Calibration and validation of a SWMM applied to *Caneiro de Alcântara* in Lisbon

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ABSTRACT

In 2005 SIMTEJO, the company responsible for the integrated sanitation of municipalities belonging to Tejo and Trancão basins (Lisbon, Portugal), in the framework of the Alcântara Waste Water Treatment Plant expansion project, implemented a partial model in Alcântara sub-basin on the software SWMM - Storm Water Management Model. SIMTEJO intends to have a decision support-tool on predicting volumes of waste water to treat during wet weather and corresponding discharges on the receiving environment. SWMM simulates hydrologic processes under unsteady conditions. The recent implementation of a real time flow measuring system upstream WWTPA, associated to two real time acquisition rain gauges, allowed a proper calibration of hydrological processes and subsequent validation of the mathematical model. Herein results of this calibration and validation process applied specifically to *Caneiro de Alcântara*, a critical section of Lisbon drainage system comprised by a closed conduit concentrating the flow drained over a 2717 ha basin, are shown and discussed. Calibration was made by using two flood events while validation was made using one event. Generally, errors on the prediction of total flow volume of flood events are within 10% to 20% whereas errors on the prediction of peak discharges are within 15% to 25%. The mathematical model applied to *Caneiro de Alcântara* is thus considered reliable and constitutes a useful management model at the service of SIMTEJO, allowing discharges prediction during extreme precipitation periods at critical sections. A continuous updating calibration procedure is envisaged in order to reduce errors while cumulative data is being gathered.

KEY WORDS: *SWMM, Calibration and Validation, Flood Prediction, Urban Drainage.*

INTRODUCTION

Mathematical models are essential tools for basin management to simulate processes of rainfall-runoff transformation (Chow *et al*., 1988). These models become especially complex under unstable atmospheric conditions, requiring specific cares on their application. The success of simulation models of urban drainage are dependent, in its mathematical application, of the existence of hydrological data records and data flow metering, used for calibration and validation, of the existence of reliable cadastral information and of the model suitability to the physical characteristics of the basins (Shaw, 1984).

SIMTEJO, multi-municipal company responsible for the integrated sanitation of Tejo and Trancão municipalities, in the framework of the expansion project of the WWTP – Waste Water Treatment Plant of Alcântara, and to support the decision for the volume to be treated during wet weather conditions, requested to the National Laboratory of Civil Engineering (LNEC) a model to assess discharges in the receiving milieu. This previous study assessed discharges during a 19 years series of simulated rainfall, using the mathematical model of the drainage basin of Alcântara gully, in the city of Lisbon (Figure 1), implemented in the software SWMM - Storm Water Management Model (EPA, 2010). This simplified model of Alcântara basin was calibrated and explored but, due to the lack of measured flow and precipitation data, the results were considered of low reliability.

Now, with the installation of a permanent flow meter in Alcântara basin, upstream of the WWTP, and with the availability of synoptic precipitation data, a complete calibration and validation of the model, based on a one year period, was possible.

To manage the operation of the Alcântara WWTP, a good response from the mathematical model of Caneiro de Alcântara, in terms of water volume, is more important than the answer to the discharge peak, since the current capacity of the WWTP is limited 3.3 m^3/ s in dry weather and 6.6 m^3/s in wet weather. Large flows that are deviated from WWTP are directly discharged into the river Tagus, therefore not having influence in the exploration of the treatment plant.

Herein the calibration and validation of this mathematical model implemented in SWMM, is presented with data corresponding to the period between February to April 2011. The calibration is made partially, in the sub-basin where hydrological gauging is made (dashed region in Figure 1), between Campolide train station until Tagus outlet. Calibration parameters were upstream basin's characteristics (large scale), average width, impermeability and tilt; an analysis to different infiltration models was made as well. Afterwards, an example of an application of the model during a flooding period is shown, showing reliable that results indicating the usefulness of the actual calibrated model for the management of the treatment plant.

