



## A case study of rainfall-derived infiltration and inflow on a separate sanitary sewer system

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5 **Abstract.** Rainfall-derived infiltration and inflow (RDII) can interfere with the performance of domestic wastewater drainage  
6 systems. It is also a major cause for the deterioration of the functional performance in those systems and for the occurrence  
7 of domestic wastewater untreated discharges to the water environment. In most cases, the actual size and location of these  
8 inflows are unknown. To assess this subject of RDII, a detailed knowledge of the network is required as well as a diagnosis of  
9 the problem, namely, the type of inflows, the magnitude of their occurrence and the location of the most relevant impacts. This  
10 paper presents the application of a methodology to estimate RDII on a Portuguese case study.

### 11 1 Introduction

12 Separate wastewater sewer systems are designed to convey sanitary and stormwater in separate sewers. There are three major  
13 components of wastewater flow in a sanitary sewer system: base sanitary flow, groundwater infiltration and rainfall-derived  
14 inflow and infiltration (RDII), more commonly referred to as inflow (EPA, 2014). This inflow may be considered excessive  
15 when it compromises the systems performance or when the cost for its transport and treatment exceeds the cost to eliminate it.  
16 Often, excessive inflow is collected during rainfall via illicit connections from roof leaders, house drains, sump pumps, or  
17 stormwater sewers, as well as through defects in pipes and manholes (Harold, 2007). Sewers which are found connected from  
18 the stormwater drainage system must be disconnected and rerouted as soon as possible.

19 After a strong rainfall event, performance of separate sanitary sewer systems may decrease significantly due to inflows which  
20 can cause, among others: an increase of operation and capital costs of sewers and wastewater treatment plants; a decrease of  
21 pipe capacity which potentiates untreated wastewater discharges, and consequently increases pollution; occurrence of floods  
22 (Amorim *et al.*, 2007).

23 Despite the significant investments made in the last decade in Portugal, in many cases wastewater systems performance is far  
24 from satisfactory, with the perception that RDII largely contribute to this situation (Almeida e Cardoso, 2010). This problem  
25 is well known by wastewater utility managers, who recognize that it is an important cause of functional performance  
26 deterioration. Thus, it is essential to adopt appropriate methodological approaches and to select suitable actions to promote the  
27 gradual reduction of RDII, in order to increase system efficiency and effectiveness in economic, environmental and operational  
28 terms.

29 This paper presents the application of an estimation methodology of RDII to a real case study.

### 30 2 Rainfall-derived inflow and infiltration, modelling and performance evaluation

31 Undue connections between drainage systems are not easily located, since they are generally not registered. Monitored data is  
32 a very valuable source of information on the systems behaviour. Undue connections can be perceived through the analysis of  
33 flow measurement records, where the method to be used depends on whether one wants to detect connections from stormwater  
34 to sanitary pipes or vice versa. In the first case, there are abrupt variations in the hydrograph when it rains. Mathematical  
35 modelling can be used as a step forward to locate the undue connection, which can be followed by visual or CCTV inspections.



36 In the second case, dry weather measurements in the stormwater system detect undue permanent flows when rain events don't  
37 occur. If the pipe is subject to water table fluctuations, these campaigns must be carried out in the dry season, where infiltration  
38 flow is as low as possible. Once again, modelling can be used to understand how spread out infiltration is within the system.  
39 Hydraulic modelling is an important instrument for drainage systems diagnosis (Rauch *et al.*, 2002), and can be used to analyse  
40 existing sewer systems, to identify potential problems, and to design best corrective solutions (Nicklow *et al.*, 2004). Modelling  
41 enables analysing how the system functions, by reproducing its actual behaviour or by estimating the values of hydraulic  
42 variables according to pre-established scenarios, over time and along every pipe. As a support for utilities daily decisions,  
43 models allow to locate critical pipes, support the diagnosis of system performance or enable studying alternative operational,  
44 maintenance or rehabilitation solutions or comparing competing new projects. However, its potential can only be fully  
45 exploited if hydraulic measurements are performed, preferably continued and obtained over a period of time that allows to  
46 encompass different states of the system. Without calibration and validation with local data, a model is only a hypothesis for  
47 the simulation of reality (Cardoso, 2008).

