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Rehabilitation of the Alcântara Sewage Treatment Plant – Effect of the design capacity on CSO discharges

Réhabilitation de la station d'épuration d'Alcântara (Portugal) - effets de la capacité retenue pour le dimensionnement sur les rejets aux déversoirs d'orage

Luís Mesquita David*, Maria do Céu Almeida*, Maria Adriana Cardoso*, Conceição David**

* Laboratório Nacional de Engenharia Civil (LNEC DHA/NES).
Av. do Brasil 101, 1700-066 Lisboa, PORTUGAL (ldavid@lnec.pt)
** SimTejo - Saneamento Integrado dos Municípios do Tejo e Trancão SA,
Av. Defensores de Chaves 45, 1000-112 Lisboa, PORTUGAL

RÉSUMÉ

Le projet de réhabilitation de la station d'épuration d'Alcântara consiste à élaborer un système de décantation physicochimique pour traiter les écoulements des eaux pluviales et de ruissellement. L'évaluation des rejets urbains de temps de pluie a été effectuée pour différentes capacités de traitement avec un modèle simplifié pour simuler une série historique de précipitations. Le bassin versant d'Alcântara, le plus grand de Lisbonne, a été conceptualisé par deux sous-bassins en parallèle, l'un pour simuler la réponse rapide et l'autre la réponse plus lente du bassin. La période de surveillance n'a pas été suffisamment longue pour permettre de simuler la variation du débit de base. Le modèle reproduit assez bien le comportement du débit mesuré, nonobstant sa simplicité. Dans tous les cas, les résultats doivent être analysés avec précaution, notamment à cause des incertitudes des données mesurées et de l'information insuffisante sur le débit de base. Ce modèle a permis la simulation d'une série de précipitations sur 19 ans, pour six scénarios différents. Les résultats indiquent des réductions très significatives du volume, de la fréquence et de la durée des rejets de temps de pluie avec l'augmentation de la capacité de traitement. Ces réductions sont plus prononcées pour la saison balnéaire que pour le reste de l'année, une contribution assez importante pour la protection des usages récréatifs dans l'estuaire du Tage.

ABSTRACT

Within the scope of the Alcântara STP rehabilitation project, enhanced primary treatment is being installed for the treatment of wet-weather flows. A simplified model using rainfall historical series was used to assess the CSO discharges for different treatment capacities. The Alcântara catchment, the largest of Lisbon, was represented by only two sub-catchments in parallel. One sub-catchment represents the fast component of the hydrographs, and the other simulates the slower response from the catchment causing a tail in the hydrographs. The monitoring period was not long enough to allow modelling the base flow variation. Despite its simplicity, the model reproduces with significant approximation measured hydrographs. However, its results must be analysed cautiously, mainly due to the uncertainty on the measured data and on the base flow. This model allowed the simulation of a 19 years rainfall time series for six different scenarios. Results showed significant reductions of the volume, frequency and duration of CSO discharges associated with increasing the STP capacity. Higher reductions are achieved for the bathing season compared with the rest of the year, contributing to improved conditions for the recreation uses in the Tagus estuary.

KEYWORDS

Continuous modelling, CSO control, high rate clarification, STP upgrading

1 INTRODUCTION

Intermittent discharges from combined sewer overflows (CSO) are a major source of surface water pollution in urban areas. The Council Directive 91/271/EEC – *urban waste-water treatment* requires the adoption of measures to limit pollution from CSO, which shall ensure the good ecological and chemical status of the surface waters established by the Water Framework Directive – 2000/60/CE. The Directive 2006/7/EC *concerning the management of bathing water quality* brings additional challenges for the management of stormwater discharges.

Common measures to reduce pollution from CSO discharges include the improvement of CSO structures, the construction of storage and settling tanks as well as the mobilisation of the sewer system storage capacity using real time control. Source control measures may also contribute to reduce flows and pollutant loads entering into the sewers, but their implementation is often limited by the existing urban development. More recently, important efforts have been developed to increase the sewage treatment plants (STP) capacity as well as the level of treatment, including the use of high rate clarification processes, high rate filtration and final disinfection (Averill *et al.*, 2001; Harlenam and Murcott, 2001; Parker *et al.*, 2001; Marsalek *et al.*, 2003; Szabo *et al.*, 2005). Pilot and full-scale applications of ballasted flocculation systems have shown important reductions of TSS, COD, BOD, total phosphorus and heavy metals concentrations, at high surface overflow rates (Plum *et al.*, 1998; Capodaglio, 2003; Hanner *et al.*, 2004).

