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Constructed wetlands for wastewater treatment

Author:

Davor Stanković, MCE
Hidroprojekt-ing d.o.o.
stankovicd@hp-ing.hr

Professional paper

Davor Stanković

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Basic information about constructed wetlands is provided, and an emphasis is placed on constructed wetlands with subsurface flow, being the most common type of constructed wetlands in Europe. A brief account of historical development of constructed wetlands is given, including classification of constructed wetlands, main purification processes taking place in such wetlands, principal components of constructed wetlands, preliminary treatment requirements, shaping of construction wetlands, basic configuration of construction wetlands, plants and maintenance, operation in winter season, service life, and possible generation of foul odours. The theme is illustrated by an example of a recently build constructed wetland in Kaštelir. An overview of possible use of constructed wetlands in the Republic of Croatia is given in the final part of the paper.

Key words:
constructed wetlands, wastewater treatment, shaping, horizontal filter, vertical filter, preliminary treatment

Stručni rad

Davor Stanković

Biljni uređaji za pročišćavanje otpadnih voda

U radu se daju osnovne informacije o biljnim uređajima, s težištem na biljne uređaje s potpovršinskim tokom, kao najraširenijem tipu biljnih uređaja u Europi. Dan je sažeti prikaz razvoja biljnih uređaja, njihove podjele, glavnih procesa pročišćavanja koji se odvijaju u njima, glavnih dijelova biljnih uređaja, potrebnog prethodnog pročišćavanja,oblikovanja biljnih uređaja, osnovnih konfiguracija biljnih uređaja, pogona i održavanja, rada u zimskim uvjetima, tijek uporabe te mogućem razvoju neugodnih mirisa. Kao primjer prikazan je nedavno izgrađeni biljni uređaj Kaštelir, a na kraju je dan osvrt na mogućnosti primjene biljnih uređaja u Republici Hrvatskoj.

Ključne riječi:
biljni uređaji, pročišćavanje otpadnih voda, oblikovanje, horizontalni filtar, vertikalni filtar, prethodno pročišćavanje

Fachbericht

Davor Stanković

Pflanzenabwasserkläranlagen

In der Arbeit werden die wichtigsten Informationen über Pflanzenkläranlagen gegeben, mit dem Schwerpunkt auf Pflanzenkläranlagen, bei welchem das Abwasser unter der Oberfläche fließt, was in Europa den häufigsten Typ von Pflanzenkläranlagen darstellt. Die Arbeit beinhaltet eine zusammengefasste Übersicht der Entwicklung und Einteilung von Pflanzenkläranlagen, der wichtigsten Klärverfahren in den Anlagen, der Hauptkomponenten von Pflanzenkläranlagen, der notwendigen Vorklärung, der Gestaltung von Pflanzenkläranlagen, der grundlegenden Konfigurationen der Pflanzenkläranlagen, des Betriebs und der Instandhaltung der Anlagen, des Betriebs in Winterbedingungen, des Verlaufs des Betriebs und der möglichen Entwicklung von unangenehmen Gerüchen. Als Beispiel wird die neulich errichtete Pflanzenkläranlage Kaštelir dargestellt. Zum Schluss wird eine Stellungnahme zu den Möglichkeiten des Einsatzes von Pflanzenkläranlagen in der Republik Kroatien gegeben.

Schlüsselwörter:
Pflanzenkläranlagen, Abwasserklärung, Gestaltung, Horizontalfilter, Vertikalfilter, Vorklärung

1. Introduction

The term constructed wetlands generally denotes all wastewater treatment facilities in which natural plants have a specific role [1]. The name "constructed wetland for wastewater treatment" is in fact translation of the German term *Pflanzenkläranlage*, as these plants were initially conceived in Germany. In English speaking countries the term "constructed wetlands" (or treatment wetlands) is most often used, while the term "građene močvare" (literal translation of "constructed wetlands") is also often used in Croatia [2]. A typical view of a plant unit is visible in Figure 1.

Figure 1. Typical view of a constructed wetland

We should however be cautious when using the term "constructed wetland" as, depending on the context, it can have several meanings. Thus, in a broader sense, the term "constructed wetland" implies a complete waste water treatment plant [3]. Such a complete plant includes, other than shallow basins, all other necessary components and facilities, such as preliminary treatment devices and facilities, transport and handling areas, fences, etc.

On the other hand, the term "constructed wetland" is also often used in a narrower sense when it usually denotes a shallow basin in which marsh plants are planted [4]. Such shallow basins may assume various shapes, features or properties. That is why appropriate synonyms are often used for a "constructed wetland" (such as a bed, wetland body, field, marsh, lagoon, filter, etc.) in an attempt to describe, more or less successfully, the shape of such wetlands.

Constructed wetlands are most often used as the second wastewater purification stage, i.e. in most cases, before actually reaching the constructed wetland body, the wastewater is subjected to preliminary and/or primary treatment. Various biological and physical processes such as adsorption, filtration, precipitation, nitrification, decomposition, etc. take place during operation of the constructed wetland [5].

Many types of constructed wetlands can be used for treatment of various types of wastewater. They can thus be used for many purposes including [5]:

- treatment or purification of municipal wastewater
- treatment or purification of wastewater generated by individual households
- subsequent (tertiary) treatment of waste water purified at conventional water treatment plants
- treatment of some technological wastewater including seepage water from waste disposal sites and wastewater from oil refineries, or wastewater generated during agricultural production, etc.
- evacuation and mineralisation of sludge separated from the waste water purification process
- treatment and temporary retention of rain water.

2. Development of constructed wetlands

Natural wetlands have been used for quite a long time as a favourable final discharge zone for waste water. Unfortunately, this has not always been beneficial to such habitats. Initial development of real constructed wetlands, i.e. marshes built in order to treat (purify) waste water, is linked to German limnologist Käthe Seidel (1907 – 1990) who studied lakeshore bulrush (*Schoenoplectus lacustris*) at the Max Planck Institute [6]. She discovered that this plant, just like other marshland plants, has a favourable influence on the quality of water. Consequently, she started experimenting in the 1950s with the so called hydrobotanical systems.

Seidel developed a constructed wetland plant (the so called Krefeld system) composed of one vertical and several horizontal seepage beds filled with gravel and planted marsh plants. She assumed that marsh plants are responsible for the observed purification effect. It was subsequently discovered that this is not entirely true, i.e. that various microorganisms living on gravel (substrate) take in fact credit for most of the purifying action. This fact was perceived by Reinhold Kickuth from the Gottingen University who cooperated with Käthe Seidel since the mid-1960s. He tried to optimise the system by using clayey soil as substrate, with horizontal flow of water, and he propagated such system in the 1970s as the so called Root Zone Method (germ. *Wurzelraum-Verfahren*).

Kickuth considered that plants introduce oxygen into the root zone of clayey soil and that the root growth keeps this zone permeable. He also assumed that the purification effect is enhanced by aerobic and anaerobic areas in soil, large contact area of fine soil particles, long horizontal flow routes, and various biological and geochemical processes. However, even Reinhold Kickuth was only partly right as he greatly overestimated introduction of oxygen by plants into the root space. In addition, the practice has shown that the growth of marsh plant roots can not ensure a permanent permeability of clayey substrate, as clogging was experienced in some systems [6]. Such examples have negatively affected the repute of constructed wetlands plants [7].

