	25%
Park areas	12%	9%
Temporary deposits	16%	5%
Landfill	39%	46%
Other	3%	13%
Information missing	1%	2%

has also been directed towards co-incineration in already existing incineration plants, such as plants for municipal solid wastes, for biofuels (wood, peat, etc.) or coal, or plants producing building materials at high temperatures (cement, brick, etc.). A recent development in sludge handling is to fractionate the sludge into different products for use as fertilizer, energy production or as building material.

Ecological methods

Two main types of wastewater treatment schemes have developed. The one more oriented towards technical methods has been dealt with above. But it is also possible to use so-called ecological methods. These include e.g. oxidation ponds, wetlands, and land treatment. Ecological methods imitate natural self-purification reactions in land and waters and require large areas. The methods have been used mostly for small treatment plants and are sensitive to climate conditions. It is also possible to combine technologically oriented methods with ecologically oriented methods as polishing steps.

Many ecologically oriented process schemes may be used. It is possible to pre-treat the wastewater in a septic tank. This is essentially a watertight tank that serves as a combined settling and skimming tank and as an unheated, unmixed anaerobic digester. This is followed by treatment in a wetland system (Figure 17.22). Instead of wetland treatment, infiltration may be used.

Treatment in oxidation ponds rely on the natural processes of biological purification that would occur in any natural water body. In general there are three types of ponds: anaerobic, facultative, and maturation ponds, each of which has different functions. These are normally arranged in a series with an anaerobic pond preceding a facultative pond, which feeds into one or more maturation ponds. In cold climates the addition of precipitation chemicals will significantly improve the treatment results.

Land treatment of wastewater involves the use of plants and the soil surface and matrix. Different applications are irrigation (e.g. of energy forests), rapid infiltration, infiltration of septic tank effluents, overland flow, and land application of sludge. Land treatment of wastewater has been practised for centuries, but its full potential has only recently been recognised.

Wetlands are ecosystems with characteristics both of terrestrial and aquatic systems. The water table is usually at or near the surface of the land which thus is covered by shallow water. Examples of natural wetlands are freshwater marshes and peatlands. Engineered wetlands used as wastewater treatment systems include artificial marshes, ponds, and trenches. Wetlands are effective for wastewater treatment for several reasons:

- Bacteria attached to submersed roots and stems of aquatic plants.
- Sedimentation in quiescent water.
- Adsorption and filtration by roots and stems of the aquatic plants.
- Ion exchange and adsorption by wetland sediments.

Research activities have recently increased significantly on the application of ecological engineering methods for wastewater treatment. The aim of ecological engineering is not only to solve pollution problems but also to produce resources from wastewater. Studies include design and development of ponds, wetlands and farms. Indoor greenhouse applications for wastewater treatment have been built in both Sweden (Stensund) and in the United States.

The wastewater treatment at Stensund Folk College was until 2000 based on aquaculture and was used for the demonstration, research, and development of recycling through natural processes using constructed food webs. The project aimed at detoxification and recycling of wastewater resources, including nutrients for aquacultural production.

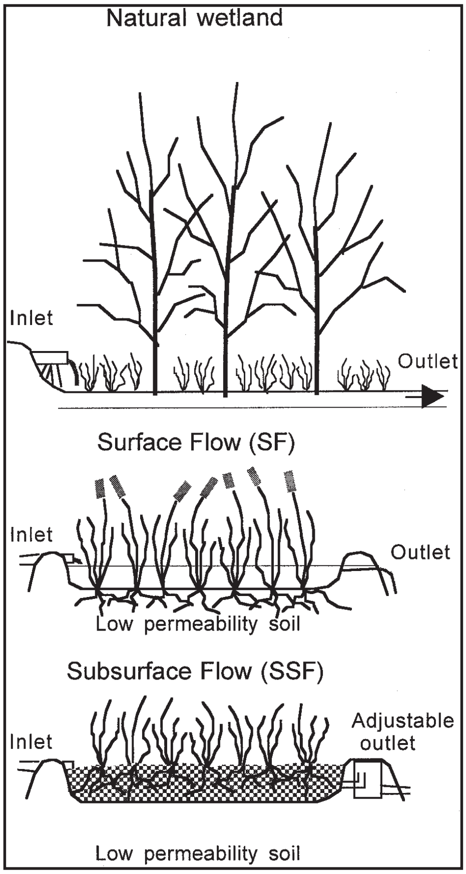


Figure 17.22. Wetlands for wastewater treatment. Different types of wetland use for wastewater. (After Kadiec and Knight, 1996.)

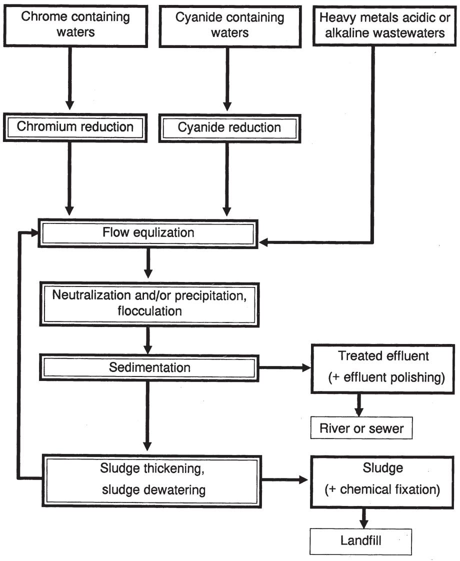


Figure 17.23. Industrial wastewater treatment. Block design for removal of metal pollutants in industrial wastewater, an example of special design wastewater treatment used in industry. Process water heavily polluted with metals, or other special chemical compounds are normally treated at the industry itself, before being channeled to the recipient or the muncipal wastewater treatment plant.

