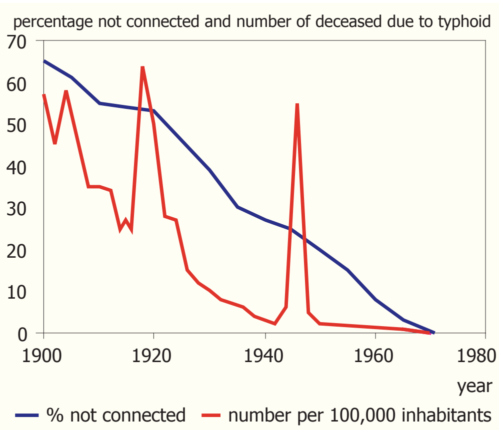
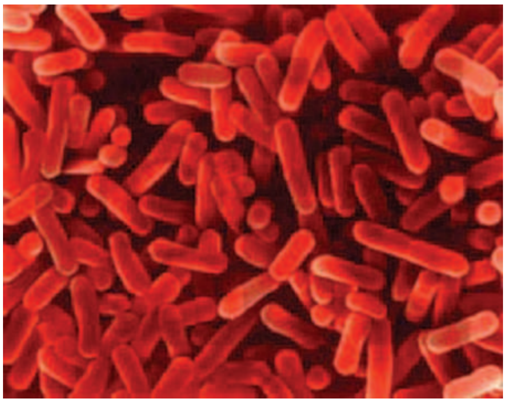
Introduction to water supply





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This handout is based on *Drinking Water, Principles and Practices* by de Moel et al.

1. Introduction to water supply

A good water supply is an essential part of human society - not only we need water to grow but also we need it for personal and domestic hygiene such as bathing and washing, which is a primary condition for good public health.

The major goal of a proper water supply system is to distribute water that can be drunk safely.

In order to produce drinking water, water is extracted from the underground, rivers or lakes (intake). As the water is not directly drinkable it must be treated according to different processes depending on the quality of the source and the requirements for drinking water (treatment). Afterwards, the water is transported to the city and distributed via a piped network to households, commercial buildings, public entities and small industries (distribution).

Water supply cannot be considered separately from wastewater. Water does not simply disappear after being used but is to a greater or lesser degree polluted. This polluted water has to be transported out of urban areas to avoid the accumulation of pollutants which can lead to disease and other problems.

Thus, after usage the water is collected in a sewer system and transported to a wastewater treatment plant (collection) where the water quality is improved (treatment) for discharge into the receiving water bodies (discharge). Therefore, the surface waters where the wastewater is discharged can be used again as a source for drinking water production

Discharged wastewater must not put an unacceptable load on a natural system. For this reason, it is necessary that wastewater is well treated before the water is brought back into the natural water cycle.

The several types of water pollution have been leading to the implementation of advanced wastewater treatment in developed countries, additionally to the standard removal of organic compounds. Nowadays, nutrient removal is applied in order to prevent eutrophication and endocrine disruptors removal (such as pesticides and pharmaceuticals) in order to avoid the accumulation of persistent organics in the environment.

2. Public health

For hundreds of thousands of years, our ancestors lived in small groups off the gains from hunting, fishing, and gathering and natural disasters such as floods, large fires and drought took their toll. Looking from the point of view of diseases, there were, however, advantages. Infectious diseases, which do not originate from local flora, but that need large populations to be transmitted, had a very small chance of spreading. Also, waste products created no large problem. Nevertheless, the life expectancy of our nomadic ancestors was low: the average age at death (the age at which 50% of a generation died) was less than 25.