Since that time, numerous studies have been made, both in Germany and in other countries, about purification efficiency of various wetland types. These studies have resulted in recommendations for the dimensioning, construction and

operation of constructed wetlands that have been published in many professional papers and technical regulations.
The number of constructed wetlands increased significantly in the 1990s, but their use was also extended to include purification of various types of effluents (such as industrial waste water and rain water). Constructed wetlands are currently widely used in many developed countries in Europe, mostly in Germany but also in Great Britain, France, Denmark, Austria, Poland, and Italy [5]. Constructed wetlands are increasingly used in Croatia as well.

3. Classification of constructed wetlands

As already indicated, constructed wetlands can assume various shapes and properties. Consequently, constructed wetlands can be classified according to various criteria [8]:
- type of plants
- flow pattern (free water surface flow, subsurface flow – horizontal and vertical)
- type of configurations of wetland cells (hybrid systems, one-stage or multi-stage systems)
- type of wastewater to be treated
- wastewater treatment stage (primary, secondary, tertiary, disinfection)
- type of preliminary treatment
- type of substrate (gravel, sand, etc.)
- type of loading (continuous or intermittent loading).

Nevertheless, the flow pattern has been generally accepted as the basic criterion. According to this criterion, constructed wetlands are classified into two basic types: free water surface (FWS) constructed wetlands, and subsurface flow (SF) constructed wetlands [4]. However, the SF wetlands are mostly used in Europe (and also in Croatia) and, depending on the direction of flow, the vertical flow (VF) and horizontal flow (HF) may be differentiated. Thus, the information presented in this paper is mostly related to SF wetlands.

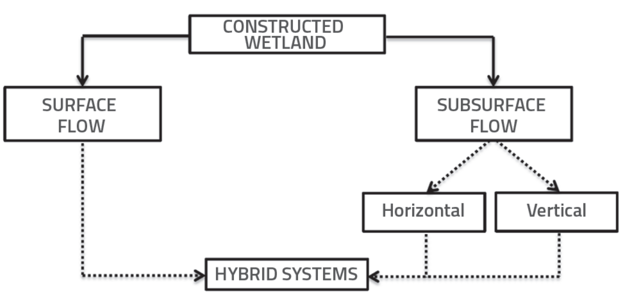

Figure 2. Classification of constructed wetlands (modified according to [5])

A typical feature of practically all types of wetlands is a shallow basin filled with some sort of filter material (the so called substrate, usually sand or gravel) in which marsh plants are planted. Waste water enters the basin and flows above the surface of the substrate (FWS constructed wetlands) or through the substrate (SF constructed wetlands). Finally, the treated wastewater is discharged through a structure that controls the depth of the wastewater in the wetland [7]. As already stated, in SF wetlands the water face is below the top of the substrate. Thus the problems with foul odour and mosquitoes, quite frequent in FWS wetlands, are avoided [5]. Certain types and subtypes of constructed wetlands can be combined into the so called hybrid systems.
In all types and subtypes of constructed wetlands, wastewater must be subjected to preliminary treatment. Such preliminary purification of wastewater is aimed at efficient removal of suspended matter and grease and oil as, otherwise, various difficulties in the operation of the constructed wetland may be experienced. The hazards include possible clogging and hence reduced efficiency of treatment, but also foul odours, etc. and, in extreme cases, complete interruption of wetland operation [4].

4. Processes, area and main parts of constructed wetlands

4.1. Main purification processes

The following pollutants are removed at SF wetlands:
- organic substances expressed as biological oxygen demand (BOD) or chemical oxygen demand (COD)
- suspended matter
- nutrients (nitrogen and phosphorus)
- pathogenic microorganisms, heavy metals and organic impurities.

Although constructed wetlands are often classified into the group of "simple" systems or "low technology" systems, the biological, physical and chemical treatment processes taking place in such systems are far from being simple. These processes occur in various zones of the main filtering layer composed of [5]:
- substrate
- root and pore water zone
- waste matter (dead particulate organic material such as fallen leaves, etc.)
- water
- air
- plants and plant roots
- biomass zones such as bacteria attached to substrate and roots.

Wastewater filtering in the filtration medium of the constructed wetland is a result of complex interactions between all these zones. Each constructed wetland contains a mosaic of zones with different oxygen levels, which initiates various processes of degradation and removal of polluted matter.
The filtration medium of the constructed wetland acts as both mechanical and biological filter. The suspended matter in the incoming wastewater, and microbiological solids, are mainly

Table 1. Overview of pollutant removal processes in SF wetlands [5]

Pollutant	Purification process
Organic matter (expressed as BOD or COD)	Undissolved organic matter is removed by sedimentation and filtration and converted into dissolved BOD. Biofilm fixes the dissolved organic matter that is then removed by attached bacteria (biofilm on plants, roots, substrate particles, etc.).
Suspended matter	Filtration. Decomposition by special bacteria in soil over a long period of time.
Nitrogen	Nitrification and denitrification in biofilm. Plant uptake (limited influence only).
Phosphorus	Nitrogen retained in soil (adsorption). Precipitation with calcium, aluminium and iron. Plant uptake (limited influence only).
Pathogenic microorganisms	Filtration. Adsorption. Natural die-off.
Heavy metals	Precipitation and adsorption Plant uptake (limited influence only)
Organic pollutants	Adsorption to biofilm and clay particles. Possible degradation over a long time by means of special bacteria in soil.

Table 2. Approximate values for determining required areas for SF constructed wetlands for various climatic conditions and for household sewage after preliminary treatment [5]

Climate / Area	Cold climate Mean annual temperature < 10°C		Hot climate Mean annual temperature >20°C	
	Horizonal flow	Vertical flow	Horizonal flow	Vertical flow
Area per resident [m²/ES]	8	4	3	1,2

retained mechanically, while the dissolved organic matter is fixed and absorbed by the so called biofilm. All organic matter is decomposed and stabilised by biological processes occurring over a longer period of time. Biological filtering in the filtration medium is based on the activity of microorganisms, aerobic and facultative bacteria in particular. These microorganisms grow on the surface of the substrate and root particles, where they form an active biofilm. Low organic load in constructed wetlands enables decomposition of not-readily degradable organic matter (organic pollutants) that are degraded by special natural bacteria present in soil. These bacteria propagate very slowly. All organic matter, suspended matter, and generated microscopic solids are eventually reduced via aerobic and anoxic processes to CO_2, H_2O, NO_3 and N_2.

A phenomenon involving introduction of heavy metals into plants has been observed in constructed wetlands. Physiological reasons for this phenomenon are still not fully known and are probably dependent on the type of plant. It should be noted that heavy metals do not disappear but are in fact retained in the plant tissue. Under normal circumstances, heavy metals are not highly significant as their concentration is usually quite low in waste water.

