UZWATER

Municipal Water Use

DRAFT VERSION

Editor:

Viktoras Račys

Kaunas University of Technology

Production by The Baltic University Programme, Uppsala University, 2015
Layout: Magnus Lehman
Cover Photo: P. Juuti.

UZWATER

Municipal Water Use

Editor:
Viktoras Račys
Kaunas University of Technology

Co-funded by the
Tempus Programme
of the European Union

This compendium is produced for the master level course in the UZWATER project. It consists of some newly written material as well as previously published texts extracted from freely available books, reports and textbooks on the Internet, dominated by publications from the Baltic University Programme. The sources used for each chapter is listed at the end of the book.

Contents

Contents

1

Municipalities and Water Use

Chapter 1.
Water Use and Sanitation through the Ages

Introduction

It is well known that the relationship between humans and water and sanitation has seen substantial changes, due to the influence throughout the ages by cultural, social and religious factors. The realization of the importance of pure water for people is evident already from the myths of ancient cultures. Religious cleanliness and water were important in various ancient cults. Ideas of the celebrity of water were connected to the general "scientific" level of the society. The first known Greek philosophical thinkers and medical writers also recognized the importance of water for the public health.

In the early 20th century the health problems associated with water pollution seemed to have been resolved in the industrialized countries when chlorination and other water treatment techniques were developed and widely taken into use. Microbiological problems related to water were largely considered a problem of the developing world. However, in the late 20th century the biological hazards transmitted by water emerged again in the post-modern Western world. Anxiety about chemical and radioactive environmental hazards and their impacts on human health mounted in the 1960s. The overall amount of known biological and chemical health hazards transmitted by water and supply systems increased during the last years.

In development world, (mostly in African, Asian and South American countries) even in today's, around 10 000 people die every day due to diseases like dysentery, cholera, and various diarrheal diseases, caused by a lack of safe water and adequate sanitation. Yet, since most of those who die are children and old people, whose death is considered "natural", or people who are more or less marginalized in their societies (e.g. refugees, the poor) or living outside areas that are important for the global economy, mortality due to these waterborne diseases is too often considered unavoidable.

UNESCO IHP discusses the world's water-related goals in the post-2015 Sustainable Development Goals proposed by the UN. The following goals were proposed with regard to water: to reduce water pollution from main sources by

30% at the national level by increasing urban waste water collection and purification to at least 80%; to increase industrial waste water purification to at least 95%; to reduce diffuse pollution by 30% and undertake actions aimed at limiting pollution at its source by 2030 (UNESCO 2014). Urban water-related issues are given such high priority due to the fact that over half of the world's population lives in urbanized areas and the rate of urbanization has never been so fast. Cities are the main water polluters. On the other hand, the quality of life in the city is determined to a large degree by water and greenery, the most important elements of ecohydrological water management that help improve the condition of the natural environment and the ecological safety of city dwellers.[1]

1.1 The First Urbanization: Earliest civilizations, Ancient Greece and Rome

The first urbanization in Europe occurred during antiquity (500 B.C. – 500 A.D.) around the Mediterranean region. The share of urban population reached some 10–20 % in the centuries around the birth of Christ. The most urbanized areas were the Eastern Mediterranean, Egypt, North Africa (modern Tunisia), the Apennine Peninsula (modern Italy), and the southern part of the Iberian Peninsula, most of which were areas of quite modest rainfall. Evolution of sanitation is shown in figure 1.1.

Alcmaeon of Croton (470 B.C.) was the first Greek doctor to state that the quality of water may influence the health of people. Various other Hippocratic treatises (mostly written around 400 B.C.) contain short comments on the influence of water on the health of people According to B.C. Vitruvius from the late first century marshy areas must be avoided when the site of a city is chosen. Pliny the Elder in the first century A.D. had in his works a long section concerning the different opinions on what kind of water is the best. One of the most famous doctors during antiquity Galen (2nd century A.D.) summarizes the preferable qualities of water the quality of the water was examined by the senses: taste, smell, appearance and temperature. Also the health of the people and animals using a water source was considered. (Juuti 2007)

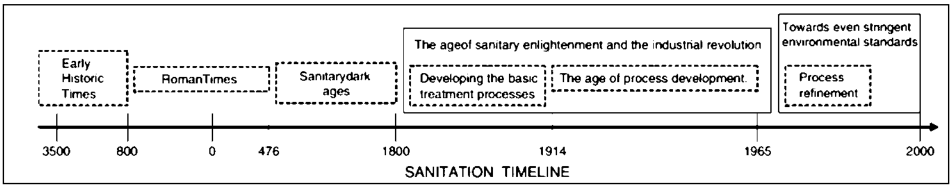


Figure 1.1 Evolution of sanitation. (Adapted from Lofrano G.,Brown J. 2010).

Throughout antiquity tasty or tasteless, cool, odorless and colorless water was considered the best, and stagnant, marshy water was avoided. These ideas were held until the end of antiquity. The ancient authors have thus made some comments about the influence of different kinds of water on the health of people, but had these comments any influence on the health of people is hard to infer. It is, however, quite safe to conclude that despite the impressive measures used to obtain pure potable water, urban centers had serious public health problems. Throughout most of human history the primary means of acquiring untainted water was to avoid the problem and bring in water from an outside source that did not require treatment.

The Greeks and Romans used different methods to improve the quality of the water if it did not satisfy their quality requirements. From written sources and archaeological excavations, we know that using settling tanks, sieves, filters and the boiling of water were methods used during antiquity. At least boiling of water, which was widely recommended by the medical authors during antiquity, would have diminished the biological risks of poor quality water. Although the boiling of water might have been feasible from a hygienic point of view, it was ecologically and economically not feasible in extensive use since firewood and other combustibles would sooner or later have become a scarce resource around the Mediterranean. (P.Juuti et al 2007)

The poor level of waste management, including wastewater, most probably involved a major risk for public health during antiquity. For instance, toilet hygiene must have been quite poor. The abundance of water that was conducted to the bath could also be used to flush a public toilet. The Romans, however, lacked our toilet paper. They probably commonly used sponges or moss or something similar, which was moistened in the conduit in front of the seat and then used to rinse their bottoms. In public toilets facilities were common to all; they were cramped, without any privacy, and had no decent way to wash one's hands. The private toilets most likely usually lacked running water and they were commonly located near the kitchens. All this created an excellent opportunity for the spreading of intestinal pathogens.

Summer and early autumn, when water resources were meager in the Mediterranean world, must have been a time when drinking water was easily contaminated, and intestinal diseases were rife as presented in several passages in the Hippocratic writings. The mortality of children, especially recently weaned, must also have been high.

Furthermore, it should be kept in mind that the celebrity of the water supply must have differed markedly in accordance with the social status of people in the

Roman towns. The rich had running water in their homes; the poor had to fetch their water from public fountains. The rich had their own baths and toilets, while the poor had to use public toilets and baths. All this must have lead to different health conditions and levels among rich and poor people.

A lot of the water in a Roman town was consumed in bath(s) connected to the aqueduct(s) (Figure 1.2a, b). Ideally shining marble walls and limpid water were considered a feature of a bath in Rome, the cleanliness of which was watched over by a ideals. Baths were probably also beneficial for public health in towns where there was an abundance and rapid turnover of water. However, in towns where water was in short supply, cisterns had to be used and the turnover of water was slow, the role of baths was probably negative for public health.

Water supply and sanitation for military needs was a primary concern of the authorities of an imperial power like the Roman Empire needing a strong military machine. The Romans did know how to obtain adequate amounts of drinking water for their garrisons, cities and troops in the field and thus successfully planned their operations according to the availability of water. Army veterans were well accustomed to baths and to an ample water supply during their active service, and they may have been a quite important pressure group for building an aqueduct and bath in a town.

1.2 The Second Urbanizations: Period of Slow Development

After the fall of the Roman Empire, water supply and sewage systems experienced fundamental changes in Europe. Medieval cities, castles and monasteries had their own wells, fountains or cisterns. Usually towns built a few modest latrines for the inhabitants, but these were mostly inadequate for the size of the population. The lack of proper sanitation increased the effects of epidemics in medieval towns in Europe.

Fundamental changes began to appear: science and knowledge were institutionalized for the first time when the development of modern universities started in the 13th century, and the agricultural world set out to industrialize from the 18th century onwards. The impressive facilities built for the conveyance of water that would have celebrated the Romans for centuries were neglected; the great baths were plundered of all their possessions. In an unprecedented historical regression, water came to be drawn from rivers and wells and to be discharged without treatment resulting in the spread of disease. It is hard to believe that at the end of the nineteenth century, only half of the Italian communes were equipped with pipes for drinking water and more than 77% had no sewers when considering the palace

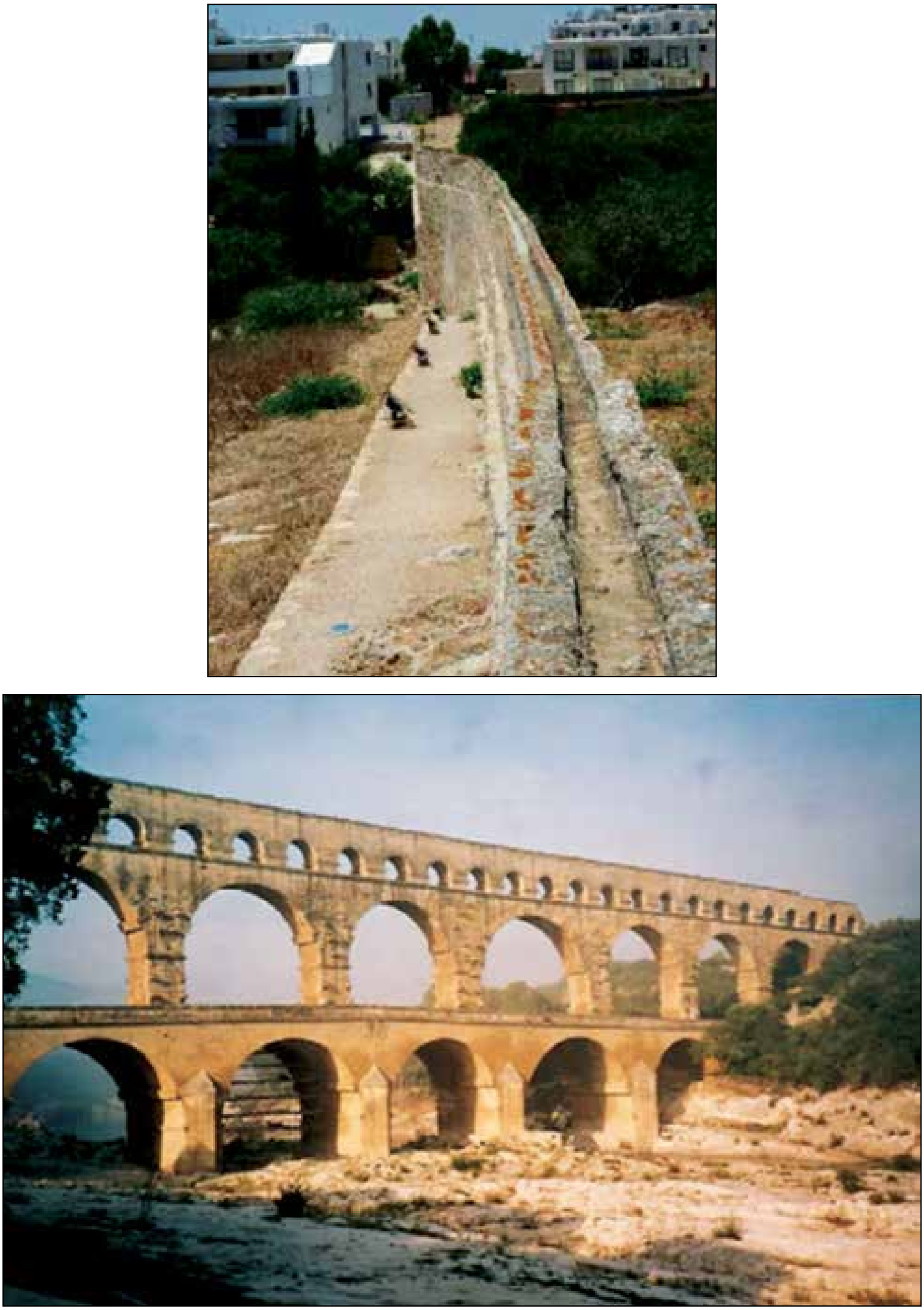


Figure 1.2 Aqueduct in Agia Napa and (Cyprus) Roman Aquaduct - Pont de Garde (France). (Photo: P. Juuti 2007).

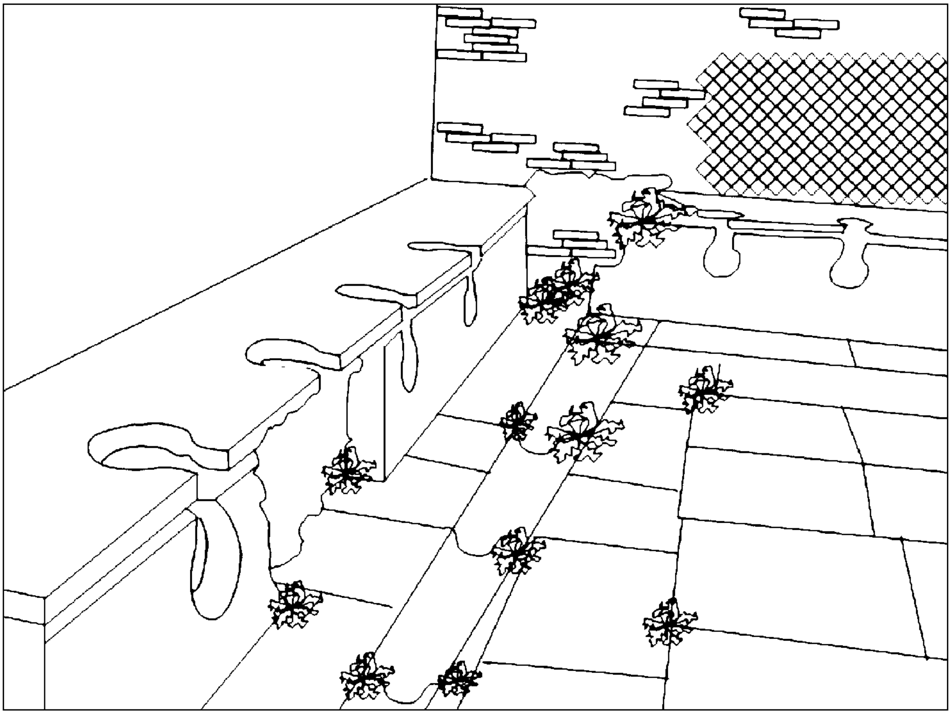


Figure 1.3 Public latrines in Ostia Rome, Italy (Adapted from Lofrano G., Brown J.2010)

of Knossos had modern channels that removed wastewater and the Romans were experts in the construction of sewers. While the 18th century brought about the Industrial Revolution, it was not until the nineteenth century that any changes were made in the way water was managed mostly hindered by economic, social and institutional constraints. Certainly the conviction, crossing whole social classes, that water"was bad", was the excuse for the lack of hygienic practices and the development of engineering techniques aimed to an appropriate management. *Throughout the Middle Ages, water was considered not healthy, dirt was covered with glitter and wigs and hygiene was associated with the occasion of guilty pleasures. Rumors spread the theory that the bathroom was responsible for opening the pores of the skin, exposing the body to every type of illness (Cooper, 2007). Water was bad for the soul and body!* (P.Juuti et al 2007)

Along with the industrialization and urbanization of the Western world, enlightened people were fascinated with the idea of progress. Ever since the 18th century, science and reason were considered to be able to lead humankind towards an ever-happier future. This was the period when the first actual water closet was developed. By 1900, the water closet became a generally accepted cultural necessity in the Western world – the same way aqueducts had been in the Roman Empire. The water closet was seen as a victory for public health without any consideration for where the human excreta went through sewer pipes.

The start of industrialization and the related growth of cities created a situation where public health and environmental problems overwhelmed city governments to a greater degree than before, and novel technology was often seen as the solution. In the 19th century, Great Britain was seen as the forerunner of modern water supply and sanitation systems, but the innovations soon spread to Germany, other parts of Europe, USA and later also elsewhere.

Sanitation in towns around Europe was one of the great achievements of the 19th century. During the century the role of water in the transmission of several important diseases – cholera, dysentery, typhoid fever and diarrheas – was realized. The final proof came when the microbes causing these diseases were discovered. Especially cholera served as a justification for the sanitary movement around the world in the 19th century.

Sensory evaluation of water quality was complemented with chemical and microbiological examination. During the 19th century, filtering of the entire water supply of a town was introduced and the systematic chlorination of drinking water started in the early 20th century. The discovery of microbes and the introduction of efficient ways of treating large amounts of water paved the way to an era in which the public health problems caused by polluted water seemed to belong to history.

1.3 The Third Urbanisation: Modern Urban Infrastructure

The 1900s was a period of extensive population growth – the global population about quadrupled while the urban population increased 13-fold. By 2000 A.D., in almost every country, over half of the population lived in urban areas. During the century industrial production increased 40-fold and the consumption of energy by a factor of tens. Water and sanitation services had a definite role in this rapid socio-economic change of the entire globe. The linkage between water pollution and waterborne diseases was suspected from death registers as early as in 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 heavily polluted with raw sewage. Even though the role of waterborne diseases has been recognized for a long time, 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. Waterborne diseases cause an average of 25 000 deaths per day in the world.

To control waterborne diseases it is necessary to maintain a high level of hygiene, especially in urban areas with large population densities. This is illustrated by the close relationship between the death rate from waterborne diseases and levels of water consumption in Stockholm over a long period of the 19th century (Figure 1.4). It has been shown that a particular problem is to separate sewage from the drinking water supply, which was not done efficiently in the 19th century. Waterborne diseases are still a problem in some areas of the Baltic region and to boil drinking water before consumption is recommended in many cities. On a few occasions when by technical error the wastewater leaks directly into the drinking water net for households, large groups of people have been reported severely ill.

The public water network began to be built in Sweden about a century ago. It was in the larger communities that the first stage of constructing municipal water and sewage management took place.

This construction is generally regarded as having been complete around 1920, by which time most of the largest cities had sewage pipe networks. The pipes replaced earlier sewage gutter leadoff, which.

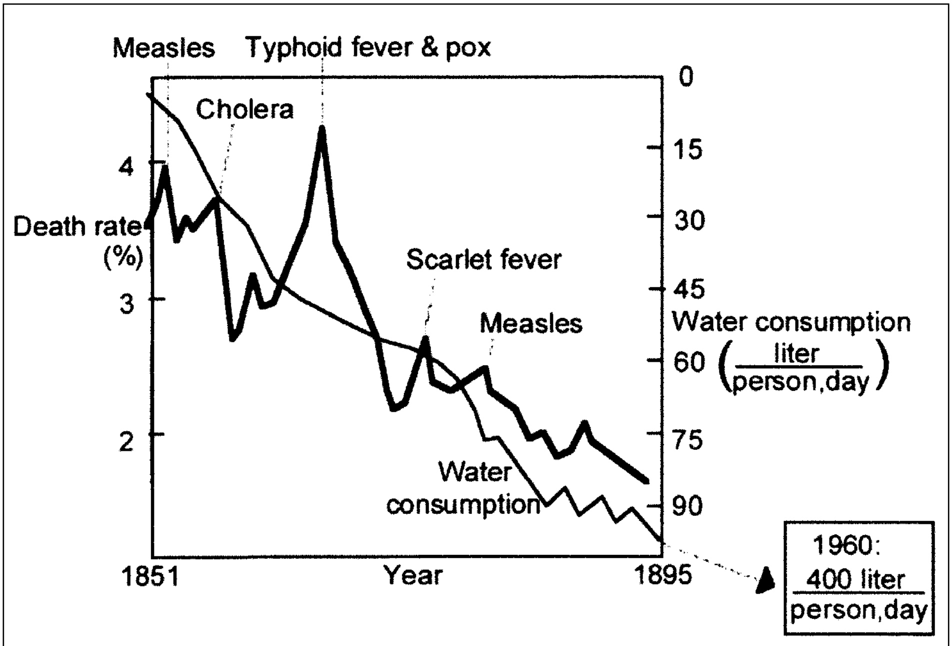


Figure 1.4 A close connection between the death rate from waterborne diseases and increased water consumption from the water network in Stockholm (Adapted from Bengt Hultman et al 2003).

1.4 The Fourth Urbanization: Future Challenges

In the historical context, the growth of urban centers has been a continuous and even an escalating trend. Many of these centers are today located in developing economies, while the ensuing problems are concentrated on the poorest people – as always. The most severe constraints include poor living conditions, a lack of democracy, poor hygiene, illiteracy, corruption and a lack of proper water and sanitation services. Especially women and children suffer from these constraints.

Today there is a global shortage of potable water. When making fundamental decisions concerning water supply and sewerage http://www.iwawaterwiki.org/xwiki/bin/view/Articles/SustainableUrbanDrainageSystem, it is also necessary to be ready to make big investments. Services that are now at a high operational level were not achieved easily and without massive inputs and efforts. This is something to keep in mind when assessing future options and considering required strategies.

The level of water supply and sanitation in a society is not necessarily bound with time and place as much as the capability of that society to take responsibility for developing the living environment of its citizens and proper policies. In some cases, the situation was even better earlier than nowadays. Decisions have been made concerning water and sanitation systems – e.g. the universal acceptance of the water closet as a cultural necessity – that through path dependence have limited future options. There have also been situations where the choice of a technology has been regarded as problematic from the first beginning but has been chosen anyway. For instance, lead pipes were considered hazardous for health already in antiquity but continued to be used in house connections until recently.

More than just a commodity, water is an economic and social good. This places responsibility for its management and oversight in the public sphere. Balancing of water use priorities, water quantity and water quality is of high importance for the futures. While water supply will continue to have the highest priority water quality issues will be relatively even more important than quantity. At the same time it is more and more important to use water wisely and avoid wastage of this important natural resource. In global context water pollution control and sanitation are probably the biggest challenges – removing substantially wastewater loadings from communities, industries and agriculture in many parts of the world.

For example, to solve these problems in Sweden a new phase of the network construction was initiated in 1955. From that time all new sewage networks were built as duplicate systems, where wastewater and stormwater were drained in separate pipes. This was done without any official recommendation.

The increases are attributed to an increase in the connection of households and small industries to the plants. The reductions are attributable to improved treatment. Developments in urban water systems have been strongly influenced by developments in society. Varying driving forces have changed priorities from an initial focus on hygienic aspects via gradual improvements of treatment methods to a focus – in addition to earlier requirements – on recycling resources, saving and recovering energy, public participation and interactions with other sectors in society. (Lundin, Ryden BUP)

Chapter 1 sources:

Blake, Nelson Manfred. Water for the Cities; A History of the Urban Water Supply Problem in the United States. Syracuse, NY: SyracuseUniv. Press, 1956.

Bengt Hultman, Erik Levlin, Lena Johansson, Nasik Al-Najjar, Puhua Li & Elzbieta Paza Municipalities And Water Use, BUP Environmental science, Chapter 13, Lars-Christer Lundin & Lars Ryden.

Foss-Mollan, Kate. Hard Water: Politics and Water Supply in Milwaukee, 1870–1995. West Lafayette, Ind: Purdue University Press, 2001.

Halliday, Stephen. Water: A Turbulent History. Stroud: Sutton, 2004.

Hardy Anne. "Water and the Search for Public Health in London in the Eighteenth and Nineteenth Centuries". Medical History. 28, no. 3 (July, 1984): 250–82.

Juuti, Katko & Vuorinen Eds., Environmental History of Water: Global View of Community Water Supply and Sanitation, IWA Publishing, 2007, ISBN: 9781843391104

Lofrano G., Brown J. Wastewater management through the ages: A history of mankind. Science of the Total Environment 408 (2010) 5254–5264

Melosi, Martin V. The Sanitary City: Urban Infrastructure in America from Colonial Times to the Present. Baltimore: Johns Hopkins University Press, 2000.

Mackenzie L. Davis Water and Wastewater Engineering: Design Principles and Practice, McGraw-Hill New York (2010) ISBN: 978-0-07-171385-6, 1301p.

Metcalf & Eddy (2003) Wastewater Engineering: Treatment and Reuse, 4th ed., McGraw-Hill, Boston, Massachusetts, pp. 429–430, 452–453, 563–886.

Tarr, Joel A., James McCurley, Francis C. McMichael, and Terry Yosie. "Water and Wastes: A Retrospective Assessment of Wastewater Technology in the United States, 1800–1932". Technology and Culture. 25, no. 2 (April, 1984): 226–263.

Chapter 2.
Municipalities and Development of Sanitation

2.1 Development of sanitation understanding. Increased contamination of water.

Households rarely had sanitary facilities, and the practice was to empty the chamber pot directly on the street. In a 1985 Italian film “Non ci resta che piangere”, the famous actor Massimo Troisi is shown in a scene walking in a medieval town and experiencing first hand “wastewater disposal”. The expression, “Look out Below” is very relevant to the practices employed during this time.

However, there were some exceptions to this. In some medieval cities, particularly in central and northern Italy, there appears to be well intentioned programs using municipal statutes to control environmental conditions to improve city life. In the “Statutes of the streets and waters of the countryside of Milano,” 1346, much space is devoted to the problem of cesspits. A regulation, repeated endlessly, prohibited the emptying of cesspits and transporting the contents in summer months. The emptying of the cesspits in Milan, was conducted by navazzari (or cisternari), a word that described the operators of the “navazze”, the carts that carried the waste collected households cesspits for transport outside the city. The regulations ensured that the public understood the advantage of using wastewater as fertilizer. The regulations also prohibited the contents of cesspits being emptied in streets, or in any of the numerous rivers crossing the city.

Unfortunately, not all rivers were protected. The Nirone River which means “black river” was named because of the wastewater discharged into it. In the 14th century in Florence, the “votapozzi” had the task to empty cesspits, distinguishing sludge which was sold to farmers for use as fertilizer from liquid waste which was disposed of in the Arno River according to a practice that was in existence for centuries (Mantelli and Temporelli, 2007).

In 1539, when plagues swept Europe, King Francois I ordered the homeowners of Paris to build cesspools for sewage collection in new houses. These continued to be used until the late 1700s. This practice helped to reduce contamination of drinking water supplies. However it is interesting to note that water from contaminated wells along the left bank of the Seine was used by bakers and had no negative on the reputation (or maybe enhanced the reputation) of extraordinary baguette! It was estimated that in 1883 in Paris there were 25,000–30,000 wells for municipal drinking water which were heavily polluted because of the leaching of cesspits and cesspools especially during rainfall.

In London, wastewater was collected in cesspits beginning in 1189 and the contents conveyed to the countryside for land application. This was done by "rakers" or "gongfermors" who removed the foul sewage from cesspools and sold it to farmers just outside the city walls. By the 1300s the city of Norwich, the second largest city in England after London, was selling "night soil" to farmers outside the walls of the city as fertilizer. In 1596 Sir John Harington designed two water closets for Queen Elizabeth I but these did not achieve popularity until adopted by Londoners late in the 1700s. Cesspits continued to be used for general domestic waste disposal until 1880.

The processing of fecal matter through sewers in Paris, by the "vendageurs", as well as in many other European cities, was seen as an archetype of wastefulness, resented by many. In Zurich the idea of disposing wastewater through sewers encountered also resistance both by property owners as well as farmers that used the waste as fertilizer. In Geneva and Basel urbane drainage systems existed since the early days of modern times, however, Basel, used the Birsig River as its main sewer.

2.2. Age of Sanitary Enlightenment and the Industrial Age

2.2.1. Britain

With the high rate of industrialization and urbanization throughout the eighteenth century, preceding and accompanying the industrial revolution, came the realization of the importance of waste and wastewater disposal. Britain was one of the first countries to begin experimentation with organized action to improve environmental conditions in the cities. The principle employed was to assume *"the solution of pollution is dilution"*. The construction of the Bazalgette sewer system in London, started in 1858 and completed in 1865, is an example of this principle. Through a series of collection sewers and pumping stations wastewater was conveyed from the streets and discharged to the Thames. There was no understanding of assimilative capacity in the river and no understanding of the need to remove pollutants prior to discharging to the river .The Thames was already pollution by the beginning of the 14th century, but in 1859, it became the protagonist of a crisis in London that would be passed into history as "the great stench" caused at least by two events: the Industrial Revolution and the closing of London’s cesspools following the introduction of the flush toilet. Victorians called the Thames a “monster soup”.

2.2.2. Germany

Although a sewer system had been constructed as early as 1842 in Hamburg, the general introduction of sewers in the German cities started with the construction of a system in Frankfurt/Main in 1867. The citizens of Basel rejected both a law on sewers (1876), as well as a remediation plan of Birsig (1881). It was not until 1896 that they accepted a collection system for black water.

2.2.3. France

On June 29, 1853 George-Eugene Haussmann took the oath as prefect of the Seine and the transformation of Paris began. Starting in 1854, Eugène Belgrand was charged by Haussmann to undertake an extensive reorganization of the network of sewers that were already in the city. Collectors were installed in the boulevard de Sébastopol and rue de Rivoli. Building owners were compelled by law to gradually modify usage so as not to increase the amount of water being directly discharged and to discharge it further downstream, at Asnières. The networks on both banks of the river were joined through a siphon at the Pont de l’Alma. However, the resulting pollution of the Seine due to the discharge of sewage caused the successors of Haussmann to adopt a different system of disposal: the collectors were extended to Acheres, where wastewater was dispersed on especially reserved fields. Starting from 1930 wastewater treatments plants were in use at Acheres, Valenton, Noisy-le-Grand and Colombes.

2.2.4. Italy

In Italy the period of great public works started later (1870–1915), the aqueduct of Serino for water supply to Naples, the aqueduct of Selino for water supply to Palermo and as last the “pugliese” aqueduct that conveyed water to Bari from the Sele River were completed. Infrastructure for the “noble ” drinking water was almost always considered a priority rather than the construction of sewers to collect wastewater in part because the cost for aqueducts was low due to the recovery of old Roman existing pipelines and construction and operation was financed by foreign companies (Sorcinelli, 1998; De Feo and Napoli, 2007).

The debate dealing with construction of the Neapolitan sewers began in 1870, involving doctors, architects, and engineers and with unusual modernity, it also faced the problem of management of solid waste. However it wasn’t until 1889 that the sewer project started (Varriale, 2007).

Based on data collected by the investigation on public health carried out in Italy in 1899, sewer systems were present in almost all major Italian cities. Giovannini (1996)reports that of the 69 cities involved in the investigation only Udine, Milan and Turin boasted efficient sewers.

Sewers in the southern cities, Syracuse, Catania, Caltanissetta, Reggio Calabria, Catanzaro, Cosenza, Potenza, Bari, Lecce, Avellino and Caserta, were considered inefficient. The small northern cities such as Treviso, Vicenza, Verona, Mantua, Bergamo, Como, Pavia, Novara, and Portomaurizio were equally as bad. The sewers in Naples, Palermo, Messina and Rome were not much better; however, it was clear that the conditions of small towns were on average worse than in major cities.

2.2.5 Sweden

The public water network began to be built in Sweden about a century ago. It was in the larger communities that the first stage of constructing municipal water and sewage management took place. This construction is generally regarded as having been complete around 1920, by which time most of the largest cities had sewage pipe networks. The pipes replaced earlier sewage gutter leadoff, which was used for flush-water and sometimes also for disposal of trash and excrement. The solution to the environmental problems of the time was to construct sewage pipe networks, an enterprise that involved a major economic sacrifice. Pollutants were removed from the municipalities to the nearest water area.

In 1859 the first water closet was installed in Stockholm, but it took many decades before the royal castle got this new convenience. The advantage of being spared the abhorred latrine collection soon became obvious and from the turn of the century most new houses in the big cities were provided with water closets. The closet outlet was connected to a single sewage pipe and the combined wastewater system was introduced. When the public water and sewage networks had been built, the use of water for various purposes increased significantly (Figure 2.1).

The inconvenience of the combined transport of toilet water and stormwater soon became noticeable. The treatment plants did not have the capacity to take care of the entire runoff during storms. A part of the untreated wastewater had to be led past the treatment plant and by passed out in the recipient. In addition, flooding of basements became more common.

2.2.6. United States

In the early 1800s, new community sewers were initially (and primarily) installed to take care of storm water; privies and "leaching" cesspools were used for human wastes. Still, a lot of human wastes from the early residents of the larger

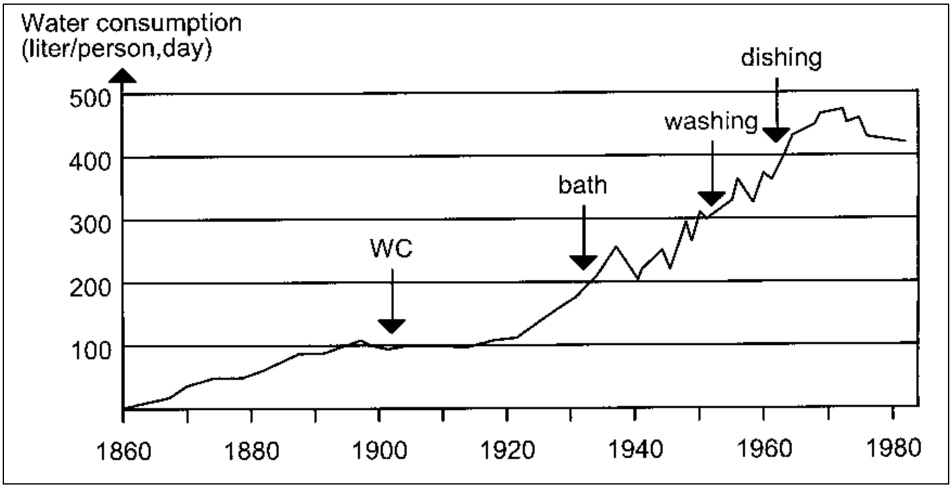


Figure 2.1 Water use in Stockholm between 1860 and 2000. (Bengt Hulman et al)

towns (following the model of their European forefathers) were unofficially put into the sewers – hose wastes were either thrown out (from chamber pots) into the streets, leaked onto the ground from poorly designed/maintained privies/cesspools, or were directly deposited on the ground; wastes were then conveyed by storm water into the streets and on into the sewers.

Large cities such as Boston and Chicago installed "sewers" beginning as early at the 1700's using hollowed out logs. In 1647, the first "water pollution control" regulation was put into effect in the British colony of Massachusetts.

2.3 Water pollution and waterborne disease and harmful microorganisms.

2.3.1 Bacteriological nature of disease

The understanding of how disease was transmitted was still developing. The miasmatic theory advocated that disease was transmitted by smell and foul odors arising from putrefaction of organic matter. This was advocated by early sanitarian Edwin Chadwick, who in the 1840s, advocated the removal of human waste by means of water, the idea was to remove the foul smells *as quickly as possible*, by means of water ideally to be deposited on agricultural fields. The sewage was instead deposited in the Thames of which many water suppliers still used as their source. In this environment John Snow established a series of experiments where he was able to show that cholera was communicable by water and was able to link a cholera outbreak in London to a single well in London on Broad Street.

The link between water and disease was still not well established and in 1873 the president of the New York board of health declared that “although rivers are great natural sewers, and receive the drainage of towns and cities the natural process of purification, in most cases destroys the offensive bodies derived from sewer and renders them harmless”. This is typical of the lack of understanding of how disease was transmitted and followed the general belief that water courses such as rivers and lakes were great sinks for purification of contaminated water.

As understanding of the bacteriological nature of disease became clearer in the late 19th century. the need to filter and treat water became apparent. After a typhoid outbreak in 1890. W.T. Sedgwic applied bacteriological methods to the investigation and was able to establish a link between contaminated water and the disease.

2.3.2 Classification of waterborne pathogens

Waterborne disease is a global burden of great magnitude. As stated by Water.org, the number of people worldwide without access to safe water is estimated to be nearly 1 billion with another 2.5 billion lacking improved sanitation (http://water.org/learn-about-the-water-crisis/billion/). Apart from causing a great number of deaths, the innumerable cases of sicknesses have a profound impact on people’s well-being and their economic performance.

Waterborne diseases are caused by pathogens microorganisms which are directly transmitted when contaminated fresh water is consumed. Contaminated fresh water, used in the preparation of food, can be the source of food bore disease through consumption of the same microorganisms. According to the World Health Organization, diarrheal disease accounts for an estimated 4.1% of the total DALY (disability-adjusted life year) global burden of disease and is responsible

Table 2.1. General classification of waterborne pathogens.
(The information is extracted from http://www.waterbornepathogens.org)

Bacterial Pathogens	Protozoan Pathogens	Viral Pathogens
Acinetobacter	Cryptosporidium	Calicivirus
Campylobacter	Giardia	Enterovirus
Escherichia coli	Naegleria fowleri	Rotavirus
Helicobacter pylori		***Norovirus***
Legionella		***Adenovirus***
Mycobacterium		
Salmonella		
Vibrio cholera		
Yersinia		

for the deaths of 1.8 million people every year. It was estimated that 88% of that burden is attributable to unsafe water supply, sanitation and hygiene, and is mostly concentrated in children in developing countries.[1]

Waterborne disease can be caused by protozoan, bacterial and viral pathogens many of which are intestinal parasites. In Table 2.1 presented general classifications of waterborne pathogens.

2.3.3 Protozoal infections

A lot of infections are caused by the protozoan pathogens. In table 2.2 are summarized that diseases. Table 2.2. General classification of protozoal infections transmission sources and general symptoms.(The information is extracted from http://en.wikipedia.org)

2.3.4 Parasitic infections (Kingdom of animalia)

In the cases then fresh water contaminated with sewage the parasitic infections can occur. In Table 2.3 are represented most common parasitic diseases.

2.3.5 bacterial infections

Bacterial infections are presented in Table 2.4.

2.3.6 Viral infections

In the cases then fresh water contaminated with sewage the viral infections can occur. In Table 2.5 are represented most common viral diseases.

Different kind of most viruses find in the water and their images are presented in fig 3.1.

Figure3.x Different kind of viruses find in the water and their image. (Adapted from Gilberg et al. 2003)

Chapter 2 sourcess:

Bengt Hultman, Erik Levlin, Lena Johansson, Nasik Al-Najjar, Puhua Li & Elzbieta Paza Municipalities And Water Use, BUP Environmental science, **Chapter 13**, Lars-Christer Lundin & Lars Ryden.

Information about different bacterial, protozoan, and viral waterborne pathogens microorganisms' disease World Health Organization

Lars Gillberg, Bengt Hansen, Ingemar Karlsson, Anders Nordström Enkel, Anders Pålsson, "About Water Treatment" Water and Wastewater Treatment: Handbook Helsingborg, Kemira, Kemwater 2003, ISBN 91-631-4344-5

G. Lofrano, J. Brown / Science of the Total Environment 408 (2010) 5254–5264

Mackenzie L. Davis Water and Wastewater Engineering: Design Principles and Practice, McGraw-Hill New York (2010) ISBN: 978-0-07-171385-6, 1301p.