Methods

Box 17.3

Removal of nutrients from wastewater

Source of wastewater nutrients

The major nutrient inputs to receiving waters come from runoff from agricultural land, from domestic and industrial wastewater and from atmospheric deposition. The reduction of runoff from agricultural land and of atmospheric deposition is a complex problem involving source control of emissions to air (energy industry, traffic, agriculture, etc.) and changes in energy production technology and agricultural practice. Nutrient control has the purpose of reducing eutrophication of natural lakes and impoundments and of preventing marine eutrophication. Most research and development has been focused on phosphorus and nitrogen removal at treatment plants.

In densely populated regions, the dominating phosphorus load on receiving waters originates from municipal wastewater. The dominating sources of phosphorus are excreta and detergents. In most countries the phosphate content of detergents is not regulated by official specifications, although many unofficial agreements exist between authorities and producers in many countries to keep the phosphate concentration below certain values. However, in some countries detergent phosphate bans have been issued, as in Switzerland for home laundry detergents. Several investigations indicate that detergent bans alone do not significantly improve the water quality except for certain cases where a high percentage of the phosphorus entering a receiving water is derived from municipal wastewater and a substantial fraction of the phosphorus is derived from detergents.

Phosphorus removal

Phosphorus removal is based on biological, chemical and physical methods and combinations thereof:

- Biological methods may employ microorganisms, macrophytes and plants to remove phosphorus through synthesis, metabolic processes and adsorption incorporating the phosphorus into biological solids.
- Chemical methods utilise precipitation, coagulation, and flocculation to incorporate phosphorus in a chemical sludge (Figure 17.18).
- Physical methods remove phosphorus from wastewater through adsorption, sedimentation, flotation and filtration.

As most of the phosphorus in wastewater is soluble, an efficient method to remove phosphorus is to precipitate the phosphorus by chemical precipitation agents and to remove the precipitate from the wastewater by some separation method. Important factors to consider are choice of precipitation chemicals (iron salts, aluminium salts, and lime), initial mixing conditions, surface charge of precipitated particles (can be controlled by the pH value) and separation methods (sedimentation, flotation, and deep-bed filters).

Process configurations with chemical precipitation may be with or without biological treatment. The main process schemes are:

- Direct precipitation, involving no biological treatment.
- Pre-precipitation, in which chemicals are added before the biological step.
- Simultaneous precipitation, in which chemicals are added directly to the biological step.
- Post-precipitation, in which chemicals are added after the biological step.

Direct precipitation is widely used in Norway with the largest facility treating wastewater from Oslo. Pre-precipitation with alum and iron salts can often be applied with minor alterations of existing biological treatment plants with primary sedimentation. Simultaneous precipitation is applicable at most existing activated sludge treatment plants. Post-precipitation is a widely applied treatment process in Sweden.

Chemical precipitation plants for phosphorus removal have now been in operation more than 20 years and practical experience has given rise to several modifications, such as two-point chemical addition. Chemical precipitation can also be incorporated in simple treatment processes such as oxidation ponds.

Figure 17.24 shows a process scheme of biological phosphorus removal. Although enhanced biological phosphorus removal is applied at many full scale plants (it has been installed in Riga, for instance), it is still a developing technology.

Removal of phosphorus may also be obtained by removal processes utilising algae or higher plants. It is well known that oxidation ponds, during warmer seasons, can produce low effluent phosphorus values, but several problems remain to be solved. These include algae in the effluent, low removals in wintertime in northern areas, and difficulties to control if the phosphorus removal is efficient. Recently the interest for the use of artificial wetlands with plants for nutrient removal has increased considerably.

The use of treated wastewater for irrigation of farmland is common in many countries. Crop uptake and sorption to the soil retains the phosphorus, and the drainage water generally has low phosphorus concentration. Disadvantages are the seasonal variations of water and the nutrient requirements of the crops.

Nitrogen removal

Control of nitrogen-related environmental problems is difficult due to the diffuse nature of many of the sources. The current upward trend in quantity of nitrate in many water bodies used for potable water and of nitrate in marine areas shows that suitable methods must be developed for nitrogen control. The several methods available for nitrogen removal at treatment plants include:

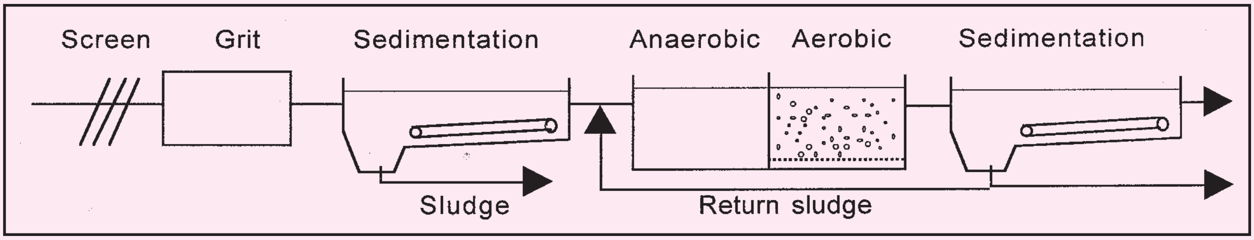


Figure 17.24. Biological phosphorus removal uses the same plant configuration as in the activated sludge method.