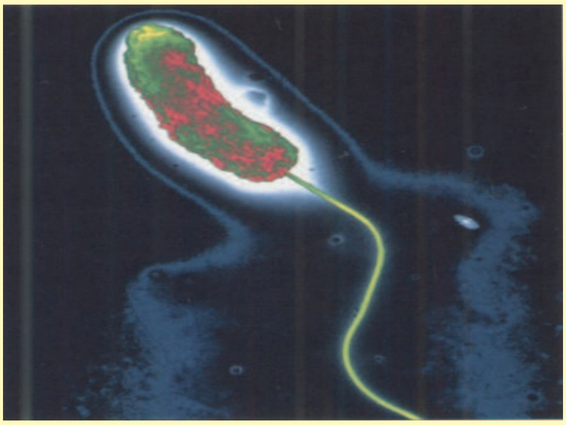
About 8000 B.C.,in the new Stone Age, man attempted to reduce his dependency on nature. Animals were kept and intentionally bred, food crops were cultivated, and places of residence became permanent. As a result of specializations, the primary production was improved by irrigation channels, reservoirs, water storage, and reliable time calculations. Disadvantages were a result of the concentration of the population: epidemics, stench and noise pollution, polluted water resulting from waste products, etc. Therefore, measures were needed for water supplies and waste disposal.
During the Bronze and Iron Ages, distant trade routes were developed.. Germs travelled across these great distances as well, causing plagues that developed into epidemics around the Indian Ocean, which was the center of the world traffic routes at that time. Each time that the border of the known world was extended, the “virginal” population fell prey to epidemics such as smallpox, cholera, the Bubonic plague, and typhoid fever.

Many infectious diseases continued threatening the people of large European cities that were expanding during the second half of the Middle Ages. The situation was so dramatic that the average age of death was between 5 and 10 years, far below the average found in the successful Neolithic cities.

The Modern Time, from about 1500, is marked by an unprecedented exchange of people, animals and plants from several continents. With this,germs and/or their diseases from still unknown regions reached the New World. For example, smallpox literally decimated the population of Mexico and Peru in the first half of the 16th century. And even in the 19th century, 90% of the population of the Fiji Islands died in a short span of time after the introduction of measles there.

In 1850 the Epidemiological Society was established in London. Doctor John Snow published his findings in 1854 about a London cholera epidemic; in ten days there were more than 500 fatal cases. He found that nearly all of the cholera patients around Broad Street used water from the same pump (Figure 1). The water had to have contained a pollutant, he theorized. Based on his findings, the epidemiologist was able to have the handle of the pump removed. Thirty years later his pollutant theory was confirmed by microbiologist Robert Koch, who had travelled to Egypt and India to find a disease breeder.
doctors realized, sometimes without even knowing the exact causes of contagious diseases, that hygiene, with regard to provision and attitude, favourably influences the health of individuals and groups. Basic provisions that were made for the whole population in the second half of the 19th century form the basis of the good public health we have today.

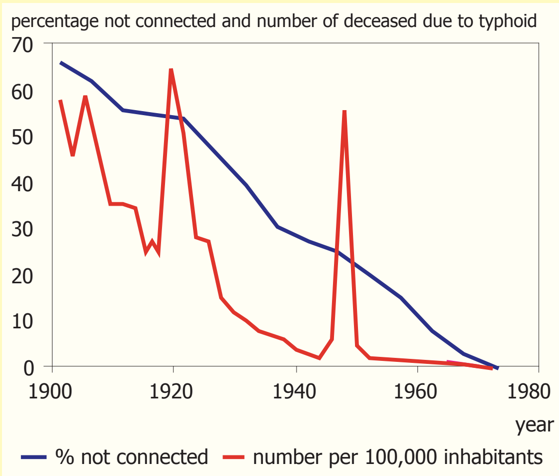
Cholera
It is presumed that the catchment area of the Ganges and the Brahmapoetra is the birthplace of this acute intestinal disease. The disease was brought to Western Europe by infected seamen. Cholera has an incubation period of 10 hours to some days and is characterized by watery diarrhea and vomiting. The loss of many liters of fluid and valuable minerals often cannot be compensated by drinking and leads to a fast death. Up until recently it was thought that mankind was the only infection reservoir. Recently, Rita Colwell showed, however, that cholera bacteria can also survive in plankton in the oceans. The disease is usually transmitted through drinking water containing cholera bacteria or through food that has been prepared with this water.
The fact that cholera epidemics occur in waves is related to the community within a population, and also to weather phenomena such as El Niño (change in ocean currents can lead to polluted water flowing inlandCholera is a disease that can flourish only under poor sanitary conditions. All energy must be directed towards the supply of reliable drinking water and food in the community.

