Water Utility Journal 8: 57-65, 2014.

Municipal wastewater treatment using constructed wetlands

G. D. Gikas[1] and V. A. Tsihrintzis[2*]

[1] *Laboratory of Ecological Engineering and Technology, Department of Environmental Engineering, Democritus Unviersity of Thrace, 67100 Xanthi, Greece. e-mail: ggkikas@env.duth.gr*

[2] *Centre for the Assessment of Natural Hazards and Proactive Planning & Laboratory of Reclamation Works and Water Resources Management, School of Rural and Surveying Engineering, National Technical University of Athens, 9 Iroon Polytechniou St., Zografou 157 80 Athens, Greece. e-mails: tsihrin@survey.ntua.gr; tsihrin@central.ntua.gr; tsihrint@otenet.gr*

Abstract: The aim of the paper is to present alternative to conventional (i.e., the commonly used biological treatment plants) wastewater treatment systems, appropriate for small communities and settlements. These systems are the natural treatment systems. The emphasis here is given on constructed wetlands (CWs). First, advantages and disadvantages of these systems are presented compared to conventional systems. Design guidelines from various EU countries for CW systems used in municipal wastewater treatment, and data on the operation of such systems in Greece are presented. Finally, the wastewater treatment facility in Korestia municipality, Kastoria prefecture, Northern Greece, is described, where this technology was employed. The system was designed as a hybrid system, consisting in series of vertical flow CW beds (1st and 2nd stage) and a horizontal subsurface flow bed (3rd stage) to serve 600 population equivalent (p.e.). The first stage consists of 3 identical beds, with a total surface area of 891 m^2 or 1.5 m^2/p.e.; the second stage comprises two identical beds, with a total surface area of 594 m^2 or 1.0 m^2/p.e., and the third stage of one bed with a surface area of 903 m^2 or 1.5 m^2/p.e. The total construction cost was 286,282 € or 477 €/p.e. The expected operating cost was estimated at 7,121 €/year, or 11.87 €/p.e./year. The use of constructed wetlands, as appropriate wastewater treatment method in small settlements, is proposed.

Key words: Constructed wetlands, Municipal wastewater treatment, Horizontal subsurface flow, Vertical flow.

1. INTRODUCTION

In many countries of Europe (e.g., Germany, Austria, the Czech Republic, Denmark, etc.) and also in the U.S.A., natural systems are widely used for the treatment of municipal wastewater of small settlements (up to 3000 p.e.). Preference is given to constructed wetlands (CWs); the reason is that these systems have several advantages compared to conventional systems, particularly when they are to be installed in small communities, i.e., they have low construction and operation costs, are simple in operation, and show efficiency and robustness in pollutant removal. For this reason, their use is widely and rapidly expanding in both developed and developing countries. Advantages are summarized in Table 1 (Vymazal 2002; Vymazal et al., 1998; Reed et al., 1995; Kadlec and Wallace, 2009; Tsihrintzis and Gikas, 2010). A main disadvantage of the use of this technology is the higher area demand for these systems compared to conventional ones.

The types of CWs mainly used in wastewater treatment are horizontal subsurface flow (HSF) and vertical flow (VF). Initially the interest was on HSF CW systems, particularly in the U.S.A. where there have been installed many such systems used for secondary treatment. The HSF CWs operate very efficiently in removal of BOD and total suspended sediments (TSS), but for complete oxidation of ammonia (nitrification) they demand a very large area due to the limited oxygen transfer. However, they are effective in denitrification (Cooper, 1999). As a result, the interest in the recent 20 years, particularly in Europe where available land is limited, has focused on VF CW systems, whose treatment capacity is mainly based on very efficient aeration of the substrate. Therefore, the reduction of BOD, COD and ammonia is high. These systems, because of their high capacity to remove pollutants and the relatively small land requirements (1-2 m^2/p.e.), are attractive in cases where other natural systems cannot be applied (Cooper and Green, 1995).

