# Natural Technologies of Wastewater Treatment

Global Water Partnership
Central and Eastern Europe

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*To Björn Guterstam (1949-2010) whose driving force inspired this publication. GWP Central and Eastern Europe – a network for integrated water resources management – hopes that this book will be a first step in changing minds so that water engineers will pursue not only conventional wastewater treatment technologies, but also more natural ways to solve sanitation problems in small, neglected communities of Central and Eastern Europe.*

*Björn's Guterstam friends*

*Danka Thalmeinerová, Milan Matuška and Igor Bodík*

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# 1 Preface

*Natural ecosystems have been used for wastewater treatment for centuries. However, this "treatment" has often represented only an uncontrolled wastewater disposal and, as a result, many valuable ecosystems have been irreversibly damaged. Natural systems for treatment of various types wastewater have always drawn attention because of low capital as well as maintenance and operation costs. However, it was only during the second part of the 20th century when the purification processes involved in wastewater treatment in natural ecosystems were used in artificially built treatment systems. Now, we can say that extensive treatment technologies such as constructed wetlands, soil filters or stabilization ponds are using processes occurring in natural habitats but do so in a more controlled manner.*

*There is a great need for wastewater treatment for all sources of pollution < 2,000 p.e. in Central and Eastern Europe and there is an obvious potential for natural treatment systems. There is more and more scientific evidence that the natural treatment systems are very efficient treatment technologies and there are many fine examples of the use of natural treatment systems for purification of many types of wastewater, sludge handling and use of purified water for irrigation. Indeed, the natural treatment systems for wastewater treatment have to compete with technical solutions, namely with so called conventional treatment systems such as activated sludge process. Unfortunately, the natural treatment systems are quite often underestimated in their treatment performance by water authorities and it is not uncommon that the water authorities are reluctant to permit the use of these systems. Also, the relatively low construction costs make natural systems less attractive for construction companies as they bring less income as compared to conventional systems. This concern was very wisely expressed as early as in 1976 by Dr. Faria during the opening talk in the conference Biological Control of Water Pollution in Philadelphia: "There is also a problem of public acceptance: how quickly can Americans accept the idea of human waste for crop fertilizer or marsh nutrient? Furthermore, the fact that biological systems are inexpensive compared to conventional systems means they will probably present fewer profit opportunities for treatment plant designers. This is unfortunate, but realistically this will also delay implementation of these systems." The reality showed that the natural treatment systems faced the same problems in many countries and in some, there problems have not been solved yet.*

*The publication "Natural Technologies of Wastewater Treatment" provides a comprehensive overview about the construction, operation and treatment performance of various types natural of treatment systems. Also, it provides information about waste management and the use of treated wastewater for irrigation. The publication is easy to follow and the theory is supported with well selected photographs and drawings.*

*The publication will be very useful tool for engineers, designers, university teachers and students, landscape planners, municipality representatives, and hopefully also for decision makers, watershed water management officers and officers in water authorities at governmental level, and particular appropriate ministries.*

*Jan Vymazal*
*November 2013*

# 2 Introduction

The Publication “Natural Technologies of Wastewater Treatment” is focused on the very topical issue of the use of natural technologies of wastewater treatment, including, among others, constructed treatment wetland , soil filters, waste stabilization ponds, aquatic plants systems, irrigation by pretreated wastewater. These natural technologies of wastewater treatment belong to the group of environmentally friendly ways of treatment and management of particular types of wastewater. However, they also, to some extent, encompass management of waste (especially organic), produced in the treatment process.

In preparation for the publication, GWP CEE carried out a questionnaire survey in 2012 that provided the necessary background information and highlighted areas that should be emphasized in the content (Bodík et al., 2012). The survey focused on wastewater collection and treatment in each of the countries, with a special emphasis on natural technologies of wastewater treatment, experiences with technologies, their expansion in the CEE countries and legislation requirements regarding wastewater treatment. Furthermore, it focused on treatment technologies, monitoring and performance efficiency. One result of the survey was a demonstrated interest in collection of information about natural wastewater technologies (constructed wetlands, wastewater stabilization ponds, soil filters, treated wastewater reuse), not only for biological treatment, but also for final or as tertiary stage, it means treatment after wastewater treatment plants (WWTP) based on conventional technologies. The survey further illustrated that a focus on small sewage sources is required- from individual households to the settlements under 2,000 inhabitants or larger, but divided into more parts in the landscape.

The content of the book was, consequently, discussed within the sustainable sanitation group of GWP CEE.

Technological procedures for wastewater treatment and new ways of the organization of the second generation for constructed treatment wetlands have been developed over the last twenty years. An increased attention is also paid to a mutual combination of various natural technologies of wastewater treatment and their utilization in the process of wastewater treatment.

The publication is divided into 22 comprehensive chapters and a summary. The issue of mechanical treatment of wastewater is elaborated into details more than the design of natural technologies, organization and treatment technologies of different types of wastewater treatment. Natural technologies can be a problem for operators if little detail of the system is wrong designed. Same impact can also be neglected operation.

Photo 1: Constructed Wetland and Stabilization Pond for village wastewater treatment (source:www.mapy.cz, GEODIS, 2013)

Natural technologies are the most than for large producer frequently used for wastewater treatment and water management ranging from individual houses, recreational and the other facilities to the settlements up to 2,000 inhabitants (p.e.), smaller industrial plants, farms. Their use is also the question of the availability of affordable land.

The authors of the publication have been dealing with this issue for many years and they have had practical experience with the operation of the device in Europe. The range of knowledge is the result of long-time research investigation, experience from the implementation, operation and monitoring. Many solutions are original, adapted to the conditions close to the EU and CEE countries. The publication is written by the popularizing form, easy to understand even for laymen, it is supplemented by a number of instructive diagrams and pictures. It includes case studies and photo documentation as well.

The crucial task of the publication is to inform the professional public, especially investors of devices for treatment of polluted surface water and mainly wastewater, project architects proposing natural technologies of wastewater treatment, operators of these facilities, professionals and the non-professional public, secondary school and mainly university students of the relevant professional orientations with possibilities of application, principles of the design, operational technologies, maintenance and modernization of the older equipment.

Conventional methods of sewerage treatment by means of small domestic wastewater treatment plants are not the subject of this work; they are described into details in many other publications stated in the list of recommended literature.

The natural technologies of wastewater treatment use natural, commonly occurring self-treatment processes that take place in the soil, water and wetland environment. The vegetation is directly involved in the treatment process, especially by the formation of favourable conditions for the development of microorganisms involved in the treatment process, and simultaneous utilization of released plant nutrients for the biomass production.

The awareness of natural water treatment methods is not new conceptually; wastewater irrigation in arid regions has been used for several millennia. Artificial water ponds were built around the medieval towns, which, inter alia, fulfilled the function of waste stabilization ponds by means of treatment wastewater discharged from the towns, the use of natural treatment ability of wetlands etc. In the 19th century, many European towns cleaned wastewater on the filtration fields. In rural areas, you can still encounter the use of ponds and small reservoirs for uncontrolled improvement of the quality of polluted surface water, also containing discharged sewage water.

Nowadays, natural technologies of treatment do not just follow the historical tradition, but also continue in the development of treatment methods on a much higher qualitatively level. These days, the main focus in the EU states is especially devoted to smaller wastewater facilities in terms of the that use natural treatment methods maximally up to the 1000-2000 inhabitants population equivalent (p.e.) although there are much larger facilities, mainly focused on the treatment of mechanical-biological cleaned wastewater.

Natural technologies of wastewater treatment are especially represented by soil filters (SF), constructed treatment wetlands (CTW) and waste stabilization ponds (WSP) that have been used in the last thirty years. Relatively considerable effort is devoted to the possibility of using aquatic plants systems in different arrangements. The recent findings are presented at seminars and conferences, especially at international congresses regularly organized by the professional groups of the organization IWA (www.iwahq.org).

In the introduction to the publication, attention is paid to the characteristic of various types of wastewater, its quantity and composition, methods of collection, storage and the necessary pretreatment. The introductory part of this publication is followed by the outlining of the characteristics of different natural ways of treatment, design principles and possibilities of reuse of treated wastewater. The authors present their advantages and weaknesses that need special attention.

The typical arrangement of wastewater treatment plants, using natural treatment, is currently undergoing considerable changes; the arrangement is modernized and supplemented by devices designated for the removal of phosphorus, ammonia, nitrate, microbial contamination and heavy metals etc. The problems of sanitary runoff provision, the principles of wastewater discharge into watercourses, infiltration of treated wastewater in the ground, design and layout of drainless systems is processed separately.

The solution of wastewater treatment plants using natural systems is closely related to the design and layout of waste management, i.e. the methods and ways of handling liquid and solid waste. Consequently, a part of this publication is dedicated to the description of the methods and procedures of managing of liquid and solid waste produced by these systems with detailed focus on the usage of biomass of macrophytes, drainage of solid waste by reed beds, and their use for the quality compost production.

A chapter is focused on the determination of the effects of wastewater and runoff water on the environment and the propitious integration of particular devices into the landscape.

An essential part of the solution is to apply appropriate monitoring, including selection of suitable indicators of the treatment processes, and the way of to assess efficiency of various treatment process in a wastewater treatment plant. Emphasis is placed on the principles of operating of natural treatment methods.

A significant parts of the publication deals with the description of the construction preparation, necessary surveys, design, construction and final inspection of the devices. Selected legislations are processed in the summary based on the questionnaire survey GWP CEE in 2012 (Bodík et al., 2012) and supplemented by the provisions applicable to individual EU states.

The publication is accompanied with a literature list of the used and recommended literature in order to expand the knowledge of the problems faced in the design, construction and operation of natural technologies of wastewater treatment.

# 3 Types of Wastewater, its Quantity and Composition

The various kinds of wastewater, which can be treated by means of natural treatment methods are municipal wastewater, polluted storm water runoff, selected industrial, agricultural and ballast water. The quantity and composition of individual types of wastewater are considerably different. This depends on many factors, and can be calculated and evaluated from the wide range of inquiries for the particular locality.

## 3.1 Typical Municipal Wastewater Quantity

The production of wastewater, according to most standards in the EU, ranges from 0.1 to 0.15 $m^3.d^{-1}$ per capita. To gain access to more accurate local data, more direct examinations are needed. In general, estimations are made based on assessment of the average daily water consumption by inhabitants, in the industry per unit of the manufactured product. According to BS 8525-1:2010 (2010), the average daily water consumption of one person is, for various activities: drinking and cooking 3 $l.d^{-1}$, personal hygiene 9 $l.d^{-1}$, dishwashing 9 $l.d^{-1}$, bathing and showering 44 $l.d^{-1}$, car wash 3 $l.d^{-1}$, watering gardens 11 $l.d^{-1}$, laundry 17 $l.d^{-1}$, flushing toilets 46 $l.d^{-1}$ and other 8 $l.d^{-1}$.

The direct consumptions of water for various purposes (activities) were evaluated from the published data in the Czech Republic and the neighboring countries. These average values are listed in the Table 3.1.

Tab. 3.1 Indicative Average Data of the Direct Water Consumption per Person per Day

| Usage | Person $l.d^{-1}$ | Usage | Person $l.d^{-1}$ | Usage | Person $l.d^{-1}$ |
|---|---|---|---|---|---|
| Drinking and cooking | 4 - 8 | Dishwashing | 8 - 20 | Flushing toilets | 30 - 45 |
| Personal hygiene | 8 - 12 | Laundry | 14 - 20 | Treatment | 4 - 8 |
| Bathing, showering | 30 - 60 | | | Miscellaneous | 6 - 12 |
| Total | 42 - 80 | | 22 - 40 | | 40 - 65 |

According to table 3.1 The water consumption in ranges between 104 – 185 l per person per day. The above stated indicative information will enable evaluation of the quantity of produced wastewater. The information on water consumption in the field of GWP CEE summarizes the questionnaire survey conducted in 2012 (Bodík et al., 2012).

## 3.2 Typical Municipal Domestic Wastewater Composition

To assess the local wastewater composition municipal, is necessary to perform surveys and even sampling of the targeted locality. Consequently, to accurately determine the composition of the wastewater, the most appropriate method is to sample, for at least a 24-hour period, including seasonal samples that should include the wet and dry weather seasons. It is crucial to determine the initial composition of the precipitation outflow, and the initial composition of the sewer system flow. The average composition of domestic wastewater water is listed in Table 3.2 a, b.

Lens et al., (2001) divide wastewater from households into grey (from showers, sinks, bathrooms, laundry), yellow (urine), and black (sum of urine, faeces and flush water); their characteristics are listed in Table 3.3. Reuse of Grey water, especially from the bathrooms, is possible after water treatment, as process water (so-called white water) for flushing toilets and urinals and watering gardens.

Tab.3.2a Indicative Data of Wastewater Contamination (Pitter, 2009)

| Type of Contamination | Substances (g .d$^{-1}$. person$^{-1}$) | | | |
|---|---|---|---|---|
| | mineral | organic | total | $BOD_5$ |
| Suspended solids | 10 | 30 | 40 | 20 |
| Non-settleable | 5 | 10 | 15 | 10 |
| Dissolved substances | 75 | 50 | 125 | 30 |
| Total | 90 | 90 | 180 | 60 |

Tab.3.2b Indicative Data of Specific Pollution Production (g.d$^{-1}$) per one capita (Pitter, 2009)

| Substances | Miner. | Organ. | Total | $BOD_5$ | COD | TN | TP |
|---|---|---|---|---|---|---|---|
| Suspended solids | 10 | 30 | 40 | 20 | 40 | 1 | 0.2 |
| Non-settleable | 5 | 10 | 15 | 10 | 20 | - | - |
| Dissolved substances | 75 | 50 | 125 | 30 | 60 | 10 | 2.3 |
| Total | 90 | 90 | 180 | 60 | 120 | 11 | 2.5 |

The group of grey water consists of: unseparated grey water, grey water from kitchens and dishwashers, washing machines and grey water from wash basins, bathtubs and showers. The production of grey water in households is approximately 55 % and in commercial buildings about 27 % of the total production of wastewater. The quantity of generated grey water varies according to places of their origin from 57 to 111 liters per person per day – for village households can be used rather lower values.

Tab. 3.3 Composition of household wastewater in kg per person and year according to Lens et al. (2001)

| Type of water | COD | N | P | K |
|---|---|---|---|---|
| Black | 27 | 4.4 | 0.7 | 1.3 |
| Grey | 20 | 0.7 | 0.2 | 0.3 |
| Yellow | 5.5 | 4.0 | 0.5 | 0.9 |
| Mixed wastewater | 47 | 5.1 | 0.9 | 1.6 |

## 3.3 Surface Runoff

If the agglomeration collects water using an combined sewer system, it is important that precipitation and runoff data is taken into account when designing a natural WT is the knowledge of the quantity and composition of surface runoff that is flowing into the WWTP by means of combined sewage systems. These will significantly influence the total quantity and composition of influent, which must be respected by hydraulic and pollution load calculation of the wastewater treatment plant.

### 3.3.1 Stormwater Quantity of Precipitation Water

The inflow of precipitation water Q is determined from the general relation:

$$Q = \psi \, . \, S_s \, . \, q_s \quad (10^{-3} m^3 s^{-1}) \tag{3.1}$$

where

$\psi$ is outflow coefficient

$S_s$ – catchment area (ha)

$q_s$ – design rainfall intensity with the considered periodicity P (l s$^{-1}$ ha$^{-1}$), for settlements up to 5,000 inhabitants with unified sewage system p=1. The features of outflow coefficients according to CSN 75 6101 are stated in Table 3.4.

Tab. 3.4. Outflow Coefficients y According to the CSN 75 6101 (Indicative Data)

| Form of Housing Development and Type of Land | | Outflow Coefficient ψ When Configuring the Area (-) | | |
|---|---|---|---|---|
| | | Flat (to 1 %) | Sloping (1 to 5 %) | Steep Sloping (Above 5 %) |
| Buildings | In Closed Blocks [1)] | 0.70 | 0.80 | 0.90 |
| | In Closed Blocks [2)] | 0.60 | 0.70 | 0.80 |
| | In Open Blocks | 0.50 | 0.60 | 0.70 |
| | In Free Housing Development | 0.40 | 0.50 | 0.60 |
| Houses | Associated in Gardens | 0.30 | 0.40 | 0.50 |
| | Isolated in Gardens | 0.20 | 0.30 | 0.40 |
| Factory Units | older (dense housing development) | 0.50 | 0.60 | - |
| | new (less dense housing development) | 0.40 | 0.50 | - |
| Paved Roads (asphalt, concrete, pavement) | | 0.70 | 0.80 | 0.90 |
| Unpaved Roads (gravel) | | 0.50 | 0.60 | 0.70 |
| Railway | | 0.25 | - | - |
| Cemeteries, orchards, playgrounds | | 0.10 | 0.15 | 0.20 |
| Green strips, fields, meadows | | 0.05 | 0.10 | 0.15 |
| Forests | | 0.00 | 0.05 | 0.10 |

*Note: [1)] paved or developed courtyards, [2)] inside the block of garden*

The required figures about rainfall are obtained by means of evaluation of ombrometric and ombrographic (precipitation-measuring) observations from the nearest precipitation-measuring stations.

Specific annual storm water runoff from hard surface areas V ($m^3.r^{-1}.m^{-2}$) is calculated from the relation

$$V = 10^{-3}.\ \phi_r.H_r \qquad (3.2)$$

where

$\phi_r$ - reduced outflow coefficient, for the lack of exact measurements, the figure of unreduced outflow coefficient $\phi$ is used

$H_r$ – reduced precipitation amount (mm), which is determined by subtraction from annual precipitation amount of rainfall smaller than 1 $mm.d^{-1}$

The figures of outflow coefficient $\phi$, according to previous research realised at Faculty of Civil Engineering University of Technology (Brno, Czech Republic), ranged from 0.75 to 0.85 at sloping roofs according to the type of roof covering, the slope and exposure, lower figures were at unglazed clay tiles, higher figures were at glazed and metal materials. At flat roofs well sealed, the outflow coefficient is in the range of 0.65 to 0.75. It is determined individually, according to arrangement at green roofs.

### 3.3.2 Composition of Stormwater

The composition of stormwater is considerably different; it depends on the contamination of precipitation by immissions, the surface structure and its contamination, the intensity and storm duration and precipitation water amount etc. The average figures of the outflow composition of precipitation water detected in Germany by Boller and Höflinger (1996) are presented in in the Table 3.5.

Tab.3.5 Content of Heavy Metals in Surface Roof and Road Runoff

| Parameter | Unit | Stormwater | Roof runoff | Road runoff |
|---|---|---|---|---|
| Dry Matter | $mg.l^{-1}$ | 10 | 63 | 289 |
| Cadmium (Cd) | $\mu g.l^{-1}$ | 2.6 | 0.61 | 5.3 |
| Copper (Cu) | $\mu g.l^{-1}$ | 12 | 446 [1)] | 115 |
| Lead (Pb) | $\mu g.l^{-1}$ | 43 | 85 | 318 |
| Zinc (Zn) | $\mu g.l^{-1}$ | 89 | 5589[2)] | 478 |

*Note: [1)] roof covering is formed by copper sheet [2)] roof covering is formed by galvanized or more precisely zinc sheet*

## 3.4 Industrial Wastewater

In industrial areas they are different types of wastewaters:

- Sewage water from employees. Its quantity is given by the consumption; the quality corresponds with sewage water from small settlements and towns - treated separately
- Stormwaters - It can be characterized by precipitation, captured in the catchment area, which must be drained; its contamination depends on the purity of the catchment area
- Technological water, removed from the manufacturing process, its quantity and composition is given by the diversity of production (water consumption per unit of production)
- Cooling water is relatively clean and is often recirculated, the part of water is gradually drained from the cooling circuit at some devices
- Water in energetic systems is always recirculated but the system produces waste from the additional water treatment, which contains high concentrations of minerals

## 3.5 Agricultural Wastewater

Agricultural Wastewater is formed through:

- Sewage water from toilets, bathrooms, kitchens produced by employees
- Technological water from separate rooms used for storing tanks with cow milk, feed ; preparation rooms, treatment machinery and vehicles, etc.
- Wastewater from livestock production, especially liquid manure, slurry, silage water etc.
- Runoff water from courtyards, yards, etc.
- Wastewater from aquacultures (fish or other aquatic animals farming, etc.)

## 3.6 Ballast Water

Ballast (extraneous) water enters the sewer system through leaks. The quantity and composition of ballast water vary considerably and depend on the condition of the sewer system, the height of the water table, its variations, object leaks, illegal connections of drainage water etc. The determination of the quantity and composition of ballast water requires a detailed survey of the above-mentioned factors. In many cases, ballast water can influence the function of the sewer system and wastewater treatment plant, adversely increases the quantity and composition of the wastewater. It is recommended to establish baseline water quality parameters (undissolved substances, specific electrical conductivity of water, organic pollution, ammonia and total nitrogen, phosphorus), as well as complementary indicators (sulphate, nitrate) that may affect the treatment effect, especially at constructed wetland wastewater plants and soil filtration. The higher levels of sulphates can cause subsequent corrosion of concrete objects, after the passageway of water through anaerobic environment of sewage objects.

### 3.7 Process water

With regard to the ongoing trend of separation and recycling of wastewater, it is also possible to mention the category of so-called process water. Process water is normally used for flushing toilets, watering gardens, respectively washing. The need for water for flushing toilets in households is about 30 % and commercial buildings up to 60 %. The need for process water for various applications in the different buildings is listed in Table 3.6.

Tab.3.6 Need for Process Water for Different Utilization in the Building (using DIN 1989-1)

| Utilization Method of Process Water | Process Water Need | |
|---|---|---|
| | Economical Measure | Non-Economic Measures |
| Toilets in Households | 24 l (person per day) | 45 l (person per day) |
| Toilets in the Administrative Building | 12 l (person per day) | 22 l (person per day) |
| Toilets at School | 6 l (person per day) | 12 l (person per day) |
| Washing Machine in the Household | 12 l (person per day) | 20 l (person per day) |
| Garden Watering | about 1.0 $l/m^2$ (on the area of the whole garden, even if just part of it is watered) | |

# 4 Management of Sewage and Stormwater Runoff

The aim of drainage is to establish complete connection and the fastest drainage of wastewater from the area of interest through a gravity driven pipe network. The individual solution is determined by means of the economic analysis, and the comparison of available options, including decentralized or centralized sewage treatment. The centralized solution assumes a formation of the sewer system that carry wastewater to one wastewater treatment plant designed for the entire area of interest addressed. The decentralized one is based on wastewater treatment in multiple small treatment plants. In specific cases, after the economic analysis, it is possible to build the sewage system from the sumps in the central wastewater treatment plant, as the alternative solution to the decentralized system of multiple wastewater treatment plants.

### 4.1 Sewage Systems

Wastewater inflow is provided by combined, separated or modified sewer systems working on the principle of gravity, pressure (hydraulic, respectively pneumatic) and vacuum (vacuum sewerage). The combined sewer system requires prepending at least one relief chamber, pumping equipment etc. for the separation of precipitation water in front of the wastewater treatment plant on the sewage network. The arrangement of the combined sewer system (network) is shown in Figure 4.1, the built with separate sewer system (network) in Figure 4.2.

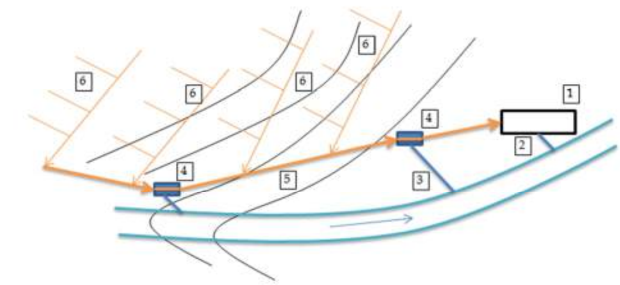


Figure 4.1 Combined Sewage System
*1 – WWTP, 2 – Treated water outflow, 3 – Separated stormwater outflow, 4 – Overflow structure, 5 – Main sewer, 6 – Urbanized areas sewer*

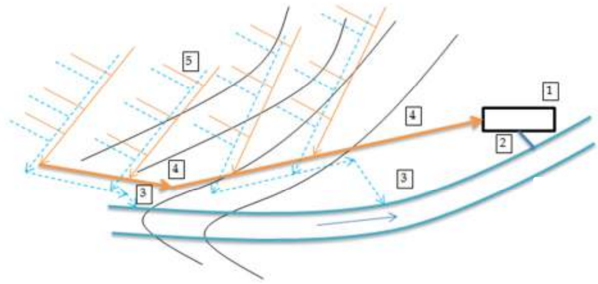


Figure.4.2 Built with Separate Sewer System

*1 – WWTP, 2 – Treated water outflow, 3 – Stormwater outflow, 4 – Main sewer, 5 – Urbanized areas sewer*

20 % that is water for washing roads, irrigation, etc. The average and maximum daily dry weather intake $Q_{24}$, $Q_d$ according to CSN 75 6401 is calculated as

$$Q_{24} = Q_{24M} + Q_{24P} + Q_B \quad (4.1)$$
$$Q_d = Q_{24M} \,.\, k_d + Q_{24P} \,.\, k_{dp} + Q_B \quad (4.2)$$

where
$Q_{24M}$ - average daily dry weather inflow of wastewater from the city
$Q_{24P}$ - average daily dry weather inflow of wastewater from processing industries
$Q_B$ - average daily inflow of ballast water
$k_d$ - daily inequality coefficient is for municipalities to 1,000 inhabitants 1.5; from 1,000 to 5,000 inhabitants 1.4; from 5, 000 to 25, 000 inhabitants 1.35
$k_{dp}$ – daily inequality coefficient in industry

Daily calculated (designed) inflow $Q_v = Q_d$ . Maximum hourly dry weather inflow $Q_h$ is calculated from the equation (4.3) and (4.4) and the data which gives higher values is applied.

$$Q_h = (Q_{24M} \,.\, k_d \,.\, k_h + Q_{24P} \,.\, k_{dp}) / 24 + Q_B \quad (4.3)$$
$$Q_h = (Q_{24M} \,.\, k_d + Q_{24P} \,.\, k_{dp} \,.\, k_{dh}) / 24 + Q_B \quad (4.4)$$

where
$k_h$ - maximum hourly inequality coefficient according to CSN 75 6401; displayed in Tab. 4.1,
$k_{dh}$ - daily inequality coefficient for industrial wastewater

Tab. 4.1. Maximum Hourly Inequality Coefficients $k_h$ (CSN 75 6401)

| Amount of Joined Inhabitants | 30 | 40 | 50 | 75 | 100 | 300 | 400 | 500 |
|---|---|---|---|---|---|---|---|---|
| Maximum Hourly Inequality Coefficient | 7.2 | 6.9 | 6.7 | 6.3 | 5.9 | 4.4 | 3.5 | 2.6 |
| Amount of Joined Inhabitants ($x.10^3$) | 1 | 2 | 5 | 10 | 20 | 30 | 50 | 100 |
| Maximum Hourly Inequality Coefficient | 2.2 | 2.1 | 2.0 | 2.0 | 1.9 | 1.8 | 1.7 | 1.5 |

## 4.2 Storm Water and Surface Runoff

In catchment areas with natural vegetation cover, the majority of the volume of precipitation water in natural environment infiltrates the soil, however, approximately 10 - 13 % flows away the surface. On the contrary, urbanized areas are specific by high proportion of impermeable surfaces (roads, courtyards, roofs), which in their centres reach 60 - 85 % of the total area. Falling precipitation water, consequently, cannot naturally infiltrate groundwater– see Figure 4.3.

Precipitation outflow from roofs, collected in gutters and by downpipes, is distributed either into the storm sewer (if any), or to accumulation and infiltration facilities, the treatment unit and storage reservoir if it is intended to be used.

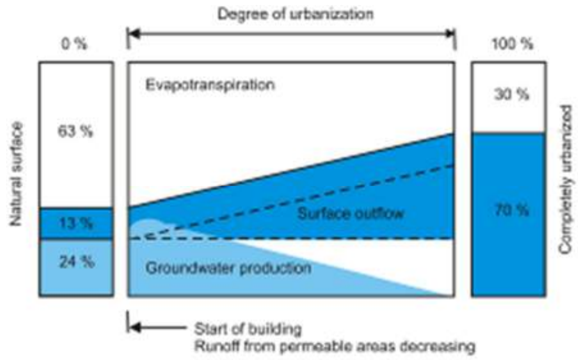



Figure 4.3 Rainwater Outflow Depending on the Degree of Urbanization Development (DWA-M153, 2007)

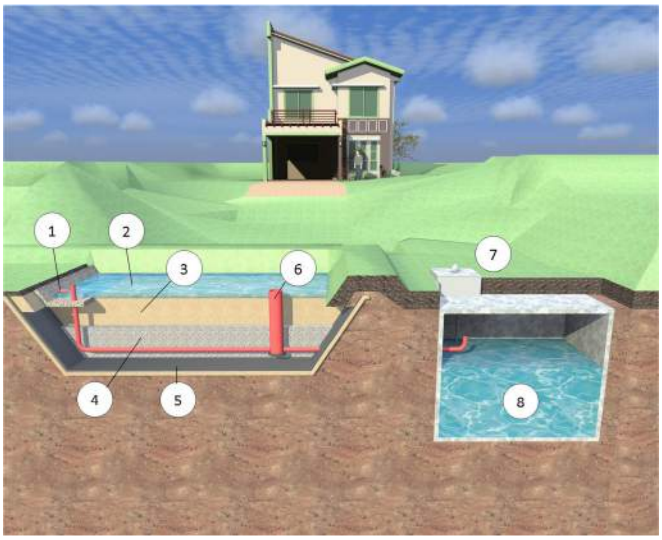
Fundamental methods for the management of storm water by Claytor (2000) are based on:

- Redevelopment of existing drainage facilities and construction of new precautions at the end of existing sewer draining precipitation water
- Use of existing ditches to divert surface outflow or their conversion to provide partial retention and sedimentation
- Arrangement of the edges of large paved areas so that surface outflow was directed to the lawn, in replacement of impermeable surfaces for permeable
- Use of green roofs on the buildings, utilizing 40-60 % of precipitation water
- Application of decentralized retention in individual buildings

## 4.2.1 Use of Precipitation Water

Precipitation outflow is used for washing, flushing toilets, household treatment, watering of gardens and green areas etc. Different ways of further use require:

- Removal of coarse impurities on self-treatment gradient sieve filter
- Capture of settleable substances in the vertical or lamellar settlement tank
- Removal of superfine impurities by filtration through mechanical filters
- Disinfection by UV radiation




Precipitation water treatment on the modified soil filter belongs to the simplified facilities. The example of a simple ground filter with the retention area is shown in Table 4.4.

Figure 4.4 Scheme of Soil Filter used for Simple Precipitation Water Treatment: 1- precipitation water inflow, 2- retention area of filter, 3-filtration environment, 4- perforated collecting environment, 5-sealing foil, 6-precipitation water, 7-inspection manholes, 8-entrance into the storage reservoir with vent chimney

More advanced treatment methods are not used on a larger scale. UV emitters are applied for the disinfections (sanitation) of precipitation water, during its use for washing, flushing and bathing.

Treated precipitation water accumulates in aboveground and underground storage reservoirs (storage tanks, cisterns) of different configuration. Storage reservoirs are designed enclosed, covered and open; tanks are made of standard plastic parts (polypropylene, fibreglass, polyethylene), concrete, steel, etc. The arrangement of ground open storage reservoir is shown in Figure 4.5.

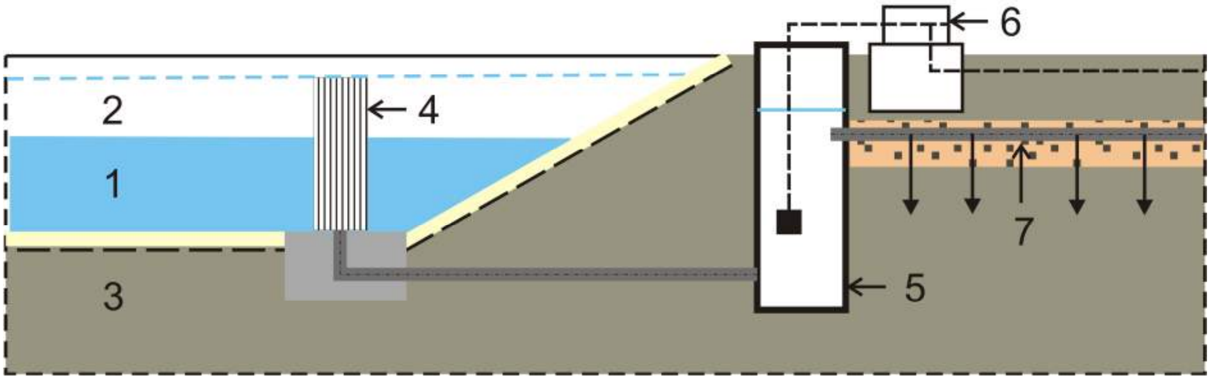



Figure 4.5 Arrangement of Ground Sealed Storage Reservoir: 1-sump, 2-retention area,3-sealing by plastic foil and protective geotextile,4- outlet and sampling equipment with soft bar screens and pivot cap, 5-suction sump, 6-pump aggregate, 7-infiltration perforated pipeline for excessive outflow (Šálek and Tlapák, 2006)

### 4.2.2 Infiltration and Retardation of Precipitation Outflow

Another possibility of the precipitation outflow utilization is its infiltration into the soil and thereby increasing of groundwater addition. The basic types of infiltration facilities consist of:

- Shallow surface infiltration from settlement tanks (artificial infiltration area)
- Natural infiltration furrows (natural terrain depression)
- Artificial infiltration grooves, infiltration trenches
- Infiltration system which is a combination of furrow - groove
- Artificial infiltration pit (well)
- Artificial infiltration small water reservoir
- Small water reservoirs with retention area and bank infiltration
- Controlled wetland with a defined infiltration area

The selection and use of various facilities depends on the marginal conditions of the site, which are favorable hydrogeological conditions, especially sufficient underground space and its capacity for precipitation water infiltration, infiltration capacity of the soil, the position of the groundwater level, the extent of precipitation water contamination, spatial conditions, etc.

This issue is processed in series of technical standards:

- CSN 75 9010 Vsakovací zařízení srážkových vod. Praha: 2012.
- DWA _ Regelwerk. Planung, bau und Betrieb von Anlagen zur versickerung von Niederschlagwasser,Arbeitsblatt DWA-A 138, 2005.
- DWA _ Regelwerk. Bauwerke der zentralen Regenwasserbehandlung und Rückhaltung- Konstruktive Gestaltung und Ausrüstung. Arbeitsblatt ATW-166,1999.
- ÖNORM B 2506-1. Regenwasser-Sickeranlagen fur Abläufe von Dachflächen und befestigten Flächen. Teil 1, Anwendung, hydraulische Bemessung, Bau und Betrieb.
- ÖNORM B 2506-1. *Regenwasser-Sickeranlagen fur Abläufe von Dachflächen und befestigten Flächen. Teil 2*, Qualitative Anfoederungen and das zu vesickernde Regenwasser, Bau und Betrieb von Reinigungsanlagen.
- VSA: Regenwasserentsorgung: Richtlinie zur Versickerung, Retention und Ableitung von Niederschlagwasser in Siedlungsgebieten, 2002.

In practice, the combination of infiltration with dual accumulation of precipitation water outflow in an open ditch (furrow) and soil environment (groove filled with filter material) is increasingly applied. Moreover, in the process of filtration via porous filter environment of soil water is cleaned – Photo 2a,b.

At the end of the furrow there is a regulation pit into which the inlet of the perforated sewage pipeline. It is located on the bottom of the groove, equipped with transverse inverted filter and on the outflow site by regulation screen. In front of the regulation screen, at the end of the sewage pipeline, there is the pipe spillway shaft connected and discharged, providing water outflow from the filled furrow.

Runoff pollution potential for the different roof material can be defined as following:

- Negligible, or zero potential: green roofs, glass, roofing tiles
- Low potential: concrete covering, artificial plastic material
- Middle potential: asphalt, fibered concrete
- High potential: Cu-, Zn-, Pb-roof sheets, asbestos

In Table 4.2., the summary of the results of a two-year monitoring process of car parks built in the frame of Masaryk University Campus in Brno are outlined. The values of contamination from concrete surfaces washed off car parks after a year were compared with the values of seepage water, after its filtration through the device of retention units – furrows with the filtration layer of a mixture of sand and soil.

Photo 2a,b: Monitoring of the process of infiltration in the combined infiltration-retardation furrow – groove to drain precipitation water from the car park (Czech Republic, Brno, Masaryk University Campus, 2009)

Tab. 4.2. Range of Values of Selected Contamination Water Indicators observed for roofs runoffs (based on DWA, ÖNORM, VSA & CSN mentioned above).

| Parameter | Unit | Sloping roofs | Flat roofs with a gravel-sand layer |
|---|---|---|---|
| pH | --- | 5.5 – 7.7 | 5.5 – 7.9 |
| Total organic carbon TOC | $mg.l^{-1}$ | 5 –10 | 5 – 10 |
| Suspended solids | $mg.l^{-1}$ | 15 – 40 | 2 – 5 |
| Chlorides ($Cl^-$) | $mg.l^{-1}$ | 0.3 - 30 | 0.3 - 30 |
| Total nitrogen (TN) | $mg.l^{-1}$ | 1.5 – 5 | 3 - 5 |
| Total phosphorus (TP) | $mg.l^{-1}$ | 0.08 – 0.15 | 0.02 – 0.05 |
| Cd | $\mu g.l^{-1}$ | 0.1 - 0.7 | 0.05 - 0.1 |
| Cr | $\mu g.l^{-1}$ | 0.5 – 6 | 0.3 – 0.6 |
| Hg | $\mu g.l^{-1}$ | 0.05 – 0.1 | 0.05 – 0.1 |
| Ni | $\mu g.l^{-1}$ | 1 – 6 | 1 – 6 |
| Cu | | | |
| Roof without Cu-accessories | $\mu g.l^{-1}$ | 15 – 50 | 15 - 25 |
| Roof with Cu-accessories | | 100 - 300 | 100 - 300 |
| Roof with Cu sheets | | 800 - 2000 | - |
| Zn | | | |
| Roof without Zn-accessories | $\mu g.l^{-1}$ | 20 - 70 | 10 - 40 |
| Roof with Zn-accessories | | 50 - 200 | 50 - 200 |
| Titanium-Zn - roof | | 1000 - 4000 | - |
| Pb | | | |
| Roof without Pb-accessories | $\mu g.l^{-1}$ | 10 - 30 | 2 - 10 |
| Roof with Pb-accessories | | 100 - 300 | - |
| Roof with Pb sheets | | 5000 - 7000 | - |

Tab. 4.3. Range of Values of Selected Contamination Water Indicators observed for parking lots runoffs (based on Hlavínek et al., 2007 and Rozkošný et al., 2010)

| Parameter | Unit | Concrete cover or pavement |
|---|---|---|
| pH | --- | 6.5 – 8.5 |
| Chlorides ($Cl^-$) | $mg.l^{-1}$ | 2 – 2000 |
| Oil substances (C10 – C40) | $mg.l^{-1}$ | < 0.02 – 1.5 |
| Σ PAH | $ng.l^{-1}$ | 4 – 200 |
| Cd | $\mu g.l^{-1}$ | < 0.1 – 1.5 |
| Cr | $\mu g.l^{-1}$ | < 1 – 40 |
| Cu | $\mu g.l^{-1}$ | 2 – 70 |
| Hg | $\mu g.l^{-1}$ | < 0.05 – 0.8 |
| Ni | $\mu g.l^{-1}$ | < 1 – 30 |
| Pb | $\mu g.l^{-1}$ | < 0.5 – 20 |
| Zn | $\mu g.l^{-1}$ | 2 – 300 |

Tab. 4.4. Range of Values of Selected Contamination Water Indicators observed for road runoffs (based on Hlavínek et al., 2007 and Rozkošný et al., 2010).

| Parameter | Unit | Concrete cover or pavement |
|---|---|---|
| pH | - | 7.0 – 8.0 |
| Chlorides ($Cl^-$) | $mg.l^{-1}$ | 5 – 15 000 |
| Oil substances (C10 – C40) | $mg.l^{-1}$ | < 0.02 – 4 |
| S PAH | $ng.l^{-1}$ | 4 – 300 |
| Cd | $\mu g.l^{-1}$ | < 0.1 – 7 |
| Cr | $\mu g.l^{-1}$ | < 1 – 120 |
| Cu | $\mu g.l^{-1}$ | 2 – 500 |
| Hg | $\mu g.l^{-1}$ | < 0.05 – 1.5 |
| Ni | $\mu g.l^{-1}$ | 2 – 300 |
| Pb | $\mu g.l^{-1}$ | < 0.5 – 400 |
| Zn | $\mu g.l^{-1}$ | 2 – 3000 |

### 4.2.3 Combination of Small Water Reservoirs with Infiltration of Precipitation Water

The method that has been neglected so far is the use of small water reservoirs with defined retention (protective) area and shoreline infiltration, or, alternatively an additional infiltration area with wetland plants. Wetland with appropriate management is a suitable alternative for this purpose; the impact of water quantity in outflow is intensified by high evapotranspiration. An example of the layout of the small water reservoir with bank infiltration is shown in Figure 4.7.