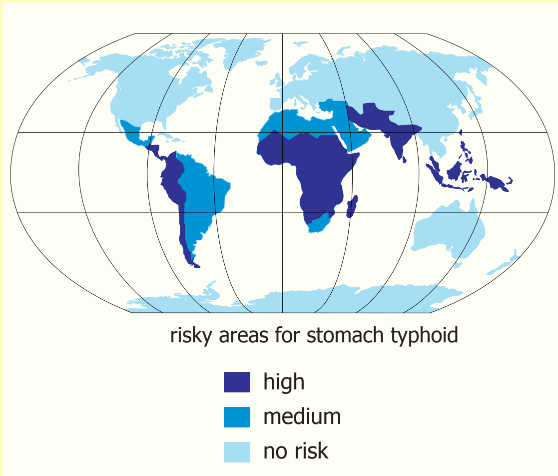


Typhoid

Another disease that played havoc among the Dutch population in the previous century and caused thousands of deaths was typhoid. The disease-causing bacteria live exclusively in humans but can also survive in water for some time. After an incubation period of 2 weeks, a series of symptoms emerges, characterized by high fever, weakness, dizziness and diarrhea. Futhermore, a slow pulse is noteworthy. Without treatment, about 15% of the patients die, depending on their resistance. Modern medicine has reduced the mortality to 3%. These days, the typical patient is someone who comes back from vacation healthy and then develops the disease.

Unlike cholera, a relatively small amount of typhoid bacteria is capable of infecting a patient. The infection is fecal-oral and can take place through drinking water, but also through hands, fleas or the soil. The typhoid problem can be solved by separating the removal of feces from the drinking water and food supplies in order to avoid disease carriers from spreading. The construction of water supply systems in the Netherlands (percentage not connected to water supply) has run parallel to the decrease in the mortality rate from typhoid.





These days we can say that the world has become one, because, strictly speaking, there are no longer any large regions that are completely isolated.
In the coming 30 years, there will be a decrease in disease and mortality figures, which will be seen from the steadily increasing life expectancies. Nevertheless, old spores will emerge again and again in new surroundings and among other population groups..

3. Water in the Romans time

The Romans regarded personal hygiene as very important. In the Roman cities there were many bath houses and public toilets, some provided with running water. Feces were transported through a sewage system (the Cloaca Maxima) to a discharge point outside the city, as well as the rainwater.. This is all more astonishing when recognizing that the Romans had no formal knowledge of hydrology or hydraulics.

Drinking water supply

The excavations in Herculaneum and Pompeii demonstrated that the inhabitants initially widrowed water from streams. In addition to this, groundwater and rainwater were used. After the building of an aqueduct, the situation changed drastically and large quantities of water were made available. As early as 100 A.D., the city of Rome (roughly 1 mil-

Legionellosis (Legionnaire's disease)

The most important microbiological discovery of recent years has been the cause of Legionnaire's disease. In the summer of 1976 some 4400 war veterans gathered in a hotel in Philadelphia. In total 149 persons became ill with symptoms that could not be traced to any known disease. The primary feature was severe pneumonia. In 1977 the cause was found: a bacterial infection from Gram-negative, rod-shaped bacteria which can multiply in water and air-conditioning systems. The organism, which was unknown until then, was named Legionella pneumophila.

The Netherlands was also frightened by an outbreak of Legionella in February 1999 in Bovenkarspel. A total of 242 people were infected through two jaccuzis at a flower exhibition, 32 people died. This outbreak led to informing health services, and also saunas, swimming pools, campsites, hotels, and the public at large. Next to this, technical measures, such as flushing pipelines, have been devised to limit the infection risks in hot water. These measures have to be carried out at those high-risk facilities (saunas, swimming pools, jaccuzis, etc.). The actual infection from the bacteria occurs through the lungs by means of aerosols (airborne bacteria).

lion inhabitants) was provided with drinking water by an ingenious system of 11 large aqueducts. The water was abstracted in the mountains ten kilometers from the city of Rome and, after having passed through a sedimentation basin, flowed via gravity by an aqueduct to the city.

The Romans' water transport system ended in central flow splitters in the city (Figure 2). From this point the water flowed by gravity to different areas in the city. Besides the central distribution flow splitter, there were often secondary splitters, through which the water was transported to private users and public establishments. The water was led to a distribution tower where it passed into an open basin. From there it was transported to homes by means of lead pipes. Those people who could not pay for a private connection to the water system collected their water from public fountains.