4.2. Required area

One of simplest (and most often used) parameters for dimensioning constructed wetlands is the specific area, i.e. the area (in m²) needed for one connected or equivalent resident. However, this parameter is not unambiguous and its value depends *inter alia* on the climatic zone, required quality of purified waste water, type of constructed wetland, etc. Furthermore, out of all climatic elements, temperature is considered to be the most significant from the standpoint of wastewater treatment (because of the influence on wastewater temperature, which in turn influences chemical reactions and biological activity). In the context of constructed wetlands, climate can generally be classified into cold climate (when mean annual temperature is below 10°C), hot climate (when mean annual temperature is above 20°C) and moderate climate (when mean annual temperature is in between these values) [5]. Approximate values for specific areas are given in Table 2. These values are related to normal wastewater quality requirements (second stage of purification, i.e. removal of BOD5, COD and suspended matter).

4.3. Principal parts

Principal or essential parts of constructed wetlands for wastewater treatment (that is of full-scale plant for wastewater treatment) are the preliminary treatment facilities (mostly representing the mechanical level of purification) and the constructed wetland itself (most representing the biological stage of purification). The operating concept of the plant, and dimensioning of its individual parts, is mostly influenced by wastewater properties and desired purification effect, and local conditions [1].

5. Preliminary treatment

The preliminary treatment is needed to ensure long-term functionality of constructed wetlands. The objective of this treatment is to retain solids and suspended matter, including also oil and grease, in order to reduce an overall wastewater load. This treatment also enables the operator to avoid some possible problems, especially clogging of constructed wetlands. The required effect of preliminary treatment, especially as related to suspended matter, is primarily dependent on the type of constructed wetland i.e. on the substrate that is to be used at the wetland. The finer the substrate (greater content of fine-grained particles) the greater suspended matter removal effect is needed to avoid clogging [1]. In case of sandy substrate, the concentration of suspended matter in the previously purified wastewater should generally be below 100 mg/l, [5].

Special care must be taken about sensitivity of some preliminary treatment procedures with regard to inflow variations. In some procedures, this can worsen purification effects and cause sludge drifting. If great inlet variations are expected, the most favourable procedures are those that enable equalisation of hydraulic load.

When selecting a preliminary treatment procedure, care must be taken about treatment of sludge that is generated in the process. Compared to other (technically sophisticated) purification plants, constructed wetlands generate primary sludge only (from preliminary treatment), which corresponds to the sludge separated at the first stage of purification at technologically sophisticated plants, but does not include the secondary sludge. Thus in case of constructed wetlands, the quantities of sludge for disposal and further treatment are much smaller. Nevertheless, if sludge treatment at the wetland site is not planned, then sludge should normally be transported for further treatment, for instance at some nearby larger-size treatment plant.

Preliminary treatment procedures that are most often used in case of constructed wetlands are the sedimentation in septic tanks, in sedimentary lagoons, and in Imhoff tanks [3]. The anaerobic stabilization of primary sludge is also often conducted in case of septic tanks and sedimentary lagoons. Selection of an appropriate procedure is influenced by several factors, such as the size (load) of the plant and available space. Sedimentary lagoons are used for greater-capacity plants and when there is enough space to accommodate such plants. Other plants with sludge sedimentation, such as baffled tanks and the UASB (upflow anaerobic sludge blanket) reactors, can also be used. They are however used for larger-size plants only [5].

In addition, and especially in case of large-size treatment plants, screens (rough, fine screens and sieves) can also be used together with the above mentioned sedimentation procedures. Also, sand traps and grease traps can be used for combined sewage disposal systems [5]. In such a case, these devices usually precede the sedimentation process (septic tank, Imhoff tank).

In special cases, the decision can be made not to resort to preliminary treatment at the constructed wetland site. In fact, septic tanks can be used at individual buildable lots when the existing devices are still used after construction of the public sewerage network. Influences of outside waters on preliminary treatment are generally smaller for septic tanks at individual households, while tank volumes are greater than in the case of a central preliminary purification [1]. The same applies to the use of pressurised sewerage (when household connection is realised with a septic tank) or small-size gravity-flow sewerage system [4].

6. Configurations of constructed wetlands

Subsurface flow constructed wetlands are dominantly used in Europe (and also in Croatia). In such wetlands, the direction of wastewater flow can be either vertical or horizontal. Regardless of the direction of flow, main parts of constructed wetlands are: inlet part, central (filtration) part, and outlet part [4]. The wetland shaping should contribute to proper orientation of wastewater flow, so that it passes (if at all possible) through the entire filtration medium [1].

6.1. Subsurface vertical flow (VF) wetland

In case of subsurface vertical flow wetland, wastewater is distributed along the surface of the filtration medium, and then percolates vertically through this filtration medium (substrate). The term "vertical filter", coined after the corresponding German term, is also often used. The following VF wetland configuration is adopted for the usual sand substrate [1]

- safety area
- plants
- covering bed
- main filtration bed
- transition bed
- drainage bed
- protective bed for sealing foil
- sealing foil or natural-material sealant
- levelling sand bed or protective bed for sealing foil.

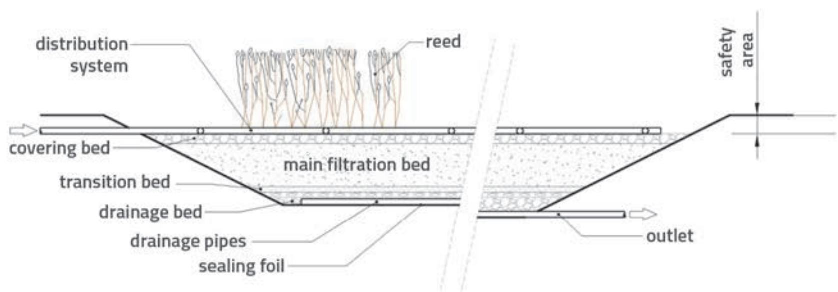

Figure 3. Schematic cross section of a vertical flow constructed wetland (modified according to [1])

Safety area denotes the height from the top edge of the basin to the bed surface. Its main purpose is to prevent wastewater overflow from the bed in case of smaller percolation rate of waste water (e.g. due to clogging or ice formation on the bed surface). In addition, it enables intentional flooding of the bed to remove weed. In most cases, this area is 20 to 30 cm in height.

Plants maintain the wetland permeable and ensure its long-term functionality. They also improve, albeit not greatly, the purification capability of the wetland.

The role of the covering bed is to protect the filtration medium from washout during distribution of waste water. In addition, it serves as protection against foul odour emission (when distribution system is covered with the covering bed). In most cases, this covering bed is made of gravel 5 to 10 cm in thickness. It should be noted that angular material or excessive thickness of the bed may prove detrimental to plant growth.

Most wastewater purification processes take place in the main filtration medium. This filtration medium should be no less than 50 cm in thickness. The surface of the filtration medium should be level and horizontal so as to enable uniform distribution of waste water, and to avoid creation of puddles on the surface.

A transition bed is sometimes placed between the main filtration bed and the drainage bed to prevent washout of finer material from the main filtration bed to the drainage bed. The drainage bed serves for evacuation of water from the wetland and, at the same time, it enables aeration of the main filtration bed from the bottom side.

The shape of the VF wetland can be selected at will. It should however be noted that regularly shaped wetlands have proven to be more favourable as the distribution system, which ensures uniform distribution of wastewater along the entire wetland area, is less complicated. If multiple bed systems are used, it is important to know that a strong filtering action can occur at the transition from coarser materials to finer materials due to sudden increase in the resistance to flow. In such cases, suspended matter can mostly be retained at that level and cause clogging.