Table 2.2. General classification of protozoal infections transmission sources and general symptoms.(The information is extracted from http://en.wikipedia.org)

Disease and Transmission	Microbial Agent	Sources of Agent in Water Supply	General Symptoms
Amoebiasis (hand-to-mouth)	Protozoan (*Entamoeba histolytica*) (Cyst-like appearance)	Sewage, non-treated drinking water, flies in water supply	Abdominal discomfort, fatigue, weight loss, diarrhea, bloating, fever
Balantidiasis, also Balantidosis	*Balantidum coli*	feacally contaminated water	Diarrhea or constipation
Cryptosporidiosis (oral)	Protozoan (*Cryptosporidium parvum*)	Collects on water filters and membranes that cannot be disinfected, animal manure, seasonal runoff of water.	Flu-like symptoms, watery diarrhea, loss of appetite, substantial loss of weight, bloating, increased gas, nausea
Cyclosporiasis	Protozoan parasite (*Cyclospora cayetanensis*)	Sewage, non-treated drinking water	cramps, nausea, vomiting, muscle aches, fever, and fatigue
Giardiasis (oral-fecal) (hand-to-mouth)	Protozoan (*Giardia lamblia*) Most common intestinal parasite	Untreated water, poor disinfection, pipe breaks, leaks, groundwater contamination, campgrounds where humans and wildlife use same source of water. Beavers and muskrats create ponds that act as reservoirs for Giardia.	Diarrhea, abdominal discomfort, bloating, and flatulence
Meningoencephalitis (primary amoebic)	Protozoan (*Naegleria fowleri*)	warm stagnant fresh water	olfactory dysfunction, eventually inability to smell and taste, nausea, rigidity of the neck, vomiting, delirium, seizures, and eventually irreversible coma
Microsporidiosis	Protozoan phylum (*Microsporidia*), but closely related to fungi	The genera of *Encephalitozoon intestinalis* has been detected in groundwater, the origin of drinking water	Diarrhea and wasting in immunocompromised individuals
Toxoplasmosis	Protozoan (Toxoplasma gondii)	faecally contaminated water	when acute: flu-like symptoms, swollen lymph nodes, or muscle aches or pains

Table 2.3. General classification of parasitic infections (Kingdom of animalia) transmission sources and general symptoms.(The information is extracted from http://en.wikipedia.org)

Disease and Transmission	**Microbial Agent**	**Sources of Agent in Water Supply**	**General Symptoms**
Schistosomiasis (immersion)	Members of the genus *Schistosoma*	Fresh water contaminated with certain types of snails that carry schistosomes	Rash or itchy skin. Fever, chills, cough, and muscle aches
Dracunculiasis (Guinea Worm Disease)	*Dracunculus medinensis*	Stagnant water containing larvae	Allergic reaction, urticaria rash, nausea, vomiting, diarrhea, asthmatic attack.
Taeniasis	Tapeworms of the genus *Taenia*	Drinking water contaminated with eggs	Intestinal disturbances, neurologic manifestations, loss of weight, cysticercosis
Fasciolopsiasis	*Fasciolopsis buski*	Drinking water contaminated with encysted metacercaria	GIT disturbance, diarrhea, liver enlargement, cholangitis, cholecystitis, obstructive jaundice.
Hymenolepiasis (Dwarf Tapeworm Infection)	*Hymenolepis nana*	Drinking water contaminated with eggs	Abdominal pain, anorexia, itching around the anus, nervous manifestation
Echinococcosis (Hydatid disease)	*Echinococcus granulosus*	Drinking water contaminated with feces (usually canid) containing eggs	Liver enlargement, hydatid cysts press on bile duct and blood vessels; if cysts rupture they can cause anaphylactic shock
coenurosis	multiceps multiceps	contaminated drinking water with eggs	increases intacranial tension
Ascariasis	*Ascaris lumbricoides*	Drinking water contaminated with feces (usually canid) containing eggs	Mostly, disease is asymptomatic or accompanied by inflammation, fever, and diarrhea. Severe cases involve Löffler's syndrome in lungs, nausea, vomiting, malnutrition, and underdevelopment.
Enterobiasis	*Enterobius vermicularis*	Drinking water contaminated with eggs	Peri-anal itch, nervous irritability, hyperactivity and insomnia

Table 2.4. General classification of bacterial infections transmission sources and general symptoms.(The information is extracted from http://en.wikipedia.org)

Disease and Transmission	Microbial Agent	Sources of Agent in Water Supply	General Symptoms
Botulism	*Clostridium botulinum*	Bacteria can enter a wound from contaminated water sources. Can enter the gastrointestinal tract by consuming contaminated drinking water or (more commonly) food	Dry mouth, blurred and/or double vision, difficulty swallowing, muscle weakness, difficulty breathing, slurred speech, vomiting and sometimes diarrhea. Death is usually caused by respiratory failure.
Campylobacteriosis	Most commonly caused by *Campylobacter jejuni*	Drinking water contaminated with feces	Produces dysentery like symptoms along with a high fever. Usually lasts 2–10 days.
Cholera	Spread by the bacterium *Vibrio cholerae*	Drinking water contaminated with the bacterium	In severe forms it is known to be one of the most rapidly fatal illnesses known. Symptoms include very watery diarrhoea, nausea, cramps, nosebleed, rapid pulse, vomiting, and hypovolemic shock (in severe cases), at which point death can occur in 12–18 hours.
E. coli Infection	Certain strains of *Escherichia coli* (commonly *E. coli*)	Water contaminated with the bacteria	Mostly diarrhea. Can cause death in immunocompromised individuals, the very young, and the elderly due to dehydration from prolonged illness.
M. marinum infection	*Mycobacterium marinum*	Naturally occurs in water, most cases from exposure in swimming pools or more frequently aquariums; rare infection since it mostly infects immunocompromised individuals	Symptoms include lesions typically located on the elbows, knees, and feet (from swimming pools) or lesions on the hands (aquariums). Lesions may be painless or painful.
Dysentery	Caused by a number of species in the genera *Shigella* and *Salmonella* with the most common being *Shigella dysenteriae*	Water contaminated with the bacterium	Frequent passage of feces with blood and/or mucus and in some cases vomiting of blood.
Legionellosis (two distinct forms: Legionnaires' disease and Pontiac fever)	Caused by bacteria belonging to genus *Legionella* (90% of cases caused by *Legionella pneumophila*)	Contaminated water: the organism thrives in warm aquatic environments.	Pontiac fever produces milder symptoms resembling acute influenza without pneumonia. Legionnaires' disease has severe symptoms such as fever, chills, pneumonia (with cough that sometimes produces sputum), ataxia, anorexia, muscle aches, malaise and occasionally diarrhea and vomiting
Leptospirosis	Caused by bacterium of genus *Leptospira*	Water contaminated by the animal urine carrying the bacteria	Begins with flu-like symptoms then resolves. The second phase then occurs involving meningitis, liver damage (causes jaundice), and renal failure
Salmonellosis	Caused by many bacteria of genus *Salmonella*	Drinking water contaminated with the bacteria. More common as a food borne illness.	Symptoms include diarrhea, fever, vomiting, and abdominal cramps

Table 2.4. General classification of bacterial infections transmission sources and general symptoms.(The information is extracted from http://en.wikipedia.org)

Disease and Transmission	Microbial Agent	Sources of Agent in Water Supply	General Symptoms
Typhoid fever	*Salmonella typhi*	Ingestion of water contaminated with feces of an infected person	Characterized by sustained fever up to 40°C (104°F), profuse sweating, diarrhea, less commonly a rash may occur. Symptoms progress to delirium and the spleen and liver enlarge if untreated. In this case it can last up to four weeks and cause death.
Vibrio Illness	*Vibrio vulnificus*, *Vibrio alginolyticus*, and *Vibrio parahaemolyticus*	Can enter wounds from contaminated water. Also got by drinking contaminated water or eating undercooked oysters.	Symptoms include explosive, watery diarrhea, nausea, vomiting, abdominal cramps, and occasionally fever.

Table 2.5. General classification of viral infections transmission sources and general symptoms.(The information is extracted from http://en.wikipedia.org)

Disease and Transmission	Microbial Agent	Sources of Agent in Water Supply	General Symptoms
Adenovirus infection	Adenovirus	Manifests itself in improperly treated water	Symptoms include common cold symptoms, pneumonia, croup, and bronchitis
Gastroenteritis	Astrovirus, Calicivirus, Enteric Adenovirus, and Parvovirus	Manifests itself in improperly treated water	Symptoms include diarrhea, nausea, vomiting, fever, malaise, and abdominal pain
SARS (Severe Acute Respiratory Syndrome)	Coronavirus	Manifests itself in improperly treated water	Symptoms include fever, myalgia, lethargy, gastrointestinal symptoms, cough, and sore throat
Hepatitis A	Hepatitis A virus (HAV)	Can manifest itself in water (and food)	Symptoms are only acute (no chronic stage to the virus) and include Fatigue, fever, abdominal pain, nausea, diarrhea, weight loss, itching, jaundice and depression.
Poliomyelitis (Polio)	Poliovirus	Enters water through the feces of infected individuals	90-95% of patients show no symptoms, 4-8% have minor symptoms (comparatively) with delirium, headache, fever, and occasional seizures, and spastic paralysis, 1% have symptoms of non-paralytic aseptic meningitis. The rest have serious symptoms resulting in paralysis or death
Polyomavirus infection	Two of Polyomavirus: JC virus and BK virus	Very widespread, can manifest itself in water, 80% of the population has antibodies to Polyomavirus	BK virus produces a mild respiratory infection and can infect the kidneys of immunosuppressed transplant patients. JC virus infects the respiratory system, kidneys or can cause progressive multifocal leukoencephalopathy in the brain (which is fatal).

Chapter 3.
Water Sources for Municipalities

3.1 Water Source Evaluation and regulation

Although the portion of the population of the United States supplied by surface water is 150 percent of that supplied by groundwater, the number of communities supplied by groundwater is more than a factor of 10 times that supplied by surface water. The reason for this pattern is that larger cities are supplied by large surface water bodies while many small communities use groundwater.

Groundwater has many characteristics that make it preferable as a water supply:

- groundwater is less subject to seasonal fluctuations and long-term droughts.
- the aquifer provides natural storage that eliminates the need for an impoundment.
- because the groundwater source is frequently available near the point of demand, the cost of transmission is reduced significantly.
- because natural geologic materials filter the water, groundwater is often more aesthetically pleasing and to some extent protected from contamination.

Groundwater as a supply is not without drawbacks. It dissolves naturally occurring minerals which may give the water undesirable characteristics such as hardness, red color from iron oxidation, and toxic contaminants like arsenic. Figure 3.2 represents process by which water is made hard.

Yield

One of the first considerations in selecting a water supply source is the ability of the source to provide an adequate quantity of water. One measure of quantity is yield. Yield is the average flow available over a long period of time.

Surface Water

When the proposed surface water supply is to be the sole source of water, the design basis is the long-term or "safe" yield. The components of the design are: (1) determination of the allowable withdrawal, (2) completion of a complete series analysis and, if the design drought duration exceeds the recorded data interval, completion of a partial duration series analysis, and (3) completion of an extreme-value analysis to determine the probable recurrence interval (return period) of a drought. The allowable withdrawal is determined from regulatory constraints. Obviously, the municipality desiring to use the surface water for supply cannot withdraw all of the available water. Enough must be left for the ecological health of the river or stream as well as for downstream users. In some cases, such as the Great Lakes, the water body is so large that the classic analysis of drought conditions is not warranted. However, the fluctuation of the lake level does impact the design of the intake structure, and it must be evaluated.

Groundwater

Unlike surface water supplies, groundwater is less subject to seasonal fluctuations and long-term droughts. The design basis is the long term or "safe" yield. The safe yield of a ground water basin is the amount of water which can be withdrawn from it annually without producing an undesired result. (Todd, 1959) A yield analysis of the aquifer is performed because of the potential for overpumping the well with consequent failure to yield an adequate supply as well as the potential to cause dramatic ground surface settlement, detrimental dewatering of nearby ponds or streams or, in wells near the ocean, to cause salt water intrusion.

Surface and groundwater comparison

Surface water is in contact with the atmosphere and is saturated with oxygen and nitrogen gases of the air. During runoff, dissolving brown-colored humic substances pollute the water. Clay and other fine particles, bacteria and microorganisms are suspended in the water. The content of dissolved inorganic substances is

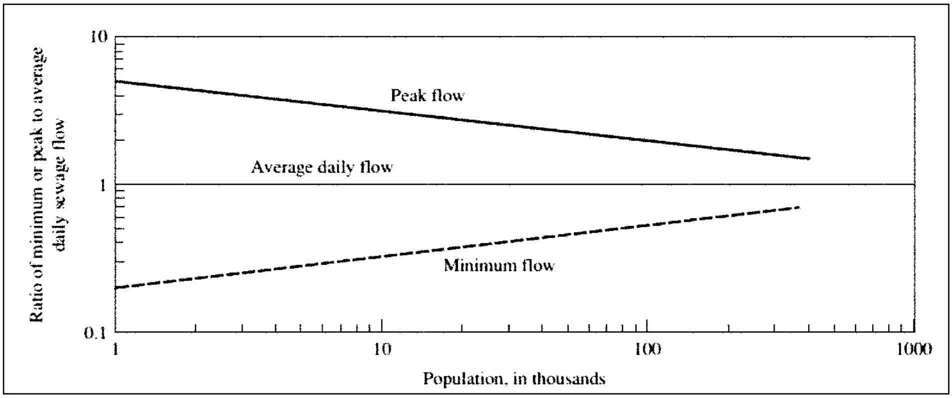


Figure 3.1 Ratio of extreme flows to average daily flow (Mackenzie, 2010)

generally low, since water during runoff normally does not come in close contact with soluble mineral substances.

During groundwater formation, water is filtrated and becomes clear and practically free from microorganisms. Organic substances in the water are biochemically oxidized, consuming oxygen and producing carbon dioxide. During the first phase of oxidation, humic acids are produced, which at complete oxidation are further degraded to carbon dioxide and water. The humic acids are dissolved in the water and the water becomes acid. The diffusion of oxygen is much better in air than in soil, where oxidation of organic material is inhibited in the water saturated soil below the groundwater level. In dry soils where the groundwater level is much below the surface, almost all dissolved organic substances become biochemically oxidized during their passage through the upper soil layer. Groundwater is often oxygen-free and may then contain divalent iron and manganese compounds dissolved from soil particles. The natural process by which water becomes hard is shown schematically in Figure 3.2. As rainwater enters the topsoil, the respiration of microorganisms increases the CO^2 content of the water.

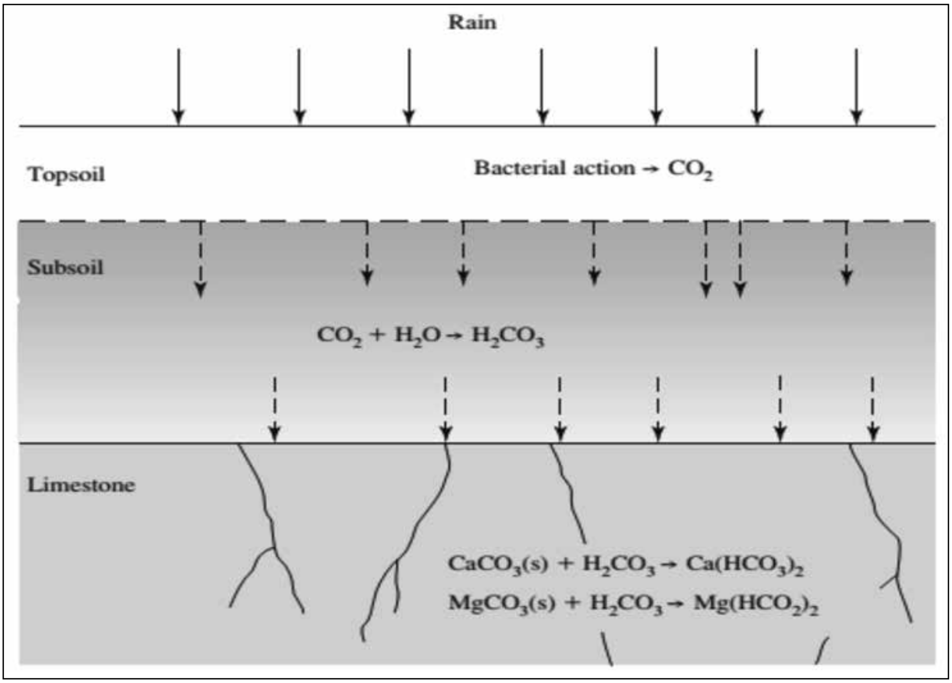


Figure 3.2 Natural process by which water is made hard. (Source: Mackenzie 2010)

The similar process is common for other metals. As the water infiltrates the soil, the pH-level is increased and metal ions are exchanged with metal ions from the soil particles. Table 3.1 shows the contents of urban groundwater from Gothenburg and rural groundwater from western Sweden. Differences in surface water and groundwater quality are shown in Table 3.2 (Lekander, 1991).

Reclaimed Wastewater

Another source of water is recycled or reclaimed water. In regions where potable water is scarce, literally hundreds of communities are recycling wastewater for nonpotable uses. This provides aninitial means of extending a fully exploited water source. A half dozen cities, including El Paso, Texas and Los Angeles, California, are using treated wastewater to recharge potable aquifers. Los Angeles has been doing so since 1962 (Pinholster, 1995).

Table 3.1. Median, maximum and minimum contents of substances in urban groundwater at 12 places in Gothenburg and rural groundwater from 24 places in Western Sweden

	Urban			Rural		
Substance	median	max	min	median	max	min
pH	6.8	8.0	4.4	5.6	8.6	3.9
Alkalinity, mg HCO_3^-/l	447	1511	4.9	5	1130	-14.7
Sulphate, mg SO_4^{2-}/l	47	465	2	12	114	0.4
Nitrate, mg NO_3^-/l	7.6	226	0.1	0.4	28	0
Total hardness, mg Ca^{2+}/l	153	413	7.3	6.1	375	0.9

Table 3.2. Comparison of surface water and groundwater quality (Kiely, 1997)

Parameter	Surface water	Groundwater
Temperature	Varies with season	Relatively constant
Turbidity and suspended solids	Varies and is sometimes high	Usually low or nil
Mineral content	Varies with soil, rainfall, efluents etc	Relatively constant at high value
Divalent iron and manganese in solution	Some	Always high
Aggressive carbon dioxide	None	Always some
Dissolved oxygen	Often near saturation, except when polluted	Usually low, requires aeration
Ammonia	Only in polluted waters	Levels found to be increasing
Hydrogen sulphide	None	Usually some
Silica	Moderate levels	Levels found to be increasing due to agricultural pollution
Nitrate	Generally none	Levels found to be increasing due to agricultural pollution
Living organisms	May have high levels	Usually none

Nowadays water source quality regulation

The **Water Framework Directive** (Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy) is a European Union directive which commits European Union member states to achieve good qualitative and quantitative status of all water bodies (including marine waters up to one nautical mile from shore) by 2015. It is a framework in the sense that it prescribes steps to reach the common goal rather than adopting the more traditional limit value approach.

The Directive aims for 'good status' for all ground and surface waters (rivers, lakes, transitional waters, and coastal waters) in the EU. The ecological and chemical status of surface waters is assessed according to the following criteria:

- Biological quality (fish, benthic invertebrates, aquatic flora)
- Hydromorphological quality such as river bank structure, river continuity or substrate of the river bed
- Physical-chemical quality such as temperature, oxygenation and nutrient conditions
- Chemical quality that refers to environmental quality standards for river basin specific pollutants. These standards specify maximum concentrations for specific water pollutants. If even one such concentration is exceeded, the water body will not be classed as having a "good ecological status".

Spatial management of river basins

One important aspect of the Water Framework Directive is the introduction of **River Basin Districts**. These areas have been designated, not according to administrative or political boundaries, but rather according to the river basin (the spatial catchment area of the river) as a natural geographical and hydrological unit. As rivers often cross national borders, representatives from several Member States have to cooperate and work together for the management of the basin (so-called transboundary basins). They are managed according to River Basin management Plans, which should provide a clear indication of the way the objectives set for the river basin are to be reached within the required timescale. They should be updated every six years.

3.2 Drinking water quality

3.2.1 Drinking water quality characterization

The following four categories are used to describe drinking water quality:

1. Physical: Physical characteristics relate to the quality of water for domestic use. They include color, turbidity, temperature, and, in particular, taste and odor.
2. Chemical: Chemical characteristics of waters are sometimes evidenced by their observed reactions, such as the comparative performance of hard and soft waters in laundering. Most often, differences are not visible. However, in some cases, such as the oxidation of iron, the reactions result in highly objectionable color.
3. Microbiological: Microbiological agents are very important in their relation to public health and may also be significant in modifying the physical and chemical characteristics of water.
4. Radiological: Radiological factors must be considered in areas where there is a possibility that the water may have come in contact with radioactive substances. The radioactivity of the water is of public health concern in these cases.

3.2.2 Physical Characteristics

Color

Dissolved organic material from decaying vegetation and certain inorganic matter cause color in water. Occasionally, excessive blooms of algae or the growth of aquatic microorganisms may also impart color. Often the color in water is not true color but apparent color that results from a colloidal suspension. Tea is an example of apparent color. While color itself is not usually objectionable from the standpoint of health, its presence is aesthetically objectionable and suggests that the water needs appropriate treatment. Taste and Odor.

Taste and odor

(T&O) in water can be caused by foreign matter such as organic compounds, inorganic salts, or dissolved gases. These materials may come from domestic, agricultural, or natural sources. Algae are frequently the source of T&O in surface water supplies. T&O can also result as a byproduct of chlorine disinfection. Drinking water should be free from any objectionable taste or odor at the point of use.

Temperature

The most desirable drinking waters are consistently cool and do not have temperature fluctuations of more than a few degrees. Groundwater and surface water from mountainous areas generally meet these criteria. Most individuals find that water having a temperature between 10 C–15 C is most palatable. Municipal drinking water is not treated to adjust the temperature. However, the temperature of the water may be an important water quality objective for a client and may be an important consideration in the selection of the water source.

Turbidity

The presence of suspended material such as clay, silt, finely divided organic material, plankton, and other particulate material in water is known as turbidity. The unit of measure is a nephelometric turbidity unit (NTU). It is determined by reference to a chemical mixture that produces a reproducible refraction of light. Turbidities in excess of 5 NTU are easily detectable in a glass of water and are usually objectionable for aesthetic reasons. Clay or other inert suspended particles in and of themselves may not adversely affect health, but water containing such particles may require treatment to make it suitable for disinfection. In general, turbidity reduces disinfection efficiency by consuming the disinfectant and shielding the microorganisms. Following a rainfall, variations in the groundwater turbidity may be considered an indication of surface or other introduced pollution entering the aquifer.

3.2.3 Chemical Characteristics

Arsenic

Arsenic occurs naturally in some geologic formations. It is widely used in timber treatment, agricultural chemicals (pesticides), and the manufacture of computer chips, glass, and alloys. Arsenic in drinking water has been linked to lung and urinary bladder cancer.

Chloride

Most waters contain some chloride. The amount present can be caused by the leaching of marine sedimentary deposits or by pollution from sea water, brine, or industrial or domestic wastes. Chloride concentrations in excess of about 250 mg/L usually produce a noticeable taste in drinking water. Domestic water should contain less than 100 mg/L of chloride to be palatable.

Fluoride

In some areas, water sources contain natural fluoride. Where the concentrations approach optimum levels, beneficial health effects have been observed. In such areas, the incidence of dental caries (tooth decay) has been found to be below the 1evels observed in areas without natural fluoride. Many cities choose to add fluoride to the water supply to reduce the incidence of dental caries. The optimum fluoride level for a given area depends upon air temperature because temperature greatly influences the amount of water people drink. Excessive fluoride in drinking water supplies may produce fluorosis (mottling) of teeth, * which increases as the optimum fluoride level is exceeded.

Iron

Small amounts of iron frequently are present in water because of the large amount of iron in the geologic materials. The presence of iron in water is considered objectionable because it imparts a reddish color to the water, stains bathroom fixtures and laundered goods with a yellow to reddish-brown color, and affects the taste of beverages such as tea and coffee.

Lead

Lead occurs in drinking water primarily from corrosion of lead pipes. Lead exposure is associated with a large number of pathological effects including but not limited to interference with red blood cell formation, kidney damage, and impaired cognitive performance.

Manganese

Naturally occurring manganese is often present in significant amounts in groundwater. Anthropogenic sources include discarded batteries, steel alloy production, and agricultural products. It imparts a dark brown or black color to water and stains fixtures and cloth that is washed in it. It flavors coffee and tea with a medicinal taste.

Sodium

The presence of sodium in water can affect persons suffering from heart, kidney, or circulatory ailments. When a strict sodium-free diet is recommended, any water should be regarded with suspicion. Home water softeners may be of particular concern because they add large quantities of sodium to the water.

Sulfate

Waters containing high concentrations of sulfate, caused by the leaching of natural deposits of magnesium sulfate (Epsom salts) or sodium sulfate (Glauber's salt), may be undesirable because of their laxative effects.

Zinc

Zinc is found in some natural waters, particularly in areas where zinc ore deposits have been mined. Zinc is not considered detrimental to health, but it will impart an undesirable taste to drinking water.

Toxic Inorganic Substances
Nitrates (NO_3), cyanides (CN), and heavy metals constitute the major classes of inorganic substances of health concern. Methemoglobinemia (infant cyanosis or "blue baby syndrome") has occurred in infants who have been given water or fed formula prepared with water having high concentrations of nitrate. Cyanide ties up the hemoglobin sites that bind oxygen to red blood cells. This results in oxygen deprivation. A characteristic symptom is a blue skin color, which gives the syndrome its name, cyanosis. This condition is called cyanosis. Cyanide also causes chronic effects on the thyroid and central nervous system.

The toxic heavy metals include arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), lead (Pb), mercury (Hg), selenium (Se), and silver (Ag). The heavy metals have a wide range of effects. They may be acute poisons (As and Cr 6 , for example), or they may produce chronic disease (Pb, Cd, and Hg, for example).

Toxic Organic Substances
There are over 120 toxic organic compounds listed on the EPA's Priority Pollutant list. These include pesticides, insecticides, and solvents. Like the inorganic substances, their effects may be acute or chronic.

3.2.4 Microbiological Characteristics

Water for drinking and cooking purposes must be made free from pathogens. These organisms include viruses, bacteria, protozoa, and helminthes (worms). Some organisms that cause disease in people originate with the fecal discharges of infected individuals. Others are from the fecal discharge of animals. Unfortunately, the specific disease-producing organisms present in water are not easily identified. The techniques for comprehensive bacteriological examination are complex and time consuming. It has been necessary to develop tests that indicate the relative degree of contamination in terms of an easily defined quantity. The most widely used test estimates the number of microorganisms of the coliform group. This grouping includes two genera: Escherichia coli and Aerobacter aerogenes. The name of the group is derived from the word "colon". While E. coli are common inhabitants of the intestinal tract, Aerobacter are common in the soil, on leaves, and on grain; on occasion they cause urinary tract infections. The test for these microorganisms, called the Total Coliform Test, was selected for the following reasons:

1. The coliform group of organisms normally inhabits the intestinal tracts of humans and other mammals. Thus, the presence of coliforms is an indication of fecal contamination of the water.

2. Even in acutely ill individuals, the number of coliform organisms excreted in the feces outnumbers the disease-producing organisms by several orders of magnitude. The large numbers of coliforms make them easier to culture than disease-producing organisms.
3. The coliform group of organisms survives in natural waters for relatively long periods of time but does not reproduce effectively in this environment. Thus, the presence of coliforms in water implies fecal contamination rather than growth of the organism because of favorable environmental conditions. These organisms also survive better in water than most of the bacterial pathogens. This means that the absence of coliforms is a reasonably safe indicator that pathogens are not present.
4. The coliform group of organisms is relatively easy to culture. Thus, laboratory technicians can perform the test without expensive equipment.

Current research indicates that testing for Escherichia coli specifically may be warranted. Some agencies prefer the examination for E. coli as a better indicator of biological contamination than total coliforms. The two protozoa of most concern are Giardia lamblia and Cryptosporidium parvum. Both pathogens are associated with gastrointestinal illness. The dormant Giardia cysts and Cryptosporidium oocysts are carried in animals in the wild and on farms.

3.2.5 Radiological Characteristics

The use of atomic energy as a power source and the mining of radioactive materials, as well as naturally occurring radioactive materials, are sources of radioactive substances in drinking water. Drinking water standards have been established for alpha particles, beta particles, photons emitters, radium-226 and -228, and uranium.

Although no standard has been established for radon, it is of concern because it is highly volatile and is an inhalation hazard from showering. Its decay products (218 Po, 214 Po, and 214 Bi) release alpha, beta, and gamma radiation.

3.2.6 Raw Water Characteristics

The quality of the raw (untreated) water plays a large role in determining the unit operations and processes required to treat the water. A comparison of the source water quality with the desired finished water quality provides a basis for selecting treatment processes that are capable of achieving the required treatment efficiency.

In addition to the regulated constituents discussed under "Water Quality Standards" in the next section there are a number of other common analyses used to assess the characteristics of the water with respect to potential treatment requirements. That is, the need for treatment, the difficulty of treatment, and the unit operations and processes that may be required. These are listed in Table 3.3 by the test used for their determination.

If the client's water quality objectives include a soft finished water and the source water is a groundwater or a surface water with a large groundwater contribution, the dissolve cations and anions as well as alkalinity, carbon dioxide, pH, and total hardness are of particular interest. For surface water that will not be softened, sodium, alkalinity, conductivity, pH, and total organic carbon provide useful information beyond the regulated compounds.

For expansion of existing plants, these data may be readily available. Because groundwater quality is not highly variable, annual grab samples provide sufficient data for plant design. Becausesurface water is often highly variable in composition, more extensive time dependent data are desirable.

The ability of a selected design to consistently meet regulatory and client water quality goals is enhanced when the range of the source water quality is within the range of quality that the plant can successfully treat (Logsdon et al., 1999).

In addition to the chemical analyses, it is imperative that the design engineer conduct a sanitary survey (AWWA, 1999). This is a field investigation that covers a large geographic area beyond the immediate area surrounding the water supply source. The purpose of the sanitary survey is to detect potential health hazards and assess their present and future importance. This assessment includes such things as landfills, hazardous waste sites, fuel storage areas, industrial plants, and wastewater treatment plants.

Table 3.3 Common analyses to characterize raw water

Alkalinity	Iron
Bicarbonate	Manganese
Carbonate	Magnesium
Total	pH
Ammonia	Nitrate
Arsenic	Nitrite
Calcium	Silica
Carbon dioxide	Sodioum
Chloride	Total hardness
Conductivity	Total Kjeldahl nitrogen
Hydrogen sulfide	Total organic carbon
Hydroxide	Turbidity

3.2.7 Water Quality Standards

Water quality primary standards are a crucial element in setting the design criteria for a water supply project. (Guidelines for drinking-water quality, fourth edition. World Health Organization 2011) The standards apply to both the treatment plant and the distribution system. Secondary standards also provided for the establishment of an additional set of standards to prescribe maximum limits for those contaminants that tend to make water disagreeable to use, but that do not have any particular adverse public health effect. These secondary maximum contaminant levels are the advisable maximum level of a contaminant in any public water supply system. The primary and secondary maximum contaminant levels are the maximum allowed (or recommended) values of the various contaminants. However, a reasonable goal may be much lower than the MCLs themselves.

3.3 Drinking water consumption

3.3.1 Drinking water design capasity

A fundamental prerequisite to begin the design of water supply facilities is a determination of the design capacity. This, in turn, is a function of water demand. The determination of water demand consists of four parts: (1) selection of a design period, (2) estimation of the population, commercial, and industrial growth, (3) estimation of the unit water use, and (4) rating of the variability of the demand.

Water supplied by municipalities may be divided into:

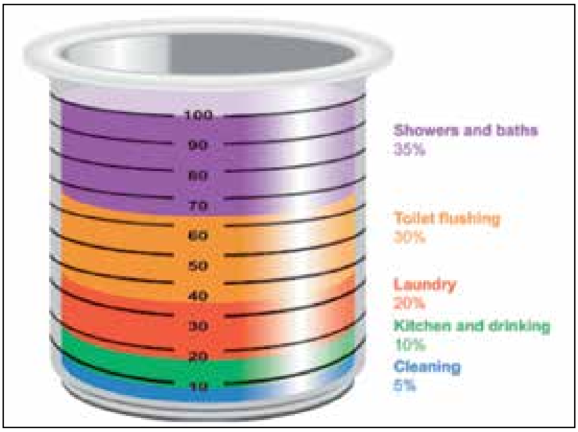
- Household use
- Use by industries connected to the central network
- Public services (schools, hospitals etc.)
- Losses and own municipal use

The production of drinking water in Sweden is shown in Table 3.4 At a total household consumption of 200 l/p/d (liters per person per day), the percentage

Table 3.4. Drinking water consumers in Sweden 1994 (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

Figures in table are 20 years old



is it for the world or
Sweden??

Figure 3.3. The percentage distribution of water use for various household purposes (Copyright © 2014. Kimberlite Softwares Pvt. Ltd., India. All rights reserved. World of Chemicals.)

distribution of water use for various household purposes is shown in Figure 3.3 (Copyright © 2014. Kimberlite Softwares Pvt. Ltd., India. All rights reserved. World of Chemicals.)

3.3.2 Reducing of drinking water consuption

There are many ways to reduce an area's water consumption without neglecting crucial functions of the water supply.

- Reducing leakage from water distribution networks
- Making industrial process more efficient
- Making faucets and water-consuming equipment in households, schools and the like (washing machines, dishwashers, low-flushing toilets etc.) more efficient
- Artificial groundwater production (to reduce evaporation)
- More efficient irrigation (to reduce evaporation)
- Reuse and re-circulation of treated wastewater

Generally, households water users can be divided into two basic groups: system users (such as residential users, industries, and farmers) and system operators (such as municipalities, state and local governments, and privately owned suppliers). These users can choose from among many different water use efficiency practices, which fall into two categories:

- Engineering practices: practices based on modifications in plumbing, fixtures, or water supply operating procedures
- Behavioral practices: practices based on changing water use habits

Engineering practices for residential users involves low-flush toilets, toilet displacement devices, low-flow showerheads, faucet aerators, pressure reduction, gray water use, landscape irrigation, xeriscape landscapes (xeriscape landscaping uses all of the following: planning and design, soil analysis, selection of suitable plants, practical turf areas, efficient irrigation, use of mulches, and appropriate maintenance (Welsh et al., 1993).

Behavioral Practices for residential users involve changing water use habits so that water is used more efficiently, thus reducing the overall water consumption in a home. These practices require a change in behavior, not modifications in the existing plumbing or fixtures in a home. Behavioral practices for residential water users can be applied both indoors in the kitchen, bathroom, and laundry room and outdoors.

Engineering Practices for System Operators involves metering, submetering, leak detection, water main rehabilitation, water reuse, well capping.

Planning and management practices for system operators involves pricing, increasing block rate, or tiered pricing, decreasing block rate pricing, time-of-day pricing, water surcharges, public education (How water is delivered to them, the costs of water service, why water conservation is important, how they can participate in conservation efforts.)

The highest amount of water savings, 20-35 liters per person and day (87.5%), can be achieved by installing new low-volume-flushing toilets. A 20-year old toilet bowl uses about 8-9 liters per flushing. A modern toilet bowl often uses 6 liters and a water-saving toilet uses less than 3 liters. The urine-separating water toilet uses about 5 to 8 liters per person and day. (However, if the toilet bowl uses too small an amount of water, problems may arise due to blockage of the small sewer pipes.) Installation of new water-saving dishwashers can reduce water use by 20-30 liters per person and day (62.5%) and modern washing machines reduce water use by 10-20 liters per person and day (50%).

3.3.3 Virtual water

The growing water concerns and issues have led to the development of new concepts. One such idea is ‘virtual water’ concept. This is regarded as one of the water saving methodology in product production. It refers, in the context of trade, to the water used in the production of a good or service. Hoekstra and Chapagain have defined the virtual-water content of a product as “The volume of freshwater used to produce the product, measured at the place where the product was actually produced.” It refers to the sum of the water use in the various steps of the production chain.

Professor John Anthony Allan from King's College London and the School of Oriental and African Studies have created this concept, which measures how water is embedded in the production and trade of food and consumer products.

Virtual water trade refers to the idea that when goods and services are exchanged, so is virtual water. When a country imports one tonne of wheat instead of producing it domestically, it saves about 1,300 cubic metre of real indigenous water. If this country is water-scarce, this water 'saved' can be used towards other ends. If the exporting country is water-scarce, however, it has exported 1,300 cubic metre of virtual water since the real water used to grow wheat will no longer be available for other purposes. (Copyright © 2014. Kimberlite Softwares Pvt. Ltd., India. All rights reserved. World of Chemicals.)

3.4 Evaluation of process options

In the design process, the data gathered from different sources would be sufficient to begin screening alternative supply and treatment options. In most cases a number of options will be available.

3.4.1 Plant sizing and layout

Once the preliminary selection of the water treatment unit operations and processes has been, rough calculations are made to determine sizes to be used in examining feasibility of site locations and cost. The elements to be considered in plant sizing include:

(1) number and size of process units, and

(2) number and size of ancillary structures.

The layout should include: (1) provision for expansion, (2) connection to the transportation net, (3) connection to the water distribution system, and (4) residuals handling system.

Number and Size of Process Units

To ensure the provision of water to the public water supply, in general, a minimum of two units is provided for redundancy. When only two units are provided, each shall be capable of meeting the plant design capacity. Normally, the design capacity is set at the projected maximum daily demand for the end of the design period. The size of the units is specified so that the plant can meet the design capacity with one unit out of service. Consideration should also be given to the efficiency/effectiveness of the process units with the low demand at start up of the facility.

Number and Size of Ancillary Units

The ancillary units include: administration building, laboratory space, storage tanks, mechanical building for pumping facilities, roads, and parking. The size of these facilities is a function of the size of the plant. In small to medium sized facilities, particularly in cold climates and when land is expensive, administration, laboratory, pumping and storage are housed in one building. The storage tanks include those for chemicals, treated water, and in some instances fuel. Space for storage of chemical residuals must also be provided.

Plant Layout

When space is not a constraint, a linear layout generally allows the maximum flexibility for expansion. Redundancy is enhanced if the units are interconnected in such a way that the flow through the plant can be shuttled from one treatment train to another. Because chemicals must be delivered to the plant, connection to the transportation net becomes an integral part of the layout. Likewise, because residuals are generally transported off-site, the residuals handling system is an integral part of the plant layout.

Plant location

Ideally a site comparison study will be performed after alternatives have been screened and rough sizing of the processes is complete. Many factors may preclude the ideal situation. For example, in highly urbanized areas the availability of land may preclude all but one site. In some cases the availability of land may force the selection of processes that fit into the available space. Given that more than one site is available; there are several major issues to be considered. Cost is a major element in the selection process. In addition, the site should allow for expansion. The location of the plant relative to the transportation net, raw water supply, and the service area should be weighed carefully. The physical characteristics of the site alternatives that must be evaluated include the potential for flooding, foundation stability, groundwater intrusion, and the difficulty in preparing the site. For example, the need for blasting of rock may make the cost prohibitive for an otherwise ideal site. Other issues to be considered include wetland infringement, the availability of alternate, independent sources of power, waste disposal options, public acceptance, and security.

Chapter 3 sources:

1-Bengt Hultman, Erik Levlin, Lena Johansson, Nasik Al-Najjar, Puhua Li & Elzbieta Paza Municipalities And Water Use, BUP Environmental science, Chapter 13, Lars-Christer Lundin & Lars Ryden.

2-Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy

3-Guidelines for drinking-water quality, fourth edition. World Health Organization 2011

4-Mackenzie L. Davis Water and Wastewater Engineering: Design Principles and Practice, McGraw-Hill New York (2010) ISBN: 978-0-07-171385-6, 1301p.

5- EPA. “Ground water and drinking water - Customer Service.”

6-SanPin 2.1.4.1074-01 “Drinking Water. Hygienic requirements for water quality of centralized drinking water supply. Quality Control.”

7-SanPin SanPin 2.1.4.1116-02 “Drinking Water. Hygienic requirements for water quality, packaged in a container. Quality Control. “

??

Table 13.2. Video materials for chapter 1-4 ”Municipalities and water use “

Chapters	Video	Time Min Sec
1. Urban Water Use and Management	1.0.1_WaterTP 1.0.2_WWTP Tour	3:21 26:1
1.1. Municipalities and Water Use	1.1.1_Urban WW Manage 1.1.2_Ecovillage 1.1.3_Water Use 1.1.4_Recycling Water 1.1.6_Media filtration process 1.1.7_Spiral wounded membranes	9:24 19:1 2:31 2:11 3:37 3:21

Chapter 4
Water Supply and Water Purification

4.1 Urban water supply regulation

Guidelines for the assessment and improvement of service activities relating to drinking water have been published in the form of International standards for drinking water such as ISO 24510.

European Union

The EU sets legislation on water quality. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, known as the Water framework directive, is the primary piece of legislation governing water. The Drinking Water Directive relates specifically to water intended for human consumption.

