# Performance assessment of a storm water system in an estuarine area – dafundo case study

*Liliana Santos [a, b, c] *, Maria Adriana Cardoso [a], Ana Galvão [b]*

[a] LNEC, Laboratório Nacional de Engenharia Civil, Av. do Brasil 101, 1700-066 Lisboa, Portugal

[b] CERIS, Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa, Portugal

[c] Itecons, Instituto de Investigação e Desenvolvimento Tecnológico para a Construção, Energia, Ambiente e Sustentabilidade, Rua Pedro Hispano, s/n, 3030-289, Coimbra, Portugal

## Abstract

Performance assessment is an important management tool in the water sector, and its integration on storm water systems' management is recognised to benefit storm water utilities. A performance assessment framework for urban storm water systems has been developed, comprising objectives, assessment criteria, and performance indicators. The objective of the present work is to test and demonstrate the applicability of the framework as part of the internal validation process. The framework components are evaluated in terms of their definition, relevance, and feasibility, in conjunction with their application to a case study, in an estuarine area served by conventional storm water systems, by developing a performance assessment system. The identified performance failures were related to flooding occurrences, illicit domestic connections to storm water pipes, insufficient hydraulic capacity, and lack of self-cleaning capacity. Different intervention solutions were studied based on the infrastructure asset management planning AWARE-P software. Suggestions to improve the system's performance and to obtain data for non-calculated performance indicators were proposed.

**Keywords:** estuarine area, framework, internal validation, performance assessment, storm water systems.

**doi:** 10.22181/aer.2022.1002

* *Corresponding author :*
E-mail: liliana.santos@itecons.uc.pt

# Avaliação de desempenho de um sistema de águas pluviais em zona estuarina – caso de estudo do dafundo

*Liliana Santos* [a, b, c *], *Maria Adriana Cardoso* [a], *Ana Galvão* [b]

[a] LNEC, Laboratório Nacional de Engenharia Civil, Av. do Brasil 101, 1700-066 Lisboa, Portugal

[b] CERIS, Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa, Portugal

[c] Itecons, Instituto de Investigação e Desenvolvimento Tecnológico para a Construção, Energia, Ambiente e Sustentabilidade, Rua Pedro Hispano, s/n, 3030-289, Coimbra, Portugal

## Resumo

A avaliação de desempenho é uma importante ferramenta de gestão no setor da água e a sua integração na gestão dos sistemas de águas pluviais poderá beneficiar as entidades gestoras de água. No presente trabalho foi desenvolvido um quadro de avaliação de desempenho para sistemas urbanos de águas pluviais, composto por objetivos, critérios de avaliação e indicadores de desempenho. O objetivo do trabalho é testar e demonstrar a aplicabilidade do quadro de avaliação, como parte do processo de validação interna. Os componentes do quadro geral de avaliação são analisados em termos da sua definição, relevância e viabilidade, através do desenvolvimento de um sistema de avaliação de desempenho aplicado a sistemas convencionais de águas pluviais numa zona estuarina. As falhas de desempenho identificadas correspondem a ocorrências de inundações, ligações domésticas indevidas a coletores de águas pluviais, capacidade hidráulica e de autolimpeza insuficientes. Foram estudadas diferentes soluções de intervenção com base no *software* de gestão patrimonial de infraestruturas AWARE-P. Foram propostas sugestões para melhoria do desempenho do sistema e para obtenção de dados em falta para indicadores de desempenho não calculados.

**Palavras-chave:** avaliação de desempenho, quadro de avaliação, sistemas de águas pluviais, validação interna, zona estuarina.

**doi:** 10.22181/aer.2022.1002

[*] *Autor para correspondência:*
E-mail: liliana.santos@itecons.uc.pt

# 1 Introduction

Over the past decades, storm water systems (SWS) have been a relevant part of urban infrastructure. The significant challenges in managing these systems are related to the increasing urbanisation, climate change effects on rainfall patterns and sea level, as well as the need to ensure the protection of people, properties, and goods, and the environmental, economic, and social sustainability (Charlesworth 2010).