Removal of nutrients from wastewater

Methods
Box 17.3

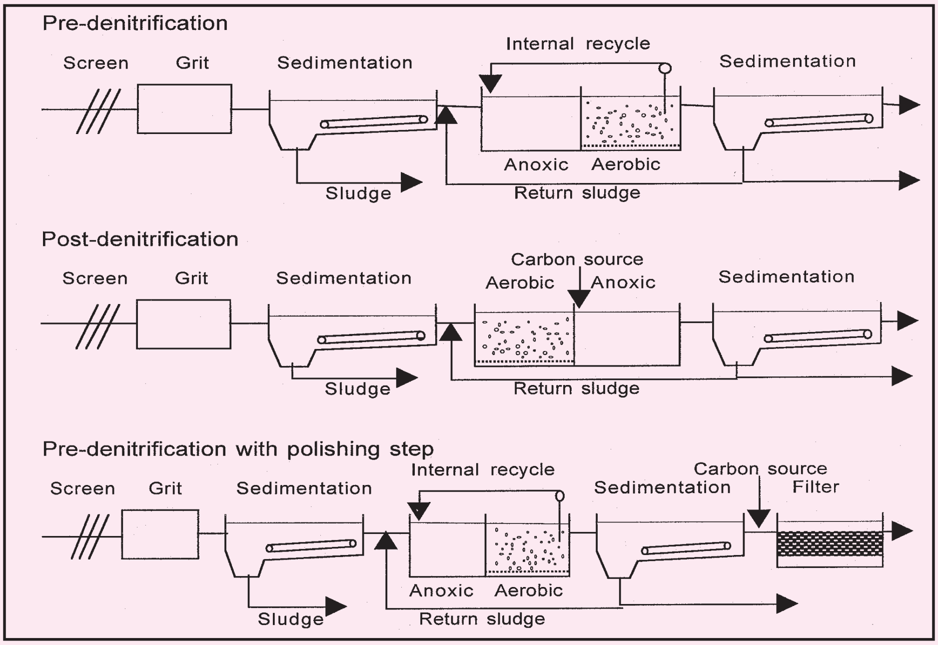


Figure 17.25. Nitrogen removal. The plant configuration allows nitrification and denitrification.

- Assimilation of nitrogen by microorganisms (bacteria, algae, etc.) and plants.
- Biological reduction (denitrification) (Figure 17.25).
- Chemical reduction of nitrate and nitrite or chemical oxidation of ammonium to nitrogen gas.
- Ammonia stripping (air or steam).
- Selective ion exchange.
- Precipitation of magnesium ammonium phosphate.
- Electrodialysis and reverse osmosis (non-specific methods).

Biological processes generally provide the most economical means for controlling nitrogen in wastewater effluents except for special wastewaters with toxic substances or high nitrogen concentrations. Biological nitrogen removal utilises reactions also occurring in biological nitrogen cycles in nature.

Nitrogen may also be removed in land and wetland treatment systems. Mechanisms involve both assimilation of nitrogen in, for instance plants, and bacterial reactions with nitrification-denitrification.

Combined methods for decreasing eutrophication

In order to decrease eutrophication problems e.g. in the Baltic Sea, it is necessary to remove both phosphorus and nitrogen from wastewater. The methods described for phosphorus and nitrogen removal, respectively, can easily be combined. The main combined treatment systems are:

- Combination of nitrogen removal by nitrification-denitrification and chemical precipitation.
- Combination of biological phosphorus removal and nitrogen removal by nitrification-denitrification. The treatment system can be a modified activated sludge process with one zone without nitrate and oxygen (for inducing phosphorus removal mechanisms), one zone without oxygen (for denitrification), and one zone with oxygen (for nitrification) (Figure 17.26).
- The use of land or wetland treatment systems.

A whole spectrum of process configurations is possible and an important task is to optimize design and operation of nutrient removal for a specific application (plant size, plant location, wastewater characteristics, etc.).

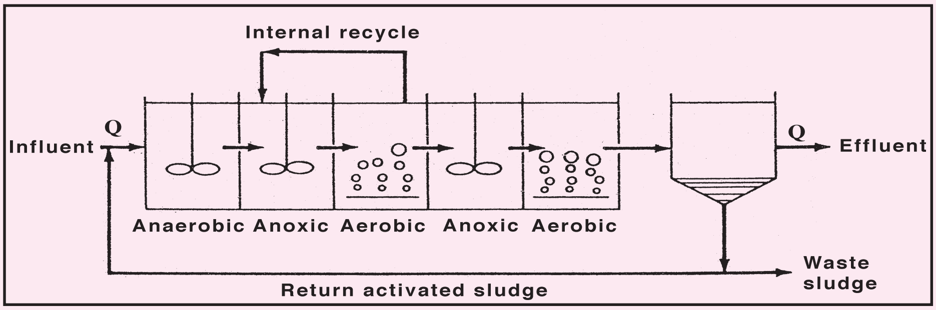


Figure 17.26. Combined nitrogen and phosphorus removal. The so-called Bardenpho process. (After Lindsley et al., 1992.)

Methods

Box 17.4

Removal of pollutants from industrial wastewater

Variety of industrial wastewater

The diversity of modern industry and of industrial processes makes rigid classification of wastewater according to composition virtually impossible. Most industries process or manufacture a variety of products, each giving a specific wastewater composition. Industrial wastewater discharges thus differ substantially both in origin and characteristics. But the complexity is even greater. Waste streams that have similarities to different industrial wastewater include leakages from deposits, runoffs from airports, wastewater from agriculture, and many others.

The largest volumes are those of cooling waters. These are often not at all polluted, except for thermal pollution, of course, and do not pose a serious environmental problem. The storm runoff waters are collected from the industrial area after rainfalls. These waters might be contaminated by all kinds of spills in the industrial process, such as oil products. The process water is used in the industrial process itself. In some processes, such as pulp and paper production, the amounts of water used are often very large and the water becomes heavily polluted. When emitted directly to a recipient they constitute a serious pollution problem. Today in many plants process water is recirculated, saving both the environment and costs in the industrial process. Process water from the food industry and perhaps hospitals constitutes a sanitary problem and makes the receiving waters unusable for recreational purposes. Sanitary wastewater is the water from toilets, kitchens, etc., and is always produced from a large working place. Finally boiler water is used in the production of steam and electricity. Chemicals added to the boilers, as well as constituents removed from the raw water, add to this wastewater flow.

Six types of industries

Industries may be classified in many ways, but the following six groups highlight the variation of wastewater problems connected to industrial processes.