Each member state is responsible for establishing the required policing measures to ensure that the legislation is implemented. For example, in the UK the Water Quality Regulations prescribe maximum values for substances that affect wholesomeness and the Drinking Water Inspectorate polices the water companies.

United States

In the United States, the Environmental Protection Agency (EPA) sets standards for tap and public water systems under the Safe Drinking Water Act (SDWA) The Food and Drug Administration http://en.wikipedia.org/wiki/Food_and_Drug_Administration(FDA) regulates bottled water as a food product under the Federal Food Drug and Cosmetic Act (FFDCA). Bottled water is not necessarily more pure, or more tested, than public tap water. Peter W. Preuss, head of the U.S. EPA's division analyzing environmental risks, has been "particularly concerned" about current drinking water standards, and suggested in 2009 that regulations against certain chemicals should be tightened.

Russian Federation

Further information: water supply and sanitation in Russia

- A list of normative documents that regulate the quality of drinking water in Russia:
- Sanitary norms and rules SanPin 2.1.4.1074-01 “Drinking Water. Hygienic requirements for water quality of centralized drinking water supply. Quality Control. “
- Sanitary norms and rules SanPin 2.1.4.1116-02 “Drinking Water. Hygienic requirements for water quality, packaged in a container. Quality Control. “

4.2 Local water supply and treatment

Water for treatment and subsequent public consumption is normally supplied from surface water bodies (rivers, lakes and reservoirs) or from groundwater aquifers. Traditionally, surface waters have been the major sources, but groundwater sources have become more and more attractive. Groundwater is more likely to be of better quality than surface water and accordingly, treatment costs will be considerably lower. The quality of Swedish groundwater is often so good that treatment is unnecessary. Groundwater can be abstracted from a well and pumped straight to the households for consumption. However, there are sometimes problems with groundwater quality, of which high iron (Fe) and manganese (Mn) concentrations are the most common. These compounds have negative influences on the taste, color and stain properties of the water. Increasing the oxygen content in the groundwater reduces these negative effects. A simple way of aerating groundwater is to pump it up from the groundwater aquifer and let it undergo aeration before infiltrating it again. The aerated water then infiltrates into the ground, but is not allowed to reach the original groundwater level before it is abstracted for consumption.

An aeration facility can be easily constructed by abstracting artesian groundwater that forms a cascade that will flow over stones placed on the ground. As explained above, the water will infiltrate into the ground after aeration but is not allowed to reach the original groundwater level before it is abstracted by abstraction wells. The distance from the artesian groundwater cascade to the abstraction wells can be fairly short, 25-30 meters.

One problem that can arise, especially in agricultural areas, is contamination of groundwater by nitrate. In Sweden, this problem is sometimes found in the southern parts of the country. If the nitrate concentration exceeds the limit (50 mg NO_3-/l), the particular groundwater source must be abandoned since there is practically no economical possibility to treat nitrate-contaminated water.

The interest in groundwater as a raw water source has increased, not only due to its higher quality, but also because the need for consumption water has increased. One way to increase the amount of groundwater is to infiltrate surface water. This is called artificial recharge of groundwater. The method can be used to increase the amount of groundwater for a small town and can also be applied on a larger scale.

4.3 Water transport in central systems Water distribution network

The water distribution network should meet the criteria of good delivery security and good water circulation. Three main kinds of networks are available:

(1) Branch networks in which every point in the water distribution net is supplied from only one direction (Figure 4.1). The system involves fairly low investment expenses. One disadvantage is that in cases of operational stoppage a relatively high number of users may be without water supply.

(2) Circulation networks in which every point in the system is supplied from two or more directions (Figure 4.2). The circulation system is somewhat more costly in initial investment expenses but has a higher level of water delivery safety.

(3) Combinations of branch and circulation networks (Figure 4.3).

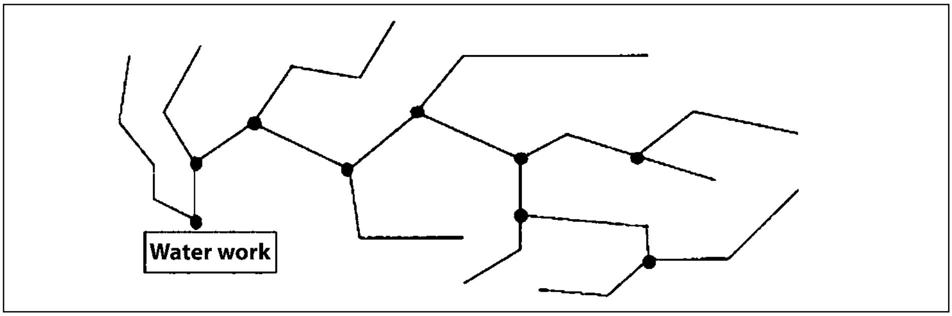


Figure 4.1. Branch water-distribution network. (Adapted from Bengt Hultman et al. BUP chapter 13)

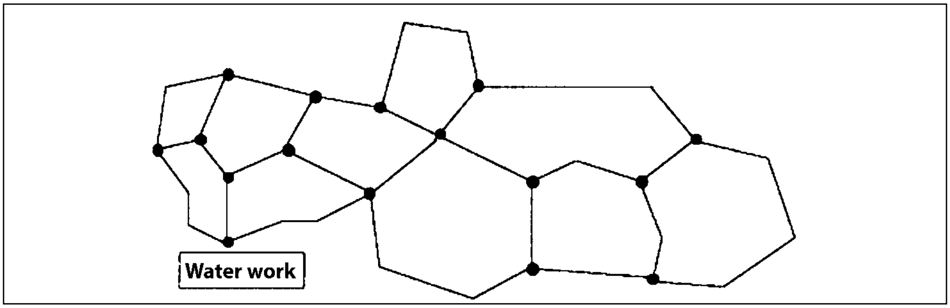


Figure 4.2 Circulation water-distribution network. (Adapted from Bengt Hultman et al. BUP chapter 13)

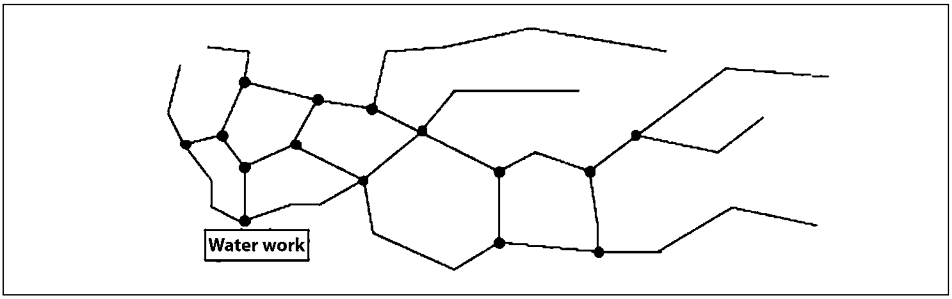


Figure 4.3 Combined branch and circulation water - distribution network. (Adapted from Bengt Hultman et al. BUP chapter 13)

4.4 Water purification in central systems

4.4.1 General purification technologies

About 25 % of the water supplied by municipalities in Sweden comes from groundwater, while 25 % is from artificial infiltration and 50 % from surface water.

If the surface water is not clean the normal procedure is to combine artificial infiltration with both pre- and post-treatment. Pre-treatment can consist of microstraining or rapid filtration, for example. Post-treatment is normally alkalinisation, which reduces corrosive properties of the water. In some cases, removal of iron and manganese is necessary. A typical treatment scheme is illustrated in Figure 4.4.

Surface water treatment must be carried out in several steps and the lower the water quality of the water source, the more stages that are normally required. A typical water treatment plant is shown in Figure 4.5

Surface water is normally pre-treated with screens and sometimes a pre-disinfection step is included to facilitate further disinfection. Chemicals are added to quickly coagulate impurities, and the following steps are flocculation and flock separation. Separation normally requires sedimentation or flotation, followed by rapid filtration. Disinfection agents are added to remove remaining pathogens. In the last treatment step, chemicals such as lime, sodium carbonate and/or sodium hydroxide are added to yield water with as low corrosive properties as possible. The treated water is then pumped to the distribution net.

4.4.2 Slow sand filter construction and principles of operation

There is an increasing interest in using slow sand filters to reduce natural organic matter (NOM) in consumption water. A slow sand filter is primarily intended for biological treatment of the water, but it must also possess physical and chemical

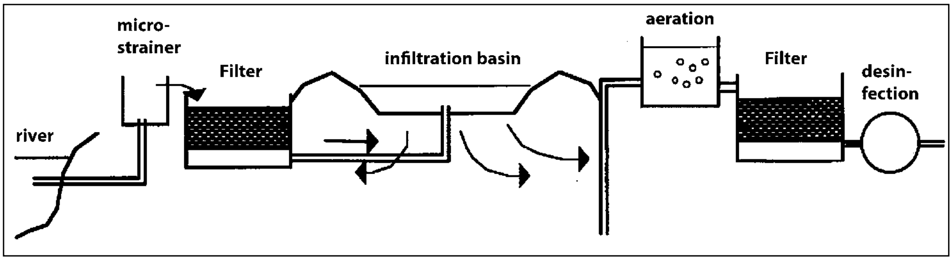


Figure 4.4 Treatment system with artificial infiltration. (Adapted from Bengt Hultman et al. BUP chapter 13)

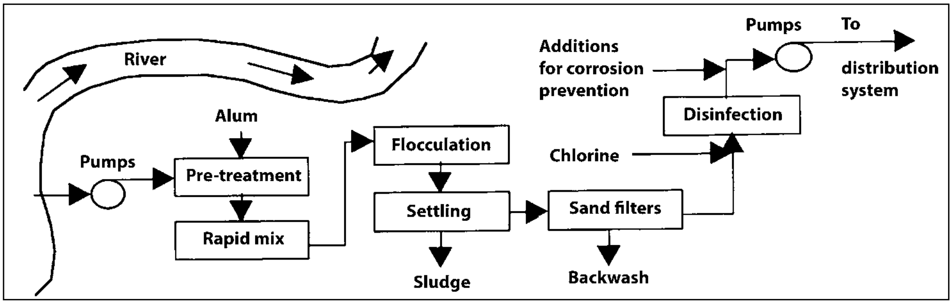


Figure 4.5 Flow sheet of a typical municipal treatment plant for a surface water supply. (Adapted from Bengt Hultman et al. BUP chapter 13)

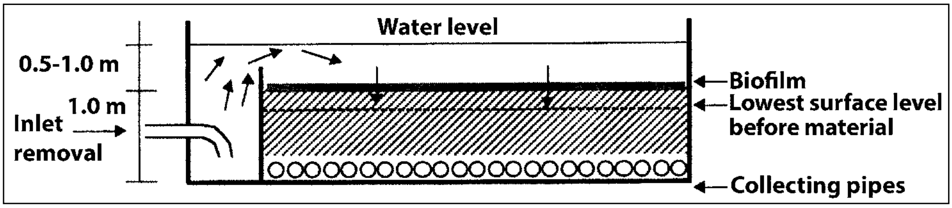


Figure 4.6. Slow sand filter. (Adapted from Bengt Hultman et al. BUP chapter 13)

removal capacities to work satisfactorily. The slow sand filter reduces odor and taste that are caused by organic matter.

The basic principles of a slow sand filter construction are shown in Figure 4.6. The thickness of the filter in the beginning is approximately 1 m and the particle size of the sand grains is roughly 0.30 mm. Every time the filter is cleaned, 15-25 mm of the sand layer are removed. When the filter measures only about 0.75 m, the filter material must be replaced with new material.

In some cases, especially larger water treatment plants, the slow sand filter is preceded by a chemical pre-treatment step, but a slow sand filter can also work as the only water treatment step.

A biofilm will develop on the top of the slow sand filter after a certain period of time depending on the quality of the water being treated. This must be removed regularly, as infiltration capacity will otherwise decline. However there are no differences in water yield in slow sand filters preceded by a chemical pre-treatment step and those with only one treatment step.

4.4.3 Coagulation and floculation

Coagulation and flocculation are essential components of conventional water treatment systems that are designed to:

- Remove infectious agents,
- Remove toxic compounds that have adsorbed to the surface of particles,
- Remove precursors to the formation of disinfection byproducts, and
- Make the water palatable.

Surface water supplies contain organic and inorganic particles. Organic particles may include algae, bacteria, cysts of protozoa, oocysts, and detritus from vegetation that has fallen into the water. Erosion produces inorganic particles of clay, silt, and mineral oxides. Surface water will also include particulate and dissolved organic matter, collectively referred to as natural organic matter(NOM), that isa product of decay and leaching of organic detritus. NOM is important because it is a precursor to the formation of disinfection byproducts. Groundwater treated to remove hardness, or iron or manganese, by precipitation contains finely divided particles.

Both the precipitates and the surface water particles may, for practical purposes, be classified as suspended and colloidal. Suspended particles range in size from about 0.1µ up to about 100 min diameter (Figure 4.7). Colloidal particles are in the size range between dissolved substances and suspended particles. They are in a solid state and can be removed from the liquid by physical means such as very high-force centrifugation or by passage of the liquid through filters with very small pore spaces. Colloidal particles are too small to be removed by sedimentation or by sand filtration processes.

The object of coagulation (and subsequently flocculation) is to turn the small particles into larger particles called flocks, either as precipitates or suspended particles. The flocks are readily removed in subsequent processes such as settling, dissolved air flotation (DAF), or filtration. For the purpose of this discussion coagulation means the addition of one or more chemicals to condition the small particles or subsequent processing by flocculation. Flocculation is the process of aggregation of the destabilized particles and precipitation products.

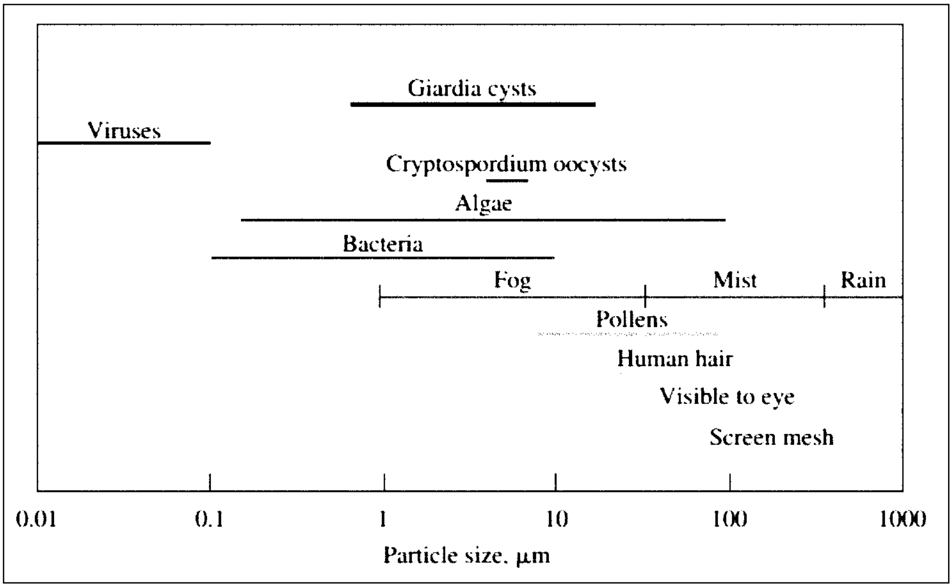


Figure 4.7 Particulates in water and miscellaneous other reference sizes. (Adapted from Mackenzie L. Davis, 2010)

Coagulants

Inorganic coagulants used for the treatment of potable water exhibit the following characteristics:

- They are non toxic at the working dosage.
- They have a high charge density.
- They are insoluble in the neutral pH range.

Physics of Coagulation

There are four mechanisms employed to destabilize natural water suspensions:

- Compression of the electric double layer,
- Adsorption and charge neutralization,
- Adsorption and interparticle bridging, and
- Enmeshment in a precipitate.

Although these mechanisms are discussed separately, in practice several mechanisms are employed simultaneously. High turbidity, high alkalinity water is the easiest to coagulate. Alum, ferric chloride, and high molecular weight polymers have been used successfully for these waters. Control of the pH is of utmost importance in coagulating high turbidity, low alkalinity water. Polymers function well. Addition of a base maybe required for alum and ferric chloride. Alum and ferric chloride at high doses can coagulate low turbidity, high alkalinity waters. A combination of alum followed by polymer often works well. For this system, that is, low turbidity and high alkalinity, polymers cannot work alone. Coagulant aids maybe required.

Low turbidity, low alkalinity waters are the most difficult to coagulate. Neither polymers nor alum/ferric chloride work alone when the turbidity and alkalinity are low. pH adjustment is required. Direct filtration should be considered for this type of water. Coagulation of color is very pH dependent. Alum, ferric chloride, and cationic polymers are effective at pH values in the range of 4 to 5. The flocks that are formed in coagulating color are very fragile.

Flocculation theory

Smoluchowski (1917) observed that small particles undergo random Brownian motion due to collisions with fluid molecules and that these motions result in particle to particle collisions. Langelier (1921) observed that stirring water containing particles created velocity gradients that brought about particle collisions. These observations provide the basis for describing the mechanisms of flocculation.

Chemical sequence

The addition of multiple chemicals to improve flocculation is common practice. The order of addition is important to achieve optimum results at minimum cost. Typically, the addition of a polymer after the addition of hydrolyzing metal salts is most effective. Ideally, the polymer addition should be made 5to 10 minutes after the addition of the hydrolyzing metal salt. This allows for the formation of pinpoint flocks that is then “bridged” by polymer. In conventional water treatment plant design this is rarely possible because of space limitations.

4.4.4 Membrane processes application for drinking water purification

Many other treatment processes can be used to supplement the treatment scheme in Figure 4.6. Active carbon may be used to remove various organic micropollutants and foul taste in the raw water. In recent years membrane technology, especially in small plants, has been introduced as an effective way of removing pollutants without having to add chemicals.

Reverse osmosis (RO), nanofiltration (NF), and electrodialysis are membrane processes that use the differences in permeability of water constituents as a separation technique. The membrane is a synthetic material that is semi permeable;

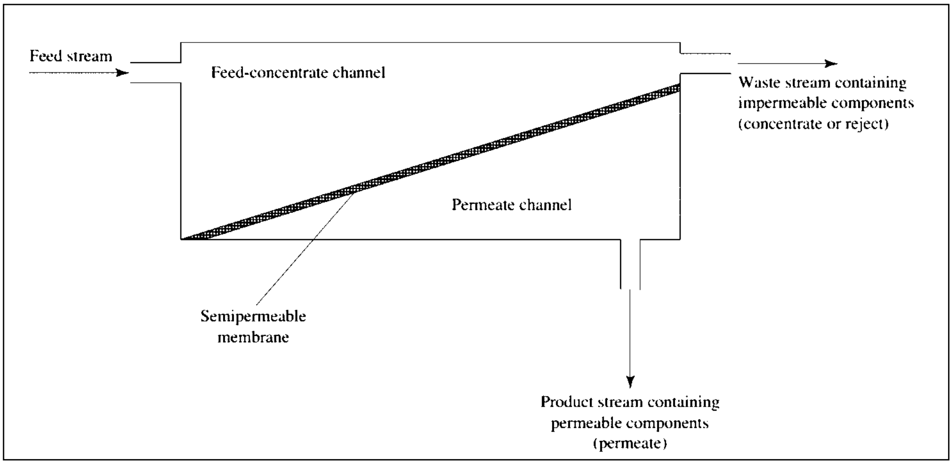


Figure 4.8 Schematic of separation process through reverse osmosis or nanofiltration membrane. (Adapted from Mackenzie L. Davis, 2010)

fig 13

that is, it is highly permeable to some constituents and less permeable to others. To remove a constituent from the water, the water is pumped against the surface of a membrane resulting in a separation of product and waste streams as shown in Figure 4.8.

Four types of pressure driven membranes are generally recognized: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). The hierarchy of the processes is identified by the types of materials rejected, operating pressures, and nominal pore sizes on an order-of-magnitude basis. These are shown schematically in Figure 4.9. In the past, there was a distinction made between RO and NF membranes based on their original manufactured properties and permeation capabilities. The differences have blurred with the introduction of new RO membranes. The new RO membranes, called “loose” RO, “softening membranes,” and “low-pressure” RO, have discriminating characteristics similar to the NF membranes. Although the distinctions are important from a theoretical point of view, the remainder of the discussion will treat NF/RO systems together for design and operational considerations.

4.4.5 Mechanisms of Disinfection

The mode of action by which disinfectants inactivate or kill microorganisms is dependent on a large number of variables. This brief overview is limited to some of the common water disinfectants and two broad classes of microorganisms: bacteria and viruses.

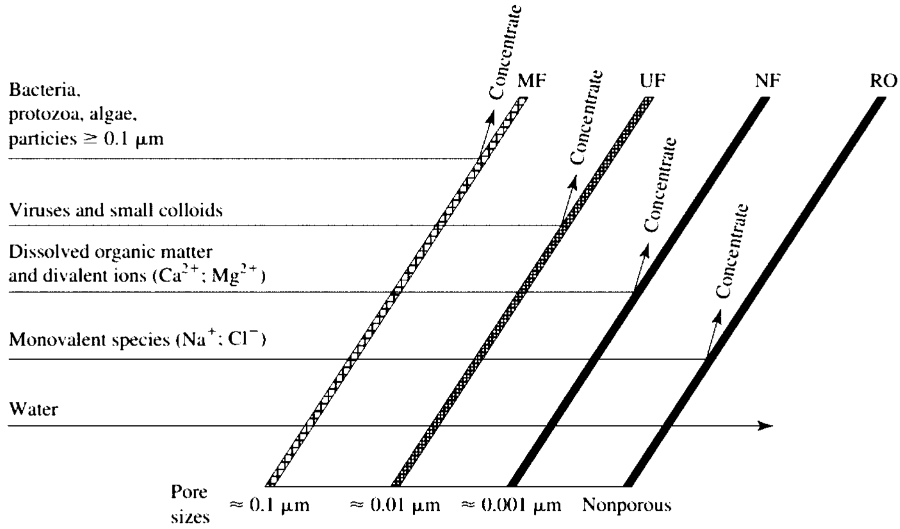


Figure 4.9 Common constituents removed by membrane processes. MF - microfiltration; UF - ultrafiltration; NF - nanofiltration; RO - reverse osmosis (Adapted from Mackenzie L. Davis, 2010)

Chlorine

The chlorine must penetrate into the bacterial cell to cause inactivation. In bacteria, respiratory, transport, and nucleic acid activity are all adversely affected. In bacteriophage, the mode of action appears to be disruption of the viral nucleic acid, while in poliovirus the protein coat is affected.

Chlorine Dioxide

The Chlorine Dioxide physiological mode of inactivation is attributed to disruption of protein synthesis. Disruption of capsid functions in activates viruses.

Ozone

Ozone although complicated by measurement difficulties, physicochemical damage to DNA appears to be the mechanism of inactivation of both bacterial cells and poliovirus. This includes attack on the bacterial membrane, disruption of enzymatic activity, and nucleic acids. The first site for virus inactivation is the virion capsid.

UV Radiation

The UV radiation causes specific deleterious changes in microorganism nucleic acids. DNA absorb slight in the ultraviolet range – primarily between 200 and300 nanometers (nm). UV light is most strongly absorbed by DNA at 253.7 nm. If the DNA absorbs too much UV light, it will be damaged and will be unable to replicate. It has been found that the energy required to damage the DNA is much less than that required to actually destroying the organism. The effect is the same. If a microorganism cannot reproduce, it cannot cause an infection

Chapter 4 sources

1- Mackenzie L. Davis Water and Wastewater Engineering: Design Principles and Practice, McGraw-Hill New York (2010) ISBN: 978-0-07-171385-6, 1301p.

2- Bengt Hultman, Erik Levlin, Lena Johansson, Nasik Al-Najjar, Puhua Li & Elzbieta Paza Municipalities And Water Use, BUP Environmental science, Chapter 13, Lars-Christer Lundin & Lars Ryden.

3 -ISO 24510 Activities relating to drinking water and wastewater services. Guidelines for the assessment and for the improvement of the service to users

4-"The Water Framework Directive: A New Directive for a Changing Social, Political and Economic European Framework". European Planning Studies, (Taylor and Francis Group) 11 (3): 299–316.

Chapters	Video	TIME MIN:SEC
1. Urban Water Use and Management	1.0.1_WaterTP	3:21
	1.0.2_WWTP Tour	26:1
1.1. Municipalities and Water Use	1.1.1_Urban WW Manage	9:24
	1.1.2_Ecovillage	19:1
	1.1.3_Water Use	2:31
	1.1.4_Recycling Water	2:11
	1.1.6_Media filtration process	3:37
	1.1.7_Spiral wounded membranes	3:21

II

Urban Wastewater Treatment

Chapter 5
General Wastewater Contamination, Collection and Treatment Design Considerations

5.1 Age of stringent environmental standards

5.1.1 Growing environmental standards in the World

Wastewater is not a new phenomenon. Every city throughout history has produced contaminated water.

In older civilizations it was simply emptied onto the street, or at best led away into a ditch. As a result, diseases such as cholera spread easily through cities, and the stench must have been indescribable.

The problem of contaminated water was understood back in the time of the Romans. In around 400 BC the Romans laid the first sewer in Rome, known as the Cloaca Maxima. By taking away wastewater in a closed system they succeeded in improving the city environment. There are letters from that time that describe Rome as smelling as sweet as the mountains.

The treatment of wastewater is a more recent invention. The first places to introduce wastewater treatment were early industries, which could inflict severe local pollution on the recipient water. This began at the end of the nineteenth century, but it was not until around the 1930s that municipal wastewater treatment became more widespread. Initially the water was simply treated mechanically, but as the years passed and urbanisation increased, the treatment methods became more sophisticated. Today we can purify wastewater to any degree required; it is simply a matter of how much we are willing to pay and what requirements have to be met.

Although advanced wastewater treatment has only been developed in recent decades, we have understood the principles of mechanical, biological and chemical treatment for at least a hundred years. Since then, development has concentrated mainly on learning about the mechanisms and how the various techniques can be combined. With today's state of knowledge of the different water treatment processes we can combine the best of several worlds and treat wastewater efficiently.

The 20th century witnessed a revolution in wastewater management, environmental science and societal views towards pollution. Scientific discovery, debates on societal priorities and government interest evolved through the century beginning with unhindered pollution and ending with attempts an increasing control.

A milestone was the Eighth Report (1912) of the Royal Commission on Sewage Disposal which introduced the concept of biochemical oxygen demand (BOD) and established standards and tests to be applied to sewage and sewage effluents which were copied by many other countries. Streeter and Phelps (1925) and Imhoff and Mahr (1932) pioneered aeration/deaeration models that allowed scientists to predict allowable BOD loads to surface waters.

Governments began to mandate waste treatment. Before the First World War led to the interruption of installation of wastewater treatment facilities, they were constructed in the main cities of Europe (Seeger, 1999; Cooper, 2007).

However political ideology interfered with wastewater management in some countries. For example, when the national socialist party came into power in Germany, they brought with it a change in the practice of wastewater treatment: the priority was given to agricultural utilisation in the form of widespread irrigation of wastewater according to the "Blood and Soil" ideology rather than treatment of the pollutants prior to use.

The Second World War also delayed development of wastewater treatment until 1948 causing increasing pollution to the waters. In addition many wastewater plants were damaged during the war and not rebuilt for many years. After the end of the war there was rapid progress in wastewater treatment in the United Kingdom and the United States, but not Europe.

By 1950 pollution debates focused on water quality standards and stream use classification, necessary precedents to the development of a waste management policy. As early as the beginning of the twentieth century, there was an understanding of the general association between chemical water pollution and toxicity. A further advance in the understanding of environmental contamination came about with commercially available gas chromatography and atomic absorption spectrophotometry in the late 1970. This allowed for accurate characterization of pollutants.

5.1.2 Growing environmental standards in Sweden

The public water network began to be built in Sweden about a century ago. It was in the larger communities that the first stage of constructing municipal water and sewage management took place. This construction is generally regarded as having been complete around 1920, by which time most of the largest cities had sewage pipe networks.The pipes replaced earlier sewage gutter leadoff, which was used for flush-water and sometimes also for disposal of trash and excrement. The solution to the environmental problems of the time was to construct sewage pipe networks, an enterprise that involved a major economic sacrifice. Pollutants were removed from the municipalities to the nearest water area.

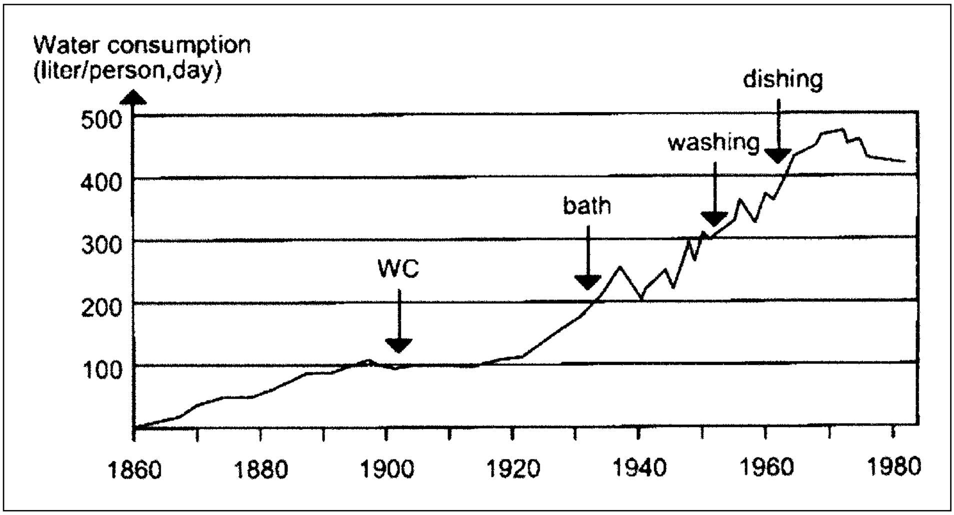


Figure 5.1 Water use in Stockholm between 1860 and 1980 (Cronström, 1986).

In 1859 the first water closet was installed in Stockholm, but it took many decades before the royal castle got this new convenience. The advantage of being spared the abhorred latrine collection soon became obvious and from the turn of the century most new houses in the big cities were provided with water closets. The closet outlet was connected to a single sewage pipe and the combined wastewater system was introduced. When the public water and sewage networks had been built, the use of water for various purposes increased significantly (Figure 5.1).

The inconvenience of the combined transport of toilet water and stormwater soon became noticeable. The treatment plants did not have the capacity to take care of the entire runoff during storms. A part of the untreated wastewater had to be led past the treatment plant and by passed out in the recipient. In addition, flooding of basements became more common.

To solve these problems a new phase of the network construction was initiated in 1955. From that time all new sewage networks were built as duplicate systems, where wastewater and stormwater were drained in separate pipes. This was done without any official recommendation.

The latest construction phase of sewage systems started with the 1969 environmental protection legislation. Due to generous governmental subsidies, an extensive network of high-grade sewage treatment works was completed in the 1970s.

In Sweden there are now approximately 2 000 municipal wastewater treatment plants and plants with tertiary treatment, i.e. biological and/or chemical

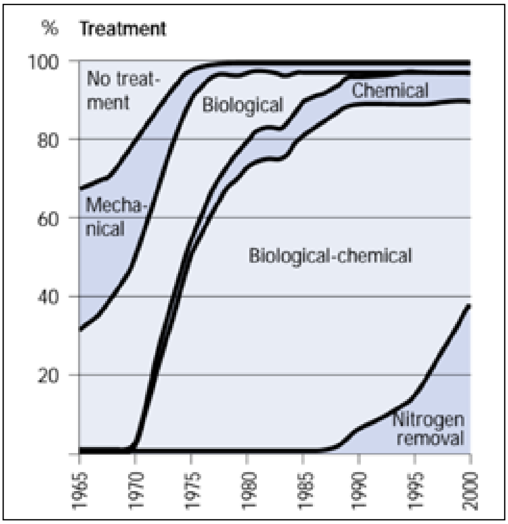


Figure 5.2 Municipal wastewater treatment in Sweden, 1965-2000 (Bengt et al. BUP).

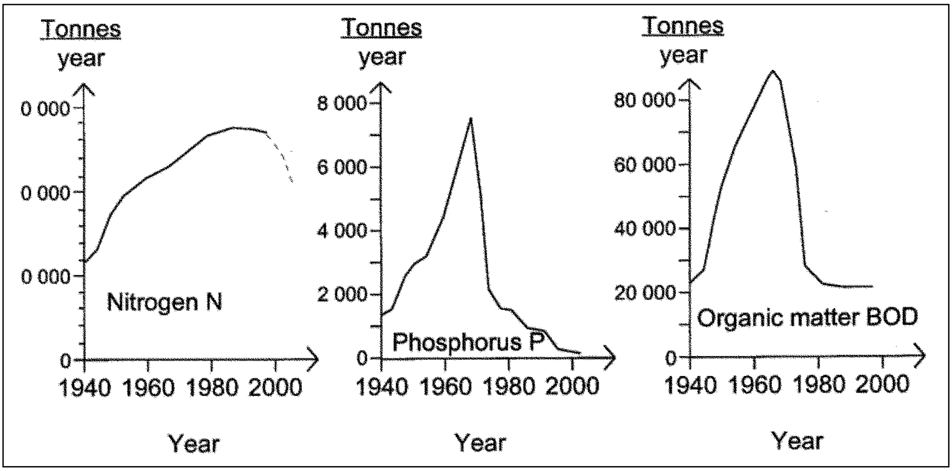


Figure 5.3 Discharges of nitrogen, phosphorus and organic matter from municipal wastewater treatment plants. (Bengt et al. BUP)

treatment, which serve 95 % of the population in towns and districts with more than 200 inhabitants (Figure 5.2). As a result of improved municipal wastewater treatment, pollution discharges have been reduced substantially (Figure 5.3).

Developments in wastewater treatment systems have been strongly influenced by developments in society. Varying driving forces have changed priorities from an initial focus on hygienic aspects via gradual improvements of treatment methods to a focus – in addition to earlier requirements – on recycling resources,

Table 5.1. Developments in Swedish water and wastewater handling systems

Time period	Driving forces in society (examples)	Effects on environment	Remedies
Before 1930	Population growth; urbanisation	Contamination of local water sources; 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; rapid growth of economy	Impairment of the environment due to discharges of different substances, although compensated by different remedies	Improved environmental quality especially on a local scale due to decreases of discharges
1990 -	Increased awareness of environmental issues and its relation to life style	Gradual building of water and wastewater handling infrastruc- ture incl. different treatment steps (cf. Figure 1); efficient control of industrial discharges	Development of Agenda 21; multi-disciplinary approaches to problem solutions; use of international environmental standards as EMAS and ISO14000

saving and recovering energy, public participation and interactions with other sectors in society. Developments in water and wastewater handling systems are illustrated in Table 5.1.

It is increasingly being recognized that the real causes of pollution are not the discharges that should be controlled and contained within sewage treatment, but rather the society's non-harmonised socio-economic development. In the future, the transfer of environmental control to internal elements of the economy and of general overall management will be a major task of the coming decades. This is often termed prevention, intensive environmental management or sustainable development. The success of this shift will greatly depend on whether legislation and policy-making are able to live up to the complex and challenging requirements of the next century and the changing attitudes of societies. The future framework of water pollution control will be much wider than that of today, will incorporate soft and hard elements belonging to various disciplines and sectors and should incorporate a large number of feedback mechanisms. It will cover, among other issues of non-point source management, policy making, project evaluations, institutions and public opinion.

5.2 Components of Wastewater contamination

5.2.1 Characteristics of Domestic Wastewater

Wastewater classification

Wastewater may be classified in to the following components:

- Domestic or sanitary wastewater. Wastewater discharged from residences, commercial (e.g., banks, restaurants, retail stores), and institutional facilities (e.g., schools and hospitals).
- Industrial wastewater. Wastewater discharged from industries (e.g., manufacturing and chemical processes).
- Infiltration and inflow (I/I).Water that enters the sewer system from ground water infiltration and stormwater that enters from roof drains, foundation drains, and submerged manholes.
- Storm water. Runoff from rainfall and snow melt.

Domestic or sanitary wastewater is a mixture of toilet water, grey-water, industrial wastewater, drainage water, and, in a combined system, also stormwater. The composition of wastewater is a mixture of pollutants coming from the different sources.

The nature and composition of wastewater

Contaminants

Wastewater contains most of the substances found in our society. These can be divided into:

- suspended solids
- oxygen-demanding substances
- nutrients
- bacteria
- viruses
- parasite spores
- heavy metals
- environmentally harmful substances

Another way of classifying contaminants is to divide them into organic and inorganic matter. The organic contaminants generally comprise around one-third each of dissolved, colloidal and suspended solids. The inorganic material mainly comprises dissolved substances.

Physical Characteristics of Domestic Wastewater.

Fresh, aerobic, domestic wastewater has been said to have the odor of kerosene or freshly turned earth. Aged, septic sewage is considerably more offensive to the olfactory nerves. The characteristic rotten-egg odor of hydrogen sulfide and the mercaptans is indicative of septic sewage. Fresh sewage is typically gray in

Table 5.2 Organic constituents of municipal wastewater.

Substance	Percentage organic carbon in wastewater
Carbohydrates	11–18%
Proteins	8–10%
Free amino acids	0,5–1,5%
Higher fatty acids	23–25%
Soluble organic acids	7–11%
Esterified fatty acids (fat)	9–12%
Surfactants	4–6%
Others	25–28%
The concentration of organic substances is usually measured as: • biochemical oxygen demand (BOD) • chemical oxygen demand (COD) • loss on ignition (LOI) • total organic carbon (TOC)	

color. Septic sewage is black. Wastewater temperatures normally range between 10ºC and 20ºC. In general, the temperature of the wastewater will be higher than that of the water supply. This is because of the addition of warm water from households and heating within the plumbing system of the structures. One cubic meter of wastewater weighsapproximately1,000,000 grams. It will contain about 500 grams of solids. One-half of the solids will be dissolved solids such as calcium and sodium salts as well as and soluble organic compounds. The remaining 250 grams will be insoluble. The insoluble fraction consists of about 125gramsof material that will settle out of the liquid fraction in 30 minutes under quiescent conditions. The remaining 125 grams will remain in suspension for a very long time. The result is that wastewater is highly turbid.

Chemical Characteristics of Domestic Wastewater.
Because the number of chemical compounds found in wastewater is almost limitless, we normally restrict our consideration to a few general classes of compounds. These classes often are better known by the name of the analytical procedure used to measure them than by what is included in the class. The biochemical oxygen demand (BOD 5) test is a case in point. Another closely related test is the chemical oxygen demand (COD) test.

The COD test is used to determine the oxygen equivalent of the organic matter that can be oxidized by a strong chemical oxidizing agent (potassium dichromate) in an acid medium. The COD of a waste, in general, will be greater than the BOD 5 because more compounds can be oxidized chemically than can be oxidized biologically and because BOD 5 does not equal ultimate BOD.

The COD test can be conducted in about three hours. If it can be correlated with BOD 5, it can be used to aid in the operation and control of the wastewater treatment plant (WWTP).

Total Kjeldahl nitrogen (TKN) is a measure of the total organic and ammonia nitrogen in the wastewater. * TKN gives a measure of the availability of nitrogen for building microbial cells, as well as the potential nitrogenous oxygen demand that will have to be satisfied.

Phosphorus may appear in many forms in wastewater. Among the forms found are the orthophosphates, polyphosphates, and organic phosphate. Together, these are referred to as "total phosphorus (as P)". The broad categories of BOD, COD, TKN, and suspended solids are divided into subcategories.

New analytical methods have made it possible to determine the levels of organic toxins, or environmentally harmful substances, more accurately. This means that some completely new expressions will be introduced in the future. These include chlorinated hydrocarbons. The following terms are used as measures of chlorinated hydrocarbons:

TOX = Total Organic Halides
AOX = Absorbable Organic Halides

However, the concentrations of organic environmental toxins are often very low, which means that these analyses have their limitations. Organic environmental toxins can become concentrated in the sludge that is removed from the treatment process. These can include PCBs, toluene, nonyl phenol and PAH. Analyses for these substances are therefore carried out on the sludge.

The current nomenclature used to characterize wastewater constituents used in the design of biological wastewater treatment processes and their shorthand designations are shown in Table 5.3.