This study was a first step in the integration of the recently available flow and precipitation data, following the integration of an updated cadastral survey in the model of the Alcântara basin, for the improvement of the model.

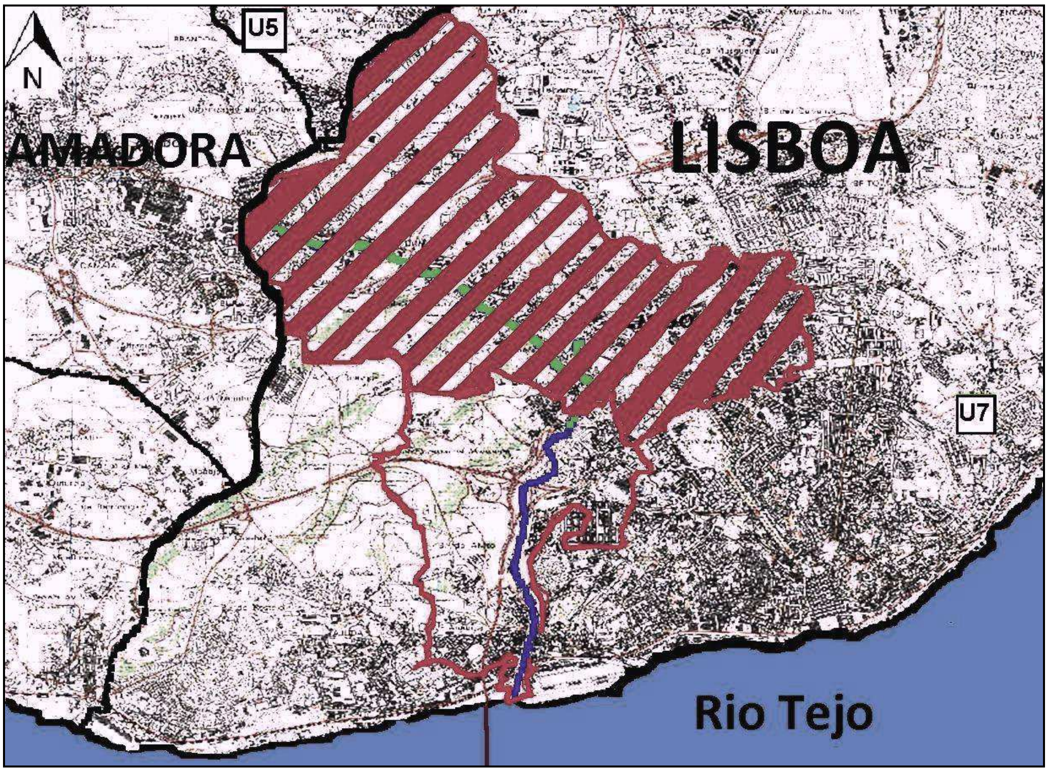

Figure 1. *Caneiro de Alcântara* drainage basin. The sub-basin herein calibrated is represented by dashed lines.

PREVIOUS STUDIES

The first studies about Alcântara basin emerged within the European project "Implementation of the hydraulic analysis for the rehabilitation of urban drainage systems in the member states", funded by the European program SPRINT SP98 / 2, which took place between 1994 and 1996, where Alcântara watershed was the Portuguese case study (Matos *et al.*, 1998). A second model, with representation of sub-basins and gully traps, was developed in the simulation program MOUSE (2000), for the simulation of the system hydraulic behaviour, based on modelling by event. This simulation program, briefly described in Cardoso *et al.,* 2006, has a detailed representation of hydrological and hydrodynamic phenomena and aims at simulating the hydraulic behaviour of the system for individual events. In 2006, at the request of SIMTEJO, LNEC implemented a mathematical model from Alcântara basin section, with the total superficial basin representation, using the simulation program SWMM, being this model pre-validated with measurements obtained in the previous SPRINT project SP98/2.