Recently, an interest on "hybrid" systems has also emerged; these systems are also called combined because they are a combination HSF and VF (or other) CWs in series. In hybrid systems, the disadvantages of individual HSF and VF CWs diminish because one system complements the other. Alternative ways of placing the beds in series have also been tested. In one setting, there are one or two HSF CW beds followed by one or more VF beds, or, in an alternative arrangement, the VF CWs are placed before the HSF CWs. Studies showed that, in the first case, removal of BOD and COD is achieved satisfactorily, but denitrification is not sufficient because of limited carbon. The alternative arrangement, with the VF beds placed first, gave better results. Cooper (1999), who studied systems with different ways of HSF and VF bed arrangement, concluded that VF beds should be placed at the beginning of the system, because if it is designed properly, it can achieve satisfactory removal of BOD, COD and bacteria, and moreover, complete oxidation of ammonia to nitrate ions. Also, with this arrangement, a significant amount of total nitrogen is removed.

Table 1. Comparison between conventional wastewater treatment systems and constructed wetlands (Vymazal 2002; Vymazal et al., 1998; Reed et al., 1995; Kadlec and Wallace, 2009; Tsihrintzis and Gikas, 2010).

Conventional Systems	**Constructed wetlands**
They use non-renewable energy sources both in construction (concrete, steel) and operation (electricity, chemicals etc.)	They use renewable energy sources (i.e., solar energy, wind etc.)
They produce large quantities of by-products (e.g., sludge) which need further treatment	They produce small quantities of by-products (e.g., harvested plants) which do not need further treatment
They have many mechanical parts, which implies increased needs for personnel, and high maintenance costs	They do not have (or have minor) mechanical parts, i.e., their operation and maintenance costs are low
They require specialized personnel for the operation	They do not require specialized personnel for the operation
They have high construction and operation cost	They have comparable or lower construction and minimal operation cost
They have low area demand	They have a relatively large area demand

In Greece, constructed wetlands for municipal wastewater treatment are not very widespread. There are few such systems, e.g., in Nea Madytos, Thessaloniki prefecture, in Gomati, Chalkidiki prefecture, and elsewhere, which are used for municipal wastewater treatment of these small settlements. In recent years, efforts have been made to expand and propagate the use of these systems and in other areas of the country, because of their advantages over conventional systems (e.g., activated sludge). The purpose of this paper is to summarize CW use and describe the Korestia wastewater treatment plant, with a view of contributing to the effort to expand constructed wetland use as the preferred wastewater treatment system in small municipalities and settlements.

2. DESIGN OF WASTEWATER TREATMENT PLANT USING CW SYSTEMS

Wastewater treatment plant (WTP) designs, including CWs and other natural systems, is very diverse. The size estimation of HSF and VF CWs is based more on experience and knowledge gained over the last 20-30 years, both from laboratory studies (e.g., Akratos and Tsihrintzis, 2007; Stefanakis and Tsihrintzis, 2012a; 2012b; Tsihrintzis and Gikas, 2010) and large-scale experiments (Boutin et al., 1997; Gikas et al., 2007; 2011; Tsihrintzis et al., 2007; Gikas and Tsihrintzis, 2010; 2012).

For VF systems, the required bed surface area depends on the organic load and is expressed as unit area per population equivalent (m^2/p.e.). The surface area required for each stage of the system can be adjusted depending on the climate, the required level of pollutant removal, and the hydraulic load. Typical values include: (a) 1.2 m^2/p.e., divided into three or more identical units for the first stage; and (b) 0.8 m^2/p.e. divided into two or more identical units for the second stage. Research in France showed that 2 m^2/p.e. is a sufficient surface area to achieve satisfactory nitrification, while sizes larger than 2.5 m^2/p.e. did not show any nitrification efficiency improvement (Molle et al., 2004). In France, among CW systems treating municipal wastewater, VF CWs are more widespread. The particularity of these systems is that there is not pretreatment, e.g., Imhoff or sedimentation tanks, before the VF beds, but raw sewage is fed directly to the first stage CWs (after coarse screening). This makes it easier to manage the sludge produced at the surface of the bed, in comparison to the management of the primary sludge from Imhoff or settling tanks. Such systems have been used for about 20 years in France; over the years, they have gained good reputation as most suitable in that country, particularly for municipal wastewater treatment in small settlements (Molle et al., 2004; Paing and Voisin, 2004).