The simultaneous existence of different types of water supply was probably designed to compen-

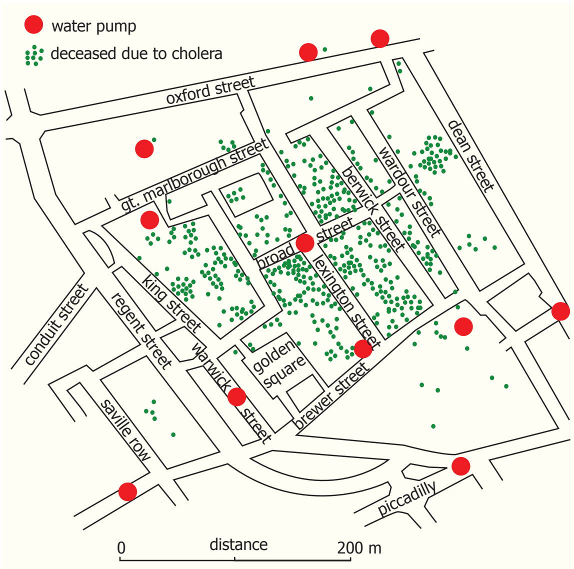


Figure 1 - Broad Street pump

sate for dry periods and varying capacities of the aqueduct. What is known for sure is that the aqueduct was cleaned at specific times, stopping the water supply entirely. Reservoirs that could cover these maintenance periods were most probably not built. The city of Ostia,., had storage basements (cisterns) that probably provided a buffer for periods of low water supply.

The rainwater that fell on roofs was collected in an “impluvium” that was located at the bottom of an atrium. From there, the water was transported to a cistern. The collected quantities of water were enough to supply the drinking water needs of 5 to 6 people for one year. Only the houses of the rich were fitted with an “impluvium,” and they usually also had a well from which groundwater was collected.

The knowledge that the Romans had about the basic design of water transport systems was left to us in the form of a book written by Sextus Julius Frontinus.. From his writings we can deduce that the Romans did not know how to calculate the flow through a pipe. As a result of our better knowledge of the laws of mechanics, we now know, for example, that a pipeline can burst as a result of thrust-forces that can occur in the bend of a pipeline. If the bend is not anchored, the pipeline cannot cope with these forces. The Romans could not rationally explain why their pipelines collapsed. They assumed, therefore, that it was due to the spirits. By building an aqueduct where a lead pipeline changed directions, they assumed that the spirits disappeared out of the water through the free water surface.

Figure 2 - Roman flow splitter

A striking phenomenon in aqueduct design is that the secondary and tertiary pipelines had standardized dimensions. That can be seen from the well-known dimensions of the aqueducts, and height differences. Calculations show that the slope was between 5 and 33 m/km. The water velocity in the pipelines was between 0.6 and 1 m/s. If we would build similar aqueducts today, we would derive approximately the same design with very similar results. We can nowadays conclude that a velocity in a pipeline of 0.8 to 1.2 m/s generally leads to the most economical design.

Sewage system

Almost every house in the Roman cities had a toilet; and bigger houses sometimes had multiple toilets in one area (Figure 3). Feces were collected in cesspools. Houses that were connected to the public water system also had their toilets connected by pipes to the system. The water that was transported to the toilets also flushed out the toilets, thereby ensuring good personal hygiene. The collected feces and urine had market value. Feces were used as fertilizers, while urine was involved in the production of leather and wool.

Beneath almost every street there was a sewer that primarily served to discharge wastewater from toilets and kitchens, as well as from the overflow of “impluviums” and springs. Rainwater was discharged both above the ground, via the street, and under the ground. The transport of rainwater via the street was a very practical and economical solution.

Often, when referring to antique sewer systems, the Cloaca Maxima is mentioned. This is a sewer, of which a section still exists, that was built in Ancient Rome in order to discharge wastewater and rainwater into the Tiber River. . The Cloaca Maxima is also an indication of the Romans’ knowledge and skill in the area of design and construction of large hydraulic structures.

Figure 3 - Roman public toilet

Wastewater treatment

As far as we know, the Romans did not give much attention to the treatment of wastewater. This was not considered a necessity. On the one hand, except for Rome, city populations were quite small. On the other hand, wastewater discharge, at least in Rome, went directly into the Tiber River. The Tiber is a large river that could probably handle the wastewater without too many problems.