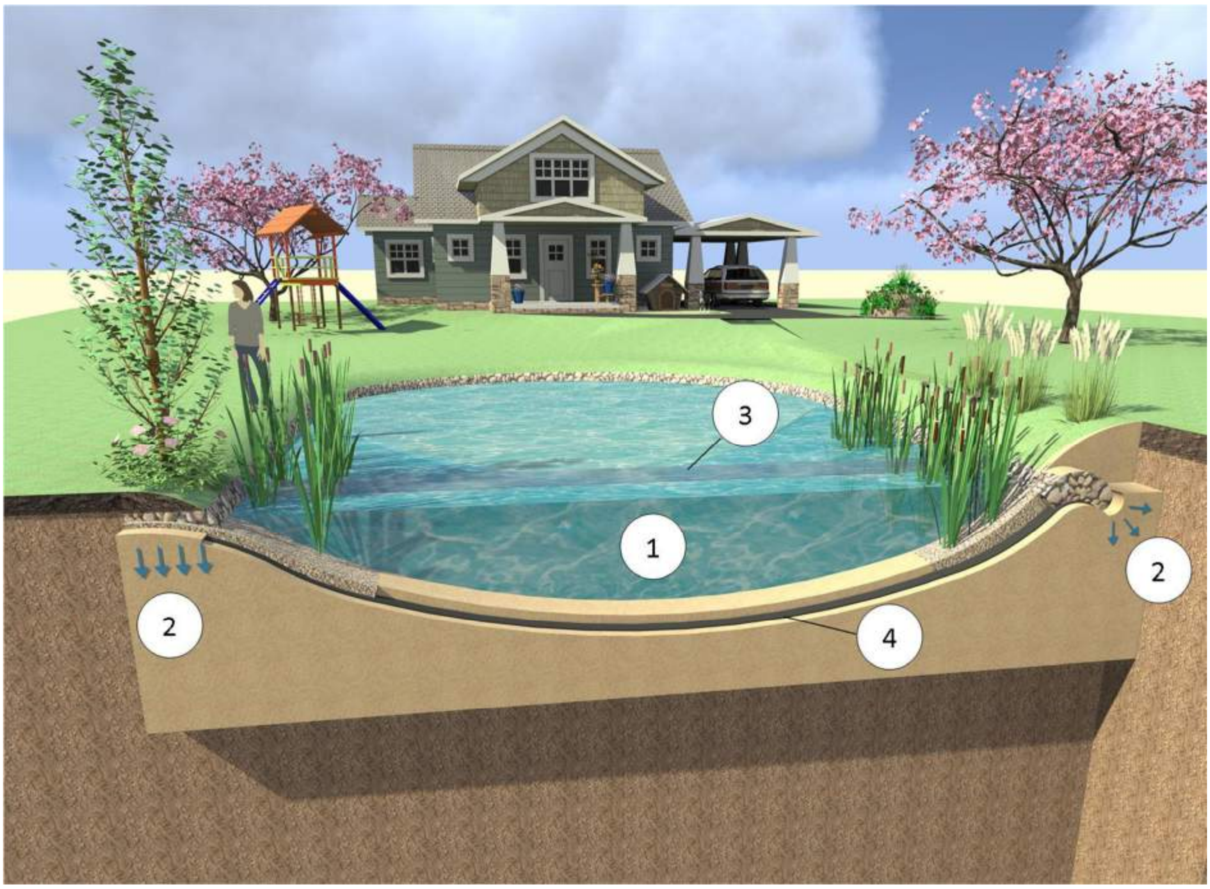



Figure 4.7 Small Water Reservoir with Retention Space and Bank Infiltration. *(Retention space = area where it is possible to move water level)*

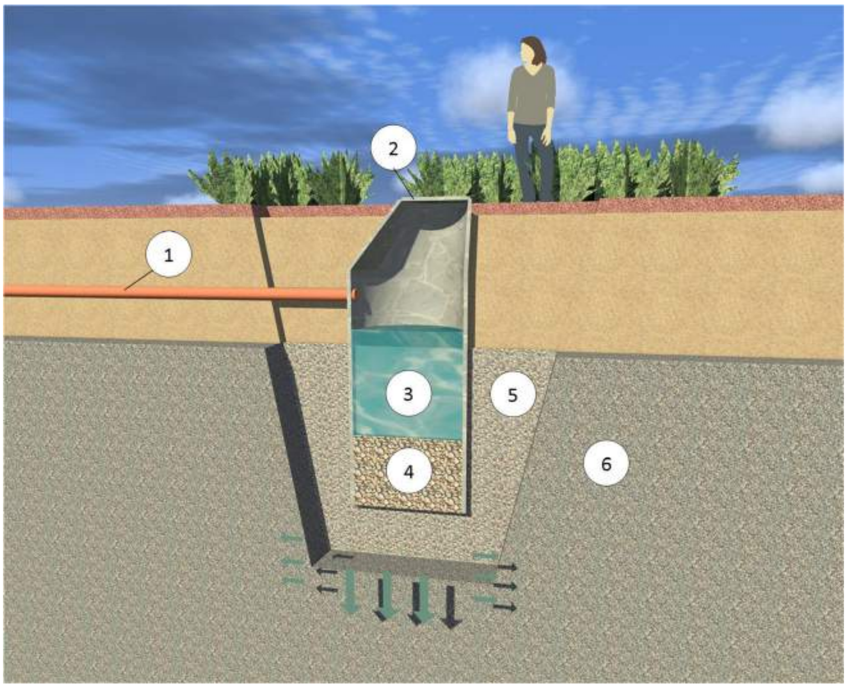



Figure 4.8 Storage Precipitation Water Reservoir with Attached Wetland Filtration Zone

In Figure 4.8, there is a small water reservoir, similar to the previous solutions, equipped with a retention area, supplemented by an infiltration area with macrophytes, ensuring water infiltration from the retention area and evapotranspiration.

# 5 Natural Technologies of Wastewater Treatment

Natural technologies of wastewater treatment use modified natural self-treatment processes that take place in the ground soil, water and wetland environment. These ways of treatment are classified according to the treatment technology and general arrangement. A brief summary of particular natural treatment ways is given in Table 5.1.

In the case of the use of natural methods for wastewater treatment, it is necessary to pay special attention to the process of pretreatment, which means removal of suspended solids. It is also necessary to prevent washing away insoluble substances and formed sludge further on the equipment for biological water treatment (soil filters, constructed wetlands, stabilization ponds) by means of the proper design (adequate dimensioning) and the proper operation as well as maintenance of mechanical pretreatment facilities.

The main design principles of mechanical pretreatment:

- Sufficient dimensions of devices (screens, sand traps, grease traps, biological septic tanks and sedimentation tanks).
- To ensure sufficient retention time even at higher flow rates associated with runoff (combined sewer).
- Simplicity of operation
- Appropriate sludge and waste management
- Good access to different parts of structures to allow regular maintenance.
- Covering of sedimentation space at sedimentation tanks – not to allow the development of algae in water (formation of secondary pollution); covering is not necessary at sand traps where there is sufficient flow and short retention time of water.

Tab. 5.1 Use of Natural technologies of Treatment

| Type | Possibilities of the Use in Facilities |
|---|---|
| a) Soil (ground) filters | |
| Vertical flow without vegetation | Treatment of stormwater and sewage of smaller and middle producers |
| Horizontal flow without vegetation | |
| b) Constructed treatment wetland | |
| Horizontal surface, combination of surface and horizontal subsurface flow | Wastewater and contaminated surface water treatment in favourable climatic conditions |
| Horizontal subsurface flow | Sewage treatment; year-round operation |
| Vertical flow downwards | |
| Vertical flow up | Wastewater Treatment, predominantly in the summer |
| Vertical flow with intermitted flow | Sewage treatment; year-round operation |
| c) Waste Stabilization Ponds | |
| Aerobic low-loaded | Surface runoff and wastewater treatment |
| Aerobic high-loaded | Wastewater treatment in climatic favorable areas |
| Aerobic continuously with aeration | Intensive wastewater treatment, continuous aeration |
| Final purification | Final treatment of wastewater after biological treatment steps |
| Anaerobic | Anaerobic treatment pre-ranked aerobic treatment |
| Anaerobic storage | Wastewater treatment of campaign producers |
| d) Aquatic plants systems and Bioeliminators | |
| Pond and aquatic plants systems | Wastewater treatment and treatment by means of duckweed, algae, cyanobacteria |
| Combination of aquaculture with aquatic plants systems | Municipal and Industrial wastewater treatment |
| Bioeliminators | Wastewater treatment tanks with submersed meshes for algae biomass attaching |
| e) Irrigation by wastewater (minimally mechanically treated) | |
| Irrigation by municipal wastewater | Growing season irrigation or annual irrigation |
| Irrigation by industrial wastewater | Growing season operation or non-growing season irrigation |
| Irrigation by agricultural wastewater | Vegetation irrigation by silage and process wastewater |
| Irrigation by liquid sludge and slurry | Utilization of fertilizing effect of liquid waste |
| Evapotranspiration systems with zero discharge | Vegetation (usually willow) irrigation in on controlled bed by municipal wastewater |

## 5.1 Different types of natural treatment methods

Natural treatment methods are mainly used for wastewater treatment from decentralized houses, small settlements, dwelling, hotels, recreational facilities, restaurants and summer camps, smaller municipalities or their parts, usually up to 2000 p.e. According to the composition of wastewater, these methods are also applicable for treatment of industrial wastewater from the food processing industry, trade facilities (workshops) and selected small industrial plants, landfill leachate treatment, organically low-loaded agricultural runoff and wastewater agricultural facilities, polluted storm water runoff, erosion washes of polluted surface water.

Wastewater with high organic content of and high load of fats, oils, oil derivatives, extremely acidic or alkaline mine water, extremely polluted water from roads and car parks and industrial wastewater containing toxic substances exceeding the limits of toxicity, wastewater with the excessive content of surfactants, pesticides, radioactive substances, wastewater from hospitals, veterinary facilities, rendering plants, etc. are without pretreatment (treatment) inappropriate to unusable for natural technologies of treatment. The summary of the use of these methods of water treatment can be found in the literature Kadlec and Wallace, 2009; Liénard et al., 2004.

## 5.2 Advantages of Natural Technologies

The advantages of natural treatment methods lie mainly in the natural character of the sewage facility, the possibility of its inclusion in a favourable environment, in relatively simple technological implementation, lower operating costs, investment costs comparable with conventional wastewater treatment plant, low energy consumption, possibilities of being overload by ballast water, the possibility of short-term and long-term shutdown, relatively rapid incorporation of the treatment process and achievement of the performance efficiency quality target in a short period of time after the start of operation, removal of the part of nutrients, especially nitrogen and phosphorus by biomass uptake, treatment of organically low-loaded wastewater that cannot be treated by conventional methods (treatment plants based on activation processes). At the irrigation by treated wastewater, the economic effect is based on the use of water and fertilizer value of wastewater, total use of plant nutrients, improvement of soil fertility and thus significant rise of crop yields simultaneously with the high treatment effect of topsoil (Šálek and Tlapák, 2006).

Groups of constructed treatment wetlands for water and wastewater treatment by the used kind of vegetation and by the water flow direction (Fonder and Headley, 2010):

- surface flow with emergent vegetation
- surface flow with submerged vegetation
- surface flow with floating leaved vegetation
- surface flow with free-floating vegetation
- surface flow with floating emergent vegetation
- surface flow with woody emergent vegetation
- sub-surface flow horizontal with emergent vegetation
- sub-surface flow horizontal with woody emergent vegetation
- sub-surface flow vertical with emergent vegetation

## 5.3 Limitations of the Natural Technologies

Drawbacks of natural treatment methods do not primarily consist in the technology of natural treatment methods but in poor design and the lack of functionality of the mechanical pre-treatment stage, creating conditions for the rapid clogging.

A certain disadvantage is the relatively high area, low efficiency in removing ammonia nitrogen in classic simple arrangement in the anaerobic filtration environment of constructed treatment wetland. The problem of oxygen regime and nitrification of ammonia was, from the research point of view, satisfactorily resolved by the facilities of the other generation, particularly by using pulsed filling or emptying of filters (intermitted flow filters, irregularly flow systems, etc.).

The most common natural methods of treatment include constructed treatment wetlands, soil filters, stabilization ponds, especially final treating stabilization ponds and the use of aquatic plants or floating islands. Globally, irrigation by treated wastewater clearly dominates.

# 6 Pretreatment Technologies

Besides pollution indicators routinely monitored, raw sewage contains, a number of other substances, such as pieces of rags, fibers, hair, thread, feces, grease, household trash, remnants of fruit and vegetables, plastic, various containers, pieces of wood. A stream of water at the bottom of the drainage may be, particularly in the rainy season, also entrained with heavier materials such as gravel, pieces of brick, etc.

For this reason, the mechanical pretreatment stage is an important part of any treatment plant. It protects the mechanical parts and/or the filter material of distribution layers from damages and clogging. It prevents clogging of pipes, gutters, vents and protects pumps from damage. It also serves to capture finer particles of sludge, which would unnecessarily affect the performance the biological system of the plant. A properly functioning mechanical pretreatment stage helps achieving good results in the outflow from constructed treatment wetlands.

In the case of extensive technology, the focus is on ease of the use devices, which require minimal maintenance.  In an extensive mechanical wastewater pretreatment, the pretreatment usually consists of hand-raked screens, manually moved out of the sand trap, multi-chamber biological septic tank or settling tanks channels.

The quality of mechanical pretreatment is especially important in extensive technologies such as ground filter, constructed treatment wetlands or stabilization ponds. The proper design and use will significantly reduce clogging of the filter material. The poorly designed mechanical pretreatment stage can lead to serious reduction of hydraulic conductivity and sludge moving from pretreatment device to next part of treating system.

Combined sewage system serves to drainage of precipitation and wastewater. Disposable flow increase caused by inflow of precipitation and water from snow melting that far exceeds the normal flow of sewage. It causes flushing canalization and brings the sewage pollution from other municipalities (washes away from roads and car parks), and from agricultural farms (rinsing the area), from the premises. This brought pollution loads the wastewater treatment materially and from the point of volume may, in the case of malfunctioning of mechanical pretreatment, result in clogging of soil filters and constructed treatment wetland and wastewater stabilization ponds.

Photo 3a,b: Mechanically Raked Screens

Before the main object of mechanical cleaning, there are typically set bar screens and sand trap, or even grease trap. In the following text a brief description of the selected objects of mechanical pretreatment is provided.

## 6.1 Bar Screens

Bar screens (examples shown in Photo 3), together with the gravel trap are parts of the coarse pretreatment of the waste water treatment plant. Their purpose is to remove large floating objects and particles in water floating.

Bar screens routinely collect twigs, rags, containers, grass clumps, larger pieces of fruit, etc. Screens are made up of a series of steel rods of circular, rectangular or trapezoid profile. They are embedded in a frame placed in the trough inlet usually angled at 30 ° - 60 ° (manually raked bar screen is placed at an angle of 45 °). Depending on the distance between bars, it is possible to distinguish coarse screens (the distance between bars is greater than 60 mm) and fine (distance between bars is less than 20 mm).

The trap material (so called screenings) is removed either by hand wiping or mechanically. One of the important design parameters is the speed of water flow in the inlet trough, which should be in the range of 0.3 to 0.9 m/s. Water speed below this threshold will favor the sedimentation of sand and if the speed is greater, the captured material may move to next part.

For small municipalities, set up only screens with manual cleaning is feasible. For larger municipalities (more than 600 p.e.), fine mechanically raked screens are recommended.

The captured screenings must be disposed of as hygienically hazardous material. Commonly, they are disposed by storing them in containers after disinfection of lime or chloride of lime within the area of the treatment plant and after the filling of containers they are transportation to final disposal in a disposal site. The average production of screenings at coarse screens gives 2-3 liters per one p.e. per year (Dohányos et al., 1994).

## 6.2 Sand Trap

The sand traps (examples shown in Photo 4) target the removal of sand, gravel and other substances of similar nature with the size of 0.2 mm. The principle of the removal of these substances is to reduce the flow rate in the tank, which leads to their sedimentation. Flow rate, however, should be in the range from 0.15 to 0.45 m/s (to be settled only the inorganic part of the suspended solids. The amount of sand is dependent on topography, type of surface drainage area, etc. The amount of drained sand is in the range 5-12 l / (person.year). If a slit trap is used organic material the sedimentation often occurs. For this reason, it is necessary to collect and drain traps of floating material, usually hypertrophied sludge. According to the analyses of domestic and municipal wastewater treatment, this material can be used in agriculture, after analyzing the level of microbial and heavy metals contamination. However, it is necessary to carry out the separation of the sludge from the inert component. Cleaning of slots and sloping boards using e.g. broom must be regular, preferably daily.

Photo 4a,b: Sand Traps

According to the direction of flow we distinguish the sand traps horizontal, vertical and traps with transverse circulation. The simplest case, and in extensive treatment of waste water is the most common trap chamber, which consists of two or more narrow trough which purified water flows. Flow distribution is governed using division work gate. It is usually sand trap with two parallel channels, which are connected together at the maximum water flow. During normal water flow one channel is used and the other can be evacuated.

The main disadvantage of these devices is the flow rate variation, which will result in changes in the of sand removing. In an effort to address these shortcomings sand traps with controlled speed were developed. It is a horizontal sand trap fitted at the end by spillway, diaphragm. The diaphragm with its reduced profile stirs the water in the trough, and thus increases the flow area and the flow velocity remains constant (Dohányos et al., 1994).

The other types of sand traps are mostly with mechanical operation (clearing sediment) and not used in cases of extensive wastewater treatment.

## 6.3 Septic Tanks

A septic tank is a reservoir for wastewater with overflow. In the past it was often used for its simplicity and low costs. Septic tank cannot remove $BSK_5$ (only 15 – 30 %), $CHSK_{Cr}$ (only 0 – 20 %), N-$NH_4$ not, only insoluble particles 50 – 60 % (by norm CSN 75 6402). Efficiency in these parameters depends on retention time and arrangement of the septic tank. Since it does not guarantee the fulfilment of effluent concentration of pollutants, it is used as the first treatment step before soil filters, biofilters, biodiscs, and constructed treatment wetland or wastewater stabilization ponds.

A septic tank represents a settling tank in which a partial anaerobic removal of organic substances and anaerobic settled sludge stabilization takes place. Due to the fact that in a normal septic tank there is not the separation of sediment and digestion space, there is a deterioration of effluent by digesting sludge. This fact can be improved by using a septic tank with multiple chambers, usually three, with openings protected by scumboard that extend at least 0.15 m above the water level and 0.30 m below the water level. The scumboard prevent floating sludge to flow from one chamber to the other. The total volume of the septic tank is proposed according to the mean retention time of the effective area of the septic tank and the required septic tank sludge area. The mean retention time of 3 days is recommended. The sludge space volume of 50 % to 60 % is added to the volume of the effective area of the septic tank.

The septic tank size is calculated from the equation (CSN 75 EN 12566-1):

$$V = a \cdot n \cdot q \cdot t \qquad (6.2)$$

Where

a coefficient of sludge area (usually a = 1,5)
n number of connected inhabitants
q specific water consumption per person [$m^3$/d]
t mean retention time [d] (usually t = 3 days)

The effective area of the septic tank should not be less than 3 $m^3$, with the smallest dimensions for the depth (from the surface of the water) 1.3 m, the clear width 0.9 m and clear length of 1 m. It is recommended to empty the retained solids in the septic tank at least once a year and when the height of sludge reaches one third of effective height, and about 0.15 meters of digesting sludge is kept in a septic tank for the inoculation. The use of septic tanks with more than three chambers (6 to 10) in the Czech Republic showed that it is not necessary to empty the sludge each year. The septic tank in operation for several years without clearing of sludge was proved to be functional. When implementing a similar septic tank it is recommended to raise the height of the septic tank by inspection holes with covers that provide access to the inside to control the height of the sludge.

A well designed septic tank is able to reduce $BOD_5$ concentrations in about 15 - 30 % and the concentrations of suspended solids in about 50 %.

## 6.4 Imhoff Tank

It represents a settling tank whose purpose is to capture the fine sludge particles. It is a deeper retention reservoir, which is divided by the bottom with the slot. In the upper part there is sedimentation, settled sludge falls through the slit into the below situated rotting area in which there is the anaerobic stabilization. The inlet into the settling area should be adjusted so that the wastewater was evenly distributed throughout the cross-sectional area of the trough. The floating barrage reaching at least 0.3 m below the surface and 0.2 m above it must be fitted before the drain from the settling compartment. The slope of inclined walls of sedimentation area should be at least 1.4:1, the width of the slot must be at least 0.12 m. When designing the rotting space of the Imhoff tank into which the excess sludge is not fed, a specific capacity of 150 l / p.e. is proposed.

Imhoff tanks are usually cleaned twice a year. They are simple, easy to use and reliable. It is appropriate to maintain the level in the individual sections of tank clean, regularly, preferably daily, collect floating debris, residues of fat and store them in a container. Sloping walls of settling space and slots from settled particles should also be cleaned regularly, e.g. by broom.

Photo 5a.b: Excavated Settling Tanks

## 6.5 Settling tanks

Especially excavated settling tanks can be ranked among the devices of mechanical pretreatment for extensive treatment ways (Photo 5).

Under favourable conditions and for small wastewater treatment plants in municipalities from 100 to 200 p.e. it is possible to design a pair of excavated sealed settling tanks. They are operating alternately; one is in operation, the second tank is emptied and cleaned from sediments. The retention time according to the own experience from Germany, is proposed min. 3 days. The use of these types of settling tank without rectifying structures with irregular cleaning, lacking floating scumboard to prevent leakage of floating sludge is not recommended. The treatment efficiency of such tank is low; there is also the danger of floating and bulking sludge, which is documented in Photo 6.

Photo 6: Small Settling Tank Overgrown with Filamentous Algae

The sedimentation process in these tanks is influenced by a number of negative factors and phenomena:

- Absence of rectifying structures, flow inequality, formation of short-circuit currents
- Flotation and leakage (outflow) of floating sludge
- Difficult cleaning of bottom (if there is only one tank, which is still in operation)

A pair of excavated tanks is applicable to store surface washes, it fulfills the function of settling tanks, the operation is alternating, one tank is in operation, and the second is drained and then cleaned out.

## 6.6 Anaerobic wastewater pretreatment

Anaerobic digestion is a specific wastewater pretreatment. It is characterized by the absence of oxygen and due to the presence of anaerobic microorganisms, the organic matter (dissolved and solid) present in the wastewater is broken down into simpler, easily degradable, under appropriate conditions up to biogas (methane and carbon dioxide as the main component of biogas). Anaerobic processes are used mainly for higher concentrations of wastewater and at higher operating temperatures, where the efficiency of removal of organic pollutants is higher (Gašpariková, 2005). Table 6.2 compares anaerobic and aerobic processes of various technological aspects.

Tab.6.2. Comparison of anaerobic and aerobic processes

| Comparative parameter | Anaerobic process | Aerobic process |
|---|---|---|
| Energy consumption | Low | High |
| Construction costs | Simple | Demanding |
| Sludge production | Low | High |
| Nutrient consumption | Low | High |
| Reaction rate process | Low | High |
| Nutrients removal | Minimal | Very good |
| Rise time of the process (start-up) | Long | Short |

Anaerobic processes are an attractive method for household and municipal wastewater treatment especially in developing countries. At the end of the last century, various anaerobic reactors technological modifications such as UASB reactor, anaerobic filter, the anaerobic fluidized bed reactor, anaerobic SBR system were successfully launched. Widest application was made by the

UASB system, which is actually a fairly successful full-scale applications especially in countries with a warm climate and lower requirements on the quality of treated effluent water, such as in India, Colombia, Brazil and so on (Draaijer, 1992; Schellinkhout, 1992; Chernicharo, 1998). UASB reactors achieve a removal efficiency of 50 – 78 % (COD), the inflow concentrations ranged from 58 to 303 mg/l COD, at retention time HRT = 8 to 10 hours.

Considering the constantly increasing requirements for outflow parameters, anaerobic reactors were gradually integrated into the anaerobic-aerobic systems where anaerobic portion amounted to an effective degree of pretreatment and increased aerobic stage effluent quality to the desired level. This combination of processes could fully exploit the advantages of both systems. In the case of anaerobic pretreatment it is energy cheap and relatively effective removal of organic pollutants with low production of sludge to allow more efficient dimensioning of aerobic final treatment. Subsequent aerobic stage can benefit from these advantages and depending on the outflow quality requirements; it is possible to choose different levels of aerobic final treatment. Due to the low initial concentration and temperature of wastewater, the biogas production is usually low and economically uninteresting.

On a global scale, decentralized systems are proven combination of UASB + constructed treatment wetlands. UASB systems are quite effective at removing suspended solids, which is for the follow CTW system a big advantage. A disadvantage would be the presence of lower fatty acids (volatile fatty acids), such as acetic acid in the effluent from the anaerobic stage, which may be unfavorable for the CTW vegetation. Despite some disadvantages of UASB-CTW system, it can be concluded that effective pretreatment of UASB stage can reduce the investment costs for the construction of CTW up to 36-40 %, mainly due to the reduced surface area of the CTW. Thus constructed system reaches a relatively high efficiency of COD removal (70-83 %), suspended solids removal (48-91 %) in practice, but slightly lower in nutrients (total nitrogen 27-70 %, total phosphorus 26-89 % - Alvarez 2008).

Interesting results have been achieved by a combination of anaerobic filter and an activation part in a compact domestic wastewater treatment plant “ANAComb” used for wastewater treatment in the range of 10-250 p.e., when the devices achieved outflow parameters in the range 30 - 120 mg/l (COD), 6-25 mg/l ($BOD_5$) and 6-78 mg/l for suspended solids. An effective process of nitrification (50%) was also observed. Denitrification was not achieved due to the lack of an organic source. The devices operated with relatively low energy consumption, when compared with similar size aerobic wastewater treatment plants, achieved a reduction in energy consumption by up to 25-40 %, which was mainly due to the inclusion of anaerobic pretreatment (Gašparíková, 2005).

## 6.7 Pretreatment technologies Pollution Removal Efficiency

As already mentioned, in the case of extensive technologies the emphasis is on simple of use. For this reason, in extensive treatment plants the mechanical wastewater pretreatment usually consists of coarse, hand-raked screens, manually cleaning of the sand trap and simple soil sedimentation tanks, septic tank or Imhoff settling tank. The amount of Suspended solids captured in settling tanks, determines the costs of maintenance of the constructed treatment wetlands and soil filters, speed of their clogging and intervals of stabilization ponds desludging.

A well-functioning mechanical pretreatment is the key element of the whole treatment system. An exception is the “French system” working without primary treatment. Raw wastewater in this system is distributed on the surface of unsaturated vertical flow constructed wetlands, operated with intermittent flow.

The following Table 6.1. provide an overview of long-term treatment efficiency for selected parameters from monitoring of extensive wastewater treatment plants in the Czech Republic.

Table 6.1. Summary of Mechanical Pretreatment Efficiency in Czech Republic (Mlejnská et al., 2009)

| Locality* | COD | $BOD_5$ | SS | $NH_4$-N | TN | TP |
|---|---|---|---|---|---|---|
| | [%] | [%] | [%] | [%] | [%] | [%] |
| A | 55 | 55 | 30 | - 10 | 10 | 20 |
| B | 30 | 45 | 10 | 20 | 25 | 18 |
| C | 25 | 35 | 60 | - 15 | 0 | 10 |
| D | 25 | 35 | 25 | 10 | 15 | 15 |

*Explanatory notes:* 
*A shallow rectangular concrete settling tank*
*B excavated settling tank*
*C septic tank*
*D Imhoff tank*

While for each of these groups of mechanical pretreatment the efficiencies for the various forms of nitrogen are similar, with Imhoff tanks, the situation is more complicated, because in the efficiencies there are considerable individual differences.

The results show that one cannot clearly determine which type of septic tanks is the most efficient. When comparing the overall efficiency, however, with some exceptions, the Imhoff tanks seem to be the least efficient, which is in contradiction to theoretical expectations. Probably when evaluating the influence of the lack of maintenance and improper draining mode on the monitored wastewater occurred. This phenomenon has been observed and reported on many of the monitored wastewater plants and the operator should be alerted to the risk of decreased efficiency of septic tanks.

## 6.8 Effect of Pumping on the Quality of the Pretreatment

Proper functioning of mechanical pretreatment significantly affects the pumping of wastewater, which can cause hydraulic impact. The retention time in the settling tank would be in the case of extensive sewage in the range of two to four hours at the design flow rate, and one hour in the case of maximum flow. At lower values of the retention time the settling tank cannot completely fulfill its function; indeed there is a thread of leaching of primary sludge in the constructed treatment wetland, soil filter or waste stabilization pond. In the event that wastewater is pumped to the mechanical pretreatment from the accumulation tank, hydraulic impact can be limited by setting a short period of pumping. This setting, however, puts high demands on the pump, which must withstand the operating mode consisting of the constant switching between running and standing.

## 6.9 Sewage Collection and Disposal

In case that settlement is represented by scattered development, or they are remote buildings with uneconomical costs to build a sewer system connection, is the solution sewage collection and disposal (by cesspools).

A cesspool is an underground watertight tank without outlet used for collecting of wastewater. Their constructions are only where sewage water or wastewater containing toxic substances cannot be discharged into the sewer system with the central wastewater treatment plant or where such wastewater cannot be for economic or other reasons treated in a separate small wastewater water treatment plant, in a separate wastewater water treatment plant for industrial wastewater or otherwise disposed in a special way. Other water than wastewater must not be carried into the cesspool. Cesspools, as drainless tanks, must not be provided by drain and overflow. All the inlet and collected wastewater from the gutter in the cesspool must be emptied and hygienically disposed of. The cesspool is positioned so that it has access to admittance or arrival. Between the outer wall of the cesspool and the outer wall of the building has to be a minimum distance of 1.0 m.

The minimal distance of cesspool including inlet from the wells for domestic water supply is:
- 5 m at a low permeable environment (e.g. alluvial and slope clay, loamy-stony rubble, earthenware gravels and sands, loess, tuffs and tuffites, sandstone with a clayey, kaolin, calcic or other sealant;
- 12 m at permeable environment (e.g. gravel, sand, very sandy loam, sandy-stony rubble, porous coarse-grained sandstone, highly fractured rocks.

The minimal distance of cesspool including the inlet from the public and private wells for water supply is 12 m at low permeable environment and 30 m at the permeable environment.

The proposal of the cesspool is recommended as sump design size accumulation space V in liters for sewage and wastewater is calculated by the equation:

$$V = n \cdot q \cdot t \qquad (6.1)$$

where
n number of people connected;
q specific average daily rate (inflow) of wastewater discharged into cesspool in l/(p.e. per day);
t time interval of emptying cesspool in days.

When calculating the volume of storage space in the septic tank, it is necessary to take into account the volume of vacuum track and it is recommended to allow for security provision for above-average water consumption. Increasing the storage space cesspool reduces this reserve. It is not recommended to have the volume of accumulation space of the cesspool less than 3 $m^3$.

The construction of the cesspool must withstand the anticipated effects of gravity roofing and backfill, accidental surface loads, hydrostatic pressure of the filling tanks and potential buoyancy of groundwater. If necessary (usually because of the additional security of static load capacity of cesspool delivered as packaged and/or site assembled product), it is proposed to concrete the cesspool. Concrete encasement is made of concrete or reinforced concrete according to the type, purpose and place of the use of cesspool. In case of placement as follows concreted cesspool below the groundwater level it is necessary to avoid the penetration of ground water to packaged and /or site-fitted product of cesspool by means of external waterproofing concrete encasement (concrete housing) of the cesspool or custom design packaged and/or site assembled product cesspool.

The lining must be designed with regard to the underground water table. The bottom of packaged and /or site assembled product of the septic tank is usually fitted to a tolerable and level concrete slab. To prevent leakage of gas into the living areas, the space of the cesspool should be ventilated by brought out vent pipe above the roof of the building drainage and ventilation completed by head. The smallest diameter of vent pipe should be 100 mm. The ventilation requirement of shafted version does not fit the system of vent pipe that is closed under the roof by means of pre-inlet valve. Inlet pipe of wastewater is installed below or next to inlet but so that the axis of the inlet pipe is directed outside the orifice.

Cesspool must be emptied regularly at intervals as needed and its content properly disposed of. The part of the draft standard is also a recommended procedure for the disposal of the content of cesspools.

To avoid overflowing cesspools, it is necessary to check the level of wastewater in the cesspool regularly. When exceeding the limit dimension levels in sewage cesspool drainage systems, the internal sewage system must not be used (i.e. inlet must be stopped).

# 7 Constructed Treatment Wetlands

Constructed treatment wetlands are natural wastewater technologies. They are constructed filtration systems planted with wetland vegetation (most often reed, reed canary grass, and cattail) with defined filter material and direction of wastewater flow (an example see Photo 7). The basic principle of this method of cleaning is the flow of wastewater through the filtration system, which is planted with wetland vegetation. Filter material must be permeable enough to avoid clogging and subsequent surface flow. When the wastewater passes through the material, the treatment occurs, carried out by the complex intertwining of chemical, physical and biological processes. The water flows through the filter horizontally or vertically at the constructed wetland wastewater treatment plant. Schematic cuts through individual variants of constructed wetlands show the following Figure 7.1 and 7.3.

Photo 7: Small Constructed wetland Treatment Plant

Constructed treatment wetlands (also called „reed beds“) represent a biological treatment stage (secondary and/or tertiary) of wastewater treatment plants. It is based on slow filtration of pretreated wastewater. It may also be used for tertiary treatment of effluent from mechanical-biological treatment plant. Type of constructed wetland treating raw wastewater (without sedimentation pretreatment) also exist (so called French system), however they operate in a different mode.

Constructed wetlands are similar to wetland habitats from the point of view of character and also the ongoing treatment processes. In Austria and Germany, there are also used the terms "bepflanzte Bodenfilter", "Pflanzenkläranlagen" or "Abwasserreinigung mit pflanzenbewachsenen Bodenfiltern". The International Terminology of Constructed Wetlands is described into the details by Fonder and Headley (2010).

Constructed Treatment Wetlands

Constructed treatment wetlands (CTW) are ranked to the so-called natural (sometimes also called "extensive") technologies. These ones are constructed water tight beds filled with a filter material and planted with locally relevant, or ornamental, wetland vegetation (most often reed, reed canary grass, cattail, iris, reed sweet grass). The filter environment must fulfil the pre-defined requirements in terms of hydraulic conductivity and load of wastewater by pollution, flow rate, frost penetration, or the possibility to bind phosphorus and heavy metals. The filtration material must be sufficiently permeable to prevent clogging.

Advantages of CTW

- Aesthetic integration into the environment, increase in biodiversity of the landscape by creating an artificial wetland
- They favorably affect the microclimate in the immediate vicinity due to the relatively significant evaporation of water by vegetation
- Very energy-saving treatment element, it can function without electricity supply
- Operation costs are low
- A relatively simple construction, it is possible to construct it on the self-help basis, or with the use of human resources and machinery of municipalities and communes
- The proper design can achieve high treatment effects of insoluble substances, organic and bacterial contamination
- Pulse emptying, or filling of filters may sufficiently provide oxygen saturation of the environment and the removal of ammonia nitrogen
- The removal of ammonia nitrogen is sufficient even during the implementation of constructed wetland filter with the vertical flow when the filtration environment is not still saturated with water
- Continuously washing filters, permanently filled with water with the anaerobic environment may serve to denitrification of wastewater – removal of nitrate nitrogen
- When there is an appropriate arrangement, it is possible to backwash particularly smaller filters by treated wastewater without the necessity of filter material extraction

Disadvantages of CTW

- When used as the main treatment stage, there is the high surface demand (depending on the design from 2 to 5 $m^2$ per capita equivalents in case of the request for the removal of insoluble substances, ammonia, organic and bacterial pollution)
- In the basic configuration – the filter with the continuous horizontal flow, permanently filled with water has the low effectiveness in removing ammonia nitrogen
- Stable removal of phosphorus from water is only possible by using special filtration materials with elevated sorption capacity with limited potential of P removal (Arias et al., 2001; Vohla et al., 2011; Jenssen et al., 2010)
- The risk of clogging of the filtration material in case of inappropriately designed pretreatment or insufficient function and maintenance (sludge pumping, slot cleaning) of the installations of mechanical pretreatment
- Difficult regulation of the ongoing processes, particularly in case of necessity of quick adjustments and changes

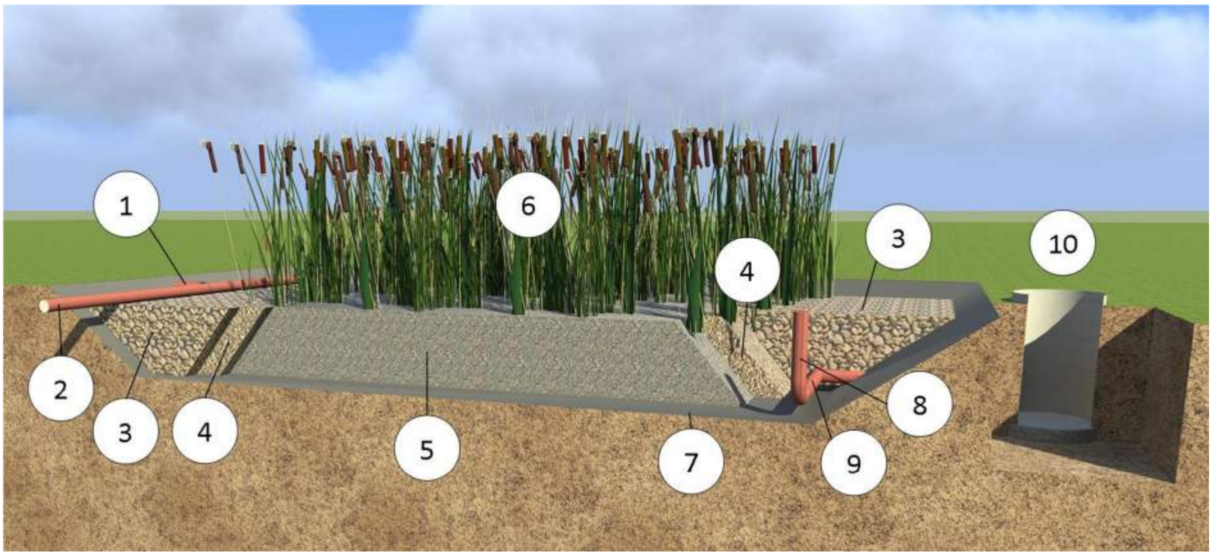



Figure 7.1 View through Constructed wetland Filter with Horizontal Flow and Drainage Regulation Shaft

Horizontal flow treatment wetlands can also be established as two or three consecutive treatment beds (filters) with filter material of different granulation and different plants. An example of typical smaller horizontal flow treatment wetland in Slovenia is shown in Fig. 7.2.

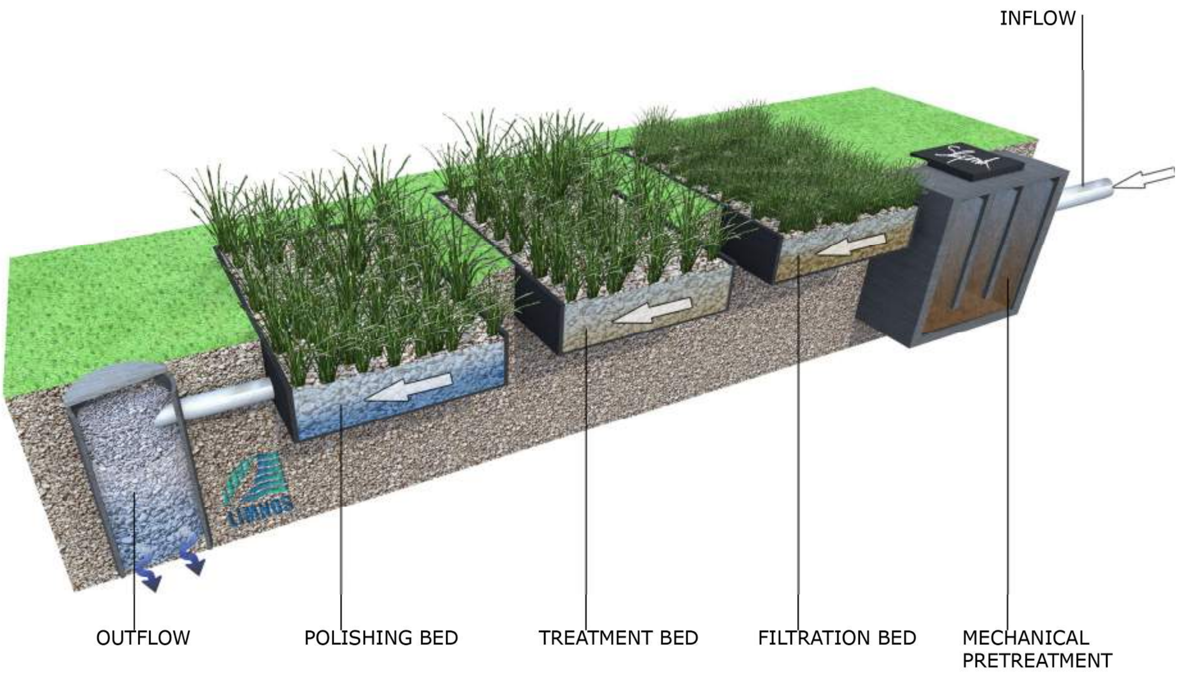



Figure 7.2 An example of horizontal flow constructed wetland layout with different filter material and vegetation of each treatment beds

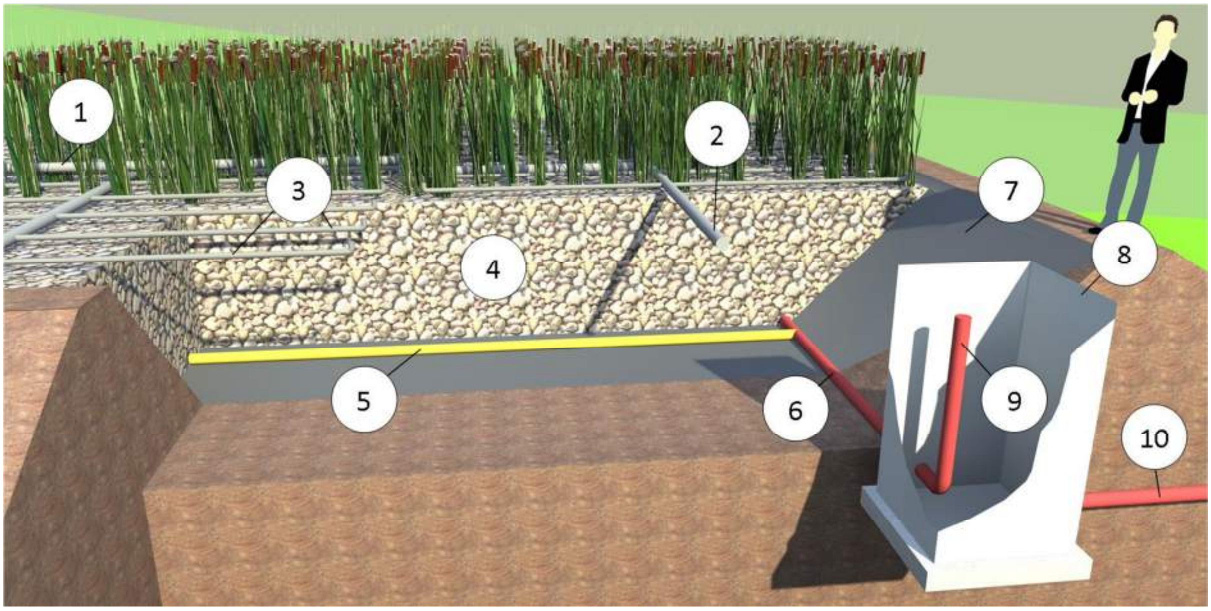



Figure 7.3 Side view of a Vertical Flow Filter with Wetland Vegetation. 1-inflow pipe, 2-distribution pipe, 3-more detailed distribution pipe system, 4-main filter material 5-collection pipe system, 6-collection main pipe, 7-lining, 8-inspection shaft, 9- Regulation pipe, 10-outflow pipe

## 7.1 Application of Constructed Treatment Wetlands and Removal Efficiency

As follows from the character of the CTW, they are a very suitable solution of biological wastewater treatment, especially in discontinuous operation of wastewater sources (recreational buildings, cottages, summer camps), large fluctuations in the concentration and the amount of wastewater and influent of diluted wastewater, e.g. from combined sewerage.

