Constructed Wetlands

Sustainable Wastewater Treatment for Rural and Peri-Urban Communities in Bulgaria

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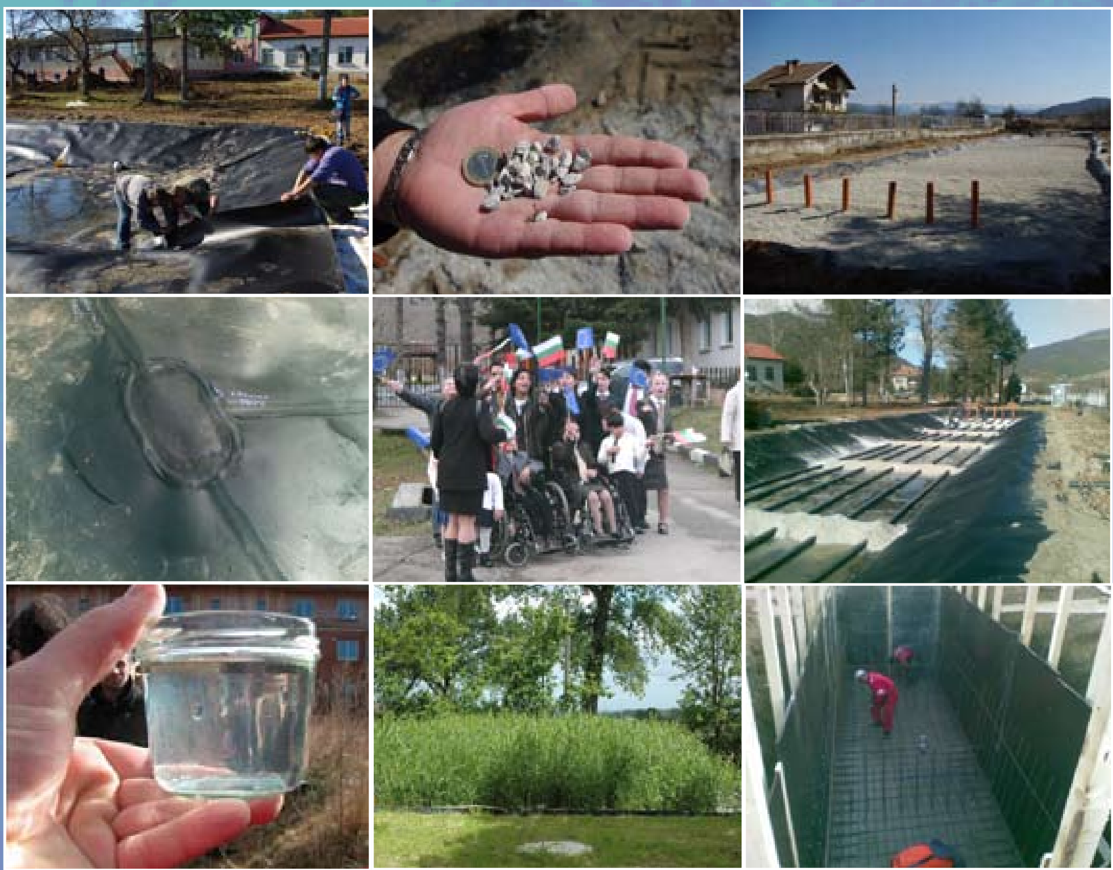
Case Study



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Contents

I Introduction

Sanitation, including wastewater collection and treatment systems, for small communities are a matter of concern in order to protect public health and the environment, especially the sources of drinking water. In many rural areas, a high number of treatment facilities are needed, but those that are installed are usually small in size. Due to differences in rural and urban settings, treatment facilities in rural areas must meet a number of criteria specific to these regions:

Robust and reliable technology: Due to seasonal activities and a smaller structure size, rural wastewater treatment facilities are, compared to urban facilities, often subjected to high seasonal and even daily variations in wastewater flow and load, and thus require a resilient technology that ensures an adequate effluent.

Easy to maintain and operate: Operation must be easily maintained with locally available staff and support. The technology should work sufficiently also in cases of interrupted electricity supply.

Financially sustainable: Investment and operation costs must be affordable for the local community. Low energy and maintenance inputs keep the overall running costs low.