ADAPTATION AND MODEL CALIBRATION

This work began with the collection of flow and rainfall data, recorded through a flow meter installed on *Caneiro de Alcântara* and of two rain gage respectively installed in the grounds of WWTP Chelas (U7) and in the building of the Firefighters of Pontinha (U5). The data covered the period between February and April 2011.

For the purpose of the present study, a new dry weather hydrograph (base flow tributary) was updated and compared with the hydrograph used in the 2006 model (Figure 2). This so-called dry weather hydrograph constitutes the base flow for the simulation since it represents inflow ensuing from domestic use, independent on weather conditions.

The calibration process aimed at (i) minimizing the volumetric differences between measured and simulated flows and (ii) the difference between measured and simulated peak flow, and at obtaining similar hydrograph shapes.

The volumetric and peak errors of the hydrograph are calculated according to expressions 1 and 2.

$$\text{Volume}_{\text{error}} = \frac{\text{Total Volume}_{\text{measured}} - \text{Total Volume}_{\text{estimated}}}{\text{Total Volume}_{\text{measured}}} \quad (1)$$

$$\text{Peak}_{\text{error}} = \frac{\text{Peak}_{\text{measured}} - \text{Peak}_{\text{estimated}}}{\text{Peak}_{\text{measured}}} \quad (2)$$

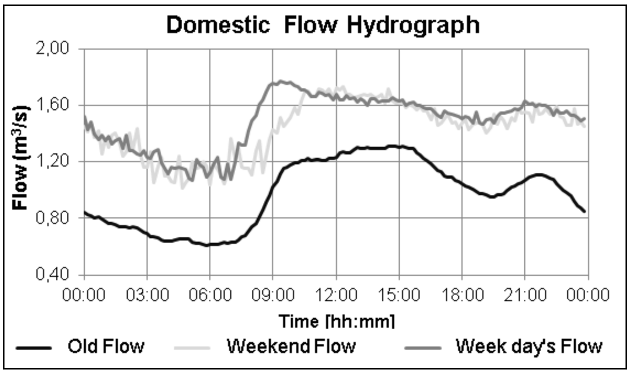

Figure 2. Domestic flow hydrograph in dry weather.

Asymmetric acceptance criteria for the simulation results consider the following intervals [-10%, +20%] for the volumetric error and [-15%, 25%] for peak flow error. Hydrograph shape is evaluated by looking at time evolution of measured and simulated data. The model was calibrated in order to make the volumetric errors within the range of acceptable values, assigning lowest weight to peak to errors since the flow meter data for high flow rates was less reliable.

Two wet periods were used for calibration purposes, the first from 5th to 9th March, with five flow peaks, and the second from 11th to 15th March, with four flow peaks.

Calibration basin parameters were set to: average width (Width = 4000 meters), terrain inclination (slope = 15%) and percentage of impervious area (impervious = 40%). The infiltration model that allowed better results was the Horton model, different from the previously used Curve Number model, showing a more appropriate response to flood events.

A sensitivity analysis of the various basin parameters was made. For the basin average width, an increase of the value will cause an increase of volume and peak flow. The slope is directly related to the flow speed and the surge flow rate; the higher the slope the larger the velocity. The ground impermeability is directly related to the volume of water, since it defines basin infiltration; when this is lower, the amount of rainwater flowing to the water course is higher.

Model calibration was considered achieved for calibration errors shown in Table 1. Criteria above mentioned were not always achieved during some peak periods, but generally the results were considered satisfactory.

Table 1. Calibration errors

Error's (%)	Volume	Peak 1	Peak 2	Peak 3	Peak 4	Peak 5
1st Period	-1,9	8,3	16,0	-46,4	9,9	-15,4
2nd Period	-7,8	4,0	-41,1	-91,3	10,1	-

VALIDATION

To validate the model a third wet period was used, within the timeline already set (February to April 2011), with three peak flows. Figure 3 presents the estimated and measured flow data used on the model validation, with normalized errors, in terms of volume, of 5% and, in terms of peak flow of 42%, 34% and 18%, respectively for P1, P2 and P3.

