ASSESSMENT OF THE EVOLUTION OF INFILTRATION IN COSTA DO ESTORIL DRAINAGE SUBSYSTEM

Alice Pereira Rosmaninho

Civil Engineering Department

May 2017

Abstract

Infiltration problems tend to aggravate with infrastructure aging, with important consequences regarding its technical and economic performance. The present communication aims to assess the evolution of infiltration in Costa do Estoril drainage subsystem, based on monitoring data collected in the same flow measuring points in 2000 and 2015. The infiltration flow rates were estimated by conventional methods, and performance indicators were also determined. The results were compared to verify any decreases or rises infiltration flows during this period, relating them to rehabilitation interventions performed by the wastewater utility. Furthermore, in situations where an increase in stormwater contributions was observed, the results were used as a primary instrument for the proposed mitigating measures.

Keywords - Infiltration, inflows, performance indicators, urban drainage, wastewater.

Introduction

In urban drainage systems, undue inflows are a concern for management entities. Certainly, those inflows contribute to increasing the cost of operating drainage systems and wastewater treatment plants (WWTP), reduce their effectiveness and compromise sustainability management of drainage systems in urban areas.

The problem of infiltration tends to worsen with the age of the systems, having important consequences on their technical and economic performance. The costs associated with infiltration are high, justifying the investment in studies that allow to know the extent of the problem and quantify it.

Correct quantification of infiltration in the drainage network is a key issue in problem-oriented rehabilitation management with a view to mitigating these issues (Kracht et al., 2008) and also in order to measure the effectiveness of actions implemented for this purpose. Although it is not feasible to eliminate all infiltration water from urban drainage systems, it is required to know and control the problem as much as possible.

One of the alternatives is the quantification of the magnitude of infiltration flows that can be made using a set of indicators that objectively evaluate the infiltration flows, considering the characteristics of the drainage systems (Cardoso et al., 2002).

In short, the investment in the study and quantification of infiltration in urban drainage systems have high interest for fund managers, not only because it minimizes the various mentioned impacts, but also because it can function as an indicator of the structural state and environmental efficiency of the systems (Rodrigues, 2013).

In the context of this document, it is intended to evaluate the evolution of the infiltration in the drainage subsystem of the Estoril Coast, based on monitoring data collected in 24 flow measurement points in 2000 (analysed by Cardoso et al., 2002) and 2015. The results were compared to verify eventual reductions or increases in infiltration flows in this period, relating them to interventions carried out by the management entity or using the results, in situations of increased contribution of infiltration flows, as a preliminary instrument for the proposal of measures to mitigate the problem.

Infiltration in urban drainage systems

The estimation of infiltration flow rates in a drainage system is not a simple matter and it is both in the design phase and in the exploration phase. In the design phase, the estimate is usually made, in accordance with Regulatory Decree No. 23/95, as being equal to the annual average flow, to estimate the design flow rates; In the exploration phase, the estimation can be made based on different methods and is carried out to evaluate the technical and economic performance of the system.

The infiltration is defined as the infiltration of unwanted and unpolluted water into the drainage network, originating from groundwater (Metcalf and Eddy, 2003). It is common to consider undue flows (or simply infiltration), which flow to the systems through structural deficiencies in the sewers (joints, connections) or through the walls of the manholes, base infiltration (regardless of the state of conservation of the sewer). It is common to have additional infiltration to the base infiltration that occurs after a precipitation event ends and has a variable duration depending on the characteristics of the respective drainage basin, such as area, percentage of waterproofing, average slope, soil hydrogeological characteristics, conservation of networks, among others.

In a drainage system, the infiltration flows present high spatial and temporal variability. The magnitude of this phenomenon depends on: the position of the network elements relative to the water table; the conservation status of drainage networks; the length of the nets, the diameter of the sewers, the number of the manholes and connecting junctions; Of the soil type; The occurrence of precipitation; among other factors (White et al., 1997; Gamboa et al., 2000).