Environmentally and climate sound: The technology should require little energy and be climate friendly. The treated effluent should be able to be re-used in agriculture.

Both wastewater collection and treatment should be considered within a regional planning process to ensure long-term sustainability under various conditions. Treated wastewater, available in reliable quality and quantity, is a valued resource in rural/agricultural areas for irrigation or re-use as a fertiliser.

1. Scope of this Case Study

The scope of this case study is to provide information about the principles and guidance for the design of subsurface flow constructed wetlands as a sustainable wastewater treatment option, especially for small communities in Bulgaria, based on German national guidelines.

After the first two chapters explaining the background and principles of constructed wetlands, the design and construction of the subsurface flow constructed wetland in Vidrare are described in chapter III. This is the first constructed wetland of this type in Bulgaria and treats the domestic wastewater of nearly 80 population equivalents (PE).

This report targets decision-makers on ministerial and municipal level, authorities and utilities as well as consultants and NGOs with a technical background and working in the field of sanitation and wastewater management.

It should be noted that this case study cannot serve as a general design manual. Any design will vary according to different boundary conditions such as composition and load of the inflowing wastewater, length and type of the sewerage etc. To design an adequate constructed wetland, an expert should be consulted from the field to properly adapt it to the local conditions.

2. What is a Subsurface Flow Constructed Wetland?

Constructed wetlands (CWs) are ‘‘engineered systems, designed and constructed to utilise the natural functions of wetland vegetation, soils and their microbial populations to treat contaminants in surface water, groundwater or waste streams" (ITRC 2003). Constructed and planted filter beds provide the space for biological treatment of effluent. The main performance is the bio-chemical treatment in the biofilm of the filter bed. Filter beds usually contain one of two different types of filtering material, usually sand or gravel.

Constructed wetlands were first used in Germany over 40 years ago for the treatment of domestic wastewater treatment mostly in rural areas. In addition, constructed wetlands have now been adapted to also treat wastewaters from agriculture, industry and landfills.

Constructed wetlands are usually defined according to their flow regime in the filter bed. There exist both free water and subsurface flow constructed wetlands; and the flow through the filter bed can be either vertical or horizontal. Today, subsurface flow CWs are the predominant wetland type in Europe.

A constructed wetland comprises a pre-treatment step (settling tanks) for the sedimentation of solid organic matter in order to reduce the load and avoid clogging of the filter bed. A type of constructed wetlands without this pre-treatment has been successfully developed in France (therefore often called the French system).

This case study only deals with subsurface flow CW and with coarse sand as filter bed material.

Constructed wetland for greywater treatment in Vorarlberg, Austria

Constructed wetland for municipal wastewater in Örlinghausen, Germany

3. What Type of Wastewater can be Treated in a Constructed Wetland?

Constructed wetlands are able to treat different urban and rural wastewater flows. The quality and quantity arising from the different sources can significantly vary.

Urban wastewater, according to the EC Urban Waste Water Treatment Directive (UWWTD), is defined as a mixture of domestic and industrial wastewater, see the following table. Rainwater (run-off rainwater) is considered within the urban wastewater flow in case of combined sewerage.

In rural areas the total quantity of wastewater treated is usually greater than that which would be produced from an equivalent urban population. This is due to rural networks, which are usually longer than urban networks, being susceptible to additional sewer infiltration water thorough, for example ground water infiltration by leakages and illegal connections. This significantly increases the total quantity wastewater to be treated, and should be taken into account when planning a treatment facility.

Urban wastewater				
Domestic wastewater		Industrial wastewater	Sewer infiltration water	Run-off rainwater
Toilet wastewater (Urine, brownwater (faeces + flush water)	Greywater (Water from personal hygiene, kitchen and laundry, not from the toilets)			Is included in the urban wastewater in case of combined sewerage
10,000 – 25,000 liter/person/year depending on the type of toilet	25,000 – 100,000 liter/person/year depending on the status of water saving devices in the households	Quantity depends on the industrial activities in the agglomerations and their wastewater management	Quantity can be high depending on the sewerage condition	Quantity depends on the climate and the sewerage type

Definition of urban wastewater

Constructed wetlands can be used for the following wastewater streams (GIZ 2011):

- Domestic wastewater
- Greywater
- Urban wastewater from combined or separated sewerage
- Industrial wastewater treatment such as effluent from paper mills etc.
- Sludge dewatering and mineralization of faecal sludge or sewage sludge

This case study outlines an example of domestic wastewater treatment in Vidrare. In case of other wastewater streams, the design must be adapted according to the different hydraulic and organic loads.

