MODELING OF THE HYDRAULIC BEHAVIOUR OF CONSTRUCTED WETLANDS

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Abstract

The main domain of this work consisted in the study of the hydraulic and hydrologic behaviour of constructed wetlands (CW) used for wastewater treatment The study was based in the collection and analyses of flow data coming from two treatment plants, situated in Odemira, southwest region of Portugal. The data was collected between July 2005 and May 2006. Three types of Hydrograms were constructed with this information: hour flow, daily average flow and daily maximum flow. A statistical study permitted to add a correction to some inaccurate values of flow rate, caused by some disturbing phenomena, like the formation of foam. The observation of these hydrograms showed a daily pattern in the evolution of the flow entering the treatment plant, characterized by the human activity of the served population. It was also observed a reduction of the peak flow entering each component of the treatment plant. Performing a water balance to the constructed wetland, it was possible to evaluate the high importance of the evapotranspiration (ET) in the loss of water in this part of the treatment plant, reaching, in some periods, more than 80% of the entering volume. Another objective of this work consisted in the development of a simplified mathematical model to study the hydraulic behaviour of the constructed wetland, considering parameters like the flow entering the wetland and the hydraulic conductivity of the filling medium. Constructed wetlands are treatment systems in which the flow is hydraulically controlled by downstream, in subcritical flow, which is why it can be modeled in a simplified approach using a water surface profile curve. One of the principal conclusions was that the hydraulic conductivity is an important data in the determination of the hydraulic behaviour of the constructed wetland, influencing the hydraulic retention time of the wastewater and, therefore, the treatment efficiencies.

Key words: wastewater treatment, constructed wetland, hydraulic behaviour, hydraulic mass balance, water profile.

1. INTRODUCTION

Nowadays, one of the major environmental concerns in European countries regarding water issues is the quality of water bodies, where wastewater discharges play a major role. With most of the large European cities already served by wastewater treatment plants (WWTP), the current challenge lies in small agglomerations, which often face difficulties related with shortage of material and human resources.

In the last decades some important measures as been taken to improve the wastewater treatment, like the implementation of conventional technologies, as well at the research and development of new technologies, which can be adapted to the specifications of the populations served. In Mediterranean countries like Portugal and Spain, the interior regions have a large number of small agglomerations where a significant part of the population lives. As these agglomerations are commonly scattered through the territory, decentralized solutions are usually applied because there is little or no scale economy in the implementation of centralised systems (Galvão, 2007a; Matos, 2003).

The constructed wetlands (CW) are an efficient and economically feasible technology to treat domestic wastewater of small villages (Galvão, 2007a; Kadlec, 1996). The treatment consists in the flow of the wastewater within the medium that fills de wetland, in which occurs the development of the hydrophytes plants (macrophytes), removing the pollutants presents in the water (IWA, 2000). These systems present high treatment efficiencies, mainly in the reduction of BOD_5, COD and TSS, as well as microbiological concentrations, performing biological treatment at a secondary level with low operation and maintenance needs (Wallace, 2006; Kadlec, 2003).

Evapotranspiration (ET) in constructed wetlands provides a flow reduction, which can be relevant to reduce the total pollutant load discharged to the water body. The high temperatures characteristic of summer periods in Mediterranean areas favour significant evapotranspiration rates in constructed wetlands, and zero discharge can occur at least during part of the day (Chen, 2002, Galvão 2007b).

This paper presents a new approach to constructed wetlands, focusing on horizontal subsurface flow beds. A simplified mathematical model describing flow and water level inside the bed is presented. An estimation of the evapotranspiration (ET) in two full-scale constructed wetlands will also be presented.

2. MATERIAL AND METHODS

2.1. CASE STUDY - SITE DESCRIPTION

Two full-scale wastewater treatment plant (WWTP) constructed wetlands (CW) located in Alentejo, in the south region of Portugal, have been monitored since July 2005 regarding inflow and outflow. Sampling campaigns were also performed to evaluate the efficiency of the wetlands in terms of pollutant removal.

The WWTP treats the effluents from Fataca and Malavado, two small agglomerations located 4 km apart, with design populations of 200 and 350 inhabitants, and surface area of 213 and 719 m^2, respectively. Each WWTP has a grid chamber, a septic tank and one CW. Figure 1 shows a global view of Fataca WWTP and of the ultrasound transducer associated with a V-notch weir used to measure the flow upstream the constructed wetland.

