Dynamic modelling of the drainage system of Lage basin as support for evaluation of undue rainfall flows

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Abstract

With the increasing expansion of urban centers, it is increasingly recognized the importance of the proper functioning of urban drainage networks. The aging of urban drainage infrastructures together with the gradual reduction of permeable areas in urban areas, promotes the problem of undue inflows in wastewater drainage systems. This problem favors the increase, sometimes significant, in the flow volume that reaches the WWTP and does not require this type of treatment. Undue inflows inevitably lead to an increase in the operating costs of drainage systems and WWTPs, reducing their effectiveness and compromising the sustainability of their management. Therefore, it's primordial the realization of studies and projects with the aim of finding solutions to the mitigation of this problem which the wastewater managing entities have been confronted with. The dynamic models can be a useful tool for quantifying the magnitude of this problem and for the evaluation of the performance of urban drainage systems. This dissertation consists in the creation of the dynamic model of the drainage subsystem of Costa do Estoril, belonging to the metropolitan area of Lisbon, and the calibration, in dry and wet weather, of a pilot urban basin (Lage basin) for further evaluation of their structural performance and quantification of the undue inflows. The results obtained with this study will support the work of managing entities and will allow, in the future, the definition of mitigation measures for undue inflows.

Keywords: Assessment of structural performance; Dynamic simulations models; Infiltration; Modelling; Wastewater drainage systems; Undue inflows.

1. Introduction

With the increasing environmental awareness and the advancement of technology, water from domestic, commercial, industrial and agricultural use is sent, through a suitable drainage system, to Waste Water Treatment Plants (WWTP), where, under safe environmental conditions, this kind of waste water suffers a large decontamination process.

A major treat to the proper functioning of wastewater drainage systems and WWTP's, is the undue flow of rainfall which, in certain cases, can occur in considerable quantities along sewage drainage networks. This phenomenon tends to worsen with the growth of urban centers, which causes a reduction of impermeable areas. This factor along with the advanced age of drainage systems, contribute to the increase of undue inflows.

The undue flows can tease serious problems in the environment and public health and lead large consequences, with the increase in the operating costs of drainage systems and WWTPs, to a technical and economical level for management entities, reducing their effectiveness and jeopardizing the sustainability of their management (Kracht et al., 2008). Therefore, the costs and consequences associated with this problem justify the investment in studies that provides the possibility of knowing it's the real magnitude of this problem and, if possible, quantifying it.

Dynamic simulation models, as a resource for undue inflows studies, are great tools for the evaluation and performance management of drainage systems, for the detection of the origin of the problem and for the elaboration of plans of action for their mitigation.

1. Case of Study

The company Águas do Tejo Atlântico (AdTA), responsible for hundreds of kilometers of collectors, several pumping stations and WWTP's, is the managing entity of the drainage subsystem of Estoril Coast. This dissertation emerges to complete a research project under development in Portugal, iAFLUI ("Iniciativa Nacional para o Controlo de Afluências Indevidas") and consists in the creation of a mathematical model, with SWMM (Storm Water Management Model) software, based on monitoring data, of the domestic separative drainage subsystem of Estoril Coast, represented in Figure 1, and the analysis and quantification of undue inflows in a pilot basin (Lage basin). This drainage subsystem is one of the largest systems in Portugal, covering an area of approximately 245 km^2 and serves about 720 000, that shows a pseudo-separative behavior, with a significant influence of rainfall inflows.

Figure 1- Estoril Coast drainage subsystem

This subsystem, basically, consists in a general interceptor with about 25km; 120 km of 20 gravitational emissaries, which are developed along water lines; 9 flow lift stations; 1 WWTP (Guia WWTP in Cascais) and a 3km long submarine emissary which launches the treated effluent flow in the sea (Martins, 2008 e Brito, 2012). This drainage system is equipped with many flowmeters, distributed throughout the drainage network, and 5 rainfall measurement stations.

As already mentioned, after the physical construction of Estoril Coast drainage subsystem, will be realized an analysis and quantification of the Lage basin undue inflow in wet weather. This emissary is one of the biggest and longest in Estoril Coast drainage subsystem, with about 42km^2 and 13km long, and is equipped with 4 flowmeters, designated by Q028, Q03B, Q04 and Q07 (represented with red in Figure 1).