4. Does the Effluent of a Constructed Wetland Meet the Standards for Discharge or Re-use?

Subsurface flow CWs can treat wastewater to a standard suitable for discharge to surface water or for various re-use applications. In any case, the constructed wetland needs to be approved by the local authorities.

There are no specific EU regulations for such on-site treatment systems. According to the Urban Wastewater Treatment Directive (UWWTD 1991), agglomerations with more than 2,000 population equivalents (PE) must set up appropriate treatment (removal of 70-90% BOD, COD and SS[1]), and also the agglomerations with less than 2,000 PE which already have a sewerage network (Article 7 of the UWWTD). For agglomerations with less than 2,000 PE lacking any central sewerage network, there are no standards to meet.

On the other hand, the Water Framework Directive (WFD 2000) regulates the quality of the receiving waters, surface or ground waters. In cases where the effluent is to be discharged into environmentally sensitive areas, the local authorities can require advanced standards. If the treated wastewater is intended for re-use there are guidelines set by the WHO (WHO 2006). The design of the subsurface flow CW should be in line with the desired effluent quality for disposal or re-use.

The most common type of re-use is irrigation in agriculture, such as drip irrigation or subsurface irrigation for lawns, green spaces or crop production. In this case, utilisation of nutrients contained in the wastewater rather than nutrient removal is desirable. Relevant guidelines must be followed to ensure this practice is hygienically safe for crop consumers and workers in contact with treated wastewater. International standards for re-use and guidelines can be found in WHO (2006).

Constructed wetlands can significantly remove pathogenic indicators by 1 – 3 log orders, similar to technical activated sludge systems. Greywater which has been treated in subsurface flow CWs usually meets the standards for pathogen indicators for safe discharge to surface water without further treatment. In the case of domestic and urban wastewater, further treatment e.g. in a pond or UV treatment might be necessary, depending on the intended re-use application and standard.

Treated effluent of a constructed wetland

[1] Biochemical oxygen demand [BOD_5 at 20°C] 25 mg/l O_2 (70-90 % percentage of reduction)
Chemical oxygen demand [COD] 125 mg/l O_2 (75 % percentage of reduction)
Total suspended solids [SS] 35 mg/l (90 % percentage of reduction)

5. What are the Relevant Costs for Constructed Wetlands?

The investment costs of constructed wetlands are dependent on the price of the land on which the treatment plant is to be constructed; as it needs more space than a technical plant, but less space than a pond. The costs also depend on the price of the coarse sand needed to fill the filter bed (GIZ 2011), and the staff costs for the construction.

Financial decisions should not only take the initial investment into account but also the running costs for operation and maintenance in the long-term. Constructed wetlands require much lower running costs as no technical aeration is needed and less operators´ time. The only devices that requires electricity are the pumps. If there is a natural slope that can be used instead of pumps, the constructed wetland can be operated without electricity demand.

II Design Considerations

1. Pre-treatment Step

A successful physical pre-treatment step is necessary to ensure a good performance from this type of constructed wetland. Unsatisfactory pre-treatment may lead to a build-up of solids in the inflow area, odour nuisances, clogging of the filter or blockages of the distribution pipes. The pre-treatment can be realized as primary sedimentation in settling tanks. For small scale plants, septic tanks are typically used. Primary sludge from these tanks should be removed regularly (e.g. once or twice a year).

Design criteria for settling tanks: 2 or 3 chamber settling tanks, the pre-treatment includes the settling zone (hydraulic residence time: 4 hours) and the storage volume of the sludge until the emptying (0.9 l/d*PE)

One alternative pre-treatment step to the settling tanks is the Imhoff tank which simultaneously treats and reduces the primary sludge (Imhoff 2006). Secondly, a pond can be an option for pre-treatment but it tends to smell and requires much more space than settling tanks or an Imhoff tank.

