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SIMPLIFIED SANITATION SYSTEMS

INTEGRATED APROACH

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ABSTRACT

The following dissertation addresses the behaviour of wastewater budgets in small agglomerations and the effect flow variations induces into the hydraulics of wastewater treatment plants (WWTP) constituted by one septic tank followed by a constructed wetland.

The data considered in this work regards flow records coming from a small community, relative to the entrance to a septic tank. Flows were collected during an extensive field study, between July 2nd and December 17th of 2007.

From the WWTP inflow records, a characteristic curve of the flow evolution along the day was developed. The goal of this study was to describe the behaviour of flows coming from a small agglomeration, with about 40 permanently inhabitants.

With the purpose of understanding the response of a septic tank, a simulation program was developed that reflects the hydraulics involved on water balances.

A case study was also developed, regarding the application of the simulation programs to the septic tank monitored in the field study, and a comparative study was performed. The simulation results were subsequently used to model the constructed wetland outflow, using an existing program, in order to achieve integrated modelling of the WWTP hydraulic behaviour (septic tank and constructed wetland).

The analysis of the WWTP inflow data to the treatment plant enabled to identify relevant facts and confirm information available in the literature, while relatively to the developed model it can be considered useful, taking into account the results obtained.

Key-words: mathematical modelling; septic tank; small agglomerations sanitation; wastewater flows.

1. INTRODUCTION

The main problems associated with the sanitation of small agglomerations in Portugal are mainly due to its characteristic geographical dispersion. This geographical condition favours the development of decentralized treatment plants, which do not present an economy of scale as large systems do.

In this context, the treatment schemes composed by a septic tank followed by a constructed wetland can be considered a good option as a sustainable solution to treat wastewater from small populations, being an alternative with similar construction costs or even lower when compared to the traditional options, like activated sludge or trickling filters. It also has the advantage of presenting reduced operation and maintenance needs.

2. CHARACTERIZATION OF THE MONITORIZED TREATMENT PLANT

The WWTP that was monitored in the present study is composed by a septic tank followed by a constructed wetland, and serves the population of Fataca. This small village is situated in the Alentejo, approximately 4 kilometres from Odemira. Nowadays this treatment plant serves a population that varies between about 80 people during the summer and 40 residents during the rest of the year.

This wastewater treatment plant was designed to serve a population of 200 habitants. The treatment scheme of the plant includes a grid chamber, followed by a septic tank and finally a constructed wetland. Figure 1 presents a view of the treatment plant of Fataca.

Figure 1 – Fataca's wastewater treatment plant.

3. RESIDUAL WATER FLOWS

On Fataca treatment plant the continuous measurement of flows is achieved through ultrasonic level measurers, associated with a weir with a known discharge curve. The measures of level occur on 3 sections of the WWTP: on the septic tank entry (section 1) and exit (section 2) and in the outlet of the constructed wetland as well (discharge from the constructed wetland).

Levels in each section are stored in dataloggers, every 5 minutes, and the corresponding flows were analyzed from July 2nd to December 17th The flows data analyzed are dated from July 2th to December 17th of 2007.

The weir discharge curves for section 2 and section 3 were determined experimentally (Galvão, 2008).

3.1 DETERMINATION OF THE WEIR DISCHARGE CURVE OF SECTION 1

In order to determine the weir discharge curve of section 1 there were made several measures of flows crossing it and the correspondent water height above the weir crest. Figure 2 presents the weir installed in section 1, which is rectangular with 10 cm wide.

Figure 2 – Section 1 discharge of Fataca WWTP.

After the measurement an adjustment was made to the general form of a weir discharge curve (1) to determine the adimensional parameters a e b.

$$Q = a \times h^{b} \quad (1)$$

Q - Flow [l/s];

h - Water height above the weir crest [mm].

The measured flows and respective water heights, as the correspondent adjustment to equation (1), are displayed on Figure 3.

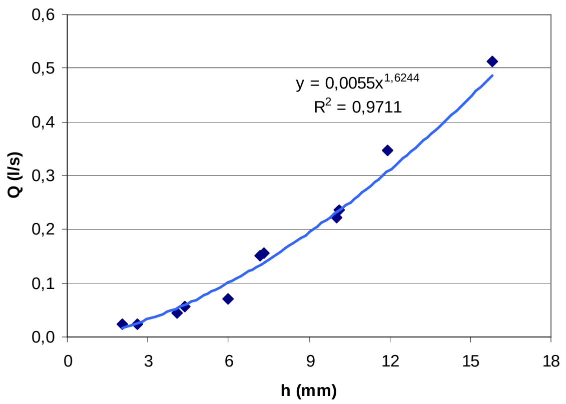

Figure 3 – Adjustment of flows and height values in section 1 to a weir discharge curve.