2. Methodology and Data

The construction of the model begins with the introduction of the physical elements of the Estoril Coast drainage subsystem, such as collectors, visit chambers, emergency discharges, pumps, etc., which, for that, the managing entity had to provide a lot of cadastral data. After completing this whole process, was made the debugging of possible errors that could exist in the model (final result represented in Figure 2)

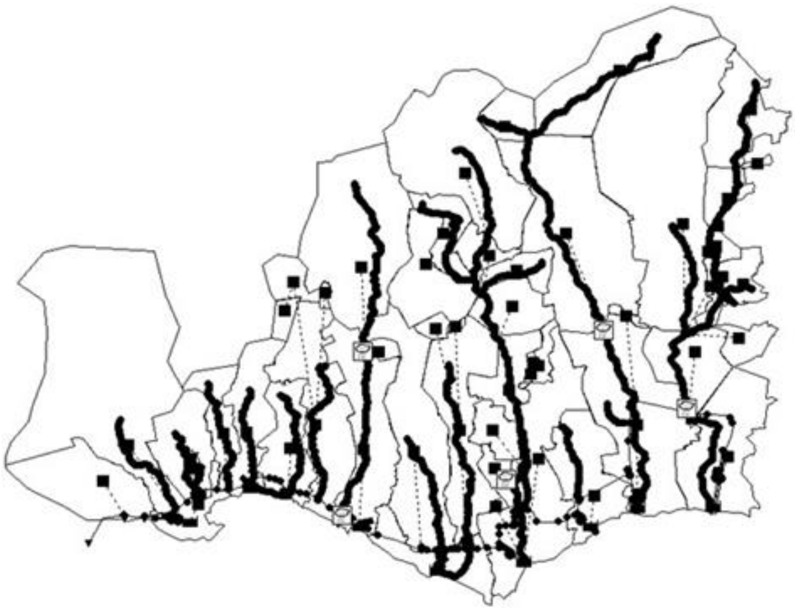

Figure 2- Result of the mathematical model of the Estoril Coast drainage subsystem

In order to be able to quantify undue rainfall flows in the Lage basin, it's necessary to perform its calibration process and, for that, it's crucial to have cadastral data on daily flow volumes, registered by flowmeters along the basin, during the period under study (01/11/14-31/10/15). The calibration and validation in dry and wet weather is essential for obtaining a model that represents reality in the best way possible. Therefore, the calibration of Lage basin will start with dry weather by choosing, randomly, 3 days in the summer time (11/07/15 for calibration, 03/09/15 for calibration e 07/09/15 for validation) and 3 days in the winter time (02/11/14 for calibration, 16/03/15 for calibration and 05/04/15 for validation). After this calibration is concluded, will begin the calibration in wet weather and, for this calibration and validation, will be used two rainfall events: one in the winter time lasting 3 days (17/01/15 until 19/01/15) and another one in summer time lasting 1 day (06/14/15). By an iterative process of constant simulations, it's possible to estimate a set of values that reflect a good functioning of the model of the Lage basin for dry and wet weather. For the calibration and the validation of the both types of models, dry and wet weather, were considered the following criteria (WAPUG, 2002): volumetric error inside the interval [-10%; +20%]; maximum flow error inside the interval [-15%; +25%] and comparation of the shapes of the simulated flow hydrograms with the hydrograms of real measured flows. The volumetric error and maximum flow error are calculated through the equations (1) and (2), respectively.

$$Volumetric\ Error = \frac{Measured\ Flow\ Volume - Simulated\ Flow\ Volume}{Measured\ Flow\ Volume} \times 100 \qquad (1)$$

$$Maximum\ Flow\ Error = \frac{Mximum\ Measured\ Volume - Maximum\ Simulated\ Volume}{Maximum\ Measured\ Volume} \times 100 \qquad (2)$$

3. Calibration Lage Basin

To do the analysis only in Lage basin, was necessary to separate this basin from the rest of the model. The mathematical model of Lage basin consists in more than 500 nodes (visit chambers) and 500 junctions (collectors), 3 emergency discharges and 19 sub-basins, the final result of this model is represented in Figure 3. Both calibrations were made by steps: the Lage basin was divided in 4 regions (separated by the 4 flowmeters). The flows, inserted into the model as the calibrations were performed, were created using standard hydrograms previously estimated by Rosmaninho (2017).

