Assessing the Environmental Performance of Urban Wastewater Systems, with emphasis on Microbiological Contamination: Development of Microbiological INSA Model

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Abstract

The evaluation of the environmental performance of urban drainage infrastructures is a domain of knowledge that has gained increasing importance, and often there is no consensus on how this greatness must be measured or compared. The Microbiological Integrated Simplified Approach (Microbiological INSA) presents itself as a systematic methodology of assessing the environmental performance of drainage systems, producing graphs and tables of performance, that are easy to interpret and compare, constituting a tool of great utility and importance in operational management for entities who manage sanitation systems. This tool allows the evaluation of the environmental performance of systems even in situations where there is lack of data or information concerning to its operation. The development of this paper aims to: (I) *Development of an integrated wastewater model, based on microbiological contamination (Microbiological INSA),* (II)*Development of an automatic program for the implementation of the Model* (III) *Application of the methodology Microbiological INSA to the drainage basin of Algés-Alcântara;* (IV) *Validation of the new model by comparison of the results obtained by applying the Integrated Simplified Approach based on microbiological contamination, with the results obtained by modeling INSA, based on the parameter Chemical Oxygen Demand (COD).*

Key-words: Urban drainage systems; environmental performance evaluation; performance indicators; management systems; decision support; rehabilitation.

1. Introduction

Initiatives to be undertaken in the field of urban drainage seek sustainable development, they intend to streamline and optimize the available resources through the implementation of integrated and cost-effective actions (Coelho, 1997). The available tools for analysis, diagnostic and benchmarking systems include methods based on observations by inspection, mathematical models and monitoring systems. Mathematical models are an important instrument; however produce results often complex and difficult to interpret. The results of the monitoring, if available, provide a large volume of data, which can be difficult to interpret. To effectively achieve the intended goals is necessary to develop new tools to support both the diagnostic performance of systems and decision making rehabilitation interventions. In this context, and in a modern business perspective, the use of integrated approaches that reflect the quality of service practiced becomes an indispensable tool in support, to the management of urban drainage systems as it complements and enhances the knowledge obtained through more complex models calculations. The Microbiological INSA model is based on the concept of indicators $(\mathrm{I_d})$ or performance indices $(\mathrm{ID_{pond}})$ system, which integrate the contribution of the various system components (sewage networks, Waste Water Treatment Plant and receiving environment) and its application is especially intended in situations studies design and rehabilitation work or improvement on existing systems in which there is a lack of data and information relating to the system under study. It simplifies the analysis and evaluation of the most appropriate interventions compared to the more complex or sophisticated models.

2. Literature review

Environmental assessment, based on performance indicators, enables the definition of integrated aspects that must be evaluated in order to obtain better control, understanding and improvement on these activities, as well as support the decisions. Performance evaluation can be applied in any sector of the organization, from the highest levels of administration and management, to specific areas of activity (PBM SIG, 1995).

In this context, the International Water Association (IWA) has promoted the development of a Performance Indicators system (ID) for the services of water supply and wastewater. The system defined, was intended to provide the management tools and integrated management objectives on any aspects related to the provision of water and wastewater (Alegre, *et a*l. 2000). A sure sign of global relevance of an integrating framework of performance indicators under the provision of water supply and wastewater comes from recent developments in the field of international standardization as part of the work developed by Technical Committee ISO/TC 224, which aims to normalize a framework to the evaluation and characterization of activities related to water supply services and waste water (Alegre *et al*., 2011).

In the original edition of the manual for water supply services were recommended six groups of indicators: water resources, human resources, infrastructural, operational, quality of service and economic – financial. According to the authors, the handbook of IDs for wastewater services, published following the IDs manual for of water supply systems, kept the general principles and approach set out in the original edition, meaning that the definition of IDs and context of its use were made similarly. This is due to the fact that the general approach and format used in the original edition have been widely accepted and produced appropriate results. Thus, water and wastewater IDs share a common structure and many indicators and variables, however, the most significant differences between the main characteristics and service requirements of the two types of systems require some differentiation. (Alegre *et al.,* 2011). According to the author, a performance indicator is the value resulting from the combination of several variables, usually a ratio of these, expressed in specific units, and the degree of trust which indicates the quality of the data represented by this indicator. The same authors consider that the performance indicators measure the efficiency and effectiveness of a service provided by an entity and the information they provide allows the comparison of the results, with values of the same indicator over time or values of other entities.

Given the increasing relevance of these issues, it is intended to characterize the situation in Portugal regarding to environmental performance evaluation of water supply systems, sanitation systems, wastewater treatment plants and solid waste, through the presentation of the results published by the Regulatory Authority and Waste Water Services, in its annual report (RASARP), for the year 2011 (Systems Water Supply Systems and Sewage) and Inspection general for the Environment and Spatial Planning (MAOTDR, 2004), which characterizes the situation of domestic WWTP, in 2000 and 2001. In this paper are also referred two research programs developed by national and international entities: The National Initiative for Performance Evaluation of ETA and Urban WWTP "PASt21" and The Multilateral and Scientific Network Program “COST” (European Cooperation in the field of Scientific and Technical Research), due to its contribution to the development of the sector.