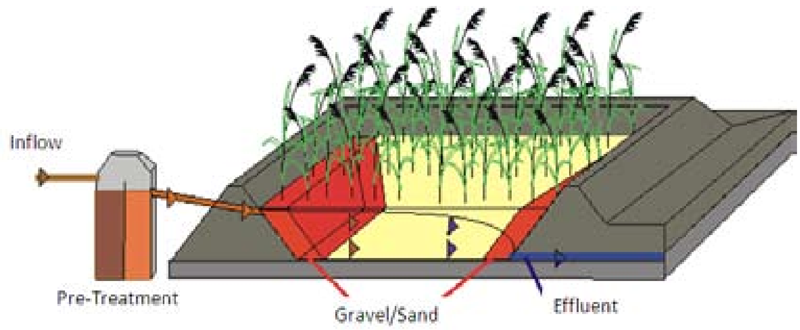
Only the French system, discussed in Chapter III, does not require any pre-treatment step due to different design of the filter layers and flow regime in the filter beds.

View into the settling tank for pre-treatment of greywater

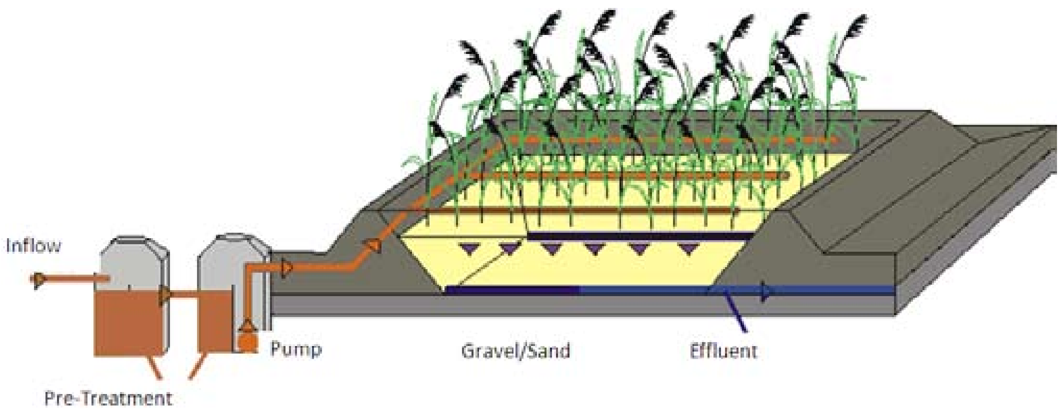
2. Horizontal and Vertical Flow Constructed Wetland

General design of the constructed wetland

Following pre-treatment, the effluent is passed through a soil filter, which can be either vertical or horizontal. The influent should be fed intermittently to provide aerobic conditions in the filter.



Horizontal flow constructed wetland with pre-treatment (www.bodenfilter.de)



Vertical flow constructed wetland with pre-treatment (www.bodenfilter.de)

Horizontal flown soil filter: design criteria for the filter area is 5 m^2 per PE for domestic wastewater, hydraulic surface load max. 40 mm/day and mass surface load 16 g O_2/m^2*d Chemical Oxygen Demand (COD). The depth of the filter is 0.5 – 1.0 m. The filter contains coarse sand (mixture of sand and gravel).

Vertical flown soil filter: design criteria are 3.5 - 4 m^2 per PE for domestic waste water, 80 mm/day hydraulic surface load and mass surface load 20 g O_2/m^2*d COD. The depth of the filter is 0.5 – 1.0 m. The filter contains coarse sand (mixture of sand and gravel). At the bottom a drainage layer with drainage pipes made of plastic is implemented.

In both cases, the design criteria may vary depending on the average yearly temperatures.

Performance of horizontal and vertical flown constructed wetlands:

The results in terms of organic matter achieve more than 80% COD removal and thus achieves common standards for discharge. Pathogenic indicators are removed by 1 – 3 log orders.

If the effluent is discharged into eutrophic or sensitive receiving water such as bathing water, nutrient removal might be required. Due to aerobic conditions in subsurface flow systems, a partial nitrification takes place, but denitrification is limited. To ensure N-removal, a two-stage-constructed wetland (first vertical/second horizontal flow) is needed to meet the requirements for discharge.