1) The chemical manufacturing industries emit e.g. oil products.
2) For the food, beverage and pharmaceutical industries the organic content in the wastewater is a major problem.
3) The apparel industries, e.g. the production of textile and leather goods, emit large amounts of both toxic inorganic chemicals and oxygen-consuming organic chemicals.
4) The material industries include e.g. the pulp and paper industry, the steel industry, the metal plating industry, the iron-foundry industry, the rubber industry, and the glass industry. These produce in several cases large amounts of toxic chemicals, heavy metals, and organic pollutants.
5) The energy and power-related industries, e.g. processing of coal and oils, the steam power industry, and nuclear power plants use large amounts of cooling water. The handling of radioactive material illustrates how a pollutant might be extremely strictly regulated, and kept under control.
6) The service industries, e.g. laundry trades and the photographic processing industry, again use large amounts of sometimes toxic chemicals.

Separation of different wastewater streams is a necessary prerequisite for the efficient handling and treatment of industrial wastewater.

Production technology

For the management of industrial wastewater, the focus should not only be directed towards the wastewater treatment methods. Equally or even more important are e.g. changes in production technology, suitable choice of raw materials, recirculation of water and separation of wastewater streams before the wastewater is treated.

In the future wastewater management should give more attention to possibilities of closing the lifecycle of products from design, via production to final consumption and disposal. This should be effected in such a way as to ensure that it results in little or no pollution. These methods are commonly known as clean technologies and may include:

- The development of new production processes and the improvement of existing ones.
- The development of new wastewater treatment methods.
- The efficient management, handling and reuse of raw materials and energy.

Waste minimization techniques are often used synonymously with clean technologies.

Advanced wastewater treatment

Several methods are available to remove heavy metals produced in for example metal finishing industries from wastewater streams. These include chemical precipitation, ion exchange, electrodialysis, and reverse osmosis. Sometimes metals are chemically transformed, by reduction or oxidation, in order to facilitate further treatment. An example of treatment of a metal-containing industrial wastewater is the case of metal finishing (see figure 17.23).

The treated effluent may be supplied to a sewer or river or be recycled. The obtained sludge may be specially treated by chemical fixation to diminish the mobility of metals before final disposal in specially designed landfills. Possibilities for recovery of the metals should first be evaluated.

Micropollutants, often called specific pollutants or refractory pollutants, include a number of organic compounds and inorganic substances such as heavy metals. Increased awareness of micropollutants is a result of better knowledge of the toxic and carcinogenic properties of certain pollutants, even in very low concentrations, and improved analytical methods for the identification of the pollutants.

A major problem in the development of suitable treatment technologies for organic micropollutants is the large number of compounds to be considered and the virtually infinite combination of these compounds which may be found in any given wastewater stream.

Advanced wastewater treatment has shown some limitations. In general only some components are significantly degraded, detoxified or destroyed in wastewater treatment plants, such as biodegradable organic material and pathogens. Most substances are concentrated in the treatment plants (such as phosphorus, metals and organic micro-pollutants) and removed by the sludge. Careful consideration must be given to further sludge handling and disposal. Possible discharges of pollutants into the air must also be considered.

IMPLEMENTATION OF WATER AND WASTEWATER HANDLING PRACTICES

Latvia

The present improvement of water supply and sewerage facilities in Latvia commenced in 1990 with the identification of hot spots through HELCOM. From this starting point, the water supply, sewerage systems and treatment plants in the three largest cities Riga, Liepaja, and Daugavpils, in particular Riga, have been very much enlarged.

During the 1990s improvements in water systems were very high priority in Latvia. In the early part of the period some 90% of all environmental investments went to this sector, especially treatment plants. It seems typical that improved water and sanitation is a first priority when a country has the possibility to invest in improvements in the environment and also that the inhabitants are willing to pay for such investments even if the economy of the country is weak.

For small and medium sized towns, with a population from 2,000 to 75,000, the Ministry of Environmental Protection and Regional Development set up a strategy called "800 Plus," for identifying the priorities for financial and technical assistance, i.e. activities that are equitable and also optimise the use of available funds to achieve the most environmental improvement for the least cost. A series of priorities were derived for the improvement of sewerage facilities. Public health consideration is top priority followed by improvements where ecologically important areas are at risk from pollution. The next priority is rivers that do not meet their designated quality objectives.

To develop the priorities for improvements data was collected on the receiving water quality and the condition of the sewerage infrastructure. The river water quality data indicated that Latvian rivers are not significantly polluted by organic pollutants. The main reason is that many of the rivers are large compared to the pollution load and have great capacity for self purification. There are, however, local areas where pollution is a problem, especially where untreated or partially treated effluent is discharged to rivers and streams where the dilution is small. Toxic and inorganic pollution, i.e. heavy metals and nutrients (phosphorus and nitrogen) are a greater cause of concern. The highest concentrations of these pollutants were reported along the coast in the vicinity of estuaries and ports, particularly the Daugava and Lielupe estuaries where there are high concentrations of heavy metals in the sediments. Beaches have

Kaunas Water

Kaunas was one of the five priority hot spots in Lithuania; the raw sewage from the city was discharged directly to River Nemunas and further to the Kuronian Lagoon without treatment. Efforts to develop Kaunas Water into a cost effective and self reliant company started in 1991 in co-operation with Swedish partners financed by Sida. It included the construction of the wastewater treatment plant, renovation of the town sewer system, and introduction of a modern water supply system.

In 1995 Kaunas City signed a loan agreement with the European Bank for Reconstruction and Development, EBRD; the construction of the treatment plant started in 1996. In 1999 the plant had successfully installed mechanical and chemical treatment systems (Figure 17.27), while biological treatment has to wait for further financing.

The raw waste water has a Biological Oxygen Demand (BOD) of approximately 200 mg per litre. After treatment, this has decreased to 50-60 mg per litre, a reduction of 70 %; phosphorus decreased by 80 per cent, and nitrogen levels by 10 per cent. Biological treatment will be needed to achieve HELCOM's requirements for a discharge level below 15 mg BOD per litre.