It is found that the evolution in the field of urban drainage has been directed primarily to the rationalization and optimization of resources through the adoption of integrated and more cost-effective actions. Improving the quality of service provided by managers has become a priority issue in the field of sanitation. The availability of tools for the assessment of service levels or performance of the systems, has assumed a growing importance given the contribution to knowledge, of the actual impact of the interventions and investments over the behavior and improvement of infrastructure. In Portugal, and especially in a time of great financial constraints for institutions, it becomes very important to develop methodologies or approaches to assess funding priorities, particularly regarding the selection of projects and interventions more relevant. In Portugal, in most cases, the available information that characterizes the system lacks quality and is often insufficient. The development and application of detailed models are usually incompatible with the level of depth required to studies, with response times desired and existing field data. The Microbiological Simplified Integrated Approach (Microbiological INSA) developed in this paper, is especially suited to studies in which the use of complex models may prove difficult or practically impossible due to the available data. This approach intends to assess overall performance of sanitation systems (collectors and WWTP) in an integrated and simplified way. The Microbiological INSA model can be generalized to systems with different Drainage basins, arranged both in series and in parallel, and one or more treatment plants discharging to the environment.

3. Development of Microbiological INSA

3.1. Model Overview

The Microbiological INSA presents itself as a methodology that has advantages over the more complex calculation models, due to its simplicity assessing the performance evaluation of sanitation systems. This methodology provides a quantifiable, performance-oriented means of comparing and prioritizing different upgrading actions or rehabilitation scenarios (e.g., WWTP upgrading, stormwater source control, reducing overflows by increasing storage or by increasing the hydraulic capacity of the system). It is based on the concept of indicators ($\mathrm{I_d}$), which integrate the contribution of the various system components (sewage networks, Wastewater Treatment Plant and receiving environment). The evaluation of the relative degree of pollution of systems is performed by determining indicators of performance deficiency ($\mathrm{I_d}$), under both dry and storm weather conditions, using Equation (1):

$$I_d = \frac{C_{médio}}{C_{medio.hip.}} \tag{1}$$

where $C_{médio}$ represents the pollution load discharged into the receiving waters by the integrated system (sewers and WWTP) and $C_{medio.hip.}$ is the theoretical reference load discharged into receiving waters by a separate sewer system in which all domestic wastewater is treated in an adequate secondary wastewater treatment plant (WWTP) and all the stormwater is discharged directly without being submitted to any treatment. Higher values represent worst environmental performances.

As in most numerical models of water quality, the chemical oxygen demand (COD) is used as a general indicator of organic pollution. However, identically to other performance assessment tools (Benedetti et al., 2006, 2008 quoted in Ferreira, 2007) other pollutants such as BOD, TN, TP and microorganisms may be selected. In this context Microbiological INSA was developed based on the following microbiological parameters: concentrations of Escherichia Coli (E. Coli) and Fecal Coliforms (F.C.) in wastewater (c_{AR}), rainwater runoff (c_{AP}) and WWTP effluents (c_{ET}).. In the absence of more detailed local information, the $C_{medio.hip.}$ is estimated considering the following values (Table 1):

Table 1 – E. Coli and Fecal Coliforms concentration in wastewater ($\boldsymbol{c_{AR}}$), in rainwater runoff ($\boldsymbol{c_{AP}}$) and in WWTP effluents ($\boldsymbol{c_{ET}}$)

	(unid.)	Fecal Coliforms	Esherichia Coli
c_{AP}	NMP/100 ml	6,70E+04	3,17E+04
c_{AR}	NMP/100 ml	5,01E+07	5,50E+04
c_{ET}	NMP/100 ml	2,00E+03	5,00E+02

Performance deficiency indicators may be determined through Equation (1), both in wet weather or dry weather ($I_{d,i}$ *or* $I_{d,TS}$, respectively), considering different rain events with known intensities and frequencies. It is then possible to estimate an annual performance deficiency index (ID_{pond}) considering the average annual duration of each rain event (D_{med_i}) and of the dry weather period (D_{med_TS}), as expressed by Equation (2).

$$ID_{pond} = \left[\sum_{i=1}^{n} (I_{d,i} \times D_{med\_i}) + (I_{d,TS} \times D_{med\_TS})\right] \Big/ \left[D_{med\_i} + D_{med\_TS}\right] \tag{2}$$

3.2. Model expressions

The Microbiological INSA can be applied to wastewater systems serving single drainage basins, and to multiple drainage basins in series with the sewer lines. The equations and numerical model presented in the following paragraphs were deduced considering single drainage basins. The equations for wastewater systems serving multiple drainage basins in series or in parallel with the sewer line are summarized in Appendix A.

The quantification of dry and wet weather flows is required to determine $C_{médio}$ and $C_{medio.hip.}$ values. Average dry weather flow (Q_m), can be subdivided into two fractions: the amount of wastewater that reaches the WWTP through the sewer system (Q_{ma}) and the amount directly discharged into receiving waters without any treatment (Q_{md}), as expressed by Equations (3) and (4):

$$Q_{ma} = t_a \times Q_m \tag{3}$$

$$Q_{md} = (1 - t_a) \times Q_m \tag{4}$$

where t_a is the fraction of population served by the wastewater system.