Three typical compositions of untreated domestic wastewater are summarized in Table 5.4. Because there is no "typical" wastewater, it should be emphasized that these data should only be used as a guide. The pH for all of these wastes will be in the range of 6.5to 8.5, with a majority being slightly on the alkaline side of 7.0.

Contamination levels in wastewater show large variations between different locations depending on the type of local industry, storm water handling and the leakage of ground water.

Table 5.3 Definition of terms used to characterize important wastewater constituents used for the analysis and design of biological wastewater treatment processes (Source: Metcalf & Eddy, 2003)

Constituent	Definition
BOD	
BOD or BOD5	Total 5-d biochemical oxygen demand
sBOD	Soluble 5-d biochemical oxygen demand
UBOD or BODu	Ultimate biochemical oxygen demand
COD	
COD	Total chemical oxygen demand
bCOD	Biodegradable chemical oxygen demand
pCOD	Particulate chemical oxygen demand
sCOD	Soluble chemical oxygen demand
nbCOD	Nonbiodegradable chemical oxygen demand
rbCOD	Readilybiodegradable chemical oxygen demand
rbsCOD	Readilybiodegradable soluble chemical oxygen demand
sbCOD	Slowlybiodegradable chemical oxygen demand
bpCOD	Biodegradable particulate chemical oxygen demand
nbpCOD	Nonbiodegradable particulate chemical oxygen demand
nbsCOD	Nonbiodegradable soluble chemical oxygen demand
Nitrogen	
TKN	Total Kjeldahl nitrogen
bTKN	Biodegradable total Kjeldahl nitrogen
sTKN	Soluble (filtered) total Kjeldahl nitrogen
ON	Organic nitrogen
bON	Biodegradable organic nitrogen
nbON	Nonbiodegradable organic nitrogen
pON	Particulate organic nitrogen
nbpON	Nonbiodegradable particulate organic nitrogen
sON	Soluble organic nitrogen
nbsON	Nonbiodegradable soluble organic nitrogen
Suspended Solids	
TSS	Total suspended solids
VSS	Volatile suspended solids
nbVSS	Nonbiodegradable volatile suspended solids
iTSS	Inert total suspended solids
	Note:b - biodegradable; i - inert; n -non; p - particulate; s - soluble.

Table 5.5 shows approximate typical contaminant concentrations in municipal wastewater, expressed in grams per person equivalent per day (g/person/day).

It is also possible to divide COD into substances that are biodegradable and how quickly they are broken down. The composition of wastewater can also be classified according to particle size, volatile fatty acids (VFA), proteins, etc., as shown in Figure 5.4.

Domestic wastewater contains grey-water from washing dishes, washing and bathing and toilet water urine and faeces. Table 5.6 shows the average values of pollutants and nutrients in Swedish domestic wastewater in gram per person and day. A major part of the nutrients originates in the urine. Grey water contains nu-

Table 5.4 Typical composition of untreated domestic wastewater (Adapted from Metcalf & Eddy, 2003)

Constituent (all mg/L except settleable solids)	**Weak**	**Medium**	**Strong**
Alkalinity(asCaCO3)	50	100	200
Ammonia (free)	10	25	50
BOD5(asO2)	100	200	300
Chloride	30	50	100
COD (asO2)	250	500	1,000
Total suspended solids (TSS)	120	210	400
Volatile (VSS)	95	160	315
Fixed	25	50	85
Settleable solids, mL/L	5	10	20
Sulfates	20	30	50
Total dissolved solids(TDS)	200	500	1,000
Total Kjeldahl nitrogen (TKN) (asN)	20	40	80
Total organic carbon (TOC) (asC)	75	150	300
Total phosphorus (asP)	5	10	20

Table 5.5 Typical contaminant concentrations in municipal wastewater.

Contaminants	**g/p•d**
Chemical oxygen demand (COD)	120–180
Biochemical oxygen demand (BOD7)	60–90
Phosphorus (P)*	2,0–3,5
Nitrogen (N)	10–14
Suspended solids (SS)	70–90
Total solids (TS)	150–250

trients in small amounts, with the exception of phosphorus. The average amount of grey-water is about 150 litres per person and day. The phosphorus content of grey-water depends on the use of phosphate detergents. When no phosphate detergents are used, the phosphorus content is estimated at 0.15 g/p/d. When mainly phosphate detergents are used, the content is estimated at 1.0 g/p/d.

The content of industrial wastewater can vary greatly and depends on the type of industrial process used. For instance, mercury may be released from dental practices. Source control and demand of treatment of process water have gradually decreased the pollutants originating from industrial wastewater. In Sweden, every municipality may state restrictions on what substances that may be supplied to the sewer net, for example, limiting values or prohibition of certain

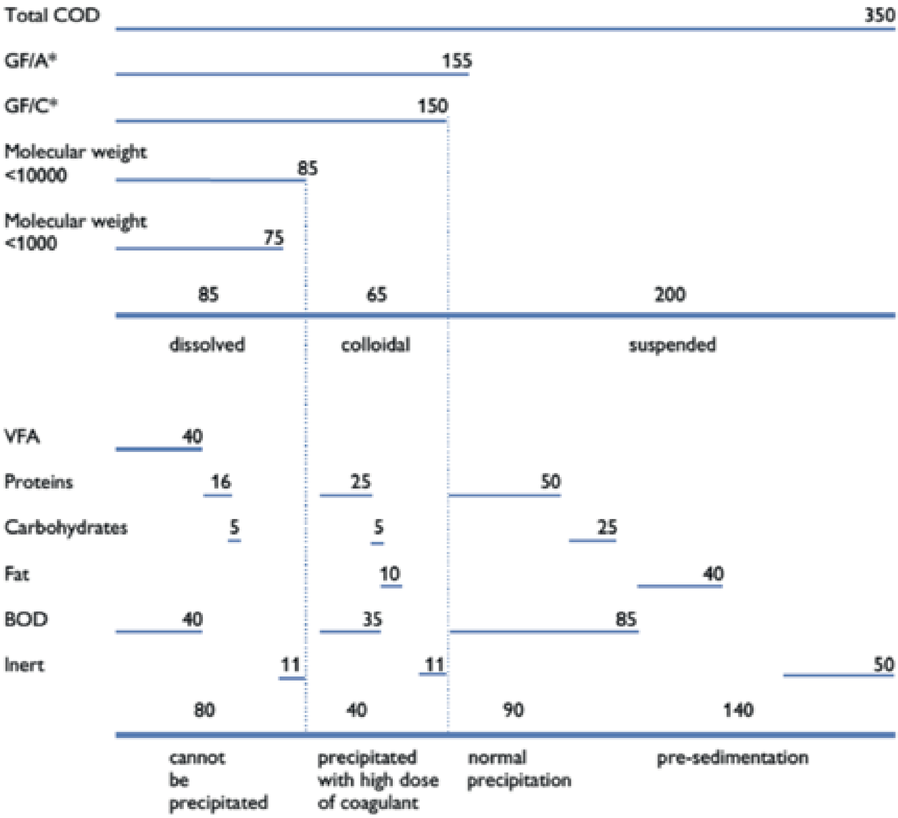


Figure 5.4 COD distribution in wastewater, according to HYPRO method, g COD/m3 (Adapted from Gilberg et al., 2003)

substances. These restrictions are valid for both connected industries and households. Industrial processes with continuous discharge are easier to trace and stop than household discharges with a more random occurrence. In general, there has been a decrease in the metal contents due to less metal use in society. Examples include a change to lead-free gasoline, a stop in the use of mercury thermometers, and a ban on cadmium in paints and in finishing. Wastewater from restaurants and offices has a composition more similar to domestic wastewater.

The content of industrial wastewater can vary greatly and depends on the type of industrial process used. For instance, mercury may be released from dental practices. Source control and demand of treatment of process water have gradually decreased the pollutants originating from industrial wastewater. In Swe-

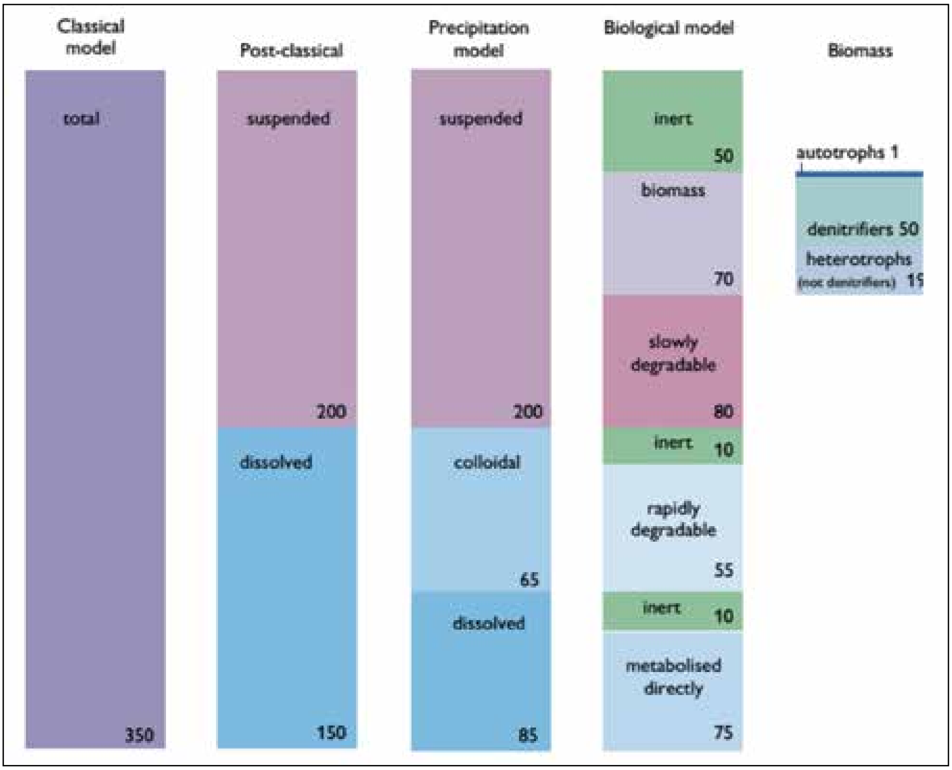


Figure 5.5 COD distribution in wastewater, g COD/m3. More advanced methods than the classical and post classical models are needed in order to choose adequate sewage treatment process. (Adapted from Gilberg et al., 2003)

den, every municipality may state restrictions on what substances that may be supplied to the sewer net, for example, limiting values or prohibition of certain substances. These restrictions are valid for both connected industries and households. Industrial processes with continuous discharge are easier to trace and stop than household discharges with a more random occurrence. In general, there has been a decrease in the metal contents due to less metal use in society. Examples include a change to lead-free gasoline, a stop in the use of mercury thermometers, and a ban on cadmium in paints and in finishing. Wastewater from restaurants and offices has a composition more similar to domestic wastewater.

Drainage water is water from house foundations and groundwater leaking into the sewer pipes. The water originates from rainwater that has infiltrated the soil. Since the soil acts as retention storage, the flow variations are not as large as for the stormwater. The flow follows the variation in stormwater flow with a detention. During extreme rainfall of long duration the drain-water flow can

Table 5.6. The average values of pollutants and nutrients in Swedish domestic wastewater

	Urine (g/p/d)	Faeces (g/p/d)	Grey-water (g/p/d)	Total (g/p/d)
Dry substance	80 (46%)	60 (34%)	35 (20%)	175
Suspended solids	27 (63%)		16 (37%)	43
BOD7	20 (42%)		28 (58%)	48
Nitrogen. N	11 (82%)	1.5 (11%)	1.0 (7%)	13.5
Phosphorus, P	1.0 (48%)	0.5 (24%)	0.6 (28%)	2.1
Potassium, K	2.5 (63%)	1 (25%)	0.5 (12%)	4.0

become too high, causing spilling of untreated water and flooding of basements. The content of drain-water is the same as that of groundwater.

5.3. Stormwater composition

Stormwater originates from runoff of rainfall on roofs and streets. Pollutants in stormwater originate from surfaces such as streets and roofs that are washed with the rainwater. The variation in pollutant content is large and varies depending on the type of surface that the runoff comes from. Stormwater has generally a higher content of metals and suspended solids and a lower content of oxygen consuming substances (BOD and COD) than domestic wastewater. At high flows the pollutants are diluted by large amounts of water and the pollutant content decreases. In duplicate systems, stormwater is often led to a recipient without treatment. Depending on rainfall, stormwater has a high flow variation and dilutes the wastewater so that the pollution content decreases when the stormwater content is high. However, the first flush contains high concentrations of pollutants. The largest problem with stormwater is that the amount of water to treat increases and that the flow sometimes can be so high that untreated wastewater must be bypassed to the recipient. This water, storm sewage, is a mixture of stormwater and other wastewater. However, the pollutant content of stormwater is often less than for normal wastewater due to dilution of wastewater with large amounts of stormwater. At high stormwater flows there is also a risk for flooding of basements.

Chapter 5 sources

1-Bengt Hultman, Erik Levlin, Lena Johansson, Nasik Al-Najjar, Puhua Li & Elzbieta Paza Municipalities And Water Use, BUP Environmental science, Chapter 13, Lars-Christer Lundin & Lars Ryden.
2-EPA. "Ground water and drinking water - Customer Service."

3-Lars Gillberg, Bengt Hansen, Ingemar Karlsson, Anders Nordström Enkel, Anders Pålsson, “About Water Treatment” Water and Wastewater Treatment: Handbook Helsingborg,Kemira Kemwater 2003, ISBN 91-631-4344-5

4-ISO 24510 Activities relating to drinking water and wastewater services. Guidelines for the assessment and for the improvement of the service to users

5-Mackenzie L. Davis Water and Wastewater Engineering: Design Principles and Practice, McGraw-Hill New York (2010) ISBN: 978-0-07-171385-6, 1301p.

6-Metcalf & Eddy (2003) Wastewater Engineering: Treatment and Reuse, 4th ed., McGraw-Hill, Boston, Massachusetts, pp. 429–430, 452–453, 563–886.

7-”The Water Framework Directive: A New Directive for a Changing Social, Political and Economic European Framework”. European Planning Studies, (Taylor and Francis Group) 11 (3): 299–316.

Chapter 6
General Wastewater Collection and Pretreatment Design Considerations

6.1 General principles of sewer collection system design

6.1.1 General definitions and considerations

The design of a sewer system generally includes the following steps: preliminary investigations, a detailed survey, the actual design, and preparation of final drawings. With the addition of a discussion of sewer nomenclature, appurtenances, and confined space safety issues, these topics form the outline of this chapter.

The design of the sewer network in a collection system is an iterative process based on the required capacity of the system for the anticipated flow rates. Trial pipe diameters are selected for the network of pipes, and a hydraulic analysis is performed for the anticipated range of conditions. Of the numerous issues that must be addressed in the network design, the following will be presented in this section:

- Estimation of wastewater flow rates.
- Pipe material selection.
- Design criteria.
- Design equations.
- Collection system layout.
- Design of a lateral or branch.

The various types of sewers in a typical wastewater collection system are described in Table 6.1 and are illustrated in Figures 6.1.

TABLE 6.1 Nomenclature of sewers in a typical collection system

Name	Description
Lateral	Lateral sewers form the first element of a wastewater collection system. They collect the wastewater from buildings and convey it to a main sewer.
Main	The main sewer conveys wastewater to trunk sewers or intercepting sewers.
Force main	This term is used to describe a pressurized pipe that is used to convey wastewater.
Trunk	Trunk sewers are large diameter sewers that are used to convey wastewater from main sewers to treatment facilities or to intercepting sewers.
Interceptor	The interceptors are very large diameter sewers that are used to intercept a number of main or trunk sewers and convey wastewater to treatment facilities.

Figures 6.1 .Lateral with exploded view of connection to main (Adapted from Mackenzie. 2010)

6.1.2 Pipe material selection

The principal sewer material for pipes with small or medium diameters is polyvinyl chloride (PVC). For larger pipe diameters, ductile iron pipe (DIP), high density polyethylene (HDPE) pipe, or reinforced concrete pipe (RCP) maybe specified. Truss pipes are becoming more common for larger pipe diameters.

Vitrified Clay Pipe (VCP). This classic pipe material has demonstrated its durability in use in the United States for over a century. It has a high resistance to corrosion and abrasion. Its major disadvantage is its high mass per unit length that makes it more difficult to handle and increases installation costs. It is rarely installed today. This pipe is made of clay or shale that has been ground, wet, molded, dried, and fired in a kiln. Near the end of the burning process, sodium chloride is added to the kiln. It vaporizes to forma hard waterproof glaze by reacting with the pipe surface. The firing of the clay produces a vitrification of the clay that makes it very hard and dense (Steel and McGhee, 1979). The pipe is manufactured with integral bell and spigot ends fitted with polymeric rings. It is available in diameters from 75 mm through 1,050 mm and lengths up to 3 m(ASCE, 1982). Pipes are typically joined with push-on gasket joints.

Polyvinyl Chloride Pipe (PVC). This pipe is made by extrusion of polyvinyl chloride. It is available in diametersfrom10 mm through 1.2 m and lengths up to 6 m (ASCE, 1982). Rubber gasket bell and spigot type joints are used to connect the pipes. This pipe has been in use for over half a century. It is almost exclusively the material of choice for pressure and vacuum sewers. Its advantages are corrosion resistance and low mass per unit length. It is subject to attack by certain organic chemicals and excessive deflection if improperly bedded. The low mass per unit length gives it some cost advantage in installation.

Ductile Iron Pipe (DIP). Its primary application for sewers is for force mains. Because wastewater is often corrosive, current practice is to use a cement mortar lining and an asphaltic outer coating. Epoxy coating maybe used in trunk sewers. DIP manufacturers recommend that the pipe be encased in a loose-fitting flexible polyethylene tube (0.2 mm thick) when the pipe is to be placed in corrosive soils.

High-Density Polyethylene (HDPE). This pipe material was primary use as an alternative pressure pipe for force mains.

Reinforced Concrete Pipe (RCP). Precast RCP is manufactured by a variety of techniques including centrifugation, vibration, packing, and tamping for consolidating the concrete in forms. Adjustment of the wall thickness, concrete strength, and reinforcing allow for a wide variety of strengths. The pipe is manufactured with integral bell and spigot ends. It is available in diameters from300 mm through 5.0 m, and lengths up to 7.5 m (ASCE, 1982). These pipes are typically joined with push-on gasket joints. The normal service for RCP is for trunk lines and interceptor sewers. Its major limitations are its high mass per unit length and its susceptibility to crown corrosion.

Truss Pipe. This pipe is made of PVC or acrylonitrile butadiene styrene (ABS). It consists of dual walls with a truss system between the walls. Sometimes the space between the walls is filled with cement. It is more rigid than PVC pipe but shares the same ease of construction.

6.1.3 Crown corrosion.

The corrosion of the crown of a sewer is the result of biochemical reactions in the sewage and in the condensed moisture at the crown of the sewer. With long sewer reaches and little oxygen transfer from the air in the sewer, or when sewage sits for long periods between pumping in force mains(e.g., in residential areas with little or no nighttime flow), the sewage becomes anoxic or anaerobic. Under these conditions, the sulfate in the sewage is reduced to sulfide. At the usual pH level of domestic sewage, the sulfide is converted to hydrogen sulfide. In poorly ventilated sewers, moisture collects on the walls and the crown. Hydrogen sulfide dissolves in this moisture. As such it does no harm.

Bacteria capable of oxidizing hydrogen sulfide, in particular those of the genus Thiobacillus are always present in sewage. At high flows, these bacteria are brought to the walls and crown where they adhere after the high flows recede. They oxidize the hydrogen sulfide to sulfuric acid by the following reaction (Sawyer et al., 2003):

This strong acid-attacks acid soluble materials such as concrete, iron, or steel. The corroded crown fails under the load of soil above it. These processes are summarized in Figure 6.2 .

Figure 6.2 Formation of hydrogen sulfide in sewers and “crown” corrosion resulting from oxidation of hydrogen sulfide to sulfuric acid. (Source: Sawyer et al., 2003.)

6.1.4 Labour safety

Water and wastewater handling involves many labour safety risks for the operating staff. These may be divided into:

- Physical risks, including mechanical injuries,drowning in open basins or sewer nets, use of electrical equipment, fire and explosions, noise and traffic.
- Chemical risks due to breathing of dangerous gases and aerosols, swallowing of toxic substances, or skincontact with dangerous substances.
- Biological risks due to breathing, swallowing or skin contact with different biological agents.
- Physical risks due to sole works, stress etc.

In general, mechanical injuries are the most important factor for injuries at work. Risks due to soleworks and stress are difficult to assess but important to consider. Specific risks in labour works at water and wastewater facilities are related to chemical and biological risks.

Much attention has been paid to the formation of toxic gases in wastewater handling. Sulphides may be supplied to the sewer net from industries and may be formed in the sewer net or in the treatment plant under conditions where no oxygen and nitrate are present. A common example is pressure pipes for transport of wastewater. Sulphides are in equilibrium with hydrogen sulphide, which may be released into the atmosphere. The main problems related with hydrogen sulphide are:

- Odour problems (rotten eggs).
- High toxicity (Table 6.2).
- Corrosiveness towards copper, iron and silver.
- Possible oxidation to sulphuric acid and subsequent corrosion of concrete and metals.

Other gases of concern include:

- Explosive gases that may be supplied to the sewer net (for instance from gasoline and solvents) and methane gas (for instance produced in anaerobic digestion).
- Low oxygen concentrations in areas with low ventilation and removal of oxygen due to biological reactions.
- Chlorine gas used in disinfection of water and wastewater.

Table 6.2. Effects of hydrogen sulphide exposure at various concentrations (Subcommittee on Hydrogen Sulfide, 1979)

Many chemicals used in water and wastewater treatment such as: acids, bases, sodium hypochlorite, precipitation agents and polyelectrolytes are potentially dangerous and should be handled carefully.

Biological agents may cause diseases among workers at water and wastewater handling facilities. Pathogens may be swallowed through direct contact. Aerosols from wastewater treatment contain endotoxins that may cause fever in exposed personnel. Contact with wastewater by the skin may cause diseases such as hepatitis and Weil's disease.

6.1.4 Pipes slope.

All sewers shall be designed and constructed to give mean velocities, when flowing full, of not less than 0.6 m/s.

Slopes are commonly calculated using the depth of the invert of the pipe. Minimum slopes to achieve 0.6 m/s are shown in Table 6.3 . Slopes greater than these maybe desirable to maintain self-cleansing velocities at all rates of flow, for construction, or to control sewer gases. A mean velocity of 0.3 m/s is usually sufficient to prevent the deposition of the organic solids in wastewater. To prevent deposition of mineral matter, a mean velocity of 0.75 m/s is required. Slopes that result in mean velocities of 0.5 m/s have been used, but these require frequent cleaning (Metcalf & Eddy, 1981).

Sewers1.2 m and larger should be designed and constructed to give mean velocities, when flowing full, of not less than 0.9 m/s.

Oversizing sewers to justify flatter slopes is prohibited. The use of larger pipes at flatter slopes will reduce the velocity well below the self-cleaning velocity.

The erosive action of the material suspended in the wastewater depends on the nature of the material and the velocity at which it is carried along. The erosive action determines the maximum safe velocity of the wastewater. In general, maximum mean velocities of 2.5to 3.0 m/sat the design depth of flow will not damage the sewer (Metcalf & Eddy, 1981).

Where velocities greater than 4.6 m/s are anticipated, special provision must be made to protect against displacement by erosion and impact. Sewers on slopes greater than 20 percent must be securely anchored.

The slope between manholes must be uniform. In general, sewers less than or equal to 600 mm in diameter must be laid with straight alignment between manholes. Curvilinear alignment of sewers large than 600 mm maybe permitted if compression joints are specified. Slopes must be increased with curvilinear alignment to maintain a minimum velocity above 0.6 m/s. The recommended practice is to use extra manholes and straight alignment between manholes.

Table 6.3 Recommended minimum slopes for gravity flow sewers (adapted from Mackenzie, 2010)

Nominal diameter, mm	Minimum slope, m/m n 0.013	Minimum slope, m/m n 0.010	Capacity, flowing full, m^3/s
200	0.0033	0.0020	0.019
250	0.0025	0.0015	0.029
300	0.0019	0.0011	0.042
350	0.0016	0.0009	0.058
375	0.0014	0.0008	0.066
400	0.0013	0.0008	0.075
450	0.0011	0.0007	0.095
500	0.0010	0.0006	0.118
600	0.0008	0.0005	0.170

Table 6.4 Typical manhole spacing for straight runs

Pipe diameter	Spacing
375 mm or less	120 m or less
450 to 750 mm	150 m
825to 1,200 mm	180 m
1,200 mm or greater	460 m

The design criteria for sewers are summarized in Table 6.5

Table 6.5 Typical design criteria for gravity sewers

Parameter	Recommendation	Comment
Pipe material	PVC	For main sewers
Pipe diameter	200 mm minimum	Nominal diameter
	Size to carry peak flow rate	See Table 19-2
Slope	To achieve 0.6 m/s	Flowing full, Manning's n 0.013, see Table 19-2
Maximum velocity	2.5 to 3.0 m/s	
Depth to crown	H = D/6 minimum	For dead load; granular soil
Alignment	Straight between manholes	600 mmor less
Manholes	Place at:	
	junction of two sewers change in vertical alignment change in horizontal alignment change in pipe size at end of each line	
Drop manholes	When inflow and outflow	inverts differ by more than 0.6 m
Manhole	diameter 1.2 m minimum	Access 0.6 m

6.1.5 Design of a Main

The design of a sewer main is the starting point for computations for a network. The flow chart provides an introduction to the process. Experience and circumstances will reveal a number of alternative methods for solving the problem.

The check of the velocity at the design capacity is to evaluate whether or not the velocity at the design flow rate will be self-cleaning. The decision point in the flow chart that requires an evaluation of the question “Is increase in slope reasonable?” requires some judgment and experience to make a choice. A beginning criterion is that if the velocity is less than or equal to 0.45 m/s, it is unlikely that increasing the slope to achieve 0.6 m/s is reasonable. This is because the required slope will be so steep that it will drive the sewer into the ground and ultimately require numerous lift stations. In the event that the desired velocity cannot be achieved, the client should be advised of the likelihood that frequent cleaning will be required.

Figure 6.3 Surface profile and Sewer profile arrangement examples. (Adapted from Mackenzie. 2010

6.2 Alternative sewers

6.2.1 System Descriptions

The most common alternative sewer systems are small-diameter gravity(SDG), pressure, and vacuum sewers. Although these systems are predominately used for very small, remote areas providing service to populations less than 200 people, they have found special application with significantly larger populations (Guertin, 2007). The following paragraphs compare these systems and outline their design. For detailed guidance on their design the reader is referred to the Water Environment Federation publication entitled Alternative Sewer Systems (WEF, 1986) and commercial literature from companies supplying these systems.

Small-Diameter Gravity (SDG).

The SDG sewers maybe either constant gradient or variable gradient. Both use small diameter pipes to carry septic tank effluent to a treatment facility. The septic tanks are an essential part of the system as they provide a place for removal of heavy solids, grease, and grit that would otherwise plug the pipe. The advantages of SDG sewers over conventional sewers include lower capital cost because of reduced pipe and installation costs; clean-outs instead of manholes; reduced lift station costs because of pretreatment and flow attenuation by the septic tanks; and reduced I/I. Another potential advantage is reduction in treatment costs because of septic tank pretreatment. Disadvantages of SDG sewers include maintaining and pumping the septic tanks, odors, and corrosion because of the anaerobic conditionsin the septic tank that result in hydrogen sulfide production.

Pressure sewers

The two major types of pressure sewer systems are the septic tank effluent pump (STEP) system and the grinder pump (GP) system. The STEP system, like the SDG system, requires a septic tank for the same reasons as the SDG system. The GP system grinds the solids in a small tank on the residence property and pumps the wastewater into the pressure pipe system.

The benefits of pressure sewers primarily relate to installation costs because the sewer uses small diameter pipe that is laid just below the frost penetration depth. Some site conditions particularly favor pressure pipe systems. These include hilly terrain, rock outcropping, high water tables, and lakefront property that lack a natural slope for a gravity sewer. Because the pipe is pressurized, I/I is not a problem.

Potential disadvantages include higher operation and maintenance cost because of the need to maintain the numerous pumps in the system. Severe corrosion of the electrical and mechanical equipment, particularly from the STEP system, maybe encountered.

Vacuum sewers

These systems depend on a central vacuum source. A valve is used to separate the gravity portion of the waste system from the vacuum at the source. When the valve opens, a slug of wastewater followed by a slug of air enters the pipe system. The slug of wastewater is propelled into the main by the differential pressure of the vacuum and the air slug. The wastewater in the main flows to the lowest local elevation by gravity. When the next upstream valve opens, the new slug pushes the downstream slug further downstream. After a number of these sequential valve openings, the wastewater arrives at a central vacuum source and a transfer device, such as a pump, moves the wastewater to a treatment plant or an interceptor sewer.

The advantages of the vacuum system are similar to those for the pressure system. In addition, higher dissolved oxygen in the wastewater, central power usage at the vacuum station, and reduced concern for exfiltration of waste are beneficial.

The disadvantages include higher energy and operating costs, the need for exact grade alignment, greater infiltration potential, and less tolerance to flows exceeding the design flow. In addition, vacuum systems are limited in their capability to lift sewage.

6.2.2 General design considerations

Small-diameter gravity sewers

The preliminary considerations in the design of SDG sewers are the same as those for a conventional gravity sewer, that is, mapping, flow rate estimation, and so on. SDG sewers have a minimum recommended diameter of 50 mm. Pressure-rated pipe materials such as PVC are recommended. Manning's equation is used for the design. An item of concern in the design is to ensure that the maximum hydraulic gradient does not cause backflow into an individual or group of septic tanks. Backflow prevention valves maybe required. Pump discharge lines should have check valves to prevent drawback backwater entry from the sewer. Manholes should be avoided because they result in additional water, grit, and other debris.

Pressure sewers

Flow design values are commonly based on the number of houses being served. WEF(1986) provides graphical estimating guides based on research conducted in the 1970s and1980s. Pipe materials will be subject to a constant variation in working pressures. Therefore, the piping system should be designed based on cyclic surging. Fatigue failure must be considered in the design. Pressure rated PVC has generally been the pipe material of choice. In contrast to pressure water distribution systems, in GP systems the layout of the collection system is dendritic. STEP systems may have loops with valves to provide predicable flow directions. The looping provides alternative routing when repairs need to be made. Either Manning's equation or the Hazen-Williams equation is used for design. The Hazen-Williams equation is most often used. The value of C usually varies between 140 and160 for PVC pipe. When using the GP system, the design velocity should be greater than 0.6 m/s. A velocity of 0.3 m/s is adequate for the STEP system because the septic tank removes a majority of the grit and grease. Pumping "uphill" is usually the preferred practice. In some cases "downhill" pumping is unavoidable. When downhill situations occur, air enters the pipeline. This results in two-phase flow and high headlosses.

Vacuum sewers

The pipe materials used for pressure sewers are suitable for vacuum systems. Pipe diameters are on the order of 75to 100 mm. The difficulty in design is the fact that the flow regime is two phase and cyclic. WEF(1986) provides design equations.

TABLE 19-6 Relative characteristics of alternative sewers (Adapted from Mackenzie, 2010)

Sewer type	Ideal topog-raphy	Construction cost in rocky, high ground-water sites	Sulfide potential	Mini-mum slope or velocity required	O/M requi-re-ments	Ideal power requirements
1	2	3	4	5	6	7

Chapter 6 sources

1-Bengt Hultman, Erik Levlin, Lena Johansson, Nasik Al-Najjar, Puhua Li & Elzbieta Płaza Wastewater Treatment Systems, BUP Environmental science, Chapter 15, Lars-Christer Lundin & Lars Ryden.

2-ISO 24510 Activities relating to drinking water and wastewater services. Guidelines for the assessment and for the improvement of the service to users

3-Mackenzie L. Davis Water and Wastewater Engineering: Design Principles and Practice, McGraw-Hill New York (2010) ISBN: 978-0-07-171385-6, 1301p.

3-"The Water Framework Directive: A New Directive for a Changing Social, Political and Economic European Framework". European Planning Studies, (Taylor and Francis Group) 11 (3): 299–316.

4-EPA. "Ground water and drinking water - Customer Service."

Chapter 7
Municipal Wastewater Preliminary and Primary (Mechanical) Treatment Considerations

7.1 General considerations on mechanical treatment

The simplest form of wastewater treatment is to remove the contaminants mechanically. Mechanical treatment is usually carried out in two stages. First the coarse contaminants are removed by means of screens and sand traps. The remaining suspended solids are allowed to sink to the bottom in a sedimentation basin. Using this method, around 50–60% of suspended solids and around 30% of BOD can be removed from wastewater.

The coarser contaminants, such as rags, twigs, scraps of food, etc., are separated mechanically by passing the water through screens. These treatment screens are coarse, with gaps ranging in width between 3 and 20 mm, which means that relatively large particles pass to the next treatment stage, the sand trap.

The heavier contaminants, such as sand, gravel and coffee grounds, sink to the bottom of the sand trap. The sand trap is designed specifically to separate the heavier particles. Often the sand trap is combined with some means of aeration to keep the water oxygenated (aerobic) and facilitate grease removal, as well as removing heavier particles. A sand trap normally has a retention time of around 20 minutes.

After the sand trap, the remaining suspended contaminants are allowed to settle in a larger sedimentation basin. This basin is charged with 1-3 m^3 of water per $m^2$of basin area each hour, depending on the treatment process. In other words the basin has a surface load of 1-3 m/h.

The normal retention time for water in the basin is 2–3 hours.

Because mechanical treatment only removes around one-third of the oxygen demanding contaminants (BOD) from the water, and only some of the contaminants containing nitrogen and phosphorus, this treatment method is generally inadequate by itself and should therefore only be regarded as a preliminary stage. The main benefit of mechanical treatment is to prevent the formation of sludge mounds around the outflow in the recipient waterway.

This treatment method has nevertheless been the dominant process around the world. It is simple, requires a small investment and is easy to operate. Despite everything, this process does clean water to some extent and is therefore better than no treatment at all. Mechanical treatment also forms the first stage of more sophisticated treatments and is known as primary treatment.

Mechanical treatment produces sludge quantities (primary sludge) of around 50–60 g SS/p•d, which is thickened to a total solids (TS) content of 4–6%, which is equivalent to 0,8–1,5 l/p•d.

Figure 7.1 Mechanical treatment stages. (Adapted from Gilberg et al, 2003)

7.2. Preliminary wastewater treatment in bar racks and screens, design considerations.

The nomenclature of racks and screens is typically based on their purpose and the size of the openings. Table 7. 1 provides a summary of the types. The size range of the openings as a means of differentiation is not well defined.

Table 7.1 Nomenclature of racks and screens (Daukss, 2006, WEF)

Type	Typical opening	Typical use
Trash racks	40–150 mm	To prevent logs, stumps, and large heavy debris from entering treatment processes. Principally used in combined sewers a head of pumping units. In WWTPs, frequently followed by coarse screens.
Bar racks or coarse screens	6–75 mm	To remove large solids, rags, and debris. Typically used in WWTP.
Fine screens	1.5–6 mm	To remove small solids. Typically follows a coarse screen.
Very fine screens	0.25–1.5 mm	To reduce suspended solids to near primary treatment level. Typically follow a coarse screen and/or fine screen. Maybe used when downstream processes do not include primary treatment.
Microscreens	1μm–0.3 mm	Used in conjunction with very fine screens for effluent polishing

Figure 7.2 Mechanically cleaned coarse screens: (a) front-cleaned, front-return chain driven, (b) reciprocating rake, (c) catenary, and(d) continuousbelt. (Source: Metcalf & Eddy, 2003.)

Bar screens design consideration

Location. In nearly all cases, screens should be installed ahead of the grit chambers to prevent fouling of the grit chamber equipment.

Velocities. The approach velocity should be at least 0.4 m/s to minimize deposition of solids in the channel. The velocity through the screen should be less than 0.9 m/sat peak flow rates to minimize forcing of material through the screen (GLUMRB, 2004).

One of several alternatives are employed to regulate the velocity through the screen. Placement of a control structure such as a Parshall flume downstream of the screen or control of the wet well operating levels can be used. Sizing the channel for velocity control by widening the channel at the screen is another technique that maybe employed.

Channels. Dual channels must be provided. Typically they are constructed of concrete. They must be capable of being isolated by the use of slide gates or recesses in the channel walls for the insertion of stop plates or stop logs. The term stop log is derived from the early use of wooden logs set in a groove to stop the water flow. Modern stop plates are made of extruded aluminum. The channel invert should be 75to 150 mm below the invert of the incoming sewer (GLUMRB, 2004).

The channel dimensions are selected to achieve the approach velocity constraints. The floor of the channel should be level, or should slope downward through the screen without pockets that may trap solids. Fillets (Figure 20-6) are provided to minimize the accumulation of solids. The channel approach to the screen should be straight and perpendicular to the screen for a distance equal to 10 times the depth of flow (Metcalf & Eddy, 1972).

Figure 7.3 Two channels with bar racks. (a) Top channel is isolated by stop plate or slide gate. (b) Slide gate.(c) Stop plates in channel. (d) Channel fillets. (Sources: Mackenzie L. Davis; 2010)

Screenings handling

Screenings from the rake are usually discharged directly in to a hopper or movable container. The design must provide head space above the deck for the discharge as well as the screen return and motor assembly (see Figure 7.3). The spacing required is particular to the manufacturer's model that is selected. Finer spacing results in wetter screenings. Wetter screenings create handling and transport issues.

7.3 Fine Screen Options

There are a number of options in the selection of fine screens and very fine screens. The screen size (opening) is often based on the downstream processes to be employed. There is no definitive classification scheme, but several broad categories maybe defined. These include the following:

- Band screens. Perforated panels attached to a drive chain act as the screening mechanism. The flow pattern maybe through the front and back side of the panel. In this configuration a brush and spray bar clean the back side of the screen. In an alternate configuration, the center-feed band, wastewater enters through the center of the screen and exits out the sides.

- Bar screens. These are similar to bar racks but with finer openings. They are front clean/back return.
- Drum screens. The screening medium is mounted on a cylinder that rotates in a flow channel. The flow maybe from inside the drum to the outside with screenings captured on the interior surface, or the flow maybe from the out-side in.
- Step Screens ® . This design consists of two step-shaped sets of thin vertical plates. One is fixed and one is movable. They alternate across the screen face. The movable plates rotate in a vertical motion to carry the solids up to the next step and ultimately to the top where they are discharged.

Table 7.3 Characteristics to consider in selecting a fine screen

7.4 Coarse solids reduction

An alternative to capturing coarse solids on bar racks and/or screens is to use a mechanical device to shred or grind the solids and return them to the flow. Three of the most common devices are comminutors, macerators, and grinders.

There is a divergence of views on the desirability of using this technique for handling coarse solids. One view is that the coarse solids should be removed from the wastewater early in the flow scheme to eliminate downstream problems. Another view is that the shredded material is easily handled by downstream processes. Of particular concern are rag and plastic materials that forms trigs or ropes that wrap around pump impellers, accumulate on clarifier mechanisms and air diffusers, clog sludge pipelines, and foul heat exchangers. Plastic limits the potential for land application of biosolids. For certain processes, such as membrane bioreactors (MBRs), or the requirement to produce Class A biosolids, coarse solids reduction is not an option. Fine screens must be used.

Comminutors

A typical comminutor uses a stationary horizontal screen to intercept the solids in the flow and a rotating or oscillating cutting bar to shear the material. The solids are reduced in size to between 6 and20 mm. They pass downstream. Although they were commonly used in the past, most new facilities use screens, macerators, or grinders.

Macerators

Macerators are slow-speed grinders that typically use two sets f counter rotating blade assemblies(Figure 20-9). The tolerance on the macerator blades assemblies is small enough (typically, 6 to 9 mm) that the material passing through is effectively chopped. This chopping action reduces the potential for producing ropes of rags and plastic

Grinders

Grinders pulverize the solids by a high-speed rotating assembly. The cutting blades force the material through a stationary grid that encloses the assembly.