48 Monitored data is therefore a valuable input for modelling also, which requires hydraulic pipe data and precipitation data.  
49 Measuring flow rates for quantifying infiltration is particularly difficult, especially when dealing with reduced flow rates or  
50 water height. Estimating infiltration flows can also be done through the analysis of flow hydrographs or by using tracers, such  
51 as floating solids, fluorescent liquids or chemical tracers (De Bénédittis, 2004; Kracht *et al.*, 2003). The minimum values of  
52 the hydrographs are related to sanitary discharges at night, to the time necessary to flow upstream connections and to the  
53 groundwater infiltration. Minimum flows can also vary over time, due to the rise of the water table after a rainy period. De  
54 Bénédittis (2004) presents a more complete framework for the determination of infiltration and exfiltration. Cardoso (2008)  
55 presents values related to these occurrences from bibliography and from regulatory and legislative limits present in several  
56 countries.

57 Choosing the rain events to model has to address a few concerns. To start, any record above zero in the precipitation records  
58 may be considered a rain event. However, if it has reduced intensity and duration, then surface runoff may not occur, whenever  
59 the precipitated water volume is lower than infiltration or surface retention volumes. Even if surface runoff occurs, it may not  
60 be totally intercepted by the drainage system under study. In this case, it is important to identify, among the available rain  
61 events, which ones are of interest for evaluating the effects of precipitation in the drainage system (that result in changes in  
62 the hydrograph). In WaPug (2002), Jørgensen *et al.* (1997) and Bertrand-Krajewski *et al.* (2000), recommendations are made  
63 regarding which characteristics rain events should have (in intensity, total precipitation and event duration) to be identified as  
64 relevant for modelling RDII. In addition, it is also recommended to group the precipitation events according to the impact on  
65 the pipe flow (Saul, 1997), that is, to analyse the flow hydrograph first and then to group the rain events that have occurred  
66 since the flow moved away from the dry weather pattern until it returns to this pattern. When there are water retentions in the  
67 system or the infiltration component assumes a significant proportion, a flow component is registered in the hydrograph,  
68 frequently some days after the rain event.

69 Performance assessment is a means for objectively quantifying the capabilities and deficiencies of the systems, supporting  
70 decision making (Cardoso, 2008). It is supported on performance indicators, which are quantitative efficacy and efficiency  
71 metrics that allow the diagnosis of the current situation of the infrastructure. The characteristics of the available data  
72 determines the scale of the assessment: for a less detailed assessment, on a global scale, it is possible to use only monitoring  
73 data; a detailed assessment, on a pipe scale, requires modelling results.

74 The Portuguese decree law on the design of urban water infrastructures establishes design criteria for the beginning of operation  
75 and for the project horizon. These criteria are of a constructive nature (for example, establishing minimum and maximum pipe  
76 slopes) and of a hydraulic nature (for example, establishing minimum and maximum velocities). Some of the legal criteria, in  
77 particular those of a hydraulic nature, can be used to assess, at any given moment, how the infrastructure is performing.



78 Although constructive criteria do not in themselves constitute performance appraisal criteria, they are often the explanatory  
 79 factors for any performance shortfall in a non-performing system.

80 Cardoso (2007) defined twenty-six performance indicators, of which eleven relate to hydraulic performance and fifteen to  
 81 environmental performance for the evaluation of the technical performance. Estimating rainfall derived inflow and infiltration  
 82 was one of the criteria under consideration.2 Methodology

83 As mentioned, RDII can be assessed in different ways. In the case study, a two-step based methodology was adopted, namely  
 84 i) hydraulic modelling and assessment and ii) calculation of performance indicators.

### 85 **2.1 Hydraulic modelling and assessment**

86 There are several computer applications available in the market, commercial or freeware, that allow building hydraulic models  
 87 for drainage systems

88 In the case study, Storm Water Management Model (SWMM) from Environmental Protection Agency (EPA) was used.  
 89 SWMM is used throughout the world for planning, analysis and design related to stormwater runoff, combined and sanitary  
 90 sewers, and other drainage systems in urban areas. Furthermore, SWMM is freeware and has a vast user community that  
 91 participates intensely in forums and newsgroups.