If high standards for phosphorus removal and hygienic parameters are required, additional steps (e.g. chemical precipitation for P removal, disinfection) should be applied.

Reference for the design of constructed wetlands

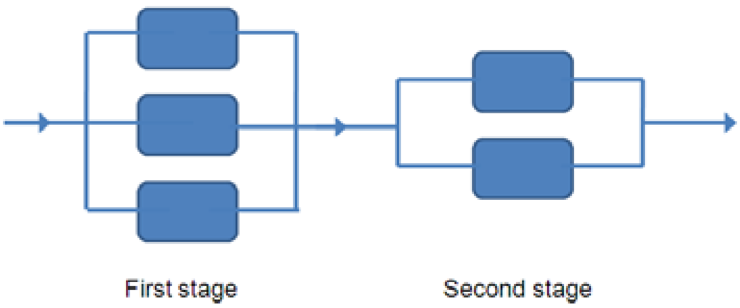
DWA (2006). A 262. Principles for the Dimensioning, Construction and Operation of Planted Soilfiters for Urban Wastewater Treatment. German Association for Water, Wastewater and Waste (DWA)

Constructed wetland for domestic wastewater treatment in Poland

3. French System

Whilst the two systems outlined above are fully functional, an alternative system was developed in France which requires no pre-treatment. The French system feeds the soil filter vertically with raw wastewater. The flow of the influent must be greater than the infiltration speed in order to correctly distribute the sewage over the whole bed surface (intermittently).

The French system is usually applied for urban wastewater from combined sewers where the wastewater quality is more diluted due to run-off water. It always needs two stages and parallel beds in each stage, see scheme below.



Top view scheme of a serie of vertical flow constructed wetlands (French system) (EC 2001)

First stage

The design of the French system comprises two stages each with parallel soil filters as seen in the figure. The first one has three parallel soil filters. If one is active, the others are in a resting phase. The design criteria for the filter area is 1.2 - 1.5 m^2 per PE for this first stage. The media in the filter contains gravel in the upper layer to avoid clogging. The total depth is around 80 cm.

Second stage

The second stage is provided with two parallel soil filters which are used alternating and fed intermittently like the first stage. The design criteria for the filter area is 0.8 m^2 per PE. The media in the filter is sand and the total depth is 80 cm.

Performance of the French system:

The results in terms of organic matter achieve more than 80% COD removal which is similar to the other systems. Pathogenic indicators are also removed by 2 – 3 log orders.

This two step constructed wetland can provide an efficient nitrogen removal if adequately designed and can achieve requirements for discharge into sensitive areas.

The reduction in phosphorus depends on the adsorption capacity of the media and the age of the plant but is usually limited.

Reference for the design of constructed wetlands (French system)

Agence de l´Eau Seine Normandie (1999) Guides des procédés épuratoires intensifs proposés aux petites collectivités, Nanterre

III Case Study Vidrare

1. Background

The Home of Handicapped People in Vidrare, part of the municipality in Pravets, Bulgaria, wanted to build a treatment plant for the domestic wastewater produced by the centre (from the kitchen, toilets and laundry) in order to improve the existing situation.

Home of Handicapped People in Vidrare

Effluent of the old septic tanks in a gully

Together with the municipality of Pravets, the non-governmental organisations WECF and EcoWorld2007 of Bulgaria started the activities in 2008. A water meter was installed in the Home in order to estimate the quantity of wastewater produced. The stakeholders in Vidrare and Pravets were informed about constructed wetlands as a suitable low-tech option for improved wastewater treatment.

After a meeting on-site, the decision was made to build a constructed wetland for wastewater treatment in the yard of the Home; designed to be attractive in appearance. The municipality agreed to permit the installation of the first constructed wetland in Bulgaria, hoping that it would also serve as a demonstration plant that could be replicated by other municipalities.

The German Federal Environment Foundation (DBU) approved the proposal submitted by WECF and EcoWorld2007 and ensured the main funding. The planning and design was carried out by Otterwasser (Lübeck/Germany) and Ecoproject (Bulgaria). The tender was won by the Bulgarian Interstroy group, and construction began in October 2010 to be finished in April 2011 (a break of three months was required due to harsh winter conditions). The site will also be surrounded by a fence.