Figure 7.3 Photo and isometric drawing of a macerator. (Sources: Metcalf & Eddy, 2003.)

Design Considerations

The capacity and redundancy requirements for solids reduction devices are the same as those for coarse screens. They may be located downstream of grit chambers to reduce wear on the cutting mechanism, but typically they are placed ahead of grit chambers to prevent rags, bags, and other debris from fouling the grit removal equipment. As with the screens, channels are constructed with a by pass and provisions for isolating the channel and dewatering it when maintenance is required. Typical head loss through these devicesis100 to 300 mm and can approach 900 mm in large units at maximum flows.

Because these units are sold as stand-alone devices, no detailed design is required. However, manufacturers' data must be consulted for data on recommended channel dimensions, capacity, headloss, submergence, and power requirements. In evaluating alternatives, the ratings should be decreased by about 80 percent because the manufacturers use clean water to establish the ratings(Metcalf & Eddy, 2003)

7.5 Grit removal

Sand, gravel, broken glass, egg shells, and other material having a settling velocity substantially greater than the organic material in wastewater is called grit. Grit removal is provided to protect mechanical equipment from abrasion and wear; reduce the formation of deposits in pipelines and channels; and reduce the frequency of digester cleaning that is required because of accumulated grit.

A secondary, but none-the-less extremely desirable goal of the grit removal system is to separate the grit from the organic material in the wastewater. This separation allows the organic material to be treated in subsequent processes.

Grit removal alternatives

There are four general types of grit removal systems: horizontal-flow grit chambers, detritus tanks, aerated grit chambers, and vortex-flow grit chambers. The horizontal-flow grit chamber is, fundamentally, a velocity-controlled channel. The velocity is controlled by a proportional weir or Parshall flume. The detritus tank is a square horizontal-flow grit chamber. The tank is basically a sedimentation basin with a very short detention time. The flow is directed across the tank by a series of gates or weirs and discharges over a weir that runs the length of the opposite side of the tank. In aerated grit chambers, air is introduced along one side of the tank near the bottom and causes a spiral roll pattern perpendicular to the flow through the tank (Figure 7.4). The vortex systems rely on a mechanically induced vortex to capture grit (Figure 7.5).

Figure 7.4 Spiral roll pattern in an aerated aerated grit chamber. (Source: Metcalf & Eddy, 2003.)

While they have been used for many decades, horizontal-flow grit chambers and detritus tanks are no longer favored in the United States. The remainder of this discussion focuses on the preferred alternatives: aerated grit chambers and vortex chambers.

Aerated Grit Chamber. As the wastewater moves through the chamber in a spiral pattern (Figure 20-12), heavier grit particles settle to the bottom of the tank. Lighter particles that are principally organic remain in suspension and are carried out of the tank. The velocity of roll of water across the bottom of the tank controls the size of particles of a given specific gravity that will settle out (Albrecht, 1967; Sawicki, 2004). The rolling action induced by the air diffusers is independent of flow through the tank. The rate of air diffusion and the tank shape govern the rate of velocity of the roll. The particles that are settled out are moved by the spiral flow of the water across the bottom of the tank to a grit hopper or trough. The grit is removed from the hopper with one of the following: chain and bucket collectors, screw augers, clamshell buckets, or recessed impeller or air lift pumps.

Vortex Grit Chamber. Wastewater is brought into the chamber tangentially(Figure 20-13). At the center of the chamber a rotating turbine with adjustable-pitch blades along with the cone shaped floor produces a spiraling, doughnut-shaped flow pattern. This pattern tends to lift the lighter organic particles and settle the grit into a grit sump. The effluent outlet has twice the width of the influent flume. This results in a lower exit velocity than the influent velocity and thus prevents grit from being drawn into the effluent flow. It should be noted that centrifugal acceleration does not play a significant role in removing the particles. The velocities are too low. Solids are removed from the sump by a grit pump or an air lift pump. Typically, air or water scour is used to loosen the compacted grit just before it is removed from the chamber.

Figure 7.5 Vortex grit chamber. (Source: Metcalf & Eddy, 2003.)

7.6 Primary treatment

7.6.1 Introduction

Primary treatment is the first process in the wastewater treatment plant to remove a significant fraction of organic particulate matter (suspended solids). These suspended solids contribute to biochemical oxygen demand (BOD_5) of the wastewater. Thus, removing suspended solids also reduces BOD_5. The process is important because the reduction of suspended solids and BOD_5 lowers the oxygen demand, decreases the rate of energy consumption, and reduces operational problems with downstream biological treatment processes. Primary treatment also serves the important function of removing scum and inert particulate matter that was not removed in the grit chamber. The scum consists of grease, oil, plastic, leaves, rags, hair, and other floatable material.

The principal form of primary treatment is sedimentation. Consequently, this process is often referred to as primary sedimentation. It is the oldest and most widely used unit operation in wastewater treatment. Other modifications and alternatives that have seen increasing use are enhanced sedimentation, fine screens, and ballasted flocculation/sedimentation.

Design Philosophy

Historically, the design goal of primary treatment has been framed in the context of an arbitrary percentage removal of total suspended particles without a justification for the selection of the percentage removal or a means of assessing whether or not the goal has been achieved. A currently evolving philosophy is that the primary clarifier should be designed on the basis of the oxidative capacity of the downstream biological processes. Primary clarifiers can remove more BOD and solids for less operational cost than any other treatment process in use today (Wahlberg, 2006). Thus, it makes both economic sense and design sense to remove, to the maximum extent possible, the settleable solids and settleable BOD by primary settling.

From an operational perspective, under most situations the design should minimize the conditions that promote biological activity in the primary clarifier. An exception to this approach occurs when biological phosphorus removal is to occur downstream possible, the settleable solids and settleable BOD by primary settling. From an operational perspective, under most situations the design should minimize the conditions that promote biological activity in the primary clarifier. An exception to this approach occurs when biological phosphorus removal is to occur downstream. In this case, the primary clarifier maybe used to generate volatile fatty acids to promote biological phosphorus removal (Wahlberg, 2006).

Alternatives

Circular and rectangular tanks are the most common configurations. Square tanks with circular sludge collection mechanisms have been used. These have generally proven unsatisfactory because of sludge build up in the corners, and fouling of the more complex sludge collection mechanism. Stacked rectangular tanks have been used where space is highly restricted. They have a much higher construction cost and require more complex structural design. Plate settlers have become an important design alternative in primary sedimentation. Of the alternatives, rectangular and circular tanks with and without plate settlers are favored for primary sedimentation. The following discussion will focus on these preferred alternatives.

7.6.2 Circular tanks

In circular tanks the theoretical flow pattern is radial. The wastewater is introduced either in the center or around the periphery(Figure 7.6). The center-feed type is more commonly used for primary treatment. The wastewater is carried to the center of the tank by either a pipe suspended from a bridge or one that is encased in concrete below the tank floor. At the center of the tank, flow enters a circular feed well that is designed to distribute the wastewater flow equally in all directions.

Small circular tanks (9 m diameter) have sludge removal equipment supported on beams spanning the tank. Larger tanks have a central pier that supports the equipment. Access for service is provided by a bridge-walkway. The bottom of the tank is sloped to form an inverted cone. The sludge is scraped to a hopper located near the center of the tank.

To provide redundancy, a minimum of two tanks is provided. Tanks are typically arranged in pairs with a flow-splitting box between them . Concrete is commonly used for construction of tanks for municipal systems. Circular tanks are favored because they require less maintenance, the drive bearings are not under wastewater, and the construction cost is generally lower than that for rectangular tanks. The disadvantages of circular tanks are that they require a larger footprint because they cannot be built with a common wall, and that they require more yard piping and pumping facilities.

7.6.3 Rectangular tanks

Although transverse and vertical flow tanks have been used, the typical primary settling tank is designed for longitudinal flow. (Figure 7.7) The flow enters and exits through the narrow ends. Wastewater is carried to the tank in a covered channel. It enters the tank through one or more inlet ports. A baffle is provided immediately downstream of the inlet to dissipate the inlet port velocity and distribute the flow and solids equally across the cross-sectional area of the tank.

Figure 7.6 Circular primary center-feed setting tank. (Source: Metcalf & Eddy, 1991.)

Typically chain-and-flight scrapers are used to remove sludge. The chain-and flight system differs from that used in water treatment plant settling tanks in that the "return" of the flights is placed at the top of the clarifier to remove scum. Sludge is carried to a hopper at one end of the tank. In larger tanks, this hopper will be a transverse trough with a cross collector that carries the sludge to one side of the tank where the sludge take-off pipe and pump are located. Because the tanks are typically built in multiple units for redundancy, a common sludge pump may serve several clarifiers.

Rectangular tanks are favored when space is a constraint because they may be constructed with a common wall and piping arrangements are more economical than for circular tanks. They have had the disadvantage that drive bearings are under water. The use of nonmetallic equipment in the tanks has significantly reduced the maintenance needs of rectangular tanks.

Figure 7.7 Rectangular primary settling tank. (Source: Davis and Cornwell, 2008.)

7.6.4 Sedimentation basin design

General. The general design criteria for both circular and rectangular tanks are presented here. The special considerations that apply only to one or the other type are discussed separately in later sections that deal with these types specifically.

Redundancy. Multiple units capable of independent operation are requiredfor all plantswhere design average flows exceed 380 m^3/d(GLUMRB, 2004).

Hydraulic load. The historic hydraulic design approach was to use the design average flow rate. The peak flows maybe a factor of 2 or 3 times the design average flow and in extreme cases, especially in very small communities or those with combined sewers, it may be as high as10 to 15timesthe design average. Young et al. (1978) suggest that the peak four-hour flow rate is an appropriate basis for design. If the design philosophy is to maximize the efficiency of the primary clarifier in order to minimize the load on the downstream biological processes, then the hydraulic design should address the peak flow. This maybe accomplished by equalization , or by sizing of the primary clarifier for the peak flow, or a combination of these techniques. An equalization basin provides a means of damping the peak flow, but it does not eliminate it.

An alternative approach is to design for less extreme peak-to-average flow rates in the primary clarifier and to design the biological treatment unit to handle the increased BOD load during peak flow events. This approach is advocated when low BOD loads predominate and a less efficient primary clarifier provides the organic matter required to support the microorganism mass. This condition frequently occurs in small plants at start-up.

Recycle streams from waste activated sludge, thickening supernatant, digester supernatant, dewatering operations, and backwashing must be considered in the hydraulic load. The potential for surges from these sources to disrupt the performance of the clarifier is high (WEF, 1998). The use of the primary clarifier as a thickener for waste activated sludge is particularly troublesome and should be avoided except in extenuating circumstances. However, it is recommended that the piping system be designed so that the primary tank can be used when the waste activated sludge thickener is out of service. Surges from other recycle streams should be minimized or returned during low-flow periods.

Overflow rates. Recommended overflow rates range from 30 to 50 m/d($m^3/d \cdot m^2$) at average design flow without waste activated sludge recycle (Metcalf & Eddy, 2003; U.S. EPA, 1975). Recommended peak hour overflow rates range from60 to 120 m/d(Metcalf & Eddy, 2003; Reardon, 2006). GLUMRB (2004) recommends an overflow rate of 40 m/d at the average design flow and 60 to 80 m/d at the peak hourly flow.

Where waste activated sludge must be returned to the primary clarifier, the recommended overflow rates at average design flow range from 24 to 32 m/d. The peak hour overflow rates range from 40 to 70 m/d (Metcalf & Eddy, 2003). GLUMRB recommends a peak hour overflow rate less than 50 m/d when waste activated sludge is returned to the primary clarifier.

Hydraulic detention time. Typical theoretical hydraulic detention times range from 1.5 to 2.5 hours with a typical value of 2.0 hours. While not explicitly stated, it is assumed that these detention times are at the average design flow rate. Actual detention times maybe considerably less han this. For example, reported dye tests on a tank with a theoretical detention time of 202 minutes had an actual detention time of 74 minutes (Daukss and Lunn, 2007).

From data presented by Wahlberg (2006), it appears that the fraction of solids removed by settling reaches a maximum in about 30 minutes at average design flow rates. This coincides with a 30 minute flocculation time to achieve the minimum supernatant concentration (Parker et al., 2000).

Low-flow periods at plant start up may result in substantially longer detention times with resultant septic conditions. Detention times of more than 1.5hourswithout continuous sludge withdrawal may result in resolubilization of organic matter. This will reduce BOD removal efficiency and potentially result in odor problems (WEF, 1998). Multiple tanks allow more flexibility during the start up of a new plant.

Velocity. In practice, the linear flow-through velocity has been limited to 0.020 to 0.025 m/s to prevent scour and resuspension of settled solids (WEF, 1998).

Weirs and weir loading rates. The most common type of weir plate is one made with 90-degree v-notches at 150 or 300 mm intervals. This design is selected in preference to a flat plate or a square notch weir that are subject to unbalanced flow if they are not perfectly level and/or they are subject to wind effects (Tekippe, 2006).

Weir loading rates have little effect on the performance of primary settling tanks with wall depths greater than 3.7 m (Metcalf & Eddy, 2003). In practice weir loading rates seldomexceed120 m3/d· m of weir length in plants with average design flow rates less than 3,800 m3/d or 190 m3/d· min plants treating more than 3,800 m3/d(WEF, 1998).

However, Metcalf & Eddy(2003) reported loading rates ranging from125to 500 m3/d· m with a typical value of 250 m3/d· m.

Sludge hoppers. Because the raw sludge is very sticky, it tends to accumulate on the sludge hopper sides, in corners, and arch over the sludge draw-off piping.

To minimize these effects, the sludge hopper side walls should have a minimum side wall slope of 1.7 vertical : 1 horizontal (60 from horizontal), and the bottom dimension should not exceed0.6 m. Extra depth sludge hoppers for sludge thickening are not acceptable (GLUMRB, 2004).

Table 21-1 Typical design criteria for primary sedimentation basins (Mackenzie, 2010)

7.7 Other primary treatment alternatives

Three modifications/alternatives maybe used in primary treatment. Enhanced sedimentation and plate settlers are modifications to standard sedimentation, and fine screens are used in lieu of sedimentation. Each of these will be discussed in the following sections.

7.7.1 Enhanced sedimentation

The simple act of promoting increased contact between particles at the inlet of the sedimentation basin is a form of enhanced sedimentation. More commonly, enhanced sedimentation refers to the addition of chemicals. This practice is called chemically enhanced primary treatment (CEPT)., the addition of chemicals, followed by gentle agitation results in coagulation of particles. The resulting increase in particle size enhances the efficiency of sedimentation. Increases of 40 to 80 percent in organic carbon removal and60 to 90 percent in total suspended solids removal can be achieved in shorter settling times than conventional sedimentation. CEPT is most effective if a complete treatment train, including rapid mix, coagulation, and sedimentation, are provided. However, substantial improvements can be achieved by adding the chemicals to aerated grit chambers or other upstream facilities for mixing, and using the inlet structures of a conventional primary settling tank to provide flocculation.

Alum($Al\ _2(SO)_4\cdot\ 14H_2O$) or ferric chloride ($FeCl_3$) added in conjunction with anionic polymers are the chemicals most frequently used. Current practice is to use metal salt doses on the order of 20 to 40 mg/L in combination with polymer doses of less than 1 mg/L. Metcalf & Eddy(2003) recommends velocity gradients for flocculation in the range 200 to 400 s1. The use of metal salts also results in precipitation of phosphorus. This maybe a positive step in meeting discharge standards. It also maybe detrimental to the downstream biological processes that require phosphorus. As an alternative, anionic polymers alone in high doses(8 mg/L) are effective coagulants that do not remove phosphorus(Reardon, 2006). CEPT maybe used on an intermittent basis to achieve effective primary sedimentation during peak hydraulic events. This approach uses less chemicals and produces less sludge to handle.

7.7.2 Plate settlers

Although plate settlers have not been commonly used in municipal wastewater treatment plants in the United States, they have been used extensively in Europe. Metcalf & Eddy(2003) suggests an appropriate application is in conjunction with CEPT.

The common design isa countercurrent flow pattern. The influent is fed under the plates or tubes and flow is upwards. Solids settle to the plate and slide down the surface to the bottom of the tank. For primary sedimentation applications, they increase the settling area by a factor of 8 to 10. This permits a smaller footprint or increases the capacity of existing overloaded tanks. They have been reported to produce a more dilute sludge. This may increase the cost of sludge handling.

Chapter 7 sources

1-Bengt Hultman, Erik Levlin, Lena Johansson, Nasik Al-Najjar, Puhua Li & Elzbieta P∏aza Wastewater Treatment Technologies, BUP Environmental science, Chapter 14, Lars-Christer Lundin & Lars Ryden.

2-Daukss, P. (2006) "Design Considerationsfor Screening," presentedat Michigan Water Environment Association ProcessSeminar, GrandRapids, Michigan, November, 2.

3-Lars Gillberg, Bengt Hansen, Ingemar Karlsson, Anders Nordström Enkel, Anders Pålsson, "About Water Treatment" Water and Wastewater Treatment: Handbook Helsingborg,Kemira Kemwater 2003, ISBN 91-631-4344-5

4-Forstner, G. (2007) "Screen Selection Simplified," Water Environment & Technology, October, pp. 60–64.

5-GLUMRB (2004) Recommended Standards for Wastewater Facilities,Great Lakes–Upper Mississippi River Board of State andProvincial PublicHealth andEnvironmental Managers, Health Education Services, Albany, New York, pp. 70-1–70-7.

6-Krebs, P., D. Vischer, and W. Gujer (1992) "Improvement of SecondaryClarifier Efficiency by Porous Walls," Water Science Technology, vol. 26, nos. 5/6, pp. 1,147–1,156.

7-Keller, J., C. Wallis-Lage, andI. Crabtree (2006) "The Fine Art of Screening," Water Environment & Technology, De cember, pp. 52–55.

8-Mackenzie L. Davis Water and Wastewater Engineering: Design Principles and Practice, McGraw-Hill New York (2010) ISBN: 978-0-07-171385-6, 1301p.

9-Metcalf & Eddy (2003) Wastewater Engineering: Treatment and Reuse, 4th ed., McGraw-Hill, Boston, Massachusetts, pp. 396–417.

10-Pettit, M. V. (2006) "Rectangular Clarifiers," in Clarifier Design, 2nd ed., Water Environment Federation Manual of Practice no. FD-8, pp. 499–581.

11-Reardon, R. D. (2006) "High-Rate and Wet Weather Clarifier Design Concepts and Considerations," Clarifier Design, 2nd ed., Water Environment Federation Manual of Practice no. FD-8, p. 71–77.

12-Sawicki, J. M. (2004) "Aerated Grit Chambers Hydraulic Design Equation," Journal of Environmental Engineering,vol. 130, no. 9, pp. 1,050–1,058.

13-Tekippe, R. J. (2006) "Circular Clarifiers," in Clarifier Design, 2nded., Water Environment Federation Manual of Practice no. FD-8, pp. 397–488

14-Wahlberg, E. J. (2006) "Primary Clarifier Design Concepts and Considerations," in Clarifier Design, 2nded., Water Environment Federation Manual of Practice no. FD-8, pp. 9–42.

15-WEF(2006) in Clarifier Design, 2nded., Water Environment Federation Manual of Practice no. FD-8.

16-Wilson, G., G. Tchobanoglous, andJ. Griffiths(2007a) “The NittyGritty: Grit Sampling and Analysis,” Water Environment & Technology, July, pp. 64–68.

Chapter 8.
General Considerations on Municipal Wastewater Secondary (Biological) Treatment

8.1 General considerations on biological treatment

8.1.1 About biological treatment

Biological treatment is normally the second treatment stage in a wastewater treatment plant and is therefore also known as secondary treatment. Usually the water is first treated mechanically (primary), and then undergoes a biological treatment stage that is designed to separate and break down organic contaminants with the aid of microorganisms. The contaminants are converted into a biological sludge (= cell mass).

The decomposition cycle is a very complex process that consists of a long series of subsidiary reactions. The rate of decomposition depends on many factors. In addition to oxygen content, pH, microorganisms, temperature, contaminant type, toxic substances and treatment method, the particle size of the contaminants is also very important.

The contaminants in wastewater are primarily broken down by bacteria. These bacteria usually specialise in breaking down a specific substance or group of substances. As mentioned previously, wastewater contains a variety of different contaminants, which means that a number of different species are used in biological treatment. The above-mentioned factors, such as oxygen content, temperature, etc., also influence the combination of species that are chosen.

The bacteria that are used in biological treatment are not the same sort of bacteria we usually think of. They are not disease-causing (pathogenic) bacteria, but naturally occurring bacteria that are found in soil and water. In a biological treatment process these bacteria are simply brought together in large numbers to tackle the decomposition process in a limited space.

Biological treatment systems are normally designed to break down organic substances. Nutrient salts, such as nitrogen and phosphorus, are only marginally reduced in a normally loaded, conventional biological treatment system. Only the proportion of nitrogen and phosphorus that is assimilated (taken up) by the cell mass is removed. Usually we would expect this to be equivalent to a BOD_5/N/P ratio of 100/5/1 based on the influent values. The TS content of this sludge, the excess sludge, would contain around 7-10% N and 1-3% P.

A biological treatment process also contains other microorganisms in addition to bacteria. A variety of different higher-level species (protozoa and metazoa) are always present in the treatment process. Just like the various species of bacteria, these species carry out various tasks in the treatment process. Some live by eating particles and free-swimming bacteria (see activated sludge process). Others live on dead or living bacteria and organisms. There are worm-like organisms (oligochaetes) that tunnel through the biomass and improve water penetration and hence also treatment efficiency.

There is one thing these organisms all have in common. They aid the water treatment process and reduce sludge production. A well-cultivated fauna of protozoa and metazoa is a sign of an effective biological treatment process.

Three types of biological processes are used in wastewater treatment: anaerobic, aerobic and anoxic decomposition.

8.1.2 Anaerobic decomposition

An anaerobic process occurs in the absence of oxygen or nitrate. When oxygen is not present in wastewater the contaminants are decomposed anaerobically. Organic substances are converted to methane, carbon dioxide and water. A small fraction of the organic matter is also converted into new biomass.

Anaerobic decomposition is normally only used for the treatment of heavily contaminated industrial wastewater, and as a general process for stabilising sludge, when it is known as digestion.

Anaerobic decomposition is considerably slower than aerobic processes. The bacteria cannot exploit the available "food" – the substrate – as effectively, and therefore grow more slowly. A large proportion of the food is used to produce energy, and only a small fraction to build up biomass. One (1) kg of COD yields around 0,1 kg of biomass. The rest is used to generate energy for the organism and produce methane gas, which has a high energy content.

Figure 8.1. Stages in methane production from complex organic materials (Adapted from Kiely,1997).

To increase the decomposition rate in anaerobic decomposition the temperature of the sludge or water is usually increased. The temperature in a digester is normally around 35°C. Municipal wastewater in Nordic countries usually comes in at a temperature of between 5°and 20°C. This is too low a temperature for an anaerobic process to be considered suitable. Even in warmer parts of the world, where the average temperature is up to 25°C, anaerobic decomposition is still inadequate.

In the case of industrial wastewater, especially from the food industry, anaerobic processes can be very attractive as this water is sometimes at high temperature, is highly concentrated and has low flow rates.

8.1.3 Aerobic decomposition

This process, which takes place in the presence of oxygen, means that the microorganisms use oxygen in the water to oxidise organic matter and produce carbon dioxide and water, as well as biomass.

As mentioned above, the aerobic treatment process is considerably faster than the anaerobic process, thanks to the presence of oxygen. This means that the bacteria can make better use of the substrate and can create biomass more readily. One (1) kg of COD yields around 0,5kg of biomass, while the rest is used to generate energy.

The aerobic process is also affected by temperature. Too low a temperature reduces the decomposition rate, but this can be compensated for by increasing the concentration of microorganisms. The aerobic treatment process can work well at temperatures down to 5°C and is considerably less sensitive than the anaerobic process.

When municipal wastewater is treated using the aerobic process the microorganisms may be made to grow on a solid carrier material in what are known as biofilm processes (immobilised cultures), or they may be freely suspended in the aqueous phase in the form of biological flocs, (suspended cultures)

8.1.4 Anoxic decomposition

The anoxic process is similar to the aerobic one, but in this case the bacteria "breathe" using oxygen obtained from nitrate, rather than using added oxygen. The decomposition process produces carbon dioxide, water and nitrogen gas. This process is therefore used for nitrogen reduction (see the chapter on Denitrification) since nitrogen is released from the water as gas. Anoxic decomposition is not as fast as the aerobic process but it is considerably faster than the anaerobic process.

This process will only work in the presence of organic substances (BOD/COD), since heterotrophic bacteria are unable to use carbon dioxide to build biomass.

One (1) kg of COD yields 0,5 kg of biomass, i.e. the same quantity as aerobic processes. This process must be carried out in the absence of free oxygen, since the bacteria prefer to use oxygen than nitrate for respiration. Immobilised and suspended bacterial cultures can also be used for anoxic treatment.

Figure 8.2 Amount of biomass produced in different treatment conditions (Adapted from Gilberg et al, 2003)

8.2 Suspended grow technologies application

8.2.2 Suspended cultures

Activated sludge process

During treatment with activated sludge the biologically active microorganisms are suspended in sludge flocs in the wastewater. A sludge floc, or biofloc, consists mainly of a specific type of bacteria, known as floc-forming bacteria. To provide adequate oxygen and achieve good contact between the sludge flocs and the water, large amounts of air (oxygen) are pumped continuously into the bottom of the activated sludge basin. Alternatively the water can be oxygenated using surface aerators. In this case the water is sprayed into the air as a fine mist so that it takes up oxygen from the air.

In order to break down the organic matter quickly the microorganisms are concentrated in the activated sludge basin. This is achieved by recycling most of the sludge that is removed from the subsequent sedimentation stage. Only a small proportion of the sedimented sludge is removed from the process as excess sludge in order to compensate for the continuous growth in biomass (figure 3:6).

Figure 8.3 Activated sludge process. (Adapted from Gilberg et al, 2003)

The microorganisms in the activated sludge are able to take up and degrade dissolved organic contaminants in the water and adsorb suspended colloidal particles. This process results in the formation of carbon dioxide, water and biomass.

The organic substances in the water, expressed as BOD, are distributed as follows:

The above figures vary with the sludge age.

Bacteria in an activated sludge can be divided into three groups: free-swimming, floc-forming and filamentous.

Free-swimming

Free-swimming bacteria are single or pair-forming bacteria that are suspended freely in the water. These can be likened to very small particles. The bacteria are so small that they do not have time to fall out as sediment in the following sedimentation stage. The free-swimming bacteria are the ones that multiply fastest in an activated sludge process. But because they are too small to form sediment with the sludge they are flushed out of the activated sludge stage and are lost from the treatment plant. Free-swimming bacteria also serve as food for many of the other microorganisms that are present in the activated sludge process.

There are always free-swimming bacteria in an activated sludge process since they are present in the wastewater that comes into the treatment plant. If they are not eaten up or separated in some other way in the treatment plant then the treated water will be opaque (cloudy). Low sludge age (see page 52) favours free-swimming bacteria.

The floc-forming bacteria normally account for the majority of biomass in an activated sludge process. Floc-forming bacteria are able to grow in clumps because they have a sticky polymer-like surface that makes them stick to each other. As a result they form larger particles (bioflocs) that are large enough to fall out in the subsequent sedimentation stage.

The floc-forming bacteria multiply more slowly than the free-swimming bacteria, and therefore require a longer retention time (sludge age) in the activated sludge stage to prevent them being flushed out. The minimum sludge age is 1–2 days. The growth of the bacteria is temperature-dependent, which means that a low water temperature requires longer sludge retention time.

Filamentous bacteria

Filamentous bacteria are bacteria that grow “in-line” and form long, hair-like filaments in the bio-sludge. These bacteria normally multiply the slowest and are favoured by high sludge age, low temperature or unusual conditions in the activated sludge process.

A high concentration of filamentous bacteria can cause severe operating problems in an activated sludge plant. The reason is that they make the sludge so fluffy and bulky that it does not easily fall out in the subsequent sedimentation basin, which can become completely filled with bio-sludge. This means that biological sludge is discharged with the water from the treatment plant and causes elevated emission levels. The bulky sludge also makes it difficult to remove excess sludge and sludge for recycling.

A healthy bio-floc should nevertheless contain a small number of filaments as they give stability to the floc, just like a skeleton.

8.2.3 Operating parameters

The most important operating parameters for the activated sludge process are sludge load, sludge age, oxygen concentration and suspended solids(SS).

The sludge load is the ratio between the amount of nutrients supplied (= amount of organic matter) and the existing amount of microorganisms.

Figure 8.4 Sludge load calculation (Adapted from Gilberg et al, 2003)

Treatment processes in activated sludge plants can be classified into three main groups depending on the sludge load (F): high, normal or low load.

The average retention time in an activated sludge basin depends on the load on the activated sludge process. A plant with a low load has a large volume and hence a relatively long retention time, while one with a high load can get by with a small volume and hence a short retention time. If the treatment plant has a very effective primary treatment stage (e.g. precipitation) then the volumes can be reduced drastically, since the majority of organic substances are removed at this stage.

Table 8.1 Retention times for active sludge process. (Adapted from Gilberg et al, 2003)

Process load	Retention time (hours)
High	0,6–2,0
Normal	2,5–6,0
Low	8–24
Extended aeration	>24

Sludge age

Sludge age is the average time in days that a sludge particle spends in the aeration basin Sludge age is the ratio between the existing amount of sludge in the biological treatment stage and the amount of sludge removed each day.

Figure 8.5 Sludge age calculation formula (Adapted from Gilberg et al, 2003)

Oxygen concentration.

In an aerobic process oxygen is used continuously to break down contaminants. The oxygen concentration in the process should not drop below 1–2 g O_2/m^3 in order to avoid operating problems. The oxygen consumption depends on the actual sludge load.

The lower the sludge load, the more oxygen is required to reduce a given BOD concentration. If the sludge load is low, oxygen is also needed to break down the activated sludge to a greater extent. Low sludge load also leads to nitrification, which considerably increases oxygen consumption.

Oxygen consumption without nitrification is calculated using the formula:

In the case of a normally loaded activated sludge plant, the energy consumption is around 0,9–1,3 kWh/kg BOD_{red}.

MLSS (Mixed Liquer Suspended Solids)
MLSS is the concentration of suspended solids in the activated sludge basin. The MLSS concentration is normally kept constant in the aeration basin but varies from season to season. Treatment plants with a high sludge age and nitrogen treatment normally have a higher MLSS concentration. The values are in the range 1,5–5 g/l.

MLSS can be a measure of how active an activated sludge plant is. The higher the concentration, the more bacteria there are in the basin. However, MLSS is a measure of suspended solids in the basin, and includes both organic and inorganic SS, so it does not correlate directly with the bacteria content.

VSS (Volatile Suspended Solids)
Many treatment plants also analyse for volatile suspended solids, VSS, which is a measure of the organic content of the activated sludge, and in most cases can be equated with the bacteria content. An example that clarifies the difference between MLSS and VSS is the case of a treatment plant that switched from simultaneous precipitation to pre-precipitation. The VSS content then increased from 67% to 78% because the precipitation chemical contributed to sludge production during simultaneous precipitation. If the SS content was kept constant it led to a 16% increase in the biomass, and hence the same increase can be expected in the treatment capacity.

Sludge indexOne measure of the sedimentation performance of a sludge is the sludge volume index, which is obtained by dividing the sludge volume by the concentration of suspended solids in the activated sludge. The sludge volume is the amount of sludge that is obtained after 30 minutes of sedimentation, and is expressed in ml/l. The lower the sludge index, the better the sedimentation performance. Normally the sludge volume index is 60–150 ml/g.

For sludge volumes lower than 300 ml/l the sludge index is calculated using the formula:

A high sludge index indicates that something has gone wrong in the activated sludge process. Sludge bulking has occurred, probably as a result of too high concentration of filamentous bacteria, which make water treatment more difficult

For sludge volumes in the range 300–800 ml/l the following formula is used:

Sludge production

The amount of excess sludge that is produced during the activated sludge process depends on the load on the treatment stage. A normally loaded plant that has a pre-sedimentation stage produces roughly 0,7–0,8 kg of excess sludge per kg of reduced BOD_7 One requirement is that the concentration of suspended solids in the effluent water from the sedimentation stage stays between 10 and 20 mg/l.

Figure 8.6 Excess sludge production (kg/kg reduced BOD) against sludge load for three treatment processes. (Adapted from Gilberg et al, 2003)

Energy consumption

An activated sludge process requires large amounts of energy. As mentioned previously, it requires between 0,9 and 1,3 kWh to remove each kilogram of BOD. This energy is not just used for pumping oxygen into the basins. Even if the oxygen concentration is satisfactory, a certain minimum amount of air must be injected to keep the sludge moving. Otherwise, some of the sludge would fall out in the activated sludge basin and the treatment efficiency would be impaired.

Normally this is not a problem, since the amount of oxygenating air that needs to be added is greater than the amount of air needed for agitation. If the oxygen requirement is low then the activated sludge basin can instead be equipped with agitators to prevent accidental sedimentation.

The energy consumption of the activated sludge process has fallen in recent years thanks to new types of aerators that permit more efficient oxygenation. Reducing the BOD load on an activated sludge naturally also decreases the energy consumption, since it reduces the oxygen consumption and sludge volumes. The BOD load in the biological stage can be reduced by precipitation, for example.

Treatment efficiency

The degree of reduction of BOD depends on the way the activated sludge process is operated. The more time the bacteria are given to break down the contaminants, the more effective the treatment.

The degree of decomposition also depends on the composition of the impurities of the water. If the influent water contains a high proportion of compounds that are difficult to break down then a longer retention time is required.

Degree of decomposition of BOD in activated sludge process:

Plant with high load	60–90%
Normal load	85–95%
Low load	90–99%
Membrane bioreactor	

In recent years membrane technology has begun to make an appearance in biological treatment in the form of membrane bioreactors (MBR). These use membranes to separate the bioflocs in an activated sludge process, instead of sedimentation. The membranes have pores that allow the passage of dissolved substances, but not particles.

8.3 Biofilm technologies application

8.3.1 Biological beds

The treatment of wastewater in biological beds is based on a system of sprinklers that allow water to percolate through a bed of material that is also aerated by large quantities of air. The bed supports a culture of microorganisms that live on the organic contaminants present in the water. A large proportion of the organic substances can be removed in this way

Assuming that there is unlimited access to oxygen, the efficiency of the process depends on the area of contact between the carrier material and the wastewater.

The most common bed material in older plants is crushed stone or pumice with a particle size of 70–90 mm and a specific area of 40–60 m^2/m^3. However, more modern plants use a plastic filler that can have a specific area of 100–250 m^2/m^3. There is less risk of clogging with these new materials, since they have larger cavities.

Sludge separation

When the growth of microorganisms on the carrier material reaches a certain thickness the water trickling through the bed carries away some of the biofilm. This is separated in the form of sludge in the subsequent sedimentation basin.

It should be noted that biological beds usually allow passage of a fraction of finely suspended material that may be difficult to remove. It is therefore recommended that chemical precipitation is carried out after the biobed.

Energy consumption

Biobeds were originally an energy-efficient alternative to activated sludge treatment. But the development of new agitators in recent years means that the difference is now relatively small. In general, the energy consumption is around 0,9 kWh per kg of reduced BOD_7.

Load

A stone-filled biobed can treat 0,8–1,2 kg $BOD_7/m^3$of bed volume each day if a BOD reduction efficiency of 80–85% is required. The BOD load can be doubled if biobeds containing plastic filler material are used.

Biobeds with plastic filler are useful for treatment prior to an activated sludge process if wastewater is heavily contaminated and they can be designed to cope with 3–5 kg $BOD_7/m^3/d$. On the whole a biobed is more effective per unit volume than an activated sludge basin.

Treatment efficiency

Biobeds are normally designed for a maximum BOD reduction of 80–85%, and are known as heavily loaded biobeds. Further improvements in treatment efficiency require extensive recirculation of wastewater. For economic reasons it is often cheaper to use the activated sludge process instead. It is however possible to use biobeds for nitrification.

8.3.2 Bio-rotor

The bio-rotor is based on the same principle as the biobed, i.e. the wastewater passes through a carrier material, which in this case is attached to a rotating drum or disc on which the microorganisms grow.Wastewater passes through a trough in which the bio-rotor is partially immersed.

Oxygenation is achieved by rotating the drum.The sludge production and treatment efficiency are comparable with those of the biobed.

Energy consumption

The process is relatively energy efficient and is often used for small municipal plants and heavily contaminated industrial wastewater. The load on a bio-rotor can be up to 15–30 g BOD_7per m^2 of rotor area per day. The energy consumption of a bio-rotor is usually given as around 1,1 kWh/kg of reduced BOD_7.

8.3.3 Suspended biofilm (moving bed process)

One technology that is used increasingly often is biofilm processes that have a suspended carrier. The biofilm grows on small plastic carriers that float in the water. A sieve in the outflow of the bioreactor prevents the pieces of plastic from escaping with the water. The biofilm that grows on the plastic carrier material eventually works loose and has to be separated after the reactor in the same way as the sludge from a bio-bed or bio-rotor.

The original process uses a carrier material of polythene with a density of 0,95 g/cm^3. The carrier material is formed from small pieces of tube that are 10 mm in diameter and 7 mm long. The pieces have a cross on the inside and fins on the outside to maximise their specific area. The effective specific area when the tank is two-thirds filled with carrier material (the usual filling density) is 325 m^2/m^3. The high specific area means that moving bed bioreactors are very small and compact. The retention time in a plant designed solely for BOD reduction is 30-60 minutes. A reactor designed for nitrogen reduction has a retention time of 3-4 hours, compared with 12-18 hours for an activated sludge plant that delivers the same efficiency.

The use of suspended carrier material is particularly suitable when the time comes to upgrade an activated sludge plant that already has a large capacity. It is then simply a matter of using as much carrier material as required to achieve the desired treatment efficiency.

This process is also especially suitable for use in combination with chemical post-precipitation in heavily loaded plants, since it permits a very compact plant. There is a major need for plants of this type in many cities that are close to the sea and have limited space available for a wastewater treatment plant.

8.3.4 Biological filters

In recent years, new biofilm reactors have been developed, particularly in France, that are similar to traditional sand filters. In other words the water passes – upwards or downwards – through a filter bed consisting of a coarse filter material that is usually similar to Leca (a lightweight aggregate). The biofilm grows on the surface of the particles.

Incoming sludge and sludge produced by the treatment process itself mean that the filter gradually becomes clogged and must be back-flushed every so often. The plant therefore operates on a discontinuous basis, just like a conventional sand filter. Biological filters are very effective, but are used primarily with pretreated water and for nitrification, for example.

8.3.5 Fluidised bed

Another way of building compact biological treatment plants is to use fluidised bed technology. Sand grains of a specific size are used as the carrier material for the microorganisms. Wastewater is pumped up through the bottom of a tank at a constant flow rate, which keeps the sand grains suspended in the aqueous phase. This ensures extremely good contact between the microorganisms and the water, which means that the retention time can be kept short.

The disadvantage of this process is that it is difficult to operate under aerobic conditions due to limited oxygen transport. It is nevertheless ideal for anoxic operation and can be used for denitrification. If the respiration process is based on nitrate then a very high bioactivity can be achieved per unit volume. Oxygen cannot dissolve fast enough in the water.

Chapter 8 sources

1-Bengt Hultman, Erik Levlin, Lena Johansson, Nasik Al-Najjar, Puhua Li & Elzbieta P∏aza Wastewater Treatment Technologies, BUP Environmental science, Chapter 14, Lars-Christer Lundin & Lars Ryden.

2-EPA. “Ground water and drinking water - Customer Service.”

3-Lars Gillberg, Bengt Hansen, Ingemar Karlsson, Anders Nordström Enkel, Anders Pålsson, “About Water Treatment” Water and Wastewater Treatment: Handbook Helsingborg,Kemira Kemwater 2003, ISBN 91-631-4344-5

4-ISO 24510 Activities relating to drinking water and wastewater services. Guidelines for the assessment and for the improvement of the service to users

5-Mackenzie L. Davis Water and Wastewater Engineering: Design Principles and Practice, McGraw-Hill New York (2010) ISBN: 978-0-07-171385-6, 1301p.