Stormwater generated by a given rain event (Q_p) is considered subdivided into two fractions: the amount that enters the combined or partially separate sewer system draining to the WWTP (Q_{pa}) and the amount that is directly discharged into receiving waters through surface runoff or through separate stormwater sewers (Q_{pd}). These fractions can be computed by Equations (5) to (7), respectively:

$$Q_p = C \times I \times A \tag{5}$$

$$Q_{pa} = \varphi \times Q_p \tag{6}$$

$$Q_{pd} = (1 - \varphi) \times Q_p \tag{7}$$

where C is the rational method coefficient, I is the average rain intensity, A is the catchment area and φ is a coefficient related to the percentage of stormwater entering the sewer system. The parameter φ assumes a value of 1 in combined sewer systems, between 0 and 1 in partially separate systems and 0 in separate systems.

Considering the overall capacity of the system, overflows occur if the flow entering the system (stormwater flow, Q_{pa}, plus the dry weather flow, Q_{ma}) exceeds its capacity ($Cap_{sist,Bi}$) as expressed by Equation (8):

$$Cap_{sist} \geq Q_{ma} + Q_{pa} \tag{8}$$

The overall capacity of the system is given by the most restrictive infrastructure in terms of hydraulic capacity (including the WWTP) and corresponds, in most cases, to the hydraulic capacity of an infrastructure connecting different drainage basins. It can correspond to the installed pumping capacity, to flows discharged by weirs or regulation valves associated with them, or it can be estimated by Manning equation (for sewers and interceptors), considering full flow. In these cases, the Manning's roughness coefficient should be calculated from field measurements, or estimated through field inspections based on pipe materials and conditions.

Under overflow conditions, the fraction Q_{pa} can be further subdivided in two parts as expressed in Equations (9) and (10). These parts include the fraction that enters the system and is treated in the WWTP (Q_{paa}), and the fraction that enters the system but is discharged as overflow without being treated (Q_{pad}).

$$Q_{paa} = \begin{cases} Q_{pa} \ if \ \ Q_{ma} + Q_{pa} \geq Cap_{sist} \\ Cap_{sist} - Q_{ma} \text{ otherwise} \end{cases} \tag{9}$$

$$Q_{pad} = Q_{pa} - Q_{paa} \tag{10}$$

The average E. Coli or Fecal Coliforms concentration of overflows (c_m) may be estimated using Equation (11) that expresses a mass balance:

$$c_m = \frac{Q_{ma} \times c_{ar} + Q_{pa} \times c_{ap}}{Q_{ma} + Q_{pa}} \tag{11}$$

Equation (11) does not take into account the increase usually observed in pollutant concentrations during the initial phases of hydrograms, mostly due to first flush effects (i.e., the mobilization of material accumulated during antecedent dry weather periods).

The theoretical reference load discharged ($C_{medio.hip.}$) and the actual load discharged ($C_{médio}$) into the receiving waters both by the sewer overflows and the WWTP, are evaluated through Equations (12) and (13).

$$c_{medio} = \frac{V_{ar} \times c_{ar} + V_{ap} \times c_{ap} + V_{exc} \times c_{exc} + V_{treated} \times c_{ET}}{V_{ar} + V_{ap} + V_{exc} + V_{ET}} \tag{12}$$

$$c_{medio.hip} = \frac{V_{ap} \times c_{ap} + V_{treated} \times c_{ET}}{V_{ap} + V_{ET}} \tag{13}$$

Where V_{ar} represents the volume of wastewater entering the system on a daily basis, V_{ap} is the volume of stormwater generated that flows into the rain collector that transports domestic wastewater, V_{exc} is total runoff discharged into the receiver environment, c_{exc} is the average concentration value of F.C. or E. Coli in the wastewater and stormwater mixture, $V_{treated}$ is the volume of the flow which receives treatment in WWTP and c_{ET} represents the average concentration value of Fecal Coliforms or E. Coli in the effluents of the WWTP. These variables can be computed by Equations (14) to (17):

$$V_{ar} = Q_{ma} \times 24(h) \times 3600(s) \times 10^{-3} \tag{14}$$

$$V_{ap} = Q_{pa} \times 24(h) \times 3600(s) \times 10^{-3} \tag{15}$$

$$V_{exc} = V_{excWWTP} + V_{overflows} \tag{16}$$

$$V_{treated} = Q_{treatedWWtP} \times 24(h) \times 3600(s) \times 10^{-3} \tag{17}$$

Where V_{exc} represents the volume of wastewater and rainwater discharged into the environment, without any treatment, and $V_{treated}$ is the volume of water treated in the WWTP (Equations expressed in Appendix A).

To eliminate the variation of the I_d values, verified in comparison to Ferreira, F. (2006), the obtained results should be affected by an expression of the type that follows (Equation 18):

$$(I_{d,i}\ ou\ I_{d,TS}) \Big/ \left[\frac{10^{a}}{10^{b}}\right] \tag{18}$$

Where $I_{d,i}$ represents the performance deficiency indicators, both in wet weather or dry weather ($I_{d,i}\ or\ I_{d,TS}$, respectively), a represents the maximum value of the exponential defined for the concentration of F.C. or E. Coli in wastewater. (–), b represents the minimum value of the exponential defined for the concentration of F.C. or E. Coli in wastewater (–).