Due to cyclic distribution of wastewater along the bed surface, additional energy, i.e. the use of pumps, is most often needed to enable proper operation of VF wetlands. This system of wastewater distribution ensures proper introduction of oxygen, which as a rule enables good nitrification. However, the nitrogen removal level is relatively low unless additional technical measures are used. The removal of nitrogen may be improved by recirculation of the already purified wastewater, or by combining the VF wetland with a subsequent horizontal flow filtration system.

6.2. Subsurface horizontal flow (HF) wetland

In case of a subsurface HF constructed wetland, wastewater is distributed at the inlet part along one side of the bed and flows horizontally through the filtration medium, in the direction of the outlet part of the wetland. The term "horizontal filter", coined after the corresponding German term, is also often used to denote this type of wetland (Figure 4). The HF wetland consists of the following parts [1]:

- inlet part
- transition bed
- main filtration bed
- transition bed
- outlet part
- sealing foil or natural material sealant
- levelling sand bed or protective bed for sealing foil

Just like in case of a VF wetland, a safety area 20 to 30 cm in height should be provided between the top edge of the wetland and the bed surface, so as to prevent spilling from the basin in case of reduced permeability, and to enable planned flooding of the basin. Plants are an important part of the wetland as they improve the purification level while also ensuring a long-term functionality of the wetland.

The inlet part is composed of coarser material and its function is to ensure uniform distribution of water along one side of the HF wetland. Sudden change in permeability is prevented by the use of variable grading between the inlet part and the filtration part of the wetland. This is important as, under certain circumstances, sudden change in permeability can result in clogging.

Most wastewater purification processes take place in the main filtration bed. A uniform flow of wastewater through this bed must be ensured. In addition, this bed must retain the wastewater for a sufficient period of time. The top surface of the filtration bed should be horizontal so as to ensure uniform flooding of the wetland, when such action is needed.

A transition bed is situated between the filtration bed and the outlet part of the wetland. This bed serves for ensuring filtering stability between various gradations so that finer particles are not evacuated through the outlet part of the system. The outlet part serves for evacuation of treated water from the HF wetland. In most cases, it is made of gravel, and a drainage pipe is placed at its bottom. The bottom of the wetland must have a downward incline toward the outlet part to enable proper evacuation of water from the filtration bed.

The shape of the HF wetland is defined by the required inlet part and the

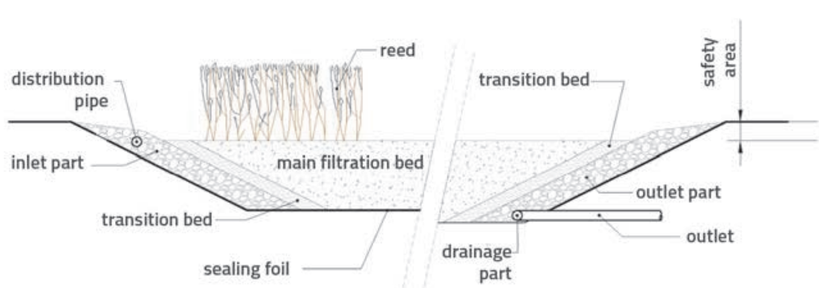

Figure 4. Schematic cross-section of a subsurface HF wetland (modified according to [1])

distance of flow through the wetland. In general terms, the cross-section of the inlet part should be as great as possible, so that the wastewater distribution is most often operated along the longer side of the bed. The flow length depends on the filtering material.
As a rule, HF wetlands can be operated without additional energy, i.e. without the use of pumps. The introduction of oxygen into the filtration bed is somewhat lower compared to VF wetlands, and so the nitrification is poorer. However the total removal of nitrogen, due to better denitrification, is generally better compared to VF wetlands. If adequate hydraulic dimensioning is provided, the HF wetlands can also be used for the treatment of combined sewage.

6.3. Filtering material (substrate)

In constructed wetlands, wastewater treatment processes generally take place in the main filtration bed that must be composed of an appropriate filtering material. A sufficiently long contact between the waste water and filtering material is needed for proper realisation of mechanical, biological and chemical purification processes. That is why wastewater flow through filtering material must be uniform and wastewater must remain in this zone for a sufficient period of time [1].
To ensure a uniform flow through filtering material, this material must be sufficiently permeable. Otherwise a surface flow will occur. A high permeability is obtained by the use of a coarser material, but the time the water remains in this zone will be shorter and the total grain area will be smaller. Development of microorganisms in the filtering zone is significantly affected by the grain area. That is why these conflicting requirements must be reconciled during selection of an appropriate filtering material. In addition to chemical stability of filtering material, the stability of grain size distribution must also be taken into account. In fact, it is necessary to prevent finer particles from moving into the bottom area of filtering material, as this could negatively affect the permeability. A general estimate of the filtering material permeability can be made by means of a grading curve. However, for a more accurate estimate it would be necessary, if possible, to conduct permeability testing in laboratory. In addition to information about the filtering material properties, its proper placing is also highly significant for hydraulic permeability of the constructed wetland. Also, compaction must be avoided during the substrate placing activity.
Gravel and sand are used as filtering materials or substrate in constructed wetlands. Bound filtering materials were also used in the past but, today, their use is discouraged due to a high clogging hazard [4]. Gravel is characterized by high hydraulic permeability, but it has a relatively low reaction surface, and hence a small purification potential. Usual gradings are 4/8 or 8/16 mm. That is why it is used in cases when a high hydraulic permeability is required ($k_f > 10^{-3}$ m/s). In such cases, a sufficient stay of wastewater must be provided for by means of appropriate structural measures [1]. Sand permeability (k_f) values from 10^{-3} to 10^{-4} m/s are normally used for vertical flow and horizontal flow wetlands. Usual gradings are 0/2 and 0/4. The use of washed sand is recommended as a means to reduce the fine particles content [4]. The use of sand with dominant proportion of round particles is also suggested. Due to its sufficient hydraulic permeability and a high purification potential, sand is quite favourable for purification of wastewater, and for the treatment of combined sewage and rain water.

6.4. Wastewater inlet

The wastewater inlet structure must provide for a uniform distribution of wastewater across the wetland volume so that the filtering material is used to its utmost.

6.4.1. Vertical flow (VF) wetlands

In VF wetlands wastewater is distributed via the pipe system along the entire surface of the basin. The distribution must be operated in intervals, i.e. intermittently. This is necessary so as to enable introduction of air into the vertical flow wetland in between those distribution intervals. If quantities are excessively low, i.e. if distribution intervals are too frequent, wastewater might penetrate directly under the distribution pipe openings. In order to ensure a long-term efficiency of this intermittent distribution system, pumps are often installed and used for transporting the wastewater to the VF wetland. In other words, the flow of wastewater into VF wetland is mostly operated under pressure, which additionally ensures a uniform distribution of wastewater along the surface of the filtering material, as a consequence of a more uniform distribution of pressure along the entire distribution pipes network.
When selecting diameter of pipes used in the pipe distribution system, it is necessary to take into account the volume of the pipe system and losses due to friction. It is also necessary to provide a sufficient number of pipe openings (holes), which must be uniformly distributed along the surface of the filtering area. A minimum 8-mm hole diameter is recommended.
Plastic pipes or, less often, metal pipes are normally used in the pipe distribution systems. When selecting materials, care must be taken about resistance to ultraviolet rays and temperature deformations. To ensure a good protection against freezing, distribution systems should be shaped in such a way that wastewater flow by gravity is ensured after the end of distribution. All lines in which wastewater may remain for a longer period of time should be placed below the freezing depth.