Within the scope of the Alcântara STP rehabilitation project, the largest STP of Lisbon, the Actiflo® microsand ballasted flocculation technology is being installed for treatment of wet-weather flows. This paper describes a study carried out by Laboratório Nacional de Engenharia Civil (LNEC) aiming to evaluate the potential benefits on CSO discharges of treating wet-weather flows, considering three STP design capacities. The benefits were assessed in terms of frequency, volume and duration of CSO discharges. This study was based on the continuous modelling of the Alcântara catchment, using an historical rainfall series.

2 THE ALCÂNTARA STP

The Alcântara STP was built in the 1980's, serves a population of about 760 000 inhabitants from Lisbon, Amadora and Oeiras Municipalities and discharges to the Tagus estuary. It is being rehabilitated aiming to upgrade the wastewater treatment, to control and treat odours and to improve landscape integration. The STP will be totally covered by a roof garden, and the wastewater treatment will incorporate advanced technologies, namely the Multiflo® process for the primary treatment, the Biostyr® for the biological treatment and the Actiflo® process for treatment of wet-weather combined flows (Veolia, 2009a,b,c). The secondary effluent will be disinfected since the Tagus estuary has recreational uses.

The STP is located at the downstream area of the Alcântara urban catchment, which has about 3200 ha in Lisbon and Amadora Municipalities. Despite the sewer systems is separate in many upstream catchment areas, the downstream sewers and the main interceptor sewer (caneiro de Alcântara) are combined. Currently 75% of the dry-weather flow reaches the STP by gravity (through caneiro de Alcântara) and 25% is pumped from downtown areas and neighbour catchments. The current average dry-weather flow is about 1.3 m^3/s, which is expected to increase to 2.1 m^3/s in 2030, as a result of increasing pumped flows from the neighbouring catchments.

Within the scope of the STP rehabilitation project, SimTejo, the wastewater utility responsible for this system, requested LNEC to carry out a study in order to assess the potential reduction of CSO discharges by increasing the STP capacity from 3.3 m^3/s to 6.6 m^3/s, as well as to 10.0 m^3/s. The reduction should be assessed in terms of frequency, volume and duration of untreated discharges, both per year and per 5-month bathing season (May to September).

3 METHODOLOGY

3.1 General description

The methodology followed in this study consisted in building a simplified model of the Alcântara catchment using a computational program developed by David (2006). The simplified conceptual model was developed for long-term continuous simulations aiming: i) to provide statistics for each scenario either of STP hydraulic capacity or storage and treatment tanks capacity; ii) and to allow the fast batch running of a sequence of several scenarios, producing synthesis graphs in order to assess the benefits of combining different measures. The model was developed in MS Excel®, making use of Visual Basic for Applications. It has three modules: the hydrological module; the water quality module (not included in this study); and the mass balance module. The hydrological module represents the whole catchment by a reduced number of sub-catchments disposed either in series or in parallel. Initial and continue losses as well as the flow propagation may be simulated in each catchment by one of the following three methods: the linear time-area curve, the linear reservoir model and the Clark model. For each scenario, mass balances are calculated in a hypothetical storage, treatment and overflow structure located downstream (David and Matos, 2005).

The Instituto Geofísico Infante Dom Luiz historical time series with 19 years duration was used.