6-”The Water Framework Directive: A New Directive for a Changing Social, Political and Economic European Framework”. European Planning Studies, (Taylor and Francis Group) 11 (3): 299–316.

Chapter 9.
Biochemical Process Configurations for Oxidation and Nitrification.

9.1. Activated sludge process configurations for BOD removal and nitrification

Overview

Suspended growth means that microorganisms are in a flock matrix in the wastewater suspension. Examples are the activated sludge process, stabilization ponds and aeration lagoons. The activated sludge process is shown in Figure 9.1. Influent wastewater is supplied to an aeration basin in which organic material is oxidized to carbon dioxide and water and sludge is produced containing microorganisms and non-biodegradable suspended solids. The produced sludge is removed as excess sludge for further sludge treatment.

Figure 9.1. Typical layout of activated sludge process. (Adapted from Bengt Hultman et al)

There are many process arrangements of the basic activated sludge process. Some of the configurations used for oxidation of biodegradable COD and nitrification. Selected activated sludge configurations for oxidation of biodegradable COD and nitrification : plug flow (conventional); step feed(step aeration); complete mix; oxidation ditch; sequencing batch reactor; staged activated sludge; contact stabilization; conventional with selector; tapered aeration; extended aeration.

Because nitrifying bacteria grow much more slowly than heterotrophic bacteria, systems designed for nitrification generally have much longer hydraulic and solids retention times.

Plug Flow. This is the conventional arrangement where flow enters one end of a long narrow tank and exits at the other (Figure 9.3a). The solid line in Figure 9.2 illustrates how substrate and oxygen demand vary along the length of the tank. Oxygen demand is highest in the first 20 percent of the tank because of substrate oxidation. Oxygen demand along the remainder of the tank is due to endogenous respiration. If the concentration of substrate is high, it may lead to complete depletion of dissolved oxygen. Oxygen depletion maybe detrimental to some of the microbial population. It may also result in fermentation or partial oxidation that results in organic acid production and a drop in pH.

Step feed
Although it is frequently called step aeration, step feeding is a more accurate descriptor (Figure 9.3b). In this modification of the plug flow configuration, the influent flows into the aeration tank at several locations along its length. The benefit of this arrangement is that it reduces oxygen demand at the head end of the tank. This is shown by the small-dashed line in Figure 9.2.

Complete mix
This process is a completely mixed stirred tank reactor (CSTR). It is illustrated in Figure 9.3c. Because the influent is "immediately" diluted with the contents of the tank, the substrate concentration and dissolved oxygen (DO) are uniform over the reactor volume. This is illustrated by the large-dashed line in Figure 9.2. While this arrangement overcomes the high initial loading and DO problems in a plug flow system, its removal efficiency is not as high.

Oxidation ditch
An oval or race-track channel equipped with mechanical aerators provides the benefits of plug flow and completely mixed reactor in one tank (Figure 9.3d). The energy used for aeration also provides mixing. The mixed liquor completes the circuit in 5to 15 minutes. The flow in the channel dilutes the incoming wastewater by a factor of 20 to 30. As a result, the process kinetics approaches that of a completely mixed reactor but with plug flow along the channel. In typical designs, there is no primary treatment. Although the flow completes a circuit in a short time, the hydraulic detention time is relatively long. This system may be operated to achieve denitrification as well as BOD reduction. It is relatively easy to operate and achieves better treatment than oxidation ponds. This process typically finds application in smaller, rural communities where space is not limited.

Figure 9.2 Changes in contaminant (substrate) concentration and oxygen (DO) uptake rate along the reactor length: for plug flow (PF, solid lines), step aeration (SA, small-dash lines), and continuous-stirred tank (CSTR, large-dash lines) reactors for a typical loading with a dilute wastewater. (Source: Rittmann and McCarty, 2001.)

Sequencing Batch Reactor (SBR)
The SBR is a completely mixed reactor that is operated on a batch basis. It has application in small communities where space is limited and/or treatment requirements do not permit the use of oxidation ponds. This system may be operated to

achieve denitrification as well as BOD reduction. These systems have five steps that are carried out in a timed sequence: (1) fill, (2) react (aeration), (3) sedimentation, (4) decant the supernatant, and(5) idle (Figure 9.3e).

The design principles for this reactor are keyed to the following treatment steps(NEIWPCC, 2005):

- Fill. During this phase the basin receives influent wastewater. Three scenarios maybe selected:
- Static fill. In this scenario there is no mixing and no aeration while the wastewater is entering the tank. This scenario is used during initial start-up of the facility. Static fill maybe used in plants that do not need to nitrify or denitrify to save power during low flow periods.
- Mixed fill. In this scenario aeration is minimized by the use of mechanical or jet mixers. Because there is no aeration, the wastewater/microorganism system becomes anoxic. This is used to promote denitrification. Anaerobic conditions can also be achieved to promote the release of phosphorus.
- Aerated fill. In this scenario both aerators and mechanical mixing maybe employed. In batch processes the oxygen uptake rate is a factor of concern for two reasons. First, the cell concentration is very high at the beginning of fill, and, second, the maximum reactor BOD concentration also occurs at this time. From a design perspective, this mode of filling requires a significantly higher air supply than is required in subsequent steps. Thus, the aeration system is overdesigned for the majority of the operating sequence.

Two alternatives are available. One is to begin with a mixed fill (anoxic) and then switch to an aerated fill after some portion of the wastewater has been added. The other alternative is to provide a feedback control to decrease the air flow rate and energy consumption in subsequent steps (Schroeder, 1982).

- React. During this phase aeration and mixing units are on. No wastewater enters the basin. Most carbonaceous BOD removal occurs during this phase. With an appropriate aeration duration, nitrification will also occur in this phase. If anaerobic fill is employed, the phosphorus released during fill plus some additional phosphorus is taken up during this phase.
- Settle. Air and mixing are turned off. The activated sludge is allowed to settle. This is a critical step both for the recovery of biomass for the next cycle and the production of an effluent that is low in suspended solids.
- Decant. A decanter is used to remove the clear supernatant that is to be discharged. It needs to remove clear liquid without entrapping surface scum or entraining settled sludge.

- Idle. This step occurs between the decant and fill phases. Depending on the flow rate, this phase maybe long or short. At high flow rates, this phase maybe eliminated. At low flow rates, this phase maybe very long. If this phase is too long, the sludge may become anaerobic.

Staged activated sludge

In this system several completely mixed tanks are placed in series (Figure 9.3f). Although each tank is mixed, the contents do not mix among them. Three or more tanks in series approximate a plug-flow system. This system provides the advantage of the plug flow system's efficiency as well as that of the complete mix system's capacity to deal with high organic load and ability to maintain acceptable DO levels.

Figure 9.3. Selected activated sludge configurations for oxidation and nitrification. (Sources: Adapted from Rittmann and McCarty, 2001 and Metcalf & Eddy, 2003)

Contact stabilization

Wastewater is mixed with return activated sludge in a reactor that has a relatively short detention time. This contact reactor takes advantage of the fact that the most readily biodegradable COD is oxidized or stored in a relatively short time and the fact that particulate COD is adsorbed on activated sludge flocks in the same time frame. The treated wastewater is separated from the activated sludge in a settling tank. The wastewater is discharged and the settled activated sludge is sent to a second reactor (called a stabilization tank) where aeration is continued. Here the stored and adsorbed COD is oxidized (Figure 9.3g). The advantage of this system is the reduction in overall tank volume. The disadvantage is that the system requires substantial operator skill and attention.

Conventional with selector

Somewhat like the contact stabilization process, the detention time in the selector is too short for complete BOD oxidation. The detention time is shorter than that provided in the contact stabilization process. This system promotes the formation of flocks that will settle. The selector is followed by an aeration tank of conventional design (Figure 9.3h).

Tapered aeration

This is an alternative to step feeding. The air supply is increased at the head end of the conventional plug-flow tank. It is tapered to lower levels along the tank.

Provided that the inlet organic load is not so high that oxygen cannot be supplied to meet the demand, this system reduces power costs and equipment sizes.

Extended aeration

This process is used primarily to treat wastewater flows from small residential communities. Process aeration is extended to 24 hours or more. Under these conditions endogenous respiration governs the oxidation process. This minimizes the sludge mass. While these systems can achieve good results, they have experienced problems with poor settling sludge, low pH due to nitrification, and high suspended solids in the effluent when operated in a conventional plug-flow reactor. With adequate operator supervision, these problems have been successfully overcome when extended aeration has been applied in an oxidation ditch. (Figure 9.3 d)

The activated sludge process was first introduced in Manchester in 1914. The design principles of suspended growth processes maybe broadly separated into two categories: those based on experience and those based on microbial biochemistry and microbial population dynamics. The remaining suspended growth treatment systems fall into the second category. The completely mixed, conventional plug-flow, and batch reactor models that are presented in the next section serve as means of showing the relationship between several design variables for suspended growth processes. Mass balance relationships and applied microbial biochemistry relationships provide the basis for other process design relationships. Typical design parameters for commonly used processes are summarized in Table 9.1.

Table 9.1. Typical design parameters for carbonaceous BOD oxidation and nitrification (Adapted from Metcalf & Eddy, 2003.)

SRT – solids retention time; MLSS – mixed liquor suspended solids; HRT – hydraulic residence time; RAS - return activated sludge, % of average design flow rate.

[a] For nitrification rates maybe increased25–50%.

[b] MLSS and HRT in contact basin.

[C] MLSS and HRT in stabilization basin.

N/A - not applicable.

Sludge return

Among the major decisions in developing a suspended growth reactor design is the selection of the mixed liquor volatile suspended solids (MLVSS) concentration and the corresponding mixed liquor suspended solids (MLSS) concentration. This selection is not simple. It depends on the objective of the reactor, settling characteristics of the sludge, and the rate of recycle of sludge (called the sludge return rate or sludge return, or return activated sludge—RAS).

A high MLVSS concentration is desirable because it leads to a smaller reactor and lower construction costs. But this may lead to a larger settling tank to handle the sludge load. In addition, a higher MLVSS also requires a higher aeration rate to meet the increase in oxygen demand.

Increasing MLVSS also requires increasing the rate at which sludge is returned from the settling tank. Finally, a higher MLVSS may lead to a higher effluent suspended solids and BOD in the effluent.

For a typical good settling sludge the maximum return sludge concentration is in the range of 10,000 to 14,000 mg/L. With poorly settling sludges the maximum return sludge concentration maybe as low as 3,000 to 6,000 mg/L. For operational flexibility the return sludge pumping rate must be adjustable. Typically, the maximum sludge return rate is set equal to the design flow rate.

Sludge production

An estimate of the sludge production is important for process design of the sludge handling facilities and the aeration system. As a suspended growth process removes substrate, the substrate is converted into new cell material. This cell material is activated sludge. The sludge will accumulate in the process if it cannot be processed by the sludge handling facility. Eventually, the sludge inventory will exceed the capacity of the system and will exit the secondary clarifier as suspended solids. The estimate of the amount of oxygen required for biodegradation of carbonaceous BOD is determined from a mass balance of the bCOD concentration and the amount of biomass wasted from the system. The amount of biomass wasted is a function of the amount of sludge produced.

Two methods of estimating the sludge production are used. The first is satisfactory for preliminary design. It is based on rules-of-thumb and published data from existing facilities.

9.2 Attached grow process configurations for BOD removal and nitrification.

In fixed film reactors microorganisms form a biofilm on a surface that may be stones or plastic materials. Organic materials, oxygen and nutrients diffuse into the biofilm. Oxygen is often a limiting factor in the biofilm and therefore it has an aerobic and an anaerobic part. The products formed are removed by diffusion into the wastewater. Produced sludge is washed away and removed in a following separation step. Because of their stable operation and relative ease of operation, trickling filters were the method of choice for secondary treatment of municipal wastewater early in the 20th century. There are some differences between activated sludge processes and attached growth process but main there are four:

- Activated sludge processes are more economical.
- Activated sludge processes are more flexible.
- Activated sludge processes can meet more stringent effluent standards.
- Odor complaints are more frequent when rock filters are used.

Figure 9.4. Biological reactions in the biofilm of a trickling filter. (Adapted from Hultman et al, BUP)

Figure 9.5. Trickling filters, rock (Sources: M. L. Davis and Brentwood Industries).

Nonetheless, modern technologic improvements in media and forced air aeration have made attached growth processes more attractive in recent years. This is especially so where an existing facility maybe in corporate into a plant upgrade. The requirement for less skilled personnel for operation and the advantage of using less energy than activated sludge processes are often serious considerations favoring attached growth process selection.

The most common processes are trickling filters and rotating biological contactors. In trickling filters, wastewater distributors introduce wastewater to a tank. Air is supplied by natural ventilation or by a fan (Figure 9.5).

Design Loading. Trickling filters are classified according to the applied hydraulic and organic load. The hydraulic load maybe expressed as cubic meters of wastewater applied per day per square meter of bulk filter surface area ($m^3/d\cdot m^2$) or, preferably, as the depth of water applied per unit of time (mm/s or m/d). Organic loading is expressed as kilograms of BOD_5 per day per cubic meter of bulk filter volume ($kg/d\cdot m^3$). Common hydraulic and organic loadings for the various filter classifications are summarized in Table 9.2.

Typical applications are summarized in Table 9.2 .

Table 9.2 Comparison of different types of trickling filters

Trickling filters can be applied in different biological wastewater treatment configurations. Most often trickling filters applications are represented in Table 9.3.

Rotating biological contactors have a cylindrical axis on which are mounted plastic materials (Figure 9.6). Microorganisms form a biofilm on the plastic material. The contactor rotates in a holding tank. Microorganisms are in contact with wastewater and there after exposed to air for degradation of the organic material.

Table 9.3. Typical trickling filter applications (Source: Metcalf & Eddy, 2003).

A new development in attached growth reactors is the fluidized bed. In this system microorganisms form a biofilm on, for instance, sand particles. The sand particles are in movement due to the velocity of the supplied wastewater. This treatment unit makes it possible to use much lower residence times than for the other reactors.

Attached growth reactors may be combined to allow for biological nitrogen and phosphorus removal. The reactors may also be used for anaerobic treatment of wastewater with a high content of organic materials, such as from the food industry.

Several units for biological treatment use the combination of suspended growth and attached growth. An example is the use of submerged plastic materials in the activated sludge process.

Figure 9.6. Treatment system with rotating biological contactors. (Adapted from Hultman et al, BUP)

9.3 Secondary Settling

The function of secondary settling tanks that follow trickling filters is to produce a clarified effluent. Secondary settling tanks that follow activated sludge processes also serve the function of thickening to provide a higher solids concentration for either return activated sludge or wasting and subsequent treatment.

The following discussion is divided into two parts: design principles and design practice.

Design Principles

Trickling filter

Trickling filter solids settling maybe classified as Type II flocculant settling. Because the suspended solids loading is low, the overflow rate governs design.

Activated sludge

Activated sludge solids settling classification falls into each of the four types depending on the depth in the clarifier. In the upper, clear water level, discrete flock particles settle (Type I settling). As the particles sink, they begin to flocculate (Type II settling). In the lower zones, hindered settling (Type III) and compression settling (Type IV) take place.

Both clarification and thickening are considered in the design of the secondary settling tank for activated sludge systems. Clarification is governed by the settling velocity of the light fluffy particles. Thickening is governed by the mass flux of solids in the zone where hindered settling takes place.

It is not possible to make estimates of overflow rates for clarification based on first principles. The irregular nature of activated sludge flock precludes any rational estimate of settling velocity that could be used to select an overflow rate.

Overflow Rate. The calculation of overflow rate is based on wastewater flow rate (Q_{in}) instead of the mixed-liquor flow rate, that is, Q_{in} alone and not Q_{in} + Q_R. The overflow rate is equivalent to the up flow velocity. The return sludge portion of the flow (Q_R)is drawn off the bottom of the tank and does not contribute to the up flow velocity.

The overflow rate design criteria differ for trickling filter, activated sludge, integrated fixed film activated sludge (IFAS), and moving bed biofilm reactors (MBBR) secondary settling tanks. The recommendations for each are discussed in the following paragraphs.

Trickling filter

The historic use of high overflow rates and shallow secondary clarifiers resulted in poor performance. For shallow tanks, a conservative average overflow rate of 0.09 m/h with a maximum overflow rate of 0.28 m/h is suggested (Vesilind, 2003).

GLUMRB (2004) specifies a peak hourly overflow rate of 2.0 m/h. Clarifier designs for trickling filters should be similar to designs used for activated sludge process clarifiers with appropriate feed well size and depth, increased side water depth, and similar hydraulic overflow rates(Metcalf & Eddy, 2003). Recommended overflow rates as a function of side water depth are summarized in Table 9.4.

Table 9.4 Recommended trickling filter secondary clarifier overflow rates

- Activated sludge: The previous two editions of the WEF design manual (WEF, 1998) suggested the following maximum allowable overflow rates at the minimum recommended side water depths: 1.4 m/h at average flow, 2.4 m/h for the three-hour sustained peak flow rate, 2.7 m/h for the two-hour sustained peak flow rate. A survey of design firms revealed that they prefer to select conservative overflow rates. A compilation of preferred overflow rates is shown in Table 9.5

- Integrated fixed-film activated sludge (IFAS):The overflow rates for IFAS processes as a function of side water depth are shown in Table 9.6 .
- Moving bed biofilm reactors (MBBR):The recommended range of overflow rates for MBBRs is 0.5 to 0.8 m/h (Metcalf & Eddy, 2003).

Table 9.5 Preferred secondary clarifier overflow rates for activated sludge processes (Adapted from Metcalf & Eddy, 2003, and Lakeside Equipment Corporation).

Table 9.6 Secondary clarifier overflow rates for IFAS processes

Comment

In selecting the diameter of the secondary settling tank for activated sludge processes, the design diameter must be checked for both overflow rate and solids loading. The larger of the diameters that results from these calculations governs the design.

Solids loading

When data are available to perform a solids flux or state point analysis, this is the preferred method for determining the solids loading rate. Previous editions of the WEF design manual (WEF, 1998) provided a graphical approach using Figure 9.7 to select an appropriate solids loading rate. In the absence of test data, most design engineers prefer to keep the maximum solids loading rate, including full RAS capacity, in the range of 100 to 150 kg/m^{2}d (Jayanayagam, 2006). Table 9.7 summarizes typical design ranges.

Side water depth

Liquid depth in the secondary clarifier is measured at the sidewall in circular tanks and at the effluent end wall of rectangular clarifiers. Based on historical operating data, Parker (1983) demonstrated that at similar overflow rates, suspended solids in the effluent decreased with increasing depth. He also found that variability in effluent quality also decreased with increasing depth. Most firms agree that larger tanks require greater depth. However, cost considerations generally restrict depths to less than 4.5to 5 m.

Figure 9.7 Design solids loading versus SVI. (Note: Rapid sludge removal design assumes that there will be no inventory in the settling tank. Source: WEF, 1998.)

Table 9.7 Ranges of loading rate for activated sludge process secondary clarifiers

Chapter 9 sources

1-Albertson, O. E. (2008) “Solids Loading Limitations of Rectangular Secondary Clarifiers,” Journal of Environmental Engineering Division, American Society of Civil Engineers, vol. 134, no. 1, pp. 14–21.

2-Albertson, O. E. andJ. P. Wilson (1997) “Clarifier Design Concept—Larger Is Better,” Journal of Environmental Engineering, November, pp. 1,159–1,162.

3-Davis, M. L. andD. A. Cornwell (2008) Introduction to Environmental Engineering, McGraw-Hill, Boston, Massachusetts, pp. 510–513.

4-Jayanayagam, S. S. (2006) “Secondary Clarifier Design Concepts and Considerations,” in Clarifier Design, 2nded., Water Environment Federation Manual of Practice No. FD-8, pp. 143–209.

5-Lars Gillberg, Bengt Hansen, Ingemar Karlsson, Anders Nordström Enkel, Anders Pålsson, “About Water Treatment” Water and Wastewater Treatment: Handbook Helsingborg,Kemira Kemwater 2003, ISBN 91-631-4344-5

6-GLUMRB (2004) Recommended Standards for Wastewater Facilities,Great Lakes–Upper Mississippi River Board of State andProvincial PublicHealth andEnvironmental Managers, Health Education Services, Albany, New York, pp. 70–3.

7-Bengt Hultman, Erik Levlin, Lena Johansson, Nasik Al-Najjar, Puhua Li & Elzbieta P∏aza Wastewater Treatment Technologies, BUP Environmental science, Chapter 14, Lars-Christer Lundin & Lars Ryden.

8-Mackenzie L. Davis Water and Wastewater Engineering: Design Principles and Practice, McGraw-Hill New York (2010) ISBN: 978-0-07-171385-6, 1301p.

9-Metcalf & Eddy(2003) Wastewater Engineering:Treatment and Reuse,4th ed., McGraw-Hill, Boston, pp. 452–453, 820–840, 1217–1343.

10-Parker, D. S. (1983) “Assessment of Secondary Clarification Design Concepts,” Journal of Water Pollution Control Federation, vol. 55, p. 349.

11-Peng, W, J. Rigdon, and G. Russell (2007) “Sludge Blanket Formation and Its Effects on Secondary Clarifier Performance,” Journal of Environmental Engineering,vol. 133, no.7, pp. 758–764.

12-Pettit, M. V. (2006) “Rectangular Clarifiers,” in Clarifier Design, 2nded., Water Environment Federation Manual of Practice No. FD-8, pp. 489–581.

13-Tekippe, R. J. (2006) “Circular Clarifiers,” in Clarifier Design, 2nded., Water Environment Federation Manual of Practice No. FD-8, pp. 397–488.

14-Vesilind, P. A. (2003) Wastewater Treatment Plant Design,Water Environment Federation, Alexandria, Virgina, p.7–20.

15-WEF(1998) Design of Municipal Wastewater Treatment Plants,4th ed., Water Environment Federation Manual of Practice 8, Alexandria, Virgina, pp. 11-95–11-137.

Chapter 10
Biochemical Process Configurations for Nutrients Removal

10.1. Eutrophication prevention and nutrients removal

Only small amounts of nitrogen and phosphorus, principally in runoff from cultivated farmland, are transported to surface waters in a simple agrarian economy. However, phosphate rock is mined and processed into fertilisers, detergents, animal feeds and other chemicals. The amounts of inorganic nitrogen and phosphorus needed to produce abundant algae and rooted aquatic weeds are relatively small. Lakes with annual mean total nitrogen and phosphorus concentrations greater than 0.8 mg/l and 0.1 mg/l, respectively, exhibit algal blooms and nuisance weed growths during most of the growing season. Reducing nutrient input through advanced treatment of wastewater can retard the rate of eutrophication of a water body. Emphasis should be placed on phosphorus removal, since phosphorus is considered the limiting nutrient, while methods are available to precipitate wastewater phosphate chemically. Nitrogen compounds are more difficult to eliminate and techniques for nitrogen removal are very costly.

10.2. Phosphorus removal

10.2.1 Chemical phosphorus removal

Phosphorus is present in wastewater as phosphate, both in soluble and suspended form. Only about 15 % of the total phosphorus contained in settleable particles may be removed by primary sedimentation. The principle of removing phosphorus from wastewater is therefore based on the transfer of soluble phosphorus to solid phase followed by solid-liquid separation. The phosphorus removal methods can be divided into:

- chemical treatment - chemical precipitation by the addition of lime, iron or aluminium salts
- biological treatment - assimilation in conventional plants; enhanced assimilation by process modification, algae ponds
- combined methods with chemical and biological Treatment
- others, such as: ion exchange and adsorption and terrestrial treatment (irrigation; percolation; infiltration; plant treatment)

Chemical processes for phosphorus removal can be classified, according to their location in the process stream, as direct precipitation, pre-precipitation, simultaneous precipitation and post-precipitation (Figure 10.1).

Compounds of phosphorus can be removed by addition of coagulants, such as alum, lime, ferric chloride, or ferrous sulphate. With calcium salts, phosphorus can be precipitated to low residuals, depending on the pH. The precipitate is a hydroapatite, $Ca_5OH(PO_4)_3$:

$$5\ Ca^{2+} + 7\ OH^- + 3\ H_2PO_4^- \rightarrow Ca_5OH(PO_4)_3 + 6\ H2O$$

Figure 10.1. Plant configurations for chemical phosphorus removal. (Adapted from Bengt Hultman et al)

Optimum pH for phosphorus precipitation with 12. The lime requirements are dictated by the hardness and alkalinity of wastewater. If using aluminium, a dosage of 1.5 to 3.0 moles of aluminium per mole of phosphorus as P is required over a pH range of 6.0 to 6.5. Iron can be added as $FeSO_4$ or $FeCl_3$. The iron dosage will range from 1.5 to 3.0 moles of iron (Fe^{3+}) per mole of phosphorus (as P). The optimum pH is 5.0, which is too low for conventional biological treatment.

The chemicals may be added prior to primary sedimentation, with alum and soil salts being added to the aeration tank during the activated sludge process, or chemicals may be added in a third stage following biological treatment. Chemical precipitation, especially using lime, is sometimes practiced in a third stage after biological treatment, both to remove the phosphorus and to increase the pH of the effluent in preparation for a process of ammonia-nitrogen removal.

10.2.2 Biological phosphorus removal

In a biological phosphorus-removal process, polyphosphates are accumulated by bacteria and removed with the waste in the activated sludge. As a result, 10 to 30 % of the influent phosphorus is removed during the secondary biological treatment. The bacteria are exposed to alternate anaerobic and aerobic conditions. If an enhanced biological phosphorus removal is to be achieved there must also be a sufficiently high amount of readily biodegradable low-molecular organics supplied to the anaerobic zone from the influent or from anaerobically degraded complex organics. Under anaerobic conditions bacteria hydrolyse accumulated polyphosphates to use the released energy to absorb rapidly biodegradable organic material. Under aerobic conditions the stored organic material in the P-accumulating organisms is used for growth and to synthesise new polyphosphates.

The basic principle of biological phosphorus removal is illustrated in Figure 10.2. Biological phosphorus removal is carried out using activated sludge technology and plant configuration is shown in Figure 10.3.

Figure 10.2. Biological phosphorus removal mechanisms in P-storing bacteria. (Adapted from Henze, 1996)

Figure 10.3. Plant configuration for biological phosphorus removal. (Adapted from Bengt Hultman et al)

Chemical precipitation is still the dominating phosphorus removal technology of the Scandinavian countries (Table 10.1). There has been an increase in biological phosphorus removal over the last few years. This was caused mainly by economic factors, low sludge production and the fertiliser value of the bio-P sludge. Choice of technology also depends on effluent criteria (Table 10.2). The sludge containing the excess phosphorus is either wasted or removed and treated in a side stream to release the excess phosphorus (Figure 10.4). Release of phosphorus occurs under anoxic conditions.

Table 10.1. Phosphorus removal technologies applied in Scandinavian countries in % of population with P-removal (Henze, 1996)

Table 10.2 Expected effluent quality for phosphorus removal using various treatment methods in gTP/m3 (Henze, 1996)

Figure 10.4. Flow diagram for biological removal of phosphorus. The Phostrip process (Linsley et al., 1992).

10.3 Biological phosphorus removal configurations

As discussed earlier biological phosphorus removal (BPR) requires an anaerobic zone followed by an aerobic zone. The alternating exposure to anaerobic and aerobic conditions can be accomplished in the main biological treatment process (called mainstream) or in the return sludge stream (called side stream) There are several modifications to the basic process. Among the most common are those that incorporate biological nitrogen removal. Lists of the mainstream configurations used for BPR are discussed.

Selected mainstream biological phosphorus removal configurations:

- Phoredox;
- Anaerobic/anoxic/aerobic(A2/O™);
- Bardenpho™ (5-stage);
- Universityof Cape Town (UCT);
- Sequencing batch reactor (SBR);

Phoredox

This is the name given by Barnard (1975) to represent any anaerobic/aerobic sequence to promote BPR. It is shown in Figure 10.5 . A version of this process with multiple stages is patented as A/O ™ (anaerobic/aerobic). These processes are not designed to promote nitrification/denitrification (Metcalf & Eddy, 2003). The anaerobic detention time is 30 min to 1 h. The SRT of the aerobic zone is 2 to 4 d.

Figure 10.5 Phoredox (A/O™) processes for biological phosphorus removal. (Adapted from Metcalf & Eddy, 2003.)

A^2/O ™

This is a proprietary modification of the A/O ™ process that provides internal recycle and an anoxic zone for denitrification (Figure 10.6). The detention period in the anoxic zone is approximately 1 h.

Figure 10.6 A^2/O™ processes for biological phosphorus removal. (Adapted from Metcalf & Eddy, 2003.)

Bardenpho ™ (5-Stage)

This modification of the four-stage process provides for both denitrification and phosphorus removal (Figure 10.7). The staging and recycle differ from the A 2/O ™process. The five-stage process uses a longer SRT than the A 2/O ™ and thus increases the carbon oxidation capability.

Figure 10.7 Bardenpho ™ (5-Stage)processes for biological phosphorus removal. (Adapted from Metcalf & Eddy, 2003.)

University of Cape Town (UCT)

The UCT process was developed at the University of Cape Town in South Africa. It is similar to the A 2/O ™ process with two exceptions. The return sludge is recycled to the anoxic stage instead of the aeration stage, and the internal recycle is from the anoxic stage to the anaerobic stage (Figure10.8). By returning the sludge to the anoxic stage, the introduction of nitrate to the anaerobic stage is avoided. This improves the phosphorus uptake. The internal recycle feed provides increased organic utilization in the anaerobic stage.

Figure 10.8 University of Cape Town (UCT) processes for biological phosphorus removal. (Adapted from Metcalf & Eddy, 2003.)

Sequencing Batch Reactor (SBR)
The six operational steps of the SBR denitrification process are retained, but the conditions are modified (Figure10.9). One alternative is to provide an anoxic period after sufficient aerobic time has elapsed for nitrification to occur. Another alternative is to use cyclic aerobic and anoxic periods during the react period. This minimizes the nitrate concentration before settling. Little nitrate is available to compete for rbCOD during the fill period so that rbCOD uptake and storage by PAOs can occur instead of rbCOD consumption by nitrate reducing bacteria.

Figure 10.9 Sequencing Batch Reactor (SBR) processes for biological phosphorus removal. (Adapted from Metcalf & Eddy, 2003.)

Design Practice for Phosphorus Removal
The following paragraphs outline the design practice for those portions of the BPR process that affect phosphorus removal.

rbCOD
The available rbCOD determines the amount of phosphorus that can be removed by the BPR mechanism. Metcalf & Eddy (2003) estimates that 10 g of rbCOD is required to remove 1 g of phosphorus. Observations of the influent BOD to phosphorus ratio at operating plants as a function of their design SRT are shown in Table10.3.

Table 10.3 BOD/P and COD/P ratios for phosphorus removal (Adapted from Metcalf & Eddy. 2003)

Although these data do not include rbCOD, they give an indication of the trend with respect to SRT and their relationship to the types of BRP processes. Nitrate reduction in the anaerobic tank will proceed before the BPR mechanisms. This will reduce rbCOD that is available for BPR. In processes like A ^{2}/O ™ where RAS is returned to the anaerobic tank, the plant effluent nitrate concentration (which also appears in the RAS) must be minimized to maximize the amount of phosphorus that can be removed by the BPR mechanism. Likewise, the nitrate in the return flow from the anoxic tank will limit phosphorus removal for the same reason.

Solids retention time (SRT)

BPR systems with longer SRTs are less efficient than those with shorter SRT designs. Two adverse effects on phosphorus removal efficiency are associated with lightly loaded, long SRT processes. First, because the final amount of phosphorus removed is proportional to the mass of biological phosphorus storing bacteria wasted, the phosphorus biomass production is lower so that less phosphorus is removed during wasting.

Return activated sludge (RAS)

In the A ^{2}/O ™ process the RAS is returned to the head end of the anaerobic tank. This is of concern because excessive amounts of nitrate may enter the anaerobic tank. Heterotrophic bacteria will use nitrate to consume rbCOD. This will reduce the rbCOD available for PAOs, which, in turn, will reduce the phosphorus removal efficiency. Thus, the BPR is dependent on the efficiency of the biological denitrification step. Other BPR processes avoid this problem by routing the RAS to the anoxic tank. The RAS pumping system must be flexible enough to allow RAS flow rates that vary from 25to 100 percent of the influent flow rate.

Mixed liquor suspended solids (MLSS)

Typical MLSS concentrations are given in Table 10.4. Some plants using the A ^{2}/O ™ process have operated with MLSS concentrations in the range 800 to 2,000 mg/L, but the typical range is 3,000 to 4,000 mg/L.

Table 10.4 Typical design parameters for phosphorus removal (Adapted from Metcalf, & Eddy, 2003.)

SRT = solids retention time; MLSS = mixed liquor suspended solids; HRT = hydraulic residence time; RAS = return activated sludge, % of average design flow rate.

Notes: With the exception of A/O, these processes also remove nitrogen in the anoxic stage. A/O ™ , A^2/O ™ , Bardenpho ™, and VIP ™ processes are patented.

10.4. Nitrogen removal

In municipal wastewater nitrogen is present as ammonia and as organic nitrogen. Biological and physical-chemical processes are used for nitrogen removal. Physical- chemical alternatives include ammonia stripping, selective ion exchange and breakpoint chlorination.

In biological wastewater treatment systems nitrogen is removed by assimilation (15-20 % of total nitrogen) and by the biological nitrogen removal process, accomplished in two stages: nitrification and denitrification. In the nitrification process ammonia is oxidised to nitrate by two groups of chemoautotrophic bacteria that operate in sequence:

Nitrosomonas

$NH_4^+ + 1.5\ O_2 \rightarrow NO_2^- + 2H^+ + H_2O$ + new cells

Nitrobacter

$NO_2^- + 0.5\ O_2\ NO_3^-$ + new cells

The energy released in these oxidations is used for the growth of the nitrifying organisms. Since the bacteria are aerobic, an oxygen supply is required for the nitrification process. Several factors influence the nitrification process, including pH, temperature, oxygen content and toxic substances. All of these should be taken into consideration in the design of the process. Certain heavy metals, complex anions and organic compounds are toxic to nitrifiers.

The biological nitrification processes can be achieved in either a suspended growth reactor (such as in a conventional aeration basin in an activated-sludge process or in an attached-growth reactor (nitrification is accomplished by organisms attached to a growth media as in a trickling filter).

Both suspended-growth and attached-growth systems are also used for denitrification. The biological process of denitrification transforms nitrate- nitrogen into nitrogen gas. A relatively broad range of bacteria can accomplish denitrification, as many bacteria can shift rapidly between using oxygen and nitrate (or nitrite). Denitrification is achieved when heterotrophic bacteria use oxygen from nitrate and nitrite for organic carbonaceous oxidation. The process must be performed in an anoxic environment (absence of oxygen but with presence of nitrate).

Denitrification can be accomplished using an internal carbon source from sewage or by adding biologically degradable organic material (methanol, ethanol etc.). Temperature and internal carbon source influence to the denitrification rate was shown in Figure 10.10.

For methanol the reaction can be written:

$$3NO_3^- + CH_3OH \rightarrow 3NO_2^- + H_2O + H_2CO_3$$

$$2NO_2^- + CH_3OH \rightarrow N_2 + CO_3^{2-} + 2H_2O$$

Figure 10.10 Denitrification rate for various carbon sources. (Adapted from Gilberg et al, 2003)

Typical denitrification rate for various carbon sources are given in Table 10.5. External carbon sources are easily biodegradable materials, such as methanol, ethanol, acetic acid or starch, which are added to the process. This is costly, so external carbon sources should only be used to supplement internal sources.

The removal of one gram of nitrogen requires a carbon source equivalent to 3–6 grams of COD. The denitrification rate is temperature-dependent, but not to the same degree as the nitrification rate.

Table 10.5 Characteristics of some sources of carbon.

As for nitrification, pH and temperature influence the rate of denitrification. The most commonly used systems for biological nitrogen removal are pre-denitrification (Preanoxic) and post-denitrification (Postanoxic). If the efficiency of the process is not enough for effluent requirements a polishing step using biofilters can be applied (Figure 10.11).

Selected biological denitrification configurations.

- Preanoxic: Modified Ludzack-Ettinger (MLE); Step feed; Sequencing batch reactor (SBR).
- Postanoxic: Single sludge; Bardenpho™ (4-stage); Oxidation ditch.

Figure 10.11 Plant configurations for biological nitrogen removal. (Adapted from Bengt Hultman et al)

Modified Ludzack-Ettinger (MLE). This preanoxic process is one of the most commonly used for denitrification. It relies on the return of nitrate formed in the aerobic zone to the anoxic zone (Figure 10.12). The provision of an internal recycle is the “modification” to the original process. Both the denitrification rate and the overall nitrogen removal efficiency are increased by this modification.

Figure 10.12 Preanoxic MLE processes configuration for denitrification. (Adapted from Metcalf & Eddy, 2003.)

Step feed
The step feed process can be modified to perform biological nitrogen removal (BNR). The final flow portion to the last anoxic/aerobic zone is critical in defining the final effluent concentration of NO_3-N as the nitrate in that zone will not be reduced.

Figure 10.13 Preanoxic step - feed processes configuration for denitrification. (Adapted from Metcalf & Eddy, 2003.)

Sequencing Batch Reactor (SBR)
The SBR system for BOD oxidation and nitrification is modified by an additional operational step. Although sufficient BOD and fill time are available to remove almost all of the nitrate after the settle and decant steps, a separate mixing step without aeration provides more flexibility as well as improved nitrogen removal.

Figure 10.14 Preanoxic SBR processes configuration for denitrification. (Adapted from Metcalf & Eddy, 2003.)

Single sludge
In this process a mixed anoxic tank follows the aerobic tank. To achieve high nitrate removal efficiency, a long detention time in the anoxic tank is required because the denitrification rate is proportional to the endogenous respiration rate.

Figure 10.15 Postanoxic single sludge processes configuration for denitrification. (Adapted from Metcalf & Eddy, 2003.)

Bardenpho^{TM}(4-Stage)
Both preanoxic and postanoxic processes are in corporate in the Bardenpho four-stage process (Figure10.16). The hydraulic detention time of the postanoxic stage

is about the same or longer than the preanoxic stage. In actual practice it was discovered that phosphorus removal also occurred. The process name is derived from the inventor's name (Barnard, 1974) and the truncation of "denitrification" and "phosphorus" removal.

Figure 10.16 Postanoxic Bardenpho^{TM}(4-Stage). processes configuration for denitrification. (Adapted from Metcalf & Eddy, 2003.)

Oxidation ditch

By increasing the length of the oxidation ditch to provide an anoxic zone after the aerobic zone, BNR can be achieved in a single tank. Most of the BOD is removed in the aerobic zone. Nitrate is used for endogenous respiration. A large tank volume and long sludge retention times are required for efficient BNR.

Figure 10.17 Postanoxic oxidation ditch processes configuration for denitrification. (Adapted from Metcalf & Eddy, 2003.)

Table 10.6 Typical design parameters for denitrification (Adapted from Metcalf, & Eddy, 2003.)

10.5 Combined phosphorus and nitrogen removal

Most plant configurations for nitrogen and phosphorus removal are based on biological processes and different combinations of anaerobic, aerobic and anoxic zones (Bardenpho, A^2O, UCT and their modifications), but a combined usage of biological and chemical methods is also applied (Figure 10.18). In the Bardenpho process (see Figure10.18), a sequence of anaerobic, anoxic and aerobic steps are used to achieve both nitrogen and phosphorus removal. Nitrogen is removed by nitrification-denitrification. Phosphorus is removed by wasting sludge from the system. The choice of process system is dependent on factors such as effluent requirements and influent nitrogen and phosphorus concentration to the wastewater treatment plant.

Figure 10.18 Plant configurations for combined nitrogen and phosphorus removal. (Adapted from Hultman et al, BUP, Chapter 16)

Figure 10.19. Bardenpho process for the combined removal of nitrogen and phosphorus (Linsley et al., 1992).

Pre-precipitation with nitrogen reduction -the HYPRO process
The HYPRO process is a refinement of the pre-precipitation process that also provides effective nitrogen reduction. In the HYPRO process,(see Figure 10.20) biodegradable organic substances are removed by preprecipitation in order to reduce the load on the subsequent biological process.