6.4.2. Horizontal flow (HF) wetlands

In HF wetlands, wastewater is introduced laterally into the main filtration bed (via the inlet part using drainage pipes). Unlike VF wetlands, wastewater is most frequently distributed continuously, and the flow is characterized by a free water face.

The size of the lateral infiltration zone depends on the quantity of wastewater, permeability of filtering material, and hydraulic gradient in the filtration bed. The distribution is operated via the inlet part composed of gravel or crushed stone. A transition layer with a gradually finer grading is usually installed toward the main filtration bed in order to prevent clogging at the infiltrating area of the main filtration bed.

6.5. Wastewater outlet

The wastewater outlet structure is used for evacuation or collection of the purified wastewater and its discharge outside of the wetland zone. An appropriate drainage system is built for this purpose. Wastewater is evacuated from VF wetlands along the bottom of the bed via a drainage layer made of gravel or crushed stone into which a drainage pipe system is placed. To enable drainage layer aeration as well as outwash, drainage pipe ends are led above the filtration area (this part is realized using full pipes).
In HF wetlands, the outlet part is made of gravel or crushed stone, and a drainage pipe is placed at the bottom of this layer. The outlet part should spread across the entire width of the wetland. The outlet is placed in the deepest zone so as to ensure complete evacuation. In addition, to enable washout, drainage pipes are placed above the filtering area. The bottom of the HF wetland is most often realized with a downward grade in the direction of flow. The grade ranging from 0,5 to 2 % is recommended. Just like in the inlet part of the wetland, a transition layer is realized before the drainage (evacuation) layer, with the gradual increase in grain size from the main filtration bed toward the drainage layer.
As a rule, during normal operation, a backwater action is not resorted to in constructed wetlands, the aim being to ensure free flow and full evacuation of water from the wetland. If necessary, backwater can be realized using a vertical or flexible pipe, the end of which can be fixed at the desired height in the evacuation shaft. Backwater may be necessary in the following cases:
- to control weed and accelerate growth of reed (most often in vertical flow wetlands)
- to achieve longer stay of wastewater in the wetland (in case of horizontal flow wetlands with gravel as filtering material)
- to improve reed growth or supply of water to reed (after it has been planted).

After backwater is no longer needed, care must be taken to release the water slowly so as to avoid compaction of the filtering material [1].

6.6. Wetland sealing

Constructed wetlands must be sealed at the bottom and at sides so as to:
- ensure controlled passage of waste water through the filtration medium
- prevent uncontrolled penetration of wastewater into the underground
- enable controlled backwater action, if needed.

Sealing can be either natural or artificial [1]. If the foundation soil is made of clay exhibiting sufficient thickness (50 to 60 cm) and impermeability $k_f < 10^{-7}$ m/s, then additional sealing is not required. If the foundation soil properties are not satisfactory, then the following sealing procedures can be used:
- sealing with mineral matter (clay, bentonite)
- sealing with plastic foil
- sealing with concrete.

As a rule, the sealing also extends to the sealing area above the top surface of the soil so as to enable controlled flooding, if necessary (to prevent growth of weed at the start of wetland operation). If sealing is made with plastic foil (liner), then the foil must be protected with an adequate cover in the safety area.
Plastic foils/liners are most frequently used for sealing. Among such foils, polyethylene foils are most often applied, but PVC and synthetic rubber foils can also be used.
Polyethylene liner must be resistant to UV rays and penetration of roots. Individual liner sheets are connected by welding. Liners ≥ 1 mm in thickness are most often used at constructed wetlands (2.0 mm is recommended). However, excessive thickness of liners is not advisable as thicker liners are heavier and less flexible, and their placing is more difficult. In any case, liners should be placed in such a way to avoid additional tensioning. It is also important to note that liner handling and placing is more complex at low temperatures.
Openings that are made in liners to enable passage of inlet and outlet pipes must be fully sealed. These connections are often a critical point in sealing, and must be realized with greatest care. Liners must be protected against damage (e.g. by sharp stone edges). Protection can be realized using a levelling sand layer or geotextile. However, geotextiles are most commonly used for this protection as they facilitate subsequent liner placing, and may also be an effective protection against rodents. If necessary, wire meshes can also be used to deter rodents. It is also recommended to use geotextile at the internal side as well, especially if angular material is used as drainage layer [1].
Sealing with watertight concrete is not commonly applied as this method is usually the most costly. This material is mostly used in uneven rocky foundation soil, when otherwise a thicker protective and levelling layer would be required. In special cases, such as when free space for construction is limited and when there is not enough room for soil slopes of earth-made basins, shallow reinforced-concrete basins can be realised using watertight concrete.

6.7. Plants

Although the role of plants in the purification of wastewater is rather secondary (as biological treatment is mostly carried out by microorganisms), they are nevertheless an important component of constructed wetlands. Their most important task is to keep the main filtration layer permeable, as filtration layer clogging is prevented by the growth of roots and rhizomes, and by plant movement due to wind action. In addition, the area around plant roots is a favourable medium for the growth and development of microorganisms.

Although various plants can be used in constructed wetlands, the use of autochthonous marsh plants is recommended [4]. Most commonly used plants are reed, rush, bulrush, etc.

Reeds are particularly favourable as they are the only marsh plants whose roots extend to more than 50 cm in depth, and they are also insensitive to change of water level and nutrient load. Reed forms rhizomes that mostly spread in the horizontal direction but, during its growth, conditions can be created that favour vertical root spreading. The above-ground part of the plant can reach from 1 to 4 m in height. In conditions favourable to this plant (lot of sun and abundant water supply), reed becomes aggressive and will eradicate other plants in the long run. That is why it is not useful to plant it in combination with other plants [1]. Reed does not require regular harvesting as shoots can grow through the litter. However, if reed plants are too dense (when they render difficult proper maintenance and inspection of the water distribution system), harvesting may be required every several years. Such harvesting should preferably be made in spring, before the shoots emerge. As an alternative, harvesting is also possible in autumn when litter should be left on the spot as a protection against freezing during winter months.

After planting, sufficient water should be provided to the plants. If the wetland operation is seasonal in character, water supply can be ensured by recirculation of the already purified water. Dense reed can endure dry periods of as many as six weeks. Some wastewater may be lost to evapotranspiration. That is why higher concentrations of pollutants may be observed in summer months in the purified wastewater, i.e. the purification effect can seemingly be reduced. In some circumstances, the outflow of purified water may cease altogether.

If the filtration bed is inadequately supplied in water, weeds can grow out of control, especially nettle as it likes a high quantity of nutrients. The basic measure for weed eradication consists in providing a good water supply (and if necessary a high water level can be maintained in the bed for a while). Although weeds can also be eradicated by weeding, walking on the filtration bed might damage marsh plants and compact the filtering material.