(For exemple: $1{,}00\mathrm{E}+05 < c_{AR} < 1{,}00\mathrm{E}+08, \mathrm{a} = 8\ \mathrm{e}\ \mathrm{b} = 5$)

4. Automatic application of Microbiological INSA

As mentioned before, Microbiological INSA presents itself as a methodology that has advantages over the more complex or sophisticated calculation models, due to its simplicity and simple way to assess the performance of sanitation systems. In this context a new user friendly application was develop, that makes considerably easier to apply Microbiological INSA, thus decreasing the adjustment period to the new user, while it presents itself as an indispensable tool to support diagnosis and management of urban drainage systems. The developed application, applies the methodology described, and allows the evaluation of the environmental performance in sanitation systems consisting of several drainage basins arranged in series, a maximum of 5 drainage basins. It also allows the definition of hypothetical scenarios representing changes to the sanitation system, such as rehabilitation works, a maximum of 5 sets of study and its comparison with the current situation. In this paper is also presented a user guide so that users can understand the simple fundamentals governing the application and thus they can withdraw full advantage of its capabilities.

5. Application of Microbiological INSA to Algés-Alcântara basin and results

The methodology described was applied to Algés-Alcântara drainage basins, in order to assess their environmental performance and simulate the effects, individual or combined, rehabilitation measures proposed and their implementation priority. The application of the methodology to the Algés-Alcântara subsystem aims to compare the results obtained with a model based on Microbiological contamination with results obtained previously, which were determined for the same subsystem but considering a model based on microbiological parameter chemical oxygen demand (COD).

The drainage system of Alcântara currently serves the municipalities of Lisbon, Oeiras and Amadora, being conducted for WWTP effluents at Alcântara, where they are treated. Ferreira, 2006 defined a simplified model typological front drain Algés-Alcântara, consisting of three main basins arranged in series.

The ID_{pond} limit values depend on the system analysed (namely on the level of treatment of the WWTP) and on the uses and sensitivities of the receiving waters. In case of sensitive areas or receiving waters with specific uses, which are subject to more stringent performance demands, the limit values should be stricter. Furthermore, the pollution parameter in which the INSA is based, differ accordingly to the usage/sensitiveness of the receiving waters (e.g., TN and/or TP in areas in risk of eutrophication, or fecal coliforms in areas prone to direct human contact).

The $\mathrm{ID}_{\mathrm{pond}}$ corresponding qualitative classification depends on the characteristics of the receiving waters, in addition, once the legal requirements are met, the organizational goals and objectives of the company that manages the system should be empirically reflected in the $I_{d,pond}$ classification. Consequently, this classification should be set in accordance with the company that manages the system. In the present case study, the $I_{d,pond}$ qualitative classification was established taking into account that the urban wastewater system was discharging into receiving waters identified as non-sensitive areas (according to Directive 91/271). Furthermore, the hydrodynamic of the receiving waters, which is favorable to dilution of pollutants and dispersion effects, was considered. The index classification performance gap translates qualitatively the type of environmental performance of the test solution (from " very good performance “to “very poor performance").

Due to the characteristics of self-purification and sensitivity through receptor presents two proposals for classification of disability index performance, the implementation of which depends on the parameter considered for the application of Microbiological ASI (Fecal Coliforms or Escherichia Coli). The proposed ranges are proportionate to this new methodology and result of the multiplication of the values proposed by (Ferreira, 2006) by a factor of 3 and 1.5, depending on the methodology is based on parameter or Escherichia Coli and Fecal Coliforms. The proposed classifications of the disability index of performance are shown in Table 2 and Table 3.

Table 2 - Proposed classification of the disability index of performance, depending on the sensitivity of the receiver means to the methodology based on parameter Fecal Coliforms.

IDpond value			Classification
	<	3.6	Good/Very good
3.6	to	4.5	Acceptable/reasonable
4.5	to	6	Deficient
	>	6	Very deficient

Table 3 - Proposed classification of the disability index of performance, depending on the sensitivity of the receiver means to the methodology based on parameter Escherichia Coli.

IDpond value			Classification
	<	1.8	Good/Very good
1.8	to	2.25	Acceptable/reasonable
2.25	to	3	Deficient
	>	3	Very deficient

All calculations were made on an average yearly basis, considering precipitation data obtained through the analysis of a 19 year long series of Lisbon precipitation records digitalized by Pereira, 1995. In average, rain events occur in 107 days per year (but only last for 12% of the time of the year). In Table 4 the average intensities and durations for the frequent rain events (occurring more than once a year) are presented (Table 4).

Table 4 - Annual average intensities and durations for frequent rain events in Lisbon region

Frequency	Intensity		D_{med}
(times/year)	mm/h	$l/(s \times ha)$	h/ano
0,1 x/ano	25,8	71,7	0,87
1 x/ano	13,9	38,5	1,34
2 x/ano	11,1	30,9	3,49
5 x/ano	8,0	22,3	3,93
7 x/ano	7,2	20,0	7,71
10 x/ano	6,3	17,5	11,28
15 x/ano	5,2	14,3	76,76
45 x/ano	2,7	7,6	975,58

In view of the operational and infrastructural problems that severely affect the Algés-Alcântara wastewater system performance, three main rehabilitation interventions were considered:

- Reconstruction of Monsanto main sewer (intervention A).
- Rehabilitation of all problematic weirs (intervention B).
- Connection of coastal flat areas not yet served to the interceptor (intervention C).