The adimensional coefficients a e b obtained are, respectively, of 0,0055 and 1,6244, and so the weir discharge curve for section 1 obtained is presented by equation (2).

$$Q = 0{,}0055 \times h^{1{,}6244} \quad (2)$$

3.2 MONTHLY FLOW RECORDS

Section 1 of Fataca WWTP, located at the septic tank entrance, is where the incoming effluent from the population is first measured, so those values of flows express the typical variation of the residual water affluence of the village in study.

According to the municipality, the sewage system that transports the residual water from Fataca to the WWTP is separate, meaning that the affluent wastewater is only from domestic origin. However it is possible that the system also collects stormwater, mainly during high precipitation events.

Table 1 presents a summary of the incoming average, maximum and minimum flows to Fataca WWTP for all the records analysed as well for each month separetely.

Table 1 –Average, maximum and minimum monthly flows from July to December and for the whole period.

Month	$Q_{average}$	Q_{max}	Q_{min}
July	0,1208	1,4336	0,0000
August	0,1150	0,6584	0,0000
September	0,0923	1,4167	0,0000
October	0,0786	0,6584	0,0000
November	0,0928	2,2842	0,0056
December	0,0928	1,0137	0,0056
July-December	0,1021	2,2842	0,0000

We can see that the highest flows happens during the summer months, probably due to the presence of additional population in Fataca during the summer season.

Because of the high variation of flows durind the day, which is typical of wastewater systems, the average hourly flows were calculated, in order to analyse the daily pattern of the incoming flows.

The results obtained are represented in Figure 4, including the flow data of all the records.

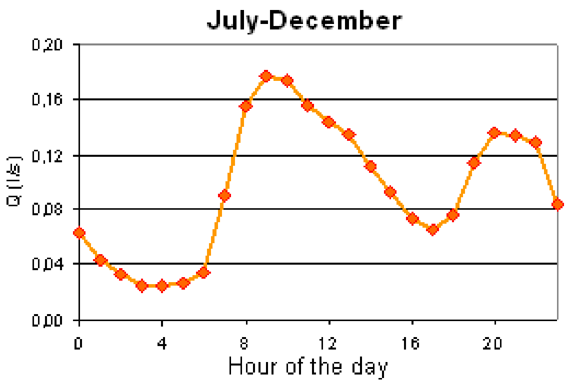

Figure 4 – Typical variation of Fataca's WWTP incoming flow along the day (hourly averages from July to mid December of 2007).

It can be seen that the behaviour of the wastewater flows that arrive to Fataca's WWTP shows a strong increase beginning at about 4:00 and ending around 9:00, having then a slow decrease until 13:00. This behaviour agrees with the time of the day when people usually do the morning hygiene and cook important meals. During the afternoon flow continues to show a decrease until 17:00, and after it rises again to once more stabilize around 20:00, which is again logical due to people arriving home and cooking another large meal (dinner). After 22:00 the flow decreases again, remaining low until the next day when it retakes the variation described before since 4:00.

In order to describe mathematically daily flows an adjustment was made of the hourly averages, which presented a sinusoidal variation, to a Fourier series with sines and cosines of degree 4. The approximation obtained with the Fourier series is presented on Figure 5.

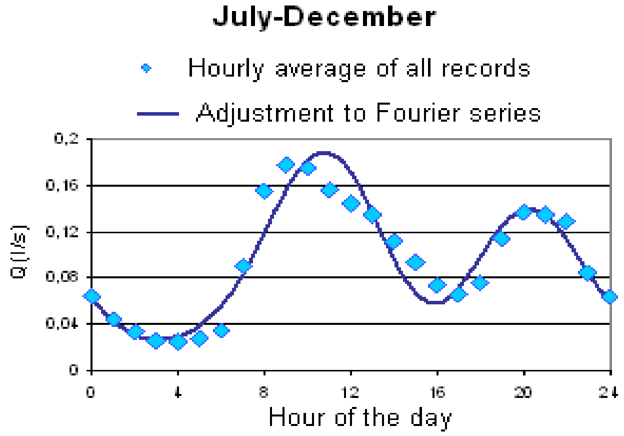

Figure 5 – Fourier series adjustment to average hourly flows.

