

Impact of Infiltration Systems on Illicit Waters in Sewer Networks [†]

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Abstract: The frequent effects of urbanization and climate change make stormwater runoff control critical. Infiltration systems can provide multiple benefits to the environment, i.e., flood risk mitigation, stormwater quality improvement, aquifer recharge, and a reduction in the activation of combined sewer overflows. However, their use must be carefully planned since they can cause illicit waters in the sewer network due to the deterioration of pipes and junctions. This study proposes a theoretical framework and a case study to assess the interaction between the deterioration of a sewer and the infiltration coming from the soil surface and/or from infiltration systems.

Keywords: illicit waters; infiltration systems; sewer network; nature-based solutions; stormwater runoff control; sustainable urban drainage systems; urban planning; sewer aging; sensitivity analysis; numerical simulation



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1. Introduction

Urban stormwater control is often critical due to both urbanization and climate change [1]. Traditional sewer networks are often insufficient to manage increasing amounts of runoff volumes during extreme rainfall events. Nature-based solutions are effective measures that can be integrated into existing drainage systems for local runoff management [2]. Among them, infiltration systems also contribute to water cycle restoration and aquifer recharge [3]. However, their benefits can be neutralized if the reduction in surface runoff is offset by the increase in groundwater infiltrations into the drainage system due to the deterioration of the sewers and of their junctions [4]. This phenomenon is not negligible, since illicit waters represent a major component of the urban drainage budget, accounting for 35% of mean annual precipitation inputs [5,6]. Several papers have been published about the impact of stormwater infiltration on rainfall-derived inflow and infiltration, discussing different models and approaches [7,8]. This paper proposes a theoretical framework and a numerical application to evaluate the effects of infiltration systems on illicit waters in sewer systems.

2. Materials and Methods

To evaluate the interaction between infiltration systems and illicit waters in sewer networks, a control volume composed of a portion of the catchment with an underlying pipeline was considered (Figure 1). This simplified model was based on the following assumptions: the control volume, of known sizes, has an impermeable bottom and uniform geologic characteristics; the water depth is constant along the pipe and the upstream in flow remains constant during the process; infiltration is just a one-dimensional vertical flow; the variation in the groundwater level in each time step has been neglected; and a constant rainfall intensity has been assumed.

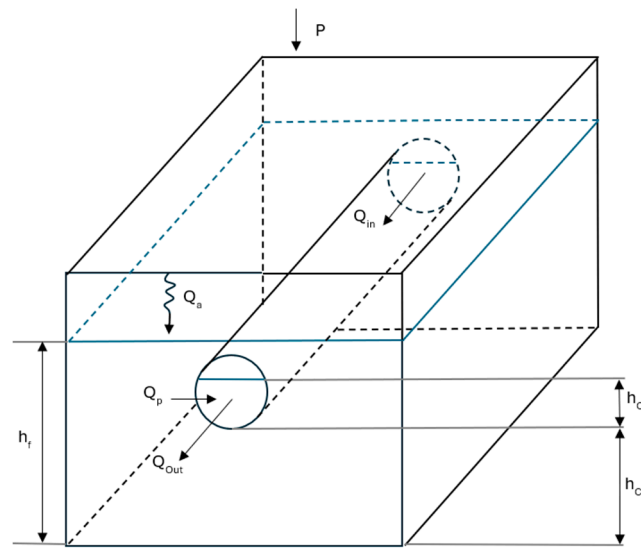


Figure 1. Schematization of the control volume. Q_{in} : inflow rate in the sewer pipeline; $Q_{p,i}$: illicit flow rate; Q_{out} : outflow rate from the sewer pipeline; P : rainfall; h_{ci} : water depth in the pipe; h_c : height of the pipe from the bottom; h_f : groundwater level; Q_a : infiltration rate.

The balance equation in the sewer pipe, at the i -th time instant, is as follows:

$$Q_{in,i} + Q_{p,i} = Q_{out,i} \quad (1)$$

The illicit flow rate $Q_{p,i}$ can be calculated according to the orifice outflow equation:

$$Q_{p,i} = t_c \cdot C_c \cdot L \cdot \sqrt{2g|\Delta h_i|} \quad (2)$$

where t_c can be defined as the transmittance coefficient (in practice, it is like a discharge coefficient), C_c is the wet boundary, L is the length of the pipe, and $\Delta h_i = h_{f,i} - h_{ci} - h_c$ is the water head. The level in the pipe h_{ci} can be estimated by means of the Chezy–Strickler equation:

$$Q(h_{c,i}) = A_c(h_{c,i}) \cdot K_s \cdot R((h_{c,i})^{2/3} \cdot \sqrt{i} \quad (3)$$

where A_c : wet cross area; V : average flow velocity; R : hydraulic radius; i : slope; K_s : roughness parameter. The water balance refers to the control volume results:

$$\frac{V_{i+1} - V_i}{dt} = Q_{a,i-Tlag} - Q_{p,i} \quad (4)$$

where V_i , V_{i+1} : water volume in the control volume at the time instants i and $i + 1$.