92 The use of SWMM implies collecting several data such as sewers and manholes registry information, amount of sewage  
 93 discharged per manhole and flow measurements. The discharge per manhole can be estimated from the product of population,  
 94 per capita water use and ratio of water rejected to the sewer system. Flow measurement can be used to calibrate the hydraulic  
 95 model. Furthermore, it is necessary to collect precipitation data to investigate RDII in a separate sanitary sewer system.

96 The hydraulic model can be used for dry-weather flow and for contributing impervious area determination. The former is  
 97 generally used to establish a dry-weather flow pattern from flowmeter data. The latter is used to estimate the amount of  
 98 impervious area wrongly connected to the sanitary sewer pipes (Brito *et al.*, 2009). When facing a separate sewer system with  
 99 unwanted stormwater sewer connections, the contributing impervious area is difficult to quantify. Being so, in such systems it  
 100 may not be useful to accurately determine the real impervious areas. This would mean that the whole amount of net  
 101 precipitation would drain to the pipes, which is of course not correct in the case of sanitary sewer systems (Brito *et al.*, 2009).  
 102 The part of runoff that derives from the hydrological model could be determined based on the rainfall volume (R-value)  
 103 method, which calculates RDII volume as a fixed percentage of the rainfall amount. Based on the R-value method and the  
 104 Rational Method, it is feasible to adopt an auxiliary parameter, contributing impervious area A', suitable to estimate extraneous  
 105 rain water flows. A' represents the amount of impervious area connected, a parameter that varies with the rainfall event (Brito  
 106 *et al.*, 2009).

107 For a proper characterization of pipe behaviour, it is considered that at least two days of dry weather flow and three precipitation  
 108 events should be modelled, and this number should be higher if dry weather patterns show significant variations or if undue  
 109 inflows of pluvial origin occur in sanitary systems (either direct inflows or infiltration) (WaPug, 2002).

### 110 **2.2 Calculation of performance indicators**

111 As referred, performance Indicators (PIs) provide key information to assess the efficiency and effectiveness of a service, and  
 112 may thus be used as a measure of a particular aspect of an utility's performance or standard of service (Matos *et al.*, 2003). PIs  
 113 are considered to be a means of aggregating information on system characteristics and data gathered from monitoring or  
 114 modelling and translated into performance values (Cardoso and Frehmann, 2010). PIs can be classified in relation to "good"  
 115 or "bad" performance.

116



117 Table 1 shows the Performance Indicators for RDII used in the case study (from Cardoso, 2008).

118



119

**Table 1 - Performance Indicators for RDII**

ID	Designation	Definition	Unit	Performance		
				Good	Average	Bad
PI <sub>1</sub>	Proportion of the sewer full section flow capacity ( $Q_{full}$ ) used by the minimum daily dry-weather flow ( $Q_{min,dw}$ )	$\frac{Q_{min,dw}}{Q_{full}}$	%	<25	25-50	>50
PI <sub>2</sub>	Proportion of the sewer full section flow capacity ( $Q_{full}$ ) used by the maximum daily dry-weather flow ( $Q_{max,dw}$ )	$\frac{Q_{max,dw}}{Q_{full}}$	%	<75	75-100	>100
PI <sub>3</sub>	Proportion of minimum daily dry-weather flow ( $Q_{min,dw}$ ) by average daily dry-weather flow ( $Q_{avg,dw}$ )	$\frac{Q_{avg,dw}}{Q_{min,dw}}$	%	<25	25-50	>50
PI <sub>4</sub>	Ratio between maximum daily dry-weather flow ( $Q_{max,dw}$ ) and average daily dry-weather flow ( $Q_{avg,dw}$ )	$\frac{Q_{max,dw}}{Q_{avg,dw}}$	-	<3	3-5	>5
PI <sub>5</sub>	Minimum daily dry-weather flow ( $Q_{min,dw}$ ) per unit length of sewer ( $L_{sewer}$ )	$\frac{Q_{min,dw}}{L_{sewer}}$	m <sup>3</sup> /(day.km)	<40	40-80	>80
PI <sub>6</sub>	Proportion of the sewer full section flow capacity ( $Q_{full}$ ) used by the maximum daily wet-weather flow ( $Q_{max,ww}$ )	$\frac{Q_{min,ww}}{Q_{full}}$	%	<75	75-100	>100
PI <sub>7</sub>	Proportion of daily wet-weather volume ( $V_{ww}$ ) by daily dry-weather volume ( $V_{dw}$ )	$\frac{V_{ww}}{V_{dw}}$	-	<3	3-6	>6