The Fourier series of degree 4 that adjust the hourly averages of the flows along a day is described by equation (3).

$$
\begin{aligned}
y(x) &= 0{,}09616 + 0{,}03787\times\cos(x\times 0{,}2638) + 0{,}01417\times\sin(x\times 0{,}2638) + 0{,}022\times\cos(2\times x\times 0{,}2638) + \\
&+ 0{,}04795\times\sin(2\times x\times 0{,}2638) + 0{,}00254\times\cos(3\times x\times w) - 0{,}0006359\times\sin(3\times x\times 0{,}2638) + \\
&+ 0{,}01471\times\cos(4\times x\times 0{,}2638) + 0{,}00447\times\sin(4\times x\times 0{,}2638)
\end{aligned} \tag{3}
$$

The quality parameters for this approximation are shown on Table 2.

Table 2 – Quality parameters of Fourier series adjustment for all the hourly flow averages for all period of records.

R^2	$R^2_{adjusted}$	*SSE*	*RMSE*
0,9883	0,9812	0,00068	0,0067

These parameters express the quality of the approximation of the Fourier curve to the average hourly flows data. The adjustment is better as R^2 and $R^2_{adjusted}$ are closer to 1 and as ***SSE*** and ***RMSE*** are near 0. As we can see the values of the quality parameters of the adjustment indicate that the approximation of the Fourier series is quite good.

3.3 SEPTIC TANK FLOWS BALANCE

The balances of the septic tank inflows and outflows were calculated in order to understand its characteristics. The results are presented on Table 3.

Table 3- Fataca's septic tank Inflow volumes (section 1), outflow volumes (section 2) and volume balance to all months and all study time.

Month	*Afluent volume (l)*	*Efluent volume (l)*	*Volume balance (l)*
July	239592	211499	28094
August	293101	244677	48424
September	56601	59978	-3377
October	148495	117090	31405
November	240954	186182	54773
December	128726	81312	47413
July-December	1107470	900737	206733

The balance means that the wastewater passing through section 2 is less than the wastewater that is entering the septic tank in section 1, and that shouldn't happen. The probable explanation for that behaviour is that the septic tank loses water by infiltration due to internal fissures.

3.4 MAXIMUM DAY FLOW

The maximum day flow in a given period was considered as the average of the highest daily flows. However, it is important to have in account the contribution of precipitation and infiltration on the measured flow in the entry of Fataca WWTP septic tank. Precipitation was taken into account by calculating the average of the highest daily flows excluding the days when it rained more than 5 mm. On the other hand, the water component coming from the infiltration can be taken in account by subtracting from the average maximum daily flows the average minimum flows of the same day. The maximum day flow without both components of precipitation and infiltration can be determined by conjugating the two calculation methods and is considered to be the domestic maximum day flow. On Table 4 are the results of the maximum day flows considering all recorded values and for each month of the studied period with all wastewater components, without the contribution of precipitation, without the infiltration water and also with neither of the two contributions.

Table 4 – Fataca's maximum day flows to different flow considerations.

	$Q_{maximum\ day}$(l/s)			
Month	*With all residual water componets*	*Without pluvial component*	*Without Infiltration component*	*Without precipitation and infiltration components*
July	0,5007	0,4880	0,4938	0,4809
August	0,5344	0,5344	0,5212	0,5212
September	0,6209	0,5207	0,6105	0,5115
October	0,3944	0,4057	0,3888	0,4001
November	0,6633	0,4648	0,6560	0,4584
December	0,5529	0,5529	0,5444	0,5444
July-December	0,5414	0,4920	0,5328	0,4835

By observing the results it can be seen that the contribution of infiltration is present on all months, while the stormwater component isn't relevant in August and September. However, from a global point of view, the precipitation induces a higher increase on the maximum day flows than infiltration.

Equation (4) presents the relation between the maximum day flow and the average day flow (Sousa e Monteiro, 2007). According to the regulation Decree mº 23/95 from the Portuguese law, the daily peak factor can be estimated through equation (5).

$$Q_{\max imum\_day} = Q_{domestic\_average} \times fp \quad (4)$$

$$fp = 1{,}5 + (60 / \sqrt{Pop}) \quad (5)$$

$Q_{\max imum\_day}$ - Maximum day flow (l/day);

fp - Daily peak factor (-);

$Q_{domestic\_average}$ - Domestic flow average [l/(day)].

The values for the domestic maximum day values calculated from equation (4), with the domestic average flows of Fataca for the considered period, are presented on Table 5.

Table 5 – Fataca's daily peak factors without infiltration and precipitation contributions.

Month	f_p
July	5,51
August	4,94
September	6,49
October	5,80
November	6,04
December	6,66
July-December	5,69

It can be seen that for the daily peak day factors are almost steady and present the values from around 5 to 7. The lowest value is in August, when probably the population is higher, and the lowest is in December, because the population is lower.