7. Basic configurations of constructed wetlands for wastewater treatment

As already indicated, constructed wetlands are mainly used for the secondary treatment and in most cases, before reaching the filtration bed, wastewater is subjected to preliminary and/or primary treatment. In simple terms, it can be said that a pre-treatment and the first stage of purification is conducted during preliminary treatment, while the treatment conducted in constructed wetlands is a "biological" treatment. This also defines the basic configuration of constructed wetlands for wastewater treatment in which, after preliminary treatment, the water is treated in filtration beds and is then released into a final discharge zone. Biological treatment can be made using subsurface horizontal flow (HF) wetlands (horizontal filters) or subsurface vertical flow (VF) wetlands (vertical filters), or a combination of the two (hybrid wetlands). A very common configuration is the vertical flow wetland that is followed by a horizontal flow wetland. This combination is especially favourable when additional wastewater cleaning requirements have been set (nitrogen removal). Basic configurations are shown in Figure 5 for HF wetland and in Figure 6 for VF wetland. In addition to these basic configurations, attention should be drawn to a special configuration that has been developed and implemented since 1990s in France, and is therefore known as the "French system" [10]. In the French system (Figure 7), after screening (or even without screening), raw wastewater is

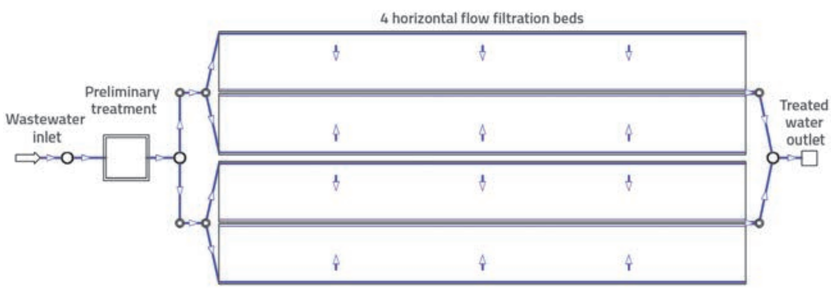

Figure 5. Configuration of HF wetland for wastewater treatment

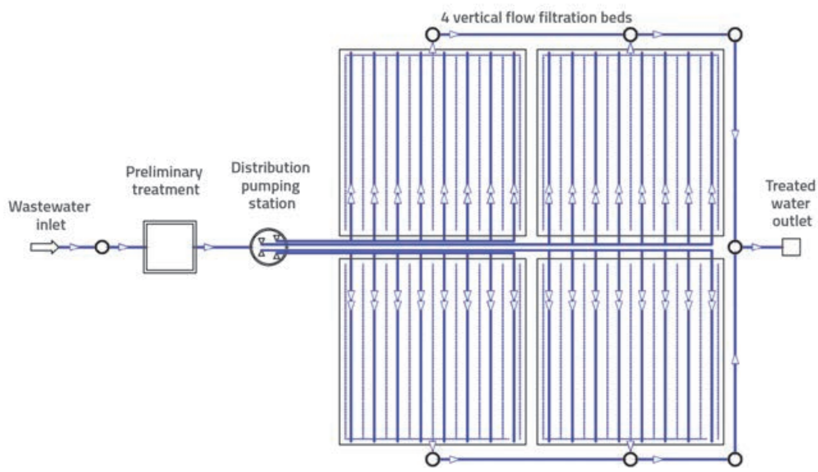

Figure 6. Configuration of VF wetland for wastewater treatment

distributed to the first stage beds that are shaped as vertical flow beds and are filled with gravel. The wastewater is distributed using distribution pipes > 100 mm in diameter. Unlike traditional VF beds, these distribution pipes do not have holes along the pipe length, and thus wastewater leaves the pipe at its end. After preliminary treatment at first stage beds, wastewater is distributed to the second stage beds for further treatment. Second stage beds are also vertical flow beds, but are made of coarse sand substrate. It is recommended to divide the first stage, i.e. the raw waste water treatment, into three beds, onto which wastewater is distributed

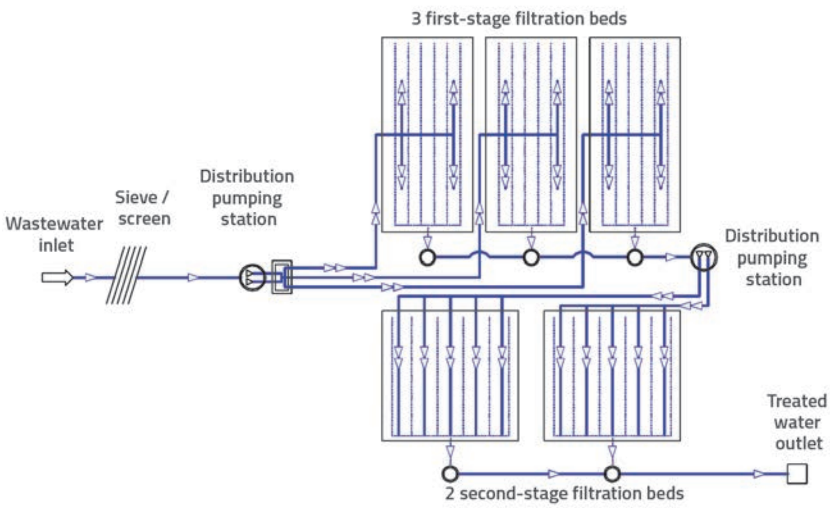

Figure 7. Wetland configuration according to French System

intermittently (in phases). In other words, all raw wastewater is distributed to one bed for three to four days, after which this bed rests for six to eight days, during which time other beds are being used. The purpose of this procedure is to control the growth of biomass and to maintain aerobic conditions in the beds. The second stage is usually divided into two beds, and the operation is conducted as in traditional VF beds. Reed is used as planting material for these beds. Sludge accumulates and mineralises at the surface of the first stage beds (sludge accumulation is about 1.5 cm per year). The sludge is removed every ten to fifteen years, i.e. when the sludge layer reaches 20 cm in height. Sludge can in principle be reused in agriculture.

The treatment efficiency is approximately 90 % COD (chemical oxygen demand), 96 % TSS (total suspended solids) and 95 % TKN (total Kejeldahl nitrogen).

It is considered that the above described French System has a considerable potential for use in municipal waste water treatment systems (mostly for domestic wastewaters) [5]. It is simple and does not require much space (approximately 2.0 m^2/PE). However, such systems must be fenced-off so as to prevent uncontrolled access. That is why the system is inadequate for use at the level of individual households. In fact, the contact with wastewater near houses and gardens could cause hygienic problems. In addition, two pumping stations are often needed for wastewater distribution.

8. Operation and maintenance of constructed wetlands

8.1. Regular operation and maintenance

Appropriate operating instructions must be prepared for every constructed wetland. These instructions should contain a detailed and generally understandable description of necessary inspections and maintenance operations, and the data about frequency of such operations. In addition, measures to be taken in emergency situations must also be included. Every constructed wetland must be operated in accordance with requirements based on which it has been designed, especially with regard to the quantity of wastewater and concentration of pollutants. Operation difficulties may otherwise be experienced in the long run [1].