3.2 Rainfall and in-sewer flow measurements

A short term flow survey was carried out in the Alcântara catchment, from January to March 1996, in the scope of the European Project SPRINT SP98/2 "Hydraulic Analysis for Urban Drainage Rehabilitation", (Cardoso *et al.*, 1996, 1997). Measurement gauges included 6 raingauges, 8 flowgauges in the interceptor system “caneiro de Alcântara” and 1 tide level gauge located downstream, as illustrated in Figure 1. There was only one flowgauge located at a downstream section of the Alcântara main sewer (PM5), just upstream the STP. Given the heavy rainfall events, only one week of data was obtained for this gauge (from 20th to 27th January), since two sets of sensors were washed out by large pieces of debris during high stormwater flows. Therefore, despite having two months of flow data for other locations in several Alcântara subcatchments, the period with simultaneous data for the whole Alcântara catchment area is limited. In this period, several rain events occurred, totalizing more than 100 mm of rainfall (note that the annual average is 690 mm). The maximum rainfall intensities occurred on 23rd January.

The period preceding the flow survey was extremely rainy as well. Cumulated rainfall until 20th January from the antecedent 30, 60, and 90 days were, respectively, 380, 540 and 690 mm. For the three months previous to the survey it had rained as much as for the average year (690 mm).

Once the period of data at the Alcântara downstream monitoring section was short and rainy, the dry-weather hydrograph for the whole Alcântara catchment was estimated based on simulations using partial dry-weather hydrographs measured in the other monitoring sections, as well as on studies carried out by SimTejo,. In Figure 2, the estimated hydrograph has an average daily flow of 1.0 m^3/s and a maximum flow of 1.3 m^3/s.

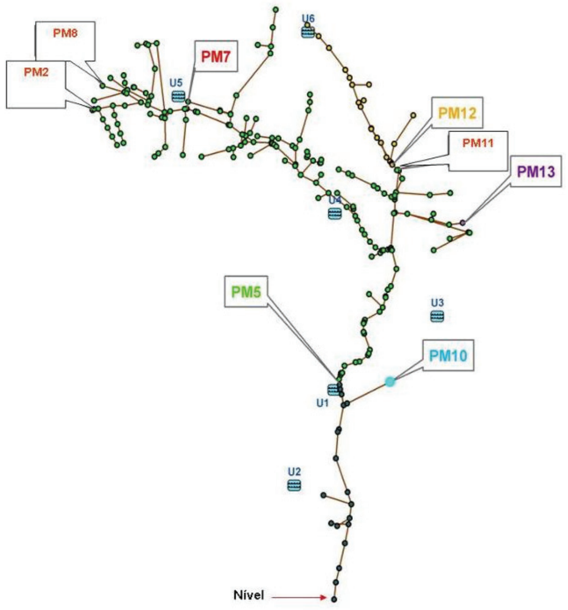

Figure 1 - Rainfall and flow measuring locations at the Alcântara catchment

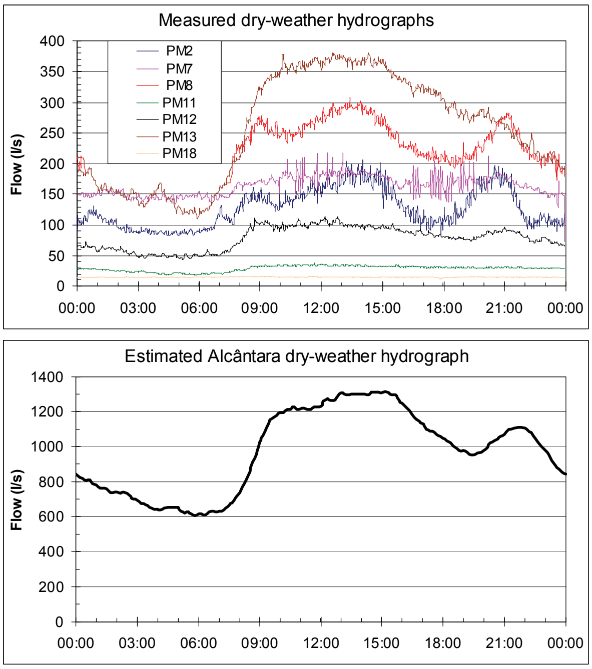

Figure 2 – Measured dry-weather flows at upstream gauges and estimated Alcântara dry-weather hydrograph at STP

3.3 Model building and calibration

The conceptual model was built and verified using the in-sewer flow at the Alcântara downstream section (PM5), measured from 20th to 27th January 1996. Simulations were run using the average rainfall series from the 6 raingauges installed within the catchment and also using the individual rainfall series, in order to evaluate the effect of the rainfall distribution in the hydrographs.