There are two types of SWS: conventional SW pipe systems and non-conventional systems. Conventional SW pipe systems (e.g., underground pipe network and other components), whose main objective is collecting and draining the surface runoff in urban areas to control flooding, have been complemented or replaced by alternative drainage solutions, such as sustainable urban drainage solutions (SUDS). These latter systems are implemented to minimise the impacts of urban development on the hydrologic cycle and receiving waters quality, maximise the biodiversity and amenity benefits (Charlesworth, 2010) and reduce the infrastructure management costs (Porse 2013).

Given the different types of SWS and their inherent management complexity, the integration of performance assessment in SWS management may benefit water utilities and municipalities. Performance assessment has become a common practice in the water sector, although incipient in the SWS sector (Santos et al. 2019). In this context, a performance assessment framework (PAF) was developed for SWS (Santos et al. 2021), which is objective-oriented, and comprises objectives, assessment criteria, and performance metrics, mainly performance indicators. The application of the PAF by a water utility leads to the definition of a performance assessment system (PAS), which is based on the selection of objectives regarding the requirements of systems' functioning, followed by the selection of assessment criteria and performance metrics, mainly performance indicators (PI). It is applicable to different types of SWS (conventional systems and SUDS), scales, and performance dimensions. The framework aims to constitute a reference basis for SWS, following the best practices and recommendations, and it intends to be comprehensive, objective, standardised and flexible in its adaptation.

The purpose of the present work is to test and demonstrate the applicability of the PAF, as part of an internal validation phase. The PAF components were evaluated in terms of definition, relevance, and feasibility, by developing a PAS for a Portuguese case study in an estuarine area located in Dafundo, served by SW pipe systems. From the assessment, performance vulnerabilities were identified as well as the need to collect data for non-calculated performance metrics. Intervention solutions were studied regarding their performance vulnerabilities.

# 2 Material and methods

## 2.1 Method overview

The PAF was developed in line with the recommendations of the ISO series 24500 2007 (ISO 24510:2007, 24511:2007, 24512:2007). These standards recommend an overall step-by-step assessment process based on the definition of objectives, respective assessment criteria and PI (Santos et al. 2021).

The test of the PAF corresponds to the internal validation phase, during which the PAF is applied to the selected case study, adapted from previous studies where information was available, supporting the development of a PAS. Through the internal validation phase, PAF components were evaluated in terms of their applicability in a series of rounds, focusing on performance metrics definition, their relevance to the decision-making process and respective feasibility to be obtained. The internal validation phase comprised the following steps: i) selection of a case study and analysis of its characteristics; ii) definition of performance objectives and establishment of assessment criteria and performance metrics, namely PI, applicable to the case study; iii) calculation of performance metrics, based on the available data; iv) interpretation of performance results; and v) study of intervention solutions through the application of the AWARE-P software.

## 2.2 Dafundo case study

The Dafundo catchment was selected, adapted from the project "MOLINES – PTDC/AAG-MAA/2811/2012" (Cardoso et al. 2016, Beceiro 2016). The Dafundo catchment is located in Oeiras municipality, in Portugal (38º41'57''N; 9º14'16''W), managed by the water utility of SIMAS Oeiras e Amadora. It comprises a dense urban area, with residential and commercial land-use types, served by separated wastewater and SW pipe networks, on the right marginal area of Tagus estuary, within the Junça River catchment.

This area was selected given the linkage between the hydrodynamics of the estuary and the SW network and the availability of 1D/2D mathematical simulations, which provides better spatial information on flooding propagation. In addition, data were available regarding SW pipe system characteristics based on the inspection and monitoring surveys carried out between 2014 and 2015. Regarding the SWS, the area can be divided into two catchments, linked through a vertical drop, controlling the flow from upstream and reducing the possibility of pipe surcharge in the lower area. The upstream catchment had 87.15 ha, 78 % imperviousness and the elevation varied between 8 m and 92 m. The downtown area covered 2.7 ha with 84% impermeable surfaces and an elevation ranging between 3 m and 8 m. Due to the topography and the channelization of the Junça River, flooding was not recurrent in the upstream catchment, being more likely to occur at Dafundo downstream area (Cardoso et al. 2016). The SW pipe system has 1.8 km of concrete pipes, with rectangular (400x50 mm – 2200x1250 mm) and circular cross-sections (110 – 900 mm). The runoff was transported and discharged through the channelized Junça River and a parallel duplication channel built to reduce the flooding occurrences in 2001.