The director of the Home agreed that there should be an appointed staff member responsible for the maintenance of the constructed wetland. This staff member will be instructed by Otterwasser.

2. The Vertical Flown Constructed Wetland in Vidrare

2.1. Design of the Wastewater Treatment

The wastewater treatment plant consists of a settling tank for the pre-treatment and the planted soilfilter for the biological step.

At the moment 88 children and adults are living in the Home for Handicapped People. 25 of the inhabitants are using diapers. 65 persons are working in shifts. Apparently 25 persons are working in one shift together. The whole home has a capacity of 95 beds.

Pre-Treatment

In order to calculate the dimensions of the pre-treatment step the maximum number of beds (95) was multiplied by the water supply per bed (115 l/bed*d, according to the Bulgarian Regulation N4) (see below).

Settling volume:

Conventional treatment settling times for primary clarifiers require a retention time of 2 hours. For constructed wetlands, however, it is recommended that this be extended to up to 4 hours to avoid solids clogging the top layer of the filter bed.

The maximum inflow is calculated as follows:

Wastewater volume: 115 l/(bed*d) resulting in 115 l/(bed*d) * 95 beds = 11 m^3/d

The wastewater accumulated in 8 hours, so the maximum wastewater volume per hour was:

11 m^3/d: 8 h/d = 1.4 m^3/h

Calculation of required settling volume: 1.4 m^3/h * 4 h = 5.5 m^3

Sludge storage volume:

In addition to the settling of the incoming solids, a volume for storage of the sludge over a defined period has to be calculated.

Volume of sludge: 0.9 l/p*d (Imhoff 2006)

The yearly volume of sludge stored was also calculated: V_S = 0.9 l/p*d * 365 d/yr * 76 p = 25 m^3

The required volume for the settling tank was calculated from the volume of solids in the settling and the sludge stored: V_S = 5.5 m^3 + 25 m^3 = 30.5 m^3

It is recommended that the settling tank will be emptied every 6 months, so the calculated tank volume was reduced as follows: V_s = 25 m^3/2 + 5.5 m^3 = 18 m^3

Biological step: planted soilfilter

In order to calculate the dimensions of the constructed wetland the figures for the wastewater load were used. It was assumed that 28 % (27 children) of the Home's younger inhabitants (totalling 95 children) were using diapers. For the load of the employees, it was calculated 8 PE. The resulting PE was 95-27+8 = 76 PE. The German standard (DWA A 262 2006) recommends that 3,5 m³/PE of space be used for the building of the constructed wetlands.

The area required was calculated as follows:

$$A = 3.5\ m^2/p * 76\ p = 266\ m^2$$

The area required was divided into two filter beds of 133 m² each.

Residual materials:

Settling tank: The sludge from the settling tank has to be taken out once or twice a year. It needs to be treated/stabilised and might be used as soil conditioner and fertiliser in agriculture if the quality is according to the standards. Otherwise the sludge must be disposed via a conventional wastewater treatment plant.

Planted soil filter: After the growing phase of two seasons, the plants have to be cut and removed once a year.

Generally the soil filter bed has to be exchanged, at least partly, as soon as there is a clogging of the filter bed. Experiences with constructed wetlands show that filter beds usually stay more than 20 years without the need to replace it.

2.2. Construction of the wastewater treatment

The wastewater from the toilets, the showers, the kitchen and the laundry flows by gravity into the settling tank for pre-treatment. The settling tank comprises two equal-sized chambers where the solids are separated. In this case study, the pre-treatment tank was constructed with reinforced concrete, pictured below.

Pre-treatment step: 2 chamber settling tank. 3rd chamber pumping shaft

The overflow runs into the pumping shaft, pictured as a small compartment at the far end in the picture above. Two to three daily, nearly 3 m³ of pre-treated wastewater is pumped onto the surface of the planted soil filter (biological step) via the distribution pipes.

From the bottom to the top, the soil filter comprises the following layers:

1. Levelling layer - depth around 10 cm
2. Geo-textile layer – provides protection against roots and burrowing animals (e.g. moles or rats)
3. Impermeable liner (HDPE 1.5 mm) - prevents the uncontrolled flow of water in or out of the filter
4. Conventional drainage pipes with a diameter of DN 100 or DN 150 - for the controlled outflow of the treated water. Composed of gravel (2/8 grain size), with a depth of more than 20 cm. A small sampling shaft should also be built.
5. Biological treatment layer – composed of sand (0/4 grain size), with a depth of more than 50 cm.
6. Cover layer – composed of gravel (8/16 grain size). Contains distribution pipes and is planted with reed. The layer has to protect the pipes and help to distribute the wastewater over the whole area.