The system was simplified and modelled as two sub-catchments in parallel. One sub-catchment represents the fast component of the hydrographs, resulting from the impervious areas; the other sub-catchment simulates a slower response that causes a tail in the hydrographs, attributed to the pervious areas contribution. The dry-weather hydrograph was added to the resulting downstream hydrograph. The base flow was represented considering a constant value, because the duration of the monitored period at the Alcântara downstream section (PM5) was not long enough to allow the calibration of the conceptual model for the base flow.

In Figure 3 the monitored hydrograph is compared with the modelled results at PM5. Model parameters are presented in Table 1. The model was calibrated based on the rain events occurred in the first 4 days (upper graph in Figure 3) and was verified for the remaining events. Despite the acceptable results obtained, the linear reservoir coefficients were still slightly changed to improve these results.

Figure 3 shows that the shapes of the modelled and measured hydrographs are similar, and that the model slightly underestimates the lower flow peaks and overestimates the higher ones.

Baseflows at PM5 are significantly high, which may result from a network in poor condition allowing the affluence of high infiltration or groundwater flows. Moreover, the severe rainy period that preceded the flow survey may have contributed for soil saturation and for the high infiltration flows. Additionally, as reported by the company that carried out the survey, the measurement uncertainty at section PM5 is significantly higher than that associated to the other monitoring sections (ADS, 1996). Therefore, model calibration and results analysis must take this into consideration.

	Sub-catch 1	**Sub-catch 2**	**Base flow**
Contributing area (ha)	1600	1600	
Linear reservoir coefficient (K)	40 minutes	200 minutes	
Until 25/01/1996			7.7 m^3/s
After 25/01/1996			4.7 m^3/s

Table 1 - Model calibration parameters

Figure 4 compares the monitored and modelled cumulated volumes at PM5. Curves are presented both for the total cumulated volumes and for the event-per-event cumulated volumes. For the higher intensity events, the most significant deviations occur for the 2nd and 3rd events (see Figure 4), with relative deviations of respectively -14% and +7%, with respect to the measured flow, and of -29% e +14%, with respect the stormwater component only. For the succession of lower intensity events occurred from 25th to 28th January, the relative deviations for the entire period are close to zero (the relative deviations for each sub-event are not relevant for the analysis due to the reduced magnitude of the sub-events). For the entire range of events (from 20th to 28th January), total modelled and measured volumes are similar.

Additional simulations using rainfall data from specific raingauges (instead of the average rain from the 6 raingauges) led to improved results in specific events, confirming that some differences in the hydrographs can be explained by the spatial rainfall distribution. Some model tendency to underestimate or overestimate flow peaks may also be due to the rainfall peak attenuation that results of using average values.

These results show that the simplified model provides an appropriate reproduction of the hydrographs measured at PM5. However, sources of uncertainty have to be considered. For instance, calibration was carried out using conditions of heavy rainfall what may add a bias when simulating continuous rainfall series.