Primarily physical processes of filtration and sedimentation remove suspended solids. Organic compounds are removed primarily by microbial aerobic and anaerobic respiration; colloidal particles can then be removed from the wastewater by filtration, sedimentation or adsorption.
To some degree there is the removal of nitrogen, namely the processes of ammonification, nitrification and denitrification. Phosphorus removal occurs primarily by binding of phosphorus onto the filter material and trapped sediment and by wetland vegetation biomass sampling. The removal of the other pollutants was also observed from wastewater (heavy metals, surfactants, specific organic substances, etc.). Bacterial contamination is significantly reduced (Kadlec and Wallace, 2009). From the summary of long-term survey of constructed treatment wetlands can be stated as very effective (Vymazal and Kröpfelová, 2009) in removing of organic and suspended solids. The influence of vegetation (macrophytes) in the treatment processes, including the collection of nutrients, depends on the type and the state of health of vegetation maturity, its density and involvement, the character of biomass development, the growth phase – and the season.

The published results of extensive surveys associated with the evaluation of treatment efficiency of constructed wetland with the horizontal subsurface flow states the following average efficiencies (Vymazal, 1995; Šálek a Tlapák, 2006; Rozkošný, 2008; Mlejnská a kol., 2009; Vymazal, 2009):

- $BOD_5$ 85 %
- COD 75 %
- SS 80 %
- $NH_4$-N 30 %
- TP 35 %

The authors Vymazal and Kröpfelová (2009) summarize the findings from the removal of organic pollution in constructed treatment wetlands in the world. The relation for the estimation of the concentration of $BOD_5$ in the effluent according to the concentration in the influent was derived from the measurements of more than 900 sets of samples from constructed treatment wetlands: C($BOD_5$ outflow) = 0.51 * C($BOD_5$ intake), $R^2$ = 0.835, range of load flow 0.3 – 8, 580 kg/ha per day. The relation for the indicator CHOD was derived from more than 500 sets of samples from constructed treatment wetlands: C(COD outflow) = 0.56 * C(COD inflow), $R^2$ = 0.902, range of load flow 3.3 – 14, 769 kg/ha per day (Vymazal, Kröpfelová, 2009, see fig. 7.4).

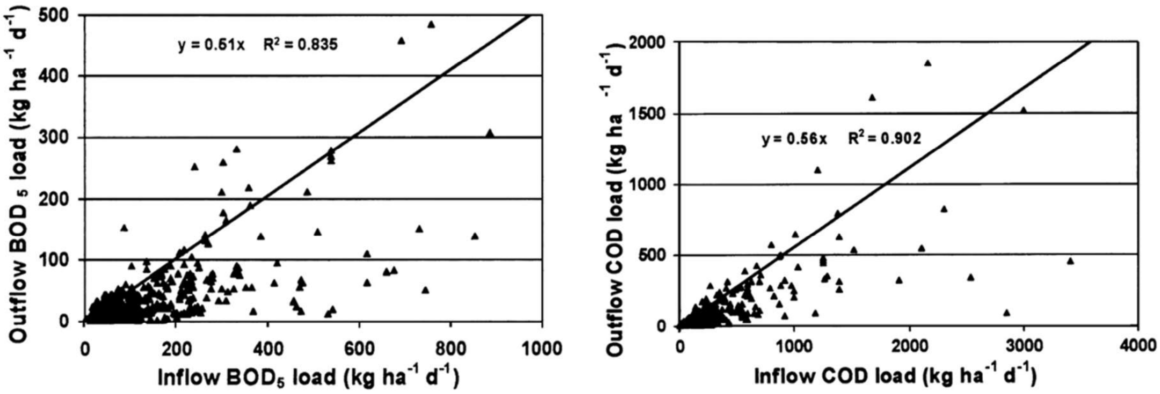



Figure 7.4 Relationship between inflow and outflow $BOD_5$ and COD loadings (Vymazal and Kröpfelová, 2009)

Foreign experience (ÖNORM B 2505:2009) showed that the filter of constructed treatment wetlands with the vertical subsurface flow with intermittent inflow can successfully operate at an organic load of 20 g COD/$m^2$/d additionally. Brix and Arias showed effective removal at BOD loading rates of 60 g/$m^2$/d (i.e. 4$m^2$ for the connected person). It has also been demonstrated that during the summer months (May to October) and wastewater temperatures higher than 12°C, the specific surface area can be further reduced up to 2 $m^2$ for the connected person that ensures adequate required level of pollution, including ammonia nitrogen. The lower figure can then be used in the design of such devices for installations with the seasonal operation.

In the following table there is a comparison of long-term average runoff concentrations from treatment wetlands with the vertical flow of water filled pulse (VF) and horizontal subsurface water flow (HSSF) from the surveys of constructed treatment wetlands in Germany (Börner et al., 1998), Austria (Haberl et al., 1998) and Slovenia (Istenič et al. 2013).

The results show that HSSF CTW systems have sufficient efficiency of removal of suspended solids and organic matter. VF CTW systems have higher efficiency of removal of ammonia, nitrogen and thus produce significantly lower effluent concentrations, as shown in the table. However, HSSF CTW can be used in case of the requirement for the reduction of total nitrogen outflow because their efficiency of the nitrate nitrogen removal thanks to the prevailing anaerobic conditions and high degree of denitrification is higher than at VF CTW. They can therefore be used as a final treating stage behind the other types of wastewater treatment plants, as it is realized e.g. in Austria, Denmark has over 600 of these system operating.

When using the sorbent, the removal efficiency of ammonia nitrogen (using zeolite as filter material) and phosphorus from wastewater is considerably increased. This is used especially during the non-growing (non-vegetation) period when there are unfavourable conditions, particularly the low temperature of influent water.

Table 7.1 Comparison of Outflow Concentrations from Horizontal Subsurface Flow Filters (HSSF) and Vertical Filters (VF) of CTW

| Filter Type | VF | | HSSF | | |
|---|---|---|---|---|---|
| Indicator / Country | Germany | Austria | Germany | Austria | Slovenia |
| COD (mg/l) | 68 | 37 | 102 | 49 | 40 |
| $NH_4$ -N(mg/l) | 9 | 8 | 36 | 15 | 8 |
| $NO_3$-N(mg/l) | 65 | 35 | 7 | 8 | 4 |
| TN (mg/l) | 67 | --- | 52 | --- | --- |
| TP (mg/l) | 3 | --- | 5 | --- | --- |

A very frequently discussed issue related to the operation of the CTWs, is the ensuring of adequate functionality in the winter, i.e. non-vegetation, period. In the climatic conditions of Central Europe, it is possible to consider the part of the year from mid-October until the end of March, according to the macrophyte vegetation growth period. It has been proved that treatment efficiency for Suspended solids substances, organic pollution ($BOD_5$, COD), phosphorus and microbial contamination in non-vegetation (non-growing) period (in the winter) is practically similar to the efficiency in the growing season (Rozkošný a Mlejnská, 2010). The ammonia nitrogen is expected lower performance in the non-growing period; however, it does not have to necessarily mean non-fulfilment of allowed values in the effluent, but it must be taken into account in the preparation of project documentation.

It is possible to operate CTWs successfully, also in the higher altitudes. Žáková and Žák (2005) give examples of domestic wastewater treatment plants 600-700 m above sea level (Kořenov-Polubný; Dolní Černá Studnice), which have been in operation since the early nineties. There are constructed wetlands implemented in higher altitudes also in other countries, e.g. in Slovenia (Photo 8) at Planina Razor 1300 m, Rakitna 790 m and Lisca 947 m above sea level. They were designed to remove organic pollution from mountain huts or small settlements and reach desired discharge value (unpublished).

Photo 8: Example of subsurface horizontal flow CTW in Slovenia during winter and summer.

HSSF CTWs with saturated conditions in filters are not very effective in removing ammonia (lack of oxygen in the filter bed) and phosphorus (commonly used gravel has little ability to precipitate or adsorb phosphorus). When using materials with high sorption capacity (e.g. thermally expanded clays, blast furnace slag), the elimination of phosphorus may be significantly improved (Vohla et al, 2011). In this case, it is necessary to design the system so sorption material can be easily exchanged (use of gabions, sacks etc.). An example of an application is shown in Photo 9.

Photo 9: Example of Using Removable Sorbent Packed in Jute Sack

Previous investigations have demonstrated that the main process of elimination of phosphorus from wastewater during passing the filters of CTWs is the sorption to the filter material as well as the captured sludge particles (Mlejnská et al., 2009). Within the growing season vegetation can contribute to the reduction of phosphorus amount in wastewater, but biomass should be removed during the season (*Phalaris arundinacea*) or at the end of season (*Phragmites australis*).

The retention of microbial contamination is high, for coliform and thermotolerant coliform bacteria the elimination usually ranges between 2-3 orders of magnitude. The detailed monitoring of CTWs from 1999 to 2008 showed an average reduction of fecal coliform (thermotolerant) and coliform bacteria by 98 % and the high efficiency of the removal of all bacterial contamination without seasonal fluctuations in the range of 95-99 % was confirmed (Mlejnská et al., 2009).

Nowadays, a broad research is being carried out, but also the realization of wastewater treatment plants with the intensification of the CTW removal efficiency especially for nitrogen removal, using intermitted flow, additional aeration (Kadlec a Wallace, 2009). Another approach is a compact design of the combination of the HSSF CTW with continual flow and the VF CTW with the intermitted flow (Vymazal a Kröpfelová, 2009; Garcia-Perez et al., 2008). This arrangement can be built by placing the siphon, or more precisely electrically operated lock, into the shaft on the outflow of treated wastewater from the filters of the constructed wetland wastewater treatment plant. Another solution is cascade arrangement of multiple smaller beds, which requires steep terrain. When cascading arrangement, adding a buffer tank with electro valve can also make influent wastewater treatment.

## 7.2 Constructed Treatment Wetland Design Parameters

### 7.2.1 Horizontal Flow Constructed Wetland

CTWs with horizontal flow are designed according to the following equation, which is derived from the equation of kinetics of the first order for the removal of $BOD_5$ assuming piston flow (Kadlec et al., 2000):

$$A = - (Q / k) . \ln ((C_o - C^*) / (C_i - C^*)) \quad (7.2)$$

where

$C_i$ inlet BOD concentration, (mg $l^{-1}$)
$C_0$ outlet BOD concentration, (mg $l^{-1}$)
$C^*$ background BOD concentration, (mg $l^{-1}$)
$A$ surface area of the constructed wetland filter ($m^2$)
$K_{BOD}$ rate constant of pollution depletion (m $year^{-1}$)

Simple equation without background concentration for surface area calculation (Šálek and Tlapák, 2006):

$$A_h = Q_d(\ln C_o - \ln C) / K_{BOD5} \quad (7.3)$$

where
where

$A_h$ surface area of the constructed wetland filter ($m^2$)
$Q_d$ average flow rate of wastewater ($m^3\ d^{-1}$)
$C_o$ $BOD_5$ at the inlet to the filter ($mg\ l^{-1}$)
C $BOD_5$ at the outlet from the filter ($mg\ l^{-1}$)
$K_{BOD}$ rate constant of pollution depletion ($m\ d^{-1}$)

The European Directive from 1990 recommends for treatment of urban sewage water the reaction constant value $K_{BOD} = 0{,}1\ m\ d^{-1}$, which usually gives the design area of constructed wetland 5 $m^2$ $p.e.^{-1}$. This value was proved to be very suitable. The average design area of constructed wetland wastewater treatment plants is 5 $m^2$ $p.e.^{-1}$.

By means of analyzing 624 CTWs around the world, the average value of 0.122 $m\ d^{-1}$ (for influent $BOD_5$ on the constructed wetland filter > 40 $mg\ l^{-1}$) was found out - Vymazal et al., 2008.

For the efficient removal of ammonia and phosphorus it is necessary to choose the reaction constant considerably lower – about 0.025 $m\cdot d^{-1}$ (Vymazal et al., 2008), or to choose CTWs with the vertical flow filter with pulse filling or emptying. Vymazal (2009) reports the efficiency of the removal of ammonia nitrogen in 53 CTWs operated in the Czech Republic for the period 1989-2007 averaged 34 %. As the reason for this low efficiency he states especially anaerobic conditions in the filters. Prokešová (2010) showed that the optimal depth of lowering the surface within the pulse filling or emptying, in terms of increasing the concentration of oxygen in water, is 0.40 to 0.50 m, resulting in an increased oxygen concentration of 3-5 mg/l. The optimal depth for the implementation of pulse emptying and filling was in the range from 0.4 to 0.6 m in investigations carried out by the authors.

Optimal dimensions of the entire CTW help to ensure an appropriate preliminary survey that will provide information on the amount of water consumed at the source of wastewater and information about the quality of this water.

### 7.2.2 Vertical Flow Constructed wetland

Design parameters of CTWs with vertical flow in detail demonstrate Kadlec and Wallace, 2009. An important parameter is the hydraulic load – in the case of the most commonly used gravel – sand fraction 2 – 4 mm, the recommended range is 0.03 – 0.06 $m^3/m^2$ per day. The height of the filtration material should be from 0.9 to 1.5 m. Rate constants of pollution depletion were identified from 0.055 to 0.16 m/d for $BOD_5$ and from 0.027 to 0.11 m/d for ammonia nitrogen. For more detailed information see also Nivala et al. 2013, Brix et al. 2005 and Langergraber et al. 2009.

## 7.3 Design Layout of Constructed Treatment Wetland

### 7.3.1 Horizontal Subsurface Flow Constructed Treatment Wetland

The establishment of the HSSF CTW consists especially in excavation of a level basin or a flat basin with a constant bottom slope. Both the bottom and the walls of the basin must be properly compacted to prevent additional deformation. Isolation of the bed is usually practiced by placing of plastic liner. The liner should have a thickness of 1 to 1.5 mm is often used for smaller beds; with larger beds it is much favourable to use sealing foil from PE-H of the thickness from 1.5 to 2 mm. It is possible to use too clay, but it's using is a problem for large surfaces, because isn't easy manipulation with clay materials; clay is cleared, sticks, slides, etc. The protective geotextile is placed on the compacted or subgrade surface on which is laid e.g. waterproof foil with resistance to UV radiation, ozone and aging, for temperatures from -45 °C to 130 °C and which his again covered by a protective geotextile. The liner must be watertight, is pulled up above the operating level and ends by filling up into the terrain of the slope or covered with pieces of turf or tiled with stone.

The basin must be filled by filter material carefully to avoid rupture isolation. Maneuvering of heavy machinery on the surface is excluded. In the case of natural occurrence of low permeable clays (hydraulic conductivity of soil $<10^{-8}$ m/s) it is possible to use them as a sealing barrier.

The most suitable filter materials are alluvial river gravels with oval grains, mostly of quartz origin with recommended porosity 0.40 – 0.45 and hydraulic conductivity (0.1 – 1.5) m $s^{-1}$. Otherwise, it is also possible to use crushed stone quarry. Operational experience has shown that it is not advisable to use different fractions of the filtration material because then it is very difficult to ensure a homogenous hydraulic conductivity of the bed. At present, coarse materials (gravel, crushed stone) with a grain size of at least 4-8, or more precisely 8-16 mm are used for filtration beds. HSSF CTW can also consist of more consecutive treatment beds (filters) filled with sand of different granulation sizes: e.g. first bed with coarser material of 8-16 and 16-32 mm, second bed with finer material 4-8 and 8-16 mm and the third bed with the finest sand of 2-4 and 4-8 mm which is an usual design practice in Slovenia (Figure 7.2.). The depth of the filter is 0.5, 0.7 and 0.5 m for the first, the second and the third bed, respectively. The inclination of treatment beds ranges from 0.5 to 1.5%. For distribution and collection zones macadam (coarse gravel fractions above 100 mm) are the most frequently used and the gravel size is recommended to be > 100 mm. The entire constructed wetland is after filling with filter material flooded and the surface of filter material is aligned to the water level.

### 7.3.2 Vertical Flow Constructed Treatment Wetland

Vertical Flow CTW is similar to the horizontal flow CTW, only the direction of water is vertical. Filtration material of VF CTW is finer than horizontal filters. In practice, sand is often used and recommended, specifically is the best using a fraction 0.2-4 mm. For a proper function of the vertical filter, the height difference between the inlet and outlet from the filter is very important. Due to the fact that the main processes taking place in the filter are chemical and biological processes, it is necessary to protect them against particles that could cause the clogging. For this reason the good mechanical pretreatment is very significant.

A vital condition for a good function of the filter is a uniform distribution of wastewater over the entire surface area and access of air into the filtration layers.

The rectangular shape of the vertical filter can be recommended.

With regards to specific design requiriments, there is also possible to design vertical flow treatment wetlands without mechanical pretreatment. More information brings f.e. Molle et al. (2005) and Reeb and Liey (2010).

### 7.3.3 Water Distribution

Wastewater in CTW filters is distributed mostly by means of plastic pipes (PVC, PE etc.). Due to the requirements for height arrangement of filters in relation to the inflow and outflow, pipes are not placed in a non-freezing depth. Freezing can be prevented by thermal insulation backfill. A manifold is designed to evenly distribute mechanically pretreated wastewater across the entire width of the inlet part of the filter (both types). Regular maintenance and treatment of the manifold and outlet openings are very important. There are many types of wastewater distribution. One is to bring wastewater into the center of the of the inlet edge and from this place discharge is taken out by several separate pipes into the focus of individual zones. The nodes in diverting shaft solve regulation. Distribution is maintained above the level of the filter and backfilled with gravel used in the distribution zone. This way uniform distribution of influent, e.g. 3-9 outlets, can be achieved and it is sufficient to clean it once a year.

The distribution by means of a perforated pipe is often used into which wastewater from distribution shaft is supplied (in the case of more beds or from the mechanical pretreatment facility, on one side of the filter. This does not guarantee an even flow of wastewater around the entire inlet edge of the profile, and if wastewater flows only in one place, there may be the local congestion and clogging of the filter. Moreover, it is difficult to clean longer manifolds and therefore it should not only be discharged at the end above the surface but access to the central part is also recommended. Pipes are then the most frequently placed on the surface and stratified by coarse stones. According to local weather conditions it is necessary to take into consideration the realization of two distribution pipelines. The first one for normal operation located at the surface of the filter or better on the surface, the second one in greater depth that will be determined for the use in the period with severe frost.

Regulation overflow in revision shaft proved to be useful to the level regulation in saturated beds, that is formed by adjustable flexible hose (or plastic pipe) suspended on a frame and the bottom part connected to the drainpipe. The regulation is smooth and safe. For flexible shaft spillways it is necessary to take into account the lifetime of suspension (plastic chain is recommended) and regular treatment of spillway edge. The other disorders have not occurred so far. It is advantageous to supplement these facilities with a plastic based outlet slide valve cap.

Regulation device for smaller wastewater treatment plants is usually fitted into the shaft pre-manufactured from suitable plastics (polypropylene). The shaft diameter is usually from 60 to 100 cm; alternatively it may have a square or rectangular cross section. The shaft is fitted in a trench on the underlying layer of reinforced concrete. It is also possible to mount only gravel underlayer, according to local conditions.

## 7.4 Role of Vegetation in Constructed Treatment Wetland

Although the presence of macrophytes in the CTWs is not probably crucial for the considerable increase of treatment performance, plants fulfil many important functions:

- Protection and stabilization of the surface of the filter material
- Formation of a suitable environment for microorganisms present in the filter material
- Partially protection against clogging of the filter material
- Oxygen supply to the area close to the roots of macrophytes – formation of aerobic and anoxic zones in the immediate vicinity
- Enhance the aesthetic effect and allow positive integration into the landscape
- Improve the microclimate properties by high transpiration

- Reduction of runoff of treated wastewater to the opportunity to design drainless systems
- Nutrient depletion and vice versa supply of carbon from decomposing organic residues

The role of wetland vegetation in CTWs is still being researched. The previous results have confirmed that the vegetation has a definite influence on the treatment process. The subject of the research is two factors: the amount of oxygen in the root zone and nutrient consumption. All the wetland plants (macrophytes) absorb and accumulate a range of macro- and microelements, including nutrients, heavy metals etc. They are also distinguished by the ability to bind mineral nutrients into organic matter among all the other plants According to the research referred to in the literature (Húska, 2003; Kröpfelová et al., 2009; Vymazal et al., 2010a), the elements are preferentially distributed to the underground plant organs, with the exception of calcium, which is preferably supplied into leaves. The range of accumulation depends on the concentration of the elements in wastewater. E.g. when there was three times higher increase in the concentrations of P, K and Zn, it was observed that common reed plants also accumulated more nitrogen and it was preferably stored in aboveground organs. The location of plants to influent of wastewater also had the effect on the rate of accumulation (Húska, 2003). The values of nitrogen and phosphorus content in dry matter of biomass were found in the range of 20-50 $g/m^2$ per year, depending on the availability of nutrients. The timing and frequency of harvesting and wastewater load size have great influence on the nutrient content in biomass, as well (Květ, 2003). The greatest accumulation of nutrients in the aboveground organs occurs in early summer. On the contrary, in old growth in the winter the nutrient content is low. However, the harvest in the growing season only tolerates reed canary grass. Reed cut in the growing season regenerates very badly. All these findings result in the statement that the rational estimation of removal of nutrients by biomass is 5-10 % (up to 20-25 %) of the wastewater load supplied to the filters (Květ, 2003).

Other important functions of vegetation in the CTWs include stabilization and thermal insulation of filter material in the winter (it helps to maintain higher temperatures – e.g. at temperatures –10 °C there is the reduction and at the further decline (-5 °C) the discontinuation of nitrification) and formation of structures serving as carriers of microbial population involved in treatment processes (for the filter planted with reed the population density was observed on the roots of plants 1 to 2 orders of magnitude higher than on the surface of mineral particles - Květ, 2003). Organic residues also serve as a source of organic carbon necessary for treatment processes.

Diffusion of oxygen into the filtration material was detected in the area of fine roots and root tips. The identified amount of oxygen supplied to the filter material by macrophytes ranges in values 5-12 $g.m^{-2}.d^{-1}$ (Květ, 2003); other authors published 5 and 45 $g.m^{-2}.d^{-1}$ of wetland surface area, depending on plant density (Boon, 1985; Lawson, 1985). However, current estimates are that the transfer is more typically 4 g of oxygen per square meter (Brix, 1994; Vymazal et al., 1998).

Practically, aerobic conditions are present only in the vicinity of roots and rhizomes; otherwise anaerobic conditions prevail in the filter material, especially in the inlet part of the filters (Květ, 2003).

The most widely used wetland plants include common reed (*Phragmites australis*), reed sweet-grass (*Glyceria maxima*), reed canary grass (*Phalaris arundinacea*), cattails (*Typha latifolia* and *Typha angustifolia)*, sedges (*Carex sp.),* and others (*Schoenoplectus, Juncus, Iris, Sparganium, Acorus, Butomus, etc.).*

Generally, it is good for planting to use seeds and rhizomes of plants originating from the same climatic conditions in which the newly built treatment plants of filters are located. The summary of existing knowledge about the vegetation of selected CTWs:

CTWs plants are usually planted with common reed (*Phragmites australis*). From the other plants that are planted to CTWs there is reed canary grass (*Phalaris arundinacea*) on the first position, less frequently used are cattails - *Typha latifolia* a *Typha angustifolia*. For the edges there are sometimes designed clumps of other wetland plants to improve the aesthetic appearance (e.g. yellow iris - *Iris pseudacorus*, common clubrush, reed sweet-grass and others).

The use of all these plants is shown to be suitable, however appropriate plant species have to be selected according to the design of the wetland. Different plant species also have different root depths and forms, which can affect treatment performance.

With growth of planted seedlings it was observed that there is faster and more consistent involvement than in clumps of vegetation when there are significant losses. Planting of pre-planted seedlings should be preferred. The planting density – at reed 4 plants per 1 $m^2$ and at reed canary grass 10 plants per 1 $m^2$ mostly seems to be sufficient.

There is inconsistent approach to mowing vegetation: in some CTWs it is not required to harvest reed by planners, on the other ones it is ordered in the operating rules once a year. Reed canary grass is usually harvested in all CTWs – in some only once a year, on the others twice a year. There is also the difference in the period in which the vegetation is harvested (summer-June to July, autumn or spring).

In the opinion of many experts, it is not necessary to mow reed, at least not annually. Out of the question, reed must not be mown in spring and summer period, because the vegetation would be weakened. If there is mowing in autumn or winter period, care should be taken to ensure that the cut is higher than the water level can reach. If the water penetrated rhizomes, the plants will not survive. With regard to the aesthetic aspect of the operation of CTWs and also for easier control of the surface of filters and distribution piping it can be recommended to harvest biomass of reed annually.

It is necessary to mow reed canary grass because it generates large amount of easily degradable organic matter, which must be removed from CTW filters. The best variant is to mow reed canary grass twice – the first mowing in summer (June to July) and the second one in autumn (let plants lie on the filter surface as insulation and dig them in spring). In any case, it is not appropriate to mow plants in spring because of damage of young budding offshoots. It is also possible to mow the vegetation of reed sweet-grass (*Glyceria maxima*).

The harvested material is often burned off the CTW filter or composted, which is the way that should be prioritised. Only exceptionally reed canary grass is dried on hay. In some places there was found out burning of mown reed on the CTW filter, which is inappropriate. In any case it is not convenient to burn mass on the constructed wetland filters. There is a re-enrichment of the system in substances bound in vegetation cover and there may also be vegetation damage.

In some cases reeds harvested in autumn are left on the treatment beds until spring in order to enable additional insulation during winter. Later in the spring they are removed and composted. Biomass of harvested reed canary grass can be used for animal feed, only if the analysis of the content of hazardous substances is made and there is a certainty that wastewater is not contaminated by heavy metals or other pollutants. Reed can be used to produce mats and rustles of cattail serve as a material for hand making of small objects. Due to potential bacterial contamination biomass should be dried at higher temperatures in drying rooms.

Temporary short-term flooding of filter material has proven to be a good means of fighting against weeds. Prolonged flooding hinders the development of reed and supports the development of biomass of floating plants such as duckweed (Lemnaceae) that prevents access of air and generates a large amount of degradable organic matter.

The spring water level increase in CTW filters is recommended against weeds, the terminal buds and young offshoots of reed must not be sunk. The use of herbicides cannot be recommended.

Trees should not be located in the immediate vicinity of CTW, they shade the constructed wetland filters and by means of self-seeding process cause weed infestation by problematically removable seedlings of trees and bushes. Deciduous trees also mean intake of degradable organic matter by leaves fall (clogging of filter material, supply of organic matter and nutrients). Weed infestation of filters by woody plants can be regulated during mowing of macrophyte vegetation.

It is also important for the projects of CTWs to contain a section devoted to vegetation – including sufficiently precise pieces of information on the nature of the proposed plants, the method of planting and care of vegetation. After the completion of the construction the data should be specified and concretized in handling and operating rules.

Photo 10: Photographic Documentation of the Care of Wetland Vegetation on the Monitored Constructed Treatment Wetlands

CTW Hostětín (CZE) – Mown vegetation of reed canary grass after mowing in summer (left) – high-grown vegetation of reed canary grass during the growing season (right)

CTW Olší nad Oslavou (CZE) – Vegetation of reed during the growing season (left) - constructed wetland filters after burning of old growth of reed in March – old growth is burned on constructed wetland filters (right)

CTW at Čehovice (CZE) – reed during spring period approximately one month after burning old growth (left) – constructed wetland s after burning of old growth of reed in March – old vegetation is burned outside the constructed wetland filters (right)

CTW at Dražovice (CZE) – Vegetation of reed is not mown, harvested or burned – a view of vegetation during the spring period at the time of sprouting of new shoots of reed (left) – a view of constructed wetland filters with high-grown vegetation of reed in the middle of the growing season (right)

# 8 Soil Filters

Soil filters are technological devices belonging, like as constructed wetland wastewater treatment plants and waste stabilization ponds, to the group of natural technologies of water treatment. Like the other devices, they can be divided into filters with vertical, horizontal and radial flow, but soil filters are without vegetation, often realized in underground. From terrain you can see only revision pipes that protrude from the grass or another terrain finish. The combination of these filters rarely occurs. It is necessary to ensure that the flow of treated wastewater is uniform throughout the whole filtration process. The advantages of soil filters include the organic character of the device, the possibilities of favourable integration into the environment, a simple technological design, relatively low investment and operating costs, minimal energy needs, possibilities of binge overload, relatively good treatment effect from the beginning of the operation, the ability to short-term and long-term shutdown, and treatment of organically low-loaded wastewater that cannot be cleaned with the usage of other intensive methods such as activation dry treatment. The disadvantages of soil filters include clogging, less effect on ammonia removal and relatively large surface intensity.

Depending on the type of treated wastewater, the depth of filtration layer varies (Šálek - Tlapák, 2006):

- treatment of surface water (precipitation water from roofs and car parks, etc.): shallow filters with a thickness of 0.6 to 0.8 m
- wastewater treatment for small producers – medium deep filters with a depth of 0.8 to 1.6 m, and the depth of 0.8 to 1.2 m can only be used for the second stage of biological treatment (placed behind the conventional wastewater treatment, constructed wetland treatment plant, biodisc treatment plant, sprinkling filters or a biological pond)
- the first stage of biological treatment – deep multilayer filters with a thickness of at least 1.6 m (usually up to 2.4 m)

Table 8.1 Types of Soil filters According to the Filling, the Use, The Load and Roughly Indicative Treatment Effect (Šálek-Tlapák, 2006)

| Filtration Environment | Load h [m] | | Treatment Effect [%] | |
|---|---|---|---|---|
| | Average | Maximum | $BOD_5$ | SS |
| Light loamy soil | 0.005- 0.015 | 0.020 | 95 | 98 |
| Fine-grained sand (1-2 mm) | 0.020- 0.040 | 0.060 | 90 | 85 |
| Coarse-grained sand (2-4 mm) | 0.060- 0.100 | 0.150 | 80 | 85 |
| Fine-grained sand (1-2 mm) | 0.040- 0.080 | 0.125 | 80 | 75 |
| Coarse-grained sand (2-4 mm) | 0.100- 0.150 | 0.250 | 75 | 70 |

Soil filters can be designed without vegetation, with only soil surface layer of (Photo 11), providing, if necessary, the thermal insulation during the winter period. An alternative is to sow grassland or specifically selected plants on the surface. In the presence of wetlands, there is a possibility to control the water level in the filter since the combination is already the constructed wetland wastewater water treatment plant. If fast-growing energetically usable trees are present, the locked level in the filter is proposed. When treatment, the physical, chemical and biological processes naturally occurring in the soil are utilized (Šálek and Tlapák, 2006).Filters are mostly based in the excavated basin; consequently, the wastewater must be appropriately hydraulic isolated from the ground. This is also applicable to filters of constructed wetland wastewater treatment plants. Filters with finer fillings are applied as final treating equipment for biological wastewater plants. They are commonly used as the master device to the biological treatment after mechanical pretreatment. In

this case, they require reliable coarse pretreatment and mechanical treatment preferably in an Imhoff tank. Small producers can apply a three or multi-chamber septic tank.
In terms of decentralized systems of wastewater disposal, the most suitable combination is a septic tank + soil filter. With proper design, this solution represents a full treatment of wastewater from the house.


Photo 11: Soil Filter (Author of the photograph: Archives VÚV TGM Praha)

The quality of runoff water from a well-functioning soil filter reaches the quality of treated wastewater from mechanical-biological wastewater treatment plants by measurements made at several treatment plants of this type in the Czech Republic (Mlejnská and Wanner, 2008; Mlejnská et al., 2009). It is possible to discharge the treated wastewater into the recipient and public sewerage, or in compliance with the statutory conditions to soak. Mlejnská and Wanner (2008) found that the treatment efficiency of several soil filters with the average inlet concentrations was COD 480 $mg.l^{-1}$, $BOD_5$ 219 $mg.l^{-1}$and SS 196 $mg.l^{-1}$: average removal efficiency COD 82 %, $BOD_5$ 90 % and SS 83 %. In case that ammonia nitrogen is present, the average removal efficiency was 39 % at the average inlet concentration 33 mg/l. Also, the phosphorus removal efficiency was found quite high, namely 47 %, the average inlet concentration of 6.3 $mg.l^{-1}$.

Soil Filters
Soil filters fall into a group of filtration devices, serving as either the main treatment stage, or as tertiary final treatment. Soil filters are designed with vertical flow upward or downward, horizontal flow in the saturated, partially saturated and unsaturated filtration environment. These are regular cylindrical or prismatic plastic or reinforced concrete tanks and excavated tank with suitable waterproofing. Most of soil filters are placed in the ground so that the presence of the treatment cannot be identified from the terrain. Ventilation chimneys may be discharged only above the ground and they also serve as a partial oxygenation of the filtration environment of in the soil filter.
Advantages of soil filters

- Very energy-saving treatment element, functioning without electricity supply
- Low operation costs, low demands on operation
- The proper design can achieve elevated treatment effects
- Soil filters with flow in unsaturated filtration environment (non-flooded) are also suitable for the removal of ammonia pollution
- When there is a convenient arrangement, it is possible to backwash filters by treated wastewater without the necessity of filter material extraction.

Disadvantages of soil filters

- When used as the main treatment stage, there is the high surface demand (up to 5 $m^2$)
- The risk of clogging of the filter material in case of inappropriately designed pretreatment
- For covered soil filters (located in the terrain) it is difficult to control the state of the filtration environment and the process of the filtration
- Soil filters with the saturated filtration environment (flooded) remove ammonia pollution inadequately

## 8.1 Soil Filter as the Separate Treatment Unit

The basic design parameters of filters used as the second stage of biological treatment (e.g. behind three-chamber septic tanks, sedimentation tanks, etc.) are the filter surface, depth of the filtration layer and hydraulic loading on the filter. The soil filter area is calculated (Šálek and Tlapák, 2006) as follows:

$$S_F = \frac{p.e. \cdot Q_d \cdot k}{h_d} \quad [m^2] \qquad (7.5)$$

where

p.e. – the number of connected inhabitants

$Q_d$ - average daily production of wastewater by one inhabitant [$m^3.os^{-1}.d^{-1}$]

*k*- coefficient characterizing local conditions (*k* = 1.0 to 1.6)

$h_d$ - hydraulic loading of the filter (daily filling hydraulic load) [$m.d^{-1}$]

Hydraulic soil filter loading *h* depends on the composition of the wastewater, previous treatment, height, the type of filter material and required treatment effect. When using the filter as the first stage of biological treatment, it is necessary to design lower values. For water treatment, it is possible to design higher values. As an indication, these values are shown in Table 8.1, where a lower figure is determined for more strongly contaminated water, i.e. the values of $BOD_5$ over 250 $mg.l^{-1}$.

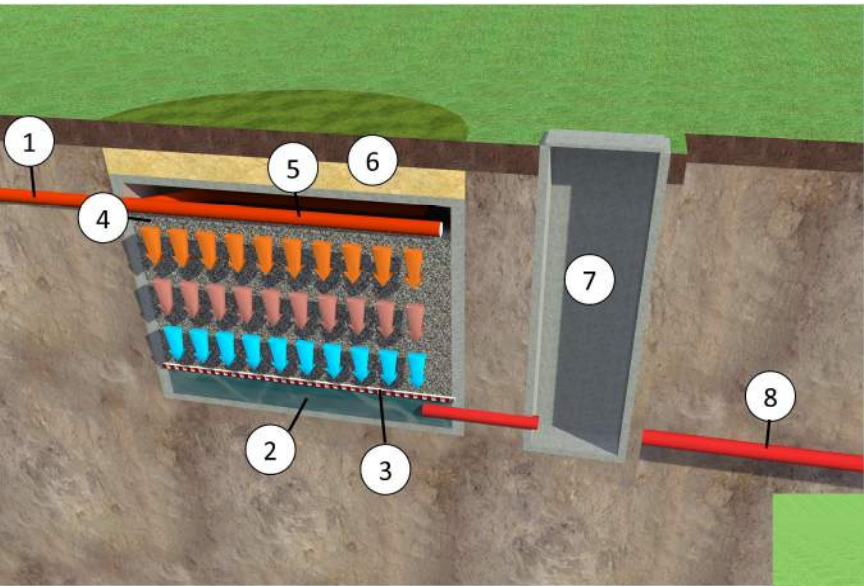



Figure 8.1 Vertical flow in unsaturated filtration environment downwards, even distribution of flow across the filter surface, sampling the filtered water from the bottom (1 – inlet, 2 – collecting space under the soil filter, 3 – fixed sieve of resistant material, 4 – filtration material, 5 – distribution pipe, 6 – initial backfill sand or clay, 7 – control shaft, 8 – drain)

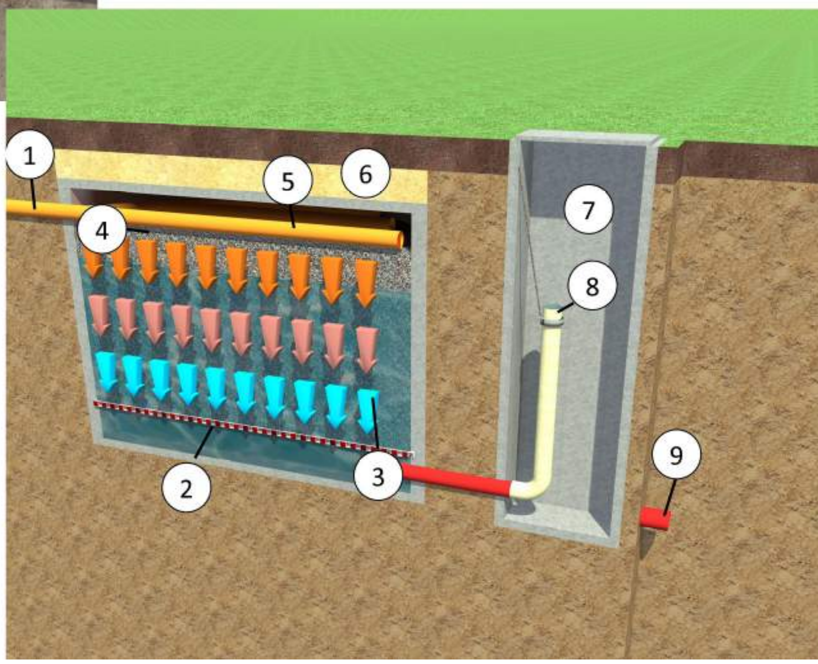



Figure 8.3 Vertical flow in saturated filtration environment upwards, even distribution of flow across the filter surface, sampling the filtered water from adjustable weir (1 – inlet, 2 – collecting space under the soil filter, 3 – coarse sieve, 4 – filtration material, 5 – drain pipe, 6 – initial backfill sand, 7 – control shaft, 8 – outflow pipe)

It is possible to divide soil filters for treatment and final treating of wastewater into four fundamental groups according to the way of hydraulic flow and basic arrangement, shown in the following figures.