According to German regulations (ATV A262, 1998) for WTP design using CWs, pretreatment is required by sedimentation in Imhoff tanks before applying wastewater to the CW beds. Also, the German regulations require a larger bed surface area (2.5 and 5.0 m^2/p.e. for VF and HSF CWs, respectively) relative to the "French" design. Studies have shown that the combination of anaerobic ponds and VF CWs gave very good results in the treatment of municipal wastewater, achieving efficiencies greater than 90% for BOD, COD and TKN (Kayser et al., 2003).

There is limited experience on the efficiency of anaerobic stabilization ponds in the removal of organic load under Mediterranean climate conditions. A pilot anaerobic pond was constructed for municipal wastewater treatment in Gallikos River (Thessaloniki prefecture) and the performance in mean removal of BOD, COD and TSS was 50%, 53% and 64%, respectively (Papadopoulos et al., 2003). According to Mara and Pearson (1987), anaerobic ponds in Bavaria (Germany) work satisfactorily at temperatures quite lower compared to those in Mediterranean countries. The minimum design volume used in Germany is based on a volumetric rate of 100 g BOD/m^3/d, i.e., about 0.5 m^3/p.e. (Mara and Pearson, 1987). Thus, Mara and Pearson (1987) suggest for anaerobic pond design in Mediterranean countries: (a) where the winter temperature is lower than 15°C, i.e., a temperature range where the action of *methanobacters* stops, the value of Bavaria, i.e., 100 g BOD/m^3/d, with a BOD removal at about 40%; and (b) in the summer, the organic load can be increased up to 300 g BOD/m^3/d or about 0.17 m^3/p.e. To avoid odor problems, the load must be less than 400 g BOD/m^3/d, if the sulfate ion concentration at the inlet is less than 500 mg SO_4/L (Alexiou and Mara, 2003). A solution to the problem of odors can also be given by covering the anaerobic pond (Papadopoulos et al., 2003). Finally, sludge from such ponds can be transferred to a sludge treatment wetland (STW; Stefanakis and Tsihrintzis, 2012a). STW beds can be designed to accept loads of about 30 kg/m^2/yr (Reed et al., 1995), while recent research under Mediterranean conditions has shown that they operate effectively with loads up to 75 kg/m^2/yr (Stefanakis and Tsihrintzis, 2012a).

The WTPs operating in Gomati and Nea Madytos, North Greece, were designed following the German approach. Their treatment efficiency has been tested expensively (Gikas et al., 2007; 2011). There is pretreatment using settling tanks and Imhoff tanks, respectively (Gikas et al., 2007; 2011). However, in these facilities, the surface area of the CW bed (1.8 and 1.2 m^2/p.e., respectively) is lower than the values the German regulations propose. Nevertheless, data on operation of the Gomati (Gikas et al., 2007) and Nea Madytos (Gikas et al., 2011) facilities are very satisfactory in pollutant removal (Table 2; Tsihrintzis and Gikas, 2010).

Table 2. Mean pollutant removal in WTP using CWs in Greece (Tsihrintzis and Gikas, 2010).

Parameter		Gomati[a]			Nea Madytos[b]		
		Influent	Effluent	Removal %	Influent	Effluent	Removal %
BOD	(mg/L)	487.2	35.4	92.3	305.0	28.0	90.8
COD	(mg/L)	568.7	47.2	91.7	445.6	49.0	89.0
TKN	(mg/L)	93.8	18.2	80.3	86.9	14.0	83.9
NH_4-N	(mg/L)	67.7	9.1	87.5	68.8	11.1	83.8
OP	(mg/L)	6.1	3.3	45.7	4.4	3.7	17.4
TP	(mg/L)	11.4	4.4	61.3	7.8	4.8	38.8
TSS	(mg/L)	200.0	13.6	93.2	139.7	13.4	90.4
TC	(N/100 mL)	47.9×10^6	0.05×10^6	99.9	63.8×10^6	0.08×10^6	99.9

[a]Mean value of 37 data; [b]Mean value of 44 data

3. WASTEWATER TREATMENT PLANT IN KORESTIA MUNICIPALITY

3.1 Study area and preliminary measurements

The municipality Korestia (N: 40°37'12", E: 21°12'02") is located in the northern part of the prefecture of Kastoria, Northwest Greece. The area of the municipality is about 12,228 ha and the main productivity sectors are agriculture and livestock. Based on census data for 1991 and 2001, the population of the municipality was 1128 and 1000 residents, respectively, representing a decrease of 12.8% (mean annual decrease of 1.3%). In year 2006, when the project was designed, the population was 500 residents.

