A non-traditional approach to assess infiltration in the largest trunk sewer of an urban catchment in Lisbon, Portugal

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Abstract: This paper presents a non-traditional approach to assess infiltration in urban sewer systems, based on a three level methodology. Each level requires different input data and, depending on that, provides an outcome with a higher or lower degree of precision. Level I and Level II methods were successfully applied to a case study in Portugal, namely to the northern part of the largest urban drainage basin in Lisbon, Alcântara. The core water stream in this basin is channelized and corresponds to the main interceptor of the combined sewer system. The wastewater flow (in 15 minutes intervals) was analysed at different sewer sections and several samples of wastewater, drinkable water and groundwater were collected inside the basin. Results show that the infiltration in northern Alcântara is likely to be 0.30 m^3/s, which corresponds to approximately 35% of the dry weather wastewater flow (excluding infiltration).

Keywords: Infiltration, oxygen isotopes, sewer systems

Introduction

The success in urban sewer systems management depends on the knowledge about the quality and quantity of effluents that drain into the pipes and eventually get to the wastewater treatment facilities.

Groundwater infiltration influences both the operation costs and the long term sustainability of urban sewer systems. By increasing the total volume and diluting the wastewater pollutants, it compromises the treatment processes and affects the systems' structural conditions. In Portugal, there is no record of outstanding projects carried out to study this well-known phenomenon. However, innovative approaches have been analysed in the European context, being the APUSS (Assessing Infiltration and Exfiltration on the Performance of Urban Sewer Systems) project a good example.

The main objective of this work is to develop and apply a three level methodology to quantify groundwater infiltration into urban sewers. The approach used in each level depends on the available data and on the level of investment intended by the responsible entities. Furthermore, this study intends to evaluate the appropriateness of conventional and non-conventional methods and study possible links between them, which can improve their results. To test the presented methodology, Levels I and II were applied to the major trunk sewer of the most complex wastewater system in Lisbon, located in the northern part of Alcântara basin, in Portugal (Figure 1).

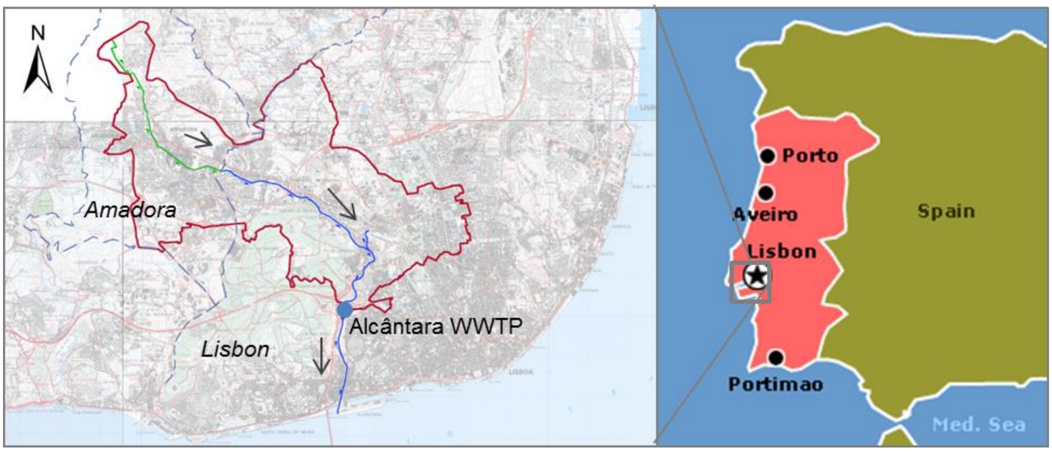

Figure 1: Geographical identification of the studied urban basin and its main trunk sewer. In this figure, arrows point the flow direction and the dotted line represents the borders between the Municipalities of Lisbon and Amadora.

Material and Methods

As previously mentioned, the approach presented in this paper can be divided in three levels, progressively demanding in terms of input data, but also providing increasingly precise results (Table 1). The results from Level II method can be used to confirm the reliability of Level I and calibrate the Level III simulation model.

Table 1: Schematic presentation of the three levels from the presented methodology, and brief description of their principles and requirements.