Figure 1 – Global view of Malavado WWTP and of the ultrasound transducer used to measure the flow.

Three ultrasound transducer where installed in each WWTP, measuring every five minutes the flow in three specific points: 1-Upstream the septic tank (entrance of the WWTP); 2-Downstream the septic tank and upstream the CW; 3-Downstream the CW (exit of the WWTP). These points are identified in this paper as F1, F2, F3 and M1, M2, M3, corresponding to Fataca and Malavado WWTP, respectively. The data obtained by the ultrasound transducer where collected and memorized in data loggers, situated inside a control box, as shown in Figure 2.

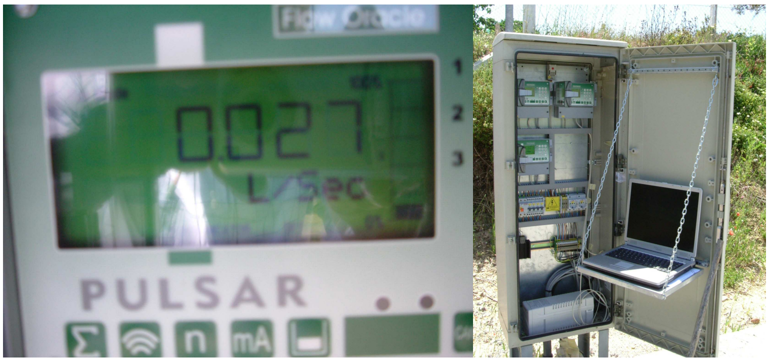

Figure 2 –Visualization of a data logger and the control box where the information is memorized.

2.2. SIMPLIFIED MATHEMATICAL MODEL TO EVALUATE THE HYDRAULIC BEHAVIOUR ON CONSTRUCTED WETLANDS

A simplified mathematical hydraulic model was developed in order to predict flow and water profile along the CW. The model considers Darcy's law for porous media (Quintela, 1998), and the boundary conditions of the outlet structure, considering parameters like the fixed flow entering the wetland and the hydraulic conductivity of the filling medium.

Constructed wetlands are treatment systems in which the flow is hydraulically controlled by downstream, in subcritical flow, which is why it can be modeled in a simplified approach using a water surface profile curve.

Precipitation, evapotranspiration and infiltration are not considered in the water budget.

3. RESULTS AND DISCUSSION

3.1. HYDROGRAMS CHARTS: REAL FLOW, DAILY AVERAGE FLOW AND DAILY PEAK FLOW

The flow readings was recorded every 5 minutes and than used to build three different types of hydrograms charts, representing the flow evolution during a certain period of time: real flow, daily average flow and daily maximum flow.
The Figure 3 represents the evolution in time of the inflow in Fataca WWTP, registered in April 2006.

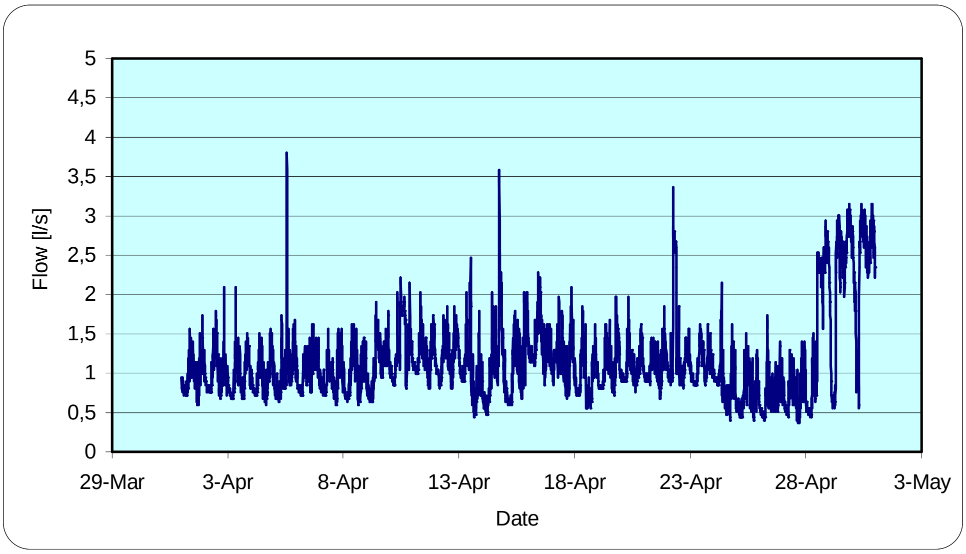

Figure 3 – Inflow of Fataca WWTP, in April 2006.