Operation and Management

Operation of the public water supply and sewage system, was in the hands of the city council. Citizens were responsible for the operation of those facilities that were situated on private property. The operation was formidably organized.

The transport of drinking water to private homes had to be paid for. In the same way as today, payment was made according to the amount of water that was used. The Romans assumed that the amount of water that was transported to a particular house was proportional to the area of the pipe that transported it there. Sometimes the lengths of the pipes from the flow splitter to the different house sites were equal, in which case the assumption was correct, but this was not always the case,. Users who lived far away from the flow splitter complained that they received less water than the people who lived close to it.

Suppose a certain pipeline is twice as long as another. A calculation made using simple hydraulic formulas shows that the discharge through the longer pipe will be approximately 30% smaller than in the case of the shorter pipeline. Using simple volumetric measurements, the person who was connected to the longest pipeline could show that he received less water than his neighbor who lived closer to the flow splitter. However, the judges assumed that one of the consumers cheated with the measurements, and, if that was not the case, they assumed that it had something to do with the gods.

Rome was not the only Roman city that was supplied with water via an aqueduct transport system. For example, Cologne (Germany) was supplied with water by an aqueduct that had a length of 80 km (Figure 4). In Heerlen, Maastricht and Nijmegen, archeological remnants have been found of the Roman bathing culture.

The Romans built and maintained waterworks that ensured a good living and working climate in the cities. The design and construction of the aqueducts and the distribution networks were prime examples of their engineering skills, which were only matched after 1850 A.D.

After the collapse of the Roman Empire, the Roman water systems fell into decay. The Romans' acquired specialized knowledge was also not preserved. Once again people in the cities had to rely on water from wells, surface water, and rainwater collection. Feces and garbage were dumped on the street and/or thrown in the canals, and there was a lack of personal hygiene. Refreshing the urban surface water rarely took place.

As a result of the worsened conditions, the population decreased due to the Plague, contagious diarrhea sicknesses and smallpox. In about 100 A.D. Rome had about 1 million inhabitants, but by 600 A.D. this had been reduced to about 20,000!

Today, almost every household in the Netherlands is connected to the drinking water network (99.8%). Via this network, hygienically safe, clear and colorless water with a good taste is provided.

During the last few decades, water use has increased considerably. In 1850 about 10 liters of water per person per day were used, whereas, in the year 2014, water usage increased to 126 liters

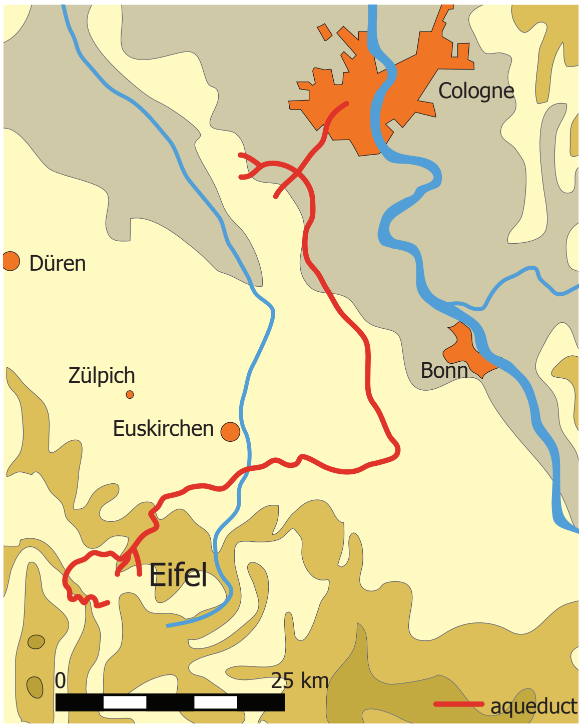


Figure 4 - Roman aqueducts from the Eifel to Cologne (Germany)

pp/d. Because the general population could make use more and more of good quality drinking water, people started using water for other purposes than drinking. Over the last 20 years, water usage has stabilized as a result of public awareness campaigns about saving water.

4. Water worldwide

Water plays an extremely important role in the world. Some even call it the gold of the 21st century, in the same way as oil was seen in the 20th century. The available water supply is becoming relatively smaller, because of human consumption and the many types of water pollution.