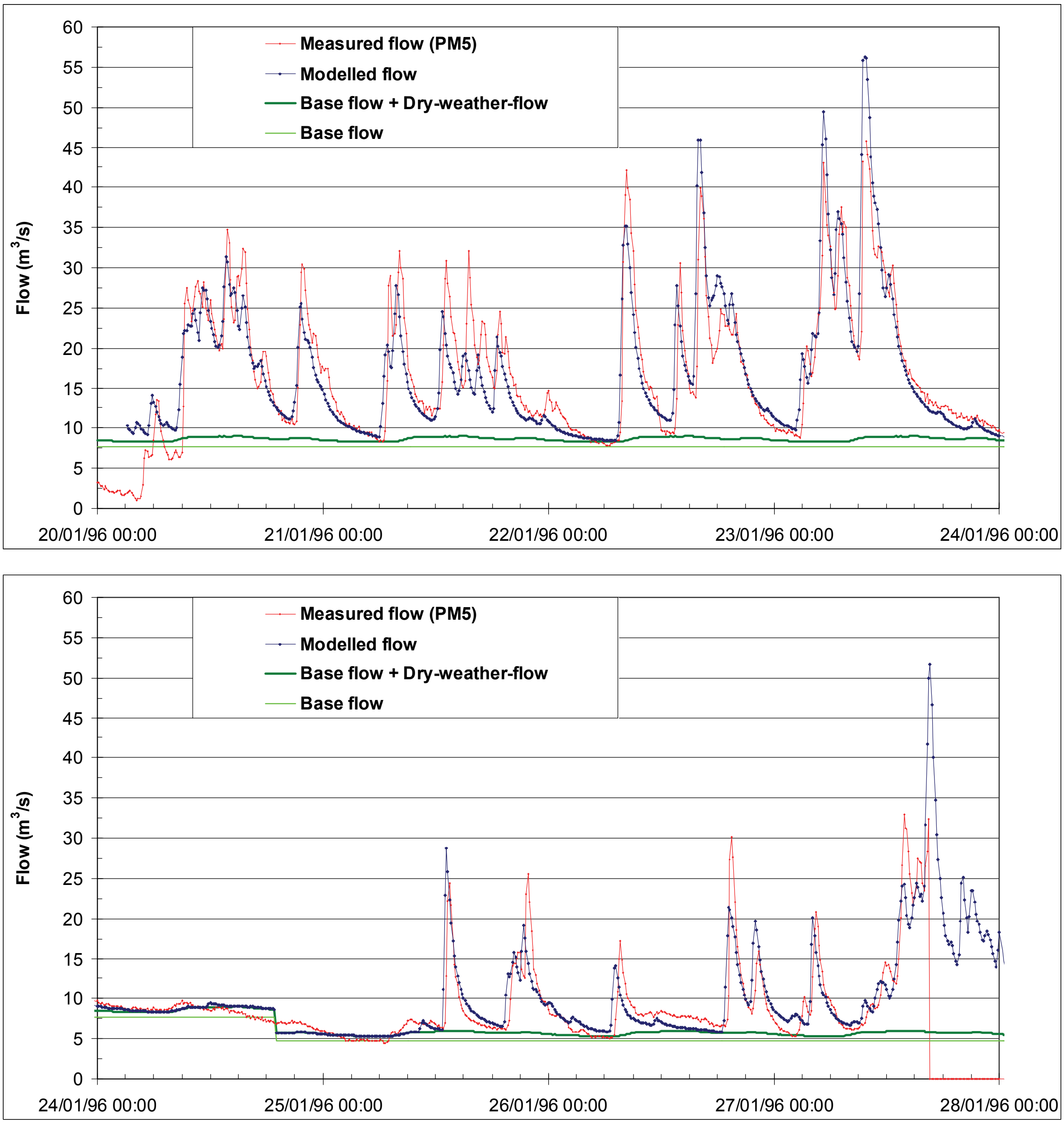

Figure 3 - Monitored and modelled hydrographs at PM5

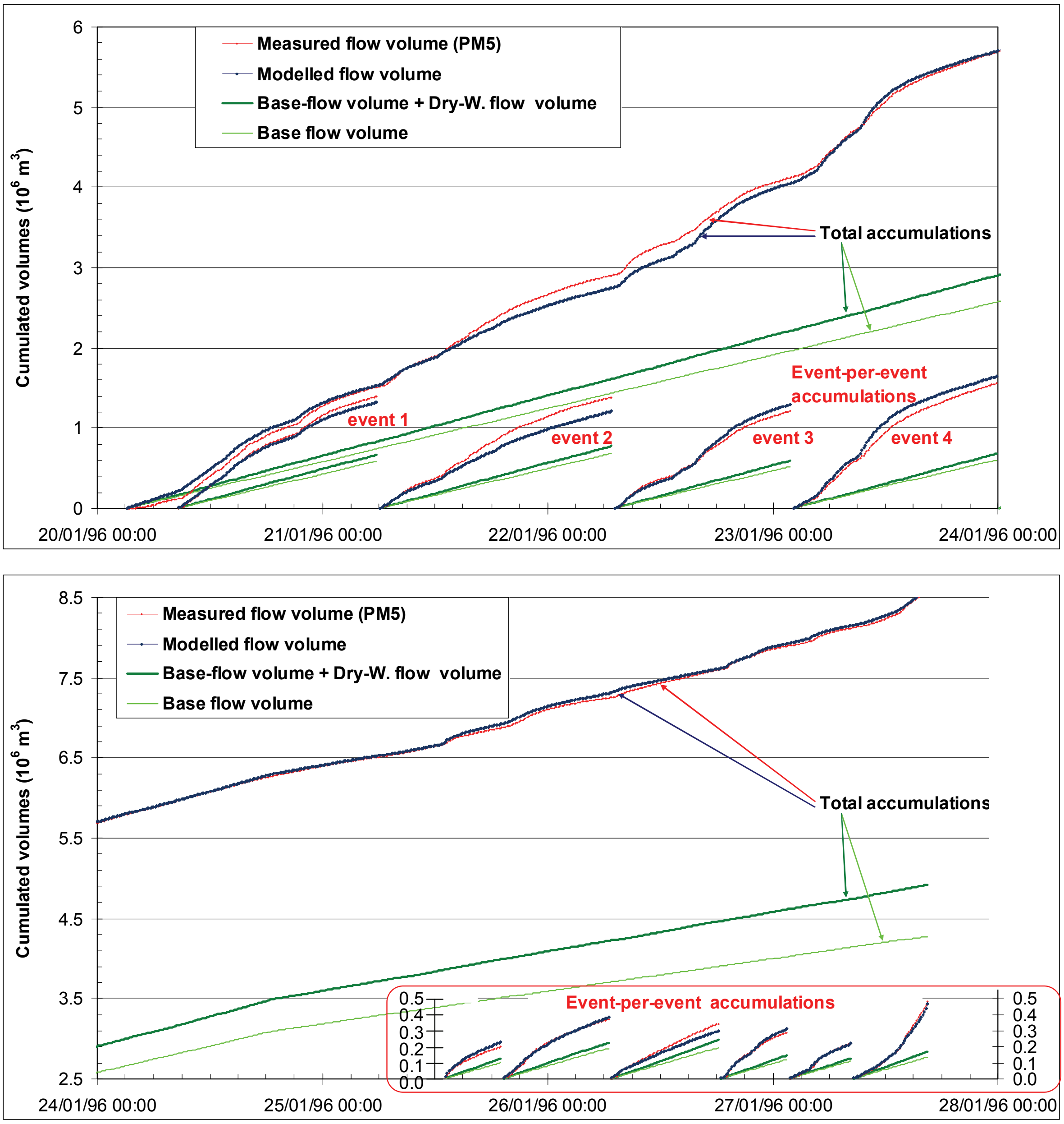

Figure 4 - Measured and modelled cumulated volumes at PM5

3.4 Long-term simulations

Long-term simulations were run using a 19-year long digitised rainfall series (1973-91), for six reference scenarios. These scenarios, defined by SimTejo, result from the combination of three STP capacities (Q_{STP} = 3.3 m^3/s; Q_{STP} = 6.6 m^3/s; and Q_{STP} = 10.0 m^3/s) with two scenarios of average dry-weather flows (Q_{DWF} = 1.5 m^3/s in year 2010, the first year of operation; and Q_{DWF} = 2.6 m^3/s in year 2030).

However, as previously discussed, model uncertainty is high due to the uncertainty of the available flow data, particularly with respect to the base flows. The variation of base flows could not be modelled, due to the lack of calibration data. Also the dry-weather flows may be significantly higher than the values considered in the reference scenarios, due to the contribution of infiltration flows. Therefore, sensitive analysis was carried out in order to evaluate the influence of Q_{STP} and of Q_{DWF}, in the three CSO discharge indicators: volume, frequency and duration.

4 RESULTS FROM LONG-TERM SIMULATIONS AND DISCUSSION

Table 2 presents for the six reference scenarios the annual and the bathing season average values of the three CSO discharge indicators (volume, frequency and duration).