## 120 3 Case study

### 121 3.1 System description

122 The case study is a small sanitary sewer system located in Lisbon Metropolitan Area, Portugal. The urban catchment has a  
 123 very heterogeneous occupation with buildings up to 5 floors, a supermarket, a police station, schools and some shops.  
 124 Estimated residential population is about 4,018 inhabitants. The sewer network is about 11.8 km long and has around 1,577  
 125 domestic and 205 non-domestic service connections. Most sewers are made of PVC with 200 mm of diameter (which is  
 126 minimum diameter allowed by the Portuguese design decree law). The system has a pumping station that raises wastewater  
 127 from a lower to a higher elevation of the network. At the final end of the system there is a flowmeter that measures the amount  
 128 of wastewater delivered by the Municipality to a public company that will convey it to the wastewater treatment plant. A study  
 129 made by Municipality concluded that the total amount of potable water sold in the urban catchment of the case study was lower  
 130 in about 56% than the wastewater delivered to the company for treatment. This is a huge difference that can only be explained  
 131 by some kind of RDII.

132 From a hydrogeological point of view, Portugal is a favoured country and major groundwater unit of the Iberian Peninsula is  
 133 the huge Tagus-Sado aquifer system. Despite the case study is located above the Tagus-Sado aquifer system in a first approach,  
 134 groundwater infiltration was not utility's major concern and the study will focus mainly on the inflow component.

### 135 3.2 Flow and precipitation data

136 The flowmeter installed downstream the system measures the amount of wastewater delivered by the Municipality to the  
 137 wastewater treatment plant (WWTP). Flow data was available for a period of 181 days (from 5th June 2014 to 2nd December  
 138 2014), and has a 15 minutes time step. . This time step is not the most suitable to allow a comparative analysis with precipitation  
 139 data, once precipitation events have high variability within 15 minute periods.

140 Precipitation data from a rain gauge temporarily installed in a neighbouring municipality was available. Despite the rain gauge  
 141 not being located in the catchment area, it was the only in the surroundings where data with a time step smaller than 1 hour  
 142 was accessible. Precipitation data for a period of 1 year (from 3<sup>rd</sup> February 2014 to 4<sup>th</sup> February 2015) was gathered.



143 The annual climatologic bulletins of 2014 and 2015 from the Portuguese atmospheric and ocean institute evidence that 2014  
 144 was the rainiest of the last 25 years and 2015 was the sixth dryer year since 1931 and the fourth since 2000, respectively.  
 145 Since flow data refers only to the second half of 2014, the analysis will merely focus on this period.

### 146 3.3 Hydraulic modelling and assessment

147 The hydraulic model was built based on information provided by the Municipality which included registry data from the pipes  
 148 and manholes. Some additional verifications were necessary, since some data were inexistent (e.g. pipes without diameter) or  
 149 were wrongly attributed (e.g. pipes with negative slope). A total of 443 manholes and corresponding pipes were modelled.  
 150 The Portuguese design decree law has several dimension criteria to be checked, such as maximum length between manholes  
 151 ( $L_{max} = 60$  m), minimum sewer diameter ( $DN_{min} = 200$  mm), minimum and maximum slope ( $i_{min}$  and  $i_{max}$ , 0,5 and 15%,  
 152 respectively) and minimum depth ( $h_{min} = 1,2$  m). Table 2 shows the percentage of pipes that don't comply with design criteria.  
 153

**Table 2 – Percentage of sewers in noncompliance with dimension design criteria**

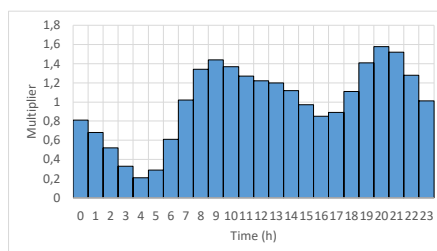
Design criteria	$L_{max}$	$DN_{min}$	$i_{min}$	$i_{max}$	$h_{min}$
Noncompliant sewers (%)	0.7	0.0	19.4	1.1	3.0

154  
 155 Most criteria are complied with. Nevertheless, the minimum slope is a concern in this system, which may limit drainage  
 156 capacity. For each of the criteria, noncompliant pipes location was identified in a report for the utility.