Los Angeles

Los Angeles is a city that grew enormously within a short period of time. In 1900, the city had 100,000 inhabitants, and in 1994 9,000,000. At the beginning of the 20th century, the water supply consisted of rainwater catchment and a rapidly diminishing groundwater supply. That is why plans were made by the Los Angeles Department of Water (LADWP) to try to cope with the increasing demand. The Los Angeles Aqueduct was built (Figure 5), which provided Los Angeles with water from Owens Lake. The water had to be transported over a distance of 370 km. This was, however, not a problem, because Owens Lake lay 1,300 meters above Los Angeles.

The farmers opposed the intake of water from the lake. The once so fertile agricultural land dried up as a result of the extensive abstraction of water from the lake. Between the farmers and the LADWP, a couple of armed conflicts took place, with casualties on both sides. These conflicts were called the "water wars."

By 1924 Owens Lake had totally dried up and, in 1941, the existing aqueduct was extended to Mono Lake. In 1978 the inhabitants around Mono Lake realized that it was also drying up. A committee was established and lawsuits were filed in order to save the lake.

For the city of Los Angeles, this situation meant that a large investment had to be made into saving water and water recycling. Over the last 60 years people have changed their way of thinking about water. Since 1980, not only are economic considerations deemed important, but environmental issues play just as important a role.

South Africa - Lesotho

South Africa is a dry country (Table 1) with a wide range in rainfall, both in time and place. The

Figure 5 - Los Angeles water supply

southeastern part of South Africa has the greatest rainfall by far, and the relatively short rivers carry this water almost directly into the Indian Ocean. The large metropolis of Johannesburg is situated near the gold mines. It lies on a plateau (1,500 m above sea level) in a dry part of the country and the water supply for this area is, therefore, problematic. In the past, several rivers in Kwazulu-Natal were redirected towards Johannesburg.

Quite a distance to the south of Johannesburg lies the wet mountain kingdom of Lesotho. In the western part of Lesotho 800 mm of rain falls per year, while in the eastern part 1,200 mm falls. The water is transported by the Orange River to the southeast and flows into the Atlantic Ocean. This is too far away to be used by Johannesburg as a water resource.

South Africa was interested in water from Lesootho for years. Finally, the agreement was signed in 1986 and South Africa paid for the entire water export project and its maintenance and gave Lesotho 60 million Rand in water royalties per year. Lesotho borrowed money from the World Bank and started building a dam. The water can be transported from the dam through a tunnel bored through the mountains and carried by gravity to Johannesburg.

Eventually, this project benefited both parties. South Africa has water for the increasing need in Johannesburg and Lesotho sells water and produces its own electricity. By 2020 four dams will have been built and a network of pipelines and tunnels will supply 82 m^3/s of water to South Africa.

Namibia

The capital, Windhoek, lies about 1,000 m above sea level, far from any river. And, just like in many parts of South Africa, there is very little groundwater available. Since 1968, Windhoek has treated household wastewater, as well as surface water. Windhoek was, in fact, the first city in the world that reused treated wastewater for drinking water purposes (Figure 6). As a result of the increasing water demand, the amount of reused wastewater has been increased from 2 to 7 million m^3 per year.

Table 1 - Worldwide differences in the water balance

Area	Rainfall (mm)	Evapo-transpiration (mm)	Useful rainfall (mm)
World	750	545	205
Europe	734	425	319
Africa	686	547	139
South Africa	475	410	65
Namibia	280	265	15

This is, however, not sufficient to satisfy the future water demand there.

The use of sea water is not yet an alternative option, because Windhoek lies too far from the sea and too high above sea level, and desalination is a very expensive procedure. For these reasons, engineers are now looking at permanently flowing rivers in the Namibian territory. There are only three: one on the southern border and two on the northern border of the country. The most logical option is to use the water from the Okavango River, a large, permanently flowing river that begins in Angola and ends in Botswana. In Botswana, the river flows into a depression, the Okavango Delta, and evaporates. The Okavango Delta is ideal for birds and animals and is thus a very important tourist attraction. Botswana is now worried that this nature reserve will be adversely affected if Namibia withdraws water from the Okavango River, despite the fact that Namibia only needs a relatively small amount (0.17% of the average river discharge and 3% to 10% of the river's minimum discharge). Because of these issues, negotiations have been going on for many years.