## 2.3 Definition of performance objectives, assessment criteria and performance metrics

Regarding the previously analysed characteristics, performance objectives were established for the case study. They were aligned with the water utility's management goals and were considered as relevant in its context. The next step consisted of identifying the assessment criteria and performance metrics, namely PI, for each objective that would allow the assessment of the objectives' accomplishment. The definition of the performance assessment system relied on an iterative process in different rounds. After this phase, a preliminary performance assessment system was provided to be applied to the case study.

## 2.4 Calculation of performance metrics

The calculation procedure started by compiling the available data reported for the case study and proceeded to the calculation of performance metrics. For the metrics based on mathematical simulations, the rainfall events to include were defined, as well as the climatic scenarios. The mathematical models were built, calibrated, and verified on previous studies (Beceiro 2016). The calibration phase was carried out for 10 selected rainfall events, with different rainfall intensities, to support the determination of the following parameters: the coefficient for the Rational Method C that better replicates the hydrological behaviour of the upper area catchments; the shape and concentration time in the lower area sub-catchments; and the degree of obstruction in sewers that reproduces the historical flooding occurrences based on the historical information provided by the responsible entities (Beceiro 2016). Additional mathematical simulations were carried out using the software DHI Mike Urban 2017, within the current work scope.

Rainfall events corresponding to 10-, 20- and 50-year return periods were simulated. These rainfall events had 20 minutes of critical duration, a total duration of four hours, and they were based on the intensity-duration-frequency (IDF) curves for Lisbon (Matos 1987) in the current and future climate scenarios. The future climate scenario (2011-2040) considered an aggravation of 7 % of the rain intensity and a 10 cm aggravation of the tidal regime (Monjo et al. 2018). The 2011-2040 period was considered given the expected lifespan of the existent storm pipe system. In addition to the tidal regime, different scenarios concerning the operational condition of the system were also included in simulations, which correspond to frequent outfall obstructions, as described in Beceiro (2016).

When the available information did not allow the quantification of performance, a qualitative assessment was carried out, highlighting the need to improve data collection procedures. If no data were available, recommendations were identified for its collection, referring to the respective associated benefits.

After calculating performance metrics, a data quality evaluation based on reliability and accuracy bands (Alegre et al. 2016) was included. The comparison between performance results and objectives compliance was carried out based on the establishment of reference values for each performance metric, enabling the classification of performance as good, acceptable, and unsatisfactory. The reference values were adapted from the literature or according to the type of system under assessment and its context.

## 2.5 Study of intervention solutions

The study of intervention solutions followed the multicriteria methodology applied in infrastructure asset management (IAM) (Alegre and Coelho 2013, Carriço 2014). The purpose was to demonstrate how PAS may complement the application of IAM plans.

The first step consisted in identifying the systems' performance vulnerabilities. Then, the relevant objectives for the decision problem were defined, and assessment scenarios were established. Intervention solutions were defined, and may be of different types, such as infrastructural, operation, and maintenance. The current system was also considered as an alternative.

After structuring the decision problem, performance metrics were defined and aligned with objectives. The selected aggregation method was the AWARE Plan (Alegre and Coelho 2013). This method is an adaptation of the weighting sum method, and it enables to order the intervention solutions, with the normalisation of metrics and assignment of weighting coefficients. The normalisation considers a scale between 0 and 3, in which 0 corresponds to the worst metric value and 3 to the best one. For each metric, the scale conversion is defined based on reference intervals that are associated with a three-colour code (red [0-1[, yellow [1-2[, green [2-3]). The normalised scale with the corresponding colours allows a qualitative assessment, supported by the association of qualitative classes (unsatisfactory, acceptable, and good) to the respective colours, i.e., red, yellow, and green. The weighting coefficients for each metric are defined according to a scale of five classes: very low (0.5); low (0.75), medium (1.0), high (1.5), and very high (2.0). The global value of intervention solutions is calculated as follows (Carriço 2014):

$$V(a_i) = \frac{\sum w_j \times g_j(a_i)}{\sum w_j} \quad \text{(eq.1)}$$

in which: $V(a_i)$ – global value for intervention solution i; $w_j$ – weighting coefficient of metric j; $g_j(a_i)$ – normalised value (between 0 and 3) of metric j for the intervention solution i.