	Level	Brief summary
Level of data requirement and precision in the outcome results	I	Total wastewater flow series analysis. It is required to assume, *a priori*, a percentage for the contribution of domestic and industrial wastewater in the daily minimum flow.
	II	Analysis and comparison of the isotopic composition of drinking water, groundwater and total wastewater. This method can be used to validate the results from level I and calibrate the level III model.
	III	Development of a proper computational model that simulates the infiltration process by taking into consideration not only the sewer system characteristics but also the physical and hydrological properties of the natural catchment.

Level I consists in analysing time series of total wastewater flow in the key sections of the sewers and determine the infiltration by assuming a night minimum fraction for wastewater.

The time period must be significant (never less than six months, covering dry and wet weather) and the time interval between consecutive measurements should be lower than one hour. In the presented case study, one year of 15 minutes gapped wastewater flow records was analysed, which summed up to a total of 208 dry weather days. Based on ENGIDRO and HIDRA (2007), it was assumed that only 10% of the night minimum flow was caused by domestic and industrial wastewater.

In a short description, Level I method consists in applying equation 1 to obtain the fraction of infiltration in the mean total wastewater flow (k). This equation requires the selection of the minimum value measured in the studied sewer section (Q_T^{min}), the determination of the average dry weather total wastewater flow (Q_T^m) and the assumption of a minimum factor (f_P^{min}), which will be considered to be 10% (as previously mentioned).

$$k = \frac{Q_T^{min}/Q_T^m - f_P^{min}}{1 - Q_T^{min}/Q_T^m} \qquad 1$$

Level II provides more precise results since it includes a chemical investigation, in addition to the flow analysis. It lies on the $\delta^{18}O$ method presented by De Bénéditis and Bertrand-Krajewski (2004) and consequently implies the collection of water samples from all types of water that can contribute to the total wastewater flow. Since the drinkable water in Alcântara basin is captured around 100 km away from Lisbon, the isotopic ratios of local groundwater and drinking water were expected to be different. Hence, the isotopes method might be applicable.

In order to apply the Level II method, several samples were collected from five different sites (Figure 2), during a three day summer campaign.

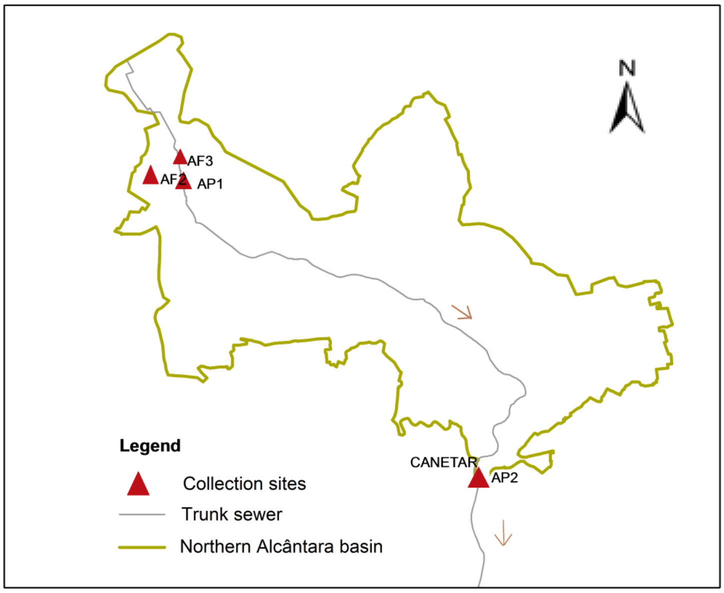

Figure 2: Sites where Level II samples were collected (AF refers to groundwater sites, AP to drinkable water and CANETAR to wastewater).

The isotopic ratios obtained for each collected sample in this work's case study summer campaign are presented in Figure 3.