In parallel, as the provision of drinking water was modernized, the water consumption decreased to 150 litres per person and day, from the previous 400-500.

The complete cost of the project up to now is 96 M USD, of which 51 went to the treament plant. Financiers (figures in M USD) were EBRD 14,9, NEFCO 3, EU-Phare 5,2, Sida 3,8, Finland 1,5, Lithuania 50. (Source: http://www.sida.se/Sida/.)

Figure 17.27. New wastewater treatment plant being built in Kaunas. Compare figure 17.10. (Source: http://www.sida.se/Sida/jsp/Crosslink.jsp?d=621&a=2896. Photo: Courtesy Sida.)

Figure 17.28. Nowy Targ wastewater treatment plant. The plant was constructed with Polish-Swedish co-operation (Swedish International Development Cooperation Agency, Sida) in 1995 and has been used by researchers from both countries studying and developing wastewater treatment technology. (Photo: Jozef Trela.)

also been closed due to a large number of coliform bacteria in the water. The sewerage infrastructure data was based on a database of 1,123 sewerage systems. Of these 159 provided only mechanical treatment and 805 secondary treatment. Of those with secondary treatment, 721 used the activated sludge method. However, effluent sampling shows that 268 of the activated sludge plants fail to achieve compliance with the existing BOD standards.

Poland

Poland has a significant share in the Baltic Sea pollution due the fact that Polish territory has more than half of the total population of the Baltic Sea drainage area, and 40% of agricultural land. The Wisła and Odra rivers, the main recipients of wastewater in Poland, empty in estuaries on the Baltic Sea coast. Table 17.8 shows the discharge of pollutants from the Polish rivers to the Baltic Sea. Before 1990 the wastewater treatment plants have usually been insufficient, hydraulically overloaded or in a poor technical state and many of them with only primary treatment. In the period 1990 to 2000 large sums of money were invested in wastewater treatment and the situation was dramatically improved.

Figure 17.29 shows the degree of purification of wastewater discharged into surface waters in 1990-2000. The amount of biologically treated wastewater increased from 27% to 61%. The largest increase of biologically treated wastewater from 37% to 77% has been in municipal wastewater from cities. The main part, about 63%, of industrial wastewater is only mechanically treated. In 2000, of about 2,500 million m^3 of municipal and industrial wastewater requiring treatment, almost 88% were treated before discharged into surface waters. However only 53% of the population was connected to wastewater treatment plants: 80% in urban areas and 11% in rural areas, where 38% of the population live. A dynamic growth, especially in construction of small- and medium-size municipal wastewater treatment plants with short investment cycles, took place. It caused only during the period 1996-

Table 17.8. Discharge of some pollutants into the Baltic Sea from Polish rivers in 1996. (Source: State Inspectorate for Environmental Protection, 1998.)

Pollutant	tonnes/year
BOD$_5$	225,887
COD	1,484,196
Total nitrogen	242,338
Nitrate nitrogen	107,656
Ammonium nitrogen	23,204
Total phosphorus	12,357

Table 17.9. Discharges of wastewater to Lithuanian rivers during the 1990s. The data reflects the trend of decreasing volumes and increasing wastewater treatment standards typical during the 1990s in the three Baltic States. (MPSS = Maximum Permissible Pollution Standards; md = missing data.) (Source: Cetkauskaite, Zarkov, and Stoskus, Ambio, Vol. 30, 297-305.)

Year	Total volume (mln m^3)	Untreated (mln m^3)	Treated (mln m^3)	Treated to MPSS (%)	Inadequately treated (%)	Untreated (%)
1990	446	122	324	22	57	22
1992	362	md	md	27	md	md
1994	336	68	268	25	55	20
1996	252	42	210	40	44	17
1998	217	34	183	54	30	16

2000 an increase of municipal wastewater treatment plants capacity from 7,175 tousand m^3/day to 9,281 thousand m^3/day (Figure 17.30) and the increase of the number of plants built in Poland from 1,471 to 2,417 (Figure 17.31). At present, almost 40% of municipal wastewater is treated with the use of high-effective technologies, mainly with activated sludge in multistage biological reactors, with integrated removal of carbon, nitrogen and phosphorus. There are also a number of plants under construction in large cities.

The rapid development in construction of wastewater treatment plants was possible as Poland after the system change used a large share (51% in 2000) of its environmental investments for wastewater management and protection of waters. In general the share of investments that went to environmental protection in the national economy during the last 10 years was highest in 1996 with a total of 9.6% while in 2000 it had decreased to 4.9%.

Sweden

A combined biological and chemical treatment of municipal wastewater is normally prescribed in Sweden. In certain, relatively few, cases, only biological or only chemical treatment may be required. In localities with poor recipient conditions in relation to the discharge, complementary treatment (mainly post-filtration) is prescribed in addition to biological and chemical treatment. New requirements for discharge from the Swedish treatment plants vary depending on the size of the plant and its location.

The most commonly used treatment process is a combination of biological and chemical treatment with post-precipitation. This applies to more than 80% of the treatment plants with chemical precipitation. But some of the largest sewage works, for instance in the Stockholm region, use two point-precipitation with pre- and complementary post-precipitation. A complementary filter step will, however, be installed to increase the phosphorus removal efficiency.

Strategies for nitrogen removal in Sweden are mainly based on new operational modes in the existing plants or complementary re-building of the plants, to make full use of already made investments. The dominant process technology is single-sludge nitrification and denitrification.

More stringent rules for industrial discharges to sewers, regulations on use of chemicals by authorities, and campaigns to households to reduce the use of toxic products have shown a significant improvement of the municipal wastewater effluent quality with respect to pollutants like heavy metals. Several large industries in Sweden are not connected to municipal sewers, such as the pulp and paper, iron and steel, and mining industries. Discharges from these industries also contain toxic metals and organic micropollutants.