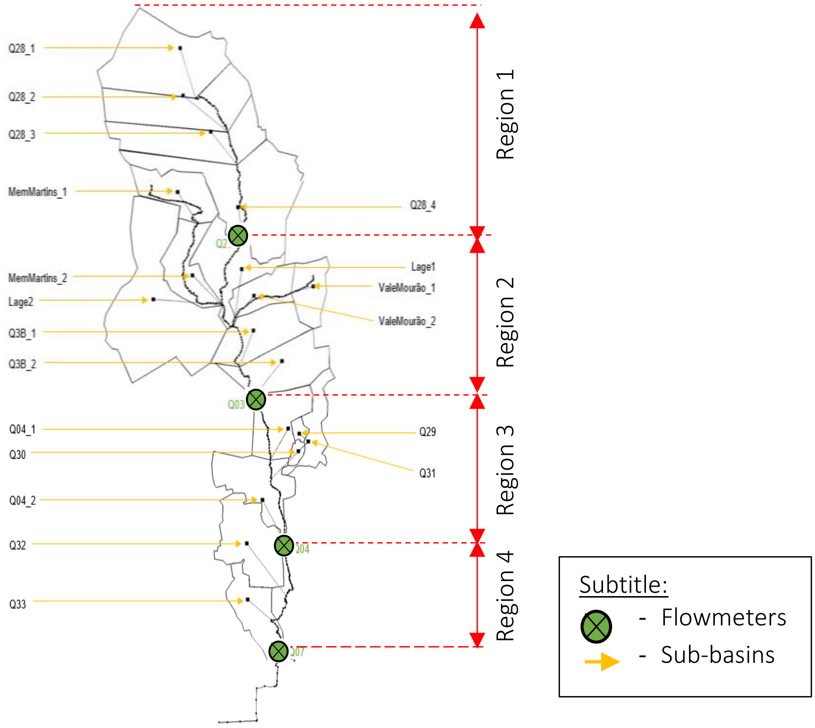

Figure 3- Final result of the Lage basin mathematic model

The Table 1 shows, as an example, the results obtained for the criteria considered in the calibrations of Lage basin, mentioned above, for region 1 for both events under analysis, in wet weather. It's visible that all the results obtained, regarding the volumetric and maximum flow errors, are within the stipulated intervals. The following Figure 4 presents the last criteria under analysis (comparation between the curves of the simulated and measured hydrograms), related to region 1 of the Lage basin of the event 1 (winter).

Table 1- Results obtained for which event during the calibration of region 1 in wet weather

Region 1 of Lage basin			
Visit Chamber	Medium flow (l/s)	*Calibration/Validation – **Wet Weather***	
LJ0010.00	156	**Event 1** – Winter time	**Event 2** – Summer Time
Measured Flow Volume (m³)		98606.90	21130.89
Simulated Flow Volume (m³)		96437.65	19959.37
Maximum Measured Volume (m³)		904.70	680.50
Maximum Simulated Volume (m³)		999.51	685.77
Volumetric Error (%)		2.2	1.1
Maximum Flow Error (%)		-10.5	-6.7