157 The amount of sewage discharged per manhole is estimated considering population, per capita drinking water use and ratio of  
 158 water rejected to the sewer system. According to the Portuguese 2011 Census, resident population in the urban catchment was  
 159 4,018 inhabitants. To estimate the average sanitary flow, drinking water consumptions in 2008 and 2012 were used. Registered  
 160 values of 193,260.5 m<sup>3</sup> and 160,688.6 m<sup>3</sup> correspond to a per capita water use of 132 and 110 L/(inhabitant.day), respectively  
 161 for 2008 and 2012. The Portuguese design decree law refers, for design purposes, that circa 80% of drinking water generates  
 162 sanitary wastewater; therefore, the corresponding per capita sewage was 105 L/(inhabitant.day) and 88 L/(inhabitant.day) for  
 163 2008 and 2012. An average value of 100 L/(inhabitant.day) was firstly considered for modelling.

164 It's interesting to compare this value to the ones obtained based on the available wastewater measurements. Dividing the  
 165 wastewater volume measured in 2014 (in 181 days, 143,647.4 m<sup>3</sup> were registered) by the resident population, a per capita  
 166 sewage of 197 L/(inhabitant.day) is obtained. This value is much higher than the others previously estimate, which may be an  
 167 indicator of the presence of RDII.

168 The dry weather inflows were obtain considering the contribution from each house hold, adjusted on an hourly basis by  
 169 applying the time pattern multipliers shown in Figure 1.



**Figure 1- Hourly dry-weather inflows pattern**

170  
 171  
 172 The pumping station was installed circa 20 years ago, and has two pumps, one for regular service and the other for emergency  
 173 purposes. These pumps, installed in a wet well, are vertical axis centrifugal pumps and were designed for a flow rate of 20.3  
 174 m<sup>3</sup>/hr. This pumping station was modelled in SWMM with a storage tank connected to a pump. The pump curve type chosen



175 was type 4, where flow varies continuously with the inlet node water depth. Two control rules were implemented, the first  
 176 starts pumping when water depth is higher than 0.5 m and the second stops pumping when water depth is lower than 0.1 m.  
 177 For dry weather, hydraulic design criteria were evaluated, such as minimum and maximum velocity ( $v_{min}$  and  $v_{max}$ , 0,6 and 3  
 178 m/s, respectively) and maximum relative water depth ( $h/D_{max}=0,5$  m). Table 3 shows the percentage of pipes that don't comply  
 179 with design criteria.

180 **Table 3 – Percentage of sewers in noncompliance with hydraulic design criteria**

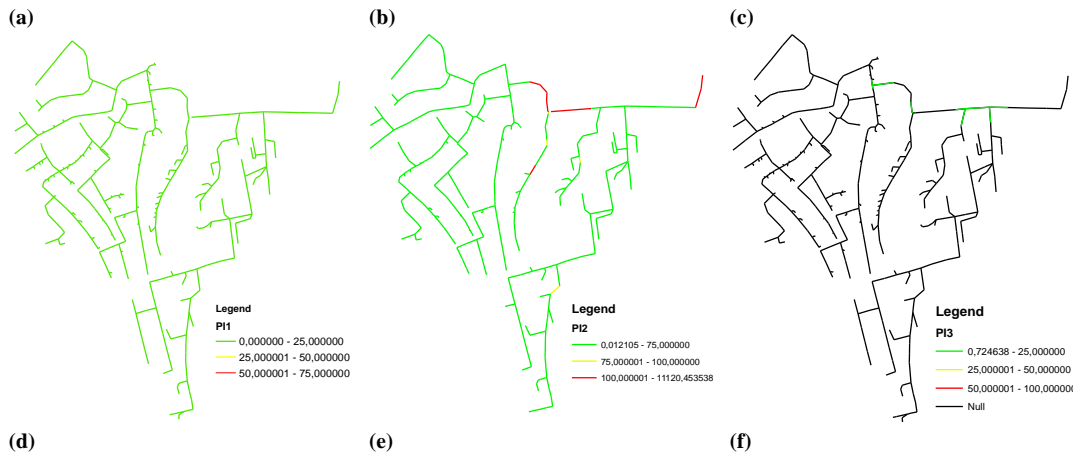
Design criteria	$v_{min}$	$v_{max}$	$h/D_{max}$
Noncompliant sewers (%)	91,9	0	1,8