The utilisation of municipal sludge in agricultural land has been recognised as an environmentally acceptable and economical method of sludge disposal in Sweden. However, the Federation of Swedish Farmers recommended its members not to use the sludge after January 1, 1990 and therefore the sludge problem is at present a subject of great discussion. Today it is used in several local smaller plants but not in a large scale. A common method is to use the sludge as soil improvement for e.g. parks and soil for flowers and bushes.

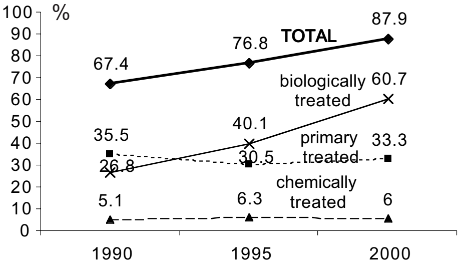


Figure 17.29. Degree of purification of wastewater discharge into waters 1990-2000 in Poland. (Source: Rocznik Statystyczny, 2001.)

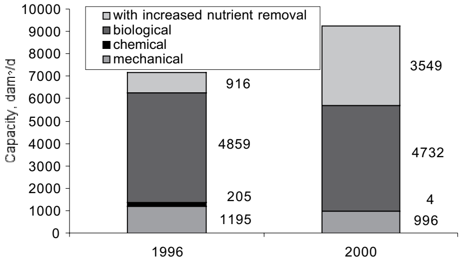


Figure 17.30. Municipal wastewater treatment plants capacity (in thousand m^3/day) in 1996 and 2000 in Poland. (Source: Rocznik Statystyczny, 2001.)

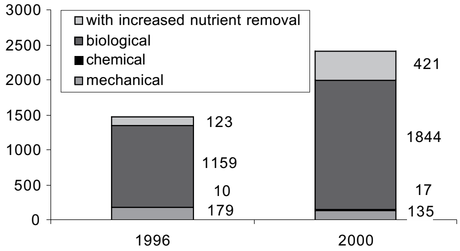


Figure 17.31. Number of wastewater treatment plants in 1996 and 2000 in Poland. (Source: Rocznik Statystyczny, 2001.)

NEW DEVELOPMENTS

Improvements in wastewater handling

The concepts of "clean technology" and "ecological engineering" today influence traditional wastewater management. Discharges of toxic substances into sewers will diminish with the application of clean technologies. This will facilitate the reuse of wastewater and the recycling of nutrients. Energy recovery in wastewater handling (use of heat pumps and digester gas) has been practised at many treatment plants, for instance in Sweden. In addition developments in physical, chemical and biological treatment methods will lead to more efficient wastewater treatment plants. The application of modern control engineering methods is another important tool for an increased process efficiency.

Future needs for improved wastewater handling has its roots in earlier practices:

Transportation of water to urban areas was the main reason for building sewers to transport wastewater from the consumers for a discharge to the recipient. This led to an infrastructure of water treatment plants, water pipes, sewers and wastewater treatment plants. Much attention must be directed in the future towards maintenance and improvement of this infrastructure.

Eutrophication has been recognised as a severe water-quality problem in lakes since the 1960s and in marine areas since the 1980s. Improvements in wastewater management strategies should be directed towards source control (substitution of phosphates in detergents), separation of wastewater streams in households (especially in local handling of wastewater), and recycling of nutrients. Possibilities of using ecological engineering concepts should be better evaluated.

Control of discharges of toxic substances like heavy metals and organic micropollutants should be directed towards changes in chemical use and production technology, water-saving methods, recycling of materials, and efficient internal treatment of process streams (clean technology). The contribution of toxic materials from households to sewers is significant, and different remedies must be considered (information campaigns, changes in consumer products, etc.). An efficient control of discharges of toxic substances into sewers is an important prerequisite for recycling of nutrients from sludge or wastewater from centralised wastewater systems.

Developments in wastewater handling cover the whole system. The many ways that are available for improvements are illustrated in Figure 17.33. The goal should be to implement these ideas to obtain sustainable water quality in receiving waters.

Figure 17.32. A local treament plant in Hågaby eco-village, outside Uppsala, Sweden, receives only urine from its inhabitants. The urine is treated to be used as a perfect fertiliser on the fields close-by in cooperation with the local farmer. The households in the village all have separating water toilets, and there is a separate sewage system for urine. The black water with feces goes to the ordinary treatement plant of the city. (Photo: André Maslennikov.)

Local and small-scale methods for water and toilet waste

A large share of the water supply and wastewater handling is local, that is for only one or a few households. The local systems typically consists of a well where ground water is extracted and an infiltration system where wastewater is returned to the soil. In some areas a septic tank is required where the toilet waste is collected. The tank is then once or twice a year emptied by a truck which takes the waste to the treatment plant. In the worst case the untreated wastewater is emptied in a neighbouring surface water stream.

These systems can be much improved and should be, especially if the system serves a neighbourhood with several hundred persons. There are several approaches all of them with the common goal to return the nutrients to farmland.

The use of so-called ecological methods for local treatment of wastewater has already been discussed. One example is the use of one or several ponds for the wastewater. These may be quite efficient, if the nutrients are recycled to fields.