The obtained global values vary between 0 and 3, and the intervention solutions are ranked according to their global value. After this process, a sensitivity analysis was carried out, and it was discussed the most adequate intervention solutions and their impact on systems performance.

## 3 Results and discussion

### 3.1 Performance assessment of the current system

The selected performance objectives and the respective PAS are presented in Table 1, including the assessment criteria and performance metrics.

**Table 1.** PAS proposed to the SWS of Dafundo and the respective performance classification and results related to the mathematical simulations of the current and future climate scenarios (2011-2040) for a rainfall event of 10-, 20- and 50-year of return periods. Reliability and accuracy bands (Alegre et al. 2016) are presented for each variable at the bottom of the table. [🟢 – good; 🟡 – acceptable; 🔴 – unsatisfactory]

| Objectives | Assessment Criteria | PI | Performance classification | Reliability | Accuracy | Performance results 10 years CS | 10 years FS | 20 years CS | 20 years FS | 50 years CS | 50 years FS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Protection of public health and safety | Built environment impacts | Residential properties affected (no$^{(1)}$/(1000 prop.$^{(2)}$.year)) | [0; 2] - 🟢<br>]2; 10[ - 🟡<br>[10; +∞ [ - 🔴 | 1) *<br>2) * | 1) [20 – 50] %<br>2) > 50 % | 0 🟢 | 0 🟢 | 0 🟢 | 0 🟢 | 0 🟢 | 0 🟢 |
| | | Road extent affected by flooding (%$^{(3)}$/year) | [0; 5] - 🟢<br>]5; 10[ - 🟡<br>[10; 100 [ - 🔴 | 3) ** | 3) [5 – 20] % | 4.1 🟢 | 13.9 🔴 | 8.6 🟡 | 17.4 🔴 | 21.7 🔴 | 29.7 🔴 |
| | | Area affected by floods (%$^{(4)}$/year) | [0; 1] - 🟢<br>]1; 10[ - 🟡<br>[10; 100 [ - 🔴 | 4) ** | 4) [5 – 20] % | 0.56 🟢 | 1.81 🟡 | 1.04 🟡 | 1.83 🟡 | 3.20 🟡 | 5.28 🟡 |
| | Flooding occurrences | Surface flooding with impacts on people and/or built environment (no.$^{(5)}$/(km$^{2\,(6)}$.year)) | [0; 1] - 🟢<br>]1; 2[ - 🟡<br>[2; +∞ [ - 🔴 | 5) *<br>6) * | 5) [20 – 50] %<br>6) [20 – 50] % | 0 🟢 | 0 🟢 | 0 🟢 | 0 🟢 | 0 🟢 | 0 🟢 |
| Protection of surface receiving waters quality | Illicit connections to SW pipes | Detected wastewater connections to SW pipes (no./(100 km.year)) | | | | ND | ND | ND | ND | ND | ND |
| Infrastructural sustainability of SWS | Systems' hydraulic capacity | Surcharging in SW pipes (%$^{(7)}$) | [0; 5[ - 🟢<br>[5; 15[ - 🟡<br>[15; 100] - 🔴 | 7) ** | 7) [5 – 20] % | 27.6 🔴 | 34.3 🔴 | 29.4 🔴 | 35.2 🔴 | 36.2 🔴 | 41.2 🔴 |
| | | Manholes or inlets flooded (no.$^{(8)}$/(100 km$^{(9)}$.year)) | [0; 2[ - 🟢<br>[2; 10[ - 🟡<br>[10; +∞ [ - 🔴 | 8) **<br>9) *** | 8) [5 – 20] %<br>9) [0 – 5] % | 93.7 🔴 | 93.7 🔴 | 140 🔴 | 234 🔴 | 281 🔴 | 328 🔴 |
| | Operational condition of SWS | SW pipe blockages (no./(100 km.year)) | | | | ND | ND | ND | ND | ND | ND |
| | | SW pipes without self-cleaning capacity (v<0.9 m/s) (%$^{(10)}$) | [0; 5[ - 🟢<br>[5; 10[ - 🟡<br>[10; 100] - 🔴 | 10) ** | 10) [5 – 20] % | 74.7 🔴 | 73.5 🔴 | 73.5 🔴 | 72.1 🔴 | 71.6 🔴 | 68.4 🔴 |
| | Infrastructural integrity of SWS | SW pipe collapses (no./(100 km.year)) | | | | ND | ND | ND | ND | ND | ND |
| | Rehabilitation of systems' components | Rehabilitation of SW pipes (%/year) | | | | ND | ND | ND | ND | ND | ND |
| | | Rehabilitation of manhole chambers (%/year) | | | | ND | ND | ND | ND | ND | ND |
| Sustainable use of resources | Efficient use of financial resources | Costs of SW pipes rehabilitation (€/(100 km.year)) | | | | ND | ND | ND | ND | ND | ND |
| | | Costs of operation and maintenance works (€/(100 km.year)) | | | | ND | ND | ND | ND | ND | ND |