As an example, for Q_{STP} = 3.3 m^3/s and Q_{DWF} = 1.5 m^3/s (dry-weather flow for the year 2010), an average volume per year of 15.6 x 10^6 m^3 is discharged without any treatment, with an accumulated duration equivalent to 26.6 days, and affecting an average of 91 days. From those discharges, 1.9 x 10^6 m^3 are discharged during the 5-month bathing season period, with an accumulated duration equivalent to 3.5 days, and affecting 16.8 days. As expected, the increase of the dry weather flow for the year 2030, will result in the increase of the three CSO discharge indicators. This is particularly significant for the duration of the discharges and for the scenario of the lowest STP capacity (Q_{STP} = 3.3 m^3/s). As can also be observed in Table 2, the increase of the STP capacity may reduce significantly the CSO discharges.

Scenario / **Discharge indicator**		**Year 2010 (Q_{DWF} = 1.5 m^3/s)**			**Year 2030 (Q_{DWF} = 2.6 m^3/s)**		
		Q_{STP} = 3.3 m^3/s	**Q_{STP} = 6.6 m^3/s**	**Q_{STP} = 10.0 m^3/s**	**Q_{STP} = 3.3 m^3/s**	**Q_{STP} = 6.6 m^3/s**	**Q_{STP} = 10.0 m^3/s**
Annual analysis	Volume (10^6 m^3)	15.6	10.4	7.4	18.7	11.8	8.2
	N. of days (days)	91	67	56	105	74	59
	Duration (days)	26.6	13.0	8.0	41.7	15.8	9.2
Bathing-season analysis (5-months)	Volume (10^6 m^3)	1.9	1.2	0.9	2.3	1.4	0.9
	N. of days (days)	16.8	11.6	8.8	20.3	12.9	9.5
	Duration (days)	3.5	1.6	0.9	5.9	1.9	1.0

Table 2 - Average CSO discharge indicators for the reference scenarios

Table 3 compares the benefits, expressed as percentage of reduction of the average values, obtained for the three indicators by increasing the STP capacity from 3.3 m^3/s to 6.6 m^3/s, from 3.3 m^3/s to 10.0 m^3/s and from 6.6 m^3/s to 10.0 m^3/s.

Scenario / **Discharge indicator**		**Year 2010 (Q_{DWF} = 1.5 m^3/s)**			**Year 2030 (Q_{DWF} = 2.6 m^3/s)**		
		Q_{STP} = 3.3 m^3/s to Q_{STP} = 6.6 m^3/s	**Q_{STP} = 3.3 m^3/s to Q_{STP} = 10.0 m^3/s**	**Q_{STP} = 6.6 m^3/s to Q_{STP} = 10.0 m^3/s**	**Q_{STP} = 3.3 m^3/s to Q_{STP} = 6.6 m^3/s**	**Q_{STP} = 3.3 m^3/s to Q_{STP} = 10.0 m^3/s**	**Q_{STP} = 6.6 m^3/s to Q_{STP} = 10.0 m^3/s**
Annual analysis	Volume (% of reduction)	33	52	29	37	56	30
	N. of days (% of reduction	26	39	18	29	44	21
	Duration (% of reduction)	51	70	38	62	78	42
Bathing-season analysis	Volume (% of reduction)	35	54	29	40	59	31
	N. of days (% of reduction	31	47	24	36	53	26
	Duration (% of reduction)	55	74	42	67	82	46

Table 3 - Benefits achieved by increasing the treatment plant capacity

Increasing the STP capacity from 3.3 m^3/s to 6.6 m^3/s results in important benefits regarding the reduction of the three discharge indicators, for Q_{DWF} = 1.5 m^3/s (33% for volume, 26% for frequency and 51% for accumulated duration). The benefits are even more evident for the bathing season analysis than for the annual analysis as well as for Q_{DWF} = 2.6 m^3/s than for Q_{DWF} = 1.5 m^3/s. Despite the benefits obtained by increasing the STP capacity, they become less pronounced for the higher values of STP capacity. Even though, enlarging the STP capacity to 10.0 m^3/s still allow significant benefits.

Results presented in Table 2 and in Table 3 correspond to specific scenarios associated with the STP capacity (Q_{STP}) and to the average dry-weather flow (Q_{DWF}). One should emphasize, as previously discussed, that model uncertainty is high due to the uncertainty of the available flow data, particularly with respect to the base flows. Also dry-weather flows may differ significantly from the values considered in the previous simulations, due to variations in the contribution of infiltration flows.

