# 5th International Conference

## on Water Economics Statistics and Finance

## on Rethinking Treatment with Asset Management

22—24SEPTEMBER2021
PORTO · PORTUGAL

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# 5th International Conference

# on Water Economics, Statistics and Finance

# on Rethinking treatment with Asset Management

Conference's Venue: ISEP Congress Center

Rua Dr. António Bernardino de Almeida, 431 4200-072 Porto

**Title**

Book of Abstracts – IWA Conferences:

5th International Conference on Water Economics, Statistics and Finance (WESF)

IWA International Conference on Rethinking Treatment with Asset Management (RTAM)

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# INTRODUCTION

The IWA 5th International Conference on WATER ECONOMICS, STATISTICS and FINANCE and the IWA International Conference on RETHINKING TREATMENT WITH ASSET MANAGEMENT were held in parallel between 22th and 24th september 2021, in the attractive city of Porto, where old-fashion houses merge with modern look spots and life-style, leaning between the shorelines of Douro's River mouth and the sea, in the north of Portugal.

The conferences were jointly organized by the IWA Specialist Group on Statistics and Economics and by the IWA Specialist Group on Strategic Asset Management.

The Conference integrated the series of conferences organized by the IWA Specialist Group on Statistics & Economics, and therefore followed the need for discussion on the major challenges of sustainable water management, water security, growing water scarcity, decreasing water quality, and increasing frequency of extreme events. These challenges require a sustainable water management where water, ecosystems and livelihoods are secured.

Developing a better understanding of the economic value of water security is a priority. A major source of water management problems is the fact that water resources have a high value which has not been fully considered by all water users and explicitly accounted for in water policies, hindering development of effective strategies for solving water crisis. There are contradictory calls on data and monitoring. Some stakeholders believe there is too much monitoring already, while others believe that there is a lack of adequate data in the water sector for efficient and transparent decision making. Such contradictions complicate efforts to improve water management and secure funding and investment.

While in some places water infrastructures are degrading and public and private utilities face major replacement and rehabilitation costs, due to a lack of asset management practices, the way professionals used to assess and design water facilities is changing. This is often a result of new approaches caused by external stress on water systems (e.g. increasing energy costs, public health concerns on emerging pollutants, climate changes, etc.), but also of imposed limitations to expenditures. Optimizing infrastructures in order to meet capital availability is surely a task for water professionals to embrace and interiorize as part of their job. But, the risk is there that society overly values this as a required effort only to get water services at adequate fair prices. Accordingly, the sector should evaluate whether its activity is being correctly communicated to all stakeholders.

Also, as highlighted by IWA, "Digital water is already here"! From big data solutions to advanced management of the distribution network to digital customer engagement programs, lots of utilities have begun the digital transformation journey. This transformation is not always easy - aging infrastructure, inadequate investment, changing climate and demographics – and so "digital water" is now seen not as an 'option' but as an 'imperative.'

During the conferences, water policy-makers and regulators, utility managers, planners and operators, scientists and academics, investing institutions, professionals, engineering developers and contractors, consultants and other water professionals debated water resource management, water governance and regulation, water statistics and data collection methods, water economics and efficiency, urban and rural water supply sanitation, and agricultural/industrial water management and the improvement of water facilities' performance and sustainability in a global context of increasing risks and complexity.

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## Urban Water Systems analysis and Sustainability

Montserrat Termes-Rifé

**Abstract:** The urban water System is an interface between water in the natural environment and an urban community. Urban water systems are facing challenges as increasing population and its concentration in urban areas and climate change. As a consequence, and in the XXI century, they should include water supply, demand, wastewater, drainage, stormwater, flood protection, and recycling water. Some countries and regions are introducing technologic and institutional changes for increasing availability of water. At the same times, developments in biotechnology, materials science, sensors, and computing are giving rise to technologies that have the potential to revolutionize urban water systems as well as increasing knowledge of natural systems. Concerning urban water systems, integration and decentralization of infrastructures are moving towards sustainability of urban water systems. In this context, the social, environmental, and economic dimensions of sustainability incorporate assets and governance and the relationships with providers and users. New frameworks are appearing as Integrated Urban Water Management, Sustainable Urban Water Management to evolve current framework as well as different ways of assessing sustainability. Nevertheless, sustainability should be integrated in each subsystem and working towards the technological sustainability, tariffs sustainability, utilities sustainability, water service sustainability or operations sustainability for reaching urban water system sustainability.

## Urban Water Systems Analysis and Sustainability

*Keynote speaker*: João Feliciano

**Abstract** Water utilities' sustainable management is an increasingly complex challenge. Population demand is rising, infrastructure is ageing, and the negative impact of climate change on water services is increasing. To face these challenges, utilities must plan investments in a way that guarantees the resilience of the infrastructure and organization in the short, medium, and long term. Thus, knowledge and innovation management are crucial. Using methodologies acquired from the participation of international projects and the close relationship with R&D institutes, AGS has been developing collaborative projects within its utilities. These collaborative projects have resulted in the collective transfer of knowledge to and from the utilities. Additionally, it has promoted the development of software tools and the establishment of an internal innovation process.