APPLICATION

After model calibration and validation, the model was already tested on a real application by SIMTEJO to an event that occurred in October 2011 (Figure 4). Volume errors were of -0.8% and 10.4% for peak flows, both within the acceptable range criteria, proving that the actual updating of the model is reliable and able to be used for WWTP exploration purposes.

CONCLUSION

The present work consisted on the calibration and validation of a mathematical model of *Caneiro de Alcântara* drainage sub-basin, previously implemented and now updated with new data, in order to enable a reliable decision support tool for the management of wastewater discharges at SIMTEJO treatment plant (WWTP).

For the different periods analysed, a good fit between simulated and measured hydrographs was obtained, particularly with regard to the volume generated.

In relation to previous models implemented on MOUSE and SWMM software, volume errors improved satisfactorily in the current model (Table 2).

Table 2. Volume errors for different models applied to Alcântara basin

Models	MOUSE	SWMM 2007	SWMM 2011
Volume Erro's [%]	14,7	24,7	4,9

Basin parameters of the upstream were adjusted yielding results with minimum errors of roughly 5%. The most significant parameters for the volume results were the average width, which was reduced to half the amount used in previous studies, and impermeability which was increased from 100% to 40%.

Regarding the peak flow results, errors are higher which may be aggravated by the low precision of the flow meter, especially important when water levels are higher and during high flow velocity periods. Subsequently, flow gauging should be improved, eventually by installing another series of flow meters or locating another flow meter in a downstream section, on the inlet situated upstream

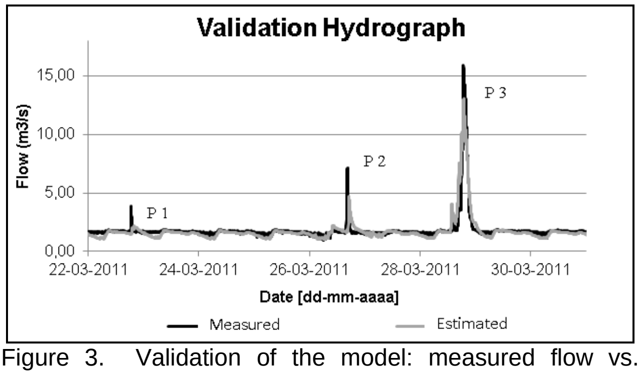

Figure 3. Validation of the model: measured flow vs. estimated flow.

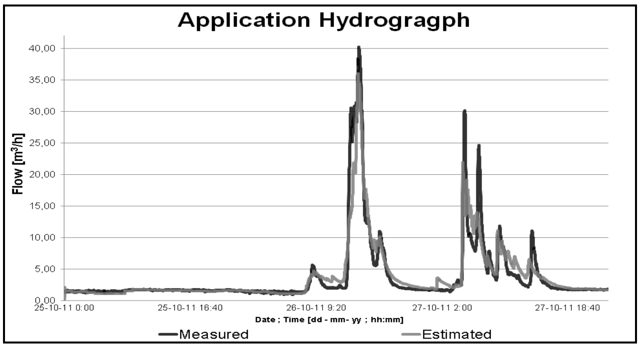

Figure 4. Application of the model: measured flow vs. estimated flow.

WWTP. Currently, after the present study, the range of velocities actually measured with the flow meter was increased, making it possible to measure values as high as 83 m^3/s and velocities until 9.9 m/s.

Errors of runoff peak vary greatly from simulation to simulation and from event to event, which proved to be a challenging task. In fact, the basin's behaviour is different depending on the intensity and duration of the event, leading to the need for calibration and validation of the model with different events of different characteristics. The mathematical model should be able to respond to these different events in a satisfactory manner.

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