The determination of infiltration rates can be done using conventional or non-conventional analytical methods. Conventional methods are based on flow analysis or chemical analysis of water, the unconventional ones, allow to estimate infiltration rates based on the analysis of isotope ratios, being called by the isotope method.

The conventional methods of flow analysis are based on the hypothesis that the total flow rate circulating in the network in dry time is composed only of two components: one relative only to waste water (domestic or industrial) and another to infiltration. Some of the conventional and unconventional methods are described in De Bénédittis (2004) for evaluation of infiltration. The methodology expressed by equation (1) (Cohen, 1998) allows, from the analysis of the daily flow measurement logs in dry time, the minimum recorded flow, the quantification of the base infiltration that occurs in a drainage system. It is assumed that the nocturnal flow rate is, on average, about 8 to 12% of the average daily flow with no occurrence of precipitation in the urban basins. For this method, it is important to highlight the fact that the average flow rate is used to estimate the infiltration and therefore has the advantage of better reflecting the characteristics of the basin in question. However, the more urban the basin is, the larger the average flows, which can lead to negative infiltration flows at very low nightly flows.

Another methodology is expressed by equation (2) and was proposed in Cardoso et al. (2002), which considers the infiltration flow corresponds to 88% of the minimum daily flow that is drained into the system.

$$Q_{inf} = \mathrm{Q}_{mín} - 0{,}12 Q_{méd} \quad (1)$$

$$Q_{inf} = 0{,}88\, Q_{mín} \quad (2)$$

where:

Q_{inf} – infiltration flow;

$\mathrm{Q}_{mín}$ – minimum daily flow;

$Q_{méd}$ – average daily flow.

Even though there is no "perfect" method to calculate infiltration flow rate, a study of the dynamics of the basin is always necessary and the estimation of infiltration rates will be more approximate based on the flow measurement combined with a minimum flow analysis, when there is a greater expression of infiltration flows.

To evaluate the performance of a drainage system, particularly about infiltration flows, it is advisable to determine performance indicators. According to Coelho and Alegre (1999), an indicator or measure of performance is a characteristic or state variable that allows, in function of the values that it assumes, to translate in quantitative terms the performance of the system. This measure can be obtained based on monitoring or modelling data of the network under analysis, varying spatially (from element to element of the network) and temporally (depending on the system requests). Cardoso et al. (2002) recommend the evaluation of performance indicators in Table 1, regarding the problems of infiltration in drainage systems.

Table 1. Performance indicators to infiltration in urban drainage systems (adapted from Cardoso *et. al.*, 2004).

Performance indicators		Comments
PI1	$\frac{Q_{inf}}{Q_{full}}$	**Infiltration full capacity utilization (%)** – this indicator allows us to the proportion of the sewer's full section flow capacity used by the infiltration flow. Its value may be assessed for a single sewer, for groups of sewers (subsystems) or for the entire system.
PI2	$\frac{Q_{inf}}{Q_{mts}}$	**Infiltration proportion of dry weather flow (%)** –The infiltration flow expressed as a percentage of the daily mean dry weather flow. This measure may indicate to the drainage management entities which sections are in good condition and which parts of sewer have to be rehabilitate.
PI3	$\frac{Q_{inf}}{\text{nº M}}$	**Infiltration per menhole (m^3/day)** –Mean infiltration flow per manhole unit. Manholes are an important source of infiltration. This indicator gives an idea of the influence of the number of manholes on total infiltration
PI4	$\frac{Q_{inf}}{L_{sewer}}$	**Infiltration flow per unit sewer length (m^3/day/km)** – mean infiltration flow per unit length of sewer. This indicator does not consider the influence of infiltration taking place in manholes or service connections. This indicator will give relevant results in systems where infiltration takes place predominantly along the sewers.
PI5	$\frac{Q_{inf}}{L_{sewer} \times P}$	**Infiltration flow per unit sewer wall area (m^3/day/(cm.km)) –** represents the influence that the area of the sewer wall has on the infiltration flows of the system. This indicator does not take into account the influence of infiltration taking place in manholes or service connections. This indicator will give relevant results in systems where infiltration takes place predominantly along the sewers too.