The drainage system in Korestia is separate, although some illegal connections to the storm sewer have been identified. Before the project, the sewage was transported by gravity to an existing outfall located in a land area of about 0.4 ha, close to the village, where an old wastewater treatment facility existed. This facility has never worked and was abandoned. Instead, sewage bypassed the facility and was filtered through a gravel trench to hold the solids, and then was discharged into the adjacent stream called "Mikro Rema"; this stream, after a journey of about 300 m, confluences to Ladopotamos river (upper part of Aliakmonas river). Before project design, a two-year record of water consumption data were made available by the municipality, showing an average annual volume of sewage of 23200 m^3/yr (64 m^3/d), which corresponds to 128 L/p.e./d.

Preliminary studies for the project were: (a) a geological - hydrological study of the area; and (b) a geotechnical study at the proposed location, where the project was to be built. This location is at the edge of a small catchment area of 5.35 km^2, which is hilly at the southern edge, while the largest altitude reaches 1351 m. The project site is crossed by the afore-mentioned small stream, whose length is approximately 5.75 km, and which, as mentioned, contributes to Ladopotamos river. The daily flow of Mikro Rema was estimated to range from 178 m^3/d in July to 5528 m^3/d in November. It also appears that there are no major aquifers at the general project location.

Water quality sampling took place of: (a) wastewater at the end of the existing sewer pipe, representing influent characteristics to the treatment plant; and (b) water in the adjacent stream (Mikro Rema), which receives the effluent from the project facility, to determine background quality characteristics. Discharge was measured using a Valeport model 801 flowmeter. Dissolved oxygen (DO), pH, temperature and electrical conductivity (EC) were measured *in situ* using WTW series instruments. Water and wastewater samples were stored in a cool box, and were transported to the laboratory for analyses. Analyses included the determination of BOD, COD, total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), ortho-phosphate phosphorus (OP) and total suspended sediments (TSS) using standard methods (APHA, AWWA, 1998). The results of the measurements are presented in Table 3.

Table 3. Physicochemical parameters of wastewater and water of Mikro Rema.

Parameter	Sewer	Mikro Rema
Discharge (m^3/d)	-	1080
pH	6.86	7.28
DO (mg/L)	4.7	7.6
EC (μS/cm)	422.0	80.2
BOD (mg O_2/L)	65.0	Not measured
COD (mg O_2/L)	293.0	53.0
TSS (mg/L)	552.0	8.0
TKN (mg/L)	13.7	4.2
NO_3-N (mg/L)	0.32	0.07
NH_4-N (mg/L)	2.20	0.20
OP (mg P/L)	0.14	0.06

3.2 Design parameters

The wastewater treatment plant of Korestia was designed for a population of 600 p.e. The discharge of wastewater per p.e. was taken equal to 150 L/d; the total flow of wastewater was 90 m^3/d. Design parameter concentrations are presented in Table 4.

Table 4. Design parameters for WTP of Korestia.

Parameter	Load (g/p.e./d)	Concentration (mg/L)
Biological Oxygen Demand, BOD	50	333
Total Suspended Solids, TSS	52	350
Total Kjeldahl Nitrogen, TKN	10	67
Total Phosphorus, TP	1.2	8

3.3 System Description

The system in Korestia was designed as a hybrid system, composed of three treatment stages. The first stage consists of three VF CWs, the second stage of two VF CWs, and the third stage of one HSF CW (Figure 1). The HSF CW was added for denitrification, although it is not common in systems of France. The surface area of the CW beds are 891 m^2 or 1.5 m^2/p.e., 594 m^2 or 1.0 m^2/p.e. and 903 m^2 or 1.5 m^2/p.e. for the first, second and third stages, respectively. The technical specifications of the CW beds, which are earth basins, are presented in Table 5. For the complete waterproofing of the beds, in order to avoid leaching of sewage to the groundwater, high density polyethylene (HDPE) geomembrane, 1 mm thick, is used. The geomembrane is protected on both sides with special geotextile, in order to avoid damage to the membrane (holes, tearings, etc.) that may be caused by direct contact with sharp-edge stones or gravel.