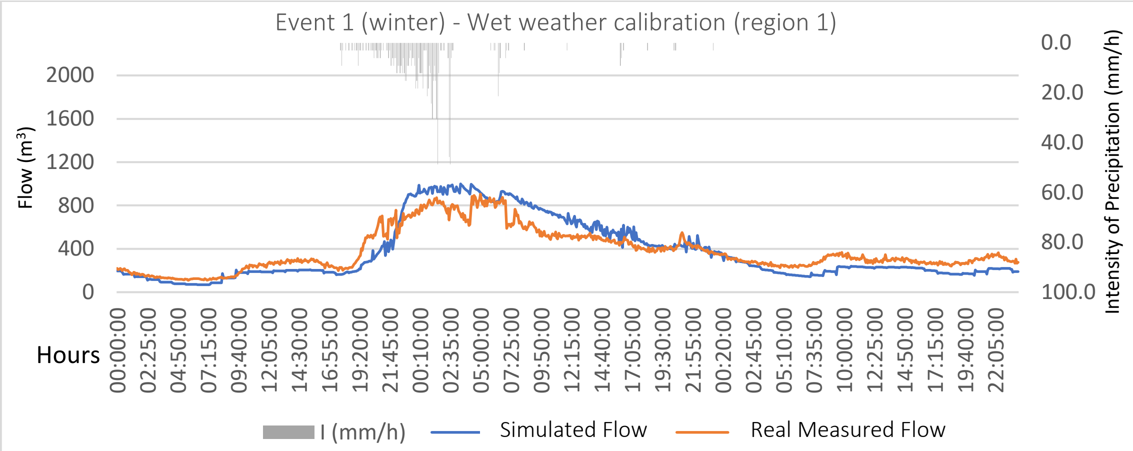

Figure 4- Comparation of the simulated flow curve with the real measured flow curve related to the calibration of region 1 in event 1, in wet weather

It's possible to affirm, by analysing the figure above, that the simulated hydrogram presents a tendency to follow the measured one and the minimums and maximums of both hydrograms happens slightly at the same time. This means that, in this case (region 1, wet weather, event 1) all the criteria are respected and, consequently, this calibration is well achieved.

In reality the sub-basins have a certain area but, in the mathematical model, that parameter needs to be estimated. The iterative process of wet weather calibration consists in estimating the areas of sub-basins that affectively contributes, with rainwater flows, for the increase of flow in the drainage system.

4. Results Analysis

4.1. Performance Indicators

In this dissertation were calculated the following performance indicators:

- Indicator 1 (I1) - % of collectors that reached the maximum capacity in wet weather;
- Indicator 2 (I2) - % of undue flow volume in dry weather.

		Where:
I1	$\frac{L_{collectors\_fullcapacity}}{L_{collectors\_total}} \times 100\ (\%)$	$\boldsymbol{L_{collectors\_fullcapacity}}$ – Sum of the lengths of all collectors that reaches full capacity in wet weather; $\boldsymbol{L_{collectors\_total}}$ – Sum of the lengths of all collectors;
I2	$\frac{Q_{min}}{Q_{ADF}} \times 100\ (\%)$	$\boldsymbol{Q_{min}}$ – Minimum flow in dry weather; $\boldsymbol{Q_{ADF}}$ – Average daily total flow in dry weather.

The Table 2 sums up the results obtained during the calculations for the performance indicator 1. The event 1 was in winter time and the intensity of the precipitation during this event was bigger than during de event 2 (summer time), which explains why the results in the event 1 are significantly superior. However, given the results for the emissaries of Mem Martins and Vale Mourão, it's possible to affirm that the major problem is focussed on the Lage emissary, is in this emissary that occurred more undue rain flow.

Table 2- Results obtained for performance indicator 1 for both events in analysis (wet weather)

		Event 1 (winter time)		Event 2 (summer time)	
	Total Comp. of collectors (m)	Comp. of collectors with full capacity (m)	**I1 - % full capacity**	Comp of collectors with full capacity (m)	**I1 - % full capacity**
Lage	12914.68	11453.98	88.7	1586.04	12.3
Mem Martins	4269.70	21.42	0.5	0.00	0.0
Vale Mourão	2213.47	198.84	9.0	23.48	1.1
Total	19397.85	11674.24	60.28	1609.52	8.3

The performance indicator 2 is relative to dry weather and was calculated for the zones of the Lage basin where the flowmeters are at. The results obtained are shown in Table 3.

Table 3- Results obtained for performence indivator 2 (dry weather)

	Flowmeter Q28		**I2** (%)	Flowmeter Q03B		**I2** (%)	Flowmeter Q04		**I2** (%)	Flowmeter Q07		**I2** (%)
Time	Q_{min} (l/s)	Q_{ADF} (l/s)		Q_{min} (l/s)	Q_{ADF} (l/s)		Q_{min} (l/s)	Q_{ADF} (l/s)		Q_{min} (l/s)	Q_{ADF} (l/s)	
Winter	77.4	182.1	42.5	123.7	236.6	52.3	131.6	261.7	50.3	153.3	282.7	54.2
Summer	37.2	145.8	25.5	66.5	174.3	38.2	71.4	204.3	34.9	91	225.4	40.4

From the analysis of the table above, it's possible to verify that the percentage of infiltration in dry weather, due to groundwater flows, for example, in Lage basin is in the rage of 25 to 55%, which doesn't interfere with the normal operation of the system. Nevertheless, should be paid an attention to the evaluation of infiltration values given that some of them exceed 50%. A more detailed study, such as CCTV, is suggested to detect possible structural problems that may justify this results in dry weather.