## Rethinking urban water management

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Water scarcity is a serious problem in most cities of the world, exacerbated by climate change due to the increased frequencies, severities, and durations of events such as floods and droughts. The scientific consensus is that the current situation will aggravate in the coming decades, which will negatively impact the sustainability of all economic sectors and population at large, as all of them depend on water availability.

Proper water planning and management have enormous significance as they provide an entry point to address broader and closely linked development objectives. Water stress all over the world is being exacerbated due to the increasing frequency, duration, and intensity of droughts, coupled with steadily higher water requirements due to a growing population, urbanisation, and economic activities, in addition to poor water management and governance practices. Water for the environment is oftentimes sacrificed, resulting in negative consequences for vulnerable communities and leading to a failure in water security (Scott et al. 2020). This, in turn, is resulting in social, economic, and environmental impacts with wide implications at local, national, and global levels (Dolan et al., 2021).

Climate change is altering the water cycle. In many regions, rainfall and flooding as well as droughts are more intense and prolonged, a situation that is expected to worsen in the future (IPCC, 2021), exposing the vulnerability of human and natural environments to its impacts. All over the world, policymakers are under increasing pressure to develop and implement proactive policies to best manage and allocate water to the different sectors during extreme events rather than react to them. Although not without concerns, policy interventions have been better planned and implemented in cities and regions in the Global North (Benson, 2012; Rey et al., 2019; Horne, 2016) compared to the Global South (Gutierrez et al., 2014; van Rensburg & Tortajada, 2021).

This presentation will focus on Singapore and how policies and water management practices have changed in advance of economic development, population growth and water demands (Tortajada and Bindal, 2020; Tortajada, et al., 2021).

Singapore has to be considered within its own context: a small island, and thus area-constrained, that has grown continuously only through land reclamation. It has no natural resources and no hinterland to provide them, and a historical dependence on outside sources of water, energy, and food. These seemingly serious limitations have been overcome, however, with long-term comprehensive planning,

policies, and innovation in all the sectors, where the overall development of the city-state, rather than the individual sectors, has been the main priority.

Since independence in 1965, when planning for water resources, water security (availability, accessibility, and affordability) has been a main consideration. To become more water-secure, the city-state has developed forward-looking, comprehensive strategies that have ensured that Singapore can meet present and projected requirements (Tan et al., 2008). These strategies have included all aspects of water resources policy, planning, management, development, governance, finance, technology, and most recently, consideration of societal behaviour. This has included diversification of water supply sources within and outside of Singapore; cleaning-up of rivers and waterways; protection of water catchments; water conservation measures; development of infrastructure; wastewater treatment and disposal; production of high-grade reclaimed water for potable and non-potable purposes (known as NEWater); and desalination. The last two have been planned to supplement local catchment and imported water, and they have effectively enhanced water security (Parliament of Singapore 2016). All this is within a regulatory and institutional framework that is modified and improved when and as required (Tortajada et al., 2013).

Climate change is adding constraints in terms of water security and Singapore has been planning for them. Within a framework of water security, planning and investment in water resources ahead of time have become even more relevant (Parliament of Singapore, 2017), as has the participation of the population and commercial and industrial sectors in using water more efficiently. The more involved the economic and social sectors are in water conservation, the more secure the city-state will be in the longer term.

Singapore has not followed any specific paradigm that has been prevalent internationally at any time. On the contrary, given its specific characteristics, it has searched for its own most appropriate alternatives, looking for solutions that will be cost-efficient in the long-term. Priorities have changed with time: from water availability to self-sufficiency, then to security and, finally, to resilience. This has resulted in policy, management and technological innovations to improve urban water management.

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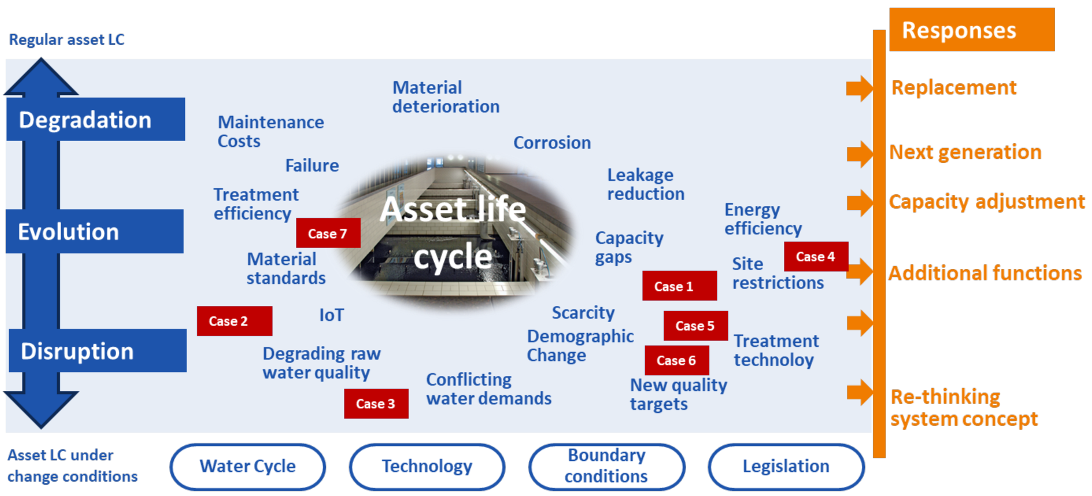
# Re-Thinking Treatment with Asset Management and the Key Role of Data Analytics