The Figure 3 shows a possible pattern on the daily inflow of the WWTP. To verify this periodic evolution on the flow entering the WWTP, the daily inflow data was analysed and showed the pattern represented in Figure 4, taking as example the 5th of April.

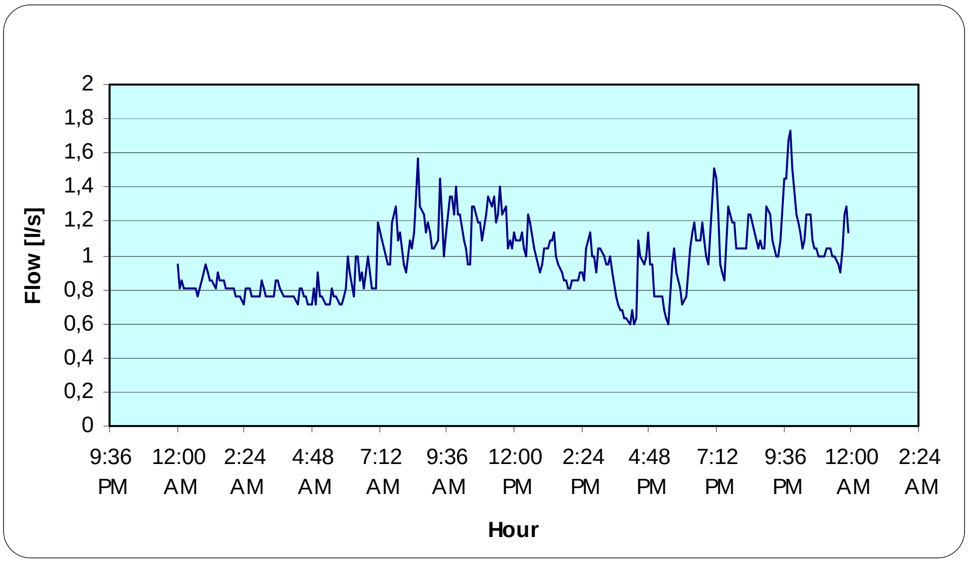

Figure 4 – Inflow at Fataca WWTP, in April 2006.

The analyses of Figure 4, permits to consider a daily pattern in the inflow of the WWTP, with minimum values of flow during the dawn and early morning (approximately from 0 a.m. and 7 a.m.) and in the afternoon (between 3 p.m. and 6 p.m.). The maximum flow values are achieved at 8.15 a.m. and 10.30 p.m.. This pattern shows a dependency between the inflow at the WWTP and the human activities that produce the wastewater. In deed, the maximum values of inflow correspond to the times when most of the population is at home and there is more consumption of water (e.g. shower use, house cooking, etc).
The Figure 5 shows the peak flow reduction between two different points (F1 and F2) of the WWTP. This peak flow reduction is due to the regulation effect of the septic tank.

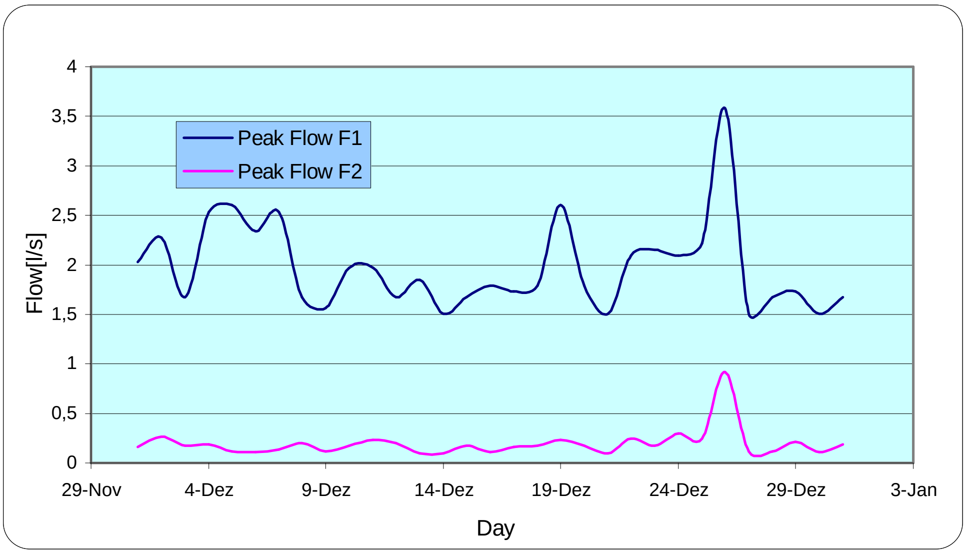

Figure 5 – Peak Flow measured in Fataca WWTP, in two different points: F1 – Upstream the septic tank; F2 – downstream the septic tank and upstream the CW.