Drainage layer with pipes

After passing the outlet shaft following the biological step, the treated wastewater is discharged into a gully that enters the nearby river.

2.3. Operation and Maintenance

Although the technology of the constructed wetland is relatively simple, a number of operational and maintenance tasks are needed to ensure the proper performance of the plant. The following table shows the activities that are needed during the year to maintain the system. It is necessary that one appointed person is responsible for the maintenance and activity plan.

	daily	weekly	yearly
General tasks			
General function control of the technical parts (warning device, control lamps)	x		
Operation diary	x		
Record water consumption	x		
Treatment plant			
Pipes and manholes			1x
Emptying the settling tank (pumping out the sludge)			2x
Visual inspection of the surface of the constructed wetland (plants, weeds, dry zones, water on the surface et al.)		x	
Function control of the pumps			12x
Visual control of the discharge		x	
Maintenance			
Pumps			1x
Analysing a sample of the effluent (frequency depends on the regulations of the water authority)			1x

Activity plan for self monitoring of the constructed wetland

The yearly maintenance of the wastewater treatment plant includes:

- Checking the settling tank damages to the concrete.
- Keeping a record of sludge output (date and volume on the operation diary)
- Controlling the intervals of feeds. The volume per pass of the pump of the constructed wetland has to be controlled.
- Controlling floating switches and pumps, and if necessary cleaning the switches.
- Ensuring clogging does not occur in the biological stage (visual inspection for wet zones, sludge appearance on the surface, trenches on the surface etc).
- Maintaining plant growth (e.g. harvesting the reed)
- General pump maintenance, including cleaning and changing the oil.
- Controlling the duration of the pass of the pump, and if necessary correcting the runtime.
- Checking for concrete damages and sludge sedimentation in the control shaft.
- Sampling of the discharged water according to the regulations of the water authority.
- Up-keep of records in the operation diary.

2.4. Costs

Investment costs

The figures listed here detail the costs incurred during construction of the constructed wetland (with a filter bed of 266 m²) in Vidrare; including pre-treatment, with required shafts, installation of pipes from the Home and to the gully.