The daily peak factors calculated with equation (5) for 40 to 80 habitants are presented on Table 6.

Table 6 –Daily peak factors according to article 125º of Regulation Decree nº 23/95 from the Portuguese law.

Inhabitants	f_p
40	10,99
45	10,44
50	9,99
55	9,59
60	9,25
65	8,94
70	8,67
75	8,43
80	8,21

The comparison between Table 6 and Table 5 shows that equation (5) overestimates the daily peak factors for small populations like Fataca.

4. WWTP'S FLOW SIMULATION

The hydraulic modelling of the WWTP was made in two steps, fist on the septic tank and after on the constructed wetland. To express the efficiency of the simulations were calculated quality factors, being them the volume balance, equation (6), and the proximity function, equation (7). The closer these parameters are to zero, the better approximation is.

$$B_{volume} = \sum_{t_{initial}}^{t_{final}} (Q_{out}^{simulated}(t) - Q_{out}^{real}(t)) \times \Delta t \qquad (6)$$

$$F_{proximity} = \frac{\sum_{t_{initial}}^{t_{final}} (Q_{out}^{simulated}(t) - Q_{out}^{real}(t))^2}{n^{o}\, values} \qquad (7)$$

To simulate the outflow from the septic tank, three different programs were developed. One of the programs is called SeptaVB and models the flow based on constant regime laws and equations. The second one is called SepCVazão and uses a weir discharge curve to calculate the flow that goes out of the septic tank and the last program is SepCVazãoExfil, which considers the same principles as SepCVazão but also a loss of water inside the septic tank due to infiltrations caused by fissures on the walls. Table 7 presents the quality parameters for the septic tank simulations with the three models.

Table 7 – Quality parameters for the septic tank simulations for all months of the studied period.

Month	***Models***	***Proximity function***	***Volume balance (l)***
July	*SeptaVB*	0,001278	29068,96
	SepCVazão	0,000879	28424,55
	SepCVazãoExfil	0,000664	-22342,48
August	*SeptaVB*	0,001931	48095,03
	SepCVazão	0,001466	47638,40
	SepCVazãoExfil	0,000891	-6487,44
October	*SeptaVB*	0,001097	31712,13
	SepCVazão	0,000823	31175,84
	SepCVazãoExfil	0,000421	-4937,09
November	*SeptaVB*	0,002039	54454,24
	SepCVazão	0,002048	54119,52
	SepCVazãoExfil	0,001398	4382,60
December	*SeptaVB*	0,004451	47547,35
	SepCVazão	0,004099	47028,03
	SepCVazãoExfil	0,002647	19793,26

The program which gives simulated flows closer to the real ones is SepCVazãoExfil, which was expected because it was designed to Fataca's septic tank losses of water by exfiltration. The programs SeptaVB and SepCVazão have very similar parameters, yet the second one denotes better results. The worst results for the both quality parameters are in November and December.

As an example, Figure 6 presents the simulated values for the month of July, as well as the measured flows.

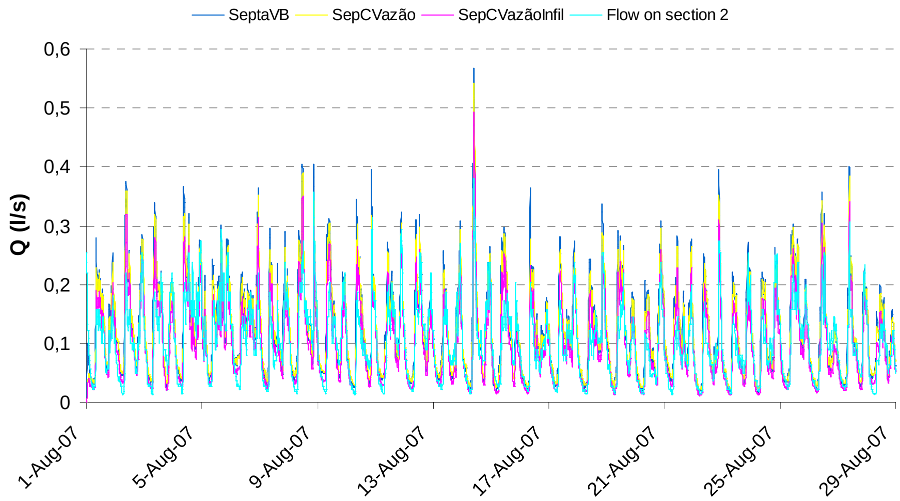

Figure 6 – Hydraulic modelling and measured outflow of Fataca's WWTP septic tank in August of 2007.