Case study

The Estoril Coast substation is managed by EPAL, Empresa Portuguesa de Águas Livres, SA and has an intervention area of about 246 km2, comprising several municipalities, namely the municipality of Amadora, Cascais, Oeiras and Sintra currently serving 648 000 population. This system consists of several gravitational emitters, a main interceptor, for a length of 155 km, by elevating systems and by a WWTP. The emissaries receive the effluents from the municipal networks and develop in parallel with the main water lines, along elongated watersheds and with a north-south orientation, as can be observed in Image 1.

In 1998, a large flow and precipitation monitoring system was installed in the Estoril Coast subsystem with many meters permanently installed in the sewers (Figure 1). This monitoring system allows a better knowledge of the operational operation of the network, provides data to allow the billing of volumes transacted between municipalities and provides information for studies of improvement or expansion of the intermunicipal system.

Image 1 Schematic representation of Costa do Estoril subsystem (adapted from Cardoso *et al.*, 2002)

The drainage system sewer is located near the bed of the streams, with frequent crossings, often deployed below the water table, enhancing the inflow of infiltration flows into the system.

In the present study, the infiltration flows determination was analysed for the winter period (November 2014 to April 2015) and for the summer period (May 2015 to October 2015). Flow data from 24 flow meters were analysed as well as the precipitation data obtained from the 5 spatially distributed meters in the basin.

Methods

To evaluate the evolution of the infiltration in the Estoril Coast subsystem between 2000 and 2016, the following methodology was applied:

1) Analysis and treatment of flow and precipitation data

Dry weather hydrograms were plotted for each flow meter, for the winter period and for the summer period. For the determination of each hydrograph, only the data corresponding to the dry days were selected, that is, the daily logs with precipitation record were recorded in the udrometers, as well as the daily records whose hydrographs were influenced by the precipitation occurred in previous days (Delayed infiltration), since it was only intended to estimate the direct infiltration. Also, excluded from the analysis were data that could somehow show the occurrence of an error in the flow measurement.

2) Infiltration flows

With the dry weather hydrograms traced and using equation (2), the daily infiltration flow rates and the daily volumes of dry weather were determined for the winter and summer periods.

3) Comparison of results obtained with previous studies

Since the values presented in Cardoso et al. (2002) relate to records from the summer 2000 period, a comparison was made between these values and the infiltration volumes obtained for the summer period of 2015 (May to October), to evaluate the evolution of these flows to the Over 15 years.

4) Aplication of performance indicators

Performance indicators associated with infiltration flows were determined, based on the proposed by Cardoso et al. (2002). However, since infiltration flows in the Estoril Coast subsystem are related to infiltration flows from the "downstream" network, and no cadastral information associated with the "downstream" drainage system (namely section flows Number of manholes) required for the calculation of indicators ID3, ID4 and ID5, only indicators ID1 and ID2 were evaluated.

Results and discussion

In Table 2 we present the comparison between the values obtained for the infiltration volume corresponding to the summer of 2015 with the values obtained in Cardoso et al. (2002), corresponding to the summer of 2000. Through the quotient between both, it is possible to find out in which sewers was a decrease or an increase in the volume of infiltration. Thus, the values in which the quotient is equal to or less than 1 (green) correspond to places where there was no increase in infiltration flows. The values between 1.1 and 1.3 (blue) represent the sewers with a small increase in infiltration flows over this period. Values greater than 1,3 and 3 (yellow) correspond to increases that may go up to a double increase in infiltration flow rate and values greater than 3 (red) corresponding to places where was a significant increase of flow rates infiltration.