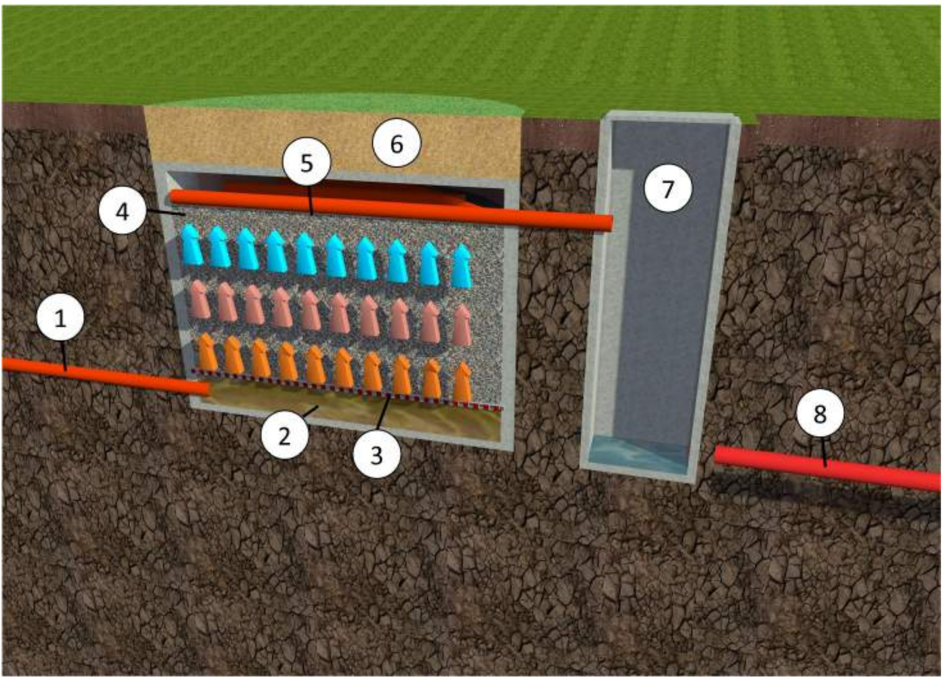



Figure 8.4 Vertical flow upwards in saturated filtration environment; alternatively vertical flow upwards in saturated filtration environment, pulse emptying of the upper part of the progressive filtration environment (1 – inlet, 2 – collecting space under the soil filter, 3 – fixed sieve of resistant material, 4 – filtration material, 5 – distribution pipe, 6 – initial backfill sand or clay, 7 – control shaft, 8 – drain)

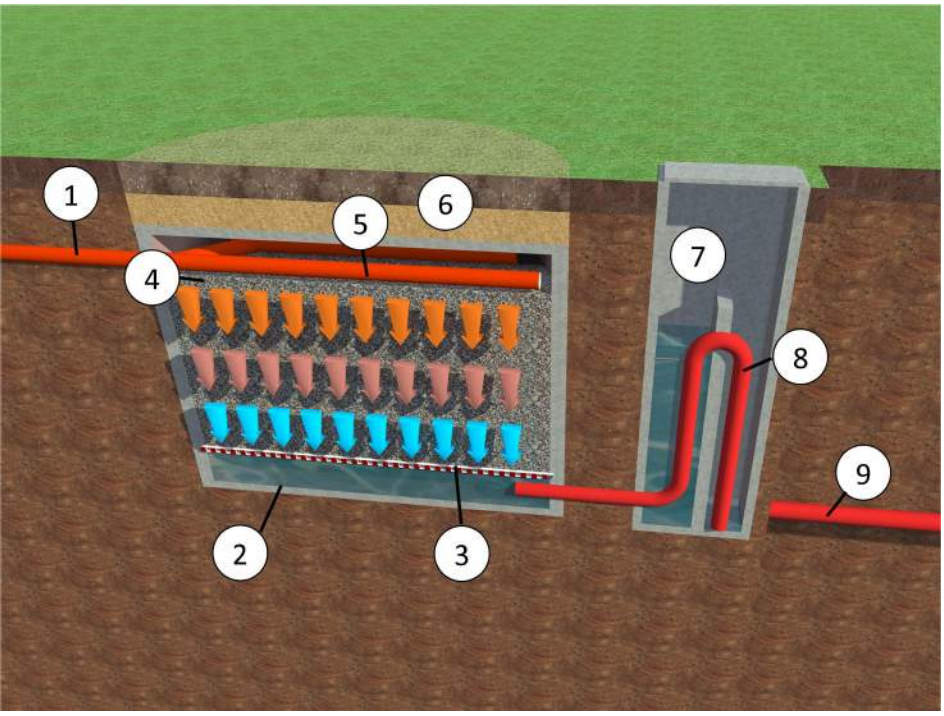



Figure 8.2 Vertical flow in saturated filtration environment downwards, even distribution of flow across the filter surface, sampling the filtered water from adjustable weir (1 – inlet, 2 – collecting space under the soil filter, 3 – present water level, 4 – filtration material, 5 – distribution pipe, 6 – initial backfill sand or clay, 7 – control shaft, 8 – regulatory flexible pipe, 9 - drain)

Soil filters are designed according to the use and the type of loading or the operation according to the following division:

- For a year or growing (frost-free) operation
- To clean mechanically treated wastewater or for treatment of mechanically- biologically treated wastewater
- With vegetation (grasses, wetland vegetation) and without vegetation
- Single and multiple –stage arrangement
- With uniform filling, pulse overflow, splashing on the filter surface
- With various filter material - homogenous, heterogeneous, arrangement in layers
- With various means of filter environment regeneration (regeneration of the upper inlet layer, the entire filling, back flushing, aeration, the use of enzymes)
- Continuous operation, intermittent operation, periodically intermittent operation (short-term, long – term) with the simultaneous aeration
- Alternatively vertical flow upwards in a saturated filtration environment, pulse emptying of the upper part of the filtration environment
- With artificial aeration
- With buffer tank allowing the uniform loading of the filter

Soil filters are also able to achieve the reported treatment values only if they are properly designed, namely the objects of pretreatment with sufficient area. Austrian standard for example requires filter ground surface more than 4 $m^2.p.e.^{-1}$ if the requirements for ammonia are required to be achieved.

Soil filters can be realized in several material variations, focusing on isolation from the subsoil:

- The foil – PP, PE, PVC, rubber – always cover from both sides of geotextile and sand underlayer with a thickness at least 5.0 cm
- Concrete tank – the establishment of the concrete slab thickness of 15 cm, establishment of precast concreting of the tank or on the spot
- Plastic tank – the product from PP, extruded PP, PE – similar to the sumps or septic tanks, square and cylindrical shapes
- Sealing by natural material – clay seal with a thickness of 30 cm – should be applied moist

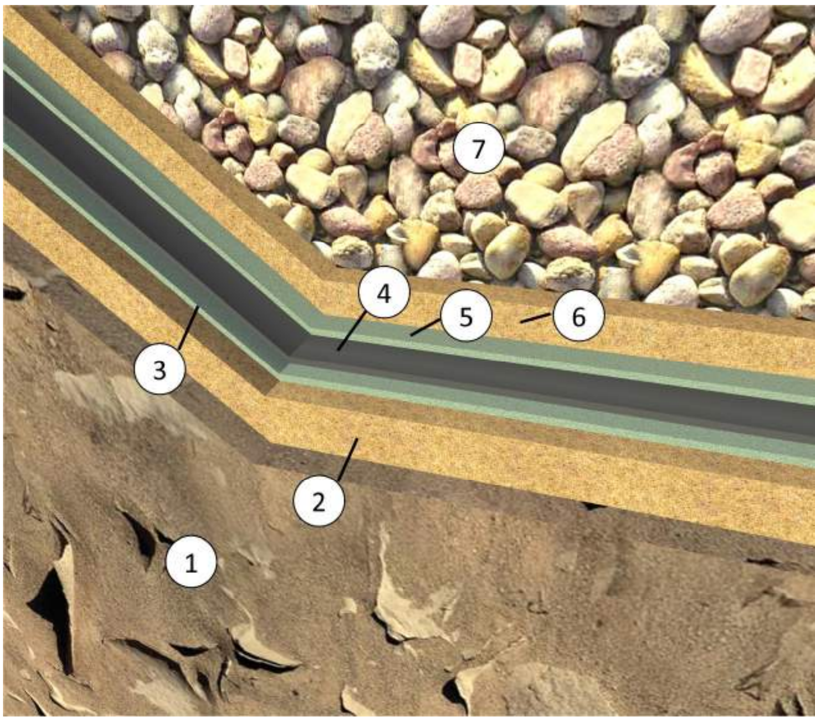



Figure 8.5: Composition of Foil Seal: 1 – original terrain, 2 – sand underlayer thickness 5 cm, 3 – geotextile, 4 – foil, 5 – geotextile, 6 – sand backfill, 7 – coarse filter material

# 9 Wastewater Stabilization Ponds

Stabilization ponds are an important part of the natural treatment ways. The desired treatment effect is achieved by physical, chemical and biological processes occurring in the aquatic environment in the presence of water and wetland biocoenosis (bacteria, phytoplankton, and zooplankton), higher vegetation and organisms.

Wastewater stabilization ponds can be divided into the categories listed in Table 9.1 according to the treatment technologies.

Tab. 9.1 List of Basic Types of Stabilization Ponds and Possibilities of Their Use

| Stabilization | Pond Type | Division | Possibilities of Utilization |
|---|---|---|---|
| Treatment and Stabilization of Physical, Chemical and Biological Properties | Aerobic Ponds | Low-loaded | Polluted wastewater treatment in the climate of Central Europe |
| | | High-loaded | Municipal wastewater treatment in the climate of South Europe |
| | | Continuously aerated | Intensive municipal wastewater treatment |
| | | Final treatment | Final treatment of treated wastewater after mechanic – biological treatment |
| | Facultative | Temporary ponds on inflow | Form the transition of anaerobic and aerobic process in one pond |
| | Anaerobic Ponds | Flow | Anaerobic wastewater treatment |
| | | Sedimentation | Prolonged sedimentation of municipal and industrial wastewater |
| | | Accumulative | Wastewater treatment of campaign producers (sugar mills, starch plants etc.) |

Waste stabilization ponds are used mainly for sewage water treatment of individual households, groups of houses, municipalities, exceptionally up to 15,000 p.e., hotels, recreation facilities, restaurants, summer camps, small plants, agricultural and industrial wastewater treatment (especially the food industry), treatment of polluted surface water and treated wastewater.

Waste Stabilization Ponds

Stabilization ponds are an important part of the natural treatment ways. The desired treatment effect is achieved by physical, chemical and biological processes, taking place in the aquatic environment with the participation of aquatic and wetland biocenosis (bacteria, phytoplankton, zooplankton), higher vegetation and organisms. Their task is to regulate and stabilize the physical, chemical and biological properties of treated wastewater. They are divided into low- and high-loaded ponds. List of basic types of WSP is in table 9.1.

Advantages of stabilization ponds Use

- Environmentally-friendly treatment of pre-treated wastewater using natural methods taking place in the aquatic environment
- Low demands on energy, significantly lower operation costs for comparable investment costs with artificial (machinery) pretreatment methods
- Relatively rapid incorporation, the possibility of short-term and long-term operation shutdown, resistant to short-term hydraulic and pollution overloads

- Comparable pollution removal efficiency treatment effect with convention methods for wastewater treatment, high efficiency removal of bacterial contamination
- The use as a third treatment stage treatment for sewage
- The convenient combination with the other natural treatment methods and final wastewater treatment, especially by means of irrigation by cleaned wastewater, aquaculture etc.
- The beneficial integration into the environment and natural landscape

Disadvantages of stabilization ponds utilization

- The main disadvantage is relatively high surface requirements for the construction of the system of biological tanks. This drawback will not be reflected in the occupation of infertile or rather otherwise economically unusable land
- Slightly lower pollution removal treatment effect in the winter when it is necessary to supply the missing oxygen by means of artificial aeration
- The necessity to capture and subsequently use excessive biomass from the tanks
- The removal of sediments (sludging process) of particular tanks and their subsequent utilization. The necessity of the sludging process of tanks is significantly lowered by quality mechanical pretreatment
- Increased costs on the maintenance of the littoral zone and surroundings of tanks (mowing of grassy vegetation)
- If don't harvested sediments or biomass, odor may occur due to the biological breakdown

## 9.1 Aerobic Ponds

Aerobic ponds with the prevailing oxygen regime belong to one of the most widely used technologies. The resulting effect of treatment of ponds depends on the technology of treatment, especially on the quantity, the physical, chemical and biological composition of inflowing wastewater, the proportion of ballast water, the temperature, characteristics of the aquatic environment, its recovery, the intensity of self-treatment processes, hydraulic conditions, the length of filtration area, hydraulic retention time, the number of ponds in series, climatic conditions, especially the temperature, precipitation, the direction and strength of wind, the number of frosty and icy days, the location of ponds in terrain, the degree of wastewater dilution, surface water inflow, etc.

### 9.1.1 Treatment Processes in Aerobic Ponds

The course of treatment in aerobic ponds according to Sládeček and Sládečková (1989), is based on saprobic succession at the inlet to the pond with anaerobic and aerobic environment following – Table 9.2.

According to the initial load biocoenosis gradually indicates each degree of saprobic system from eusaprobity (wastewater community) to limnosaprobity (surface water community). Decomposers are gradually relieved by producers and at final treatment ponds even consumers.

Tab.9.2 Summary of organism occurrence in stabilization ponds (Sládeček and Sládečková, 1989)

| Decomposer | | Producers | | Consumers | |
|---|---|---|---|---|---|
| Anaerobic Bacteria | Aerobic Bacteria | Mixotrophic Green Organisms | Autotrophic Green Organisms | Zooplankton | Fish |
| *Amoebabacter, Zoogloea ramigera, Zoogloea sp.div.*, Viterescilla sp. *Chromatium* etc. | Various kinds of coccus, rod-like, zoogloe and filamentous bacteria | *Euglena, Chlamydomonas, Chlorogonium, Chlorella, Monoraphidium,* etc. | Various types of green algae (*Scenedesmus, Coelastrum, Micractinium* etc. ) and cyanobacteria (Cyanobacteria) | Protozoans (Protozoa), rotifers (Rotatoria), daphnia (Cladocera) copepods (Copepoda) | Placing of less demanding kinds of fish |

The sources of oxygen in aerobic ponds provide inflowing surface water, partly wastewater, ballast water and the transfer of atmospheric oxygen from the atmosphere in the contact with water level. The main producers of oxygen are algae and other green water plants during photosynthesis in the vegetation period. The controlled aeration is provided by artificial aeration to which the different types of aerators are used (turbine aerator, ejector pump, microbubble aeration elements, etc.) Aerobic ponds are characterized by extraordinary treatment effect in removing coliform bacteria, enterococci, anaerobic clostridia, etc. The treatment effect reaches 96 to 99 % according to different authors.

### 9.1.2 Determination of Design Parameters

The basic design parameters of the aerobic ponds include calculating of the area, the mean depth, retention time and the number of ponds in series or in parallel. For low rate aerobic ponds Duroň (1983) recommends, on the basis of the research in the Czech Republic, load 6 g $BOD_5$ $d^{-1}$ per 1 $m^2$ with a minimum retention time of 5 days. For the winter season the additional aeration 1 to 1.5 kg $O_2$ per 1 kg $BOD_5$ is necessary.

The Directive of Germany "Grundsätze für Bemessung, Bau und Betrieb von Abwasserteichen für kommunales Abwasser", (DWA-A 201, 2005), recommends for aerobic non-aerated ponds for 1 p.e. area 10 $m^2$, assuming that the value of $BOD_5$ in the outflow does not exceed 35 g $m^{-3}$. In the design area of 15 $m^2$ per 1 p.e. the required removal of ammoniac nitrogen occurs. The retention time $t_z$ = 20 days. Filfully (in intervals) aerated ponds are designed for the volume load $BOD_5$ 30 g $m^{-3}d^{-1}$, the retention time in the dry weather flow is at least 5 days. Oxygenation ratio is recommended OC=1.5.

The water depth at the aerobic ponds is proposed in the range of 1.0 to 1.2 m by clarity of water, the lower figure is applied to the more polluted water.

The treatment effect of aerobic ponds is recommended to be determined in the relation by Uhlmann et al. (1988), its applicability has been certified in the conditions of Central Europe.

$$C_{out} = \frac{C_{in}}{\left(1 + \frac{K_1 t}{n}\right)^n} \qquad (9.1)$$

where

$C_{out}$ a $C_{in}$ – value $BOD_5$ in outflowing and inflowing water [g $m^{-3}$]

t- average retention time [d]

n- number of ponds in series

$K_1$ - „Removal Rate“, calculated on the base of detailed survey on newly built aerobic ponds by means of nonlinear regressive analysis

$K_1$ = f (volume load, temperature and delay time)

$$K_1 = \frac{t^{-1/[1.391+1.304/T+(0.061+0.05T)/L]}}{0.327+10.277/T+1/[(0.25+0.476/T)L]} \qquad (9.2)$$

where

T - is mean water temperature in the particular season of the year (°C), L = $C_{in}$ / t,

L – daily concentration volume $BOD_5$ (g $m^{-3}d^{-1}$)

### 9.1.3 Design of Aerobic Ponds

Aerobic ponds are designed in a square plane, rectangular and trapezoidal shape. Dissected irregular plan shape negatively affects the flow in ponds, requires an increased number and special location of inlets and outlets. The pond bottom is proposed in 0.5-1 % slope to the drain object. The gradients of slopes of ponds and dams are designed with regard to the stability of 1:1.25 to 1:2.5. It is essential to seal the bedrock of ponds from permeable materials by the clay layer or plastic foils such as PE-H. Upstream slopes are reinforced and nowadays, the major attention is paid to the use of natural methods of fortification. The inlet and outlet must ensure the uniform distribution of wastewater over the entire width of the pond. Aerobic ponds are situated in a series, in the number of 2 to 4 or even more; the layout of the diagram is shown in Figure 9.2. Inflowing wastewater must be well mechanically pretreated on superfine bar screens, sand and grease trap and in sedimentation pond or tank.

Wastewater in aerobic ponds flows by gravity and flows across the entire width of the pond. The system is equipped with a suitable bypass allowing, in case of necessity, the elimination of the pond. In the flat area, the fences can replace the separating dikes. Each pond must be equipped with inflow and discharge structures, alternatively safety overflow, when precipitation water is flowing into the pond. The treatment effect is increased by recirculation. The arrangement of the newly constructed system of WSPs in Southern France is shown in Photo 12.

Photo 12: Arrangement of Aerobic Ponds (Dep. Hérault France) (Štencel et al., 2004)

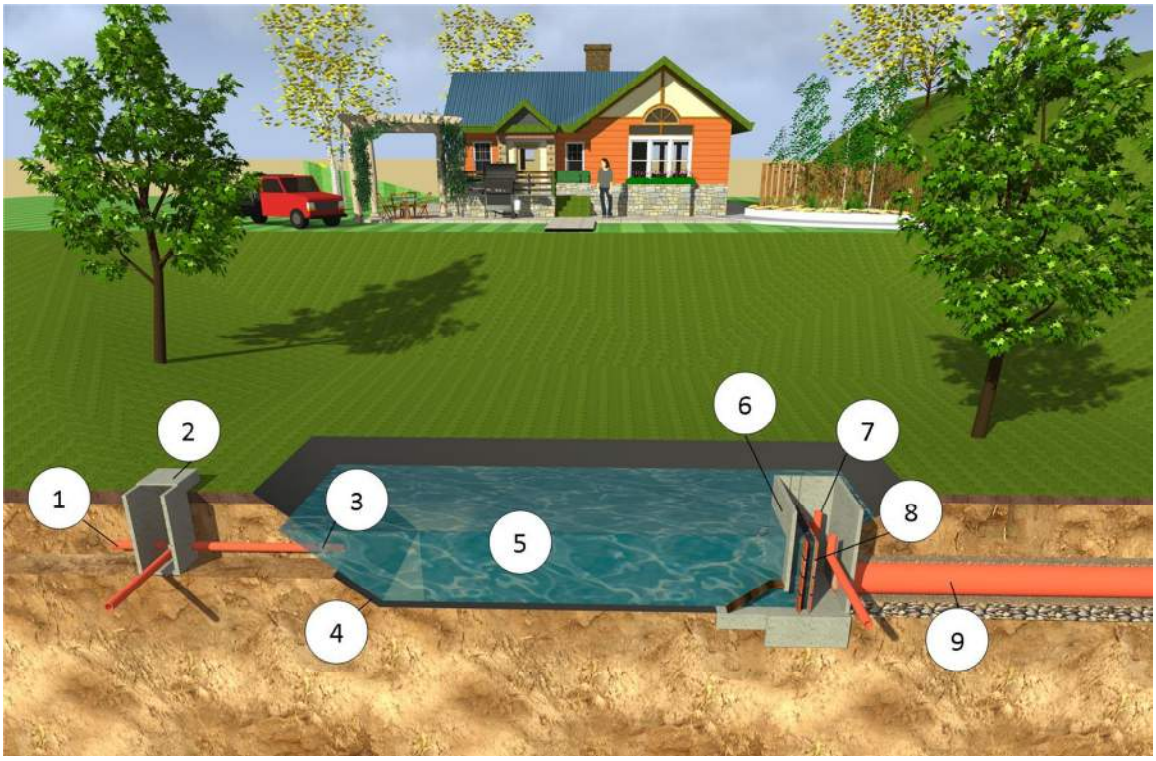



Figure 9.1 Scheme of Arrangement of Inlet, Outlet and Discharge Installations: 1-inlet, 2-two-shaft distribution, 3-dispense manifold, 4-gasket, 5-pond, 6-6-discharge device, 7-shaft spillway, 8-smpling and drain object, 9,11-drain pipe, 10-perforated sampling pipeline

The operation of ponds requires equipment with intake structures ensuring steady filling up and distribution of water on the entire surface of the pond, equipment by conversion and discharging installations and drainage facilities. Safety spillways are designed to divert precipitation water. Specific installations are designed with inlet and outlet; the regulatory installations ensure a steady distribution of water. The design of the equipment for capturing and removing of excessive biomass is important. The example of the arrangement of inlet, an outlet and discharge installation is shown in Figure 9.1.

## 9.2 Continuously Aerated Ponds

Continuously aerated ponds are a solution that is applied in areas where there is a lack of adequate and cheap land. The system is composed of aeration pond with level, turbine or ejector system aerators and the system of final treating aerobic biological ponds or one prolonged rectangular aerobic biological pond with permeable partitions. Nowadays, the

Photo 13: Arrangement of Continuously Aerated Aerobic Pond

control systems are fitted with oxygen sensor (probe). Water baffle partitions will significantly increase the treatment effect; they consist of baffles, fence made of netting with a mesh size of 10 to 20 mm, permeable windrows of quarry stone fence, etc. On the one hand, algal depositions are attached to the fence and enhance the treatment effect and on the other hand the fence also significantly contributes to increasing the uniformity of water flow in the pond. The proposed retention time is 5 or more days; specific area per 1 p.e. is proposed 2-3 $m^2$, the depth of the pond from 1.2 to 2.4 m. The scheme of the arrangement of continuously aerated ponds is shown in Photo 13.

## 9.3 Tertiary Waste Stabilization Ponds

Tertiary waste stabilization ponds mostly have the character of small water ponds, used for treatment of polluted surface water and treated wastewater. The quality function of the ponds requires:

- Uniform mixing of sewage with the water inflow into the tertiary treating aerobic pond in the mixing facility, located upstream from the inlet to the pond
- Residual contamination of wastewater loaded with the entire surface evenly the tertiary treating pond ensuring suitably spaced intakes into the pond which will provide effectively situated intakes into and simultaneously will exclude the possibility of short-circuit currents
- Do not overload the tertiary treating pond by organic pollution to avoid oxygen deficit which would endanger the final treatment effect

Suitable flow rectifiers in the tertiary treating pond are applied to eliminate the negative influence of wind and temperature changes in different parts of the pond (density currents) – see Photo 14.
Sequestration of nutrients (nitrogen and phosphorus) in the tertiary treating pond depends on the type and extent of pollution, climatic conditions (water temperature, solar radiation), weight ratio of carbon to nitrogen and phosphorus C: N: P, which should be ideally around 40:6:1, the water retention time in the pond, the shape, the arrangement, the depth of the pond, biological recovery, etc. The arrangement of tertiary treating waste stabilization pond with submersed vegetation is shown in Photo 15.

Photo 14: Waste Stabilization Pond with Gravel Shoots Rectifier Planted by Vegetation

## 9.4 Anaerobic Ponds

The anaerobic ponds treatment processes take place under anaerobic conditions. They are divided into three groups, namely flow, sedimentation (settling) and anaerobic storage ponds.

Flow anaerobic ponds are mostly prepended before the system of aerobic ponds. The required retention time of water is from 2 to 5 days. Anaerobic ponds have the ability to disrupt the complex binding of organic compounds and subsequently facilitate ongoing aerobic processes. It is usually a regular prismatic pond equipped with inflow and outflow devices that are similar to the aerobic ponds.

Sedimentation (settling) ponds are prepended before aerobic ponds. They form 3 to 5 %, exceptionally more, from the total area of the system of ponds and are used for capturing the most settle able substances. Sludge pond space must be easily drainable and mineable. There are two proposed, of a rectangular ground shape, the ratio of width to length 1:5, depth 1.2 to 2.5 m, including sludge area. The volume of the sludge area is 20 to 25% of the total area. The water retention time in the pond is 1 to 3 days.

Based on experience with the operation of wastewater treatment, and associated technologies, and the use of various installations of mechanical pretreatment including sedimentation ponds (see chapter 6), it is recommended to use and to implement Imhoff tanks and multiple septic tanks rather than these open sedimentation ponds.

Accumulation anaerobic ponds are used for sewage treatment of campaign producers, particularly from sugar mills, starch factories and distilleries. The pond should have a capacity corresponding to the total production of wastewater. The storage pond is equipped with a running installation allowing even distribution of inflowing water. Outflow facility is equipped with the movable discharge device that allows gradual discharge of treated wastewater.

### 9.4.1 Treatment Processes in Anaerobic Ponds

Anaerobic processes take place in non-oxygenated environment. The anaerobic treatment stages are associated with the temperature. At temperatures of $10^{o}$ C below zero, it is very limited. Anaerobic processes are usually manifested by odor defects that may adversely affect the neighborhood. It is important to provide the shift in pH of water reaction to slightly alkaline at the anaerobic degradation of organic matter. According Štěpánek et al. (1979) cit. in Šálek and Tlapák (2006), the most important microbial mainly anaerobic self-treatment processes are:

- Conversion of urea to ammonium compounds
- Degradation of proteins to simple degradation products. The activity of putrefactive bacteria give rise to amino acids as the first and the final products of mineralization are $CO_2$ , $H_2O$, $NH_3$ a $H_2S$
- Splitting of fatty acids molecules and significant production of methane
- Breakdown of cellulose and carbohydrates
- Reduction of sulphate to hydrogen sulphide, nitrate to nitrite, ammonia to the nitrogen gas

Oxidative processes that minimize the formation of odor defects must form the final treatment phase. Accumulation anaerobic tanks for treatment of starch, distillery and especially sugar-making wastewater are relatively well tested and proven in practice. The treatment process in the final phase will be accelerated by the additional aeration.

Photo 15: Arrangement of Aerobic Waste Stabilization Pond

# 10 Using of Aquatic plants for Wastewater Treatment

Aquatic plants treatment systems (including floating technology) have been known for several decades. Like constructed wetland treatment plants, it uses the principles based on natural self-treatment processes. Floating treatment wetland can also be compared with biological ponds. The difference is that floating wetland to improve water quality, in which they are immersed.

The known use of floating treatment wetlands can be divided into "treatment plants bed" and "free floating plants". Floating treatment wetlands differ from constructed wetlands with freely floating plants that use a higher emergent wetland plants growing on a floating carrier. The carrier is in most cases the synthetic material of low volume density.

In contrast, "free-floating plants" use alone growing floating plants such as lesser duckweed (Headley, 2006). Free-floating aquatic plants abroad are commonly used to reduce undissolved and organic matter in sewage and industrial wastewater. Compared to commonly use biological ponds these systems can achieve more efficient removal of undissolved substances and organic matter (e.g. algae) was using a shield, reducing wind and thermal mixing, etc.

Extensive underwater root system of floating plants bed provides a large specific surface for the growth of microorganisms contained in the wastewater. High growth and collection of free-floating masses of plants can also result in significant removal of nutrients and metals. Plants, however, must be harvested regularly. If not, the quality of purified water can aggravate, which is not desirable. By chemical precipitation and interception on the root system, there is also the detention of heavy metals from present water.

Although systems with free-floating aquatic plants show a very promising technology for wastewater treatment, the use of the water hyacinth is on the European territories in temperate climatic zone limited because this plant is subtropical to tropical and consequently, it is not resistant to frost and it does not hibernate in mild climatic zone. Duckweed systems are not so suitable because they do not generate extensive root system and it is necessary to provide a system of baffles so that plant duckweed could not move on the surface due to wind.

Photo 16: Artificial floating wetland with extensive root system developed after six months of operation

Floating Artificial Wetlands have been used to a limited extent to improve water quality, species habitat enrichment and enhancement of aesthetic impression in ornamental tanks. It is assumed that the plant roots play a major role in treatment processes based on the fact that the water passes directly through an extensive root system under floating mat, see Photo 16.

Floating treatment wetlands

Treatment technologies using floating treatment wetlands are based on the processes commonly occurring in wetlands and water areas. The basis is the sealed ponds filled with wastewater and supplemented with wetland and aquatic plants that utilize the nutrients from present wastewater and create the favourable environment for the development of microorganisms involved in treatment processes. The plants are also placed on a floating medium in which the aquatic plant roots or a floating porous material in which the plant grows above the surface. It is also possible to use wetland plants floating free on the surface. There is the reduction of organic pollution, consumption of the nutrients, capturing floating impurities and insoluble substances by the filtration with the interaction of bacteria that are present in the root system. Floating wetland is commonly used for treatment the pretreated wastewater, treatment of wastewater diluted by storm water and for the final treatment of wastewater behind the main treatment stage.

Advantages of floating treatment wetlands

- Environmental and natural character
- Aesthetically affecting in case of proper design of present wetland plants
- In comparison with the filtration technologies, it is not prone to environment clogging
- It captures insoluble substances which in large quantities fall to the bottom
- It is possible to achieve the significantly better removal of ammonia, nitrate, nitrite and nitrogen by means of alternating sections with and without floating plants
- The water level covered by plants prevents the growth of algae in water – plants prevent the penetration of sunlight
- A thermal insulator that will prevent cooling of the treated water in the winter may be used as a floating medium

Disadvantages of floating treatment wetlands

- When the growing process of the roots is not sufficient, the treatment effect is not satisfactory – it is necessary to count with the slow incorporation into the system
- In case of the free-floating plants, the even distribution of the plants on the water surface in the required area is challenging
- The removal of dead parts of plants above the water level and their harvest are operationally very complex
- The need of raking the bottom to prevent the recontamination of water by the decomposition of the sediment
- During the winter the treatment ability is reduced, roots are frozen in ice; the vegetation does not contribute to the treatment process
- The winter operation, especially at freezing conditions, not only requires insulation but also space heating by floating wetlands

During the last two decades artificial floating wetlands in different parts of the world have been studied for a variety of applications. Systems are used for the treatment of such waters:

- Lightening of precipitation water from combined sewerage (storm basin prior to discharge into the stream)
- Sewage and polluted runoff rainwater (involvement in terms of mechanical treatment as well as main treatment stage)
- Upstream wetlands before water supply ponds (reduction of undissolved substances in the water, stabilization)

Floating artificial wetland can also be used to increase the aesthetic value of the biological tank. Another possible example of application is to provide the environment for wildlife, such as birds or vertebrates. Artificial floating wetland can provide birds protection against some predators.

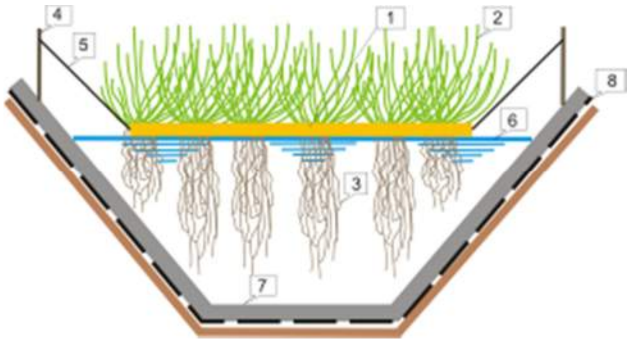


Figure 10.1 Cross section of a floating wetland for treatment of water overflown from relief chamber of combined sewerage in Belgium (Headley and Tanner, 2006)

An example of application can be the system designed in Belgium; it is intended for the treatment of water cascading from a single vent chamber sewerage network (Headley and Tanner, 2006). It is designed to cope with variable inflow of polluted water. The inflow from relief chamber is random in nature, depending on the total precipitation amount, and therefore the system has some interesting structural and design elements (Figure 10.1).

The first phase of the system consists of a sedimentation tank, lined with asphalt concrete due to isolation from the subsoil. The water then flows through the tank, which is almost completely covered with floating wetland that is easily able to cope with irregular inflow of rainwater. The floating barrage prevents large floating debris to penetrate into the zone of floating wetland; it consists of floating timbers of coir, planted with sedge (*Carex sp.*), Common reed (*Phragmites australis*), bulrush (*Schoenplectus latifolia*), cattail (*Typha sp.*) and yellow iris (*Iris pseudacoris*). Swimming of timbers is provided by a foam polystyrene and polyethylene rope, attached to the walls of the tank (Photo 17).


Photo 17: Floating wetland for treatment sewer overflow from a single sewage network in Bornem - Belgium

Preliminary data on the treatment efficiency (Headley and Tanner, 2006) showed 33-68 % removal of COD, SS 66-95 %, 24-61 % and TP, but variable values at eliminating TN. Most commercially available floating wetland systems abroad include mechanical or fine-bubble aeration to increase the content of dissolved oxygen.

## 10.1 Expected Water Quality when using Floating Treatment Wetlands

Nowadays, there is only limited amount of published data from applications of floating wetlands to increase water quality. The experience from Western Europe suggests that even in relatively oligotrophic (nutrient-poor) conditions, water under wetland will be typically have low content of dissolved oxygen (Headley and Tanner, 2006), which has a very positive effect on the removal of ammonia concentration in the water.

A more passive approach to the introduction of oxygen into the water column may include sections with free surface, facilitating the processes of photosynthesis of algae and diffusion through water

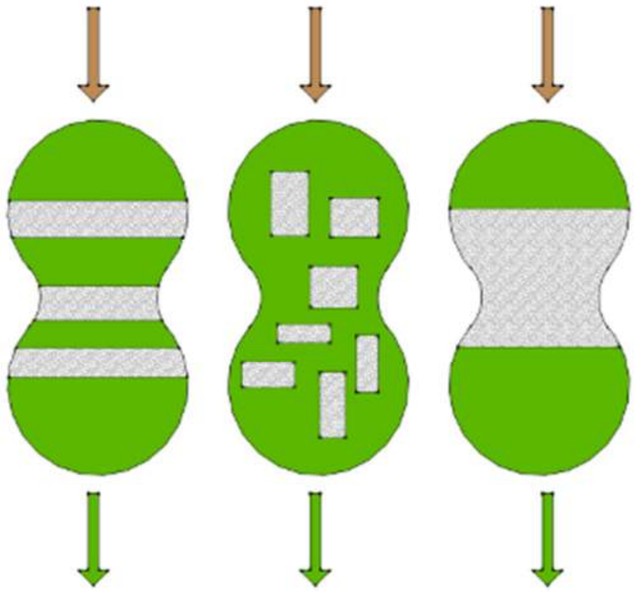


Figure 10.2 Top views of three different combinations of the tank and floating wetland. Bright areas represent floating wetlands, green areas represent zones with free surface (Headley and Tanner, 2006)

surface. In this case, the ratio of free surface to the floating wetland coverage can be an important design parameter to control the oxygen regime of the tank. Free surface zones could be incorporated into the design in various ways, as shown in Figure 10.2. Another option could be to include the output cascade aeration equipment for treatment rainwater.

Comparison with Biological Tanks

Floating wetlands are in a number of important functions different than biological tanks and constructed wetland wastewater treatment plants. Some of them are shown in Figure 10.3 and 10.4. Generally, it is preferable to use them to remove undissolved substances; on the other hand, less effective in the removal of dissolved substances. Generally, biological tanks can provide ideal conditions for the growth of algae. Although algae are useful in removing organic pollution, the excessive development can lead to deterioration of water quality by increasing of the concentration of organic matter in the water. Using a floating mat on the surface of the tank forms a barrier against the penetration of light into the water column and thereby reducing of the potential for algae growth.

Retention of heavy metals by floating wetlands is more efficient than classical constructed treatment wetland (Headley and Tanner, 2006). This is because the roots hanging under floating mat are in direct contact with purified water. In addition, plant roots are in contact with bottom sediments and soil or other filter material. So they have access only to the nutrients contained in the water column, similarly to hydroponics cultivation.

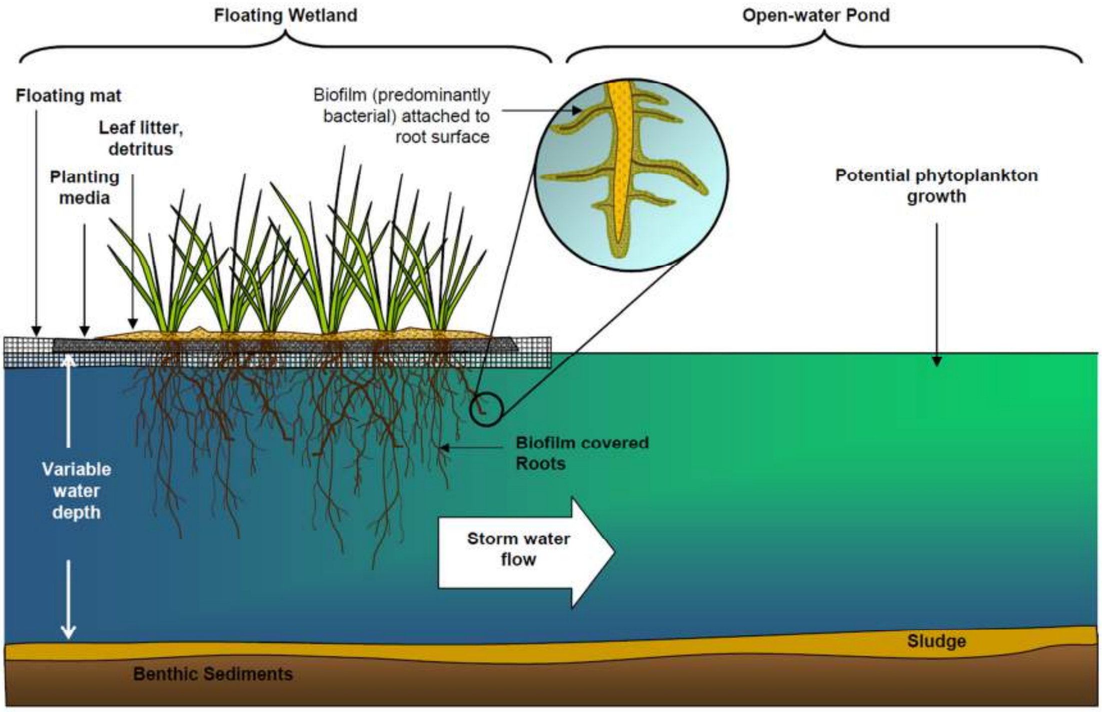



Figure 10.3 Cross section of a typical floating wetland show the main structural elements (Headley and Tanner, 2006)

Differences will probably be in sessile microbial recovery compared with artificial wetland with surface flow. As shown in Figure 10.4, the biofilm that develops on the roots of plants hanging under floating material plays an important role in the treatment process.

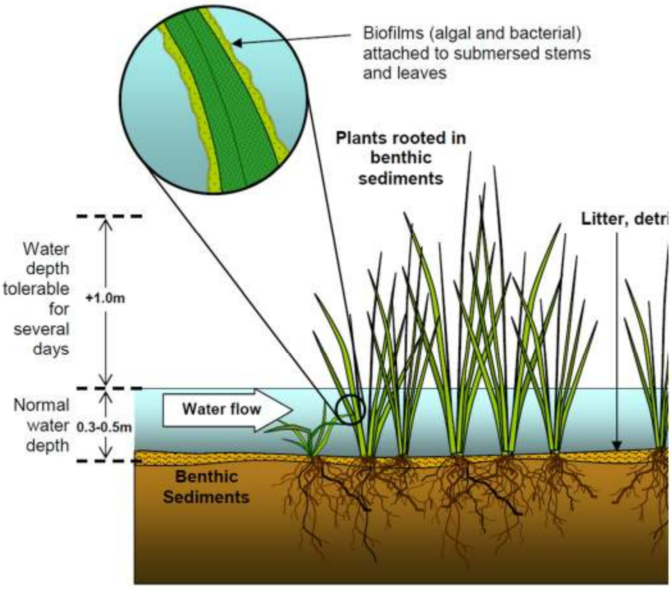



Figure 10.4 Profile of the typical artificial wetland with surface flow shows the key components and requirements for water depth (Headley a Tanner, 2006)

Floating wetlands can be used within the modular extensions especially for the intensification of wastewater stabilization ponds, since the number of people connected to the WWTP gradually increases over time and limits of the discharge gradually reduce in the long term.

## 10.2 Principle of Aquatic Plants Treatment Systems Utilization

The product of free floating plants, as mentioned above, is the biomass used for animal feed, composting and subsequent natural fertilization or other technical purposes. For small natural wastewater treatment plants for individual dwellings floating wetland can be used as output stage in the form of final treating tanks. They provide in addition to improving water quality by metabolic activity of plankton - mainly planktonic algae and higher aquatic vegetation also t he production of usable

Photo 18: Fast-growing floating aquatic plant *Pistia stratiotes* in the final treating tank (Blansko, 2010, photo Z. Žáková)

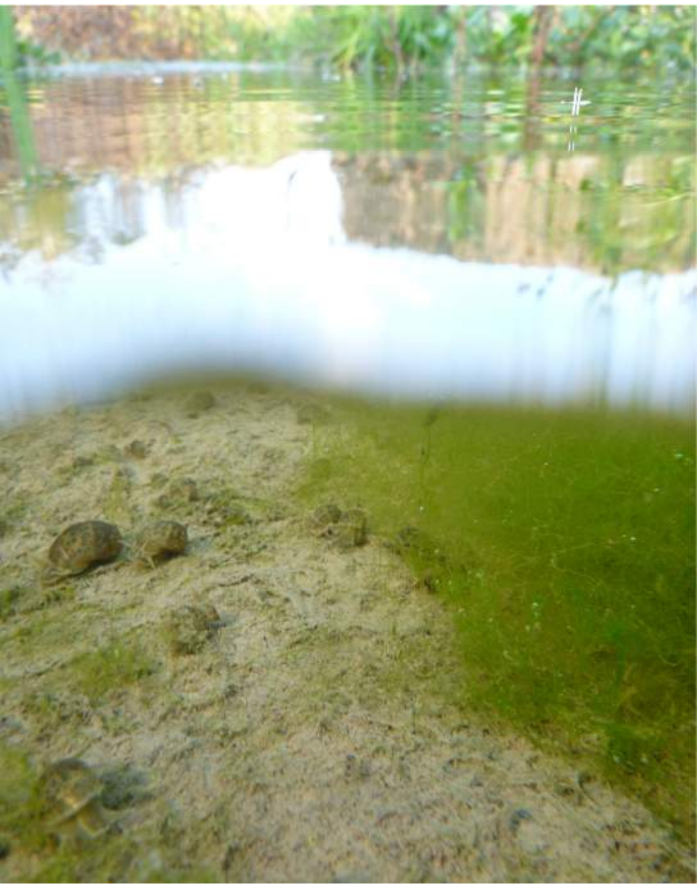
organic matter, or even fish. They can also contribute to the elimination of water evaporation from water surface.