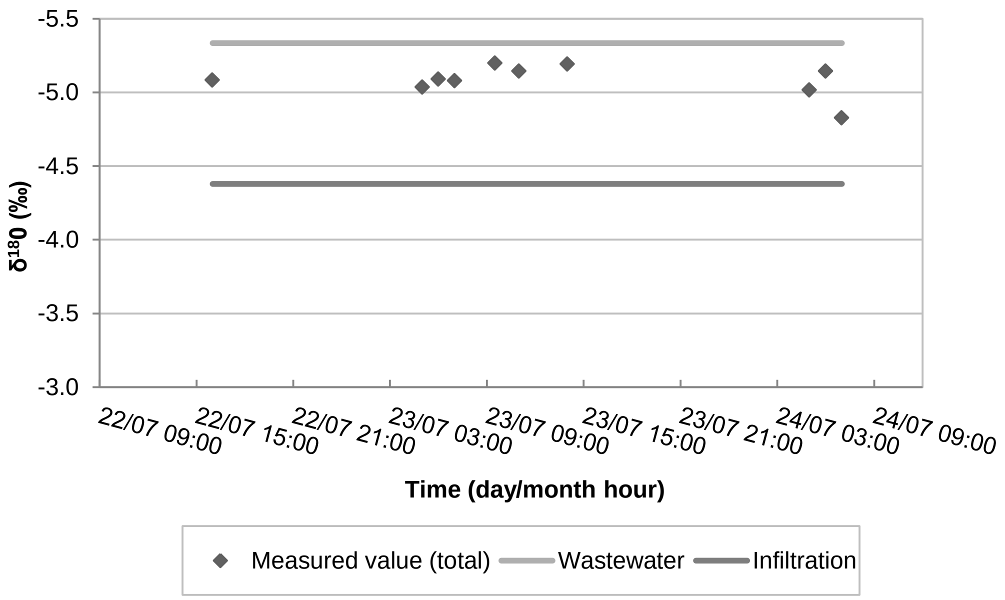

Figure 3: Values of δ^{18}O measured in the CANETAR and mean values for wastewater and infiltration.

The infiltration fraction was obtained by using the total δ^{18}O measured in the main trunk sewer (δ_T) and the average values from all drinking water (δ_{ww}) and groundwater samples (δ_{INF}). Contrary to what was presented in Level I, the infiltration fraction (b) presented in Level II refers to the amount of infiltration in the dry weather strict wastewater flow (excluding infiltration), and it can be given by equation 2.

$$b = 100.\frac{\delta_{\mathrm{T}} - \delta_{\mathrm{ww}}}{\delta_{\mathrm{INF}} - \delta_{\mathrm{ww}}} \quad 2$$

In Alcântara case study, the estimation of the infiltration fraction was proceeded by an uncertainty analysis, which is also part of the δ^{18}O method. Further explanations about this method can be seen in De Bénédittis and Bertrand-Krajewski (2004).

The third and most complex method (Level III) implies the construction of a simulation model, similar to what was proposed by Gustafsson (2000). Information on the physical characteristics of the basin, geological and hydrogeological studies and a good understanding of the pipes' structural conditions are some of the needed inputs. Level III methodology requires a considerable investment and depends on the time available, but it also guarantees more precise results. This methodology was not applied in this work's case study.

Results and Conclusions

According to the obtained results, the mean infiltration flow in Alcântara's main trunk sewer (namely in section CANETAR, shown in Figure 2) can be estimated in 0.30m^3/s, approximately.

The outcome from the first level method is that infiltration corresponds to 35% of the dry weather wastewater flow, and its mean value is 0.31 m^3/s. Similar results were obtained by the Level II method: the infiltration flow, considering only the valid samples, was averaged in 0.30 m^3/s (34% of the dry weather wastewater flow). Level II approach was only applied during summer, which means that obtained results may be non-conservative since infiltration is expected to be higher during winter time.

It must be noted that the mean infiltration flow obtained in Level II does not correspond to an average daily value. As shown in Figure 4, the time range analysed goes from 05:00 to 16:00, which means that only 11 hours of early day time were considered in this estimation. Furthermore, the interval between measurements was not constant. Therefore, the 0.30 m^3/s value represents the average infiltration flow for every instant in each a sample was collected (in CANETAR). It is also important to mention that the uncertainty analysis led to the exclusion of the results provided by some of the collected samples.

Despite of that, Level II is still considered to be more reliable and provide more precise results than Level I. The results from Level II method provide a broader analysis than Level I since instead of providing only one result, estimations of infiltration throughout the day can also be obtained (Figure 4).