Several alternatives were then evaluated, corresponding to the worst operation situations and to the gradual implementation of the proposed interventions (individually or combined):

Scenario 1 - present situation (considering a secondary WWTP and the current sewer system problems);

Scenario 2a - reconstruction of Monsanto main sewer (intervention A);

Scenario 2b - rehabilitation of all problematic weirs (intervention B);

Scenario 3 - reconstruction of Monsanto main sewer and rehabilitation of all problematic weirs (interventions A and B);

Scenario 5a - similar to Scenario 3, including the connection of coastal areas to the interceptor (interventions A, B and C);

Scenario 5b - rehabilitation of all problematic weirs and connection of coastal areas to the interceptor (intervention B and C);

6. Results and discussions

The Microbiological INSA model was applied to the Algés-Alcântara system in order to evaluate its environmental performance and to simulate the individual or combined impact of the rehabilitation measures proposed, assessing their priority. The ID_{pond} were computed for each alternative considering the average precipitation data in Table 4. The obtained values and corresponding performance classification are displayed in Figure 1 and Figure 2. Results show that, despite the investment made upgrading the WWTP, the performance of the integrated wastewater system is classified as very deficient. It is evident that the interventions A and B (or A, B and C) must be implemented to ensure an acceptable environmental performance of the system (scenario 3 and scenario 5a). The results also demonstrate that it is more effective to rehabilitate the malfunctioning weirs than to reconstruct the damaged Monsanto main sewer (ID_{pond} of scenario 2b is smaller than ID_{pond} of scenario 2a). Table 5 and Table 6 shows the ID_{pond} reduction obtained through the implementation of each alternative, in comparison with the present situation (scenario 1). The prioritization of alternatives may be based on the total cost per ID_{pond} reduction unit, also displayed in Table 5 and Table 6. The rehabilitation alternatives presenting inferior costs for the same unitary ID_{pond} reduction should be implemented first. Since alternatives described in scenario 3 and scenario 5a present the highest ID_{pond} reductions and the cost per ID_{pond} reduction unit of scenario 3 (interventions A and B) is inferior to the one determined in scenario 5a (interventions A, B and C), priority should be given to implement alternative scenario 3. It should be noticed that, globally, the rehabilitation of all problematic weirs (intervention A, included in scenario 2b), is the one with lowest cost per ID_{pond} reduction unit. Furthermore, if considered as an individual intervention, the reconstruction of Monsanto main sewer is the alternative presenting higher cost per unit of ID_{pond} reduction.

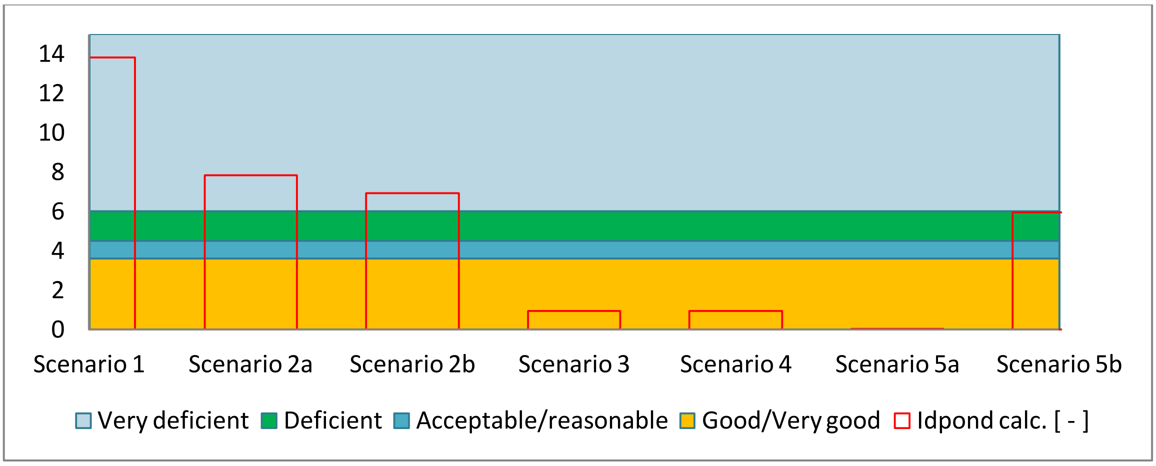

Figure 1 - $\mathbf{ID_{pond}}$ per alternative and corresponding classification, by application of Microbiological ASI based on Fecal Coliforms

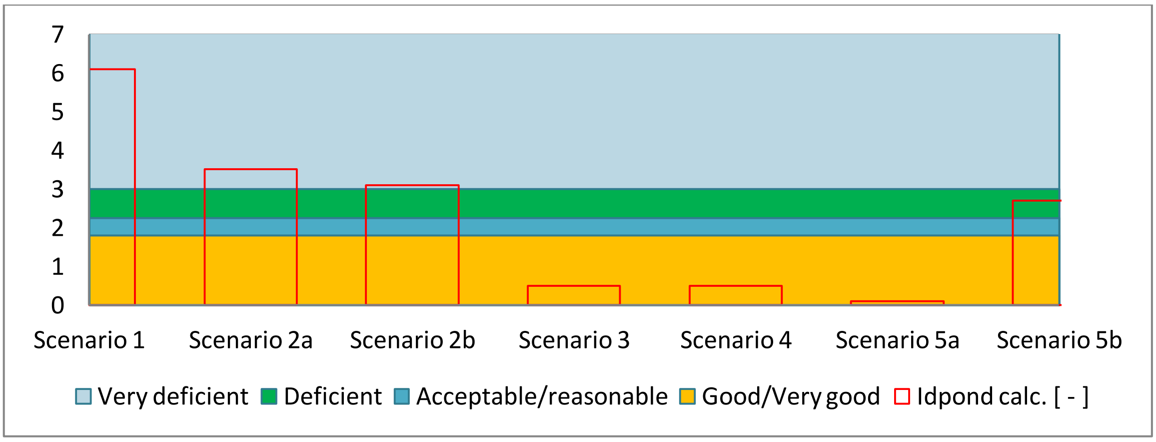

Figure 2 - ID_{pond} per alternative and corresponding classification, by application of Microbiological ASI based on E. Coli