In addition to routine checks to determine treatment efficiency, visual inspections and odour checks are generally sufficient at the operator's level. It can be assumed that the treatment efficiency is appropriate as long as the treated water leaving the wetland is clear and devoid of foul odours. Possible light colouring of purified water may be neglected.

Filtration beds themselves require very little maintenance. Maintenance of technical equipment mostly concerns cleaning of pumps and distribution lines. Reed harvesting is normally necessary only at several years' intervals. In addition, it is necessary to conduct proper maintenance at preliminary and first stage purification facilities, especially as to emptying and sludge removal. Just like in any other treatment plants, surroundings should also be properly maintained (grass mowing, etc.).

In order to document operation activities, operator is required to keep an appropriate log (diary) in which information about all activities and phenomena registered at the wetland must be entered, including analysis results.

8.2. Operation in winter

At all constructed wetlands, biological processes generally take place at a slower rate in case of lower temperatures. Thus the effect of purification may slightly be reduced in winter. It is important to check for any disturbance that might be caused by freezing of some parts of the wetland. As to organic degradation, the purification effect remains stable even at low temperatures. Nitrification is more dependent on temperature, and is reduced in winter period.

Wetland operation may be disturbed at low temperatures due to freezing of some parts of the system. The freezing hazard is dependent on wastewater temperature, which is in turn related to the size of the sewage treatment network, type of system, length of flow, etc. Depending on the type and size of the preliminary and the first stage purification, additional reduction in temperature may occur (open-air sedimentation lagoon cools down faster than the confined septic tank). Winter time operation and temperature of wastewater is significantly influenced by location of the wastewater treatment facility, i.e. by its elevation, influence of cold air or exposure to wind action. Care must be taken that wetland pipelines are placed below the freezing depth or that wastewater is not held up or slowed down in areas affected by frost. Wastewater distribution systems and possibly inlet pipelines must be realized in such a way that they remain empty after distribution of wastewater.

Freezing normally does not occur in filtration beds as sufficient heat is brought in by wastewater. Snow cover may also protect the wetland against freezing, but such protection is also offered by plants and plant litter. Ice may locally occur on the surface of vertical flow wetlands, but the wastewater flow is normally unaffected by this ice (as ice is melted at outlet points due to wastewater heat). Provided that a sufficient safety area of approximately 30 cm is ensured, there is no danger of wastewater spilling from the basin at slower flow rates.

8.3. Unpleasant odours

During wastewater purification, unpleasant odours primarily occur due to anaerobic decomposition processes. Generation of foul odours is influenced by the preliminary and first stage purification procedures: in covered and closed septic tanks foul odour emissions are much less intense than in the case of open preliminary sedimentation tanks. Open water areas do not exist in the case of filtration beds that are in regular operation, and so no odour is normally emitted. However, foul odours can be generated in the case of operation disturbances, when wastewater puddles appear on the surface of the filtration bed. Unpleasant odours may briefly be generated during distribution of wastewater in VF wetlands. If necessary, the intensity of such odours can be reduced by covering the distribution system with gravel, although this action impedes and makes difficult maintenance and inspection. Foul odours are minimised by providing conditions for the speediest possible percolation of wastewater into the filtration bed.

The extent of disturbance by foul odours depends on subjective feelings of individuals. If there are no objective hindrances, foul odour emissions are completely irrelevant. Specific odour reduction measures are effective only near residential buildings. On the other hand, when such wetlands are operated in rural areas, these measures can be unfavourable as they mostly generate greater costs, and constitute a hindrance to maintenance activities.

8.4. Service life

When considering service life of the entire constructed wetland, the distinction should be made between the service life of the wetland itself (filtration bed), and that of the corresponding technical faiclities. In the case of technical facilities, such as pumps, shafts and pipelines, a normal service life can be applied, e.g. 25 to 40 years for shafts and 8 to 12 years for pumps [1]. Service life of the entire wetland may be increased by use of long-lasting materials in all areas, e.g. for pumps, sealing elements for filtration beds, etc. Experience has shown that properly designed and operated wetlands function without any disturbance for a very long period of time. Current worldwide experience shows that the service life of constructed wetlands corresponds to the service life of other purification procedures (e.g. at least 25 years). Main criteria for determining service life of constructed wetlands are the purification efficiency, filtering material permeability, and accumulation of matter in the filtration bed.

Considering most parameters, the purification effect does not weaken over the years. In fact, an increase in efficiency can be noted for the decomposition of organic matter and removal of nitrogen. However, as to binding phosphate for the filtration body, the reduction in its content can be expected over a long term. In most cases, phosphate removal is not even needed for usual capacities of constructed wetlands.

Functionality of constructed wetlands can be hindered by clogging of the filtration bed. However, clogging can be eliminated by simple measures, and so it does not have to be a limiting factor with regard to service life of wetlands.

Measures aimed at avoiding or eliminating clogging include improvement of the preliminary purification effect, avoidance of high organic load, and optimisation of decomposition process. Decomposition processes can be optimised by an improved supply in oxygen, by an appropriate wetland operation (operation in several lines), and by operation in intervals (intermittent inflow).

If clogging can not be avoided by means of longer breaks in operation, permeability can be restored by removal and replacement of clogged layer or by its loosening. In any case, principal causes of clogging must be identified and solved.

In case of VF wetlands, the bed affected by clogging is most often situated on the surface and can therefore be very easily replaced or stripped. A replacement of no more than 10-15 cm is considered sufficient, and replacement of the entire filtration material is not necessary.

In case of HF wetlands, clogging can occur at the transition zone between the inlet part of the wetland and the main filtration bed. The clogging tendency can be prevented by gradual change of grading of filtration material, while the clogging that is already present can be resolved by soil loosening.

As wastewater load with heavy metals is usually low, significant accumulation of such metals in filtration material is not expected, and so its replacement is not necessary. The accumulation of phosphate is usually a time-limited process in which filtration material is gradually saturated with phosphates. Special filters will have to be built if it becomes really necessary to retain the phosphate.

9. Example of constructed wetland

The above discussion will be illustrated by a brief presentation of a recently built wetland for purification of wastewater. This wetland, situated in Kaštelir, was designed and built in the period from 2014 to 2016 in the scope of the *Coastal Cities Water Pollution Control Project 2*. A hybrid device based on the Limnowet system was used. Nominal capacity of the device is 1900 PE (Figure 8).

Figure 8. General layout of Kaštelir wetland

An automatic rough screen (with bars spaced at 2 cm intervals), and an Imhoff tank of 332.5 m^3 in total volume, are used for the preliminary treatment and the first stage treatment of wastewater. The facility also has a shaft accommodating submerged pumps that are used for distributing the previously deposited wastewater to filtration beds.

Biological treatment is operated via biological beds connected in series: for filtration, for treatment, and for polishing. Filtration beds are realized in form of two parallel beds, each measuring 39 x 23 m in inside plan. The flow in each bed in operated in vertical direction. Treatment beds are realised in the form of two parallel beds, also measuring 39 x 23 m in plan, but here the flow is operated in horizontal direction. At the end, there is one polishing bed, measuring 47 x 27 m in inside plan. Here the flow is operated in horizontal direction. The beds are realized as shallow earth basins. The boundary embankment is made of clay coming from excavation. The sealing is made using a polyethylene foil 1 mm in thickness, which is protected from the top and bottom sides by geotextile measuring 100 g/m^2 in specific weight. The beds are planted with reed.