ND – no data.

Considering the characteristics of the SWS and its location in an estuarine area, the following objectives were selected: protection of public health and safety, protection of surface receiving waters, infrastructural sustainability, and sustainable use of resources. These objectives are also aligned with the objectives of the water utility in their tactical plan of IAM for wastewater infrastructure 2015/2020 (SIMAS Oeiras e Amadora 2015). Based on the assessment criteria, 14 PI were chosen and only seven PI were quantified. Other PI were analysed qualitatively regarding the information available compiled during the inspection campaigns (Cardoso et al. 2016). Five PI were calculated based on the mathematical simulations for 10-, 20- and 50-year return period, for maximum tide level (2.7 m), and with obstruction at some SW pipes and the downstream part of the network. The combination of these conditions was verified to compromise the hydraulic performance highly. Considering the extent of the flooding propagation and its maximum depth, the properties affected by flooding and the number of flooding with damages were estimated.

The protection of public health and safety objective was not fully accomplished. Although no residential properties are at immediate risk of being flooded, the road extent and area affected by flooding are considerable. The higher the return period, the greater the road extent and area affected. The performance is classified as satisfactory only for the case of the 10-year return period in the current climate scenario. The future climate scenario increases the load to the system, with an aggravation as the return period increases. The impact of surface flooding on people or on the built environment was estimated to be zero, since the flooding depth is not sufficiently high (0.23 m) to affect properties. The performance result can be classified as good.

The protection of surface receiving waters was selected considering the location of the system in an estuarine area, and the estuary ecological and chemical vulnerability. This objective was not achieved. Although it was not possible to quantify all the illicit wastewater connections to SWS, it was observed a significant wastewater flow in different parts of the network during the inspection campaigns (Cardoso et al. 2016). This fact, besides contributing to reduce the hydraulic capacity of some SW pipes, also contributes to increase the estuary risk due to the probability of occurring untreated effluent discharges.

The infrastructural sustainability was also compromised. Regarding the systems' hydraulic capacity, due to the low slopes of upstream pipes, around 30 % - 40 % of the network conveys stormwater flow with a limited hydraulic capacity. During the inspection campaigns, evidence of surcharging was observed in some parts of the network. For the future scenario, the situation aggravates. For all simulations, the results obtained correspond to a poor performance classification. Additionally, for all simulations, over 90 manholes per 100 km of pipe length were flooded, which was more than three times higher for the 50-year return period. It confirms the existing limited hydraulic capacity in parts of the network. The operational condition is also critical. Even if the number of blockages per year was not quantified in the area, it was possible to observe, from the inspection, many blockages caused by sand in the pipes' cross sections, especially at the outfalls, given the natural morphodynamics of the estuary. Usually, after a cleaning operation, it would take 2-3 weeks until the outfall is again almost fully obstructed. As this metric provides essential information, these data should be collected. The extent of pipes without self-cleaning capacity is around 70 %, confirming the susceptibility of the blockages' occurrences in the network, with no significant differences between simulations for current situation and future climate scenarios. Given the high accumulation of sand in different parts of the SW network, more frequent cleaning works are recommended. Concerning the infrastructural integrity, data were not provided for SW pipe collapses. The inspection allowed to observe SW pipes with critical structural defects, and some manholes at risk of collapse. Information on the rehabilitation rate for pipes and manholes was not available. The structural condition of some SW pipes and manholes highlights the relevance to know the rehabilitation rate in order to assess its adequacy to ensure the infrastructural integrity of the network.