The modelling of hydraulic behaviour of the constructed wetland was made with the program MIZHuC (Galvão, 2008) and were used four different flow inputs: the flow that were measured at the outflow of the septic tank (and entering the constructed wetland) and the ones that were given by the three septic tank simulators. The results of the quality parameters of the modelling are exposed on Table 8.

Table 8 – Quality parameters of the constructed wetland hydraulic simulations with several origins of the input data.

Month	***Input data origin***	***Proximity function***	***Volume balance (m^3)***
July	*SeptaVB*	8,6968E-10	26,91
	SepCVazão	8,9523E-10	26,38
	SepCVazãoExfil	8,5444E-10	-23,20
	Measured septic tank outflow	7,2037E-10	-2,52
August	*SeptaVB*	8,1771E-10	44,34
	SepCVazão	8,3500E-10	43,65
	SepCVazãoExfil	4,3117E-10	-9,29
	Measured septic tank outflow	3,0922E-10	-3,06
October	*SeptaVB*	2,7087E-10	19,02
	SepCVazão	2,6960E-10	18,51
	SepCVazãoExfil	2,0115E-10	-16,61
	Measured septic tank outflow	1,2637E-10	-11,05
November	*SeptaVB*	4,6905E-07	-98,33
	SepCVazão	4,6921E-07	-98,66
	SepCVazãoExfil	4,7242E-07	-147,58
	Measured septic tank outflow	4,6997E-07	-152,11
December	*SeptaVB*	2,7830E-09	49,98
	SepCVazão	2,7769E-09	49,58
	SepCVazãoExfil	1,5238E-09	23,07
	Measured septic tank outflow	1,1726E-10	2,86

As it was to expect the simulations where the input were the flow values measured at the exit of the septic tank have the closest to 0 quality parameters and so are the best ones. Relatively to the rest of the simulations, as the values that are coming from the program SepCVazãoExfil are the closest to the measured at the septic tank's exit, is this one that presents the best results.

The simulated values and the measured flows to the month of August are represented on Figure 7, as an example.

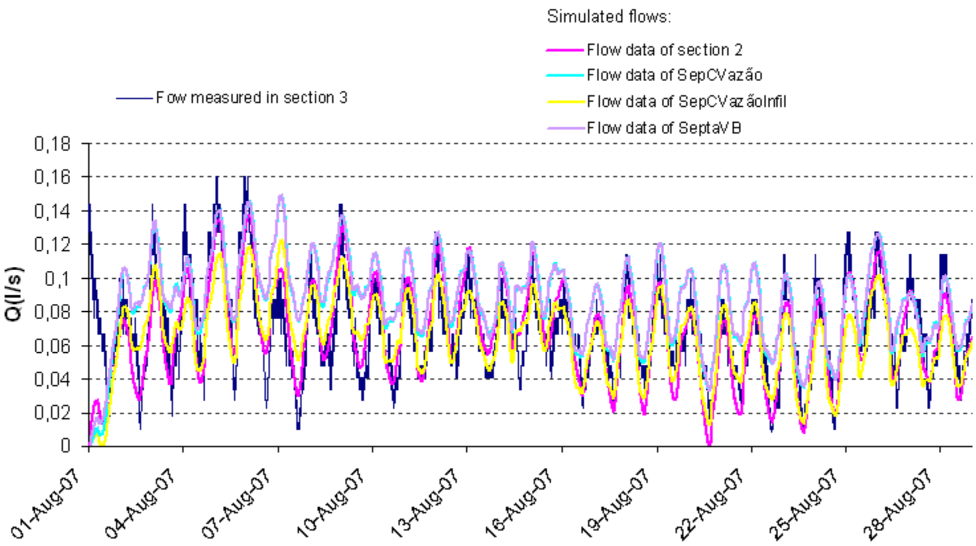

Figure 7 – Hydraulic modelling and measured outflow of Fataca's WWTP constructed wetland in August of 2007.

5. CONCLUSIONS

The population from Fataca has a wastewater flow which agrees with the usual habits of a common population.

The use of Fourier series to make an adjustment to the hourly flow averages of all the records is quite a good approximation to those values.

In what concerns daily peak factors, the values from the regulation decree formula are much higher than those calculated with the measured flows, which allows concluding that the equation is not adequate to calculate peak factors for small populations.

The development of a program named SepCVazãoExfil showed good results for the simulation of the outflows from the septic tank. This could be observed through the calculation of quality parameters like a proximity factor and a volume balance. The months that showed lower approximations were November and December, but the reasons are external to the programs.

The results obtained from the integrated simulation of the septic tank and the constructed wetland showed that the programs are, in general, adequate to model the hydraulic behaviour of this treatment scheme.

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