Depending on the type of aquatic plants it is possible to distinguish different systems:
a) systems with floating water plants (duckweed *Lemna spp*., water hyacinth *Eichhornia crassipes* (Photo 20), *Pistia stratiotes* (Photo 18), fern *Salvinia natans* named to water moss, *Azolla sp*.. etc.),

b) systems with submerged aquatic plants (Elodea canadensis, Ceratophyllum demersum, *Egeria densa*, hydrila - *Hydrilla verticillata* etc.) – photo 19,

Photo 19: Submerged parts of aquatic plants in the bank part of hydroponics tank

Photo 20: Final treating tank with floating plants on the water surface (duckweed – Lemna)



c) systems with plants rooting in the bottom with leaves floating on the surface (waterlilies – *Nymphaea spp.* (Photo 22), *Nuphar spp.,* etc.)

d) hydroponics systems with algae, or cyanobacteria (with tiny plankton algae genera *Scenedesmus, Chlorella*, filamentous algae and cyanobacteria – e.g. *Cladophora sp., Spirulina sp.*) – photo 21, with swamp plants (reed, cattail etc.) with crops (tomatoes, peppers, beet etc.), or trees.

Photo 21: Look under the water level, water with developed fibrous algae that provide nutrients consumption and oxygenation

Duckweed (*Lemnaceae*) is pleustonic small plant from the genus Lemna (duckweed) and Spirodela (rolls), living in the surface water. Systems with duckweed are possible to be easily applied, according to the experimental results, in the conditions of temperate European climatic zone for treatment and final treating of water. The use of duckweed for treatment and final treating of water has many advantages, but also limitations.

Advantages:

- Significantly absorb nutrients from the water
- Is not restricted in its development or lack of light, carbon dioxide
- It reproduce very quickly
- It can multiply its biomass within three to five days, each parent plant can make up to twenty subsidiaries in the life cycle of plants
- It is easy to harvest
- The green matter (biomass) may be added to livestock feed rations (they have high nutritional value due to its high protein content - up to 35 %)
- Biomass is suitable for composting
- Early development of algae in the water reduces the concentration of nondissolved substances in the effluent

Photo 22: Final treating tanks with water increases the aesthetic value of the system and the evaporation of water

Weaknesses:

- Duckweed root system does not provide sufficient substrate for the attachment of microorganisms decomposing organic pollution
- It is very demanding in terms of compliance with the harvest mode, because dead matter sinks to the bottom and causes secondary pollution
- Dense continuous growth of duckweed prevents diffusion of oxygen from air to water - prevents photosynthesis, prevents the growth of algae, aquatic environment under duckweed becomes to be without oxygen (anaerobic)

To maintain the high growth rate of duckweed it is necessary to harvest biomass very often, optimize harvest mode. With optimum harvest regime duckweed is capable in the summer to take a day about 2.8 $kg.ha^{-1}$ nitrogen and 0.6 $kg.ha^{-1}$ phosphorus and incorporate those elements into biologically valuable substances (Rejmánková, 1971).The production of dry matter can be up to 8 t.ha-1 (protein production 2.4 $t.ha^{-1}$). These results are commensurate with the production of proteins for our main forage.

## 10.3 Systems with Submerged Aquatic Plants

Immersed (submerged) plants absorb nutrients from the sediments from the water column. Therefore they are not suitable for water with high content of easily degradable organic matter and are used primarily for further treatment. They absorb dissolved inorganic carbon and increase the concentration of dissolved oxygen by their own photosynthesis. The elevated values of pH create optimum conditions for the volatilization of ammonia and phosphorus precipitation. Practical use of systems with submerged vegetation is not very common. They can be classified mainly as the last part of a combined natural system of sewage treatment.

## 10.4 Systems with Natant Aquatic Plants

These systems, for example with water lilies (*Nymphaea spp*.) or *Nuphar sp*. are in practice in natural wastewater treatment plants used sporadically, but in small natural wastewater plants for individual objects can find a suitable application - as a final treating ponds for the closing of combined treatment systems and for their aesthetic value and water evaporation increase (Photo 20).

## 10.5 Stabilization Ponds with Floating Islets

They can be fitted with different swamp plants with aesthetic appearance (e.g, yellow iris *Iris pseudacorus*, *Lythrum salicaria*, decorative form of reed canary grass *Phalaris arundinacea*, a minor form of cattail - *Typha minima*, different types of bulrushes *Juncus sp.div*., saw grass *Carex sp*., etc .), which in addition to improve appearance significantly contribute to the depletion of nutrients and pollutants, water evaporation, provide substrate for microorganisms, exhaust pollution, provide habitat for fish, especially in the winter months, improve the oxygen balance and enrich the water with oxygen. Furthermore, in wintertime, they prevent continuous ice cover due to movement of islets in the wind.

## 10.6 Floating plants systems

Stabilization ponds that specially uses algae and cyanobacteria for treatment of wastewater has been empirically verified in different parts of the world, including California, the Philippines, Germany, the Russian Federation. Water culture with higher plants is also characterized by the ability to remove nutrients and other substances from polluted waters. Various hydroponic culture systems have been developed that can be used for secondary treatment of wastewater and plant production. They must meet the following conditions:

- Plants must be highly tolerant to the content of substances in the wastewater and the pH value of water
- Edible portion of crops must be out of wastewater and must be adjusted before consumption

As an example, it is possible to use such systems when growing tomatoes in wastewater. Tomatoes mainly absorb a large amount of ammonium nitrogen and potassium. Experiments have shown that the contamination of nonsubmerged part of the plant by viruses (MS2 bacteriophage virus model) was neutral, over roots and aboveground part did not get any viruses into fruits. Pepper and sugar beet were also successfully grown in wastewater.

Photo 23: Treatment of water behind the household constructed wetland wastewater treatment plant in the tank with developed aquaculture

## 10.7 Design, Layout and Operation of Floating Wetlands

Systems with water plants of hydroponic and wetland plants may practically, due to the climatic conditions of Central and Eastern Europe, only be used in growing season, at the time of intensive growth of plants. Placing the device into the greenhouse space, their reheating and lightening is not economically viable.

Water treatment using water plants must in each case proceeded with the full mechanical treatment. It is advisable to use aquaculture particularly for purificaton behind mechanical-biological stage of treatment (e.g. behind small household wastewater treatment plant – photo 23) or for treatment behind the constructed wetland treatment plant, soil filter etc. They can be set on the endings of small natural wastewater treatment plants without drain with seasonal operation.

The use of floating aquatic plants for secondary treatment (tertiary treatment) significantly reduces the amount of organic pollution, nutrients and other contaminants such as metals and pesticides in the runoff.

### 10.8 Use of Produced Biomass from Floating Plants

Water and swamp water plants, grown in aquaculture in the pretreated wastewater can be used for various purposes. For example, the use of duckweed was proved to be suitable for animal feed in terms of nutritional value, but can be problematic if purified water contains higher quantities of heavy metals. Heavy metals are accumulated in the biomass of plants, and sludge at the bottom of the tank. It can be assumed that in the wastewater from individual homes, the heavy metals will occur very rarely. Therefore, duckweed can be used without problem for animal feed. Due to the high water content - around 95 %, the plants should be fed on the ground or use transport and storage in drained condition (pressing, drying, etc.). Growing floating aquatic plants for feeding purposes by breeders who have difficulties obtaining fresh food for geese, ducks, nutria, etc. in their neighbourhood appears to be very favourable.

The most common possibilities of biomass use are:

- Composting and vermicomposting (composting using California earthworm). All aquatic and wetland plants grown in final treating systems fit practically for green fertilization and mulching
- Addition into the substrate for the cultivation of edible fungi (mushrooms and oyster mushrooms). For these purposes using water hyacinth biomass was successfully verified;
- The use of biomass grown in small natural wastewater treatment plants for biogas production in our climate is not feasible due to lack of production plants. Reed canary grass seems to be the most appropriate, which is widely used as the constructed wetland wastewater treatment plant
- The use of aquaculture and floating islets in the final treating tanks at the end of drainless wastewater treatment plant to increase water evaporation and increase the aesthetic value of the garden is very advantageous (Photo 22)

Evaporation at an average monthly temperature of 15-20°C and an average water vapour pressure of 20 mbar is about 1-2 $mm.l^{-1}.m^2$. At higher temperatures it is higher, at the ingrowths of water level it increases according to the area overgrown by up to a quarter. Vegetation of floating aquatic plants or floating islands with helophytes can therefore significantly increase the evapotranspiration of water from the tank, e.g. water hyacinth increases evapotranspiration from the surface of 6 to 10 times (Šálek, Tlapák, 2006).

# 11 Reuse of treated Wastewater for Irrigation

The reuse of treated wastewater for irrigation Wastewater irrigation is the most common method of reusing Wastewater from natural ways. Wastewater irrigation is a complex, multi-economic measure that uses:

- Water quantity of wastewater that is in many cases, particularly in arid regions of Southern Europe, the only source of irrigation water
- Fertilizer value of wastewater, especially the content of plant nutrients (N, P, K, Ca, Mg), trace elements and organic-humus substances
- Treatment effect of the soil

Sewage wastewater from municipalities and appropriate wastewater from industrial (food industry) and agricultural sources is used for irrigation. Investment and operating costs are, in large part, covering the water and fertilizer value of wastewater by increased crop yields and cost savings for the construction of the first or second degree of biological wastewater treatment. The advantage is a high treatment effect of the soil, especially the binding and utilization of nitrogen and phosphorus in the creation of plant biomass. When irrigation wastewater occurs in the soil environment, it largely eliminates bacterial contamination from wastewater. Irrigation can be used as wastewater with high organic content (slurry, liquid sludge), as well as wastewater with a high proportion of ballast water.

Some drawbacks of irrigation reuse of wastewater are insecure access all year round, and the collection of wastewater. These circumstances require the construction of storage tanks. It is also necessary to take into account lower cleansing effect by irrigation out of vegetation. During irrigation by spraying, aerosols are formed and there is a certain dependence on treatment having an effect on climatic conditions, especially temperature, rainfall and solar radiation. Irrigation by purified wastewater is proposed in favourable climatic, pedological, hydrological, hydrogeological and economic conditions. Purified wastewater irrigation establishes a zone of capillary hanging water, any groundwater contamination occurs during accidents.

The limiting factors contributing to wastewater not being suitable for irrigation include a lack of land, suitable for irrigation by wastewater, in particular sanitary protection zones of water resources and medicinal resources, protective zones surrounding roads, housing estates, high groundwater levels exceeding 1.2 to 1.5 m, and inappropriate composition of the wastewater, especially the content of toxic substances exceeding the threshold of toxicity.

Wastewater irrigation

Wastewater irrigation is a complex multi-economic measure that uses water and fertilizer value of wastewater while using a high treatment effect of the soil environment to their treatment or rather final treatment. Pretreated or treated wastewater and sewage, municipal, agricultural and selected industrial for irrigation. Wastewater irrigation is in many cases only one available sources of irrigation water.

Advantages of wastewater irrigation

- Irrigation water contains significant amounts of plant nutrients (N, P, K, Ca, Mg), trace elements and organic substances able to form humus
- Wastewater irrigation is a very important intensification agent contributing to considerable increase of crop yield and fast-growing woody plants
- The treatment effect of soil environment commonly achieves and in many cases exceeds the treatment effect of other wastewater treatment methods
- Wastewater irrigation belongs to economical means of final treatment of wastewater
- Wastewater irrigation is one of few possibilities of designing of drainless systems

Disadvantages of wastewater irrigation

- The accumulation of wastewater during the off-vegetation periods is necessary for the year-round exploitation
- Much of wastewater after mechanical and mechanical-biological treatment requires prior to irrigation use either sanitation (UV radiation) or the design of protection zones around the irrigated area and setting the deferred (protective) period between the last irrigation, harvest (grazing) crops
- When overloading the soil environment with high doses of irrigation and within accidents, there might emerge the contamination of ground water
- It is not possible to irrigate crops (fruit, vegetables) consumed by man in a raw state by wastewater
- Irrigation cannot be used when close to of water sources

## 11.1 Suitability of Wastewater for Irrigation

Appropriateness of using treated wastewater for irrigation is assessed in terms of physical, chemical and biological composition; the effects on soil, plant, consumer, service, construction, machinery and technological equipment, the quality of surface and groundwater, the natural environment and its irrigated area environment are evaluated. The individual EU member states have a standard or directive that divides wastewater suitable for irrigation, usable or inappropriate for direct irrigation. The necessary degree of wastewater treatment before irrigation use is closely related to its type and composition. Irrigation use precedes the minimum mechanical cleaning, treatment mostly mechanical-biological, chemical, in justified cases. It is preferred to use wastewater irrigation facilities to final treatment of wastewater, either for another natural way to clean (constructed wetlands, stabilization ponds) or artificial (mechanical) treatment plant.

## 11.2 Hygiene Directive on Wastewater Irrigation

During irrigation by untreated wastewater, the sanitary protection zones must be defined, and it is crucial to follow the principles of management in protected water sources, resulting in a draft of time between the last irrigation and harvest, and the protection of groundwater against pollution. Sanitary protection zones of the irrigation wastewater and manure used in the Czech Republic are listed in tab.11.1

Table 11.1 Sanitary Protection Zones of the Wastewater Irrigation reference?

| Type of Wastewater | Character of Health Hazard | Sanitary Protection Zone of Wastewater Irrigation | | | | | |
|---|---|---|---|---|---|---|---|
| | | Continuous Development from | | Railways Mainroads | Public Road | Field Paths | Streams and reservoirs not used for drinking water production |
| | | irrigated areas | storage tanks | | | | |
| Wastewater | Acceptable | 50-100 | 100-1,000 | 25-50 | 10-25 | 0-10 | 25 |
| | Insanitary | 300 | 200-1,000 | 100 | 25 | 10 | 25-50 |
| Liquid Manure | Homogenized | 300 | 1,000 | 50 | 10 | 0 | 25-50 |

Withdrawal periods between the last irrigation and harvest correspond to the time interval necessary to eliminate microbial contamination. Withdrawal periods between the last irrigation by sewage, liquid manure and harvest (feeding off), used in the Czech Republic are in Table 11.2.

The health safety of treated wastewater is ensured by sanitation of UV radiation; further details are given in Chapter 14. The design of sanitary protection zones and withdrawal periods before harvest were determined from the results of the survey in the Czech Republic from the knowledge and experience of neighbouring countries, notably Poland and Germany.

Table 11.2 Withdrawal Periods between the Last Irrigation by Sewage Water and Harvest

| Crops | Wastewater Acceptable in Terms of Health | Wastewater insanitary, manure and slurry |
|---|---|---|
| a) Utility Wood | Without restrictions | 2 months before felling timber |
| Sugar beet, industrial potatoes, fibre plants | Without restrictions | Up to 14 days before harvest |
| Fodder beet, semi-sugar beet, potatoes, cereals | Up to 7 days before harvest | Up to 21 days before harvest |
| Temporary and permanent meadows, pastures and fodder | 7 days before harvest or feeding off | 21 days before harvest or feeding off |
| Vegetables used in cooked state (red beets, spinach, eggplant etc.) | 7 days before harvest | 21 days before harvest (irrigation in all ways, at the time of vegetation except for spray irrigation) |
| Vegetables used in raw state (strawberries) | Up to 14 days before harvest | It is not allowed, except for underground irrigation in period out of vegetation |
| Fruit trees and a bushes, ornamental plants | Up to 14 days before harvest | It is not allowed, except for underground irrigation in period out of vegetation |

## 11.3 Irrigation Regime during Wastewater Irrigation

Irrigation regime during wastewater irrigation depends on climatic conditions, soil properties, crop growth period; plants need moisture, crop nutrient needs, quantity and composition of the wastewater, technical conditions and possibilities of prolonged accumulation of water. Wastewater irrigation is proposed as:

a) Supplementary irrigation and non-vegetation with a predominant moisture action
b) Fertilizer irrigation with predominant effect of fertilization

### 11.3.1 Irrigation Requirements for Supplementary Irrigation

Irrigation requirement for supplementary irrigation $M_z$ ($m^3ha^{-1}$) is determined from the balance equation

$$M_z = k_z (r_1V_c - r_2 \alpha S_r - r_3W_z - W_k) \qquad (m^3.ha^{-1}) \qquad (11.1)$$

where
$k_z$ - loss coefficient expressing the average share of any losses of irrigation water with the exception of losses in the conduit
$V_c$ - total water demand of irrigated crops during the growing period ($m^3ha^{-1}$)
$\alpha$ - utilization factor-precipitation
$S_r$ - long-term average rainfall for crop growing season ($m^{3.}ha^{-1}$)
$W_z$ - water supply in the soil at the beginning of the growing season ($m^3ha^{-1}$)
$W_k$ - recoverable amount of rising groundwater ($m^3ha^{-1}$)
$r_1$- reduction factor for adjusting Vc depending on the altitude
$r_2$ - reduction factor for treatment $\alpha$ and depending on altitude
$r_3$ – reduction factor for treatment $W_z$ depending on the type of soil and the slope of the terrain; details of $V_c$ and $r_1$ to $r_3$ are given in CSN 75 0434.

The values of loss coefficients $k_z$ of irrigated area according to CSN 75 0434 makes at splash $k_z$ = 1.15 to 1.25, with soaking $k_z$ = 1.25 to 1.45, with flooding from 1.45 to 1.65 and heats $k_z$ = 1.65 to 2.50. In more complex terms, loss coefficient is determined by individual calculation.

Coefficient of utilization of rainfall $\alpha = 1 - \varphi - \beta$, where $\varphi$ is the runoff coefficient, $\beta$-coefficient of interception. In flat terrain, on structural soils, recommended for clay soils is the value $\alpha$ = 0.75, and clay soils $\alpha$ = 0.70, sandy soils $\alpha$ = 0.60, very heavy soils $\alpha$ = 0.50. Precipitation during the growing period Sv ($m^3.ha^{-1}$) in an average year for the specific crop growing season is determined from an average monthly precipitation of at least thirty contiguous series.

### 11.3.2 Non-Vegetation Irrigation

Non-vegetation (before vegetation) irrigation should create a sufficient supply of soil moisture for germination and initial crop year. The size of out of vegetation irrigation amount is calculated from the equation

$$M_{MV} = 100\, k_{MV} \left[ (\Theta_{PK} - \Theta_M) h_{MV} - 10\, a_{MV} H_{SMV} + Z \right] \qquad (11.2)$$

where
$\alpha_{MV}$ - coefficient of utilization of precipitation in the out of vegetation period
$H_{SMV}$ - amount of precipitation in out of vegetation period (autumn - winter)
Z-water loss
$k_{MV}$ – loss coefficient of irrigated area
$h_{MV}$ – depth of moisture in out of vegetation period
$\Theta_{PK}$ - field water capacity of the soil
$\Theta_{MV}$ – soil moisture

According to the research carried out in the Czech Republic, it is recommended to design only before vegetation irrigation. Out of vegetation irrigation in autumn is particularly applicable.

### 11.3.3 Irrigation requirement with the prevailing fertilization effect

Irrigation requirement with the prevailing fertilization effect ($M_{ZH}$) is determined for each crop in the standard nutrient needs to achieve planned revenue by the average nutrient content in irrigation water, multiplied by the coefficient of utilization of the nutrient ζ. Irrigation quantity in out of vegetation period with prevailing fertilization effect $M_{MVH}$ is calculated from equation

$$M_{MVH} = \frac{1000 P_{ZH}}{O_{OV} \zeta} \tag{11.3}$$

where
$P_{ZH}$ - standard plant nutrients need for fertilizer storage
$O_{OV}$ - average content of standard plant nutrient in wastewater
V - coefficient of utilization of standard plant nutrient

### 11.3.4 Calculating the Needed Size of Irrigated Area

The size of the irrigated area by wastewater $S_Z$ is determined from the relationship:

$$S_Z = \frac{Q_R - Q_O}{M_C} \tag{11.4}$$

where
$Q_R$ - total quantity of wastewater, including runoff from the irrigated area
$Q_O$- irrigation unusable amount of wastewater
$M_C$ – total amount of irrigation, $M_C = M_Z + M_{MV}$

The total required area $S_{total}$ for reuse of wastewater by irrigation is calculated by adding up the area $S_z$, road surfaces $S_k$, zones of protective areas, $S_p$ areas designated for other purposes (e.g. water treatment facilities, storage tanks, etc.) and surfaces $S_j$ areas of alternative measures to eliminate wastewater when it is not possible to irrigate, i.e. filter fields, ponds $S_r$.

$$S_{total} = S_z + S_k + S_p + S_j + S_r \tag{11.5}$$

When designing, it is also necessary to take into account the expansion of irrigation system in accordance with the expected increase in the inflow of wastewater, with a reserve of moisture for moisture wet years, etc.

## 11.4 Wastewater Irrigation Arrangement

Irrigation equipment consists of the buffer tank, water abstraction, pumping stations (photo 24), low pressure or pressure pipe distribution and detailed irrigation (watering detail).

A buffer tank is used for short-term balance of the flow, and on the order of days, they are proposed fortified and sealed, of different floor plan arrangement.

Purified wastewater is collected in the effluent from the wastewater treatment plant. The water intake structure creates a scumboard, fine screens and inlet cap. Inlet to the suction pit of pumping station is designed by gravity pipeline. The pumping station is responsible for hauling the wastewater to the irrigated area. Behind the pumping station, a specific device is placed, most often flowmeter and flow UV-lamp. The arrangement of piping network for wastewater vegetation irrigation is similar to that in pure water irrigation. The most frequently used pipe materials include plastics and steel. For year-round operation of irrigation by wastewater, irrigation pipes should be stored in a frost-free depth and adapt all the objects to winter operation.

Devices and objects on the pressure irrigation pipe network ensure trouble-free operation of the pipe network, its easy maintenance and full recovery. It is divided into the following groups of objects:

- Intersection with line structures (roads, waterways, waste, pipelines, etc.)
- Equipment and operating facilities (air eliminators, sector caps, branch pipes)
- Equipment and objects sample and drain (drain hydrants and outlet)
- Protective devices (thrust blocks, terminal blocks, compensators, ram device)
- Measurement and control objects (hydrometric equipment, pressure regulators and flow)

## 11.5 Design of Irrigation (Irrigation Detail)

The detailed wastewater irrigation is solved mainly by spraying, micro-irrigation, subsurface irrigation, furrow soaking, belt flooding and flooding.

### 11.5.1 Sprinkler Irrigation

Sprinkler irrigation is based on water splashing by circular or sector device. Nowadays, fully mechanized and automated irrigation by irrigation machines have replaced previous methods. Linear irrigation sprinklers are used in irrigation machines that on the undercarriages move along the water supply. The main pipe is connected from one or both sides the hydrants of underground pipes. The individual undercarriages are driven by electric motors. Pivot irrigators consist of a pipe with sprinklers, which is located on two undercarriages. The entire device rotates in a circle (circular arcs) around the pivot, manifold reaches a length of 300 to 600 m. Belt irrigators belong also to the most widely used irrigation machines. They are proposed in many modifications and structural arrangement. Tracked reel irrigators are composed of the chassis, hydraulic or turbine, rollable pipe with the sprinkler mounted on a covering tripod.

Photo 24: Wastewater Irrigation Trebsen (Germany)

When spraying the wastewater into the atmosphere, it leads to its perfect aeration, which is positively reflected in the rate of degradation processes and organic matter mineralization in soils.

### 11.5.2 Microirrigation

Micro-irrigation is localized on surface or subsurface irrigation, supplying small amounts of water directly to the plants in dropwise (drip irrigation), by slow discharge from pipelines or microspray. In terms of structural configuration it is divided into drip irrigation, supplying water from pipes of small diameter dropwise, irrigation point, irrigating by fluid discharge from the outlet device and microspray (microsprayers and sprinklers).

Micro-irrigation requires wastewater filtered with a minimum content of suspended solids. In the soil there is a zone of capillary hanging water formed, soil environment is sufficiently aerated and high treatment effect is achieved around 98 % in all the key indicators. The schematic layout of drip (point) irrigation is shown in Figure 11.1: raw wastewater (1) is mechanically pre-treated in a settling tank or septic (2) and then flows to a constructed wetland (3); outflow treated water from the wetland is accumulated in a reservoir (4) and via a rock or gravel filter (5) or a micro strainer is transported to drip or point irrigation system (6); each part of the irrigation system has its own regulation shaft on the inflow pipeline – grey circle, which allow to close or open the part or regulate water flow).

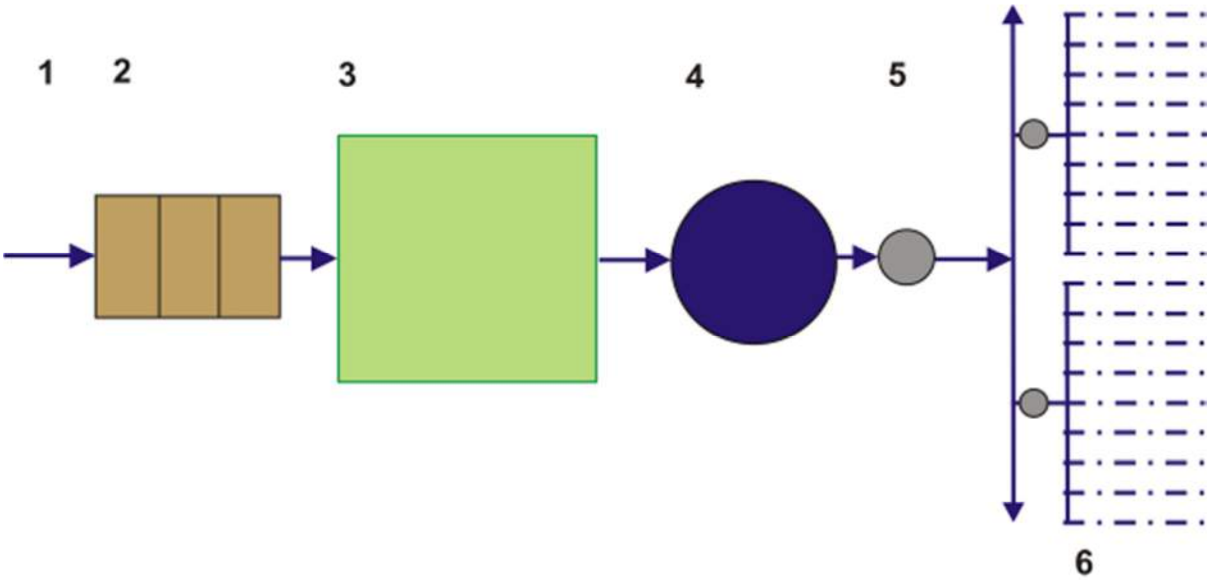



Figure 11.1 Schematic Arrangement of Drip (Point) Irrigation

### 11.5.3 Subsurface Irrigation

Within the subsurface, irrigation wastewater is fed by perforated irrigation pipe directly to the root layer where water saturates the soil profile. Water spreads upwards by the action of capillary forces, to the sides and bottom water penetrates by the action of capillary and gravitational forces. The scheme of subsurface irrigation is shown in Figure 11.2 (raw wastewater – 1 is mechanically pre-treated in a settling tank or septic – 2 and then flows to a constructed wetland – 3; outflow treated water from the wetland is accumulated in a reservoir – 4 and via a rock or gravel filter – 5 or a microstrainer is transported to subsurface irrigation system – 6; each part of the irrigation system has its own regulation shaft on the inflow pipeline – grey circle, which allow to close or open the part or regulate water flow). In the case of separate sewer systems, the collected rainwater can be transported to the accumulation reservoir (7) and used in the irrigation system. In the case of a combined sewer system, the overflow of water that is separated in the overflow facilities could be treated from suspended solids by a filter or in a stormwater tank to protect the soil and pipeline system from clogging.

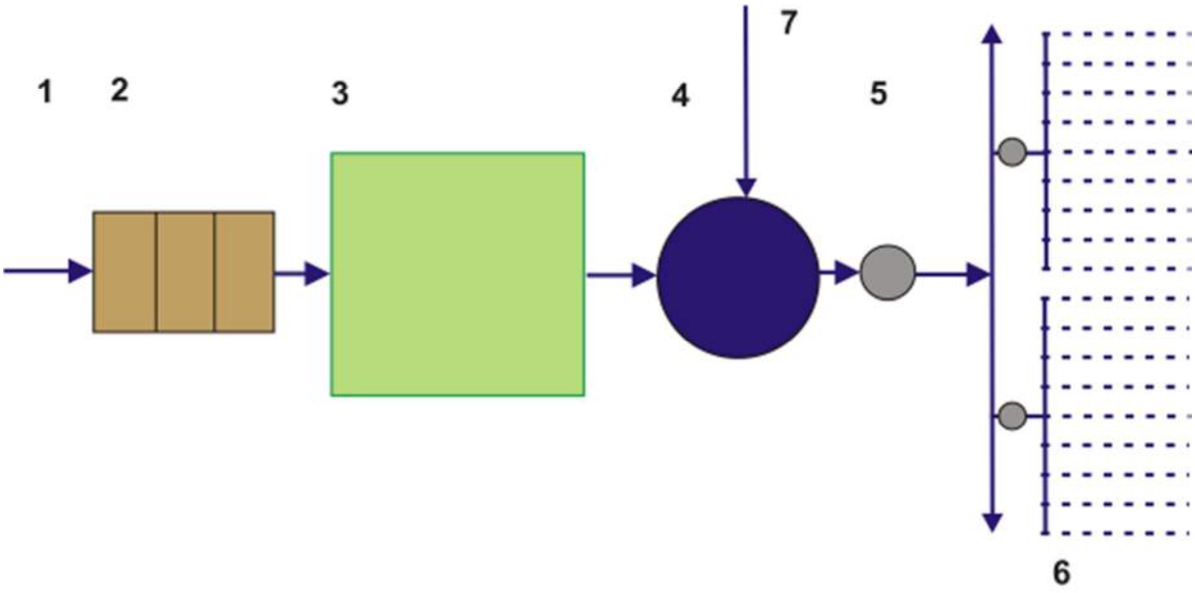



Figure 11.2 Arrangement of Subsurface Irrigation (Drain Soaking)

The irrigation pipe supplies wastewater over the impervious bedrock, which is of natural origin, it may consist of plastic film. A shallow zone fully saturated with water is created and above it, there is an unsaturated zone established by capillary elevation, extending to the main mass of roots- Figure 11.3a (Šálek, Tlapák, 2006).

Discharge from irrigation pipes establishes a zone of capillary water hanging – Figure 11.3b (Šálek, Tlapák, 2006). The gauge of perforated irrigation pipes or drains affecting soil properties is proposed from 1 to 3 m, depth of save an average of 0.4 to 0.5 m is given by the power of the main mass of roots. Water supply is proposed pressureless and low pressure.

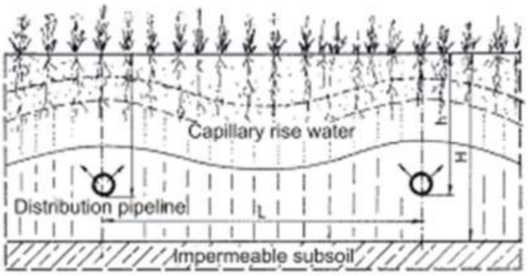



Figure 11.3a Formation of groundwater level

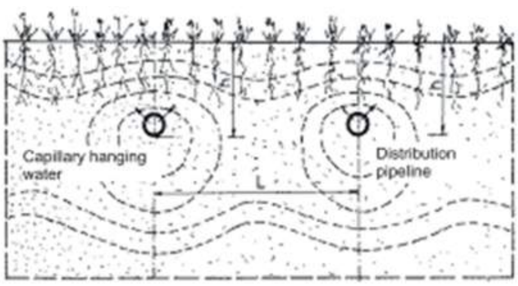



Figure 11.3b Formation of capillary hanging water

Advantages of subsurface irrigation consist mainly in a positive impact on soil structure. The soil surface is not wet. It is possible to irrigate at any time, regardless of the field work, irrigation can be fully automated. Subsurface irrigation reduces the risk of contamination of crops and workers. Subsurface irrigation is the ideal way of irrigation of wastewater produced in small settlements (houses, etc.). It is also possible to implement it in a larger scale. But there is a risk of salinization of the soil.

## 11.6 Gravity Irrigation Methods for Treated Wastewater

Gravity irrigation methods are formed by furrow irrigation, flooding belts and heats. These methods are currently automated. Their advantages are, among other things, a minimal possibility of aerosol formation and the possibility of automation of operation.

Photo 25: Arrangement of Irrigation of Fast-growing Timbers

Irrigation by furrow flooding is used for irrigation of root crops - sugar beet, fodder beet, potatoes, corn, fast-growing trees, etc. Track and length of irrigation furrows depend on the soil type and soil hydraulic conductivity, longitudinal slope, etc. The example of a fast-growing tree by irrigation is illustrated in Photo 25.

Irrigation belt flooding is based on moisturizing of soil by purified wastewater infiltration, which flows in a thin layer along the belt defined by two low dams. Optimal slope of border irrigation belts is 0.2 to 2 %, the width from 2 to 12 m, the length 60-200 m according to slope, permeability of soils. Irrigation by flooding is used in the irrigation of grassland and fast-growing trees. The controlled flooding is predominantly proposed intermittent.

Filter fields are intended for the management of excess wastewater at harvest time, for effluents from large rainfall, in winter, when there is no irrigation, etc.

# 12 Combined Wastewater Treatment Systems

Combined systems for wastewater treatment consist of mechanical pretreatment, constructed wetland (filtration reed-beds) as main facility of the biological treatment and a stabilization pond (one or more) used as a polishing step increasing treatment efficiency especially in removing nitrogen and phosphorus from water. It is also possible to combined reed-beds with soil filters, infiltration drains or irrigation facilities including fast-growing trees irrigation. Another option is a combination of constructed wetland and aquaculture facilities.

## 12.1 Constructed wetlands and stabilization ponds

The reason for stabilization ponds use in combination with constructed wetlands consists in easy operation, minimal energy consumption and maintenance, as well as the benefit of economic efficiency. Stabilization ponds are used for wastewater treatment - significantly reducing the number of coliform bacteria. These ponds occupy a special position among devices used for treatment and polishing wastewaters, creating conditions for the development of autotrophic organisms producing oxygen which is required for the oxidation of organic substances and ammonia nitrogen removal. Removal of organic substances is based on their conversion to the relatively stable organic forms such as the cells of algae, protozoa, and other zooplankton organisms.
The process of using specific species during wastewater treatment is characterized by using a variety of them and alternate between them. In the case of phytoplankton, this process is influenced by the seasons, specifically depending on the power and frequency of light, ambient temperature and predation pressure by zooplankton. The factors influencing the development of algal populations (phytoplankton) includes significant retention time, the depth of the pond and the amount of organic matter in the influent.

In cases of the monitored WWTP, the proportion of stabilization ponds was positive in the case of nitrogen and phosphorus removal. In the case of the removal of suspended solids and organic compounds expressed in terms of $BOD_5$ and COD, an increase of the concentration in the effluent occurred during the vegetation season compared to the values at the inlet from the constructed wetland filters. However, the nature of substances that present these indicators at the pond outlet is completely distinct from substances in wastewater inflows. Inclusion of stabilization ponds behind the constructed wetland filters allows for a reduction of the difference in treatment efficiency of constructed wetlands between vegetation and non-vegetation periods.

The following Photos 26 a - c show examples of the combined systems.

Photo 26 a-c: Combined wastewater treatment systems from small sources (500 p.e.) - combination of mechanical pretreatment - constructed wetland filter - biological (stabilization) pond.

# 13 Removal of Specific Pollution

## 13.1 Phosphorus

Several authors support the view that in the field, produced by-products achieve different levels of phosphorus absorption. For instance, slag as a by-product of the industrial production reaches the adsorption capacity to 44 g $P.kg^{-1}$ of slag material, depending on the concentration of iron in the material. In this case, the topsoil layer commonly reaches values from 4.2 to 5.2 g P per 1 kg of soil (Šálek, Kriška, Rozkošný, 2011). Filter material, commonly used for constructed wetland filters, reaches the sorption capacity 0.93 to 1.15 g P per 1 kg of gravel filling. Zeolites, which have generally been used for the removal of ammonium ions from wastewater, the measured values were 2.15 g P per 1 kg of zeolite. The mutual relationship between the phosphorus adsorption and extractable iron and aluminium shows that the adsorption of phosphorus is greater for extractable aluminium ions ($r^2$=0,890), than iron ($r^2$=0,736). According to the results, it can be concluded that the selected industrial materials of minor production and special absorbent materials may be used individually or in combination with mineral filling, resulting in improved treatment effects of these materials also in the pH, hydraulic conductivity and structural stability of these materials (Šálek, Kriška, Rozkošný, 2011). The review of experiences with filter materials of higher phosphorus sorption states Vohla et al. (2011).

## 13.2 Microbial contamination

At present, monitoring of microbial contamination in the effluents from wastewater treatment plants up to 2,000 p.e. is not practically set. However, there are limits on surface water, particularly bath water as defined in the Water Framework Directive (2000). Especially with little streams of water runoff pollution from wastewater treatment plants can burden the aquatic environment. Because of this fact, attention has been directed towards the efficiency of removal of microbial contamination at different levels of constructed wetland wastewater treatment plant. The proper samples were not taken.

In Germany, the microbial diversity and survival of Enterobacteriaceae in six pilot constructed wetland wastewater treatment plants were examined by the authors Vacca et al. (2005). They found the reduction of heterotrophic microorganisms and coliform bacteria about 1.5. to 2.5. To determine the diversity of bacteria of the family *Enterobacteriaceae,* they used the methods of molecular biology (PCR – SSCP). The results showed that the community found in the filters is strongly dependent on the filtration processes, the filtered material and the type of plants.

In the Netherlands, the constructed wetland wastewater treatment plant with the vertical flow was studied by the authors Meuleman et al. (2003). The constructed wetland filters were overgrown with vegetation of reed (*Phragmites australis*) and there were treated wastewater from the recreation area. During the process almost all of the population of Escherichia coli and F-specific RNA bacteriophages (treatment efficiency above 99 %) was eliminated. In another work (Toet et al. 2005) there are the results of the research of constructed wetland wastewater treatment plant with surface horizontal flow with the vegetation *Phragmites australis* a *Typha latifolia*. Up to 92% of faecal coliform bacteria are reduced by this system.

In Slovenia, the constructed wetland wastewater treatment plant treatment wastewater from the food industry was tested (Vrhovšek et al., 1996). The coliform bacteria were reduced from 99 % and faecal streptococci (enterococci) from 98 %.

The use of filters reduces the occurrence of pathogenic microorganisms present in the. The flow loss of more than 90 % (up to 98 or 99 %) is in the relative distance of 0.2 from the inflow. According to the results of water quality monitoring at several wastewater treatment plants, the mean reduction of faecal coliform (thermotolerant) and coliform bacteria occurrence was 98.6, or more precisely 98.5 % behind the biological pond (reducing the number of CFU/1ml by two orders of magnitude, or rather for coliform bacteria up to three orders of magnitude), behind the constructed wetland filters it was 90.3 or 89.4 %.

The reduction of the concentration of the thermotolerant coliform bacteria and coliform bacteria has an efficacy close to 95-99 %. Wastewater effluent concentrations have reached the level of units CFU/100 ml throughout the year for treatment plants with a large dilution of ballast wastewater.

Monitoring of concentrations of Escherichia coli and enterococci in water proved a decrease in both indicators concentrations up to three orders of magnitude, while at constructed wetland wastewater treatment plants with strongly diluted water the effluent concentrations of enterococci were 0-20 CFU/1ml and concentrations of *Escherichia coli* 0 – 5 CFU/1ml. In the Czech Republic three constructed wetland wastewater treatment plants with subsurface horizontal flow (municipal, of the size 150, 200 and 300 p.e.) were studied (Vymazal et al., 2001) from 1996 to 1997. More than 70 kinds of bacteria, amoebae, cyanobacteria, algae and protozoa with saprobiological information were detected. During the treatment process the quality was improved of 2-3 orders of magnitude. It was found that the majority of bacteria were removed in the first meters behind the manifold, behind the inlet. There were no significant seasonal fluctuations monitored.

Measuring of the microbial pollution removal in constructed wetland wastewater treatment plants from all over the world is summarized by the authors Wallace and Kadlec (2009). Summary data are shown in Table 13.1. The results also correspond to the findings from the Czech constructed wetland wastewater treatment plants and confirm the long-term high removal efficacy of microbial contamination, even during non-vegetation periods (Mlejnská et al., 2009).

Table 13.1. Reduction of Microbial Pollution by Constructed wetland Filters (Wallace and Kadlec, 2009)

| Indicator | Faecal Coliform Bacteria CFU/100 ml ($\log_{10}$) |
|---|---|
| HF – Inflow | 6.0 |
| HF – Outflow | 3.7 |
| Reduction | 2.3 |
| VF – Inflow | 5.4 |
| VF – Outflow | 3.1 |
| Reduction | 2.4 |

## 13.3 Heavy metals

According to the literature, there are good prospects to eliminate hazardous substances from wastewater (Kröpfelová et al. at al., 2010). The prospects are particularly good with reference to the adsorption of heavy metals in the filtration materials (Kadlec et al., 2000; Vymazal et al., 2010a). The results of analyses (Vymazal et al., 2010b) demonstrate the ability of constructed wetland wastewater treatment plants to capture heavy metals (above all Al, Zn, Cu, Pb, Cr, Mo, Cd etc.).

Therefore, it is necessary to carry out analyses of the filter material composition within the regard to metal content with a view to its further re-use.

The removal of heavy metals was high and amounted to more than 81 % for Mn, more than 82 % for Cu, more than 91% for Al and more than 98% for Zn. For all the metals there was a significant reduction in the concentration in the first 5 metres of the bed, which probably correlates with the fact that most of the suspended solids is held in the first part of the filter and we can assume that metals area mainly bound to suspended solids. The concentration of metals decreases in the order roots – stems- leaves, but the significant difference between the metal content in stems and leaves was not proved.