One sludge reed bed (out of planned three beds) has also been realized. It is used as a deposit for sludge that is brought in from time to time from the Imhoff tank. The bed measures 12 x 20 m in plan, and is 2.1 m deep out of which 1.5 m will be used for storing sludge over a number of years. Due to space constraints, sludge humification beds were designed as shallow reinforced-concrete tanks.

An appropriate drainage bed measuring 29 x 24 m in plan was realized as, in this zone, the treated wastewater could be discharged into the underground only.

An underground reinforced-concrete tank with the capacity of 285 m^3 was realized to enable future reuse of purified water. A smaller one-storey administration building measuring 8 x 4 m in plan was also built on the site. The building consists of an office, storage room, switchboard room, dressing room, and toilet facilities.

Figure 9. ***Kaštelir Wetland*** **– view of the polishing bed**

The total quantity of 12,338 m^3 of wastewater (or 58.2 m^2/day) was measured at measuring gauges of feeding pumps in the Imhoff tank during trial operation of the Kaštelir Wetland (from 2 November 2015 to 31 May 2016). An average daily hydraulic load was lower than the nominal load (285 m^3) as construction of the sewerage network and connection to users is still in progress. A significant increase in hydraulic load during rain events was observed. Thus the maximum daily hydraulic load, registered on 3 March 2016, amounted to 632 m^3. This points to significant infiltration/inflow during rain events that is probably due to illegal stormwater connections, which can be tolerated only in conditions of temporary overload of the device (due to insufficient end user connections). With an increase in hydraulic load, it will be necessary to control illegal connections stormwater, as otherwise the system will operate at low capacity and will be burdened with numerous problems, such as an insufficient water treatment efficiency.

Table 3. Wastewater test results

Indicator [mg/l]	**Raw waste water**			**Purified waste water**		
	min.	**max.**	**av.**	**min.**	**max.**	**av.**
Suspended matter	120	1070	542	2	10	7
COD_{Cr}	129	1920	821	6	35	17
BOD_5	49	1606	356	3	14	6

Twelve samples of wastewater and twelve samples of purified water were taken during trial operation of the facility. The samples were tested by an accredited laboratory. The following parameters were tested: suspended matter, biochemical oxygen demand (BOD_5), and chemical oxygen demand (COD_{Cr}). A summary of test results is presented in Table 3.
All purified water quality indicators meet requirements specified in relevant laws and regulations.

10. Conclusion

Constructed wetlands are now used in many parts of the world. Thus they are normally used in many developed European countries such as Germany, Austria, France, Italy, etc. Constructed wetlands are also utilised in various climatic conditions. As to climatic conditions, there are practically no obstacles to the use of constructed wetlands in Croatia. Constructed wetlands can be used in the treatment of various types of wastewater. Nevertheless, they are mostly used in the purification of municipal wastewater of smaller communities, or for smaller capacities (up to 2000 PE), and for the treatment of wastewater for individual households.
In the Republic of Croatia, limit values for emissions of all treated or untreated wastewater that is discharged into receiving waters are regulated by the *Byelaw on limit values for wastewater discharge* (Official Gazette, issues 80/13, 43/14, 27/15 and 3/16). All relevant EU directives accepted by the Republic of Croatia are included in this Byelaw. Adequately designed, built and maintained wetlands can meet limit value requirements for municipal wastewater treated at the second stage treatment plants (BPK5 ≤ 25 mg O_2/L; KPK ≤ 125 mg O_2/L; suspended matter ≤ 35 mg/L). This means that constructed wetlands can be used for the discharge of treated wastewater in sensitive areas from the communities with the load of less than 10.000 PE.
With appropriate adjustments, constructed wetlands could also meet requirements set for the third degree of wastewater treatment. For instance, if nitrogen removal is required, the combination involving vertical flow wetland followed by horizontal flow wetland, with recirculation of wastewater, could be applied. Reliable removal of phosphorus can be ensured by a separate adsorption filtration bed (which is to follow after planted beds), while replacement of substrate would also be possible after adsorption capacities are used up [5], or by a separate chemical precipitation.
Compared to other biological treatment procedures (e.g. treatment by active sludge, trickling filters, rotating biological contactors, etc.), constructed wetlands require much more physical space. This can be a limiting factor for their use, particularly in urban areas. It is nevertheless estimated that for normal application of biological wetlands (for smaller urban areas not close to urban centres) the issue of space should not be decisive, i.e. the necessary space could normally be found. In such circumstances, other comparative advantages of constructed landfills could come to light. Such advantages are: robustness in operation, low operating costs, and smaller quantity of sludge, although its subsequent disposal should be taken into account.
In Croatia, the price of constructed wetlands varies significantly, e.g. from 1,800 HRK/PE to 12,700 HRK/PE [12]. The price of construction is influenced by a number of factors, most notable ones being geotechnical and topographical conditions and the need for additional facilities (reinforced concrete tanks, operator houses, etc.) and electromechanical equipment (rough screen, fine screen, etc.).
Although the issue of constructed wetlands has been discussed in Croatia for a long time, and the first one was actually built some fifteen years ago, the level of realisation of such facilities has so far been relatively low. In a way, this could have been expected considering a generally low rate of construction of municipal wastewater treatment plants (with the corresponding drainage systems) in Croatia. In such circumstances, and especially in the context of our country's membership in the European Union, a higher level of priority has been given to the planning and construction of plants with capacities far greater than those applicable for constructed wetlands. Additional reasons are the lack of experience in the design, construction, and operation of constructed wetlands, but also the lack of relevant technical literature in Croatian language. Furthermore, it can be assumed that constructed wetlands are not particularly interesting from the commercial standpoint as very little equipment can be sold in this context, and typification is practically possible for very small nominal capacities only (at the level of individual households).
The situation is however changing for the better. The turn has come to local communities of less than 2000 PE that are much more likely to benefit from the wetland technology. The number of existing wetlands has increased (and is steadily increasing) and the same applies to wetlands under construction. Valuable experience is being gained in the process.

Advantages of constructed wetlands, and economic justification and rationality of their use, have been increasingly promoted and recognised in Croatian practice. The reason for that also lies in an increasing number of published papers. In this respect, a notable document is the *Manual for efficient use of constructed wetlands for the treatment of sewage* [4]. This manual briefly describes "good practices" in the sphere of planning, design, construction and maintenance of constructed wetlands for the treatment of sewage. A greatest number of constructed wetlands have in fact been built in Croatia in the period following publication of this manual.

It can therefore reasonably be expected that the use of constructed wetlands will additionally increase in Croatia in the oncoming years. In the framework of municipal treatment plants for the treatment of wastewater, their use will primarily be oriented toward smaller capacities (up to about 2000 PE). In such conditions, constructed wetlands are characterized by simple operation, high purification efficiency – in any case compliant with laws and subordinate legislation – and by a relatively low cost of construction, operation, and maintenance.

Note: Photographs and drawings in the paper were prepared by Emir Mešić, MCE, *Hidroprojekt-ing* d.o.o., Zagreb

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