Table 2. Comparison of results obtained to the summer of 2015 and to the summer of 2000 obtained in Cardoso *et al.* (2002)

		Summer				
Basin	Flow meter	V_{inf} (2015) (m^3/day)	V_{daily} (2015) (m^3/dia)	V_{inf} / V_{daily} (2015) (%)	V_{inf} (2000) (m^3/dia)	V_{inf} (2015)/ V_{inf} (2000) (%)
Carenque	Q_{20}	353	1078	33%	86	4,1
	Q_{21}	989	2961	33%	432	2,3
Jamor	Q_{01B}	2737	8556	32%	5443	0,5
	Q_{02}	6175	15775	39%	6048	1,0
Barcarena	Q_{24}	4941	10647	46%	3974	1,2
	Q_{25}	3601	12060	30%	2592	1,4
	Q_{27}	5642	15627	36%	6653	0,8
Laje	Q_{07}	6917	19476	36%	5962	1,2
	Q_{31}	171	582	29%	432	0,4
Sassoeiros	Q_{37}	762	3216	24%	1123	0,7
Marianas	Q_{40}	1118	3411	33%	1296	0,9
Caparide	Q_{35}	1595	2918	55%	1037	1,5
	Q_{41}	1679	3571	47%	1987	0,8
Bicesse	Q_{42}	1449	3917	37%	1296	1,1
Cadaveira	Q_{43}	566	945	60%	691	0,8
Amoreira	Q_{44}	415	1237	34%	259	1,6
Castelhana	Q_{45}	111	782	14%	86	1,3
Intercetor geral	Q_{05}	12305	35916	34%	15466	0,8
	Q_{06}	14290	41019	35%	12960	1,1
	Q_{08}	21965	67093	33%	19354	1,1
	Q_{09}	28472	79652	36%	28598	1,0
	Q_{10}	43598	105306	41%	24019	1,8
	Q_{11}	42227	101781	41%	43459	1,0

Legend:
> 3
1,3 a 3
< 1,3

Therefore, and considering that there may be some variation in the results resulting from the different statistical analysis at different times, it is possible to verify that in 70% (green) of the points was no increase of infiltration flows. This is also due to some rehabilitation that has taken place along the network.

The major increase in daily infiltration flow was recorded in the Carenque sewer, with an estimated increase of four times the estimated flow rate in 2000.

Compared to the daily volumes measured, points Q43 (Cadaveira) and Q35 (Caparide) show a relationship between the daily infiltration flow rate and the mean dry flow rate over 50%, which expresses significant volumes of infiltration, supported by the performance indicators presented in Table 3.

The color scale shows that values can be considered as revealing a low (0-25%), medium (25-50%) or high (> 50%) infiltration rate ratio (green, yellow and red). To better analyse and evaluate the implication of these two indicators, the drainage system for ID1 and ID2, using the previous color scale, was schematized in the following figures. The sections presented in black in Image 2 and Image 3 were not analysed.

Table 3. Performance indicators values

Basin	Flow meter	Winter (2015) PI1 (%)	Winter (2015) PI2 (%)	Summer (2015) PI1 (%)	Summer (2015) PI2 (%)	Summer (2000) PI1 (%)	Summer (2000) PI2 (%)
Carenque	Q_{20}	1%	37%	1%	33%	-	17%
	Q_{21}	3%	32%	3%	33%	-	24%
Jamor	Q_{01B}	2%	42%	1%	32%	2%	32%
	Q_{02}	5%	46%	3%	39%	1%	29%
Barcarena	Q_{24}	5%	40%	4%	34%	5%	40%
	Q_{25}	4%	37%	3%	30%	1%	24%
	Q_{27}	7%	43%	5%	36%	5%	48%
Laje	Q_{07}	22%	48%	13%	36%	7%	34%
	Q_{31}	-	38%	-	29%	-	50%
Sassoeiros	Q_{37}	5%	33%	3%	24%	-	34%
Marianas	Q_{40}	4%	56%	2%	33%	-	34%
Caparide	Q_{35}	14%	78%	6%	55%	5%	41%
	Q_{41}	3%	60%	1%	47%	5%	48%
Bicesse	Q_{42}	1%	48%	1%	37%	-	34%
Cadaveira	Q_{43}	1%	65%	1%	60%	-	70%
Amoreira	Q_{44}	1%	48%	0%	34%	-	17%
Castelhana	Q_{45}	1%	21%	0%	14%	-	8%
Intercetor geral	Q_{05}	6%	42%	4%	34%	-	35%
	Q_{06}	6%	41%	4%	35%	3%	30%
	Q_{08}	8%	42%	5%	33%	4%	30%
	Q_{09}	9%	45%	6%	36%	-	29%
	Q_{10}	23%	46%	16%	41%	4%	31%
	Q_{11}	-	50%	-	41%	7%	42%