# 14 Disinfection of Treated Wastewater Effluent

An essential part of the process of sewage sanitation is the disinfections of treated wastewater effluent prior to further use. Much of hitherto commonly used treatment technologies, including natural treatment methods, do not remove 100 % of the microorganisms. In particular what are often left are those pathogens that can cause diseases. We can meet the need of hygienization mainly in the use of treated wastewater for activities where a person comes into the direct contact with them, through for example treatment and household treatment, washing, flushing the toilet, watering flowers grown in the house, swimming pools, etc.

A number of technologies are used for the disinfections of wastewater, from which the most famous are chlorination, UV radiation and ozonation.

## 14.1 Disinfection of Treated Wastewater

The most used technology for disinfection of wastewater treatment plants is applicable to smaller plants, which include natural treatment methods, sodium hypochlorite and calcium and UV radiation. It is also advantageous to use membrane technologies because together with the sanitary provision it removes non-dissolved substances (suspended solids) and creates the prerequisites for both discharges into groundwater but also for further use. The summary of suitable technologies of water disinfection states Plotěný (cit. Šálek et al.2012) is illustrated in Table 14.1.

Tab.14.1 Overview of Appropriate Technologies of Disinfection of Treated Wastewater from Natural Treatment Methods taken from

| Disinfecting Agent | Form | Restrictions on the application of smaller sources of pollution |
|---|---|---|
| Sodium hypochlorite | Liquid | Corrosive, toxic, forms carcinogenic by-products, the dispensing system is necessary, efficacy depends on the quality of wastewater |
| Calcium hypochlorite | Tablets | Corrosive, toxic, forms carcinogenic by-products, the dispensing system is necessary, efficacy depends on the quality of wastewater, uneven abrasion of tablets can affect the dose |
| UV radiation | UV radiation | Requires regular maintenance and lamp replacement, deposits reduce efficacy, effectiveness depends on the quality of wastewater |
| Membrane filtration | Pore size | Membranes with small pores are able to eliminate pathogens such as reverse osmosis, an effective pretreatment of wastewater is required |

Sodium hypochlorite is an oxidizing agent that is able to disinfect water at relatively low doses. The need for chlorine, by Plotěný (cit. Šálek et al. 2012) for different types of wastewater is shown in Table 14.2. The need for chlorine dose is equal the difference between the recommended dose of chlorine (amount added to the wastewater in mg/l) and residual chlorine (sum of free and associated chlorine).

Tab. 14.2. Recommended Doses of Chlorine from Disinfection of Wastewater

| Wastewater source | Chlorine dose in mg/l | Recommended chlorine dose in mg/l at pH | | |
|---|---|---|---|---|
| | | 6 | 7 | 8 |
| Runoff from septic tank | 30 to 45 | 35 to 50 | 40 to 55 | 50 to 65 |
| Outflow from the activation | 10 to 25 | 15 to 30 | 30 to 35 | 30 to 45 |
| Outflow after final treatment [1] | 1 to 5 | 2 to 10 | 10 to 20 | 20 to 35 |

*Note: [1)] outflow after tertiary treatment (sand filters)*

Calcium hypochlorite ($Ca(OCl)_2$) can also be dosed into the water in the concentrated form of solids, is available in concentrations of about 70 % in the form of powder, granules and tablets. The potential of calcium hypochlorite, as well as sodium, decreases with respect to time. It is supplied into the wastewater in a solid form.

Ultraviolet radiation produced by low-pressure mercury lamp has the most favourable bactericidal effect at a wavelength 253.7 nm. The effectiveness of disinfection by UV radiation is affected by the amount of particular matter, turbidity, high concentration of non-dissolved substances (suspended solids) adsorbing UV radiation, uneven water flow, and sediments on silicon tube with radiator etc. To remove deposits on the quartz tube, some devices use automatic or manual wipe treatment of silicon sleeve. UV radiation is toxic to bacteria, viruses, yeasts, fungi spores and unicellular organisms. The radiation dose D by Kujal (cit. Šálek, Tlapák, 2006) is calculated from the equation

$D = E \cdot t$ $(W.s.cm^{-2})$
$E = E_0 \cdot e^{-a.x}$ $(W.cm^{-2})$

where
$E_0$ - beam energy on the surface of the emitter ($W.cm^{-2}$)
E – beam energy ($W.cm^{-2}$)
x- irradiated water layer thickness (cm)
a – absorption coefficient ($cm^{-1}$)
t – duration of action (s)

Lethal doses of UV radiations are listed in Table 14.3.

The quality function of UV emitters is ensured by prearranged effective filters capturing suspended substances such as sand filters, membrane filtration, filters with floating filling, filter material from polyurethane foam, etc.

Tab. 14.3. Lethal Doses of UV Radiation

| Type of microorganisms | UV Dose ($W.s.cm^{-2}$) | Type of microorganisms | UV Dose ($W.s.cm^{-2}$) |
|---|---|---|---|
| Bacillus anthracis | 8,700 | Mycobacterium tuberculosis | 10,000 |
| Bacillus paratyphosus | 6,100 | Salmonella | 10,000 |
| Clostridium tetani | 22,000 | Dysentery bacilli | 4,200 |
| Eberthella typhi | 4,100 | Staphylococcus albus | 5,720 |
| Escherichia coli | 6,600 | Strephtococcus lactis | 8,800 |

The use of peracetic acid ($CH_3COOOH$), biological filtration with bacterial enzymes and membrane filtration for disinfection are perspective solutions that are currently elaborated.

## 14.2 Disinfection of Stabilized Sewage Sludge

Compliance with microbiological criteria necessary for the use of sewage sludge requires their sanitation, which will ensure:

- Anaerobic or aerobic stabilization at temperature above 55°C and the retention time in compliance with this temperature over 20 hours
- Thermal sterilization (pasteurisation) at a temperature over 70 (80) °C for 30 minutes
- Alkalinization by burnt lime at pH>12, the temperature above 55°C and the retention time at least 2 hours
- Composting, when the compost maturation must achieve the minimum temperature of 55°C for 21 days

# 15 Use of natural treatment methods for wastewater tertiary treatment

Tertiary treatment of wastewater by using natural technologies is applied to enhance the overall effect of the treatment process. At this point, the water has reached such a high level of quality that further use through recycling can be expected. During the stage of final treatment, it is possible to use both natural and non-natural technology. For small sources natural technologies are often applied, particularly due to low operating costs. For larger sources, mote intensive technology is often applied, although there are exceptions in both cases.

In reference to the natural technology, the final stage predominantly consists of the reduction of nutrients, in particular nitrogen and phosphorus and to suspend solids. Nutrients need to be removed to avoid eutrophication in the case of discharges to surface waters. Furthermore, the amount of nitrogen and suspended solids should be minimized in the case of infiltration into groundwater. The content of suspended solids in treated wastewater limits re-use of water.

Recognizing the need for tertiary treatment it is crucial to design the appropriate wastewater treatment using the appropriate technologies in order to satisfy the following conditions:

- Before entering the main treatment stage, as well as discharging the water into water bodies, it is necessary to remove certain nutrients, in particular nitrogen and phosphorus
- The wastewater from the smallest producers needs to be integrated with the rest of the wastewater

- Better water quality needs to be attained before it is recycled
- When dealing with extremely polluted wastewater, a two-stage treatment process is not sufficient to attain the appropriate water quality
- Removal of specific atypical pollution that conventional layout wastewater treatment plants cannot cope
- The need to follow hygienic security of the discharged water

During this tertiary stage, the following technologies:

a) suspended solids: sand filter - similar equipment as used water treatment in swimming pools. It is arranged with a simple shaft at the bottom, used to spread the drainage. Above, there is a sand layer that assures that the surface of the sand is brought above the water intake. Another option is a more complex natural filter - detailed in Chapter 8. Further alternatives include the floating mats and islands outlined previously - a massive root system of floating plants provide filtration of the water retention of suspended solids and their subsequent precipitation and fall to the bottom of the tank.

b) nutrients: adsorption - typically a multilayer filter, wherein at least one layer has the ability to bind some of the elements - for example zeolite bind ammonia slag bind phosphorus.

Natural technologies of tertiary final treatment of wastewater

Final treatment of wastewater can be considered to be the tertiary (third) stage of treatment after the mechanical and biological stage. The design of the tertiary stage can be taken into account either from the very beginning when solving the project documentation or as an additionally solved treatment stage that will provide better treatment effect than the existing solution. It is a supplement that allows for the possibility to be specifically focused on selected parameters (residual phosphorus, ammonia, total nitrogen, secondarily produced organic pollution and insoluble substances, etc.) by means of the design and relatively easily to achieve the required runoff concentrations of pollution.

Advantages of tertiary treatment

- Low operation costs in the case of the natural technologies application
- It is possible to achieve the desired quality of runoff water with low investment costs
- The possibility to eliminate the selected pollution, such as ammonia into the zeolite filtration materials, phosphorus into the materials with the admixture of iron, etc.
- It will ensure achievement of needed runoff parameters as a complement of the main treatment process
- If necessary, the tertiary stage can be combined with alternative resources of energy
- By means of irrigation water it is possible to achieve not only a significant increase of the production of agricultural crops but also to get usable biomass as an energy resource

Disadvantages of tertiary treatment

- The tertiary stage to trap insoluble substances, based on filtration treatment, is prone to clogging
- When the sorption capacity of special filters have been reached, it is necessary to replace or regenerate the filtration material
- The tertiary degree tolerates lower load than the main treatment stage, it is not suitable to overload it with high concentrations – if so, it may not be efficient

All of the equipment, whether it is a natural biological filters or tanks are designed as a tertiary degree is always a similar procedure as in the case of an application component as the treatment stage. The difference is the input concentration of pollution, i.e. smaller design surface.

## 15.1 Examples of some arrangement of final treatment with extensive treatment technology

### 15.1.1 Filters with zeolite

An example of the use of extensive technologies for treated wastewater polishing is the zeolite adsorption filter located in a separate chamber and connected by gravitational pipeline to a three-chamber septic tank or activated sludge WWTP, shown in Figure 15.1. Mechanically pre-treated water flows from a septic tank or WWTP (1), where the water is leveled (3) by a connection pipe (5) through the zeolite filling (7), which binds ammonia, thus reducing the total nitrogen in the effluent. At the same time, it reduces the content of suspended solids, thus extending the life of the absorption facilities that is a layer of gravel (6). All facilities are built on the concrete reinforced board (4). In the case of activated sludge WWTP, where ammonia removal occurs through a nitrification process, the zeolite filter can reduce phosphorus outflow concentration. The surface level is illustrated in the figure as structure (8). The advantage of this technology is that it is simple to use. The disadvantage, however, is the need for fairly regular replacement of equipment, resulting in high operation costs.  This may be the result of the use of depleted sorption material. It is necessary to consider the granularity of zeolite 2-4 mm in order to use the material for land reclamation or as fertilizer on agricultural land.

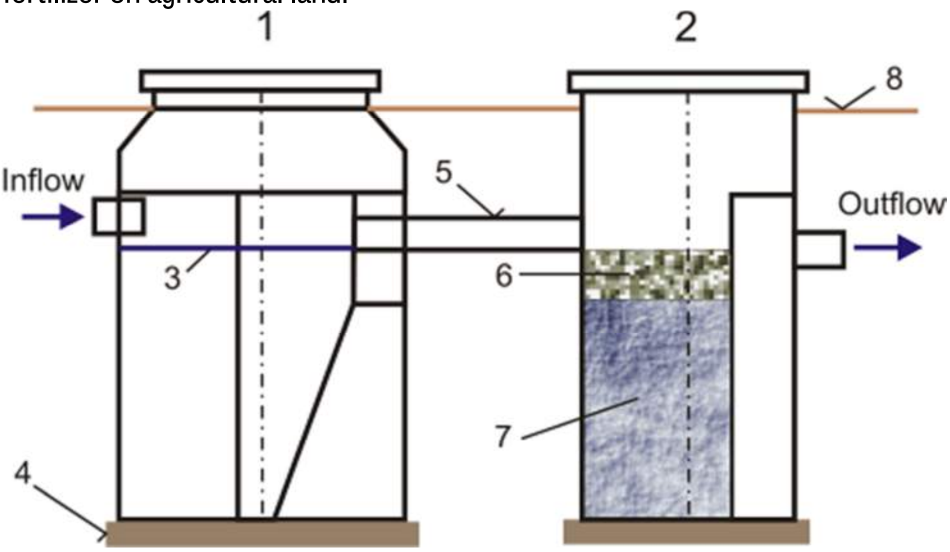



Fig. 15.1 Scheme of zeolite final treatment filter (2) for septic tanks (1) or activated sludge WWTP (1)

### 15.1.2 Other example of design

An example location of a simple device for tertiary polishing of wastewater placed on a septic tank is illustrated in Figure 15.2

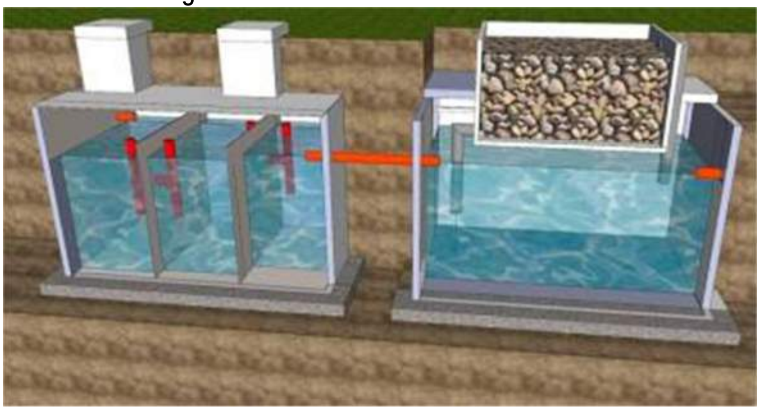


Fig. 15.2 Example of a non-traditional location of facilities for tertiary polishing the septic tank

Pretreatment of water using a biological septic tank occurs by pumping the water into a separate tank that uses a device placed at the top of the tank to continuously carry out the appropriate processes to clean the water. The advantage of this arrangement is that it allows good access to the material that has been separated from the water; however, this arrangement also implies that an additional energy input is required for pumping. To solve this issue, a small photovoltaic system has been connected to the pump, providing a 12V power source.

## 15.2 Examples of configuration polishing facilities using natural treatment methods

A fairly common arrangement is a combination treatment of constructed wetland wastewater treatment plants with final treatment of water in aerobic biological ponds (photo 27). An approximate schematic representation is shown in Figure 15.3. The flow of wastewater (1) is connected to a measurement device (2) and followed by a full mechanical treatment stage, which consists of a fine screen (3), a sand trap (4) with storage space on the sand (5) and a crevice bulk tank or multi-chamber septic tank (6) supplemented with grease traps. Biological treatment consists of two constructed wetlands (8) and a polishing aerobic biological tank with level aerators (10), supplemented by dividing fences (11), which provide uniform flow. The outlet (12) is equipped with a device to measure the flow. The treated wastewater is either discharged into the stream (13) or used for various purposes such as irrigation, technological water, etc.). This system is shown in Photo 26.

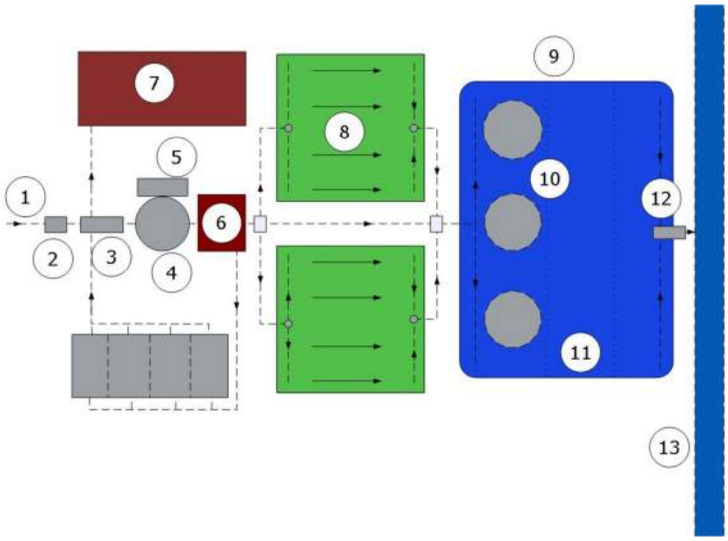



Fig. 15.3 Block diagram of a combination of mechanical treatment stages, constructed wetlands and aerobic biological tanks

Another possible way of achieving tertiary treatment is by using a cascade connection of aerobic biological irrigation tanks consisting of fast growing tree species. This is illustrated in Figure 15.4. The diagram shows the mechanical treatment stage, which is arranged in a similar manner as in the previous case. The treated wastewater from the aerobic tank with baffles (8) passes through a rotating drum sieve (1), which captures the relaxed biomass. Water flows into the suction chamber with a pumping unit (2) or by its own force through a pipeline (3, 5, 6) over the irrigated area with fast-growing trees (poplar, aspen, etc., image in Photo 29). The water is discharged into equally deep infiltration furrows. Pumping can also be used for recirculation of treated wastewater (4). Furthermore, the pump can be used to spray the surface of the pond while oxygenation occurs. The output stage of the aerobic biological pond acts as a storage pond with restricted accumulation volume.

Photo 27: The combination of constructed wetland and polishing aerobic biological tank with floating islands planted by macrophytes vegetation

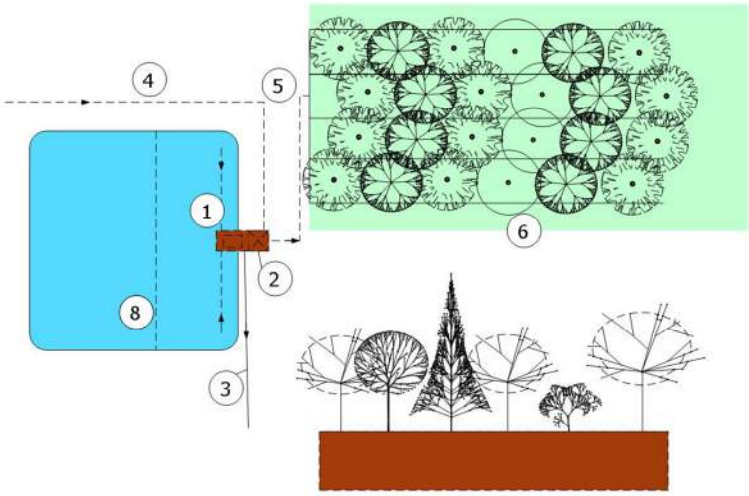



Fig. 15.4 Block diagram of a combination of biological pond and irrigation field with fast-growing trees

These structures are designed for relatively small-scale facilities such as domestic use, small to medium sized hotels and recreational facilities. For individual houses, a three-chamber septic tank equipped with safety filters in the outlet section can be used instead of the mechanical treatment stage.

Other alternatives are outlined in Section 11, 12 and 16, targeted at systems using small water evaporation tanks and controlled artificial wetlands.

# 16 Treated wastewater disposal and management

It is not strictly necessary to consider wastewater as waste. Contrarily, if its fertilizing ability is taken into account, it can be treated as a product. It is possible to state as an example the application as a source for irrigation or to generally improving a dry environment. Being aware of this, wastewater is utilized in the following way:

- Irrigation by treated wastewater resulting in increased production or transfer of nutrients into biomass
- Transfer of treated water into the atmosphere through the evapotranspiration from plants
- Infiltration of treated water into the subsoil without affecting the quality of groundwater level

## 16.1 Irrigation by Purified Wastewater

Irrigation by purified wastewater from decentralized structures is one of the effective natural technologies of treatment and final treatment of wastewater. Within the irrigation, water and the fertilizing value of wastewater is used at its current economic and ecological treatment or rather final treatment in soil environment. For irrigation, wastewater from individually standing decentralized structures is used, especially purified sewage water from flats, recreational installations and small plants is suitable because it does not contain toxic substances or agricultural by-products. The advantages of irrigation by purified wastewater are based on:

- A relatively simple construction design of the equipment for irrigation by wastewater which are structurally close to the equipment used for irrigation by clean water
- A water and fertilizing value of wastewater which significantly contributes to the increase of crop yields and rapidly growing trees; operation costs for irrigation are fully covered by the increase of yields of irrigated crops
- A high treatment effect of soil environment which his particularly reflected in binding of plant nutrients; that contributes to the increase of water quality in the landscape

Weaknesses of the irrigation utilization of wastewater include the difficulty of assuring a steady flow all year round due to lower treatment effect during off-vegetation periods that can be manifested especially in lower nitrogen consumption and thus also in the possibility of contamination of groundwater, lower dependence of treatment effect of soil on climatic conditions, especially the temperature, precipitation water and sun radiation. If the sanitation of wastewater is necessary, the disinfection by ultraviolet (UV) radiation is used for this purpose.

### 16.1.1 Water Quality for Irrigation

Wastewater can be grouped depending on their physical, chemical and biological composition, agronomic, sanitary, water management, veterinary impact on building constructions and technological equipment for water suitable for irrigation, usable for irrigation and unacceptable for irrigation of crops. The selection of suitable crops, irrigation mode, technical arrangement of irrigation, the choice of protective measures, the required level of treatment, protection of air, surface and groundwater and the overall protection of environment is related to the quality of wastewater.

For irrigation, wastewater must be minimally mechanically treated. Mostly mechanical-biological treatment is required or similar ways reaching the similar treatment effect. For the smallest producers, a biological septic tank and related natural technologies to clean wastewater is utilized. This is a conventional mechanical-biological wastewater treatment plant, microfiltration and membrane technologies, etc. for larger producers.

When designing, it is necessary to take into account the future expansion of irrigation systems in accordance with any increase of influent wastewater, with the reserve for years with excessive rainfall when it is recommended to proceed from the specifically humid year in the process of balancing.

During irrigation using treated wastewater, it is essential to define the zones of hygienic protection from the built-up area and roads and to adhere the principles of management in the protective zones of water resources, consisting in designing of the protective periods between the last irrigation and harvest and in the protection of groundwater against contamination. The protective periods between the last irrigation and harvest correspond to the time interval necessary to elimination of microbial contamination.

### 16.1.2 Design Irrigation by Wastewater

Irrigation equipment consists of a surge or accumulation tank, equipment for water abstraction, pumping equipment, low-pressure or pressure pipe distribution and detailed arrangement of water distribution on the irrigated area, so called irrigation detail.

Surge or equalizing reservoirs serve for the short-term compensation of flow rate, of the order of days, they are designed fortified and sealed, of any floor plan layout; the accumulation tanks are of similar arrangement and are used for long-term accumulation of treated wastewater. The adjusted aerobic biological tanks fulfill the function of the accumulation or surge tank. The special sieve filter is located in the sampling site for open accumulation (storage) tanks where there is the development of algae and cyanobacteria.

The pumping equipment transports wastewater to the irrigated area. The measurement device and flow UV-emitter are placed behind the pumping aggregate. For the supply and distribution of water, underground pipe network is exclusively used.

For small producers of wastewater these methods of an elaborate irrigation are proved successfully:

- Micro-irrigation that is formed by surface or subsurface point and drip irrigation supplying small amounts of water directly to plants namely in drops or gradual outflow, the arrangement is shown in the Photo 28
- Micro-spraying, using a spray nozzle and micro-sprayers for ground spraying on small distances, the possibility of aerosol formation is minimal
- Subsurface irrigation when wastewater is delivered by underground-perforated irrigation pipe network directly into the root zone of plants
- Irrigation by small sprayers, used for irrigation by spraying of grass vegetation
- Furrow soaking, suitable for irrigation of fast-growing woody plants

Photo 28: Drip Irrigation by Treated Wastewater in Arid Regions

Subsurface irrigation can be divided into two groups according to arrangement:

- Wastewater is supplied by an irrigation pipe network above the shallow stored impermeable subsoil that may be created from the plastic film, and forms the low-water-saturated zone here and above it there is an unsaturated zone created, affecting the area of the main mass of roots (Fig. 11.3a)
- The zone of capillary suspended water is created by outflow from the perforated irrigation pipe network. Spacing of perforated irrigation pipe network or drains influencing soil properties is 1 to 3 m, the depth of embedding is in average 0.3 to 0.5 m, it depends on the depth of embedding of the main mass of roots (Fig. 11.3b). The supply of water is proposed low pressure

Advantages of subsurface irrigation reside especially in beneficial effect on soil structure regardless of the field work; irrigation can be fully automated.

## 16.2 Drainless Evaporative Systems Arrangement

A number of small wastewater treatment plants from mainly decentralized structures do not have the possibility to transport treated wastewater into the suitable recipient (stream, pond, reservoir, ditch) or carry the investment costs for the construction of a sewerage as it would exceed the cost of wastewater treatment plant. Consequently, alternative ways to dispose of treated wastewater economically and ecologically are explored. One of the solutions is partial or complete drainless arrangement.

Before proceeding to this solution, the primary task is to examine the possibility the use of (treated) wastewater in the frame of water management of the decentralized structure. This measure can substantially decrease the amount of wastewater and thus the need for follow-up measure to their removal. After the successful resolution of this problem it is possible to proceed to the own partially or completely drainless water management.

Photo 29: Drainless Solution – Planting of Japanese Poplars evaporates Wastewater into the Atmosphere

### 16.2.1 Evaporation from Water Area

Designing the area needed for evaporation from biological tanks is based on the inflow of treated wastewater, evaporation from the water level, and rainfall. Precipitation data and the figures of evaporation from the water level are obtained from the nearest meteorological station in the given locality. Approximate values of evaporation, depending on the water vapour pressure and the air temperature, are illustrated in the Figure 16.1.

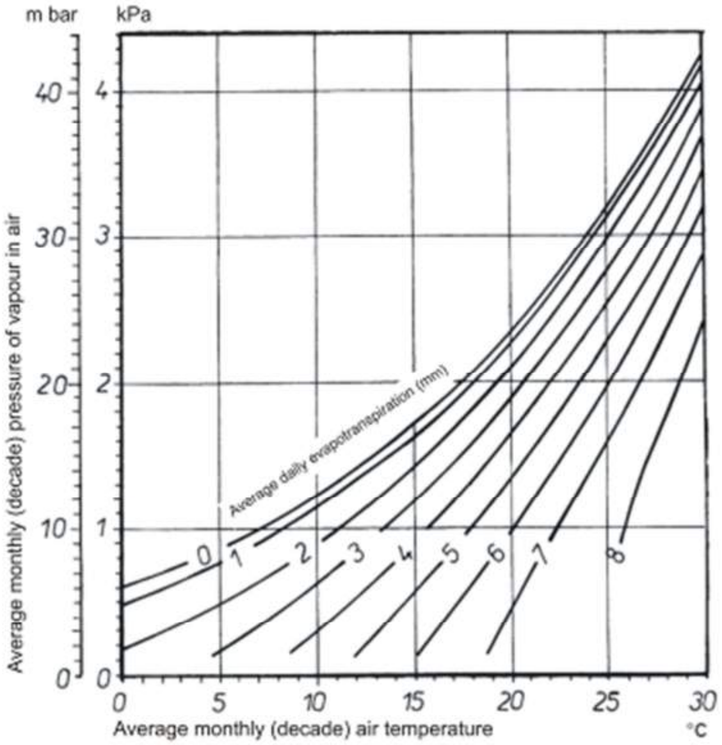



Fig. 16.1 Evaporation from the Water Level Depending on the Pressure of Water Vapour and the Air Temperature (prepared for Central Europe climatic conditions; cit. Šálek, Tlapák, 2006)

When calculating evaporation from the unit of area, it is necessary to subtract the precipitation amount from the water balance calculation. The tank must have sufficient accumulation (storage) space to compensate for disparities between the inflow of wastewater and evaporation from the water level. The shore zone of the evaporation tank is planted with wetland vegetation that contributes to water abstraction.

Surface and underground runoff, and infiltration into subsoil, is not allowed at managed wetlands due to the possibility of transfer of treated sewage water into the air. Arrangement of small household constructed wetland for wastewater water treatment plant, transferring all sewage water into the atmosphere through the physical process of evaporation is shown in Figure 16.2. Perfect mechanical pretreatment plays an important role in this case, which in case of the use of constructed wetland wastewater treatment plant as a main treatment stage is created by the oversized biological septic tank, ensuring non washing away of suspended solids into the filtration environment.

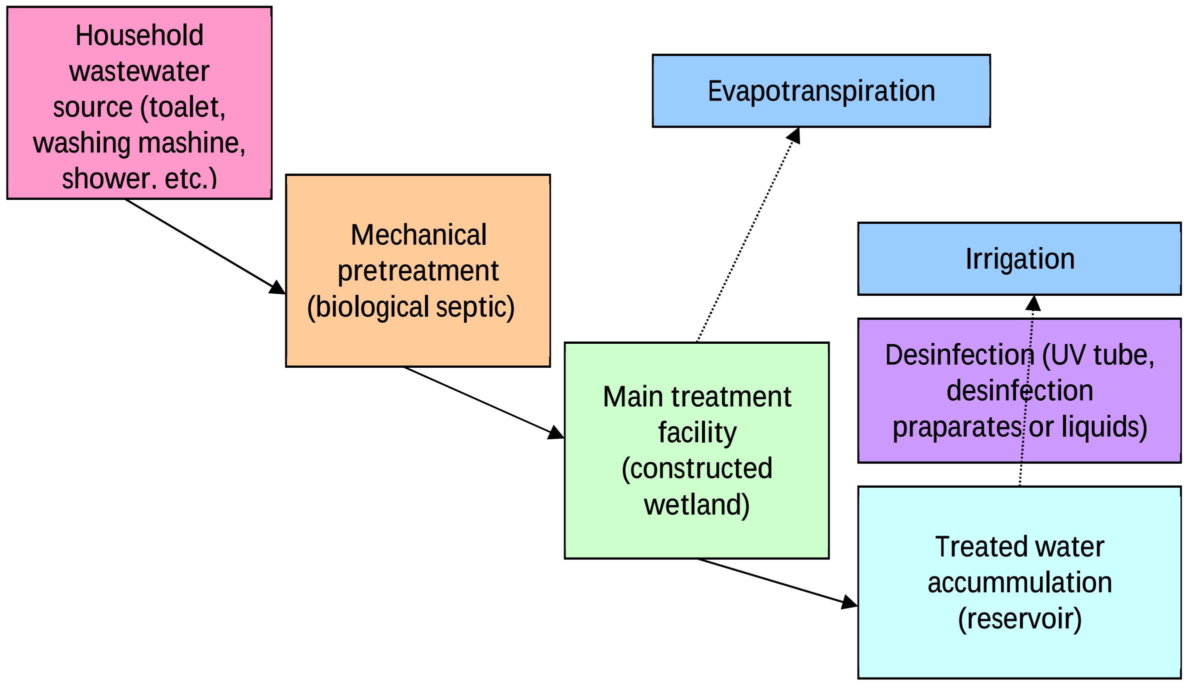



Fig. 16.2 Scheme of Drainless System Using Evapotranspiration

In the context of the known parameters such as the number of connected producers, and their daily production of wastewater, there might be two possibilities for evapotranspiration utilization:

- elimination of the amount of treated wastewater – at a fixed small area of constructed wetland wastewater treatment plant, either at the main or tertiary stage of treatment, it is possible to determine the amount of water which will evaporate during the vegetation period by means of evapotranspiration. The figure of the annual evapotranspiration from small wastewater treatment plants ranges from 900 – 1,500 litres per 1 $m^2$. By means of multiplying the known ground plan area the theoretical figure of evaporated water per year is obtained
- complete drainless system of sewage water treatment - system must be designed so that it can use, to convert treated sewage water to gaseous state by evapotranspiration, all diverted sewage water , the representation realized in practice in the Photo 30. It is also necessary in the case of all year round operation to incorporate an accumulation tank into the system serving to the retention of water during off-vegetation periods. The volume of water can thus be easily determined if the production of sewage water is known

At the beginning of the vegetation period, several options exist:
a) to export accumulated water (similarly sumps for sewage water are exported)
b) to pump water gradually on the evapotranspiration field
c) to utilize accumulated water for irrigation

Photo 30: View of Drainless Arrangement (System biological wastewater treatment plant – constructed wetland wastewater treatment plant – biological tank)

## 16.3 Infiltration of Treated Wastewater

Infiltrating water from individual buildings determined for residential housing and individual recreation or individual buildings providing service, emerging as a product of human metabolism by household activities through the soil layers into groundwater must not contain hazardous harmful substances. The discharge of treated sewage water may be authorized only in exceptional cases, on the basis of the statement of the person with a professional competence, with the respect to the impact on the groundwater quality if it is not possible technically or with the interests protected by other legislation to discharge it into surface water or sewerage system for public needs.

### 16.3.1 Preparation of Design and Layout of Infiltration Devices

An important part of the design of infiltration devices is the determination of hydraulic properties of soil environment into which treated sewage water will be infiltrated. The most important tasks include the determination of infiltration ability of soil that can be expressed as an amount of water infiltrated for a time interval or as a course of infiltration velocity on time and an accurate determination of hydraulic conductivity. Hydrogeological research is focused on gathering data to determine the capacity of a local infiltration area, i.e. the amount of water that is possible to be infiltrated into groundwater without any negative effects. It is based on the piece of knowledge of the course of inflow of treated sewage, precipitation and foreign water, the depth of the groundwater table and its variation during the year and longer periods, the course of water abstraction by evaporation and vegetation, outflow etc. It is important to determine the direction and the course (velocity) of water runoff from the infiltration area.

### 16.3.2 Treating and Final Treating Processes in Soil Environment

Within the infiltration of treated water, treatment processes occur with the contribution of soil environment. These processes are physical, physical-chemical, chemical, chemical and biological, where there are generally known facts about the effect of filtration environment:

- Maximum of captured substances is in the upper part of the soil – in topsoil; the largest binding in the soil is achieved at phosphates, ammonia, organic matter
- Treatment effect of soil is closely related to the proportion of clay particles and the content of humus
- Practically in all the cases, there is washing out of calcium and magnesium from the soil, sulphates and chlorides are in the soil bound insufficiently
- Within the filtration of sewage through the soil profile there is an intensive decomposition of organic matter, ammonium and nitrification processes
- The binding of individual forms of phosphorus is very significant, especially into iron compounds and the determination of the sorption capacity of soil
- Treatment effect of the soil is greater at low doses and low intensity of filtration, the best treatment effect is achieved at the point distribution of sewage water

### 16.3.3 Examples of Arrangement of Infiltration Devices

Equipment to ensure an uninterrupted course of infiltration of treated sewage water can be divided into the following groups:

- Surface infiltration devices formed by shallow excavated tanks in the number of at least two to three, with the possibility of the alternating operation, usually with grassland, using dissolved nutrients from sewage water, utilizing the part of water for evapotranspiration
- Thermally insulated by different ways, covered infiltration areas that allow the uninterrupted operation even in the winter

- The combination of shallowly embedded perforated manifold, designed for the summer operation with much deep stored perforated manifold, intended for the operation in the winter, schematic arrangement is displayed in the Figure 16.4
- Systems of infiltration trenches of the depth of 0.6 m with the surrounding plants of fast-growing woody plants with the high demand of water for evapotranspiration, using a significant part of nutrients
- Systems of perforated infiltration underground pipe network with the end aeration, divided into separately manageable sections
- The device for the discharge of treated sewage water into deep drill wells, etc.

In some cases, it will be necessary to design equalizing or rather accumulation, storage reservoir that will ensure the continuous operation.

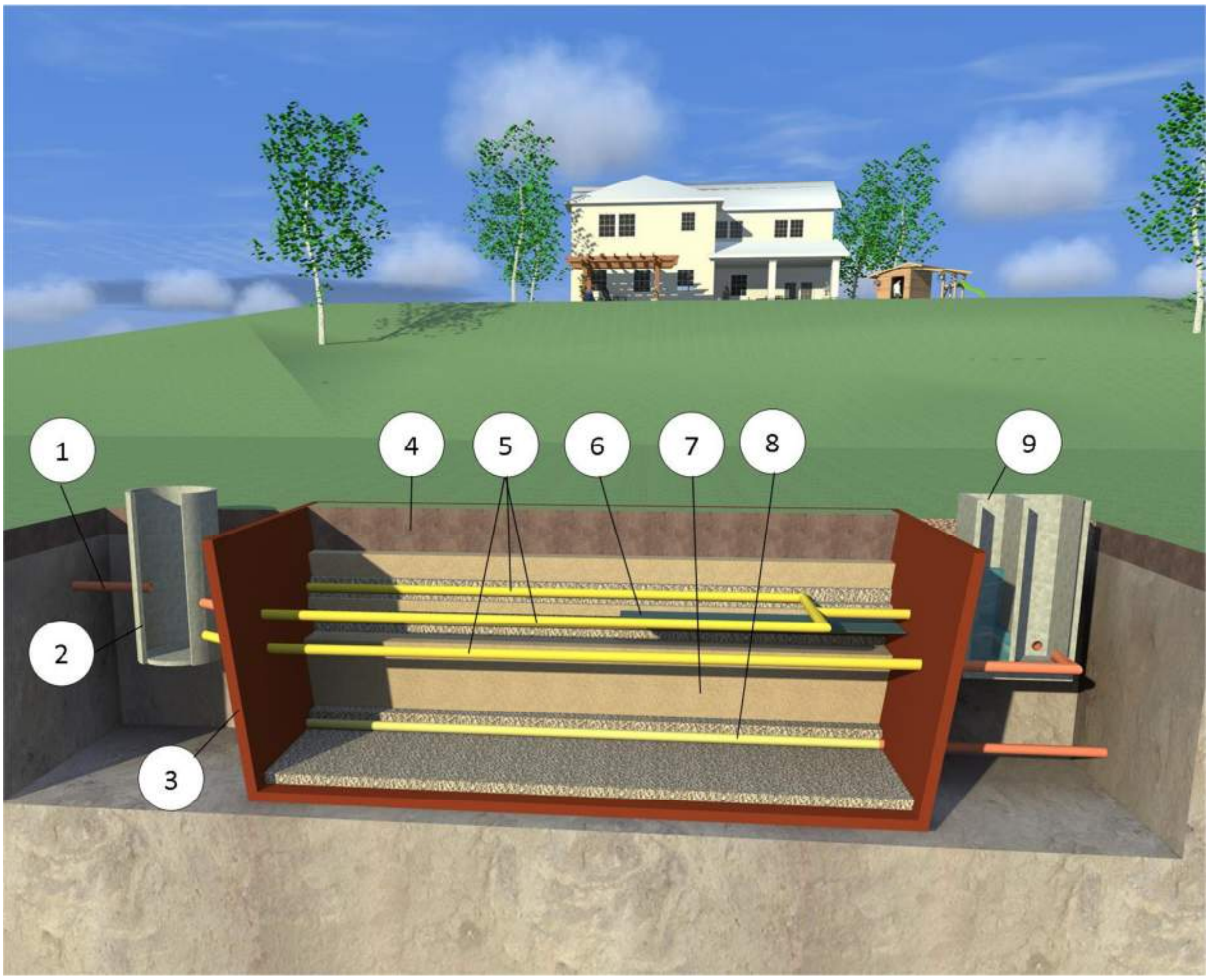



Fig. 16.3 Multi-level Arrangement of Infiltration Device, 1-inflow, 2-shaft, 3-isolation of subsoil, 4-soil profile with vegetation, 5-manifold, 6-insulating foil, 7-filtration subsoil, 8-outflow drainage, 9-regulation and inspection shaft

### 16.3.4 Risks of Infiltration of Treated Sewage Water

Within the infiltration of treated sewage water it is necessary to be consistent and to operate the device in such a way in order not to occur the risks of groundwater contamination; they rest on:

- Infiltration of nitrates
- Bacterial contamination of groundwater

- Exchange of sodium in the sorption complex of the soil and washing away of calcium and magnesium
- Change of aerobic regime in the soil environment into v anaerobic
- Insufficient binding of phosphates after the depletion of sorption possibilities.

Extremely low permeability of heavy clay soil and the associated reduction of hydraulic conductivity due to clogging of open pores are ranked to the hazardous characteristics of the filtration environment.

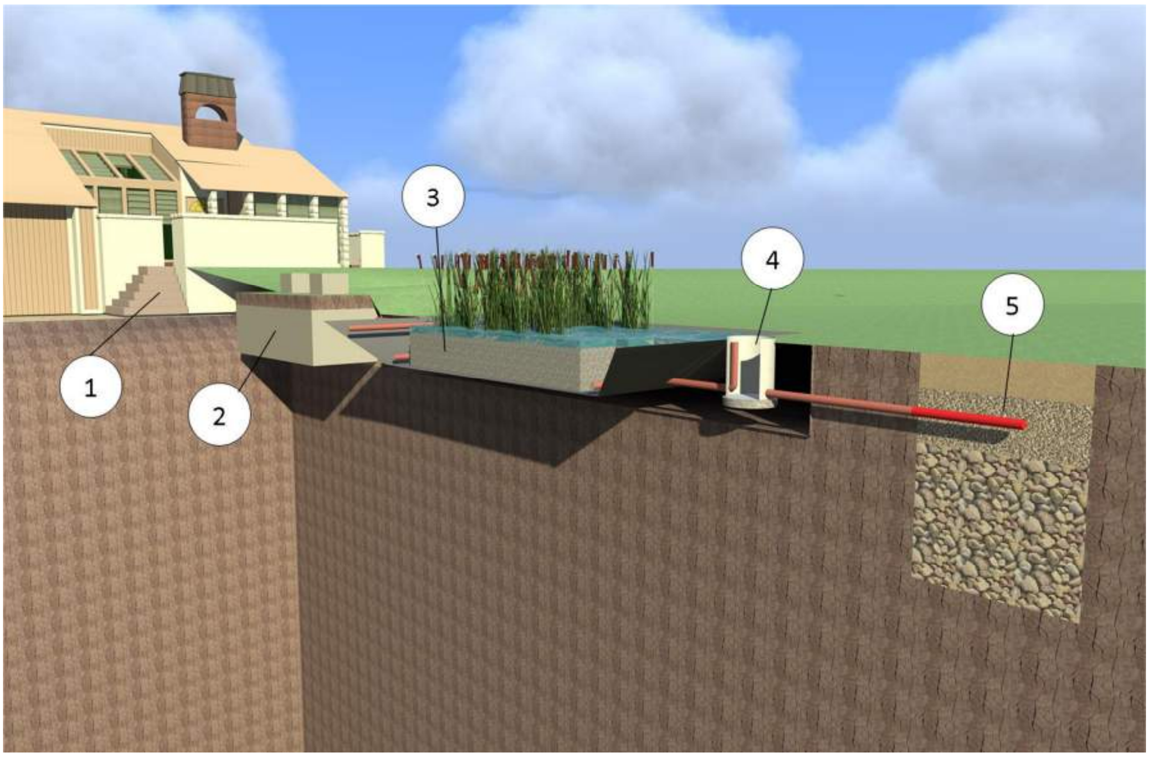



Fig. 16.4 Infiltration Arrangement after Treatment of Wastewater 1-producer of wastewater, 2-multi-chamber septic tank, 3-constructed wetland wastewater treatment plant, 4-regulation shaft, 5- infiltration area

# 17 Waste Management

Water management in water treatment plants using natural treatment methods produces a range of waste that is typical for this branch, requiring special methods of disposal. Waste from these devices can be divided into materials comprising:

- Waste and sludge from mechanical treatment stage including bar screens, sand and grease traps, sedimentation tanks, sludge from septic tanks
- Wetland plants from growing plants, biomass from biological ponds and equipment from aquaculture
- Sludge from regeneration of filter material of soil filters and constructed wetland treatment plants
- Biological sediments from biological ponds, buffer and storage tanks
- Silt and sludge from the treatment of precipitation water, filtration equipment, sludge from filters for treatment of water for irrigation and subsurface irrigation
- Grass of grassed areas near treatment facilities, waste wood from fast growing trees and maintenance of ornamental trees

Waste and sludge from small wastewater treatment plants consists mainly of waste captured on screens and fine screens, sand traps, grease and oil traps, biological septic tanks, primary and possibly secondary sedimentation.