Due to the lack of information, the sustainable use of resources was not reported. However, it is relevant to assess how financial resources are employed, to detect inefficiencies and establish investment priorities.

The metrics obtained through the mathematical simulations were classified as reliable and accurate since they are based on a calibrated and verified 1D/2D mathematical model. The other two metrics were classified as having a lower reliability and accuracy, because they were estimated based on the water depth and flooding propagation, and on the properties locations.

### 3.2 Study of intervention solutions of Dafundo

The study of intervention solutions focused on the hydraulic and operational performance because the information was available, allowing the simulation of different solutions. The protection of public health and safety, and of infrastructural sustainability are the objectives addressed in the intervention solutions. The 20-year return period was selected in the future climate scenario (2011-2040) for the mathematical simulations. Five intervention solutions were included: current system configuration with obstructions (A.0) and without obstructions (A.01), implementation of permeable pavements in the parking spaces (1594 m$^2$) (A.02), replacement of SW pipes with limited hydraulic capacity (A.03) and combination of these latter solutions (A.04). The selection of intervention solutions did not account for the respective infrastructural, economic, and social feasibility.

The proposed solutions did not influence the surcharging condition and the self-cleaning capacity, since these two metrics are highly related to the slope of pipes. Based on the AWARE- P software, three metrics were selected to evaluate the intervention solutions: road extent and area affected by flooding and number of manholes or inlets flooded (Figure 1). The weights assigned to the metrics were very high for road extent, high for the area affected and medium for the number of manholes flooded.

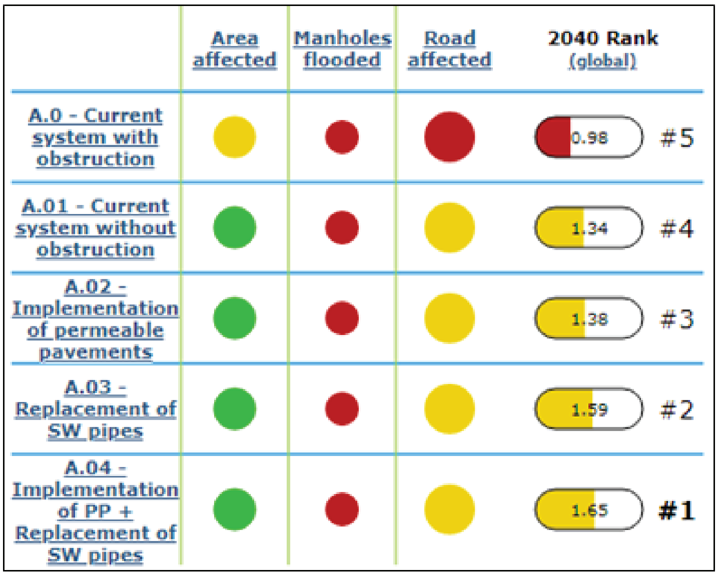


**Figure 1.** Comparison of intervention solutions for SWS, for a 20-year return period rainfall event in the future climate scenario (2011-2040) and maximum tide levels, based on the AWARE-P software

The alternatives with no obstruction have a better performance. The most attractive solution is the combination of implementation of permeable pavements and replacement of SW pipes, followed by the replacement of SW pipes solution. Since the difference between these two solutions is relatively small, it may be economically more feasible to invest in replacing SW pipes. If there is no capacity to invest on major infrastructure interventions, focusing on the cleaning of SW pipes and outfalls to decrease the flooding occurrences and their magnitude would still contribute to improve the system performance.

A sensitivity analysis was carried out regarding the change in the ranking order with weighting coefficients, but it did not change the order. Further analysis would be advisable, including the risk and cost dimensions.