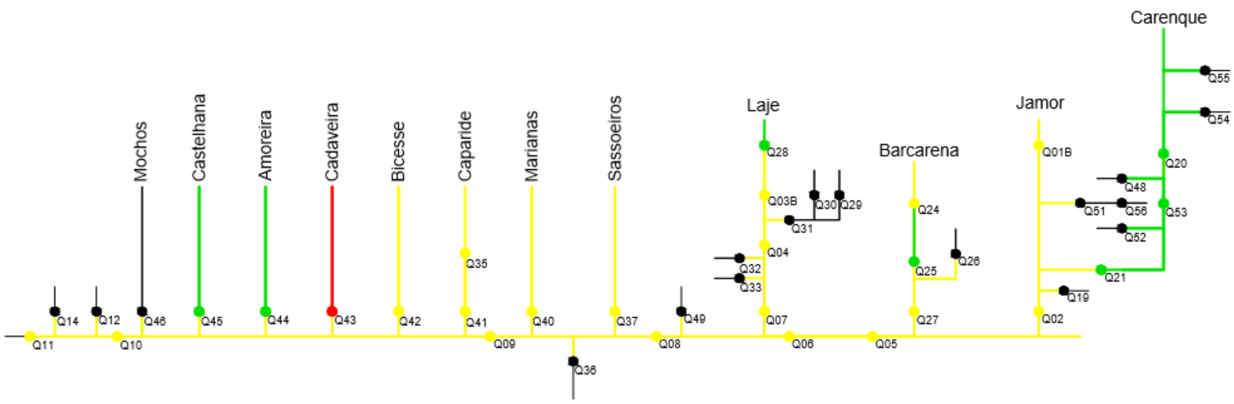

Image 2. Schematic representation of PI2 to the summer of 2000

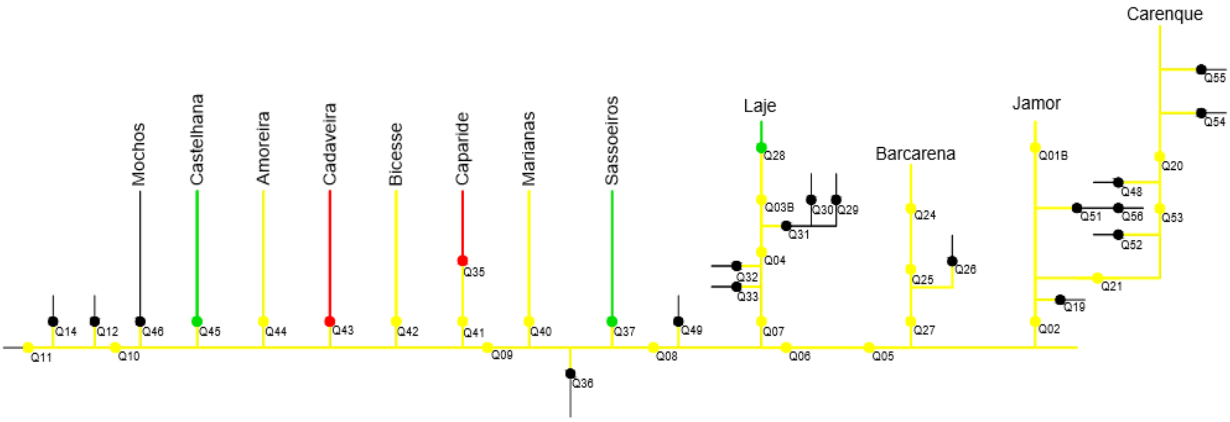

Image 3. Schematic representation of PI2 to the summer of 2014/2015

Examining the ID1 indicator, it is possible to conclude that infiltration flows affluent to the drainage system do not compromise the transport capacity of the total inflow to the system, nor did they compromise in 2000.