The organic compounds that are removed are hydrolysed to make them readily biodegradable, and then returned to the treatment process as a source of carbon. In order to choose the most appropriate treatment process, the wastewater should first be classified into more detailed constituents than COD and BOD, since these classifications are far too coarse. They are excellent for recipient control, but not for operation or selection of a treatment process. In biological processes especially, the oxygen and nitrate respiration rates of these organic compounds (COD and BOD) are highly significant.

Figure 10.20 The HYPRO process. (Adapted from Gilberg et al, 2003)

Reduction with the HYPRO process: SS > 90%; BOD > 90%; Ptot ≈ 95%; Ntot ≈ 75%.

The total hydraulic retention time, including pre-sedimentation is around 12 hours.

This method is based on using the organic matter in the wastewater as effectively as possible as a carbon source for further nitrogen reduction. In simple terms the process can be divided into two stages. Firstly, organic matter is "borrowed" by pre-precipitation from the wastewater to promote nitrification. Hydrolysis of the organic matter converts it into a more readily accessible form, and it is then returned to promote denitrification.

In addition to phosphorus reduction, the coagulant is also used to separate organic material. The reduction in organic material, often around 75%, changes the BOD/N ratio. The nitrifying bacteria thus have less competition. Sludge production decreases and the nitrifying organisms are able to grow and multiply, which means that the degree of nitrification can also increase.

10.6 Biological treatment with membrane separation

Membrane biological reactors (MBRs) consist of a biological reactor with suspended biomass and solids separation by microfiltration (MF) or ultrafiltration

(UF) membranes. The following discussion focuses on the application to wastewater systems in contrast to the water treatment applications .

Process description

MBR shave two fundamental process arrangements: (1) integrated systems that have membranes immersed in an activated sludge reactor and (2) separate systems that have a membrane module placed outside the reactor (Figure 10.21). Immersed membranes using hollow-fiber or flat sheet membranes are the most popular for several reasons. They operate at lower pressures, readily accommodate variations in the types of biosolids found in activated sludge bioreactors, concentrate biosolids without settling concerns, and, typically, have a lower life cycle cost for municipal systems. Separate systems use pressure-driven, in-pipe cartridge membranes. These are more prevalent in industrial settings (Metcalf & Eddy, 2003; WEF, 2006b).

Figure 10.21 Schematic diagram of membrane bioreactors: (a) immersed membrane, (b) external membrane. (Source: Metcalf & Eddy, 2003.)

Process arrangements for implementation of MBR for nitrification, nitrogen removal, and complete biological nutrient removal (BNR) are illustrated in Figure 10.22. In contrast to conventional activated sludge or typical BNR processes, the volume of sludge returned to the aeration basin is on the order of 400 percent of the wastewater flow.

Figure 10.22 Process arrangements for membrane bioreactors (MBR). (Adapted from Mackenzie, 2010)

10.6 Membrane bioreactor design practice

Because the membrane bioreactor (MBR) system can operate at a very high mixed liquor suspended solids concentration, it has the following advantages over a conventional activated sludge system:

(1) higher volumetric loading rates and shorter hydraulic detention times,
(2) longer sludge retention times that result in less sludge production,
(3) operation at low DO concentrations,
(4) very high quality effluent in terms of suspended solids and BOD,
(5) smaller footprint,
(6) primary and secondary clarifiers are not required.

The disadvantages of the system are high capital costs, high replacement cost for membranes, higher energy costs, and maintenance issues with respect to membrane fouling. Fine screens are required. Performance data indicate that MBR processes can achieve effluent BOD and COD concentrations much less than 5 mg/L and 30 mg/L, respectively. Ammonia nitrogen levels less than 1 mg/L and total nitrogen concentrations less than 10 mg/L have been achieved. Turbidity values less than 1 NTU can be achieved by the membrane.

Although the situation is rapidly changing, the number of membrane installations is relatively small and the length of experience with any given configuration is short. So far the experience has been excellent, but prudent engineering practice suggests that a thorough evaluation of the state-of-the-art be conducted before commitment to a MBR technology is made. The following discussion of design practice is drawn primarily from Metcalf & Eddy(2003) and WEF(2006).

Table 10.7 Range of MBR design values (Adapted from Metcalf & Eddy.2003 and WEF. 2006).

Mixed Liquor Suspended Solids (MLSS)

Immersed MBR systems have been operated with MLSS concentrations ranging from 8,000 to 18,000 mg/L. However, the very high MLSS concentrations reduce membrane flux and the aeration alpha factor. This leads to higher energy requirements. Current design practice is to use MLSS concentrations in the range of 8,000 to 10,000 mg/L.

Dissolved oxygen

Typical DO concentrations in various zones of an MBR are (WEF, 2006b):

- Anoxic: 0.0 to 0.5 mg/L
- Aerobic: 1.5to 3.0 mg/L
- Membrane: 2.0 to 6.0 mg/L

Oxygen transfer efficiency maybe adversely affected by the high MLSS concentration in the reactor because of the reduced alpha factor.

Return Activated Sludge (RAS) RAS rates of 400 percent of the influent flow rate are not uncommon.

Chapter 10 sources

1-Barnard, J. L. (1975) "Biological Nutrient Removal without the Addition of Chemicals," Water Research, vol. 9, pp. 485–490.

2-Bengt Hultman, Erik Levlin, Lena Johansson, Nasik Al-Najjar, Puhua Li, Elzbieta Paza & Rein Munter, Nutrient Removal And Sludge Handling, BUP Environmental science, Chapter 16, Lars-Christer Lundin & Lars Ryden.

3-Lars Gillberg, Bengt Hansen, Ingemar Karlsson, Anders Nordström Enkel, Anders Pålsson, "About Water Treatment" Water and Wastewater Treatment: Handbook Helsingborg, Kemira Kemwater 2003, ISBN 91-631-4344-5

4-Mackenzie L. Davis Water and Wastewater Engineering: Design Principles and Practice, McGraw-Hill New York (2010) ISBN: 978-0-07-171385-6, 1301p.

5-Metcalf & Eddy (2003) Wastewater Engineering: Treatment and Reuse, 4th ed., McGraw-Hill, Boston, Massachusetts, pp. 429–430, 452–453, 563–886.

6-Rittmann, B. E. and P. L. McCarty (2001) Environmental Biotechnology: Principles and Applications, McGraw-Hill, Boston, Massachusetts, pp. 313–346.

7-U.S. EPA (1999b) Wastewater Technology Fact Sheet: Sequencing Batch Reactors, U.S. Environmental Protection Agency publication no. EPA-832-F-99-073, Washington, D.C.

8-WEF(1998) Design of Municipal Wastewater Treatment Plants,4th ed., Water Environment Federation Manual of Practice 8, Alexandria, Virginia, pp. 4–20, 11-1–11-241, 13-4–13-8, 15–83.

9-WEF(2006a) Biological Nutrient Removal (BNR) Operation in Wastewater Treatment Plants, Water Environment Federation, Water Environment Federation Manual of Practice 30, Alexandria, Virginia, pp. 25, 105–226.

10-WEF(2006b) Membrane Systems for Wastewater Treatment, Water Environment Federation, Water Environment Federation Manual of Practice 30, Alexandria, Virginia, pp. 37–40, 58–109.

Chapter 11
Sludge Handling

11.1 General discussions about sludge processing.

11.1.1 sludge generation

Conventional biological treatment removes around 90% of influent organic contaminants. Around 30% of these contaminants are removed during presedimentation. 10% escape with the treated water, and the remaining 60% are removed in the biological stage. An activated sludge stage requires around 1,3 kWh per kg BOD. The energy consumption is therefore around 20 kWh per person per year.

Figure 11.1 Distribution of organic matter without and with pre-precipitation. (Adapted from Gilberg et al, 2003)

During pre-precipitation the distribution of organic material is different. For the same overall treatment efficiency (90%) as in the example above, the distribution might be 75% during pre-sedimentation, leaving just 15% to be removed in the biological stage. This stage can therefore be made much more compact. The energy consumption per person is then just 5 kWh per year, which represents an energy saving of around 75%.

Pre-precipitation also increases the amount of digester gas produced during anaerobic sludge stabilisation. During conventional biological treatment a large proportion of the particulate organic material is converted to carbon dioxide. But during pre-precipitation the particulate organic material remains intact in the sludge, which means that it can be converted to methane gas during the digestion process. This means that considerably more methane gas is generated when pre-precipitated sludge is digested than is the case with biological sludge.

Sludge production from pre-sedimentation increases with pre-precipitation. This is partly due to the formation of chemical sludge, and partly because more organic material ends up in the sludge during pre-precipitation than during sedimentation alone. The organic material is also removed as primary sludge and is therefore not broken down in the biological stage. After anaerobic or aerobic stabilisation, however, the total sludge content is roughly the same as for conventional treatment.

In volume terms, the quantities of sludge that require dewatering are lower with pre-precipitation than is the case with post-precipitation. There is also a reduction in the amount of secondary sludge, which is difficult to dewater, and this is replaced by primary sludge.

Sludge production from the plant also changes with pre-precipitation. Tables 3:9 and 3:10 show that there is a reduction in the amount of surplus biological sludge (secondary sludge). In comparison with post-precipitation there is no increase in the amount of pure chemical sludge (tertiary sludge).

Table 11.1 Approximate quantities of sludge produced during different treatment processes and treatment stages when $Al^{3+}$and $Fe^{3+}$are used as coagulants. The amounts refer to unstabilised sludge. (Adapted from Gilberg et al, 2003)

In the case of simultaneous precipitation, the same amounts of sludge are obtained as in post-precipitation, since the chemical sludge is removed with the secondary sludge.

11.2 Sludge handling goals (Adapted from Gilberg et al, 2003)

Sludge handling has two main purposes:

- Stabilisation of the sludge by use of different methods such as biological (anaerobic and aerobic digestion and composting), chemical (mainly using lime) and thermal (heat drying, incineration and melting).
- Volume reduction by use of thickening (gravity thickening, flotation and centrifugation), de-watering (use of centrifugation, filters and presses), drying (natural and heat drying) and incineration and melting.

Stabilisation is used to obtain a sludge that does not change with time, i.e. a stable sludge that does not cause odour problems. In addition, stabilisation may reduce the number of pathogens in the sludge, especially by use of chemical and thermal methods. Biological stabilisation removes the biodegradable part of the sludge. Heat drying and lime addition inhibits further bacterial growth. Lime-containing sludge in contact with carbon dioxide in the air is neutralised and after a certain time bacterial growth may start again. In incineration both biodegradable and non-biodegradable organic materials are removed.

Major sludge handling in Sweden is carried out for larger treatment plants: thickening, stabilisation (mainly by aerobic digestion), conditioning of the sludge before de-watering by polyelectrolytes, de-watering of the sludge (mainly using centrifuges or belt presses) and transport to final destination (mainly agriculture, landfill, land building and land reclamation).

11.2 Biological sludge stabilisation

Anaerobic digestion is a process in which organic material in the sludge is degraded without contact with air. Digestion is normally an uncomplicated process, although the risk of acid fermentation has to be considered. In unfavourable conditions the first stage of the digestion process can run away. This leads to an excess of fatty acids, which causes the pH to drop sharply and the digestion process comes to a halt.

The normal load of a digester is around 1,5 kg of organic matter per day per m^3.During digestion the concentration of organic compounds in the sludge falls by 40–60% while the concentration of inorganic material remains unchanged. The sludge from a conventional treatment plant that uses biological treatment produces around 30 litres of digester gas per person per day, while the quantity of sludge is reduced by about 35%.

The retention time in the digester is about 15 to 20 days. During the process, energy rich biogas is formed, consisting of about 2/3 methane-gas and 1/3 carbon dioxide. The biogas may be used for energy production for heating purposes or for producing electricity. If the carbon dioxide is removed the remaining methane gas may be used as a fuel for cars and busses (Figure 11.3).

Figure 11.3 Anaerobic digestion of sludge. (Adapted from Bengt Hultman et al,BUP)

In aerobic digestion the sludge is aerated for 15 to 20 days to remove biodegradable organic material in the sludge. Problems related to aerobic digestion are the energy needed for aeration and the fact that sludge cools off during the winter period. Aerobic digestion has therefore mainly come to be used at small treatment plants.

Composting is also an aerobic stabilisation process. In composting a high sludge concentration must be used, about 40-45 %. Addition of materials such as wood chips or solid wastes may help attain this. Due to high sludge concentration the heat produced during degradation of organic material increases the temperature of the sludge up to 60-80 ºC, thereby improving the hygienisation of the sludge.

Stabilisation with lime.
All biological activity effectively comes to a stop if the pH rises above 11. This fact is exploited in lime stabilisation, which involves adding enough lime to the sludge to ensure that the pH stays above 11 even after holding for around 14 days.

Stabilisation with lime has several advantages. The process is easy to control, and the investment costs are modest. The phosphates and heavy metals that are present in the sludge are bound very securely by the lime, and pathogenic microorganisms are killed effectively. In order to reduce the internal nitrogen load the high pH of the sludge can be exploited for the process known as ammonia stripping.

Lime may be added to the sludge before or after dewatering. If the lime (slaked lime) is added before dewatering it results in a sludge that is odourless and has much better dewatering characteristics. If the lime (unslaked lime) is added after dewatering it causes a sharp temperature rise in the sludge. This high temperature also pasteurises the sludge.

The disadvantage of this process is its high operating costs.

Table 11.3 Amounts of lime required for sludge stabilisation. (Adapted from Gilberg et al, 2003)

11.3 Sludge volume reduction methods. Sludge thickening.

Sludge from sedimentation and flotation units of water and wastewater treatment plants has a low concentration of solids and must thus be concentrated using various methods before disposal or use. Water in flocs exists as drainable water, capillary water and adsorbed and internal water, for instance in cells. Water may also be bound as crystallisation water to chemical precipitates.

Sludge composition
Sludge can be said to contain two main components: liquid and solids. Because of the gelatinous nature of sludge these two components cannot be separated from each other easily.

Figure 11.4 The figure shows how the various water phases are associated with sludge particles. (Adapted from Gilberg et al, 2003)

The liquid consists of water and substances dissolved in it. These may be inorganic salts, such as ammonium, and organic substances such as carbohydrates and fatty acids. When the sludge is dewatered these dissolved substances remain in the liquid. As the dry content of the sludge increases so does its gelatinous nature.

The solid substances surround themselves with compounds that have a strong affinity for water (hydrophilic system). To ensure successful dewatering these gelforming substances must first be neutralised, for example by hydrolysis (aerobic stabilisation, digestion, thermal or chemical treatment) or by adding chemicals such as polyelectrolytes that interfere with the geometry of the gel-formers.

Thickening methods like gravity thickening, flotation and disc centrifuges are used primarily to remove drainable water. Part of the water in capillaries can be removed by de-watering methods such as belt and filter presses and bowl centrifuges. The applied pressure during de-watering limits the amount of the capillary water that can be removed. Water in fine capillaries and adsorbed water can be removed by different drying methods, of which the most efficient is the use of heat drying. Finally, internal water and crystallisation water are removed using such methods as incineration and sludge melting.

In order to facilitate de-watering sludge is normally treated using conditioning methods. Such methods include the addition of chemicals like polyelectrolytes and metal salts or the use of heat or freezing.

Conditioning is a way of reducing the number of small particles and building up larger flocs. Metal salts and polyelectrolytes act as coagulation and/or flocculation agents. In heat treatment the structure of certain organic material such as proteins changes, resulting in sludge with very good de-watering properties. During the heating process much of the sludge material goes in solution, yielding a supernatant with a high concentration of organic material and nutrients. Subsequent freezing bursts the cells, thereby improving the de-watering properties of the sludge.

In Sweden the predominant conditioning agent is polyelectrolytes. Freezing is used in a few places with cold climate. During recent years there has been renewed interest in the use of heat conditioning for sludge. This is due to the excellent possibilities of reducing sludge production, of improving de-water ability as compared with the use of polyelectrolytes and of recovering different substances released during heat conditioning. Two commercial processes using this technology are KREPRO and Cambi.

The solids concentration of sludge is nearly doubled after thickening, which increases the solids content through partial removal of the liquid. The amount of concentration increase depends on the type of sludge, with activated sludge increasing to about 3 % solids and primary sludge to about 9 % solids. The most common methods of thickening are gravity settling and flotation. Conventional gravity thickening is also simple and inexpensive. It is essentially a sedimentation process similar to the one occurring in all settling tanks.

Gravity-settling thickening is carried out in tanks, which are usually equipped with a slow stirrer to provide gentle agitation, which enhances settling. Gravity thickening usually exhibits hindered settling phenomenon. The degree to which waste sludge can be thickened depends on many factors. Among the most important are the type of sludge being thickened and its volatile solids concentration. The initial solids concentration affects the degree of concentration that can be achieved. Hydraulic and surface loading rates are also of importance. The supernatant from the thickener is returned to the wastewater treatment process.

Flotation thickening is achieved by creating gas bubbles in the sludge. The bubbles attach themselves to the sludge particles, which gives them buoyancy and carries them up to the liquid surface. The accumulated sludge is removed from the surface by scrapers and the clarified liquid is returned to the wastewater treatment process. Air flotation thickening can be employed whenever particles tend to float rather than sink. A dissolved air flotation unit is shown in Figure 11.5

Flotation thickening tanks are circular or rectangular. Rectangular tanks are considered to be easier to scrape and are therefore more common. The sludge load is140–240 kgDS/m^2•d.

Figure 11.5. Flotation thickening of sludge. (Adapted from Bengt Hultman et al,BUP)

Many methods of sludge disposal involve de-watering the sludge. The objective of this de-watering is to facilitate utilisation, disposal or further processing of the sludge. Sludge de-watering is a process whereby sufficient water from sludge is removed to give it quasi-solid characteristics by a reduction of volume and moisture content in the sludge. Sludge may be de-watered by use of drying beds, lagoons, centrifuges, filter presses and horizontal belt filters.

Dried sludge can be used as a fertiliser or soil conditioner, but the costs of drying are high. Incineration can be used as the ultimate sludge disposal method when the sludge has been de-watered to yield a solids content greater than approximately 30 %. The heat of combustion of the sludge solids is sufficient to evaporate the residual water content. The residual ash has to be disposed by dumping on land or at sea. This ash is also useful in sludge conditioning and as a filter-aid in de-watering.

Sludge incineration, particularly for large cities, has the advantage of converting organic solids into ash, thereby reducing the weight and volume of solids. Alum, iron and lime sludge can be incinerated. Final disposal of the digested sludge can be on land or by de-watering and incineration. In large systems, sludge thickening or de-watering prior to lagooning or incineration should be considered.

Land spreading or burial in landfill may dispose of the de-watered cake, or it can be subjected to heat drying or incineration. Incineration-ash can be used as a road sub-grade stabiliser or to make concrete blocks or brick. Another alternative is to dispose of it by using it as a soil conditioner or in landfill.

Solids removed from lagoons are usually not suited to heat drying or incineration, and are thus taken directly to land spreading or landfill disposal. Sludge destined for drying beds may be thickened and is thus not suitable to heat drying or incineration. It is usually disposed of on land or in landfill. The sludge that is to be de-watered through vacuum filtration, centrifuging (solid bowl), filter pressing or horizontal-belt filtration may be disposed of by drying, incineration, land spreading or in landfill. In de-watering and drying there may be some enhancement of biological sludge containing alum.

11.4 Final destination of sludge

Agricultural use of sludge is often regarded as the best alternative if the pollutants in the sludge are below limiting and guidance values. However, lack of acceptance from food industry and consumers may make it difficult to use sludge in agriculture. Many attempts have been made to find agreements for agricultural use of sludge. A national consultation group has been formed in Sweden to stimulate the use of sludge in agriculture and reach consensus on different actions and voluntary precautionary measures to prevent unwanted chemicals and substances in the sewer net. Although this group has indeed reached some agreements, the future of agricultural use of sludge is uncertain and under debate. There is an ongoing discussion concerning the availability of phosphate to crops in the form of precipitated iron or aluminium phosphates.

Landfill use of sludge will probably be highly restricted in the future. In several countries (such as Germany) only sludge with a low content of organics is allowed for land deposit. Land deposit of sludge can contribute to the diffusive spread of such materials as phosphorus and metals due to leakage, and to the emission of materials such as methane gas (a greenhouse gas), methylated metal compounds (such as methylated mercury) and odours. In order to reduce landfill deposit of sludge Sweden has introduced a fee. The use of sludge for land building, restoration of land and use for covering of landfills may also be limited in the future due to lack of land and possible negative environmental effects.

Sludge incineration has attracted increased interest as a method for the final handling of sewage sludge. This technology has not as yet been practiced to any significant extent in Sweden. The investment and operational costs are rather high and obtaining a permit to build an incineration plant may also pose a problem. Therefore, attention has been directed towards co-incineration in existing incineration plants. Co-incineration may be applied in an incineration plant for municipal solid wastes, biofuels (wood, peat etc.) or coal, or in plants producing building materials (cement, brick etc.) at high temperatures. Some experiments have been done involving co-incineration of sewage sludge, mainly together with municipal solid wastes. The experiments have in general been positive although some problems have arisen related to the sintering of ashes and increased concentrations of sulphur dioxide, nitrogen oxides and volatile metals (mercury and cadmium) in the flue gases. The need of possible complementary investments in flue gas treatment or in the handling of ashes when practising co-incineration needs to be studied further. It has also been shown that the recovery of phosphorus from ashes involves many technical problems.

During the past few years there has been increased interest in extracting products from sludge. Two main commercial systems are under consideration in Sweden, the KREPRO and Cambi processes. Both of these methods have their roots in old process technologies (such as the Zimpro and Porteous processes; US EPA, 1979). Different substances, such as acids in the KREPRO process, are dissolved from the sludge by heat and pressure treatment. The main objectives of the old technologies were to decrease the amount of sludge and condition it before de-watering, while the liquid stream with various dissolved substances was mainly regarded as a problem. The Cambi and KREPRO processes aim instead to regard the dissolved substances as resources, such as improved methane production in the digester (Cambi) or the reuse of precipitation chemicals, the production of a fertiliser and separate removal of heavy metals in a small stream (KREPRO).

11.5 System design of sludge handling

The different methods for sludge volume reduction, sludge stabilization and final destination for sludge may be combined in different ways. Different options are illustrated in Figure 11.6

Figure 11.6. Different options for sludge handling. (Adapted from Bengt Hultman et al,BUP)

Chapter 11 sourcess:

1-Bengt Hultman, Erik Levlin, Lena Johansson, Nasik Al-Najjar, Puhua Li, Elzbieta Paza & Rein Munter, NUTRIENT REMOVAL AND SLUDGE HANDLING, BUP Environmental science, Chapter 16, Lars-Christer Lundin & lars Ryden.

2-Lars Gillberg, Bengt Hansen, Ingemar Karlsson, Anders Nordström Enkel, Anders Pålsson, "About Water Treatment" Water and Wastewater Treatment: Handbook Helsingborg, Kemira Kemwater 2003, ISBN 91-631-4344-5

III

Wastewater Treatment Systems

Chapter 12
Municipal Wastewater Treatment Systems Alternatives

12.1 Wastewater treatment in local systems

Subsoil infiltration systems for infiltration of wastewater, pre-treated in a septic tank, into natural soil or into buried sand filter installations are relatively simple constructions, which can handle large volumes of biologically and chemically active surfaces with long retention times. When designing such a system, considerations must be taken of the soil's particle distribution curve and of the distance to the groundwater surface.

The distribution curve of the soil's particle size determines the loading rate for the infiltration system, while the sieve analysis curve is used to determine the loading rate itself (Figure 12.1). If the sieve analysis curve falls within section B, or section A and B, the recommended loading rate is 30 l/m^2/day. If the curve falls within field A, the recommended loading rate is 60 l/m^2/day.

Figure 12.1. Grain size distribution diagram for determination of adsorption possibilities and sizing of the infiltration system. (Adapted from Bengt Hultman et al, BUP, Chapter 15)

To avoid microbial contamination of the groundwater, Swedish safety regulations stipulate that the distance from the infiltration surface to the groundwater table is not allowed to fall below one meter. The major portion of the microorganisms in the wastewater is removed in the biofilm at the infiltration surface and in the unsaturated zone above the groundwater table. This removal capacity must, however, be regarded as just an extra safety precaution.

An important aspect in establishing an infiltration system is that the groundwater table varies during the year depending on geographical location and type of soil. In Table 12.1, the variations in groundwater level over the year and in different soil types are shown.

Table 12.1. Variations in groundwater level (in infiltration areas) during the year and in different soil types. (Adapted from Bengt Hultman et al, BUP, Chapter 15)

A constructed wetland system can be designed to achieve various levels of treatment of BOD, SS, nutrients, metals, pathogens and other substances. Therefore, the characteristics of the wastewater to be treated and the desired discharge limits must be taken into consideration at an early stage of the design of a wetland system intended for wastewater treatment. Other parameters that also have to be considered at this stage are operating water depth, process loading rates, process kinetics, effects of temperature and physical configuration. The design of a constructed wetland system also includes selection of location, type of constructed wetland (surface flow wetland or subsurface flow wetland), substrata medium, vegetation, treatment units, wastewater distribution and operational scheme.

Constructed wetlands require an impermeable barrier to ensure containment of wastewater within the system. This barrier also prevents leakage of pollutants into the groundwater. The impermeable barrier can consist of in situ soils with a hydraulic conductivity of 10-8 m/s or less. If this type of material is not available, bentonite, asphalt or plastic membranes can be used to seal the treatment system. The barrier layer must be placed below the maximum depth of root development to avoid damage of the barrier from the roots, which would cause leakage. The bed of the wetland should have a slope of 1 % to enhance the hydraulic conductivity of the bed media.

12.2. Sewer and stormwater net

Three main systems are used for removal of wastewater and stormwater:

- The combined system, which transports wastewater, stormwater and drainage water in a common pipe. Most of the old districts in Swedish cities have combined systems (Figure 12.2).
- The separated system, which transports wastewater and often drainage water from building grounds in one pipe while stormwater is removed via gutters or open ditches. This system is commonly used in rural or sparsely populated areas where stormwater may be led into open ditches without negative effects. In more densely populated areas, stormwater may be handled locally through various methods, such as infiltration and wetlands.
- The duplicate system uses separate lines for the transport of wastewater and stormwater (Figure 12.3). This system is more complicated than the other

systems because of its double street and service pipes. Drainage water may be led to either the sewer or stormwater net.

Two other systems sometimes used are a system where by wastewater is transported by vacuum (vacuum system) and one that transports wastewater using low pressure (low-pressure system, LPS).

Figure 12.2. Combined system. (Adapted from Bengt Hultman et al, BUP, Chapter 15)

Figure 12.3. Duplicate system. (Adapted from Bengt Hultman et al, BUP, Chapter 15)

12.3 Wastewater treatment in central systems

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

Physical methods in which pollutants are removed or treated through application of physical forces like screening, mixing, sedimentation and filtration.

Chemical methods in which removal or treatment of contaminants is brought about by the addition of chemicals or by chemical reactions such as chemical precipitation and disinfection by chlorine and ozone.

Biological methods in which the removal of contaminants is brought about biologically through such means as the activated-sludge process.

Different unit operations, process and treatment systems may be used to remove a certain contaminant in wastewater. The treatment process can be combined to form process trains, i.e. treatment schemes in which the influent wastewater is treated until it reaches a specified water quality. For stringent requirements it is necessary to combine several treatment processes. Figure 12.4 shows an advanced treatment system for municipal wastewater with a technically oriented process scheme.

Figure 12.4. Wastewater treatment sequence with different process alternatives. (Adapted from Bengt Hultman et al, BUP, Chapter 15)

Six steps are important to consider in wastewater treatment:

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

Some of these steps will be discussed below.

12.4 Stormwater handling

Attention must being paid to urban runoff, or stormwater, as a source of pollution. Stormwater contains pollutants from many sources. In general it contains high concentrations of heavy metals and suspended solids (SS), but lower concentrations of BOD, COD, nitrogen and phosphorus. The first amount of urban runoff after a rainfall or an occasion of snow melting is the most polluted, making it an important task to treat this "first flush" before it enters a distribution system, wastewater treatment plant or natural recipients.

There are several methods of treating stormwater and it has been shown that methods employing natural separation processes are suitable to reduce the amount of urban runoff and associated pollutants. Stormwater is traditionally treated on-site, for instance in ponds, infiltration facilities or in percolation facilities. Lately, constructed wetland systems have been considered an appropriate technology for the treatment of urban runoff and several such systems have been put into operation in Sweden as well as in Europe and the United States.

Ponds for stormwater treatment (Figure 12.5) have double functions: they retain stormwater while cleaning it from pollutants through natural processes. These ponds should therefore have an impermeable bottom allowing water to infiltrate into the ground. Further on, the ponds should be long narrow (> 3:1) to obtain an adequate flow through the system. This will also reduce the risk of filling up the pond with weed. To further prevent this, a suitable depth must also be chosen, about 1-2 m. Since sedimentation of heavier particles will eventually take place in the pond, a special sedimentation unit should be placed close to the inlet. Screens need to be built in both the inlet and the outlet of the pond. An emergency outlet should also be included in the construction so that excess water can overflow. The pond can with advantage be surrounded by vegetation that also reduces pollutants.

Figure 12.5. Pond with infiltration and emergency outlet. (Adapted from Bengt Hultman et al, BUP, Chapter 15)

Infiltration facilities can be of different types: infiltration trenches, buffer strips, infiltration ditches or porous pavements (Figure 12.6). These systems also have a double function, in that stormwater can both infiltrate and be stored. When infiltrating into the ground, pollutants will be removed through biological, chemical and physical processes. Storage means that the flow will be regulated and detained before entering the recipient. Infiltration trenches are found in the unsaturated zone. If the soil permeability is high, stormwater can infiltrate directly into the ground. Otherwise a coarse material such as broken stones can be placed in the ground to form storage. In both cases, the distance to the groundwater table should be at least one meter. In buffer strips, stormwater can infiltrate directly into the ground.

Figure 12.6. Infiltration ditch (left) and infiltration in porous pavements/roads (right) (from Larm, 1994).

Percolation basins (Figure 12.7) can be constructed where direct infiltration in the ground is impossible. These types of stormwater treatment facilities are primarily intended for low-polluted runoff, but can also be considered for highly polluted water. In these latter cases, the runoff must be pretreated before being discharged into the percolation basin. The percolation basin is an excavation in the ground that is filled with a coarse material, for instance broken stone. The stormwater will percolate from the sidewalls and the bottom before it finally reaches the groundwater. To optimize percolation, the basin should be long and narrow to maximise the area of the sidewalls in relation to the bottom area that will clog due to sedimentation of suspended matter.

Figure 12.7. Percolation basin (left) for runoff from roofs and (right) for road runoff (from Larm, 1994).

Treatment of stormwater in constructed wetland systems has attracted a good deal of attention lately and several systems have been established in Sweden as well as abroad. The design of these systems is the same as for domestic wastewater treatment wetlands.

12.5 System levels in wastewater handling

In order to facilitate the design, operation and evaluation of water and waste handling systems it is necessary to generalise and simplify the system functions and the description of system components and levels.

The following requirements are important:

I The system should function in accordance with the concept of sustainable development, which means a minimisation of resource depletion and environmental degradation and a maximisation of recovery, recycling and reuse.

II The system should function logically with respect to material and energy flows in order to facilitate recovery, recycling and reuse but also to satisfy the needs of the consumers.

III The system should function in such a way as to satisfy specific goals in relation to technology, humans and society.

12.6 Ordering of water and waste handling

Water and waste handling methods might be ordered according to scale or complexity. This is illustrated in the figure below. Somewhat simplified, handling can be divided into local handling inside buildings, local handling outside buildings, central handling and regional handling. In addition, global effects of the handling must be considered. On each level many actions may be taken for improvement of the environment.

Figure 12.8 Water and waste handling methods might be ordered according to scale or complexity. (Adapted from Bengt Hultman et al, BUP, Chapter 15)

Table 12.2 Examples of ways to improve water and waste handling at different system levels

Inside buildings - Clean technology and waste minimisation in industries

- Separation methods of waste inside buildings (including new toilet systems)
- Treatment units for water and wastewater inside buildings
- Improved labour safety

Local level - Development of local handling systems with special emphasis on areas where centralised outside solutions are expensive (including different ecological methods)
- Problems related to water, wastewater and waste handling in the archipelago
- Special problems related to large industries, airports and the handling of wastes from ferries and boats

Central level - Improved treatment efficiency and transport of water, wastewater and wastes
- Use of rapid treatment processes to facilitate central location of water and wastewater treatment plants
- Maintenance and repair of existing facilitates for water and wastewater handling
- Public participation in water, wastewater and waste handling
- Management of water, wastewater and waste handling systems

Regional level - Improved use of the recipient for various purposes
- Disposal of sludge and wastes with special emphasis on recycling and long-term effects
- Role of regional planning and planning of new areas for housing and industries (including application of local Agenda 21)

Global level - Source of control of chemicals leading to depletion of the ozone layer
- Improved operation to reduce discharge of greenhouse gases

12.7 Sewer safety

The Occupational Safety and Health Administration (OSHA) defines a confined space as one that has limited or restricted means for entry or exit, is large enough for an employee to enter and perform work, and is not designed for continuous occupancy by the employee. The following are classified as confined spaces: a sewer manhole, a lift station wet well, a prefab pumping station drywell. They are a safety hazard primarily because of the potential for accumulation of toxic and explosive gases. The list of specific toxic gases includes but is not limited to carbon dioxide (in quantities sufficient to displace oxygen and cause asphyxiation), carbon monoxide, chlorine, hydrogen sulfide, and sulfur dioxide. The explosive gases include carbon monoxide, gasoline, hydrogen, hydrogen sulfide, methane, and ammonia (Mackenzy et al., 2010).

OSHA specifies the rules for entering a confined space. Table 12.3 lists appropriate equipment for entering a manhole. Among the many precautions for working in a sewer manhole, a lift station wet well, or a prefab pumping station drywell, the following three are held up as vital:

- Never work alone. Preferably, the crew should consist of three people, one of whom stays topside at all times.
- Check the atmosphere before entering—even if there has never been a problem before or "It is always ok." At least one fatality occurs each year because of this assumption.
- Use a safety harness and have a tripod and hoist topside. Entrance and egress are difficult enough without injury or incapacitation. It is virtually impossible for a rescue person to carry another individual out.
- Man-lift. If the drywell is7.5 to 9 m deep, a powered man-lift should be part of the design.

Another safety issue is manhole covers. The standard manhole cover has a mass between 110 and135kg. A heavy duty manhole cover may have a mass up to 300 kg. Improper handling may result in a lower back disorders, muscle injury, or in the worst instances crushed or severed fingers and toes. Although a pry bar and J-hook are normal components of the work crew's gear, another useful tool is a long-handle, round-blade shovel with about 5 cm of the tip removed. With the shovel blade placed between the manhole and the frame, the long lever arm of the shovel makes it easy to release the manhole from the frame. The manhole cover should never be carried by hand or otherwise maneuvered with one's hands. The pry bar or J-hook should be used to drag it away from the manhole. Likewise, in returning the cover, it should be maneuvered back near the manhole with the pry bar or J-hook and then maneuvered over the manhole with the heel of the worker's steel-toed boots. It should never be maneuvered with one's hands. There is no need to be concerned about it falling in the manhole. It is round. It will not fall in.

TABLE 12.3 Personal protective equipment (PPE) list for entering a manhole. (Adapted from Mackenzie et al, 2010)

1. Hardhats
2. Rain suits
3. Hip boots

4. Rubber gloves
5. Leather gloves
6. Overalls
7. Goggles
8. Chest harness belt with safety rope
9. Extra rope
10. First-aid kit with blanket
11. Fire extinguisher
12. Tripod and hoist
13. Ladder
14. Combustible gas and oxygen content detector.
15. Toxic gas monitor and oxygen content detector.
16. Air packs, air tanks, hose
17. Forty-five-minute self-contained air packs for emergency rescue 1 8 . Five-minute egresses cape air pack
19. Portable air blower,
20. Portable electric generator, four outlets
21. Electric lamp
22. Portable lamp
23. Flashlights
24. Tool hoisters
25. "Men working" signs
26. Traffic cones
27. Vehicle beacon warning light
28. Barricade with beacon
29. Reflective traffic vests
30. Mirrors
31. Steel toed boots
32. J-hook
33. Long handle shovel
34. Cell phone/radio

Chapter 12 sources:

1-Burszta-Adamiak, E., 2011. Odprowadzanie wód opadowych systemami do podziemnej retencji i infiltracji. Rynek Instalacyjny, 5, pp. 48–51.
2-Bengt Hultman, Erik Levlin, Lena Johansson, Nasik Al-Najjar, Puhua Li & Elzbieta P∏aza Wastewater Treatment Systems, BUP Environmental science, Chapter 15, Lars-Christer Lundin & Lars Ryden.
3-Mackenzie L. Davis Water and Wastewater Engineering: Design Principles and Practice, McGraw-Hill New York (2010) ISBN: 978-0-07-171385-6, 1301p.

4-Metcalf & Eddy (2003) Wastewater Engineering: Treatment and Reuse, 4th ed., McGraw-Hill, Boston, Massachusetts, pp. 429–430, 452–453, 563–886.

Chapter 13
Sustainable Integrated Stormwater (Rainwater and Snowmelt) Management Practice

13.1 Green and blue infrastructure, ecohydrology concepts and solutions applied around the globe

Countries that are world leaders in terms of the technical knowledge, implementation, and establishment of guidelines as well as legal, organizational and economic tools for on-site stormwater management include the USA, Canada, Australia and New Zealand. These countries were faced with the problems associated with intensive urbanization, flooding and drought much earlier than Europe and have been applying best practices for 50 years. In Europe, Germany, Scandinavian countries, the UK and France have the most experience.

The European Commission (EC 2013) defines green infrastructure as a strategically planned network of natural areas that is designed and managed so as to provide a wide range of ecosystem services. The Commission also makes reference to blue infrastructure i.e. aquatic ecosystems (rivers and their valleys, lakes, artificial reservoirs or wetlands). Both systems combined, blue and green, are a crucial tool for the natural processes of stormwater retention and purification. Green infrastructure is particularly important for the urban landscape (land ecosystems): it helps improve water cycling, supports the functioning of grey infrastructure and reduces the load on stormwater and combined sewer systems.

13.2 Concepts associated with rainwater and snowmelt management

Low Impact Development (LID):

An approach that emerged in the USA and consists of the spatial design of new and revitalized urban areas whereby landscape features (such as terrain, geological structure, aquatic and land ecosystems) determine the framework for urban development. This approach reduces the negative impact of development on newly built and neighboring space and on the natural system. Rainwater is used onsite based on retention in the landscape supported by technical solutions.

Water Sensitive Urban Design (WSUD)

An interdisciplinary approach developed in Australia that is based on the cooperation of experts in water management, architecture, spatial planning and environmental protection. It deals with all elements of the urban water cycle (precipitation, water supply, waste water collection, aquatic ecosystems) and incorporates their functionality into urban design. The goal is for the urban water cycle (especially rainwater) to mimic the natural cycle as closely as possible. Of. the example of Mordialloc Industrial Precinct in the section of good practices at the end of this guidebook.

Sustainable Urban Drainage Systems (SUDS)
These comprise technical solutions for urban stormwater collection that are more environmentally-friendly than traditional engineering solutions. Combining different modes of action allows pollution and hydraulic stress in rivers and lakes to be minimized. This UK-based approach is illustrated by the SUDS for Schools project described in the section of good practices at the end of this guidebook.

Best Management Practices (BMPs)
Stormwater BMPs comprise structural activities aimed at retaining water and eliminating pollutants, as well as non-structural activities to limit surface runoff and prevent pollution. The technical solutions of BMPs form part of all of the concepts mentioned above and therefore sustainable stormwater management is often referred to as best practices or BMPs.

Structural solutions
Structural solutions are classified in a number of ways. This guidebook uses the classification proposed by the European Day Water project and the guidelines of the US Environmental Protection Agency to select the following: pervious surfaces, plant buffer strips, and facilities for stormwater retention and infiltration.