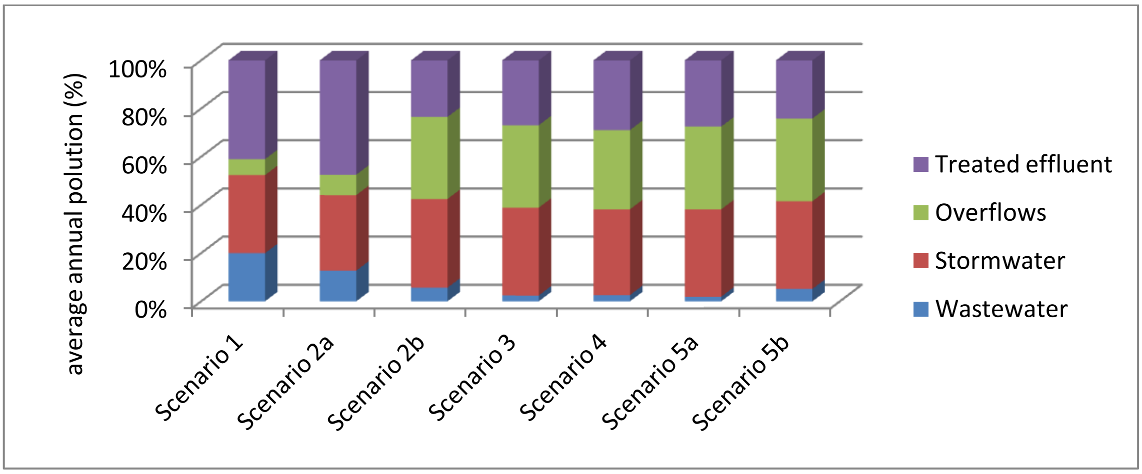

Figure 3 - Average annual pollution loads discharged into receiving waters per alternative, by application of Microbiological INSA based on Fecal Coliforms

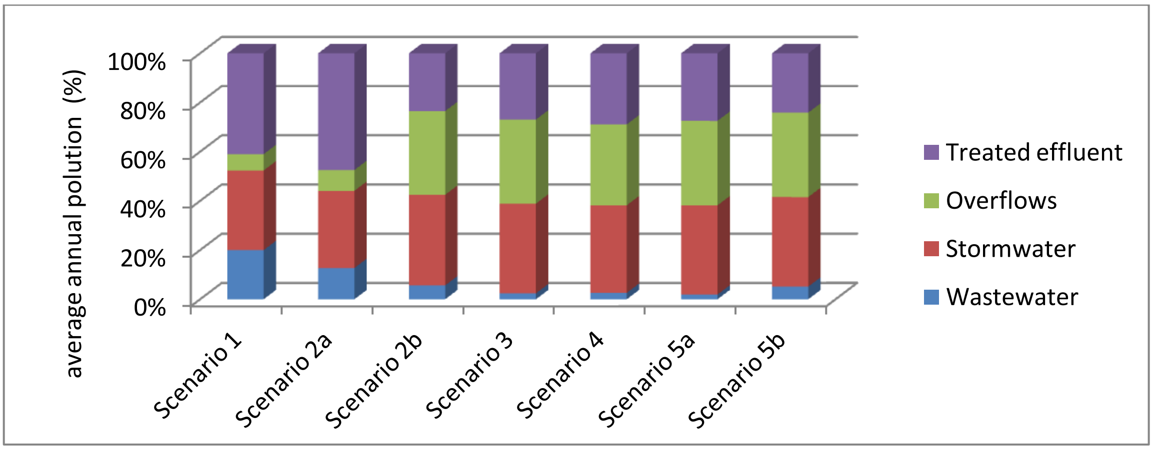

Figure 4 - Average annual pollution loads discharged into receiving waters per alternative, by application of Microbiological INSA based on E. Coli

As presented in Figure 3 and Figure 4, the Microbiological INSA also allows the estimation of average annual pollution loads discharged into receiving waters by each alternative, taking into account its origin (raw wastewater, stormwater, overflows and WWTP treated effluent). It is important to notice the considerable pollution loads present in stormwater, exceeding the annual pollution loads of overflows and treated wastewater in all alternatives. This is evidence that during wet weather (and particularly in the initial phases of the corresponding hydrographs), the pollution loads transported by urban stormwater are significant. Furthermore, these loads are frequently higher than the pollution loads discharged into receiving waters (treated effluents) during dry weather. The results obtained are similar to those obtained by Ferreira, F. (2006), as expected.

The data used for evaluating different alternatives, namely population size and intervention costs, were obtained from detailed projects promoted by SIMTEJO, S.A., and are considered accurate (Ferreira, 2006). The results show no significant variations regarding the ID_{pond} values per alternative and the corresponding $cost/ID_{pond}$ reduction unit (Table 5 and Table 6), so the priority of the proposed rehabilitation measures remains unchanged.