To verify the contribution of ET on the reduction of volume in the CW, the flow data measured in two points of the WWTP was analysed. The two points corresponded to F2, situated downstream the septic tank and upstream the CW and F3, situated downstream the CW. The Figure 5 shows the evolution in time of the flow measured in those tow points of the WWTP, considering as example the period of December 2005.

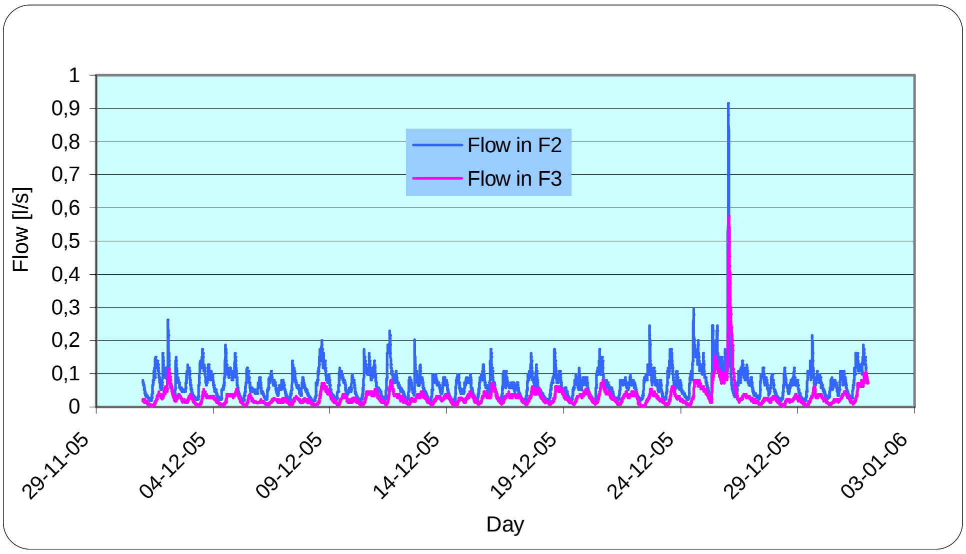

Figure 6 – Flow rate measured in Fataca WWTP, in two different points: F2 – downstream the septic tank and upstream the CW; F3 – Downstream the CW.

In Figure 5 it is easily observed that there is a reduction in the flow, and consequently in the volume of water, measured in the two different points of the WWTP. Furthermore, there is a peak reduction between the two points on the WWTP. This phenomenon explains the flow regulation that occurs in the CW. The main contribution to the reduction on the volume registered between F2 and F3 is the ET, which also contributes to the peaks reduction effect. To understand this contribution, a hydraulic and hydrological water balance was performed to both WWTP for several periods, in order to estimate the ET effect in the CW. An example for the results of the water balance, evaluated in tree distinct periods, is represented in Table 1.

Period of time	WWTP of Fataca				
	Volume F2 (L)	Volume F3 (L)	ET* (L)	ET* (L/day)	%Vol.F2
1-09-05 a 7-09-05	3,68E+04	3,47E+04	2,08E+03	2,97E+02	6%
24-09-05 a 30-0905	2,52E+04	1,79E+04	7,28E+03	1,04E+03	29%
1-10-05 a 7-10-05	4,25E+04	7,19E+03	3,53E+04	5,05E+03	83%
Period of time	**WWTP of Malavado**				
	Volume M2 (L)	Volume M3 (L)	ET* (L)	ET* (L/day)	% Vol.M2
1-09-05 a 7-09-05	8,52E+04	2,70E+04	5,82E+04	8,31E+03	68%
24-09-05 a 30-0905	7,54E+04	2,30E+04	5,24E+04	7,49E+03	70%
1-10-05 a 7-10-05	7,26E+04	2,65E+04	4,61E+04	6,58E+03	64%

Table 1 – Water balance results in Fataca and Malavado WWTP, evaluated on tree different periods.