Rackings from sieves and fine bar screens contain a number of organic compounds and about 80 % water. They must first be drained, dried and then they are disposed of in landfills or incinerators. Grease and oil traps are designed directly at the source of pollution, they are proposed separately, they are also inserted into biological waste from septic tanks, etc. Waste from grease and oil traps are burnt in the set incinerators, where there are transported in special containers.

The amount of sewage sludge can be estimated from the production: 1 p.e. produces 55 g of suspended solids, the exact figure should be determined individually.

The composition of sludge is due to the various origins and requires individual investigation. The quantity of organic and mineral substances is determined in the sludge, and it is thus necessary to pay increased attention to the content of heavy metals such as arsenic, cadmium, chromium, copper, mercury, nickel, lead and zinc in the determination of absorbable organic halogens (AOX), polychlorinated biphenyls (PCBs). If these substances occur in excessive quantities, the sludge has the character of hazardous waste. The microbiological investigation is the most important for determining of thermotolerant coliform bacteria, enterococci and Salmonella sp. In terms of agricultural use of sludge, it is important to know the content of essential nutrients such as nitrogen, phosphorus, potassium, calcium, magnesium, the content of sodium and sulphates and heavy metals. Sampling shall be carried out in accordance with ISO 5667-13 "Guidance on sampling of sludge from wastewater treatment plants" and "; preservation and transportation is carried out in accordance with ISO 10381-6 "Guidelines for the collection, handling and storage of samples".

It is necessary to stabilize the sewage sludge aerobically or anaerobically prior to loading or to perform hygienization (see chapter 14).

## 17.1 Sludge Dewatering

Sludge dewatering increases the dry matter content and removes the sludge water. There are many methods of drainage, the natural technologies of sludge dewatering are directly offered for sewage treatment plants with a natural way of treating:

- Sludge dewatering on sludge fields that are designed in a dual configuration with a solid bottom (sludge is dried by evaporation) and a permeable bottom and the filtrate outlet
- By drain with filter
- Solar drying of sludge in covered drying greenhouses
- Sludge dewatering using wetland plants (e.g. sludge drying reed beds)
- Gravity drainage by fabric filters

An alternative solution is to transport sludge by faecal cars on sludge treatment plant with sludge management or dewatering by mobile centrifuges.

### 17.1.1 Stabilized Sludge Dewatering by Wetland Plants

The high transpiration capacity of wetland plants such as common reed (*Phragmites australis*), manna grass (*Glyceria maxima*), reed canary grass (*Phalaris arundinacea*), and cattail (*Typha latifolia, Typha angustifolia*) is used for sludge dewatering. These plants use necessary nutrients for the biomass production from stabilized sludge. They form massive vegetation when they have sufficient moisture and nutrients.

The sealed and drainable sludge tank, usually of rectangular or square shape, from plastic and reinforced concrete are used for the stabilized sludge dewatering.

Sealing foils (e.g. PE-H), covered by indoor protective geotextile, or clay seals are the most commonly used for sealing of sludge lagoons.

Above the tank or lagoon bottom there is the layer of gravel with dewatering drains, fitted with filter backfill. Above it there is the layer of humus substrate with macrophytes. Arrangement of sludge lagoon is shown in Figure 17.1, reinforced concrete tanks is shown in Photo 31.

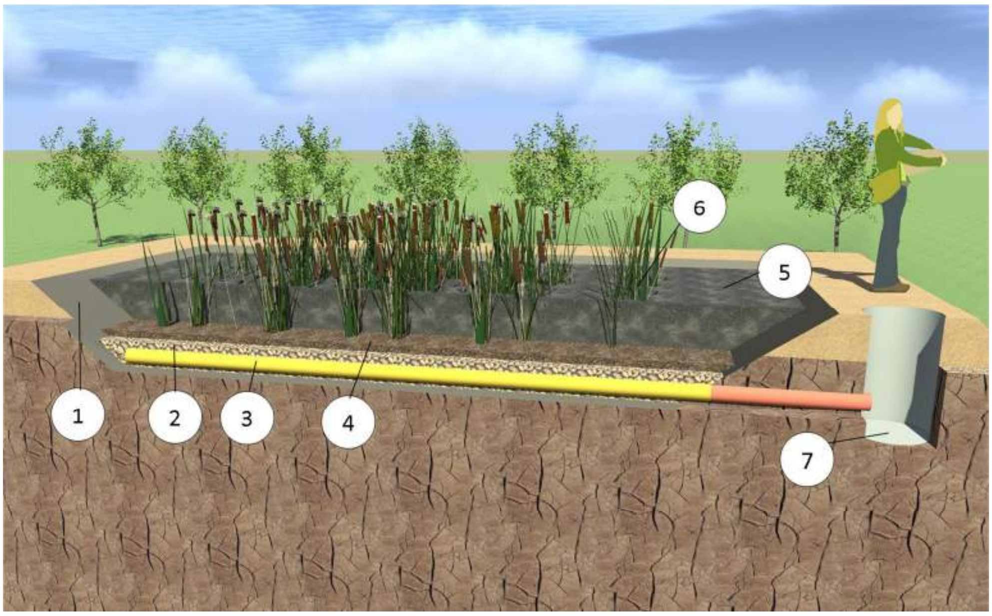



Figure 17.1 Scheme of Arrangement of Sludge Tanks: 1-insulated tank, 2-drainage distribution layer, 3-drainage pipe system, 4- decomposed material, 5- sludge layers, 6-macrophyte vegetation, 7-drained water collection shaft

The number of sludge beds depends on the number of operating years between the first and the last loading at full space of tank; it is usually six to eight tanks.

Photo 31: Arrangement Sludge Basins with Wetland Plants (France)

The filling of stabilized sewage sludge is initiated in the second half of spring, depending on the development of vegetation. Doses of sludge and their number are selected according to plant development and climatic conditions of the locality. After the growing period, the plants are mowed and kept in the tank, the biomass increases significantly the proportion of organic matter in the substrate. After six to eight years of operation, the sludge bed is filled with organo-mineral substrate, filling is stopped, the substrate is dewatered, dried, homogenized by the rotavator and ready for application or mixing with other wastes for composting.

The total load of sludge fields $M_k$ is calculated from the balance equation

$$M_k = W_{ET} + W_D - \alpha.S_R - W_P \qquad (17.1)$$

where

$W_{ET}$ - a value of evapotranspiration

$W_D$ – size of drainage runoff

$\alpha$ – coefficient of utilization of precipitation water

$S_R$ – annual precipitation amount

$W_P$ – tied water in the soil environment; all the data is substituted in the same unit mm.year$^{-1}$, m$^3$.year$^{-1}$ to a square meter, etc.

The tank sludge dewatering effect is increased by placing into plastic greenhouses, which eliminates the influence of precipitation water and makes growing season longer and creates favourable conditions for the development of wetland vegetation. Schematic arrangement is shown in Figure 17.2.

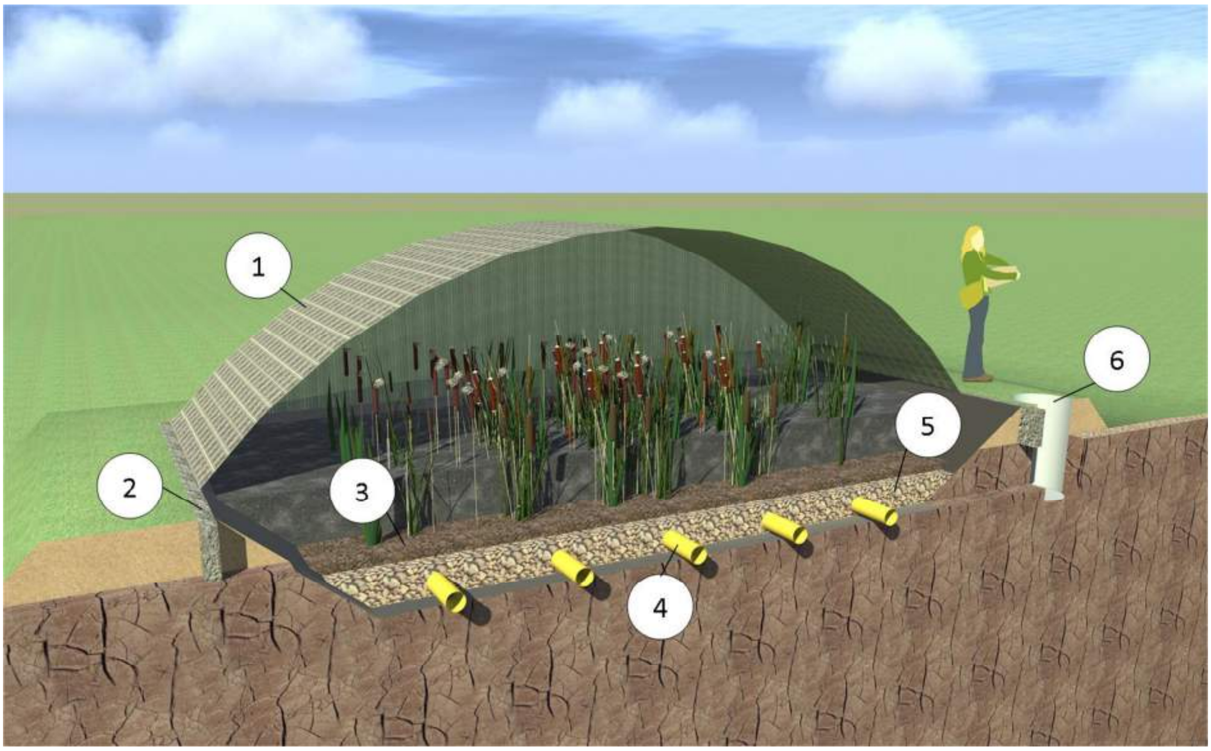



Figure 17.2 Sludge Tank in Plastic Greenhouse 1-plastic greenhouse, 2-sludge tank with wetland vegetation insulated by lining protected by geotextiles, 3-sludge layer, 4- drainage pipe, 5- drainage backfill, 6-pumping shaft

## 17.2 Disposal of Sewage Sludge

The methods of the sewage sludge use are based on:

- The use of stabilized and sanitary treated sludge in agriculture
- Composting of sludge together with other appropriate waste (biowaste, etc.)
- The use of sludge on recultivation of disturbed, eroded soil (Gascó, Lobo, 2007)

Other methods include dumping of sewage sludge, transport of sewage sludge into the sewage sludge treatment with sludge management, production of sludge pellets; different ways of combustion and pyrolysis of sewage sludge (e.g. new methods of "terra preta" or "biochar" production) are not used at small sewage water treatment plants at present time.

### 17.2.1 Direct Agricultural Use of Stabilized Sludge

Agricultural use of sludge is conditioned by several factors. These include enough suitable areas with favourable soil, geological and hydrogeological conditions, permissible sludge composition and appropriate manner of their application. Conditions for the use of modified sludge on agricultural land can be determined based on legislation of EU (EU Directive 86/278/EEC) and CEE countries. Limit values given by legislation of selected countries and this EU directive are mentioned in table 17.5.

The most important conditions for the application of sludge on agricultural land include:

- It is necessary to get the stabilized sludge into the soil within 48 hours
- It must not be used more than 50 kg dry sludge on 100 $m^2$ fertilized soil over three consecutive years

- The amount of nitrogen supplied in the sludge may not exceed 70 % of the consumption of nitrogen by plants, taking into account the content of all forms of nitrogen in the soil
- Minimum dry matter in sludge for pressure incorporation into soil by ploughshare applicators is 5%; if bio-mechanical spreaders are used, minimum dry matter content is 18%
- Sludge can be applied on agricultural land only if it meets the limit values of hazardous substances, elements (Table 17.2) and microbiological criteria (Table 17.3). Examples of given limits specified in the Tables are valid in the Czech Republic (Legislation Gov.Dec. 382/2001 Coll.)

In the soil on which sludge is used, the limit concentrations cannot be exceeded. An example of given limits is specified in Table 17.4. (Legislation Gov.Dec. 382/2001 Coll. valid in the Czech Republic).

Table 17.2 Limit Concentrations of Selected Elements in Sludge ($mg.kg^{-1}$ dry matter)

| Monitored Indicator | Limit Concentrations in Sludge in $mg.kg^{-1}$ dry matter | Monitored Indicator | Limit Concentrations in Sludge in $mg.kg^{-1}$ dry matter |
|---|---|---|---|
| As | 30 | Nickel-Ni | 100 |
| Cd | 5 | Lead-Pb | 200 |
| Cr | 200 | Zinc-Zn | 2,500 |
| Cu | 500 | AOX | 500 |
| Hg | 4 | PCB x) | 0.6 |

*Note: x) – sum of 6 congeners (28+52+101+138+153+180)*
*/see http://www.epa.gov/osw/hazard/tsd/pcbs/pubs/congenertable.pdf, 19.12.2013/*

Table 17.3 Microbiological Criteria for the Sludge on the Agricultural Land

| Sludge Categories | Permissible Number of Microorganisms (CFU) in 1g Dry Sludge | | |
|---|---|---|---|
| | Thermotolerant coliform bacteria | Enteroccoci | Salmonella sp. |
| I. | $< 10^3$ | $<10^3$ | Negative finding |
| II. | $10^3$ to $10^6$ | $10^3$ to $10^6$ | Not determined |

*Note: CFU/g dry weight – colonies forming unit*

Category I: Sludge that generally can be applied to agricultural land in compliance with the principles set out in the Regulation. Category II: Sludge that can be applied to agricultural land for cultivation of industrial crops, the soil on which there will not be grown vegetables and fruit planting fruiting heavily at least for three years after the application sewage sludge, while respecting the principles of occupational health and other provisions of the Regulation.

Table 17.4 Limit Concentrations of Selected Elements in Soil ($mg.kg^{-1}$ dry matter) Note: x) v $mg.kg^{-1}$ dry matter

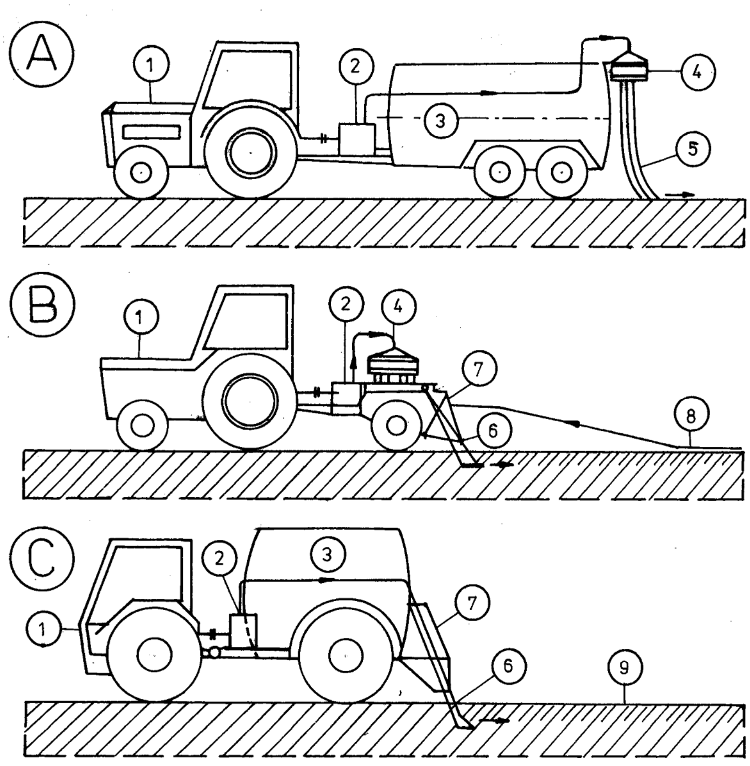
| Hazardous Elements | Limit Concentrations of Hazardous Elements in Soil | | Hazardous Elements | Limit Concentrations of Hazardous Elements in Soil | |
|---|---|---|---|---|---|
| | Common Soil | Sandy Soil | | Common Soil | Sandy Soil |
| As | 20.0 | 15.0 | Hg | 0.3 | 0.3 |
| Cd | 0.5 | 0.4 | Ni | 50.0 | 45.0 |
| Cr | 90.0 | 55.0 | Pb | 60.0 | 55.0 |
| Cu | 60.0 | 45.0 | Zn | 120.0 | 105.0 |

The rate of degradation depends on the microbial recovery, temperature, soil type and moisture, fertilizing sludge dose and the amount of organic matter. When loading soil by sludge it leads to clogging of soil, reducing processes, reducing soil reaction and soil degradation treatment effect. The application of sludge on frozen soil, snow, before and after the rain is inadmissible. The best results are achieved when applying sludge on the soil surface, and even better is the immediate incorporating sludge into soil- Photo 32 and Figure 17.3.

Table 17.5 Limit Values of Elements in Sludge in Selected Countries (Žerava, 2008)

| Country / Element | As | Cd | Co | Cr | Cu | Hg | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|
| EU Directive (86/278/EEC) | - | 20-40 | - | - | 1000-1750 | 16-25 | 300-400 | 750-1200 | 2500-4000 |
| Belgium | 10 | 10 | 20 | 500 | 500 | 10 | 100 | 300 | 2000 |
| Denmark | - | 0,8 | - | 100 | 1000 | 0,8 | 30 | 120 | 4000 |
| Finland | - | 1,5 | - | 300 | 600 | 1 | 100 | 100 | 1500 |
| France | - | 20 | - | 1000 | 1000 | 10 | 200 | 800 | 3000 |
| Netherlands | 10 | 10 | - | 500 | 600 | 10 | 100 | 500 | 2000 |
| Germany | - | 5 | - | 900 | 800 | 8 | 200 | 900 | 2000 |
| Norway | - | 2,5 | - | 100 | 650 | 3 | 50 | 80 | 800 |
| Poland | - | 10 | - | 500 | 800 | 5 | 100 | 500 | 2500 |
| Slovak Republic | 20 | 10 | - | 1000 | 1000 | 10 | 300 | 750 | 2500 |
| Sweden | - | 2 | 50 | 100 | 600 | 2,5 | 50 | 100 | 800 |
| Switzerland | - | 5 | 60 | 500 | 600 | 5 | 80 | 500 | 2000 |
| Great Britain | 50 | - | - | 600 | 130-300 | 1,5 | 80-180 | - | 330-750 |
| Czech Republic | 30 | 5 | - | 200 | 500 | 4 | 100 | 200 | 2500 |

Photo 32: Application of Liquid, Stabilized and Sanitary Treated Sludge on the Soil Surface




A. Distribution on the surface of the soil: 1-tractor, 2-pump, 3-cistern, 4-dispensing equipment, 5-application hose

B. Sludge application shallowly into the soil: 1-tractor, 2-pump, 4-dispensing equipment, 6-blade, 7- inlet sludge, 8-drawn pipe transporting sludge

C. Application of sludge from the tank shallowly to the soil: 1-tractor, 2-pump, 3-cistern, 6- blade, 7- inlet sludge, 9- site of fertilization

Figure 17.3 Different Methods of Sludge Application into Soil (Šálek, Tlapák, 2006)

# 18 Design Monitoring, Selection of Appropriate Indicators, Methods of Evaluation of Results and Efficiency

Extensive wastewater treatment plants are specific in comparison with machinery treatment plants in the relatively long retention time of wastewater in the whole wastewater treatment system. The retention time depends on actual hydraulic conditions such as the size of water flow and ranges in order of magnitude in days. Higher retention time can occur in systems complete with across the board extended final treating stabilization tank, alternatively their cascade.

The concentrations of set inflow and outflow indicators from the wastewater treatment plant are monitored once a month or four times a year for the purpose of evaluation of treatment efficacy and the comparison with the national limit values.

For the evaluation of the loss of pollution (treatment efficacy) it is possible to use approaches based on the calculation of the ratio inflow/outflow = removed load:

- The calculation of the loss of pollution according to above mentioned relation for every individual sampling and then the calculation of the average efficacy. If we take into account that the samples are cumulated between 2 and 24 hours, there is the distortion of the result because the value of outflow load is not balanced with actual inflow
- The calculation of the loss of pollution according to the above mentioned equation from long-term average inflow and outflow values. It is thus a statistical evaluation of time series from individual specific profiles
- The calculation of the real retention time in the whole system and the performance of inflow sampling after such set time. We obtain values of inflow and outflow loading which correspond each other. It is demanding to exactly determine the retention time at the wastewater treatment plant for that purpose. It means several measurements in a few days of the tracer transportation within the filter or whole WWTP. It would be necessary to carry out the measurement for different flow rate and compile the dependence of retention time – flow rate. If deciding to start from the retention time calculated according to design parameters, with the consideration of homogeneity of filtration material characteristics, considerable errors will be made because in practice, the filters can be partly clogged. Thus, this approach is suitable for purposes of research monitoring but it is probably inappropriate for purposes of operational monitoring.

The efficiency of wastewater treatment, expressed in the percentage of pollution removal in monitored indicators can be calculated from long-term average values of the concentration of the individual inflow and outflow indicators from the wastewater treatment plant i.e. before the stage of mechanical pretreatment and behind the filtration fields or behind the final treating stabilization tank. It is thus calculated on the basis of the procedure stated in point 2. It is convenient to determine the standard sampling and measuring profiles in the frame of the technological line of the wastewater treatment plant.

The last possibility of the evaluation of the wastewater treatment plant functionality is an assessment of fulfilling or exceeding of limit values, expressed by means of the number of samples exceeding the set limits for individual indicators. This procedure is also used when controlling the wastewater treatment plant. This method seems to be objective mainly in the case of wastewater treatment plants where flowing highly diluted wastewater and only assessment from the ration inflow/outflow would be distorting. This is often the case with very low values.

## 18.1 Monitoring and Treatment Effect Assessment

Typology of samples:

- 2-hour mixed sample obtained by cumulating of 8 subsamples of the same volume in the interval of 15 minutes
- 24-hour mixed sample, obtained by cumulating of 12 subsamples of the same volume collected in the interval of 2 hours

Microbiological analyses are usually carried out from the point samples. Four generally determined indicators are monitored: coliform bacteria, thermotolerant (faecal) coliform bacteria, Escherichia coli and intestinal enterococci.

### 18.2 Fixed Indicators and Methods of Assessment

At wastewater treatment plants, the fundamental indicators of wastewater pollution are the content of non-dissolved substances and organic pollution expressed by water quality parameters including mainly suspended solids, $BOD_5$, COD. These provide a frame for standardized monitoring.

The physical – chemical characteristics of water such as temperature, amount of solved oxygen and oxygen saturation, pH, specific electrical conductivity and reduction-oxidation potential are also recommended to be monitored.

In the case of higher requirements on water treatment, ammonia nitrogen and total phosphorus are used as indicators of nutrient removal and included in the monitoring process.

For the detailed knowledge and judgment of treatment processes, it is also essential to analyzed other forms of nitrogen, especially nitrate nitrogen, total nitrogen or the forms of phosphorus (dissolved phosphorus).

When talking about stabilization ponds, one of the indicators of ongoing processes is the determination of the concentration of chlorophyll in water samples, which is the representation of the amount of algae in water environment. Monitoring of water turbidity also be useful and provide a cheaper alternative of chlorophyll analysis or detailed phytoplankton determination.

Heavy metals, AOX and other indicators of water quality are monitored in specific cases.

# 19 Integration of Various Installations into Environment

When designing the wastewater treatment plant it is necessary, in addition to the functionality of the installation, to account for the environmental impact, including the integration into the landscape. This includes selecting the suitable location with the respect to the installation surrounding, selecting a location with supporting and operating vegetation, as well as the use of the aesthetic effect of the various equipment and adequate to local and climatic conditions.

Stormwater can be polluted by surface runoff transporting suspended solids, nutrients, pesticides from fields surrounding small settlements in agriculturally managed landscape, especially if the fields are cultivated inappropriately Because extensive WWTPs are used mainly for the treatment of wastewater from small settlements with combined sewer systems transporting these stormwaters to treatment plant, it is necessary to preventively design measures (through technical measures, e.g. retention and infiltration ditches) to protect sewage system from of field washes. In the absence of retention ditches or other technical measures to prevent the penetration of field washes, the torrential runoff can cause the blockage of sewerage systems. If the wastewater treatment plant is equipped with the rain relief that does not have sufficiently dimensioned relief chambers, alternatively accompanied by the flow controller, this precipitation water can significantly affect the recipient, in which the relief is introduced, e.g. hydraulic shock, turbidity, effects on organisms in the stream or stream bed damage. Due to that municipalities have a larger area of paved surfaces, drainage of precipitation water is faster and thus the flow curve is steeper.

In municipalities, it is necessary to implement such measures that would minimize the amount of stormwater and pollution flowing rapidly into the stream or to the wastewater treatment plant. For extensive treatment of wastewater that is used mainly in small settlements, the solution of combined sewerage with perfectly functioning overflow facilities and stormwater retention tanks can be supposed. The simplest solution in this case appears to be the mechanical pretreatment of water such as bar screens and sand traps and discharging of water by means of bypass pipeline into the recipient. For stabilization ponds, it is necessary to ensure that the hydraulic shock by stormwater loading do not initiate washing up of sediments from the pond to the recipient by sufficient dimensioning of the ponds. In case of the cascade of the ponds it is convenient to install the bypass canal into the second pond in order not to disturb sediments in the first pond.

Even in the case of a combined sewerage, the outflow of stormwater into the sewerage can be decreased by retention and infiltration by various ways:

- Accumulation tanks
- Porous hard surfaces, porous pavement
- Infiltration furrow
- Infiltration wells
- Infiltration pipe
- Retention and percolation tanks
- Flooding fields

Obviously, it is always more advantageous to build separate sewage system and rainwater collection system (rainwater can be collected and infiltrated). Roofs runoff can be collected and used for watering and partially replace drinking water consumption in households. The main disadvantage of a separate rainwater system is the financial costs of acquisition of the system and its maintenance including treatment and barriers or screens against penetration of leaves.

Discharge of rainwater system can be installed into the recipient or can be used open retention ponds, which may be dry, filling only by the stormwater or with permanent water retention. In small settlements a fishpond, multi-purpose water reservoir or a fire protection water tank in which some space is reserved for precipitation water fulfil this function.

Wastewater facilities must not disrupt the environment. This is especially important for households and recreational facilities located in mountains and foothill areas with high landscape value. Achieving this goal especially helps the selection and arrangement of the individual stages of treatment and the use of new knowledge, recirculation and the use of all sorts of water, and planting area with suitable plant species. The general design principles of individual devices in buildings, groups of decentralized recreational facilities consist of:

- An appropriate site selection of individual installations and their careful connection to the architecture including the detailed integration into the landscape
- Delicate design of simple and perfectly functional objects, which do not have the disturbing effect on the environment, even on the landscape and in the use of aesthetic effect of individual installations
- Practical and aesthetic to gardening landscaping of buildings and facilities and access roads;
- proposal for a meaningful retention and erosion control measures on sloping land that protects against contamination by foreign water from rural areas and prevent the formation of surface washes off in its own premises
- Reduction of the number of minor operational structures and their purposeful architectural design, possible location below the ground level such as accumulation (storage) tanks
- Maintenance of filtration and sludge fields, removing of sediment loads from the bottom of their tanks including hygienic use to improve soil quality

## 19.1 Selection of Suitable Vegetation

To achieve the appearance of small natural wastewater treatment plants and their integration into the terrain, the selection of suitable vegetation, not only for constructed wetland filters, is crucial. It is the best to use plants, situated on the surrounding natural areas.

The most commonly used plants for wetland treatment plants are common reed (*Phragmites australis*), reed canary grass (*Phalaris arundinacea*), cattail (*Typha angustifolia, Typha latifolia*), manna grass (*Glyceria maxima*), sedges (*Carex* sp.), yellow iris (*Iris pseudacorus*) - Photo 33. These plants are aesthetically monoculture and in combination of various plants.

For integration of artificial wastewater treatment plants into the surrounding installation and the landscape, it is suitable to plant an aesthetic belt or the group of trees, bushes or garden plants.

The natural aesthetic element of artificial and natural wastewater treatment systems may be small ponds, using mainly rain but also treated wastewater, planted with water lilies (*Nymphaea spp*), *Nuphar luteum* and around the shores aesthetically looking kinds of littoral species of plants (yellow iris *Iris pseudacorus*, rushes *Juncus sp*., sedge *Carex sp., Lythrum salicaria*, reed canary grass *Phalaris arundinacea* - form *Picta*, cattail *Typha spp.*, etc.). Plants significantly contribute to nutrient depletion and pollution, significantly contribute to water evaporation, enrich water with oxygen and in winter prevent continuous ice cover (more islets in the wind), which allows the survival of fish (Photo 34).

Ponds can also be used for treatment of water from smaller sources (individual objects constructions) and compose them as decorative elements – see Photo 35. Shallow biological ponds can be successfully used for biological treatment of wastewater in mountain and foothill areas.

Photo 33: Arrangement of Small Treatment Pond with Water and Wetland Vegetation

Photo 34: Small Natural Wastewater Treatment Plant without Outflow (Final Treating Tank with Floating Islands with Yellow Iris and Water Hyacinth) Forms an Aesthetic Element in the Garden

Photo 35: Example of Implementation of Final Treating Biological Tank on the Farm

## 19.2 Function of Constructed Wetlands in the Landscape

Nature ways of wastewater treatment support the main functions of the landscape, i.e. flux of water, materials and energy. The time of water retention in a constructed wetland is estimated to 2-3 days. The transpiration of water by plants and evaporation from the water surface in open tanks is realized in vegetation period.

At the constructed wetland wastewater water treatment plant Spálené Poříčí and Dražovice (both CZE) there were evaporation values measured up to 7 litres per 1 $m^2$ surface filters overgrown with reeds per day, the value of evapotranspiration 7 mm per day. In artificially constructed wetlands operated in the USA the evaporation forms half of the daily water balance (Kadlec, 2000). According to Čížková et al. (2003) the values of evapotranspiration over large areas reach 5 to 7 mm per day. The team of authors states that on the small lysimetres of the area of 1 $m^2$ vapour reaches values up to 13 mm per day. The authors recommend calculating the value of daily evapotranspiration of 10 mm. Evapotranspiration values mentioned in the literature (Přibáň, 1998) range from 1.4 – 11.4 mm per day for common reed and between 3.2 – 5.7 mm per day for cattail.

The constructed wetland wastewater water treatment plant creates landscape habitats similar to natural wetland biotopes, which gradually build a community of plants and animals dependent on water and wetland habitats. One of the previous surveys carried out is a detailed survey of flora and fauna in the vicinity of constructed wetland wastewater treatment plant in the village Hostětín (CZE), which is listed on the website: http://hostetin.veronica.cz/sites/default/files/prirodnicistenivody.pdf (19.12.2013). The implementation of constructed wetland wastewater treatment plants created here, in the combination with the final treating stabilization tank of the natural character, a significant landscape element serving as a habitat for several species of reptiles: The wetlands serve as aquatic habitats, attracting species of birds, mammals and insects. For constructed wetland wastewater treatment plants implemented in agricultural and open landscapes, it was confirmed that the environment of constructed wetland filters could be ranked to the elements of the landscape, which have a relatively high degree of ecological stability.

Constructed wetland wastewater treatment plants have a positive impact on the local landscape and microclimate due to relatively high evaporation of water during the growing season from March to October, resulting in the transfer of water into the air and favourable effect on the air temperature around constructed wetland wastewater treatment plant.

# 20 Preparation of construction. Survey works. Design and layout. Building. Final construction approval.

The feasibility study is based on the balance of total arrangement, assessment of water resources, ways of water management, methods of treatment and discharging of treated water and in preliminary economic assessment. The decision tree in the case of treatment way of wastewater sources up to 50 p.e. is illustrated in Figure 20.1.

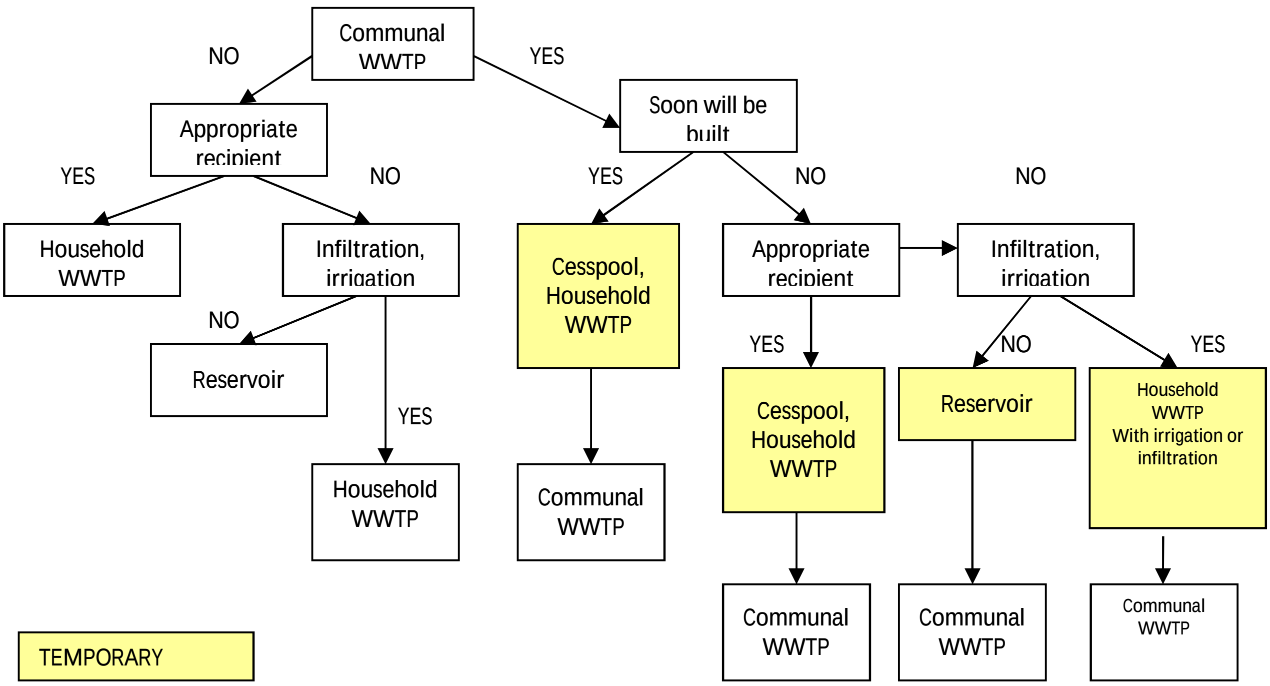



Fig. 20.1 Decision-making process for treatment of wastewater from small resources

For small wastewater treatment systems, it is beneficial to set of the European technical guidances implemented by many European countries “EN 12566”. The EN 12566 sets out a series of standards consisting of a number of parts – refer to Fig. 20.2 for their applications.

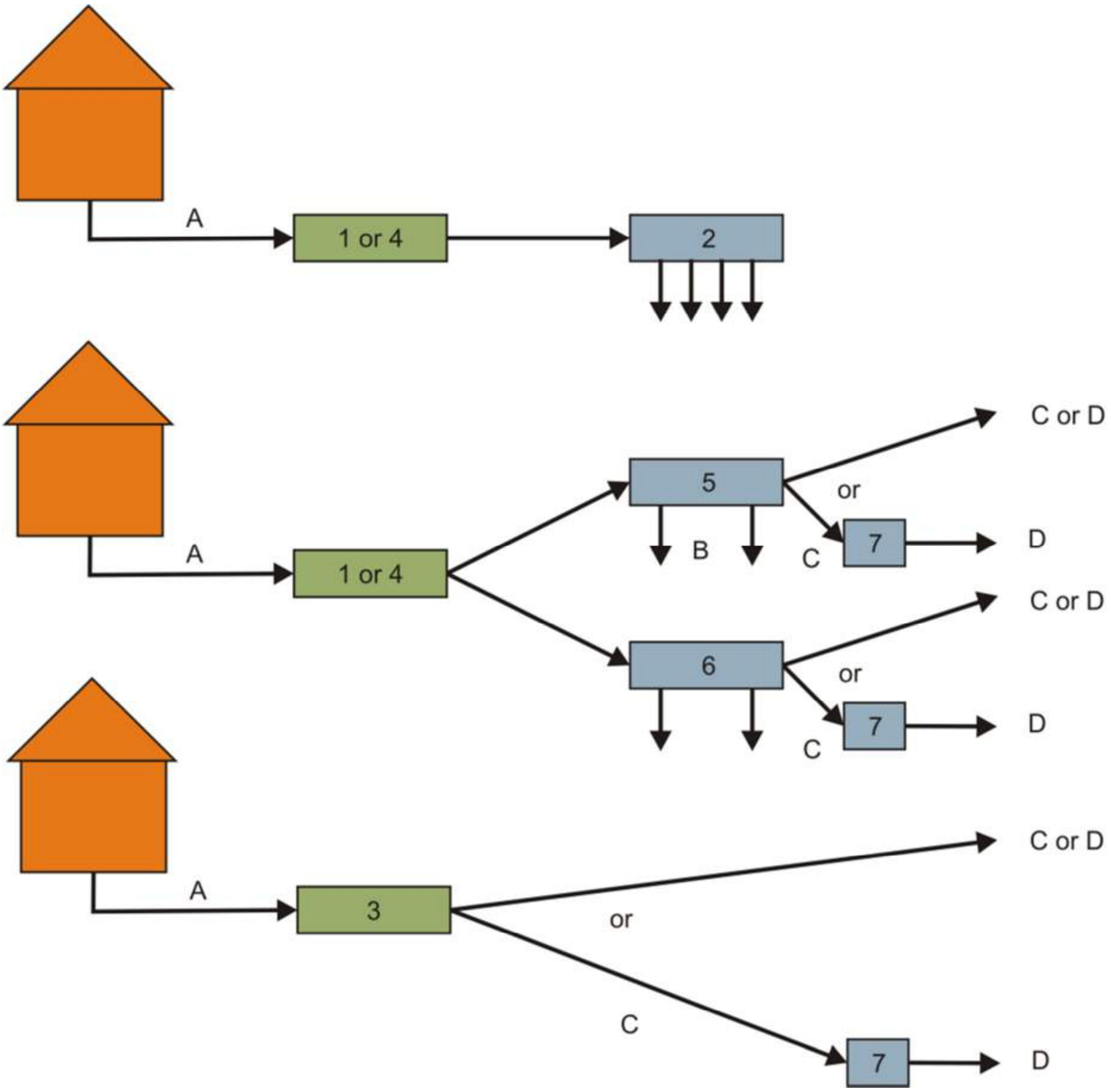



Fig. 20.2 Methods of wastewater treatment in line with EN 12566

Key:
Wastewater type
A: Raw domestic wastewater
B: Treated infiltrated effluent
C: Treated wastewater
D: Tertiary treated wastewater

Part number:
1: Prefabricated septic tank
2: Soil infiltration system
3: Packaged and/or site assembled domestic wastewater treatment plant
4: Septic tank assembled in situ from prefabricated kit
5: Pre-treated effluent filtration system
6: Prefabricated treatment unit used for septic tank effluent
7: Prefabricated tertiary treatment unit

In the case of an implementation plan for the extensive wastewater treatment plant for larger resources (up to 2,000 or 5,000 p.e.), it is convenient to proceed according to the following decision-making procedure:

1. Availability of Land
This is a key parameter in determining the use of extensive technologies. The price of land will also play a significant role in writing the economic balance.

If the available space is less than 1 $m^2$/p.e., it will be necessary to choose the solution of treatment of water by means of intensive technologies or by the connection of the sewerage system to the central wastewater treatment plant.
If the available space is in the range of 2 – 5 $m^2$/p.e., it is possible to select the combined treatment systems using extensive technologies as final treatment steps, e.g. combination of biofilter with a sedimentation tank and final treating constructed wetland filters or biodisc reactor and constructed wetland filters or aerobic tank.
If the available space is more than 5 $m^2$/p.e., it is possible to choose the combined system or to make full use of extensive technologies.

2. Distance from Housing Development
It is important to consider the possibility of odour defects and transport of aerosols from open ponds, especially aerated. The common location is in close proximity to residential buildings for small household wastewater treatment plants, including the use of constructed wetland and soil filters.

3. Required Quality of Outflow from Wastewater Treatment Plants
For particular technologies, there were described the possibilities of how to achieve the treatment effect for the individual types of contamination such as insoluble substances, organic pollution, nutrients, microbial contamination. It is essential to consider the choice of wastewater treatment plant, especially in the context of increased demand for nitrogen and phosphorus removal. If there is sufficient space and it is possible to use extensive technologies, this is possible; otherwise the most effective solution will be the use of activation wastewater treatment plant.