Therefore, aiming to extend the analysis to other STP capacity (Q_{STP}) values or, indirectly, to other dry-weather flow (Q_{DWF}) values, Figure 5 shows the variation of the average annual values of the three CSO indicators as a function of the STP capacity. STP capacities are represented in the x-axis, the average annual values for the discharged volumes and duration are in the principal y-axis, and the average values for the number of spilling days are in the secondary y-axis. This graph was established considering Q_{DWF} = 1.50 m^3/s. The average indicators for the STP capacities of 3.3 m^3/s, 6.6 m^3/s and 10.0 m^3/s are pointed out in Figure 5.

Assuming that an increase of the average dry-weather flow corresponds to an equivalent reduction of the STP capacity, average indicators for values of Q_{DWF} other than 1.50 m^3/s may also be obtained from Figure 5. For example, for the year 2030 it is expected that the dry-weather flow increases to 2.6 m^3/s, which is a value 1.1 m^3/s higher than 1.50 m^3/s. Therefore, the average indicators for a dry-weather flow of 2.6 m^3/s and STP capacities of 3.3 m^3/s, 6.6 m^3/s and 10.0 m^3/s correspond to the average indicators for a dry-weather flow of 1.5 m^3/s and STP capacities of 2.2 m^3/s, 5.5 m^3/s and 8.9 m^3/s, respectively (2.2 = 3.3 – 1.1 m^3/s, 5.5 = 6.6 – 1.1 m^3/s and 8.9 = 10.0 – 1.1 m^3/s).

Therefore, graph presented in Figure 5 provides a sensitive analysis of the influence in the three CSO indicators not only for Q_{STP} but also for Q_{DWF}.

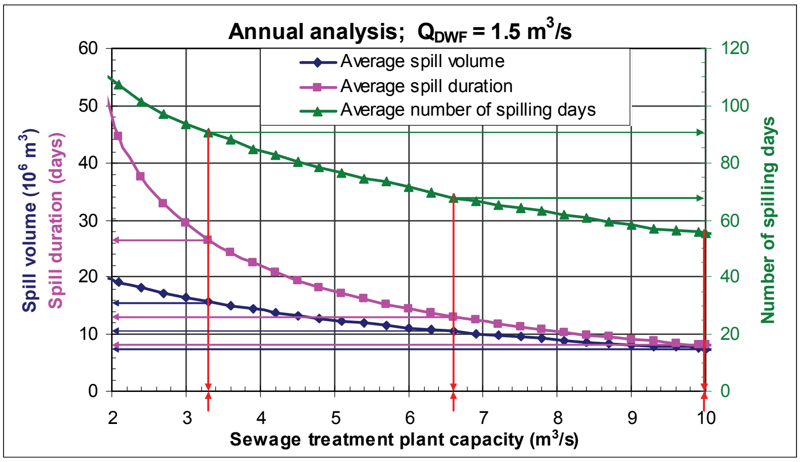

Figure 5 - Variation of the average annual values for the three CSO discharge indicators for Q_{DWF} = 1.5 m^3/s

5 CONCLUSIONS

The Alcântara catchment was modelled using a conceptual model and represented by only two sub-catchments in parallel. One catchment represents the fast component of the hydrographs, and the other simulates a slower response from the catchment causing a tail in the hydrographs. The monitoring period was not long enough to allow modelling the base flow variation. Despite its simplicity, the model reproduces with significant approximation measured hydrographs. However, its results must be analysed cautiously, mainly due to the uncertainty on the measured data and on the base flow. This model allowed simulating a rainfall time series of 19 years duration for six different scenarios.

The results show significant reductions on the volume, frequency and duration of CSO discharges when increasing the STP capacity for the designated values. Higher reductions are achieved for the bathing season compared with the rest of the year, contributing to improved conditions for the recreation uses in the Tagus estuary. Discharge reductions are also important due to the occurrence of high base flows, which is a relevant source of uncertainty.

This study allowed quantifying and assessing the expected benefits on CSO discharge, for different scenarios considered in the rehabilitation of the Alcântara STP, regarding its design capacity.

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