The porous media of the CW beds is inert material from a quarry or (preferably) from torrent deposits, but at an appropriate particle size range to avoid clogging of the filter. The porous media of the 1st stage CWs has a depth of 0.90 m and consist of 3 layers from bottom to top: cobbles 0.2 m (diameter 20-40 mm), coarse gravel 0.2 m (diameter 5-20 mm) and fine gravel 0.5 m (diameter 2-8 mm). The porous media of the 2nd stage CWs has a depth of 0.90 m and consists of 3 layers from bottom to top: cobbles 0.2 m (diameter 20-40 mm), fine gravel 0.3 m (diameter 3-8 mm) and river sand 0.4 m (diameter 0.2-4.0 mm). Finally, the 3rd stage CW is filled with 50 cm of gravel (diameter 18-30 mm). All CW beds are planted with *Phragmites australis*.

Table 5. Technical specifications of Korestia facility.

Parameter	1st stage	2nd stage	3rd stage
Type of bed	TYKP	TYKP	TYOYP
Number of beds	3	2	1
Length (m)	18.0	18.0	21.5
Width (m)	16.5	16.5	42.0
Area (m^2)	891	594	903
Depth (cm)	90	90	50
Number of plants	4 plants /m^2	4 plants /m^2	4 plants /m^2
Plant species	*Phragmites australis*	*Phragmites australis*	*Phragmites australis*