It is essential to observe the particular rules in terms of the design, construction and operation:

- To adjust the layout of the object of mechanical pretreatment of water and filters in such a way so that they can fit the terrain conditions in compliance with the design parameters and the flow regime
- To ensure the equal distribution and flow of water in filters, to eliminate the possibility of clogging, intensive clogging and mudding of the surface
- To exclude the occurrence of short-circuit currents in filters by means of suitable ground plan design
- To eliminate fitful plugging of filters by surface washes by means of the construction of detention ditches and canals in the area (according to the local situation),
- To cover the objects of the mechanical stage of pretreatment, regulation well or other objects
- To carry out the regular monitoring of the level and amount of sludge in the objects of mechanical pretreatment of water
- To carry out the regular control of outflow(visual appearance of water, turbidity, odour)
- To ensure the regular maintenance of the device, mowing the grass, care of wetland vegetation, in the case of common reed and reed canary regularly mow, to remove unwanted species from the filter surface (e.g. nettle, self-seeded bushes and trees)

Wastewater treatment plant using the soil or constructed wetland filters is a structure with its lifespan determined mainly by the lifetime period of the wetlands or filters, i.e. approximately 15 to 20 years. The lifetime period of filters depends on regular maintenance, mainly through monitoring at the level of sludge in the septic tank. In the case of an accident or malfunction, it is possible to replace the defective parts of gravel filter material and to carry out new planting by wetland plants. In the case of biological tanks, the lifetime period is determined solely by clogging. For the possibility of extracting sediments, it is essential to allow for easy access of tanks for machinery even in the project preparation.

The preparation of the construction is based on the approved local plan that contains the fundamental data of the solution of the problem with waste and precipitation water management. This introductory part is followed by exploratory work, project development, building site selection, construction, design of manipulative and operating set of rules, final inspection and pilot scheme. The procedure of works must meet the legislative requirements of the individual EU countries, which may also slightly vary. The same applies to the conditions of approval of the building permit, the way of water management and environmental protection.

## 20.1 Localization of Wastewater Treatment Plant

For the location of the wastewater treatment plant recommended principles are applied:
An Environmental Protection Area is defined by the direct distance from the edge of the continuous housing development to the outer face of the wastewater device of to the edge of the land of treatment plants. In the prevailing wind direction, the distances are appropriately extended, usually not more than twice. The distances are necessary to be adjusted at articulate or undulated terrain according to the local conditions. It is recommended to screen off the objects by means of suitable planting (*Taxus baccata* /yew tree/, *Ligustrum vulgare* /common privet/) in the direction of prevailing winds, tab. 20.1.

Tab. 20.1 Minimum Distance of Environment Protection Zone between Wastewater Treatment Plant to 30 $m^3.day^{-1}$ and Housing Development.

| Type of Wastewater Treatment Plant | Distance in m |
|---|---|
| Objects with low-noise devices, covered and ventilated above the last floor | 5* |
| Objects covered without ventilation | 20* |
| Objects uncovered with open level | 50 |
| Infiltration Device<br>Natural Methods of Treatment | According to local conditions, arrangement and hydrological assessment |

**For small buildings and in a cramped area the distance may be lesser, usually 1m.*

It is necessary to dispose the trapped products associated with the operation of wastewater treatment plants. It is particularly important to dispose the stabilized sludge that is stored in a storage area of a wastewater treatment plant. In this case, a car is used. The direct contact and handling of sludge should be quick and consequently the location of wastewater treatment plant is chosen to be as close to the road network as possible.

The distance of constructed wells and sources of potential contamination are listed in Table 20.2a,b.

Tab. 20.2a,b Minimum Distance of Public and Private Wells from Resource of Contamination according to which country?

| a)Public Wells Resource of Contamination | Minimum Distance* | | | B)Private Wells Resource of Contamination | Minimum Distance* | |
|---|---|---|---|---|---|---|
| | A | B | | | A | B |
| Cesspools, Septic Tanks, Sewer Connection | 12 | 30 | | Cesspools, Septic Tanks, Sewer Connections | 5 | 12 |

**Note: The smallest distance of household wells from the source of contamination. A – low permeable environment, such as loess, tuff, slope clay; B – permeable environment, such as gravel, sand, heavily sandy clay*

## 20.2 Investigation Works

Their purpose is to verify whether the conception of the wastewater transportation and treatment solution is realistic and to obtain input data for system design. Local development plans, the development of water infrastructure, local plans and the other strategic documents of territorial units should be helpful in the decision-making. As far as the selection of the suitable type of wastewater treatment plant, it is necessary to examine the possibilities of a direct link to the watercourse. As a last option, infiltration can be selected. In this case, proper hydrogeological research is valuable to prevent irreversible changes and problems in the further use of the structure and surrounding buildings.

Exploratory work intended for the design of natural technologies of treatment can be divided into preliminary, detailed and complementary ways; its range depends on the area extent, sewerage arrangement, volume and time distribution of the discharge of wastewater and precipitation water and the type of arrangement of collecting devices. The main task of the exploratory work is to obtain sufficient materials enabling the design of an appropriate arrangement and adequate perfectly functional way of treating.

Detailed research will be focused on the following issue:

- Determination of the general characteristics of the area, arrangement of watercourse, the solution of the sewer system and installations on it, the expected location of the wastewater treatment plant based on the approved local plan, the water regime of the immediate vicinity of the expected construction, the identification of options for the discharge, utilization of treated wastewater and precipitation water, etc.
- Urban planning requirements and potential
- Determination of required areal range of treatment plant, gaining or the construction of the detailed altimetric and topographical plan at the scale appropriate to the given solution;
- Finding out the amount, composition and course of the wastewater runoff
- Hydropedological, hydrogeological, geological research of the area and affected territories by it; structural geological research at the place of more complex installations
- Soil-mechanical research of materials at places of expected devices, including research and determination of base conditions for the possible structures
- Research of the current state of the intake devices (sewerage), discharging and accumulation devices, if some of them in the area of interest have been found
- Determination of the amount and composition of precipitation water, finding out of the possibility of inflow of foreign water from rural areas
- Detailed research of hydrological conditions of surface and groundwater around the area of interest

- Research of culturally natural (protected area), finding out of all the types of environmental protection areas
- Determination of basic meteorological and climatic conditions and their evaluation;
- Determination of the current composition of groundwater in areas of expected treatment facilities
- Economic and social research of the catchments area, finding out of property relations of areas affected by the construction of the device, the way of farming of the areas used for any irrigation by purified wastewater, crops and technology used
- Simplified research phyto- and zoocenological of the area of interest with the focus on the determination of evapotranspiration
- Finding out other interests, affecting the expected area of interest, drawing the line of placement of cable and pipelines, etc.

The range of individual exploratory work is determined in the range needed for the particular structures. When comparing the individual localities, the basic indicators are assessed and the suitable arrangement is recommended.

At proposed localities, which will be directly affected by the regulations, it is necessary to discuss the property aspects.

## 20.3 Operational Experience

Serious problems impacting the final treating stage of constructed wetland treatment plants are poor-quality, unmaintained sewer network, structurally unsuitable to dysfunctional rain separators and a number of commonly used insufficiently functional equipment of mechanical pretreatment. The requirement of quality and well-maintained sewer network is thus a priority. Relatively little is done in regards to solving issues in precipitation water management, in most cases it is not satisfactorily solved. Research on these devices identified the following shortcomings:

- Improper arrangement of inflow and outflow; faulty design, when inflow and outflow from storm water basin are located next to each other, which excludes the possibility of the satisfactory function
- Removal of sediments from storm water basin is not satisfactorily solved
- Often insufficient retention time

High Volume Septic Tanks did not acquit themselves well, the accumulated sludge produced in the process is washed away and flows with wastewater to the filters. Sludge is churned and washed away when the flow of wastewater is limited. It is very demanding to drain the covered high volume septic tanks. It is strongly discouraged to use high volume septic tanks as accumulation, settling tanks.

Ground Settling Tanks fulfil the settlement function; they are proposed to have a prismatic shape, and be sealed. If there is just one tank fulfilling the function of sand trap and settling tank, its maintenance is very difficult without shutting down the entire stage of treatment.

Settling Tanks combined with a separate decay space seem to be inefficient within the indicative tests. They require the special operation mode with frequent draining and a special way of sludge. Otherwise, there is a partial decay of sludge in the sedimentation space, resulting in leakage of gaseous productions of decay, washing away sludge particles and mixing sludge with wastewater. Some cases have been observed where the composition of the effluent wastewater was worse than the composition of wastewater influent.

Imhoff Tanks can be ranked to the most frequently used devices. These tanks fulfil their function quite satisfactorily. The treatment effect is conditioned to the quality of maintenance as described in the Chapter 6.

Specific Objects allow measurement of the flow rate. They are often constructed in the connection with the other installations. These ones are either specific spillways (triangular) or type objects supplied from the manufacturers (Parshall flume).

Equalizing Tanks allow the pulse dosing of wastewater into the constructed wetland wastewater treatment plant. This tank consists of a metal, plastic or reinforced concrete tank with dosing device a siphon tube, electric valve and outlets controllable by floats

Regulation Objects are determined to the division of influent wastewater into the individual sections. Regulatory caps on the supply line, dividing walls and weirs placed in the valve box are used. For the distribution of wastewater, the system of height-adjustable shaft spillways can also be used.

Supply and Distribution Facilities are determined for supplying water into the constructed wetland wastewater treatment plant and its distribution across the whole width of the wastewater treatment plant. The dispense manifolds from PE or PVC with an outlet orifice, located in a partition band from coarse aggregate grains with a diameter of 63-125 mm are used for the distribution of water; it is convenient to design two structures, one on the surface and the second one closer to the bottom for winter operation. The endings of the manifold are carried into the control shaft above the terrain, allowing their treatment.

Sampling and Discharge Device are usually created by the collecting drain DN 100 – DN 140 mm, placed in gravel collecting zone of the granulation at least 63 - 125 mm and it is flowed into the inspection or control shaft. The task of the control shaft is to set the water level in the filtration environment of the wastewater treatment plant. On the vast majority of reporting constructed wetland wastewater treatment plants, there are shafts with the specific wall used for this purpose. These specific walls did not work because the wooden planks expand in water and it is practically impossible to manipulate with them. Flexible hosepipes are therefore suitable.

# 21 Economic indicators – investment and operation cost.

The great advantage of extensive technologies is generally low construction and operation costs compared to conventional wastewater treatment systems (Liu et al., 2012). In Europe, the implementation costs are around €170 for 1 p.e. and operation costs is on average € 7 for 1 p.e. per year (Masi, 2012). In the Czech Republic, the implementation costs range from 765 to 1,155 € per 1 p.e. (authors survey, 2012) and the operation costs achieve on average 11 € per 1 p.e. per year (Kriška, 2012; authors survey, 2012), including the service and transporting waste for the next processing or tipping. However, the usual figures are also up to 4 € per 1 p.e. per year (authors survey, 2012). When constructing, the largest cost item is labour, representing about 50 % of costs, followed by the material representing about 30 % of the total cost. Filter material, such as gravel, concrete and building material is preferably taken from local sources. The remaining cost of 20 % is represented by produced material, including mechanical pretreatment, pipes, valves and electrical equipment (Newton a Wilson, 2008).

In Table 21.1 a comparison of costs is provided for each size group of municipal wastewater treatment plants. In Table 21.2 different types of household wastewater treatment plants for 5 p.e are compared. The mentioned costs were calculated for an average examples of WWTP based on the book authors and co-operated WWTP designers experiences from the period 2008-2009. The unit prices with depreciation and without depreciation are stated in €/m$^3$. These prices are only approximate, both municipal as well as household treatment plants, it is necessary to work out and individual budget price.

Tab. 21.1 Three Comparisons of Prices for Some Types of Wastewater Treatment Plants for Urban Sewage Treatment (Vymazal et al., 2008)

| Wastewater Treatment Plant for 60 p.e. | | | | |
|---|---|---|---|---|
| Variant | Description of Variant | Total Price | Price for Treatment of 1 m$^3$ Wastewater | |
| | | | With Depreciation | Without Depreciation |
| Variant 1 | Constructed wetland Wastewater Treatment Plant | 43,435 | 0.92 | 0.35 |
| Variant 2 | Wastewater Treatment Plant – Soil Filter | 40,570 | 0.88 | 0.35 |
| Variant 3 | Activation Wastewater Treatment Plant | 32,445 | 2.61 | 1.96 |

| Wastewater Treatment Plant for 550 p.e. | | | | |
|---|---|---|---|---|
| Variant | Description of Variant | Total Price | Price for Treatment of 1 m$^3$ Wastewater | |
| | | | With Depreciation | Without Depreciation |
| Variant 1 | Wastewater Treatment Plant with Biofilter and Constructed wetland Filters | 285,140 | 0.85 | 0.32 |
| Variant 2 | Constructed wetland Wastewater Treatment Plant | 288,070 | 0.66 | 0.13 |
| Variant 3 | Activation Wastewater Treatment Plant | 256,310 | 1.30 | 0.64 |

| Wastewater Treatment Plant for 1,000 p.e. | | | | |
|---|---|---|---|---|
| Variant | Description of Variant | Total Price | Price for Treatment of 1 m$^3$ Wastewater | |
| | | | With Depreciation | Without Depreciation |
| Variant 1 | Constructed wetland Wastewater Treatment Plant | 429,350 | 0.69 | 0.27 |
| Variant 2 | 2 Local Constructed wetland Wastewater Treatment Plants | 451,230 | 0.65 | 0.20 |
| Variant 3 | Activation Wastewater Treatment Plant | 366,700 | 1.23 | 0.77 |

Tab. 21.2 Comparison of Economic Parameters for Different Types of Domestic Wastewater Treatment Plants (Vymazal et al., 2008)

| Variant | Description of Variant | Total Price | Unit Price | | Price without Operator | |
|---|---|---|---|---|---|---|
| | | | With Depreciation | Without Depreciation | With Depr. | Without Depr. |
| Variant 1 | Constructed wetland Wastewater Treatment Plant | 6,865* | 2.15 | 0.98 | 1.73 | 0.56 |
| Variant 2 | Biodisc Wastewater Treatment Plant | 3,661 | 4.26 | 3.26 | 2.16 | 1.15 |
| Variant 3 | Activation Wastewater Treatment Plant | 2,884 | 5.25 | 4.32 | 1.88 | 0.95 |

Total price of the constructed wetland household WWTP, including septic can be lower, if the system is built by investor, not a commercial company. But an authorized supervision of building is necessary. In that case, the price can be under 2,300 € (authors survey, 2012).

# 22 Related legislation and standards

The European Union (EU) has its own legal system, which is based on the founding Rome agreement, respectively the accession treaties of the countries. A vital part of the EU legal system is also environmental EU law, which is based on the principle of global sustainability. Like the entire legal system of the EU, environmental law operates on different levels. The most important legal documents are:

- Regulations (Order) – This is the most important legislative form, mandatory and directly applicable in all Member States without possibility of changes in national legislation
- Guidelines (Directive) – This is generally the definition of EU objectives that Member States must individually transpose into national legislation under legal procedures in the country

European legislation is above national legislation regardless of whether it is adopted before or after the national law of. Regulation and certain directives have direct effect, because the national courts of the Member States concerned may rely on these regulations. Since the law laid down in Community legislation EU supersedes national laws, it must be enforced even if it is in conflict with national legislation.

The historical development of EU environmental law could be observed three basic orientations:

- Protection of public health
- Environmental protection
- Conservation and reuse natural resources, which is now the dominant orientation

EU legislation in the field of wastewater treatment and sanitation systems does in principle take into account these aspects and reflects the requirements of current legislation.

## 22.1 Sustainable Sanitation in EU legislation

The basic EU legal regulations concerning wastewater treatment are the follows:

- Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for Community action in the field of water policy (Water Framework Directive)
- Directive 91/271/EEC concerning urban waste water treatment (Directive on Urban Waste Water)

- Directive 86/278/EEC on the protection of the environment and in particular the soil, when sewage sludge is used in agriculture (the waste water in agriculture)
- Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (Nitrate Directive)

The basic directive on water protection is called the Framework Directive, which is an integrated Community policy on water and focuses on maintaining and improving the aquatic environment of the Community, with the basic idea of the prevention of further damage the aquatic environment. Directive 91/271/EEC concerning urban wastewater entered into force in 1991. Its aim is to protect the environment from the harmful effects of treated wastewater on surface water and groundwater. To achieve this, all member states have to ensure appropriate treatment of wastewater. However, although the Directive deals with small agglomerations (< 2,000 inhabitants), it does so only on a marginal basis and does not define any quality requirements for small wastewater treatment plants. However, the Directive states that decentralized treatment or other alternatives may be used instead of collecting systems where economically advantageous and beneficial to the environment. The Directive on urban wastewater regulations are outlining the minimum standards, and thus does not preclude the Member States, if they want to introduce stricter rules for large treatment, or rules for small sewage or wastewater treatment on-situ.

## 22.2 Legislative regulations for small wastewater treatment plants in Central and Eastern Europe

The specificity of Central and Eastern Europe (CEE) is the population distribution between urban and rural areas. The number of small settlements in the CEE countries is exceedingly high. More than 115,000 small settlements with less than 2,000 inhabitants represent enormous potential for managing the operation of sanitation systems, as well as the high investment costs for sanitation in the future. The number of inhabitants living in small settlements in the CEE countries is also extremely high. It can be said that currently over 42 Million inhabitants are without access to public sanitation or are waiting for proper sanitation system solution. There will become a growing requirement in the near future and it is important to know and prepare appropriately to tackle the problem.

According to the above mentioned data, it can be expected that more than 20-25 Million of inhabitants in CEE countries will have no possibility to be connected to municipal sewage and sanitation systems in the future. Consequently, it can be expected that this part of the CEE population would be served by decentralized or individual systems of wastewater treatment technologies in the future. In regards to the difficult financial situation, geographical problems with dispersed rural settlements and other problems with the natural and extensive sanitation systems could provide a chance to introduce appropriate solution for the affected population which is not covered by EU legislation in this sector and intend to EU fund support (Bodík, 2012).

Pressure to ensure adequate sanitation for the needs of the population of small rural sites is growing and individual CEE countries have been forced to address this situation by creating enabling legislation. Due to the maturity of the company in the country, the economic possibilities of the country, and pressure of population, the country gradually approached the government to define the requirements for the discharge of treated wastewater into surface respectively. Groundwater and pollution from small sources (< 2,000 p.e.), were included despite that the basic EU legislation does not outline this in detail.

### 22.2.1 Legislative requirements for the discharge of treated wastewater into surface waters

Legislation in CEE countries in terms of requirements for wastewater treatment of small settlements are different. It is based on local and national experience reflects the condition and quality of surface water and groundwater in the country and historical experience with technology for small sources of pollution. Tab.22.1 summarizes the current (2012) regulatory requirements for discharge of treated wastewater into surface water treatment plant for the size of the p.e. to 50, 50 to 500 p.e. respectively 500 – 2,000 p.e. (Bodík, 2012).

Legislative requirements for WWTP effluents with 500 – 2,000 p.e. are almost comparable in all CEE countries except for Bulgaria, where there are no limits. Surprisingly, the most rigorous effluent requirements are in Ukraine, which is a non-EU country for all groups of plants - $BOD_5$ = 15 mg/l, COD = 80 mg/l, $NH_4$-N = 0.39 mg/l. Ukrainian requirements, also for the smallest plants, are stricter than those for WWTPs > 100,000 p.e. than in all other EU countries. Such a parameter is technologically almost impossible to achieve ($NH_4$-N = 0.38 mg/l i.e. full nitrification required) for activated sludge plants. For natural treatment systems, it is rather unredeemable. Specific parameter requirements apply only in Romania including sulphides, phenols and synthetic detergents. Natural treatment plants can effectively remove these substances.

Table 22.1 Overview of legislation requirements for emission limits into surface water from small WWTPs in the CEE countries

Number of producers: <50 p.e.

| Country | BUL | CZE | EST | HUN | LAT | ROM | SVK | SLO | UKR |
|---|---|---|---|---|---|---|---|---|---|
| Concentrations | mg/l or % | | | | | | | | |
| $BOD_5$ | -- | --- | --- | --- | --- | --- | 40/70 | 30 | 15 |
| COD | -- | --- | --- | --- | --- | --- | -- | 150 | 80 |
| SS | -- | --- | --- | --- | --- | --- | --- | --- | 15 |
| $NH_4$-N | -- | --- | --- | --- | --- | --- | --- | --- | 0.39 |
| TP | -- | --- | --- | --- | --- | --- | -- | --- | --- |

Number of producers: <500 p.e.

| Country | BUL | CZE | EST | HUN | LAT | ROM | SVK | SLO | UKR |
|---|---|---|---|---|---|---|---|---|---|
| Concentrations | mg/l or % | | | | | | | | |
| $BOD_5$ | --- | 40/80 | 15 | 80 | Appropriate treatment | --- | 30/60 | 30 | 15 |
| COD | --- | 150/220 | 125 | 300 | | --- | 135/170 | 150 | 80 |
| SS | --- | 50/80 | 25 | 100 | | --- | 30/60 | --- | 15 |
| $NH_4$-N | --- | --- | --- | 4 | | --- | --- | --- | 0.39 |
| TP | -- | --- | 1.5 | 4 | | --- | --- | --- | --- |

Number of producers: < 2,000 p.e.

| Country | BUL | CZE | EST | HUN | LAT | ROM | SVK | SLO | UKR |
|---|---|---|---|---|---|---|---|---|---|
| Concentrations | mg/l or % | | | | | | | | |
| $BOD_5$ | -- | 30/60 | 15 | 50 | 50-70% | 20 | 30/60 | 30 | 15 |
| COD | -- | 125/180 | 125 | 200 | 50-70% | 125 | 135/170 | 150 | 80 |
| SS | -- | 40/70 | 25 | 75 | <35 | 60 | 30/60 | -- | 15 |
| $NH_4$-N | --- | 20/40 | --- | 4 | --- | 15 | --- | --- | 0.39 |
| TP | --- | -- | 1.5 | 4 | --- | 2 | --- | --- | --- |
| Sulphides | --- | | | | | 0.5 | --- | --- | --- |
| Phenol/SD | --- | | | | | 0.3/2 | --- | --- | --- |

**/** in CZE and SVK represent 24h/maximum values*

On the other hand, the least strict effluent legislation in all the groups is in Hungary ($BOD_5$ = 50 mg/l, COD = 200 mg/l). An interesting solution is applied in Latvia where there are requirements only for treatment efficiency (WWTP with 500 to 2,000 p.e.) or 'appropriate treatment' (WWTPs with 50 to 500 p.e.). However, with a 51 % efficiency of $BOD_5$ treatment of the effluent ie about 100 to 150 mg/l is not done an appropriately.

Effluent discharge requirements for the smallest wastewater treatment plants (<50 p.e.) exist only in Slovakia, Slovenia and Ukraine. Given the specificities of these small systems is the control of wastewater treatment plants and outflow monitoring parameters rather problematic. It is particularly uneven inflow and outflow of the WWTP and associated adequate samples of wastewater required for analysis.

### 22.2.2 Legislative limits for the infiltration of treated wastewater into groundwater

It is clear that due to the abundance of small sttlements in the CEE countries, these nations will not be able to discharge all cleaned wastewater into receiving surface water bodies. For this purpose, some countries have acceded to the definition of the quality of treated wastewater, which is then discharged into groundwater indirectly through the soil filter or soaking facilities - Tab.22.2 (Bodík, 2012).

Four CEE countries have no specific limits for discharge of treated wastewater into groundwater, i.e. it is allowed or underlined by special permits. The Czech Republic has detailed a system for groundwater discharges where effluent requirements are available also for the natural treatment plant, but in any case such discharge from “large” small WWTPs (200 – 2,000 p.e.) into groundwater is questionable. Bacteriological limits are applied in the Czech Republic and also in Ukraine.

Parameters in Hungary are very strict when it comes to nutrient removal, full nitrification and denitrification are unredeemable in natural treatment systems. The discharge into groundwater is allowed in the Slovak Republic only for plants under 20/50 p.e. and followed by positive results from geological survey. No specific legislation emission limits for small WWTPs below 2,000 (500/50) p.e. for discharges into groundwater are in force in Romania, because direct discharges into groundwater of urban wastewaters are forbidden.

Table 22.2. Overview of legislation requirements for emission limits into groundwater from small WWTPs in the CEE countries

Number of producers: < 200 p.e.

| Country | BUL | CZE | EST | HUN | LAT | ROM | SVK | SLO | UKR |
|---|---|---|---|---|---|---|---|---|---|
| Concentrations | mg/l | | | | | | | | |
| $BOD_5$ | --- | 40 | --- | --- | --- | --- | 20/40 | -- | -- |
| COD | --- | 150 | --- | --- | --- | --- | --- | --- | --- |
| SS | --- | 40 | --- | --- | --- | -- | 20/40 | --- | --- |
| $NH_4$-N | --- | 20 | --- | --- | --- | --- | | --- | --- |
| TP | --- | 10 | --- | --- | --- | --- | | --- | --- |

Number of producers: 200 - 2,000 p.e.:

| Country | BUL | CZE | EST | HUN | LAT | ROM | SVK | SLO | UKR |
|---|---|---|---|---|---|---|---|---|---|
| Concentrations | mg/l | | | | | | | | |
| $BOD_5$ | --- | 40 | Requirements should be not stringent than limits for Requirements should be not stringent than limits for > 2,000 p.e. | --- | Appropriate treatment, for SS < 35 mg/l | --- | | --- | --- |
| COD | --- | 150 | | --- | | --- | | --- | --- |
| SS | --- | 40 | | --- | | --- | | --- | --- |
| $NH_4$-N | --- | 20 | | --- | | --- | | --- | --- |
| TP | --- | 10 | | --- | | --- | | --- | --- |
| Other emission limits: E.coli /En-terococcus (CFU/100 ml) | --- | 50,000/ 40,000 | | --- | | --- | | --- | -- |

Number of producers: < 2,000 p.e.

| Country | BUL | CZE | EST | HUN | LAT | ROM | SVK | SLO | UKR |
|---|---|---|---|---|---|---|---|---|---|
| Concentrations | mg/l | | | | | | | | |
| $BOD_5$ | --- | 30 | Requirements should be not stringent than limits for > 2,000 p.e. | -- | -- | -- | -- | -- | 15 |
| COD | --- | 130 | | --- | -- | -- | -- | --- | 30 |
| SS | --- | 30 | | --- | -- | -- | -- | --- | --- |
| $NH_4$-N | --- | 20 | | 0.5 | -- | -- | -- | --- | --- |
| TP | --- | 8 | | 0.5 ($PO_4$) | -- | -- | - | --- | --- |
| Other emission limits E.coli /En-terococcus (CFU/100 ml) | --- | 50,000/ 40,000 | | 250 ($SO_4$) 50 ($NO_3$) | -- | -- | -- | --- | /10000 |

# 23 Summary

Natural wastewater treatment methods occur through natural treatment processes that take place in the soil, water or wetland environment. In some countries of Central, Eastern and Western Europe, as well as in many non-European countries, predominantly the United States of America, Canada, Australia and New Zealand, small settlements often use this treatment technology. The most commonly used technologies are waste stabilization ponds that are used for treatment, scraping or short-term accumulation of wastewater.

Other technologies that are used are extensive constructed wetlands, constructed by planting macrophytes plants and filled with gravel or other materials of different grain size. Alternatively, a vertical soil filter with load-carrying tanks can be filled with various grain sizes finer than those used for the constructed wetlands. The main difference between the two technologies is the different oxygen conditions. Whereas the vertical soil filters, the wetlands are operating under predominantly anaerobic conditions, unless they are filled in an alternative manner.

These technologies should be preceded by appropriate mechanical pretreatment of wastewater. Otherwise, it may cause gradually system clogging.

The pond technology consists of a small pond, designed specifically for this purpose. The biological bottom layer, located in permeable soils, often insulate a clay seal, plastic film or plastic clogging. It is proposed to be at the angle of 0.5 to 1 %. The ponds are used in secondary treatment of wastewater as well. They are, however, not suitable for severely polluted wastewater, toxic wastewater or extreme pH levels.

The advantages of stabilization ponds are relatively simple construction design, small footprint special equipment, energy and special technology and low operating costs. The most notable strengths include their ability to cope with significantly dilute wastewater and often with very uneven hydraulic and organic load.

The deficiencies must include a relatively large area on the need for population equivalent, treatment effect dependence on climatic conditions, the need to secure additional aeration in winter, the need for a relatively long retention time on the removal of ammonia pollution, the need for extraction of biomass and the potential for contamination of groundwater.

CEE experience with the use of constructed wetland treatment plant indicate that there may be an alternative for the biological treatment of wastewater from small sources of pollution, which is the main concern of removing suspended solids, organic and microbial contaminants. Their great advantage is the possibility of using wastewater with low concentrations of organic compounds. Other advantages include the possibility of intermittent operation and good adaptability to changes in the quality of wastewater. The disadvantages constructed wetland WWTP are entitled to their greater area compared to conventional treatment plants, low effectiveness in removing nutrients and reduced ability to control the treatment process.

A significant advantage of wetlands is the possibility of decentralization of wastewater treatment plant into a series of smaller units with a common drainage of treated wastewater into receiving waters, possibly to other common polishing unit (cascade aeration, biological pond). When designing a system for collection and treatment of wastewater in scattered rural development is necessary to assess and compare the cost of building a common wastewater sewer network and the cost of building a series of small decentralized wastewater.

Regarding the treatment performance, satisfactory treatment effect was observed for solids, organic and microbial contamination. Adequate treatment for these indicators is also provided during non-vegetation period.

Soil filters use the ability of porous filter material to support the physical, chemical and biological processes to remove contamination. As in the biofilter plays a major role Fellowship of microorganisms living on the surface of the filter material and decomposing organic pollution. Compared to the constructed wetland wastewater treatment plants, the major difference is in the amount of oxygen present in the filter material. Soil filters work in anoxic to oxic conditions. In order to maintain aerobic conditions in the filter, it is necessary to prevent flooding of the filtration system. The main process taking place in the filter is not physical filtration, while the filter is to be best protected against particles that could clog it. The crucial process is the microbial degradation of organic pollution increases living on the surface of the filter material.

The main application of soil filters has been found mainly as biofilter small household equipment. The most common are natural filters vertically dripping. Advantages and disadvantages are similar to those wetlands. The difference is in good removing ammonia by soil filters. The quality of outflow water from a well-functioning soil filter achieves the quality of treated wastewater from mechanical-biological treatment plants. Treated wastewater and can be discharged into a smoothly it can be discharged into the public sewer system. If it is not near any watercourse or public sewer is for single family homes or recreational property solution to soak into the soil.

In conclusion, the extensive technologies have their place, but they must be given appropriate care. This applies especially to mechanical treatment, which is especially wetlands and soil filters key element of the whole system.

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# 25 List of abbreviations

| | |
|---|---|
| € | Euro |
| A, S | Area, Surface area |
| Al | Aluminium |
| AOX | Absorbable organic halogens |
| $BOD_5$ | Biochemical oxygen demand (meausured and calculated in 5 days) |
| BR | Biological reservoir |
| C, Co | Concentration |
| Ca | Calcium |
| Cd | Cadmium |
| CEE | Central and Eastern European countries |
| CFU | Colony forming unit |
| Cl | Chloride |
| $CO_2$ | Carbon dioxide |
| COD | Chemical oxygen demand |
| Cr | Chrome |
| CSN | Czech technical guidance |
| Cu | Copper |
| CW | Constructed wetland |
| CTW | Constructed treatment wetland |
| DN | Nominal diameter of pipe |
| EU | European Union |
| FWS | Free water surface flow (filter or CTW) |
| GWP | Global Water Partnership |
| $H_2O$ | Water (chemical abbreviation) |
| $H_2S$ | Hydrogen suphide |
| HF | Horizontal flow (filter or CTW) |
| Hg | Mercury |
| HRT | Hydraulic retention time |
| HSSF | Horizontal sub-surface flow (filter or CTW) |
| IWA | International water association |
| K | Potassium |
| lPE | Linear polyethylene (tube, pipe, pipeline) |
| Mg | Magnesium |
| N | Nitrogen |
| $NH_3$ | Ammonia ion |
| $NH_4$-N | Ammonia nitrogen |
| Ni | Nickel |
| $NO_3$-N | Nitrate nitrogen |
| P | Phosphorus |
| p.e. | Population equivalent |
| PAH | Polycyclic aromatic hydrocarbons |
| Pb | Lead |
| PCB | Polychlorinated biphenyls |
| PCR-SSCP | Microbial community analysis method |
| PE | Polyethylene (tube, pipe, pipeline) |
| PE-H | High density polyethylene (tube, pipe, pipeline) |
| PP | Polypropylene (tube, pipe, pipeline) |
| PVC | Polyvinyl chloride (tube, pipe, pipeline) |

| | |
|---|---|
| Q | Flow |
| SBR | Sequencing batch reactor |
| SF | Soil filter |
| SS | Suspended solids |
| TN | Total nitrogen |
| TOC | Total organic carbon |
| TP | Total phosphorus |
| TW | Treatment wetland |
| UASB | Upflow anaerobic sludge blanket (reactor) |
| UV | Ultraviolet radiation |
| V | Volume |
| VF | Vertical flow (filter or CTW) |
| WSP | Waste stabilization pond |
| WWTP | Wastewater treatment plant |
| Zn | Zinc |

# 26 Definitions

Activated sludge treatment: Activated sludge is a process in sewage treatment in which air or oxygen is forced into sewage liquor to develop a biological floc, which reduces the organic content of the sewage.

Aerobic pond (lagoon): A pond or lagoon through which wastewater flows and is supplied with air by floating surface aerators or from diffusers or from submerged air pipes. High rate aerobic pond or lagoon is a shallow (0.3 to 0.5 m) waste stabilization pond, in which the light can reach the bottom, enabling algae to grow fast. It usually has no surface aerators.

Aerobic anaerobic pond (facultative pond): A waste stabilization pond which is anaerobic in the bottom layers and aerobic in the top water. In the delicate relationship between the two layers photosynthesis occurs by day in the top layer, with algae evolving oxygen and consuming the carbon dioxide given off by the bacteria that exist deeper in the pond.

Biochemical oxygen demand (BOD): BOD is a measure of the rate at which micro-organisms use dissolved oxygen in the biochemical breakdown of organic matter in wastewaters under aerobic conditions. The $BOD_5$ test indicates the organic strength of a wastewater and is determined by measuring the dissolved oxygen concentration before and after the incubation of a sample at 20°C for 5 days in the dark. An inhibitor may be added to prevent nitrification from occurring.

Biofilm: A thin layer of micro-organisms and organic polymers attached to a medium such as soil,

sand, peat, and inert plastic material.

Chemical oxygen demand (COD): COD is a measure of the amount of oxygen consumed from a chemical oxidising agent under controlled conditions. The COD is greater than the BOD as the chemical oxidizing agent will often oxidise more compounds than micro-organisms.

Collection shaft (chamber): A chamber receiving treated wastewater from the collection layer and discharging through the pipe to an outfall or polishing filter/tertiary treatment system.

Collection pipe: A perforated pipe placed at the bottom of a trench, within the collection layer connected to the collection chamber.

Constructed wetlands (CW): A wetland system supporting vegetation, which provides secondary treatment by physical and biological means to effluent from a primary treatment step. Constructed wetlands may also be used for tertiary treatment.

Distribution shaft (chamber): A chamber between the septic tank (or settling tank) and the biological treatment facility (CW, WSP, percolation area), arranged to distribute the tank wastewater in approximately equal quantities through all the treatment units or percolation pipes leading from it.

Distribution pipe: A non-perforated pipe used to connect the distribution box to an infiltration pipe.

Electrical conductivity: The ability of a conductor to pass electric current, stated commonly in microsiemens/cm, µS/cm). For water the value in µS/cm is roughly proportional to the concentration of dissolved solids. Thus 150 µS/cm corresponds to about 100 mg/l of total dissolved solids.

Geotextile: Man-made fabric, which is permeable to liquid and air but prevents solid particles from passing through it and is resistant to decomposition.

Hydraulic conductivity: The volume of water will move in a porous medium in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. In contrast to permeability, it is a function of the properties of the liquid as well as of the porous medium.

Imhoff tank: It is a two-storey settling tank with a sludge compartment directly below the sedimentation compartment, connected with it by a slot through which the solids continuously slide in. Gases from the sludge compartment are directed away from the falling solids so as not to hinder their descent, and the sludge can be removed by a pipe from the sludge compartment.

Infiltration system: Comprises percolation areas and polishing filters that discharge partially treated and treated effluent into the ground.

Maturation pond: An aerobic waste stabilization pond, usually following a facultative pond, typically 1 to 3 m deep. Algae are fewer in maturation ponds than in facultative ponds and even fish may be present in the last maturation pond. They are used for tertiary treatment of a wastewater.

Nutrient-sensitive locations: These are locations, which include rivers designated as nutrient sensitive under the Urban Waste Water Treatment Regulations and groundwater bodies, where a programme of measures are needed to achieve the objectives of the Water Framework Directive.

Organic matter: Mainly composed of proteins, carbohydrates and fats. Most of the organic matter in domestic wastewater is biodegradable. A measure of the biodegradable organic matter can be obtained using the BOD test.

Pathogenic organisms: Those potential disease-producing micro-organisms which can be found in domestic wastewaters. Organisms, such as Escherichia coli, and faecal streptococci, with the same enteric origin as the pathogens are used to indicate whether pathogens may be present or not in the wastewater.

Percolating (infiltration) filter system: A wastewater treatment system consisting of primary settlement and biological treatment (effected by distributing the settled liquid onto a suitable inert medium to which a biofilm attaches) followed by secondary settlement.

Percolation (infiltration) pipe: A perforated pipe through which the pretreated effluent from the septic tank is discharged to the filtration trench or bed.

pH: A measure of the acidity or alkalinity of water, based on its concentration of hydrogen ions.

Polishing filter: A polishing filter is a type of infiltration system and can reduce micro-organisms and phosphorus (depending on soil type) in otherwise high quality wastewater effluents.

Population equivalent (p.e.): Population equivalent, conversion value which aims at evaluating non-domestic pollution in reference to domestic pollution fixed by EEC directive (Council Directive 91/271/EEC concerning Urban Waste Water Treatment) at 60 g/day related to $BOD_5$.

Pretreated effluent: Wastewater that has undergone at least primary treatment.

Primary treatment (pretreatment): The primary treatment stage of treatment removes material that will either float or readily settle out by gravity. It includes the physical processes of screening, grit removal and sedimentation.

Reed bed: An open filter system planted with macrophytes (reeds).

Sand filter: A filtration system consisting of sand used to treat wastewater from a primary settlement tank (usually a septic tank) by biological and physical processes.

SBR Reactor (Sequencing batch reactor): A wastewater treatment that consists of a sequence of different cycles in a reactor, but flow neither enters nor leaves the reactor until the treatment is completed, i.e. it operates on a fill and draw.

Secondary treatment: The secondary treatment stage of treatment by biological processes, such as activated sludge or other (even non-biological) processes giving equivalent results.

Septic tank: A covered settling tank. It can be rectangular or circular, divided into two and more sections. The solids settle to the bottom.

Septic tank system: A wastewater treatment system that includes a septic tank mainly for primary treatment, followed by a percolation system in the soil providing secondary and tertiary treatment.

Settling tank: A horizontal or radial flow tank used to settle out solid material from wastewater. It is main facility of mechanical pretreatment stage of WWTP.

Sewage (wastewater): Water that has been used. Depends on sewer system it includes households wastewater, stormwater, ballast water, water from offices and industrial effluents.

Sewer: A pipeline or culvert transporting domestic and industrial wastewater for treatment and disposal.

Sewerage: A network of sewers.

Sludge: The solids that settle in the bottom of the primary/secondary settlement tank.

Soil filter: A filtration system consisting of a certain filter material (usually sand, mixture of soil – loess, peat and sand, mixture of fine gravel and sand, etc.) used to treat wastewater from a primary settlement tank (usually a septic tank) by biological and physical means.

Subsoil: The soil material beneath the topsoil and above bedrock.

Suspended solids (SS): Includes all suspended matter, both organic and inorganic. Along with the BOD concentration, SS is commonly used to quantify the quality of a wastewater.

Tertiary treatment: Tertiary treatment (advanced treatment) additional treatment processes which result in further treatment than that obtained by applying primary and secondary treatment.

Total nitrogen: Mass concentration of the sum of Kjeldahl (organic and ammonium nitrogen), nitrate and nitrite nitrogen.

Total phosphorus: Mass concentration of the sum of organic and inorganic phosphorus.

Treatment wetland (TW): wetland (usually constructed) used for water treatment under a specific conditions of loading, operation and maintenance.

UASB Reactor (Upflow anaerobic sludge blanket): An anaerobic treatment process for wastewater in which the wastewater flows into a bottom of the reactor and up through a sludge blanket which is composed of biological particles that have grown in the reactor.

Unsaturated soil: A soil in which some pores are not filled with water; these contain air.

Wastewater: The discharge from sanitary appliances, e.g. toilets, bathroom fittings, kitchen sinks, washing machines, dishwashers, showers, etc.

Water table: The position of the surface of the groundwater in a trial hole or other test hole.

Waste stabilization pond: A tank or pond used for wastewater treatment as a main step of biological treatment or a final treatment step of wastewater treatment.

The Global Water Partnership (GWP), established in 1996, is an international network open to all organizations involved in water resources management: developed and developing country government institutions, agencies of the United Nations, bi- and multilateral development banks, professional associations, research institutions, nongovernmental organizations, and the private sector.

The GWP vision is for a water secure world. Its mission is to support the sustainable development and management of water resources at all levels. GWP was created to foster the implementation of integrated water resources management (IWRM): the coordinated development and management of water, land, and related resources by maximising economic and social welfare without compromising the sustainability of ecosystems and the environment.

Currently, the GWP network consists of thirteen regions: Caribbean, Central Africa, Central America, Central and Eastern Europe, Central Asia and Caucasus, China, Eastern Africa, Mediterranean, South America, South Asia, Southeast Asia, Southern Africa and West Africa. The GWP Secretariat is located in Stockholm in Sweden.

GWP Central and Eastern Europe's international network comprises 12 Country Water Partnerships in Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Moldova, Poland, Romania, Slovakia, Slovenia and Ukraine and more than 150 Partners located in 15 countries.

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