The infiltration rate into the control volume Q_a can be estimated as follows:

$$Q_a = P \cdot (1 - \varphi) \quad (5)$$

where $P = I_p \cdot A$, with P : rainfall; I_p : intensity; A : control volume area; φ : runoff coefficient.

In particular, the importance of the lag time T_{lag} it must be stressed, and it describes the time taken by the rainfall to reach the aquifer. Assuming that the variation in the groundwater level is much smaller than the distance a between the soil surface and the same groundwater level, the time-lag T_{lag} can be assumed to be constant and equal to a/v_p , with being v_p the percolation velocity. Obviously, $Q_{p,i}$ also has a delay time related to the flow velocity in the pipe that, regardless, can be neglected if compared with the lag time T_{lag} due to the vertical velocity of the infiltration flow percolating in the control volume.

3. Results

The model has been applied considering two different values of the transmittance coefficient, $t_c = 0.000003$ and $t_c = 0.00001$, and six different rainfall intensities of the rainfall intensity, $i = 0$ mm; $i = 10$ mm; $i = 20$ mm; $i = 30$ mm; $i = 40$ mm; $i = 50$ mm. The other assumed data are $h_F = 2$ m, $h_C = 1.5$ m, $t_{lag} = 15$ min, $Q_{in} = 100$ l/s, $k_s = 70$ m^{1/3}/s, $D = 80$ cm, $i = 0.0004$, $\varphi = 0.5$, length of the pipe $L = 100$ m, and catchment area $A_b = 1$ ha. The values of the infiltration rate over time are shown in Figure 2.

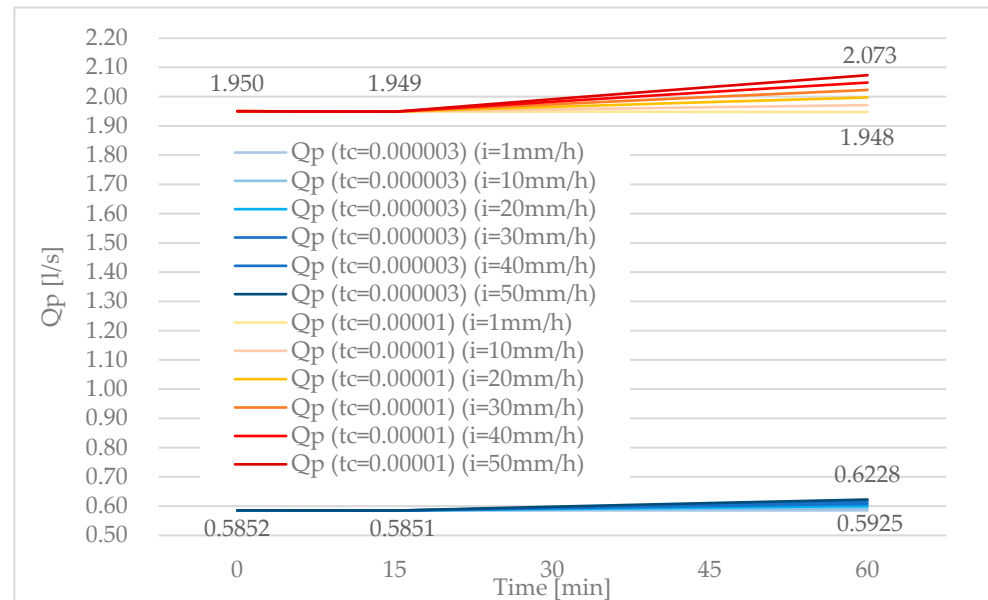


Figure 2. Illicit flow in the considered sewer for different values of rainfall intensity and transmittance coefficient.

4. Discussion

Illicit flows are a function of pipe deterioration and rainfall intensity. The rainfall effect is not instantaneous, but there is a delay depending on the type of soil and the aquifer level. This is the reason that, at the beginning (for the first 15 min in this case study), the trend corresponding to different rainfall intensities coincides. It represents the delay that the stormwater takes to infiltrate and reach the aquifer. The position of the water level in the pipe and the water level in the aquifer strictly influence the illicit flow rate. In this case, the groundwater level is always greater than the water level in the pipe for all the rainfall durations. Considering a transmittance coefficient of 0.00001, the illicit rate in the pipe decreases until $t = 15$ min, since the groundwater level decreases. Then, after this initial phase, the infiltration rate reaches the groundwater level and starts increasing; the higher the rainfall intensity, the higher is this contribution. The pipe condition improvement produces a significant reduction in illicit flows. Obviously, the infiltration rate from the surface is the same, but the groundwater level variation is not significant enough to influence the illicit rate. Decreasing the transmittance coefficient has a great impact on the illicit flow rates, not only reducing them but also reducing the influence of the rainfall intensity: 108 L/h for $t_c = 0.00001$ and 450 L/h for $t_c = 0.000003$.

5. Conclusions

This study shows the importance of evaluating the status of sewers in urban drainage systems when planning their integration with infiltration systems. As a matter of fact, it must be avoided that the amount of stormwater that is locally disposed, and therefore is theoretically supposed not to be collected by the sewer, is conveyed in the form of illicit water. Further developments of this study will consider different kinds of soil (corresponding to different hydraulic conductivities) and real rainfall patterns (not constant in time).

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