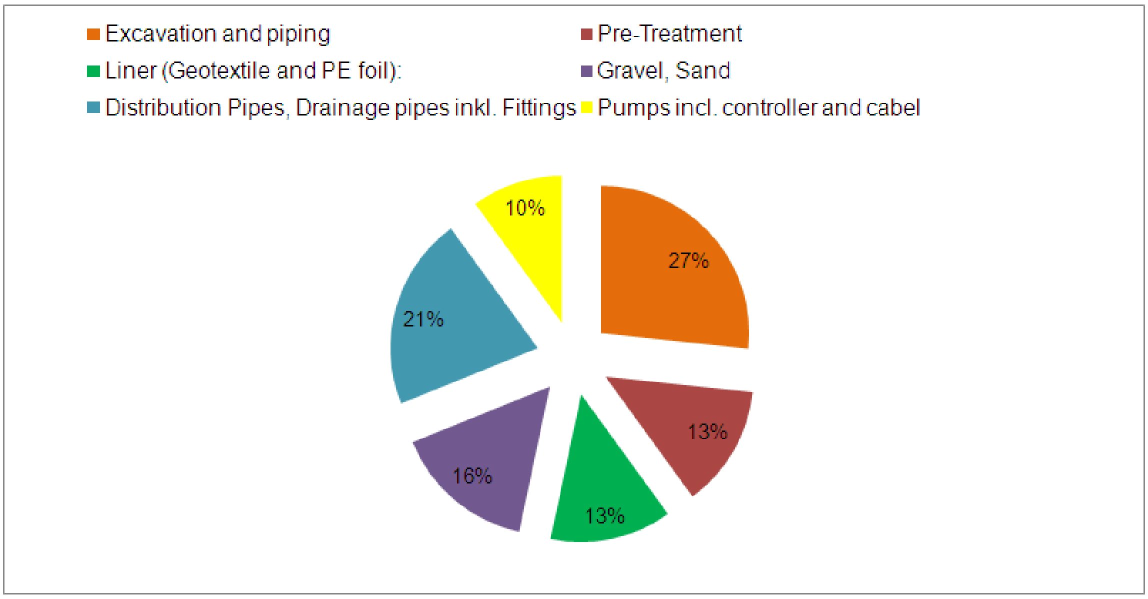


Figure showing the distribution of the investment costs in Vidrare

Investment costs	
Excavation and piping	12.000 €
Pre-treatment step (concrete)	6.000 €
Soil filter	
Liner (Geotextile and PE foil):	6.000 €
Gravel, Sand	7.000 €
Distribution pipes, drainage pipes and fittings	9.500 €
Pumps including controller and cabel	4.500 €
Total investment costs	**45.000 €**
Plus planning and design / planning application (getting the approval)	+ 10% of the investment costs

Distribution of the investment costs in Vidrare including planning and design

Operation and maintenance costs

The operation and maintenance costs are highly dependent on the local cost of energy and staff. The required time and energy supply are listed here:

- Time needed for operation and maintenance: 1.5 h / week (80 h /yr)
- Energy supply for the pumps: 2 kWh/d (750 kWh/yr)
- Sludge disposal from the pre-treatment step: 36 m^3/yr

2.5. Other aspects

Timing

Timing is often very difficult as it depends on many factors, detailed below:

Stage	Activity	Duration
1.	Design of the wastewater treatment installations incl. drawings and details:	2 months
2.	Approval by the municipality and the water authorities - if the decision makers are not familiar with the system time is needed to explain the technical aspects	3 - 6 months
3.	Tender including all documents and selection of the company	4 weeks
4.	Construction (incl. terms of delivery etc.) - highly depending on the weather	4 - 6 months
5.	Planting the reed and start-up operation	2 - 3 months

Timetable for the implementation of a constructed wetland

The most time consuming activity was obtaining the necessary permits for construction and operation of the constructed wetland. Familiarising the Bulgarian authorities with this new technology also proved time-consuming.

Developers should also be aware that unforeseen problems are likely to arise during construction. This project, for example, experienced difficulties in construction due to the presence many underground cables and pipes in the yard of the Home, which had not been mentioned in previous documentation. The construction company first had to determine the location of these pipes and wires, and then modify their plans to avoid damaging them. This was a time-consuming challenge.

Construction and Materials

It is often useful to use materials that are available in the region, such as the coarse sand and gravel. In some regions, pre-fabricated shafts made of reinforced concrete for the pre-treatment step are available. A cost comparison is recommended to check if the pre-fabricated parts are cheaper than constructing the shaft with reinforced concrete on-site. Plastic tanks can also be used. In the case of Vidrare, the construction on-site with reinforced concrete was the cheapest option.

During construction, it was necessary to visit the site regularly, ideally daily, to check on the progress and quality of the construction. Crucial installations, e.g. the welding of the liner at the outlet of the filter, need to be inspected.

3. Photo documentation during construction in Vidrare

Construction of the pre-treatment step (settling tanks):

Digging for the settling tank

Digging for the settling tank with levelling layer

Reinforcement of concrete (settling tanks)

Settling tanks completed

Planted soil filter:

Liner (HDPE 1.5 mm)

Drainage pipes

Welding the liner

Welding the liner

Welding the liner

Sand (in front) and gravel

Gravel for drainage layer

Gravel for cover layer

Completed constructed wetland, without plants

Completed constructed wetland with vent pipes in front

IV References and Further Literature

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Constructed Wetlands

Sustainable Wastewater Treatment for Rural and Peri-Urban Communities in Bulgaria

Constructed wetlands are sustainable and cost-effective wastewater treatment systems that have a number of advantages compared to conventional technical systems: they maintain a high performance, use less energy, sequester carbon, require less operation and maintenance and are better able to cope with the impacts of climate change.

In this publication, the first constructed wetland demonstration plant for 80 population equivalents in Bulgaria is discussed. The design, construction and operation of this subsurface flow constructed wetland are detailed as implemented in Vidrare, Pravets municipality.

WECF