ÁGUAS&RESÍDUOS
UMA REVISTA apesb

## 4 Conclusion

The present work aimed to test the applicability of the developed PAF, as part of the internal validation phase, through its application to a Portuguese case study, in an estuarine area served by a conventional SWS and by establishing a PAS. The application contributed to the evaluation of the PAF components in terms of their definition, relevance, effectiveness, and feasibility, leading to improvements of the PAF. The establishment of a PAS supported the identification of systems vulnerabilities of the SWS, at a hydraulic, structural, operational, and environment level, besides the factors that influence their performance and the improvement opportunities. The results of a PAS can be used to study intervention solutions at a preliminary phase and support the decision-making process. It can help to structure a further application of multicriteria analysis. It was also demonstrated that it is possible to carry out a performance assessment even in case of data gaps. When performance metrics cannot be quantified, they can be replaced by a qualitative analysis based on expert knowledge of systems functioning. This analysis can help to identify the needs of collecting quantitative data. Water utilities should invest in collecting and organising quantitative data for the selected PI, to ensure a more objective SWS performance analysis with higher reliability and quality.

## Acknowledgements

The authors would like to acknowledge the financial support from Fundação para a Ciência e a Tecnologia (FCT) for the PhD grant PD/BD/114461/2016, under the doctoral programme H2Doc (“Environmental Hydraulics and Hydrology”). The authors gratefully acknowledge the support of DHI for the supply of Mike Urban 2017 licence.

## References

Alegre H., Baptista J. M., Cabrera E., Cubillo F., Duarte P., Hirner W., Merkel W., Parena R. (2016). Performance indicators for water supply services - Manual of best practices (3rd ed.). London: IWA Publishing.

Alegre H., Coelho S. T. (2013). Infrastructure Asset Management of Urban Water Systems. In: Ostfeld, A. (Ed.) Water Supply System Analysis - Selected Topics, InTech, 49–74.

Beceiro P. (2016). 1D / 2D Integrated modelling and performance assessment to support floods management. Application to urban stormwater drainage systems in estuarine areas. Instituto Superior Técnico, Lisboa.

Cardoso M. A., Almeida M.C., Brito R.S., Beceiro P. (2016). Molines – Modelação da inundação em estuários. Da avaliação da perigosidade a gestão crítica. Modelação da drenagem urbana da bacia do Dafundo. Oeiras. Relatório 381/2016. LNEC.

Carriço N. (2014). Metodologia multicritério de apoio à decisão na gestão patrimonial de infraestruturas urbanas de água. PhD thesis. Instituto Superior Técnico, Lisboa.

Charlesworth S. M. (2010). A review of the adaptation and mitigation of global climate change using sustainable drainage in cities. Journal of Water and Climate Change 1(3), 165-180.

ISO 24510:2007. Activities relating to drinking water and wastewater services – Guidelines for the assessment and for the improvement of the service to users. International Organization for Standardization, Genebra.

ISO 24511:2007. Activities relating to drinking water and wastewater services – Guidelines for the management of wastewater utilities and for the assessment of drinking water services. International Organization for Standardization, Genebra.

ISO 24512:2007. Service activities relating to drinking water and wastewater – Guidelines for the management of drinking water utilities and for the assessment of drinking water services. International Organization for Standardization, Genebra.

Matos R. (1987). Métodos de análise e de cálculo de caudais pluviais em sistemas de drenagem urbana.

Monjo R., Pórtoles J., Gaitán, E., Redolat D., Paradinas C., Prado C., Torres L., Ribalaygua L., Russo B., Velasco M. (2018). Report on extreme events prediction - deliverable D1.3. RESCCUE Project – RESilience to cope with Climate Change in Urban arEas – a multisectorial approach focusing on water.

Porse E. (2013). Stormwater governance and future cities. Water 5, 29-52.

Santos L., Cardoso A., Galvão A. (2019). Performance indicators for urban storm water systems: a review. Water Policy 21, 221-244.

Santos L., Cardoso M. A., Galvão A. (2021). Proposal and validation of a performance assessment framework for urban storm water systems. PhD thesis. Instituto Superior Técnico, Lisbon, Portugal.

SIMAS Oeiras e Amadora (2015). Plano tático de gestão patrimonial de infraestruturas do sistema de drenagem de esgotos de Oeiras e Amadora, 2015/2020. SIMAS Oeiras e Amadora.