13.3 Structural solutions

13.3.1 Pervious surfaces

Pervious pavements, asphalt and grass pavers.
Large surfaces devoid of greenery, such as parking lots, roads and sidewalks cause the most trouble in terms of uncontrolled surface runoff. Green infrastructure is often impossible to apply. However, it is possible to use materials that allow water to infiltrate, i.e. pervious paving and asphalt. Concrete grids or synthetic reinforcement grids allow the growth of grass within the grid system (Figure

13.1). Pervious surfaces are placed on a sub-base that allows further infiltration, such as bedding made of natural material (crushed rock, sand, gravel, stones) or infiltration boxes.

Figure 13.1. Pervious surfaces: schematic representation of a concrete grid with grass on a bedding, and water percolating through a pervious surface layer (Adapted from: Sustainable Development Applications no 5, 2014)

13.3.2 Plant buffer strips

Green roofs and walls

Increasing the coverage of biologically active areas by preserving or expanding green areas (lawns, squares, green spaces, streetside greenery etc.) is vital to restore the urban water cycle. Green roofs and walls covered with vegetation (on specially prepared growing media) fit in well with this strategy, particularly in densely built areas (Kaźmierczak 2013). Depending on the construction and rain intensity, green roofs can retain all of the rain that falls on them. Other benefits include thermal insulation of buildings, increased evaporation, increased biodiversity and coverage of biologically active areas as well as providing additional space for residents to use. Green walls also help regulate temperatures, improve buildings' thermal insulation and aesthetics; the plants can feed on rainwater.

Vegetated buffer strips

Vegetated grass buffer strips are a good solution in areas with looser development, especially near roads. These slightly inclined vegetated surfaces allow the slow (horizontal and lateral) flow of stormwater from adjacent land (Figure 13.2). Plant buffer strips effectively trap sediment and associated pollutants and are therefore commonly used for pre-treatment and as protective areas for other solutions (e.g. basins).

Figure13. 2. Grass buffer strips along communication routes: schematic representation and real-world application in combination with an infiltration basin and footbridge in Aiken, USA (Photo: Clemson University)

Contouring of streets and green infrastructure

Green areas (and infiltrating facilities) must be located below communication routes in order to capture stormwater from the streets and sidewalks. The simplest way of draining a street is by allowing water to flow freely through indentations in curbs (Figure13. 3)

13.3.4 Stormwater infiltration facilities

Stormwater infiltration facilities are used on land with sufficient permeability, where the proportion of biologically active or pervious areas cannot be increased or larger quantities of water need to be managed despite the use of such areas. In principle, water that flows into these facilities leaves them by infiltrating to the ground. Other ways of discharging water (such as into the sewer system or directly to the river) are used as emergency overflows only in case of overloading.

Infiltration basins

Infiltration basins are depressed landforms covered by vegetation and characterized by high infiltration capacity and low water flow velocity (<0.15 m/s). Ideally, the slopes should be only slightly inclined and the underlying soil must be permeable. Infiltration can also be enhanced with additional infiltration layers. Infiltration basins are effective at removing pollutants and may therefore be used for the pre-treatment of water before it is diverted to other areas with blue green infrastructure. Weirs can be constructed to increase retention capacity, sedimentation and infiltration, and to reduce the drainage rate by reducing inclination. Infiltration basins may be located in areas with varied development density (Figure 13.4). Their irregular shape and diversified depth support the growth of assorted plants.

Figure 13.3. Curb indentations channel water, allowing it to flow from the streets and sidewalks. The photo shows runoff water flowing down NE Siskiyou street in Portland, Oregon, USA (Photo: Kevin Robert Perry, City of Portland)

Figure 13.4. Infiltration basin in open land (schematic representation) and densely built land (photo): in addition to retaining water this is the main element of landscape architecture in a housing estate in Portland (Photo: <greenworkspc. com>)

Detention basins

Detention basins display similar features and mode of action to infiltration basins but are larger, deeper and used to drain larger areas (above 1 ha) (Figure 13.5). Detention basins are suitable for areas with varied development density and for road drainage (especially highways). Where allowed by the quality of the conveyed waters, these basins may also serve recreational and aesthetic purposes. In catchments with significant amounts of sediment, initial sedimentation of inflowing water prevents the detention basin floor from silting up during exploitation.

Figure 13.5. Detention basin used for recreation during dry weather (schematic representation) and to collect water from the streets and parking lot. (Photo: <www.sudswales.com>)

Infiltration wells

In densely built areas where water cannot be retained on the surface, subsurface infiltration systems may be used. Many prefabricated products made of plastics for underground retention and infiltration are available on the market. Infiltration wells offer a more affordable alternative (Figure 13.6): wells filled with infiltration material covered with soil, stones or other material that receive water from surrounding impervious surfaces. Infiltration wells can occupy dozens of square meters, but are typically small (<4 m^2) and no more than 2 m deep. Lining the floor of the drainage well with geotextile fabric separates the adjacent soil from the filling material and prevents soil collapse. Water infiltrates through the floor or both the floor and sides of the well.

Figure 13.6 Cross section through a drainage well (Burszta-Adamiak 2011) and drainage well in a homeside garden in Bellis, Wynnum, Queensland, Australia.

Infiltration ditches and grass ditches

Infiltration ditches are linear sections of land typically located along roads (Figure 13.7), filled with infiltration material (similarly to a drainage well) and covered with stones, rock or vegetation.

Figure 13.7. Cross-section through an infiltration ditch (schematic representation) and infiltration ditch near Einstein hospital in East Norriton, Pennsylvania, USA

Rainwater percolates to the soil or a perforated pipe, and excess water may be diverted to traditional overflows. A popular alternative to the classic ditches made of concrete are grassed ditches, which are triangular in cross-section with gentle slopes (typically an inclination of 1:3 on the side of the road, 1:3–1:5 on the external side) that collect stormwater; part of it infiltrates and the rest is conveyed elsewhere over the surface (Figure 13.8).

Stormwater tree trenches

Stormwater tree trenches integrate underground retention with tall greenery, e.g. streetside greenery (Figure 13.9). In densely built areas, trees can also evaporate water collected directly from specially designed underground retention systems. In each case, a strip of tree plantings is connected with a cohesive underground retention, infiltration or combined retention/infiltration system that allows the flow of the retained water between plants. During heavy rainfall, excess stormwater can be captured by traditional sewer systems.

Figure 13.8. Grass ditch along tramway tracks in the city centre of Freiburg, Germany

Figure 13.9 Example of streetside greenery combined with an infiltration system, and cascade of greenery fed with water from roofs, Maynard Avenue Green Street, Seattle, Washington, USA

13.4. Above ground stormwater retention systems

Stormwater retention systems are designed to hold excess runoff from urban drainage basins and may be temporarily or permanently filled with water. Part of the water may infiltrate and evaporate, but most of it flows to receiving water bodies in the form of surface runoff or via underground pipe systems.

Dry detention ponds

Dry detention ponds are filled with water only during torrential rain. Water flowing down from roads (typically highways) or densely built up land is retained until the flood risk is gone, and subsequently discharged to a receiving water body or sewer system. The size, capacity and features of these reservoirs is variable; from the point of view of ecosystem services, the most valuable are those semi-natural dry detention ponds that integrate elements of green and blue infrastructure. In addition to their retention capacity, these areas offer attractive, open, green space for residents in rain-free periods and may be used for sports and recreation, e.g. the Liourat à Vitrolles stadium in France. Dry detention ponds may also be combinedwith urban architecture. An interesting and bold example is Benthemplein water square in Rotterdam (Figure 13.10). It serves as attractive public space during dry weather and can accommodate nearly 2 million litres of water during rain. Since its construction in 2013, maximum capacity has not been reached.

Figure 13.10 Dry detention pond of Benthemplein water square in Rotterdam, the Netherlands: photo during dry weather and visualization during wet weather

Detention ponds with continuous flow zone

Detention ponds with a continuous flow zone (Figure 13.11) are a variant of dry detention ponds, often located within aquifers. These are made up of a wider, dry upper level which is submerged only in cases of intense rain and a bed with standing water or shallow marsh (0.2–0.5 m deep). These aesthetic landscape elements are also biodiversity safe havens. Their efficacy in removing solids and heavy metals is high and comparable with retention ponds and stormwater wetlands, and may be further increased with increasing retention periods.

Figure 13.11. Detention ponds with continuous flow zones: reservoir in the Sokolowka river in Lodz and in Virginia, USA (Adapted from: Sustainable Development Applications no 5, 2014)

Retention ponds

Retention ponds are solutions used in the riverbed itself or its immediate neighbourhood (Figure 13.12). Their role is to hold water that was already conveyed to the river through direct surface runoff and via stormwater or combined sewer systems. These reservoirs attenuate extreme storm flows, thereby increasing the retention capacity of the river. Stormwater is purified primarily through intensified

Figure 13.12 Retention pond by the Sokolowka river in Lodz in 2006 when it was constructed and 6 years later, with established vegetation (Adapted from: Sustainable Development Applications no 5, 2014)

Sedimentation

Plantings may be added to aid in the biological removal of pollutants. Retention ponds are often important elements of the urban landscape that enhance the natural value of a city and serve aesthetic, educational and recreational purposes. Maintaining short retention times (<2 weeks) helps prevent colonization by cyanobacteria which can form toxic blooms in the summer.

13.5 Biological stormwater treatment systems

Biological stormwater treatment systems use macrophytes (such as the common cattail, miniature cattail, calamus, yellow iris, tule and the common reed) for stormwater purification at the edge of a receiving water body (river, reservoir, lake). Their performance can be enhanced with pre-treatment facilities: separators and sediment forebays, especially when inflowing water is heavily polluted, e.g. from the streets, parking lots or service stations. This helps maintain the proper functioning of biological systems.

Stormwater wetlands

Perhaps the most popular solution for the retention and purification of stormwater immediately before its release into aquatic ecosystems are stormwater wetlands (Figure 13.13). These are vegetated systems with extended retention periods that are permanently filled with varying levels of water. Most urban stormwater wetlands use horizontal surface flow and are most suitable during rapid stormwater flows due to their large capacity and throughput.

Figure 13.13 Schematic representation of a treatment wetland used for stormwater purification and photo showing a large stormwater wetland in Massachusetts, USA(Adapted from: Sustainable Development Applications no 5, 2014)

Submerged and floating vascular plants effectively remove pollutants and enhance sedimentation.

Sequential sedimentation – biofiltration systems

Sequential sedimentation/biofiltration systems (Figure 13.14) are stormwater treatment systems that use ecohydrological regulation. These are applied at the inflow of stormwater into a receiving water body or in the aquifer itself.

Figure 13.14. Sequential sedimentation – biofiltration system: schematic representation and pilot project in the Sokolowka river in Lodz (Adapted from: Sustainable Development Applications no 5, 2014)

The system is made up of 3 zones: intensive sedimentation (where a combination of fixed and mobile constructions modify the hydrodynamics of the chamber, increasing sedimentation); intensive biogeochemical processes (where the coarse limestone fraction captures phosphorus compounds); and biofiltration (where biogenic substances are eliminated by macrophytes). The zones are separated by gabions of coarse gravel which additionally filter the water.

Shoreline vegetated buffer strips with biogeochemical barrier

Sedimentation – biofiltration systems can be combined with plant buffer strips on the periphery of water bodies (Figure 13.15). Pollutants are removed through intensive sedimentation and assimilation by aquatic plants, as well as adsorption on biogeochemical barriers in the form of gabions filled with dolomite or limestone rock covered with a coconut mat. This solution may be applied for the pre-treatment of stormwater conveyed to rivers and other water bodies via stormwater outlets but only when the drained surface is small and water flow velocity during rain is not high enough to damage the plants.

Figure 13.15. Buffer zone with biogeochemical barrier for the pre-treatment of water conveyed directly to the reservoir: schematic representation and pilot project in the ponds of Arturowek in Lodz (Adapted from: Sustainable Development Applications no 5, 2014)

13.6 Non-structural solutions

The implementation of sustainable stormwater management solutions is not limited to technical activities but requires the establishment of a wider background. This background is formed by a widerange of non-structural (soft) measures in the following areas (EPA 2005):

- education/awareness: educating residents and information campaigns on the alternative ways of stormwater management;
- planning and management: vehicle emissions control, conscious design of the urban space, plant design, reducing the coverage of impervious surfaces and separating these from the stormwater sewer system;
- stormwater system maintenance: street cleaning, cleaning of manholes and drains, water jetting the sewer system, road and bridge maintenance, maintenance of stormwater channels as well as ditches and aquifers;
- pollutant spill prevention and cleanup: control of oil leakage from vehicles and tankers, tightness control of sanitary sewers and cesspits;
- control of waste storage: stormwater sewer labelling, collection of hazardous waste from households, collection and recycling of used oil;
- control of illicit connections: prevention, detection and elimination of illegal connections to the stormwater sewer network;
- stormwater reuse: non-consumptive use of stormwater (e.g. for toilet flushing, irrigation of municipal greenery).

The experience of the USA's National Pollutant Discharge Elimination System (NPDES) suggests that non-structural activities that engage and include multiple stakeholders (residents, schools, entrepreneurs, decision makers, politicians, artists & the media) can actually be more effective at solving stormwater-related problems than structural activities. Non-structural activities are grounded in a common understanding of the challenges of traditional urban stormwater management, the effects of decisions and activities taking place in the urban space, the need for a new approach and the associated benefits. These constitute the starting point for the creation of a platform of cooperating institutions, the establishment of guidelines, legal frameworks and procedures, as well as the creation of a culture of responsibility for common activities in both public areas (e.g. spatial planning, architecture, environmental protection, infrastructure design) and private areas (e.g. the need to retain runoff generated on one's own property).

Chapter 13 sources:

1-Iwona Wagner, Kinga Krauze. How to safely retain stormwater in the city: technical tools. Sustainable Development Applications no 5, 2014 pp.71-87

Chapter 14
Water in the Urban Space and Integrated Urban Management Practice

14.1 Integrated urban management understanding

Integrated urban management is based on three pillars:

- equal access to high-quality environment
- efficient use of natural resources for economic benefits
- maintaining ecological balance and the ability of natural systems to regenerate

In each of these pillars, water management is a key aspect because water is a valuable resource, an important element of the landscape and driving force of ecological processes. Thus, integrated urban management requires an interdisciplinary approach, multisector, multi-annual planning and extensive cooperation of many groups of stakeholders. Meeting this challenge brings tangible benefits: it allows urban renewal and increasing urban competitiveness, reduces management costs and increases urban adaptability to global changes, not only climate change, but also the demographic or economic changes.

The management of resources such as urban water is a complex matter often referred to as a wicked problem. Wicked problems are not necessarily unsolvable – they may need to be approached differently. The typical features of these problems include the following:

- there is no single, ideal solution: a number of solutions are possible because multiple stakeholders are involved and each of these may hold a different view on the best solution;
- no solution is completely bad or wholly good: these may only be better or worse depending on the spatio-temporal scale and other determinants;
- no solution may be tested beforehand – knowledge is gained as the consequences become known;
- the solution to the problem often becomes a problem in itself because not all cause-effect relationships are known;
- all of the chosen solutions require the stakeholder groups to agree and their needs to be balanced.

Accordingly, the approach to urban water management must be integrated and combine policies and strategies at various levels of decision making to ensure their full compatibility. It is also essential to address all related issues at the same time, e.g. the management of urbanized areas, integrated spatial planning, resident welfare, site competitiveness, social inclusion, environmental protection and a sense of responsibility for the environment.

The concept of integrated water resource management was defined by the Global Water Partnership as "a process which promotes the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems".

he implementation of all EU directives (including those relevant for this guidebook, i.e. the Water Framework Directive,[1]the Habitats Directive[2]together with the Natura 2000 network, and the Nitrates Directive[3]) requires an integrated approach.

The current and future threats to water quality and availability must be defined. In addition, water related habitats, species and sectors of the economy as well as the hazards of: business activity; social structure; legal mechanisms; cultural determinants; systemic determinants; technological determinants; condition of the environment must all be taken into consideration (figure14. 1).

Integrated management is based on three pillars:
1. Social equity: everyone has an equal right to access resources to the extent that guarantees dignified life, irrespective of economic status;
2. Economic efficiency: the highest possible number of users should receive maximum benefit from resources to the extent feasible and within the available water resources;
3. Ecological equilibrium: ecosystems are to be treated on a par with other water users, therefore ecosystems' right to access the necessary resources to the extent that ensures survival and sustainability must be guaranteed on a level with people's right to use resources.

At the operational level, integrated management requires the application of interdisciplinary knowledge as well as public consultations and participation to design and establish tools and implement good water management practices. Since many sectors of the economy are highly dependent on water, the solutions must also integrate multiple sectors, and stakeholders should be open and flexible in their collaboration. The success of sustainable management depends on:

1. The creation of conditions conducive to the implementation of appropriate strategies, policies and legal solutions;
2. Precisely defined roles and competences of institutions and the creation of the necessary human capital;
3. The establishment of management tools that allow the rationalization of choices and assessment of alternatives.

Other important elements include: political will and involvement, social capital and adequate financing (that provides for long-term planning and the possible returns from investment in infrastructure), and comprehensive monitoring and assessment of the effects of activities on the political and societal fronts as well as implementation-wise.

14.2 The benefits of integrated management

The perception of water as a raw material, of rivers as a flood, pollution, and disease-carrying threat, and of small retention as competition for space has led to the degradation of water resources and disappearance of naturally valuable aquatic and water-related land ecosystems (wetlands, ponds, water meadows).

The reversal of the process of degradation and the rehabilitation of degraded aquatic and water-related ecosystems[4] require joint actions by those responsible for water management and its users. In practice, this requires complex databases, expert knowledge and tools that allow the analysis, extrapolation and forecasting of resource dynamics resulting from the current and previous environmental conditions and overall human environmental impacts.

Many cities around the globe have taken on the challenge of integrated water management. Acknowledging the need to use innovative on-site stormwater management solutions is typically the first step. This helps to reduce the load on stormwater sewer systems, increase groundwater recharge, increase the efficiency of waste water purification, and consequently to improve microclimate, supporting the development of green infrastructure, and leading to improved quality of life and aesthetics for city residents (cf. chapter on technical solutions: Wagner and Krauze in this volume).

Figure 14.2. Integrated actions taken on by Philadelphia to reduce the volume of waste water flowing from stormwater overflows into rivers and to reduce urban management costs and promote green infrastructure (Adapted from EPA 2010)

Figure 14.2 shows the integrated activities undertaken in Philadelphia with regard to stormwater management. It turns out that legislation directly linked to stormwater management only improves the efficiency of stormwater use on 20% of urban land. Successful management requires the involvement of institutions responsible for establishing the appropriate legal mechanisms of exemptions and penalties (another 6% of the city's surface area), the involvement of private landowners (4%), the creation of an interdisciplinary and inter-sectoral team, a strategy to design and implement a programme of green streets (17%) and urban alleys (2%) and finally cooperation in planning urban development and forecasting and reducing its negative impact on urban water resources (8%). This way, concerted actions and policies allowed 57% of the city's surface area to be covered by integrated management which translates into stormwater runoff being reduced by 65%. At the city level, this saves around 85 million USD annually.

At the same time, integrated urban management based on an interdisciplinary approach allows the city to be revitalized and improve its competitiveness. It is also worth highlighting the reduced urban operating costs: once established, ecological systems increase their efficiency and stability due to plant growth; increasing numbers of species; the intensification of soil formation processes and consequently, improved soil water retention; intensified evapotranspiration; climate regulation; and increasing adaptation to the existing infrastructure (Figure 14.3).

Integrated urban management is about spatial, functional, ecological and social integration. In line with the concept of solving wicked problems, it is a way of defining and comprehensively approaching problems rooted in different aspects of city functioning.

14.3 Spatial integration

Cities develop in a way that fosters the creation and accumulation of economic potential and infrastructure that serves this potential. This is how we got to the point where spatial development often negatively affects urban residents' quality of life (Bolund and Hunhammar 1999). Spatial planning too, like environmental resource management, has adopted the command and control model. This model is based on the analysis of the urban spatial structure and making adjustments to the studies of determinants and directions of spatial development in response to, the predicted pace and directions of changes in the city, the need to protect valuable nature, preserve elements of suburban space for recreational purposes and to adapt infrastructure, including road networks. This model is quite static, refers to sectoral visions and strategies, and leaves little room for balancing different elements of the urban space and even less room for balancing the various components within a region. This approach has prevailed in urban management because it can speed up the planning process and uses the existing administrative structures and policies.

With the current challenges of integrated management, a new model of urban spatial arrangement is emerging that is grounded in a visionary and design-based approach. Design thinking focuses on the creation of a coherent vision of the city with rationally located residential areas, business centres, transport networks and other infrastructure. The identification of unique land elements (of both natural and cultural value) and the creation of opportunities to preserve and develop these into areas that will meet the needs of residents on the one hand, and guarantee quality of life at present and in the future on the other by including nature as a full-fledged and mandatory element of blue-green infrastructure, form an integral part of this vision. Planning the urban structure in this way allows the assumption that cities are simple systems that develop in a linear and predictable fashion to be abandoned. The city is perceived as a co-evolving natural/social system where each component is highly and equally dependent on the other. At the level of urban spatial management policy, this new approach is associated with the following consequences:

- the spatial management plan is not merely a legal tool and guideline for investments, but above all an operational plan that defines the areas for intervention within the framework of existing urban areas, as well as a tool to design urban policy and create public-private partnerships;
- local administrators play a much larger role in the establishment and execution of local spatial management plans;
- horizontal cooperation between cities and between cities and regions is given a leading role while the role of hierarchical management and vertical decision making is minimized to support greater flexibility of the planning process;
- urban spatial management acquires a longterm dimension if only due to the need to reconcile the needs and interests of multiple stakeholder groups;
- urban residents identify themselves more with the city's space.

At the operational level, this new approach:

- allows for the preservation of links between areas within the city; its natural and cultural elements, both in terms of the road network, alternative (environmentally-friendly) transport pathways, as well as green corridors and green belts around cities that ensure high quality of life. For instance, city residents may be included in the designation of natural/cultural paths and introduction of green infrastructure in recreational space in a way that opens development possibilities for small service companies;

- determines the city's role in the region as well as the network of interrelationships and interdependencies, including the joint protection of water resources, green infrastructure, and compatible development of satellite cities. For example, this approach allows to establish a common development policy, create metropolitan cultural areas, cooperate on water protection, e.g. to achieve a good ecological condition of rivers, expand and protect green corridors or minimize the negative effect of expanding road infrastructure on nature;
- allows for identification of the best possible urban structure with regard to the age, professional and economic structure of city residents. For instance, authorities in Finland are carrying out activities (backed by social studies) to adapt cities to the needs of parents with small children, while Venezuela and Brazil are making efforts to integrate districts by creating green public spaces; South Korea is recreating cities' historic image to reinstate disappearing traditions and people's relationship with rivers;
- indicates the appropriate allocation of funds for urban revitalization and development that reflects residents' needs and not the system of funds administration and management. For example, the priorities of cities in terms of grey and green infrastructure are now largely determined by the availability of EU funds; this in combination with the centralized and sectoral model of urban management leads to rehabilitation works being carried out simultaneously with the channelling of different sections of the same river. Meanwhile, the establishment of a comprehensive river programme coupled with resident involvement would help harmonize actions and create friendly, coherent and useful space;
- creates the possibility for integrating sectoral activities to achieve common goals, such as combining road design and modernization with the protection of green corridors and the protection and use of groundwater and stormwater;
- prevents the execution of individual needs and achievement of individual benefits at the expense of the local community or long-term public goals, e.g. by increasing the presence of different stakeholder groups both in the design and performance of activities; social control in terms of including the needs of all stakeholders is also enhanced.

14.4 Ecological integration

Modern management places high emphasis on the creation of systems with a substantial ability to adapt, i.e. natural systems and the services that they provide and their incorporation in infrastructure.

However, as highlighted in this and other sustainable development guidebooks, nature only plays its role when it functions as a system. This is associated with the basic features of these systems which gain particular importance in cities:

- resistance to natural and anthropogenic pressures and the efficiency of service provision (air, water and soil purification; climate regulation; water cycle regulation, water retention) depend on the number of species and their numbers/biomass per area unit. Therefore, all species should be viewed as "insurance policies for the future" in case of changing environmental conditions;
- these systems are dependent on the constant inflow of species and specimens from suburban areas to compensate losses caused by difficult living conditions for urban plants and animals on the one hand and to increase biological diversity with the richer gene pool of out-of-city areas on the other;
- without the inclusion of cities in a system of green corridors and green infrastructure, species diversity in the out-of-city landscape is also under increased pressure due to the expansion of roads (barriers for animals), urbanization processes and intensification of agriculture. Integrated design where the city and landscape are connected allows more effectivenature protection and reduces environmental hazards;
- these systems are associated with water and matter cycling at a particular scale, e.g. that of a catchment. Consequently, self-sustaining natural systems (that do not require significant input such as irrigation, compensation planting, fertilization) are impossible to maintain where these cycles are interrupted by landscape fragmentation (Wagner et al. 2013);
- external pressures may be compensated only by the size of a green area: nature has the greatest self-regulating and regenerative abilities in the central parts of such spaces and these abilities decline towards the boundaries (edge effect).

The greater the proportion of surface area to the length of the borderline, the better.In the context of city functioning, ecological integration is also about preserving the links between the city and the essential resources that it relies on, including the protection of these. The city of São Carlos in Brazil can be used to illustrate efforts aimed at integrated management. Its general development plan

(Peres and da Silva 2013) identifies the current and future strategic sources of water. This plan assumes the absolute protection of land surrounding strategic reservoirs already at this point. Therefore, no development permits are issued in the vicinity of the protected areas. In the suburban zone, areas for industrial development and residential development were also indicated far in advance based on the predicted inflow of capital and investor interest. The hydrographic conditions, underground water flow, soil permeability and plant sensitivityto anthropogenic pressures were also taken into consideration. Land for extensive and intensive agriculture was also planned, both to supply the city and to contribute to the development of the region.

From the point of view of integrated management, the incorporation of ecosystem services in the urban adaptation system to global changes requires the following:

- absolute preservation of green belts around cities and the prevention of urban sprawl;
- maintenance of green corridors that connect all urban zones with the city's green belt, and the preservation of the high quality andmulti-functionality of river valleys, i.e. the protection of their role as animal and plant migration zones (green corridors may include urban parks, alleys, old orchards, community gardens);
- the preservation of naturally valuable land, particularly aquatic and wetland ecosystems, and maintenance of the necessary hydrological conditions;
- the space and time necessary for efficiently functioning green infrastructure, guaranteed in cities' development plans;
- the creation of appropriate conditions for the rehabilitation and renaturalization of green areas and aquatic ecosystems with ambitious goals that go beyond "ecological potential". For instance, the conditions in one of the main streams in Stockholm currently allow the reproduction of 30 fish species, making it one of the most popular angling sites in Sweden (Stadbyggnadskontoret 1995).

14.5 Functional integration

One of the functions of cities is to provide residents with healthy space (cf. chapter on the links between water in the city and residents' health: Kupryś-Lipińska et al. in this volume) to meet their needs associated with work, education, leisure, provisioning, aesthetic experience and to establish their identity through contact with nature and culture. At the same time, management is aimed at ensuring sustainable urban development where physical health and welfare goes hand in hand with the quality of nature and ethics of equity. This way, integrated management promotes the multi-functionality of urban space which in turn supports social integration and resident activation.

The concept of social inclusion assumes the establishment of equal living and development conditions for different social groups, residents with different wealth levels and living in diverse parts of the city. It is important not to create closed and spatially isolated enclaves where residents cannot participate in the creation and life of a city for various reasons.

Social exclusion is not only caused by poverty, the associated unemployment and the lack of perspectives, but also by disability, old age, the distant location of residential districts, infrastructure degradation, sense of insecurity, or the dispersal of urban functions that forces residents to travel long distances.Still, it is poverty that remains one of the greatest challenges because in many cases it is inherited. Districts with a bad reputation fail to attract investors and discourage wealthier residents, further exacerbating the problem (Warzywoda-Kruszyńska and Grotowska-Leder 1996; Warzywoda-Kruszyńska 1998).

A briefing report by the Chartered Institution of Water and Environmental Management in the UK (Grant 2010) suggests that the density of green infrastructure and aesthetic, clean and openly available public spaces is inversely related to the location of areas of social exclusion. In Manchester, for example, green areas constitute at least 10% of wealthier districts that attract capital and only 2% of poorer districts. However, the report emphasizes that efforts to improve the quality and management of urban space will not yield the expected results without resident involvement in the design and implementation of urban programmes, which also helps develop a sense of identity and responsibility for a place.

By opening up high quality public space to all residents, integrated management creates the opportunities to learn, experience culture and tradition, engage in sports, stay in contact with nature and other residents, and to design urban revitalization programmes based on public participation.

This can be an effective way to eliminate the sense of alienation. Care for the entire urban space and open access to public spaces facilitate long-term spatial order and cleanness. Integrated management of the city and its nature also makes it possible to designate areas with particular functions for local communities, such as space for urban agriculture/gardening that may be a form of physical activation for seniors, education for children and adolescents, and source of income for poorer city residents.

Urban space is valuable due to its intensive use and the multiple and diverse needs of residents that go with it. Urban spatial management requires the creation of safe living conditions, flood protection, microclimate regulation, protection form temporary inundations and pollutants. The creation of alleys and parks in areas of intense traffic is also crucial to preserve air purity and protect from noise. Due to limited space resources, urban areas should integrate as many functions as possible.

From this standpoint, the protection and efforts to preserve urban green areas are particularly profitable: green areas have greater potential to serve diverse forms of resident activity than e.g. residential districts, commercial and office centres, or industrial areas. Green spaces serve as:

- transport pathways for humans, animals and plants, enclaves of greenery and biodiversity;
- areas of temporary or permanent water retention, flood protection measures;
- areas for relaxation, recreation, physical activity ("health centres");
- areas for biomass acquisition and agricultural production;
- potential areas for the production of renewable energy (water, solar, wind);
- demonstrative projects to promote: the integration of green, blue and grey infrastructure, applied arts and modern architecture; ecological technology and engineering;
- sites for ecological and cultural education as well as good traditions and practices;
- inspiration for new technologies, services, art;
- areas to promote, advertise and sell ideas/services, such as the promotion of local products, mobile cafes, location-based games;
- areas to promote the city and its links with the region.

14.6 Sectoral integration

Integrated urban management requires the integration of activities performed by multiple entities responsible for the interrelated urban elements. The key stakeholders that ought to be included at different stages of collaboration are:

- institutions responsible for infrastructure, including sanitary and stormwater infrastructure;
- institutions responsible for the expansion of grey urban infrastructure, including roads and transportation, and urban revitalization;
- municipal departments/facilities;
- departments/facilities/studios for spatial planning;

- departments for strategy and design: the new paradigm for urban water and spatial management can help develop cities' competitiveness if it is reflected in their development plans;
- departments/institutions for promotion and education: to create a new city image, to disseminate knowledge on the progressing changes and the need for these;
- institutions and offices for nature protection;
- institutions responsible for water resources at the regional level (e.g. Regional Water Management Authorities): to maintain the cohesion of policies and strategies for spatial, nature and water management;
- Offices of the Marshal: to ensure coherence of actions within the region;
- institutions responsible for environmental monitoring: these allow the monitoring of the effects of activities in the urban and suburban space, and adaptive management of their resources;
- non-governmental organizations: associations and foundations that help build social capital and include diverse stakeholders in activities that benefit the city;
- funding institutions, such as Regional Funds for Environmental Protection and Water Management that allow the financing of local activities and grassroots initiatives.

The collaborating institutions jointly establish a vision of activities based on a SWOT analysis (strengths, weaknesses, opportunities and threats analysis). With this strategy, the principles of cooperation, scope of responsibilities, and the guidelines for the achievement of short and long-term goals are clearly defined. Changes in stormwater management require actions in different spatial and time frames and hence the need to establish the mechanisms for coherent decision-making at all levels. Additionally, a system of monitoring new investments should be established and the critical boundary conditions for the effective functioning of infrastructure provided. At the same time, it is worth considering the inclusion of local companies and the academic milieu in this collaboration as their business experience and expert knowledge can help to verify the planned activities.

14.7 Integrated solutions

Integrated management promotes the use of integrated solutions that maximize the benefits for all stakeholders and support the equal distribution of costs. According to UN's pyramid of responsible management (Figure14. 4), sustainable development requires first and foremost the use of existing natural potential (capital) and combining it with social and economic capital, as well as constant efforts aimed at its development. When developing a city, authorities should first of all avoid creating pressures on the environment, or at least minimize them. If none of the solutions described above are possible, integrated repair and compensatory activities must be planned.

Each solution must be adapted to the local functions and urban structure as well as the degree of land transformation and ecological potential.

As one of the elements of sustainable development, integrated urban management is largely based on the integrated management of resources, including water. However, social capital (relationships) and human capital (abilities and awareness) play essential roles. Shifting the approach to management requires the establishment of a system to assess the efficacy of its implementation. Therefore, due to the multifaceted nature of activities, different spatial scales, and multitude of stakeholders, appropriate indicators must be worked out.

Figure14. 4. The United Nations-supported Principles for Responsible Investment established and implemented by the UNEP Finance Initiative and UN Global Compact

Twelve example indicators of successful integrated urban water management were proposed as part of the 2005–2009 SWITCH project entitled "Sustainable water management in the city of the future" <www.switchurbanwater.eu>, namely:

- protection of the hydrological cycle (the extent to which the performed activities protect or allow restoration of the disturbed water cycle);
- landscape aesthetics;
- structural and functional integration with neighbouring land (the extent to which the integrated management programmes fit into the design, structure, cultural and historic values of sites);
- correctness of design (the proposed activities, projects and programmes must be designed in a way that ensures the right use of space and human, natural and economic potential, and be adjusted to the local needs and conditions);
- precise long-term maintenance conditions for the constructed infrastructure;
- adaptive qualities of solutions (the adopted solutions should improve the city's adaptation to changing social, ecological and economic conditions);
- usefulness (multifunctional space that includes the protection of ecosystem services);

- public participation (providing for the needs of the maximum number of stakeholders and including these at different stages of management);
- costs (these should not exceed the costs of conventional management);
- combining the needs of different stakeholders;
- interdisciplinary planning;
- societal acceptance.Gabe et al. (2009) propose an even broader assessment of integrated management. The additional aspects include:
- in terms of environmental impact: increased habitat integrity, increased biodiversity, improved water quality, reduced energy use from non-renewable sources, material reuse, infrastructure recycling;
- in economic terms: economic growth (e.g. the number of new enterprises or projects), economic autonomy of the city and region (the contribution of local enterprises to the region's GDP), job creation, generating returns through integrated projects (rate of return on investment), reduced operating costs for households and enterprises, minimizing the need for vehicle transport (e.g. he length of pedestrian and cycling paths; percentage of surface area dedicated only to vehicle traffic);
- in social terms: creating opportunities for local development involving all sectors and social groups, safety, providing all stakeholder groups at all stages of life with access to infrastructure and greenery (e.g. percentage of surface area adapted to the needs of the elderly; the educational value of urban space);
- in cultural terms: creating/preserving the identity and uniqueness of sites (e.g. preserving and exposing the cultural landscape or unique natural phenomena), preserving residents' cultural identity, and the continuity of local traditions (e.g. percentage of preserved and revitalized sites of cultural value; the inclusion of local patterns in modern design).

Irrespective of the adopted indicators, the anticipated time frames for the achievement of results in each category should be specified, bearing in mind that not all activities yield immediate results.

Moreover, a cause-effect relationship can be observed for some aspects, e.g. societal acceptance of costs is associated with the achievement of multifunctional urban space.

Chapter 14 sources

1-Kinga Krauze, Iwona Wagner. Water in the urban space and integrated urban management. Sustainable Development Applications no 5, 2014 pp.89-105
2-Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora.
3-Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources
4-Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy
5-EPA, 2010. Green infrastructure case studies: municipal policies for managing stormwater with green infrastructure, Washington: EPA Office of Wetlands, Oceans and Watersheds.
6-Gabe, J., Trowsdale, S., Vale, R., 2009. Achieving integrated urban water management: planning top-down or bottomup? Water Science & Technology, 59(10), pp. 1999–2008.
7-Grant, L., 2010. Multi-functional urban green infrastructure. A CIWEM briefing report, London: Chartered Institution of Water and Environmental Management.
8-Hoyer, J., Dickhaut, W., Kronawitter, L., Weber, B., 2011. Water sensitive urban design principles and inspiration for sustainable stormwater management in the city of the future, Berlin: Jovis Verlag.
9-Municipality of Rotterdam et al., 2007. Waterplan 2 Rotterdam. Working on water for an attractive city (English summary), Rotterdam.Bolund, P., Hunhammar, S., 1999. Ecosystem services in urban areas. Ecological Economics, 29, pp. 293–301.
10-Peres, R., da Silva, R., 2013. Interfaces of urban environmental management and regional management: analysis of the relationship between Municipal Master
11-Plans and Watershed Plans. Brazilian Journal of Urban Management, 5(2), pp. 13–25. Potsdamer Platz, 2010. History and ecology, <www.potsdamerplatz.de>.
12-SCWS, 2012. In-curb water vaults, Sarasota County Water Services <www.scgov.net>.
13-Stadbyggnadskontoret, 1995. Stockholms ekologiska känslighet, Stockholm: Stadsbyggnadskontoret.
14-Wagner, I., Krauze, K., Zalewski, M., 2013. Blue aspects of green infrastructure. Sustainable Development Applications, 4, pp. 145–155.Warzywoda-Kruszyńska, W., ed., 1998. Żyć i pracować w enklawach biedy. Lodz: Institute of Sociology,
15-University of Lodz.Warzywoda-Kruszyńska, W., Grotowska-Leder, J., 1996. Wielkomiejska bieda w okresie transformacji. Lodz: Institute of Sociology, University of Lodz.
16-WERF (Water Environment Research Foundation), 2009. User's guide to the BMP and LID whole life cost models. Version 2.0, Alexandria, VA: WERF

List of video materials for the course

Chapter	Video abbreviation	TIME MIN:SEC
1.MUNICIPALITIES AND WATER USE		
	_Water TP	***3:21***
	_Ecovillage	19:1
	_Water Use	2:31
	_Recycling Water	2:11
	_Media filtration process	3:37
	_Spiral wounded membranes	3:21

Chapters	Video abbreviation	TIME MIN:SEC

	_ASIO_5GE_N	
	_ASIO_300GE_N	2:28
	_Ecovillage	3:45
	_Recycling Water	19:1
2. URBAN WASTEWATER	_WWTP Tour	2:11
TREATMENT	_Urban WW Management	26:1
		9:24

UZWATER

This compendium is produced for a master level course in the UZWATER project. It consists of some newly written material as well as previously published texts extracted from freely available books, reports and textbooks on the Internet, dominated by publications from the Baltic University Programme. The sources used for each chapter is listed at the end of the chapter. The compendia of the Uzwater project are produced exclusively for Master students free of charge at the participating Universities and is not to be sold or be freely available on the Internet.

The UZWATER project is an EU TEMPUS project. It includes 8 universities in Uzbekistan and deals with university education for sustainable water managment in Uzbekistan. Uppsala University and Baltic University Programme is one of the six EU partners in the project. Lead partner is Kaunas University of Technology.

The main objective of the project is to introduce a Master level study program in environmental science and sustainable development with focus on water management at the eight partner universities in Uzbekistan. The curriculum of the Master Programme includes Environmental Science, Sustainable Development and Water Management.

The Sustainable Development unit will include the basic methods used in Sustainability Science, in particular introduce systems thinking and systems analysis, resource flows and resource management and a series of practical tools for good resource management, such as recycling, and energy efficiency.

The specific objectives of the project are:

- to establish study centers at the partner universities in Uzbekistan
- to improve the capacity to train master students with expertise to address the severe environmental and water management problems of the country;
- to support the introduction and use in Uzbekistan of modern education methods, study materials, and e-learning tools;
- to encourage international cooperation at the partner universities;
- to strengthen capacities to provide guidance to authorities and the Uzbekistan society at large;
- to ensure the visibility and promotion of the Master Programme through web pages, printed material and cooperation with society;
- to ensure continuity of the Master Programme and long-term support of the project outcomes at partner universities beyond Tempus funding.

http://uzwater.ktu.lt