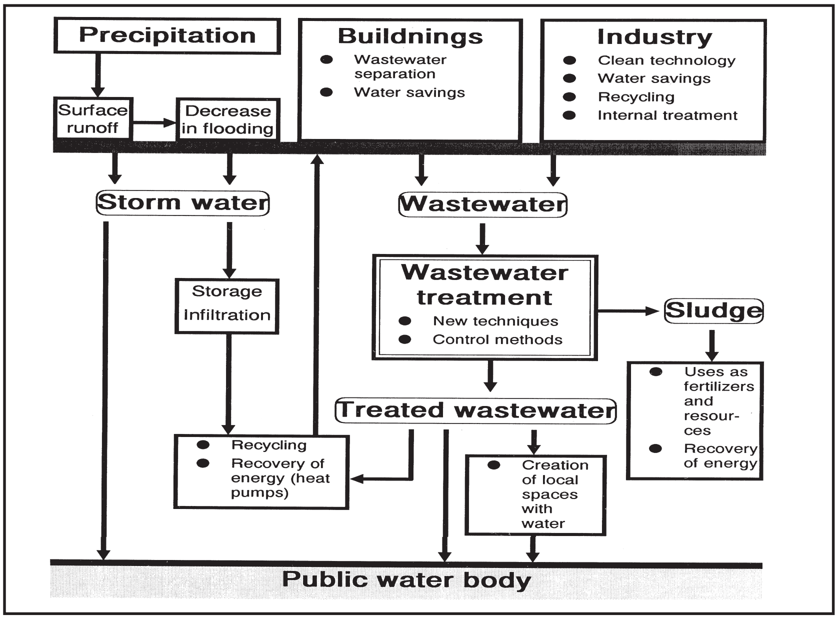


Figure 17.33. Ways to improve wastewater treatment. A series of different actions can be taken at several levels.

Waste sorting is applied when toilets are used that separate urine and faeces. The sewage system then needs to be separated for the two streams. Urine contains about 80% of the nitrogen and is a perfect and sterile nutrient with very good composition for farmland. What is needed is a tank to collect and store the urine over a period, especially when it can not be applied on farmland during winter. The faeces may either be sent to a conventional sewage system or treatment plant or treated locally. One local method is dry composting. It has successfully been used also in densely inhabited areas, and it is possible to carry out this method without producing a bad smell. If correctly built the only action required is to take out the compost in regular intervals, e.g. once a year. Separation of urine and faeces has been applied in e.g. small areas in suburbs outside Stockholm, with good results.

Integrated water management

Water resources are naturally discussed in the context of drainage areas. A drainage area, or a common river basin, is a source of water and it is also the area in which all activities related to the water influence each other and other interested parties. The parties are collectively called stakeholders. Conflicts of interest among stakeholders are natural. For example, when farming causes a decline in the quality of surface water through runoff from farmland and forces a downstream city to treat the water more extensively before it may be used in the city water supply. The costs involved for water preparation may be high, and a much cheaper option might to reduce the runoff from the farm. The example points to the potential of co-operation in a river basin. Other parties include those using a river for shipping, for fishing or those who are concerned with nature protection and tourism, in particular swimming and other beach activities, e.g. on a lake. Difficult questions arise in connection with hydropower plants that require large reservoirs, and strict regulation of a river.

Special challenges for an integrated water management approach include runoff from agricultural land which often is the major cause of eutrophication of surface water; runoff from landfills which often cause serious pollution of neighbouring water, which in the worst case might contaminate groundwater in areas where it is extracted for human consumption; and runoff from older industrial and also military areas where soil is so seriously polluted that it may contaminate ground or surface water.

Figure 17.34. A urine separating toilet. In this kind of toilet urine is collected separately, and used after storage as fertiliser in agriculture. The urine contains most of the nitrogen and is sterile. (Photo: Per G. Berg.)

There are many examples of co-operation between several activities in a drainage basin as well as serious conflicts. An example of a co-operation are the newly constructed wetlands outside a city to receive wastewater, sometimes only storm water. These have a potential to be very nice park areas with bike routes, and space for bird life as well as fishing, e.g. in Södertälje just south of Stockholm this is the case. An example of conflict is found in the Emån drainage basin in southern Sweden where a conflict between small-scale industry and nature protection interests arise, that seem less easy to resolve. In Danube at the Slovakian Hungarian border there is a now a classic conflict between shipping and nature protection interests as well as hydropower (Chapter 20). Shipping needs a constant and rather high water level while the special flora and fauna requires that annual floodings take place. The conflict was solved by building a canal alongside the natural river.

The European Union water directives request that river basin authorities be set up to manage all questions regarding water in a defined drainage basin. Such administrations have existed *de facto* in many countries although more based on co-operation than authority. The new authorities will as a first measure set up a management plan for the basin. The authorities will have to see that water quality norms are respected and determine which activity in the basin is most cost-efficient to improve in order to live up to the desired quality.

Many river basins are transnational. In these cases, trans-border water co-operation has to be created. An example where this is now done is for Daugava/Dvina which flows through Russia, Belarus, and Latvia. International river commissions have existed for a long time for many of the large international rivers, such as the Danube, Rhine, and more recently the Odra. This co-operation has especially been important in connection with the large floods that took place in both the Odra and Rhine at the end of the 1990s.

REVIEW QUESTIONS

1. Explain how the water available for human consumption is related to runoff from an area, and give approximate runoff data for the Baltic Sea region.
2. Give a short description of how the water issue in a global context, mentioning safe water, water availability, and water for agriculture.
3. Compare the natural water cycle and the water consumption cycle and explain the problems that arise with a too tight water consumption cycle.
4. Summarise the situation with regard to volume of water used in households, industry, and agriculture in the Baltic Sea region, focusing on present trends, and comparing the situation now and 20 years ago, and possible future goals regarding water consumption. Find out about the water consumption in a city in your area.
5. Give a short summary of the historic use of wastewater treatment in the Baltic Sea region including development since the early 1990s, and examine the situation in a city in your area.
6. Describe the basic steps used in a wastewater treatment plant.
7. Describe some of the ecological methods for wastewater treatment and how they may be used.
8. List some of the special difficulties with industrial wastewater and the ways to tackle them, including the cleaner production approach.
9. Describe the problem of sludge handling; list present methods of sludge removal and describe sustainable methods for sludge management; explain how sludge can be regarded rather as a resource than a waste.
10. Indicate what would be included in an integrated approach to water management, including the river basin management concept.