Mali

Figure 6 - Treatment plant in Windhoek where wastewater is reused for consumption

Djenné is one of the oldest cities in West Africa and is especially well-known for its mosque, the largest loam construction in the world. The houses also have a very unique architecture: they have been built in the traditional manner using wood and loam, resulting in the whole town, and especially its architecture, being declared a national cultural heritage site. Conservation of the city and its unique architecture is, however, being threatened by (among other things) the wastewater problems that have arisen during the construction of drinking water pipelines.

In Djenné each house has been built around a central courtyard with at least one toilet situated on the roof (Figure 7). Up until 1982, surface water was the most important source of water for drinking and cleaning. The direct availability and untreated usage of it naturally had serious consequences for public health, which could be seen, for example, in the high infant mortality rate. Nowadays, surface water is still used for washing clothes and pots and pans, and a part of the population still drinks this water. With the help of Canadian development aid, a drinking water supply plant was built in 1982, which initially provided the people with 52 public water fountains. At present 286 of the 2,300 houses have a drinking water connection, and the number is still increasing.

The total drinking water usage has increased since the construction of these resources. This results from a decrease in the availability of surface water and a change in people’s habits. These changed habits include an increase in activities such as showering and washing, as well as where these activities take place. In general, women are now washing themselves at home. Likewise, the washing of pots, pans and clothing also takes place in the home.

The increased amount of wastewater cannot be processed properly with currently available resources. At present, wastewater is sometimes discharged directly onto the street, and then evaporates or seeps into the ground, but inadequate facilities lead to its accumulation and stagnation there (Figure 8). Together with poor solid-waste collection, what results is an increased hazard for public health, a stench, and the reduced accessibility of the roads. Moreover, in a number of cases, the wastewater has eroded the loam walls, resulting in the stability of the houses being undermined.

Figure 7 - Toilets on the roof in Mali

Technological, social, and organizational solutions only have a chance of success if they are supported by the local population and if it is practical to implement them. Implementing infiltration measures seems to be the best option. This solution is simple and the local population understands and supports it.

Bangladesh

In the past, a large part of the population of Bangladesh used surface water as a source of drinking water. This caused many diarrhea-related diseases which led to a high mortality rate, especially among small children. Development aid from organizations such as UNICEF provided the people with tube wells (hand pumps), which made it possible for them to use groundwater as drinking water. Now 97% of all water used by the population is groundwater.

In 1990, another problem arose. Water that was pumped up with the shallow tube wells turned out to be badly polluted with arsenic. A problem with

Figure 8 - Accumulation and stagnation of wastewater on the street

arsenic is that it dissolves in water and cannot be tasted, seen or smelled. It is initially very difficult, therefore, to know if the water is toxic. The long-term effect of drinking water that is polluted with arsenic is skin discoloration, blisters on the hands and feet, and internal tumors (blackfoot disease). Any vitamin deficiency (particularly vitamin A) worsens these effects, which eventually can be fatal. This could mean that, in the future, 1 out of every 10 people will die from arsenic poisoning. It is not easy to find a direct link between polluted water and occurring diseases because they often only show up many years or even decades later.

A majority of the population does not know that the water is poisonous, because the government is scared that panic will break out. In Western countries there are many ways of treating the groundwater or surface water, but many solutions do not work in Bangladesh.

Colorado River

The Colorado River originates in the middle of the United States, flows via the Grand Canyon to Mexico and into the Gulf of Mexico. In 1944 a treaty

Figure 9 - Desalination plant for the Colorado River

was made between the USA and Mexico in which Mexico was guaranteed a certain amount of water. The water from the Colorado River was used, among other things, for irrigation. The drainage water from the irrigation has a high salinity, which means that the Colorado River water could be no longer used by the farmers in Mexico for agriculture. In 1961, Mexico submitted an official protest against the US concerning water quality, because agricultural production in the Mexicali Valley was adversely affected.

In 1972, a solution was found with an agreement concerning the water quality of the river. The US built the world's largest desalination plant in Arizona. This factory treats 390,000 m^3 of salt river water per day (Figure 9). Using a membrane filtration installation (reverse osmosis) the salt is concentrated into a concentrate stream, and desalinated water (an amount of 275,000 m^3 per day) flows into the river. The concentrate stream, which consists of water with a high concentration of salts, is discharged directly, by means of a pipeline, into the Gulf of Mexico.