Table 5 - IDpond reduction and total cost per IDpond reduction unit for each alternative, for application of the model based in Fecal Coliforms.

Application of Microbiological INSA, based in Fecal Coliforms						
Scenary	2b	3	5b	5a	2a	4
cost/IDpond redution unit	0,199	0,269	0,309	0,327	0,350	0,389
IDpond redution unit	6,893	12,860	7,841	13,808	5,966	12,860

Table 6 - IDpond reduction and total cost per IDpond reduction unit for each alternative, for application of the model based in E. Coli.

Application of Microbiological INSA, based in E. Coli						
Scenary	2b	3	5b	5a	2a	4
cost/IDpond redution unit	0,457	0,618	0,709	0,750	0,804	0,893
IDpond redution unit	2,999	5,599	3,412	6,011	2,599	5,599

7. Conclusions and Recommendations

For the application of the model were set two case studies , the first model will be applied based on the microbiological parameter Fecal Coliforms and in the second case study the methodology based in parameter E. Coli. The validation of the methodology is made by comparing the results obtained by applying the Microbiological INSA, based on microbiological contamination, with the results obtained by modeling parameter INSA based in Chemical Oxygen Demand (COD), and obtained by Ferreira, 2006. It is found that the values of the indicators ID_{pond} and performance index (ID_{pond}) determined by the new approach to wet weather, are quite close to those obtained using the ASI parameter based COD. The same is not true in dry weather, where the values of the indicators ID_{pond} and performance index (ID_{pond}) have much higher values than those determined by the original methodology and are strongly affected by increasing concentrations considered for wastewater and stormwater. This led to the introduction of a parameter to be affected values of the performance indicators determined ID_{pond} in order to minimize the effect described. Due to the characteristics of self-purification and sensitivity through receptor waters presents two proposals for classification of disability index performance, the implementation of which depends on the parameter considered for the application of Microbiological ASI (Fecal Coliforms or Escherichia Coli). The proposed ranges are proportionate to this new methodology and result of the multiplication of the values proposed by (Ferreira, 2006) by a factor of 3 and 1.5, depending on the methodology is based on parameter or Escherichia Coli and Fecal Coliforms, respectively. The index classification performance gap translates qualitatively the type of environmental performance of the test solution (from " very good performance “to “very poor performance"). The results indicate that the relative volumes of stormwater and wastewater treatment plants remain practically constant for the various scenarios evaluated, since these are respectively limited by the volume of precipitated water basins (entire basin contributes to runoff) and the hydraulic capacity of the WWTP. The implementation of the various steps of the rehabilitation system leads to a greater efficiency of the same and thus an increase in the flow rate detected by the system, however the capacity of the drainage system is limited by the capacity of the hydraulic structures, which cannot absorb the increase of the influent flow system, a fact which contributes to the increased portion on the surpluses flow rates and lower volumes of waste water discharged into the receiving waters. This analysis allows us to draw similar conclusions will be obtained by Ferreira, 2006, as expected. There is also the priority order of operations to perform in the system, determined in each case under study, and the same as that obtained previously, as expected since it is intended that the results are consistent regardless the methodology chosen for analysis.

Future work

- Expand the methodologies to other case studies, including the subsystem drainage of São João da Talha (also managed by SIMTEJO).
- Compare the results obtained by methodologies ASI or ASI-Mic., with those obtained by detailed modeling (*e.g.* using the SWMM or Mouse).
- Develop ASI-Mic.for application to urban drainage basins in parallel.

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Appendix A

Model expressions for Urban Drainage Basins in series

- Condition to occur overflows:

$$Cap_{sist,Bi} < Q_{ma,Bi} + Q_{pa,Bi} + Q_{jus,Bi}$$

where $Q_{pa,Bi}$ and $Q_{ma,Bi}$, respectively, are the stormwater flow and dry weather flow originated in the basin; $Q_{jus,Bi}$ represents the flow from the previous basin discharged downstream by the corresponding infrastructure and $Cap_{sist,Bi}$ its hydraulic capacity.

- Flow directly discharged into receiving water:

$$Q_{exc,Bi} = \begin{cases} 0 \;\; if \;\; Cap_{sist,Bi} \geq Q_{ma,Bi} + Q_{pa,Bi} + Q_{jus,Bi} \\ Q_{ma,Bi} + Q_{pa,Bi} + Q_{jus,Bi} - Cap_{sist,Bi} \text{ otherwise} \end{cases}$$

- Flow transported downstream:

$$Q_{jus,Bi} = \begin{cases} Q_{ma,Bi} + Q_{pa,Bi} + Q_{jus,B(i-1)} \;\; if \;\; Cap_{sist,Bi} \geq Q_{ma,Bi} + Q_{pa,Bi} + Q_{jus,} \\ Cap_{sist,Bi} \text{ otherwise} \end{cases}$$

- $Q_{pa,Bi}$ can be further subdivided in two parts:

$$Q_{paa,Bi} = \begin{cases} Q_{pa,Bi} \; if \; Q_{exc,Bi} = 0 \\ Cap_{sist,Bi} - Q_{ma,Bi} - Q_{jus,Bi} \text{ otherwise} \end{cases}$$

$$Q_{pad,Bi} = Q_{pa,Bi} - Q_{paa,Bi}$$

- Average E. Coli or F.C. concentration of overflows:

$$c_{m,Bi} = \frac{Q_{ma,Bi} \times c_{ar} + Q_{pa,Bi} \times c_{ap} + Q_{jus,Bi} \times c_{m,B(i-1)}}{Q_{ma,Bi} + Q_{pa,Bi} + Q_{jus,Bi}}$$