By comparing Image 2 with Image 3, it was concluded that there was a worsening of infiltration flows at the subsystem's global level, particularly in the initial sections of the Carenque, Caparide and Amoreira sewers. However, there was a reduction in the inflow of infiltration flows into the Sassoeiros sewer, because of some rehabilitation interventions carried out.

Conclusions

Comparing the infiltration volume data for the summers of 2000 and 2015, collected in the same measurement points, it is possible to observe the evolution of this parameter over time. It was concluded that, in 70% of the drainage system, the volume of infiltration did not increase significantly (V_{inf}(2015)/V_{inf} (2000) <1.3), and even declined in some places, due to the rehabilitation works that took place in the drainage system. The most serious situation occurred in the Carenque sewer, where are increase of 10%, approximately, was observed. This increase can be due to the structural deterioration of the sewers that worsens with time, so it is suggested a detailed inspection of the interceptor (with CCTV) to better access the causes of the problem.

To evaluate the most problematic sections, two performance indicators were analysed. It was verified that most of the system presents infiltration contributions lower than 50% of the average flow, the guiding value mentioned by Regulatory Decree nº 23/95. In two sections of the interceptor (Cadaveira and Caparide), for ID2, percentages higher than 50% were obtained, which is considered a high value, indicative of the likely degradation of the sewers. These sections are presented as priorities for detailed inspection and eventual implementation of rehabilitation interventions. It was also verified that, for some sections where rehabilitation works were recently carried out, the infiltration percentages correspond to values lower than 25% (this is the case of the Sassoeiros sewer, with rehabilitation works carried out in 2013).

References

Cardoso, A., Almeida, M.C. e Coelho, S.T. (2002). Avaliação do impacto da infiltração no desempenho de sistemas de drenagem urbana. 10º Encontro Nacional de Saneamento Básico. Braga.

Cardoso, M. A., Coelho, S. T., Almeida, M. (2004). "Sewer systems performance assessment methodology, formulation, computational application and case studies." *Deliverable 9.2: Infiltration and exfiltration performance indicators*, LNEC, Lisboa, Portugal.

Coelho, S., Alegre, A. (1999). Indicadores de Desempenho de Sistemas de Saneamento Básico. LNEC, Lisboa.

Cohen, B., Rozelman, S., Ryan,T. (1998). Removing extraneous flow in New York city – A Systematic approach yielding results. ADS Corporation, New York.

De Bénédittis J. (2004). Mesurage de l'infiltration et de l'exfiltration dans les réseaux d'assainissement. Thése de Doctorat. Institut National des Sciences Appliquées de Lyon. 16 Avril.

Ellis. (2001). Sewer infiltration/exfiltration and interactions with sewer flows and groundwater quality. INTERURBA II. Lisboa, Portugal.

Gamboa, M., Almeida, M. C., Matos, M. R., Matos, J. S. (2000). - Controlo da descarga de excedentes no sistema de saneamento da Costa do Estoril. LNEC 324/00-NES, Lisboa.

Kracht, O., Gresch, M., & Gujer, W. (2008). Innovative tracer methods for sewer infiltration monitoring. Urban Water Journal, 5 (3)(Research article), 173-185.

Metcalf e Eddy (2003). Wastewater Engineering: Treatment and Reuse (4ª ed.). New York: McGraw-Hill.

Rodrigues, V. (2013). Avaliação de Infiltração em Drenagem Urbana Recorrendo a Métodos Convencionais e não Convencionais - Aplicação ao Caneiro de Alcântara, em Lisboa. Dissertação para obtenção do Grau de Mestre em Engenharia Civil, Instituto Superior Técnico, Lisboa.

White, M., Johnson, H., Anderson, G., Misstear, B. (1997) – Control of infiltration to sewers. Report 175, CIRIA, UK.