In terms of water volume, the maximum evaporation occurred, considering the evaluation period, between 1st and 7th October, for Fataca WWTP, with 83% of inflow volume evaporation. In Malavado WWTP, a maximum of 68% of inflow volume evaporation was measured between the 1st and the 7th of September. This result shows the important contribution of ET effect on the reduction of water that enters the CW. In fact, in some cases, in extreme weather conditions (warm and dry), the outflow volume of the CW can approach zero.

3.2. DATA ANALYSIS FROM A SIMPLIFIED MATHEMATICAL MODEL

Using a simplified mathematical model and entering the parametric values like the inflow, the slope of the CW, the hydraulic saturated conductivity (HSC) and the cross area, it was possible to evaluate the water profile in the CW. The Figure 7 shows an example of a water profile resultant on the use of this simplified mathematical model.

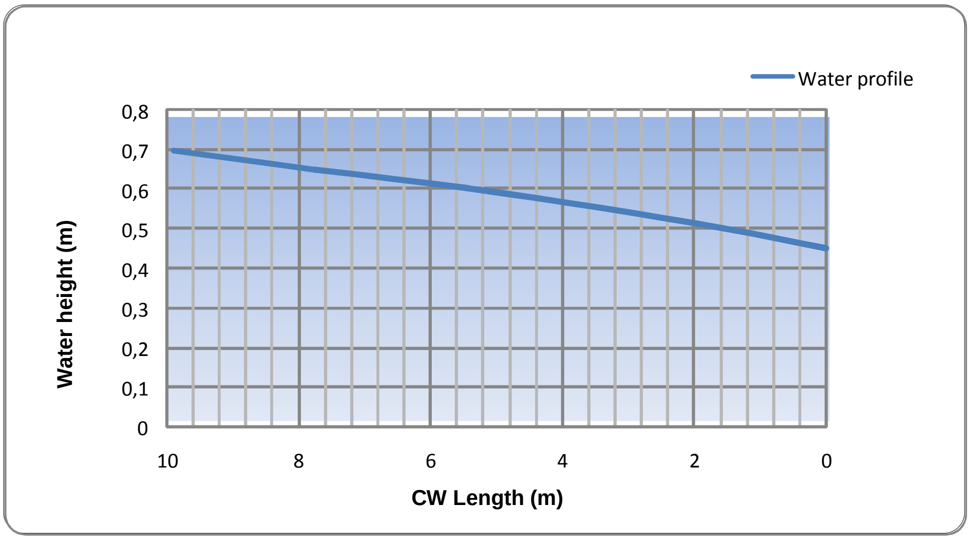

Figure 7 – Water profile obtained by using the simplified mathematical model.

A detailed study of the hydraulic behaviour of the CW can be made by changing some of the parametric values and verifying how it affects the water profile. In result of some of those studies, a conclusion was made that one of the most important parametric value in the evolution of the water profile is the HSC. In fact, a low HSC leads to a quick saturation of the filing mean by the wastewater, resulting in superficial overland flow, reducing the treatment efficiency. On the other hand, high values of HSC may lead to higher velocities, reducing the retention time and, consequently, the treatment efficiency.

4. CONCLUSIONS

The development of this work resulted in some conclusions:

a) The existence of a pattern on the daily inflow at the WWTP, directly dependent on the human activities of the populations served and, consequently, on the water consumptions. Two distinct periods were observed: a period with the minimum values of flow, at dawn and in the afternoon; and a period with the maximum values of flow, registered in the morning and in the evening.

b) The significant reduction of the peak flow entering each component of the WWTP. In some cases, these reductions correspond to 10 times the inflow peaks.

c) The statistical treatment of data provided by the ultrasound transducer, provided a simple and efficient way to verify the coherence in the values obtained and the elimination of some inaccurate values of flow rate, caused by some disturbing phenomena, like the formation of foam.

d) Performing a water balance to the constructed wetland, it was possible to evaluate the high importance of the evapotranspiration in the loss of water in this part of the treatment plant, reaching, in some periods, more than 80% of the entering volume.

e) Constructed wetlands are treatment systems in which the flow is hydraulically controlled by downstream, in subcritical flow.

f) The hydraulic conductivity is an important data in the determination of the hydraulic behaviour of the constructed wetland, influencing the hydraulic retention time of the wastewater.

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