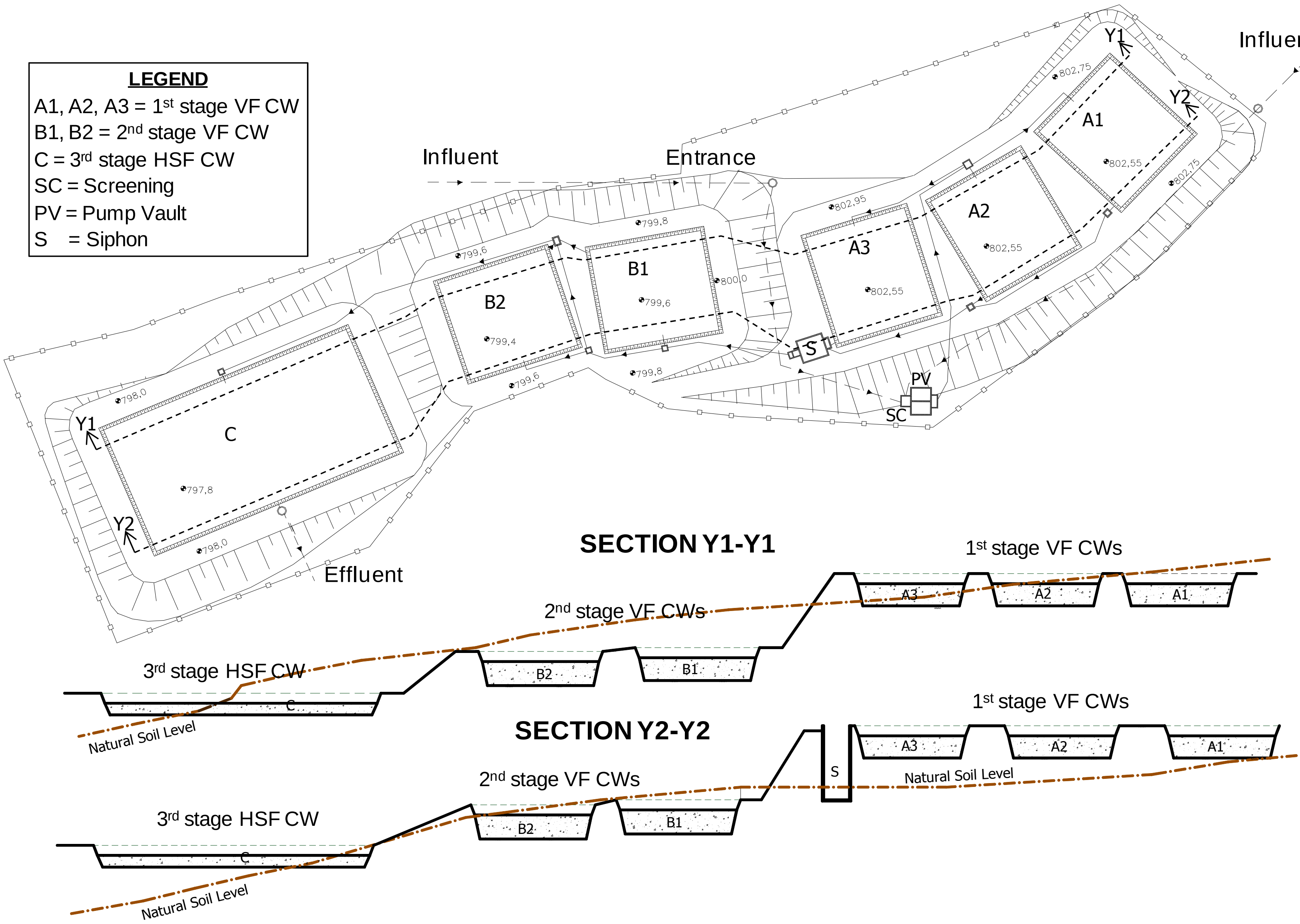

Figure 1. Facility plan view and sections Y1-Y1 and Y2-Y2 of Korestia facility.

3.4 Wastewater flow

Wastewater of Korestia village is routed to the treatment facility by gravity using two PVC pipes, and ends in a pump vault after passing a manually-cleaned coarse screen with 2.0 cm opening. In the pump vault there are two submerged pumps which operate alternately. Then, the wastewater is pumped to the beds of the first stage. This is the only place where electrical energy is used to move wastewater. Throughout the rest of the facility the wastewater is routed by gravity (Figures 1 and 2).

The pump operates periodically in order to send the wastewater to the aquatic plant beds in batches (approximately 14 m^3 each). Each CW of the first stage receives the entire organic load during the feeding phase, which is 2 days, and rests for 4 days when another basin is fed. These alternate loading and resting phases, play an important role in: (a) controlling the growth of biomass which is attached to the porous media; (b) maintaining aerobic conditions into the filter bed; (c) converting the organic residue derived from the suspended solids of raw wastewater and retained on the surface of the filter to inorganic salts; (d) insuring that there is adequate wastewater volume for good distribution on the entire surface of the bed; and (e) improving the renewal of oxygen between two feed batches (Molle et al., 2004). The effluent of the 1st stage VF CW beds drains in a siphon tank (dimensions 3.5x4.0 m), whose purpose is to feed periodically (in batches, again 14 m^3 each) the 2nd stage VF CWs, which consist, as mentioned before, of two parallel, alternately operating, beds. The feeding phase of each bed takes 3 days. Finally, the wastewater is introduced to the HSF CW bed where the principal process is denitrification for further nitrogen removal.

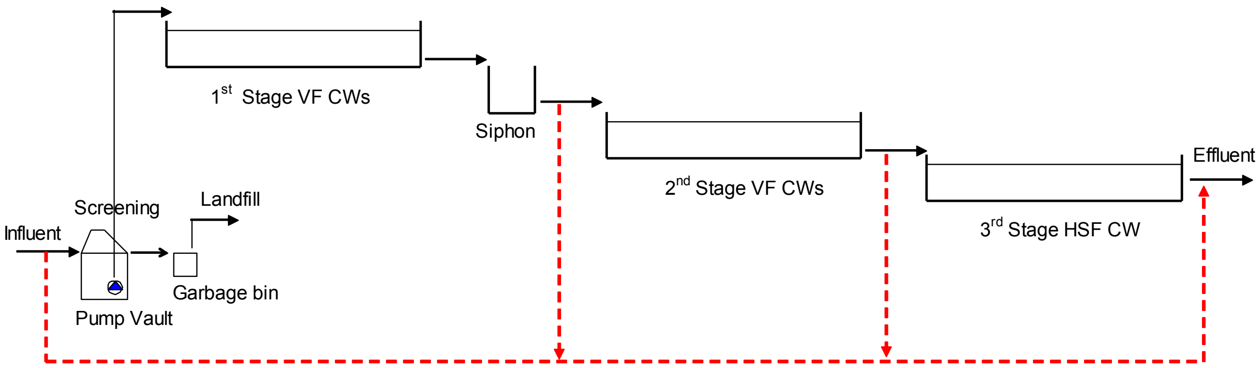

Figure 2. Flow diagram of Korestia facility.