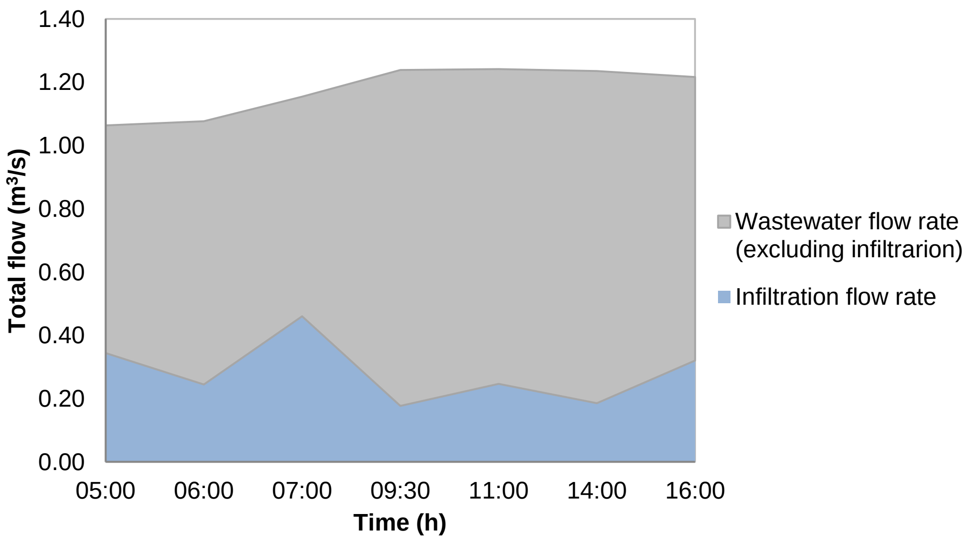

Figure 4: Hydrograph showing the distinction between the two fractions of the total flow (according to Level II method), from 05:00 h to 16:00 h.

Results presented on Figure 4 show some fluctuations in the infiltration rate, throughout the day. This might be justified by variations in the sewer's wastewater depth or discharges related to basement drainage.

In order to overcome this situation, as well as the inaccuracy that can be caused by the exclusive use of the mean infiltration value, a high probability interval is presented. It was observed that most measured values are close to their average (Figure 5). Consequently, it can be plausible to assume that the real infiltration value might vary between two limits, in which 90% of the collected samples can be fitted.

Considering the 90% probability criteria, the infiltration flow in Alcântara's main trunk sewer, during dry weather and in summer time, can vary between 0.18 m^3/s and 0.36 m^3/s (Figure 5).

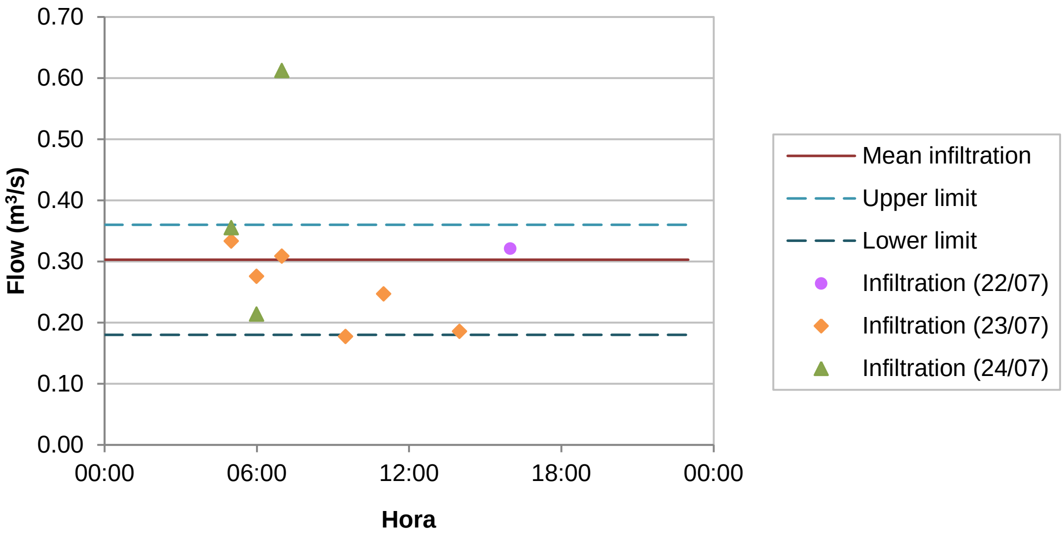

Figure 5: Infiltration flow measured in CANETAR, its mean value and upper and lower limits.

The preciseness of the obtained results for the case study of Alcântara's main trunk sewer (and other similar cases) could be improved if Level III methodology was also applied. That would provide a better knowledge on the infiltration phenomenon, namely in a wider time and space scale range. Based on the interaction between the local aquifer and the wastewater depth inside the sewer, a simulation model could predict the infiltration flow rate in a given time and section. Furthermore, the infiltration flow rate obtained in Level II could be used to calibrate a Level III simulation model.

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