181  
 182 The minimum velocity is a concern in this system, which is associable to low slopes and reduced flows in the upstream pipes.  
 183 Model validation for dry-weather flow was performed through the adjustment of per capita sewage inflow and for the pump  
 184 curve parameters. The adequacy of the simulated flow in face of the measured flow was tested for the 5 days under analysis.  
 185 The adequacy was evaluated by calculating the volumetric error and by graphical comparison between the flow series. The  
 186 volumetric errors after validation vary between -7% and 4%, which was considered acceptable. For dry weather, the ratio  
 187 between the simulated and measured flow values should have a volumetric error between -10% and 10% (WaPUG, Watewater  
 188 Users Group, Allit, 1999).

189 After model validation for the dry-weather scenario, system behaviour during rainfall events was assessed. Drainage  
 190 subcatchments (five, from SC1 to SC5) were characterized and connected to downstream manholes. SWMM requires the  
 191 definition of the subcatchment impervious area, and assumes that all this area contributes to pipe flow. Based on a preliminary  
 192 evaluation of runoff volume during wet weather, for the case study, three different contributing impervious areas were  
 193 considered ( $A_1'=16\%$ ,  $A_2'=27\%$  and  $A_3'=38\%$ ). For each of these cases, three rainy days were studied (R1 in 10 of September  
 194 of 2014, R2 and R3 in 12 and 13 of October of 2014), resulting in nine different wet weather scenarios. For these scenarios, a  
 195 few pipes surcharge and between 4 and 48 manholes are subject to sewage discharge through the manhole cover.

196 **3.4 Performance indicators**

197 Some of the results obtained by PIs calculation are shown in Figure 2.





198 **Figure 2 - Performance Indicators for RDII: (a) PI<sub>1</sub>; (b) PI<sub>2</sub>; (c) PI<sub>3</sub>; (d) PI<sub>4</sub>; (e) PI<sub>5</sub>; (f) PI<sub>6</sub> for R1 and A<sub>1</sub>'=16% scenario**

199 Both PI<sub>1</sub> and PI<sub>5</sub> relate to minimum flow. Figure 2 (a) shows that all sewers in the network are below 25% which means a  
 200 good performance in PI<sub>1</sub>. In PI<sub>5</sub>, the results obtained for the upstream sections of subcatchments give values below 40  
 201 m<sup>3</sup>/(day.km) which means a good performance. The lowest value obtained in PI<sub>5</sub> was 0.31 m<sup>3</sup>/(day.km) and the highest was  
 202 1.31 m<sup>3</sup>/(day.km). These results indicate a low concern with infiltration.

203 In the case of PI<sub>2</sub>, nine sewers have a value exceeding 100% which means bad performance in this indicator. These pipes  
 204 surcharge in dry weather without any exceptional input. This behaviour may compromise system performance. Only two of  
 205 the nine sewers are within the regulatory slope and three of them have very constrained sections. Most of the sewers (i.e. 295)  
 206 present a good performance and 4 present an average performance in indicator PI<sub>2</sub> (see Figure 2b). Nevertheless, it is important  
 207 to underline that PI<sub>2</sub> is classified as “good” for values lower than 75%, whereas the decree law stipulates as a design criterion  
 208 a maximum h/D of 50%. That is, the situation could be more critical if the IP<sub>2</sub> reference values were more similar to those in  
 209 the decree law. With circa 1.8% of the network non complying in relation to h/D (Table 3), it is foreseeable that around 75  
 210 pipes could present limitations on IP<sub>2</sub> if reference values were adjusted accordingly.

211 The indicator PI<sub>3</sub> only was computed for the sewers immediately downstream of the subcatchments. As shown in Figure 2 (c)  
 212 all sewers present an indicator below 25% which represents an overall good performance. It should be noted that four pipes  
 213 have IP<sub>3</sub> above 20%, which, even more than IP<sub>1</sub>, may be indicative of the presence of infiltration.