- Flow actually treated in the WWTP:

$$Q_{treatedWWTP} = \begin{cases} Q_{jus,Bn} if \; Cap_{WWTP} > Q_{jus,Bn} \\ Cap_{WWTP} \; if \; Cap_{WWTP} < Q_{jus,Bn} \end{cases}$$

- Flow that exceeds the hydraulic capacity of the WWTP:

$$Q_{excWWTP} = \begin{cases} 0 \; if \; Q_{jus,Bn} < Q_{treatedWWTP} \\ Q_{jus,Bn} - Q_{treatedWWTP} \; if \; Q_{jus,Bn} > Q_{treatedWWTP} \end{cases}$$

- Volume of wastewater and rainwater discharged into the environment, without any treatment (V_{exc}), and the volume of water treated in the WWTP ($V_{treated}$):

$$V_{excWWTP} = Q_{excWWTP} \times 24(h) \times 3600(s) \times 10^{-3}$$

$$c_{excWWTP} = \frac{c_{m(n-1)} \times Q_{jus,B(n-1)} + c_{ap,n} \times Q_{pa}^{n} + Q_{ma}^{n} \times c_{ar,n}}{Q_{jus,Bn}}$$

$$V_{overflows} = Q_{exc} \times 24(h) \times 3600(s) \times 10^{-3}$$

$$c_{overflows} = \frac{c_{mi} \times Q_{exc,Bi} + c_{m(i+1)} \times Q_{exc,B(i+1)} + \cdots + c_{m,n} \times Q_{exc,Bn}}{Q_{exc,Bi} + Q_{exc,B(i+1)} + \cdots + Q_{exc,Bn}}$$

- Theoretical reference load discharged ($C_{medio.hip.}$) and the actual load discharged ($C_{médio}$) into the receiving waters:

$$c_{medio} = \frac{V_{ar} \times c_{ar} + V_{ap} \times c_{ap} + V_{exc} \times c_{exc} + V_{treated} \times c_{WWTP}}{V_{ar} + V_{ap} + V_{exc} + V_{treated}}$$

$$c_{medio.hip} = \frac{V_{ap} \times c_{ap} + V_{treated} \times c_{WWTP}}{V_{ap} + V_{treated}}$$

Model expressions for Urban Drainage Basins in parallel

- Condition to occur overflows

$$Cap_{sist,Bi} < Q_{ma,Bi} + Q_{pa,Bi}$$

- $Q_{pa,Bi}$ can be further subdivided in two parts:

$$Q_{paa,Bi} = \begin{cases} Q_{pa,Bi} \; if \; Q_{exc,Bi} = 0 \\ Cap_{sist,Bi} - Q_{ma,Bi} - Q_{jus,Bi} \; otherwise \end{cases}$$

$$Q_{pad,Bi} = Q_{pa,Bi} - Q_{paa,Bi}$$

- Flow from the previous basins, discharged to the WWTP:

$$Q_{jus,Bi} = \begin{cases} Q_{ma,Bi} + Q_{pa,Bi} \;\; if \;\; Cap_{sist,Bi} \geq Q_{ma,Bi} + Q_{pa,Bi} \\ Cap_{sist,Bi} \text{ otherwise} \end{cases}$$

- Flow rate value carried in the downstream basin interceptor:

$$Q_{intercetor} = (Q_{jus,Bi} + Q_{jus,B(i+1)} + \cdots + Q_{jus,Bn})$$

- Flow actually treated in the WWTP:

$$Q_{treatedWWTP} = \begin{cases} Q_{intercetor}\ if\ Cap_{WWTP} > Q_{intercetor} \\ Cap_{WWTP}\ if\ Cap_{WWTP} < Q_{intercetor} \end{cases}$$

- Flow that exceeds the hydraulic capacity of the WWTP:

$$Q_{excWWTP} = \begin{cases} 0\ if\ Q_{intercetor} < Q_{treatedWWTP} \\ Q_{intercetor} - Q_{treatedWWTP}\ if\ Q_{intercetor} > Q_{treatedWWTP} \end{cases}$$

- Average COD concentration of overflows occurring immediately upstream of the WWTP:

$$c_{intercetor} = \frac{c_{mi} \times Q_{jus,Bi} + c_{m(i+1)} \times Q_{jus,B(i+1)} + \cdots + c_{m,n} \times Q_{jus,Bn}}{Q_{intercetor}}$$

- Average concentration of E. Coli or F. Coliforms in overflows:

$$c_{exc} = \frac{V_{excETAR} \times c_{intercetor} + V_{overflows} \times c_{overflows}}{V_{excETAR} + V_{overflows}}$$

- Theoretical reference load discharged ($C_{medio.hip.}$) and the actual load discharged ($C_{médio}$) into the receiving waters:

$$c_{medio} = \frac{V_{ar} \times c_{ar} + V_{ap} \times c_{ap} + V_{exc} \times c_{exc} + V_{treated} \times c_{WWTP}}{V_{ar} + V_{ap} + V_{exc} + V_{treated}}$$

$$c_{medio.hip} = \frac{V_{ap} \times c_{ap} + V_{treated} \times c_{WWTP}}{V_{ap} + V_{treated}}$$