3.5 Effluent quality of Korestia facility

Hybrid CW treatment systems, such as the one designed in Korestia, operate at high efficiency in removing pollutants both in European countries and in Greece. The mean performance of pollutant removal from 20 municipal wastewater treatment systems in France (Paing and Voisin, 2004) for BOD, COD, TSS, TKN and TP were 98%, 92%, 96%, 91% and 43%, respectively. Taking into account the results of France (Paing and Voisin, 2004), and those in Nea Madytos and Gomati facilities (Table 1), the expected concentrations in the effluent of Korestia facility are: BOD <20 mg/L, COD <40 mg/L, SS <15 mg/L, TKN <6 mg/L and TP <4 mg/L.

3.6 Construction and operation cost

The cost of CW wastewater treatment facilities comprises two parts: capital cost and operation cost. The capital cost refers to the cost of the land needed for the installation of the facility, the construction cost, and the engineer's and contractor's fees. The tables provided by the Hellenic Department of Public Works (General Secretariat of Public Works) for year 2010 were used for costing the construction activities of the Korestia facility. The construction cost in the various parts of the facility and the total construction cost are presented in Table 6. Cost of land is not included since the land was public.

Constructed wetlands have low operation cost, especially when the design is carefully made to have flow by gravity, thus, avoiding energy-consuming and maintenance-demanding pumps. The operation cost of the studied facility is small, because it is limited to low electric energy consumption and limited man-hours for maintenance. It is estimated that the daily electric energy consumption from wastewater lift pumps and lighting is 8.0 kWh and 11 kWh, respectively (total 19.0 kWh/d), and the man-hours that will be required for operation and maintenance of the system are on an average 2 per day. Considering the cost of electricity at 0.127 €/kWh and the labor wage at 8 €/h, the operating cost of the facility is estimated at 19.50 €/d, or 11.87 €/p.e./year, or 0.21 €/m^3 of wastewater.

Table 6. Construction cost of Korestia facility.

	Cost (€)
Inlet works, screening	29,623
First stage VF CWs	38,671
Second stage VF CWs	33,296
Third stage HSF CWs	33,162
Ancillary works (pipe network, siphon)	15,743
Electrical	19,586
Infrastructure and landscape restoration	27,164
Construction cost	197,245
Total construction cost (including professional engineers' and contractors' fees 18%, and VAT 23%)	286,282
Total construction cost / p.e. (€/p.e.)	477.13

4. CONCLUSIONS

An effective solution for wastewater treatment of Korestia municipality is presented, which utilizes the constructed wetlands technology, with low cost of construction and operation. The proposed facility is expected to operate smoothly, without problems, and further solve the problem of sludge disposal and management. Therefore, the use of constructed wetlands is proposed, as an appropriate wastewater treatment method in small settlements.

REFERENCES

Akratos, C.S., Tsihrintzis, V.A., 2007. Effect of temperature, HRT, vegetation and porous media on removal efficiency of pilot-scale horizontal subsurface flow constructed wetlands. Ecol. Eng.; 29 (2): 173-191.

Alexiou, G.E., Mara, D.D., 2003. Anaerobic waste stabilization ponds. A low-cost contribution to a sustainable wastewater reuse cycle. Ap. Biochem. Biotechnol.; 109: 241-252.

APHA, AWWA (American Public Health Association, American Water Works Association), 1998. Standard methods for the examination of water and wastewater, (20th Edition), Washington, D.C.

ATV Arbeitsblatt A262, 1998. Grundsätze für Bemessung und Betrieb von Pfanzenbeeten für Kommunales Abwasser bei Ausbaugrößen bis 1000 Einwohnerwertte, Juli 1998:2-10.

Boutin, C., Lienard, A., Esser, D., 1997. Development of a new generation of reed-bed filters in France: First results. Water Sci. Technol.; 35(5): 315-322.