214 PI<sub>4</sub> represents the ratio between maximum daily dry-weather flow and average daily dry-weather flow and can be associated  
 215 to a peak factor. The Portuguese design decree law establishes that for sanitary systems the peak factor is the ratio between  
 216 maximum flow and the annual average flow and can be determined by Eq. (1):

$$217 \quad fp = 1,5 + \frac{60}{pop^{0,5}} \quad (1)$$

218 in which fp = peak factor and pop = number of served inhabitants by the sanitary system.

219 Table 4 shows the results obtained for the five subcatchments considered in the case study,

220

**Table 4 – Results of fp and PI<sub>4</sub> obtained**

Subcatchment	Pop (inhabitants)	fp (-)	PI <sub>4</sub> (-)
SC1	378	4,6	1,58
SC2	402	4,5	1,58
SC3	234	5,4	15,54
SC4	456	4,3	12,04
SC5	2208	2,8	5,07

221 It appears that there is no direct relation between these two parameters neither in terms of magnitude nor the proportion of PI<sub>4</sub>  
 222 with the contributing population. This observation suggests the existence of other uses in addition to the domestic uses. Like





223 PI<sub>3</sub>, this indicator was computed for the sewers at the downstream end of the subcatchments. Figure 2 (d) shows that two  
224 sewers present good performance and the other three have bad performance. In these latter cases, as those don't correspond to  
225 upstream pipes, it may be relevant to carry out a more detailed survey of the wastewater contributions, in order to acknowledge  
226 possible water uses not known to the utility.

227 PI<sub>6</sub> is computed for all sewers, except for those where flow is null (see Figure 2f), for the 9 wet weather scenarios under study.  
228 For these scenarios, between 84% and 96% of the pipes presented a good performance, but between 3% and 14% presented  
229 bad performance. Most pipes have good performance in PI<sub>6</sub>. Nevertheless, a bad performance in this PI means that the pipes  
230 surcharged due to precipitation, which occurred in more than 10% of the pipes in two scenarios, which already conditions the  
231 performance of the system.

232 PI<sub>7</sub> represents the proportion of daily wet-weather volume by daily dry-weather volume and is computed for the sewers  
233 downstream the subcatchments, for the 9 scenarios. Results obtained show that all sewers present a good performance since  
234 all values obtained were below 3. This means in overview, that there is no generic problem of excess of stormwater volume  
235 from the contributing subcatchments. Nevertheless, it should not be overlooked that in every scenario there is a volume higher  
236 than dry weather volume (PI<sub>7</sub> ranged from 1.0 and 2.6), which means that there is an effective rainfall contribution in all  
237 events, even if the ranks in ID<sub>7</sub> is not concerning. What this also means is that there is a reduced proportion between the  
238 rainfall volumes and the sanitary volumes; in the case of discharging through the manhole cover, this discharge has a dilution  
239 of less than 1:3, which may constitute a problem from the point of view of environmental impact and public health.

240 In summary, considering the study of the various performance indicators, it was verified that the pipes evaluated with bad  
241 performance mostly belong to the same area in the system, namely the northern zone where the pumping station is installed  
242 and where two subcatchments connect. The remaining areas of the system presented acceptable performance results.

#### 243 4 Final remarks

244 In this paper an application of an estimation methodology of RDII to a Portuguese case study was presented. A two-step based  
245 methodology based in hydraulic modelling and assessment and performance evaluation was explained and applied. The aim  
246 of the study was to estimate the amount of RDII in the sanitary system and locate the priority intervention areas mostly  
247 concerning direct rainwater inflow. This case study is a small sanitary sewer system located in Lisbon Metropolitan Area,  
248 Portugal. The obtained results showed that there is no major overall problem of RDII in the case study. Note that the study has  
249 some limitations that can influence the final results such as i) the flow data collected showed values with large fluctuations in  
250 many days' due pump operation which was difficult to model in SWMM; ii) precipitation data were available only for 2014;  
251 iii) precipitation data were available with a time period of 15 minutes not addressing precipitation variability; and iv) the rain  
252 gauge was not located in the system subcatchments. In future works is recommended to install a rain gauge in the system  
253 subcatchments and collect precipitation data with a time period of 1 minute during an entire year. Additionally, infiltration  
254 studies could be more detailed; hydrogeological studies should be carried out in order to analyse the influence of the water  
255 table to the wastewater drainage system.

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