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The Groundwater Foundation
http://www.groundwater.org/

SIWI - Stockholm International Water Institute
http://www.siwi.org/menu/menu.html

tate Inspectorate of Environmental Protection (Poland)
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SwedEnviro
http://www.swedenviro.com

The Swedish Environmental Technology Network
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Water Environment Federation
http://www.wef.org

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http://worldwater.net/

WWAP - World Water Assessment Programme
http://www.unesco.org/water/wwap/index.shtml

GLOSSARY

activated sludge process
treatment process in oxidation ponds in which microorganisms are maintained in suspension within the liquid; the activated sludge process was developed around 1914 for the removal of oxygen-consuming substances

aerobic treatment
a biological treatment processes in the presence of oxygen, such as the activated sludge process

anaerobic treatment
a biological treatment processes in the absence of oxygen; anaerobic treatment of organic wastes may be used to obtain methane gas for energy production

artificial infiltration
surface water treated through passage through the ground, e.g. in an esker, by pumping it into the ground at one place and extracting it several kilometres away

biological treatment
the step in wastewater treatment to remove organic substances by the activity of micro-organisms; by modification of the biological treatment processes it is possible to obtain removal of nitrogen and/or phosphorus; biological treatment is often called secondary treatment

black water
wastewater arising from toilet water; it is more polluted and of a comparatively smaller volume than grey water

boiler water
water used in the production of steam and electricity; chemicals added to the boilers, as well as constituents removed from the raw water, add to this wastewater flow

chemical treatment
a treatment process with oxidation of pollutants or in which chemical precipitation is used for the removal of for instance phosphates by the addition of iron salts and aluminium salts or lime, and metals by the addition of hydroxide or carbonate of sulphide

clean technology, cleaner production, CP
changes in use of chemicals, production technology, re-circulation schemes, etc., that reduces the volume of wastewater from an industry as well as its degree of pollution

cloacae
sewers in old Rome to carry off the sewage and rainwater together and emptied directly into the river, Tiber, thus polluting its waters, which were used not only for bathing but also for drinking purposes

complementary treatment
a step in wastewater treatment using a chemical precipitation step or a filtration step; other complementary treatment methods could for instance be activated carbon, ion exchange, reverse osmosis and the use of wetland or land treatment; complementary treatment is often called polishing or tertiary treatment

cooling water
the largest volume of wastewater from industries, often not at all polluted except for thermal pollution; it does not pose a serious environmental problem

dilution method
transport of untreated or only partially treated wastewater to a large recipient where, it is assumed, it would be made safe through the self-purification and the assimilatory capacity of the recipient

GLOSSARY

ecological method
a treatment process using oxidation ponds, wetlands, and land treatment; ecological methods imitate natural self-purification reactions in land and water and require large areas

evapotranspiration
loss of water through evaporation from plants

grey water
wastewater arising from laundry, kitchen, personal hygiene, etc.

ground water
water in the ground; it constitutes about 99% of fresh water on Earth

industrial wastewater
wastewater arising from industries, which may be toxic or may accumulate in the sludge at the treatment plant; pre-treatment of the industrial wastewater is therefore often necessary

irrigation
to add water to growing crops; the largest use of water world-wide, accounting for about 70% of the total volume

natural water cycle
the cycle where water evaporates from the surface of the Earth to the atmosphere where it forms clouds and returns to the land surface as precipitation; on land the water passes through ground water, smaller streams, larger rivers to lakes, and finally to the sea

nutrient removal
advanced wastewater treatment methods to remove nutrients, nitrogen and phosphorus

physical treatment
the step in wastewater treatment using sedimentation for the removal of suspended solids; the treatment efficiency may be improved by the addition of precipitation chemicals; physical treatment is often called mechanical or primary treatment

potable water
water used for drinking

pre-treatment
the step in wastewater treatment in order to remove coarse particles and sand

process water
water used in the industrial process itself; in some processes, such as traditional pulp and paper production, the amounts of water used are often very large and the water becomes heavily polluted; today in many plants process water is re-circulated, saving both pollution of the environment and costs in the industrial process

raw water
water that enters a water works

recipient
water body in which the wastewater, treated or not treated, is emptied

runoff
the difference between precipitation and loss of water through evaporation from plants and from ground; runoff is the fresh water available for consumption

safe water
water without bacteria and toxic substances and other pollutants; lack of safe drinking water is a major cause of health problems in the developing world, causing about 30% child mortality

sanitary wastewater
water from toilets, kitchens, etc.

self-purification
the capacity of a recipient for assimilating wastewater

sewage (also sewerage)
wastewater, especially toilet wastewater

sewers
originally a system of pipes or channels with the purpose of removing rainfall without causing inconvenience or flooding, later to remove wastewater; today pipes to remove wastewater

sludge
the thick residue from primary, secondary and tertiary processes consisting of particles suspended in the water

sludge handling
a treatment process to reduce the sludge volume by thickening and dewatering and in some cases by drying or incineration and to stabilise to sludge to avoid odor problems and for hygienisation

storm runoff water, or storm water
water collected from an industrial or urban area after rainfall; this water may be contaminated by all kinds of spills in the industrial process, such as oil products

storm water
surface water collected in an area after rain or snow, discharged to one system of sewers which lead to the wastewater treatment plant or point of outfall

submarine outfalls
transporting of untreated or only partially treated wastewater into a marine area, such as the Baltic Sea, often one or a few kilometres outside the coast

surface water
water in lakes, rivers and streams

water consumption cycle
the cycle in which people retract water from groundwater (wells and springs) and surface water (rivers and lakes), treat it in water works, transport it to consumers (population, industries, general purposes, etc.), collect it as wastewater, sometimes pass it through a wastewater treatment plant, and discharge it to the recipient, i.e. a river or a lake

water works
an installation where raw water is collected and often treated, e.g. by chlorination or ozonation, before it is sent to the consumer

wastewater
water after usage, that is usually more or less polluted, from an urban area, industry, etc.

wastewater treatment plants
sewage purification plants