4.2. Quantification of undue rainfall flow and percentage of improper connections

The volumes of rainwater undue flow were estimated at the end of Lage basin. These values were determinate from the model in dry weather (without considering precipitation) and with the models of both of the events under analysis (considering precipitation). The volumes of rainwater undue flow are the results from a subtraction operation between the values in wet weather and the values in dry weather. These results are presented in Table 4.

Table 4- Final results of the volumes of undue rainflow in Lage basin, for both of the events under analysis

		Total Flow (m^3)		Undue rainflow (m^3)
		With precipitation	*Without Precipitation*	
Event 1	End of Lage basin	157150.9	60961.1	96189.7
Event 2	End of Lage basin	35901.6	20267.5	15634.1

By analysing the table above, it's possible to verify that the volumes of undue rainflow occurred were about 60% in event 1 (winter time) and 40% in event 2 (summer time). The intensity of precipitation in event 2 was lower than in event 1, which explains the difference between the results obtained for which event. The volumes obtained reflect the magnitude of this problem in the Lage basin.

The Table 4Table 5 presents the results obtained for values of each sub-basin areas introduced in the model and the respective percentage of improper connections. By analysing the results presented in this table, it's possible to verify that the area of the Lage basin that presents more problems of improper connections occurs between the Q04 e Q31 flowmeters. This zone is in Oeiras where, possibly, the houses built there are old and doesn't have two separated kinds of systems: one domestic system and another one destined for rain water. However, this contribution may also be due to the poor state of conservation of the infrastructures os the drainage system. It's relevant to do a more detailed study about this area of Lage basin in order to detect the origin of the problem.

Table 5- Results obtained for percentage of improper connections on the Lage basin

	Real Values			Model Values			
Sub-basins	Total Area (ha)	% Impervious Area	Impervious Area (ha)	Total Area (ha)	% Impervious Area	Impervious Area (ha)	% Improper connections
Total Q28	1178.69	78.24	922.21	126	30	37.8	4
Total Mem Martins	224.86	67.77	152.38	10	68	6.8	5
Total Vale Mourão	161.36	74.2	119.73	8	74.2	5.9	5
Lage 1	159.83	22.07	35.28	6	30	1.8	5
Lage 2	466.01	73.25	341.35	11	73.25	8.1	2
Total Q03B	295.72	34.97	103.41	12	55	6.6	6
Total Q04	286.91	47.6	136.56	34	90	30.6	22
Q29	11.8	68.71	8.11	6	90	5.4	67
Q30	11.69	83.65	9.78	6	90	5.4	55
Q31	74.13	45.46	33.7	17	90	15.3	45
Q32	176.01	39.17	68.95	5	50	2.5	4
Q33	137.95	34.5	47.59	3	34.49	1	2
Total			1979.05			127.2	6

5. Conclusions

The evaluation and quantification of the undue flows is very relevant for the management entities and fundamental for the mitigation of this kind of problems. Dynamic simulation models can be a good tool for the quantification of the magnitude of this problem and for the general evaluation of the performance of drainage systems.

The performance indicators represent a good instrument to support the management of drainage systems, reflecting the quality of the service practiced, and may help in economic and financial decisions of management entities. By the results obtained for I1, it's legible that the major problem is in Lage emissary, which symbolizes a lower occurrence of undue rainfall in the emissaries of Mem Martins and Valo Mourão. So, the I1 indicates which emissary needs more studies of undue flows. Through the results obtained for performance indicator 2, it's possible to conclude that the infiltration occurred in the Lage emissary in dry weather, during the year under analysis (2014/2015), was not alarming, however it's important to keep making more of studies like this.

The main objective of this dissertation was the quantification of undue flows in Lage basin. The results indicate that the volumes of rainfall flows reached 60% in event 1. This analysis contributed to a better understanding of the real magnitude of the phenomenon of infiltration in the drainage system, underlining the importance of the elaboration of more studies in this subsystems that leads to relevant measures and actions that aims to mitigate this problem.

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