Cooper, P., 1999. A review of the design and performance of vertical-flow and hybrid reed bed treatment systems. Water Sci. Technol.; 40(3): 1-9.

Cooper, P., Green, B., 1995. Reed bed treatment systems for sewage treatment in United Kingdom – the first 10 years experience. Water Sci. Technol.; 32(3): 317-327.

General Secretariat of Public Works. http://www.ggde.gr/index.php?option=com_docman&task=cat_view&gid=40&Itemid=188

Gikas, G.D., Akratos, C.S., Tsihrintzis, V.A., 2007. Performance monitoring of a vertical flow constructed wetland treating municipal wastewater. Global NEST J.; 9(3): 277-285.

Gikas, G.D., Tsihrintzis, V.A., 2010. On-site treatment of domestic wastewater using a small-scale horizontal subsurface flow constructed wetland. Water Sci. Technol.; 62(3): 603–614.

Gikas, G.D., Tsihrintzis, V.A., 2012. A small-size vertical flow constructed wetland for on-site treatment of household wastewater. Ecol. Eng.; 44: 337-343.

Gikas, G.D., Tsihrintzis, V.A., Akratos, C.S., 2011. Performance and modeling of a vertical flow constructed wetland – maturation pond system. J. Environ. Sci. Health, Part A; 46: 692–708.

Kadlec, R.H., Wallace, S.D., 2009. Treatment wetlands, second ed. Taylor and Francis Group, Boca Raton, USA. ISBN 978-1-56670-526-4.

Kayser, K., Kunst, S., Fehr, G., Voermanek, H., 2003. Controlling a combined lagoon/reed bed system using the oxidation-reduction potential (ORP). Water Sci. Technol.; 48(5): 167-174.

Mara, D.D., Pearson, H.W., 1987. Waste stabilization ponds – Design manual for Mediterranean Europe. World Health Organization, Regional Office for Europe, EUR/ICP/CWS 053.

Molle, P., Lienard, A., Boutin, C., Merlin, G., Iwema, A., 2004. How to treat raw sewage with constructed wetlands: An overview of the French systems. In: Proceedings of the 9th International Conference on Wetland Systems for Water Pollution Control, Avignon, France, 26-30 September 2004, pp. 11-18.

Paing, J., Voisin, J., 2004. Vertical flow constructed wetlands for municipal wastewater and septage treatment in French rural area. In: Proceedings of the 9th International Conference on Wetland Systems for Water Pollution Control, Avignon, France, 26-30 September 2004, pp. 315-322.

Papadopoulos, A., Parisopoulos, G., Papadopoulos, F., Karteris, A., 2003. Sludge accumulation pattern in an anaerobic pond under Mediterranean climatic conditions. Water Res.; 37: 634-644.

Reed, C. S., Crites, R. W., Middlebrooks, E. J., 1995. Natural systems for waste management and treatment, Second Edition, McGraw-Hill.

Stefanakis, A.I., Tsihrintzis, V.A., 2012a. Effect of various design and operation parameters on performance of pilot-scale sludge drying reed beds. Ecol. Eng.; 38(1): 65-78.

Stefanakis, A.I., Tsihrintzis, V.A., 2012b. Effects of loading, resting period, temperature, porous media, vegetation and aeration on performance of pilot-scale vertical flow constructed wetlands. Chem. Eng. J.; 181-182: 416-430.

Tsihrintzis, V.A., Akratos, C.S., Gikas, G.D., Karamouzis, D., Angelakis, A.N., 2007. Performance and cost comparison of a FWS and a VSF constructed wetland systems. Environ. Technol.; 28(6): 621-628.

Tsihrintzis, V.A., Gikas, G.D., 2010. Constructed wetlands for wastewater and activated sludge treatment in North Greece: A review. Water Sci. Technol.; 61(10): 2653-2672.

Vymazal, J., 2002. The use of sub-surface constructed wetlands for wastewater treatment in the Czech Republic: 10 years experience. Ecol. Eng.; 18: 633–646

Vymazal, J., Brix, H., Cooper, P. F., Green, M. B., Haberl, R., 1998. Constructed wetlands for wastewater treatment in Europe, Backhuys Publishers, Leiden.