Wolf Merkel, PhD

The keynote explores the issue of what brings an asset life to its end, under the circumstances of rapid and tremendous change in the water cycle. Water assets are embedded in the natural water cycle and create a technical extension within. Thus, water assets are always subject of changing environmental and related boundary conditions, such as climate change or resource depletion. Furthermore, demographic and structural change put pressure on water systems, with regard to their functions, reliability and economic efficiency. Society and politicians develop responses and ambitions resulting in new legislative frameworks e.g. on energy or resource efficiency, which also cause a dynamic environment for existing water and wastewater systems. Last but not least, technology development provides new solutions and approaches for more effective and efficient water systems.

In general, asset life is subject to degradation, but also to evolutionary and disruptive processes in terms of changing environments as mentioned above. Water and wastewater treatment plants are integrated in a complex water supply/disposal system. Therefore, only in the minority of cases, asset modernisation can be derived linearly from condition analysis and re-building of existing assets, but rather from the analysis of the entire water/wastewater system. With a focus on treatment, both drinking and wastewater, the keynote explores changing system conditions in 6 case studies, with a wide range of drivers and impacts on the specific treatment facility. In case study 7, the application of a value-based design approach is demonstrated, illustrating an alternative to the linear planning process.




Responses to asset modernisation needs range from replacement, applying next generation technology, capacity and functional adjustments, increased resilience up to a complete re-thinking of the overall system around the treatment facility. In all examples the need for asset data is evident, but also the limitations in terms of availability and quality. Water experts are encouraged to combine well-established procedures of asset management, namely condition monitoring, data analysis, life cycle costing with non-linear thinking, system understanding, value management and integrated planning with innovative approaches to secure water asset value for future generations.

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# INDEX

## EXTENDED ABSTRACTS

## SHORT ABSTRACTS

## POSTERS

# A GIS Tool for Assessing the Condition, Risk and Rehabilitation Costs of Sanitary Sewer Systems

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**Abstract:** This work presents a Geographic Information System (GIS) tool developed for assessing the condition, risk and costs associated with rehabilitation options of interceptor sewers and manholes. The methodology built for assessing interceptor sewers was based on closed-circuit television (CCTV) inspections, the coding system of EN 13508-2 and the inspection protocol developed by the Water Research Centre. For assessing sewer manholes, we developed our own methodology containing specific criteria for systematizing visual inspections. The implementation of this tool allowed for the gathering of updated data on sanitary sewer systems managed by Águas do Norte, SA. This data is easily available to the entire organization, reducing financial and human resources costs, and improving decision-making processes on the prioritization of future investments.

**Keywords:** Sanitary Sewer Systems, GIS Tool, Decision-Making.

## Introduction

Águas do Norte, SA, a public water and wastewater utility, currently manages an extension of roughly 3200 km of interceptor sewers in the North of Portugal. As these infrastructures expanded continuously over the past two decades, the development of an organizational asset management strategy became a necessity; a strategy that, through an efficient allocation of the available human and financial resources, could continue to ensure the quality of the services provided, promoting significant social, economic and environmental benefits.

The first stage for creating the GIS tool presented in this work began with an extensive CCTV inspection campaign of several interceptor sewers. The defects and features were coded in accordance with the EN 13508-2. Regarding manholes, we internally built a specific diagnosis sheet. The inspection data collected was initially organized in Excel spreadsheets, where a calculation model was set and tested to determine the condition, risk and rehabilitation costs of each pipeline section. The assessment of the condition (both structural and operational defects) of each pipeline section (see Figure 1) was conducted based on the protocol developed by the Water Research Centre; the condition of each manhole was determined using a methodology developed by the authors (see Figure 2). The risk assessment was made through a selection of specific criteria, weighting the likelihood and impact of a failure (see Figures 1 and 2). Additionally, we developed a calculation methodology for estimating the costs of different possibilities for rehabilitating the infrastructures according to their condition (see Figures 3 and 4).

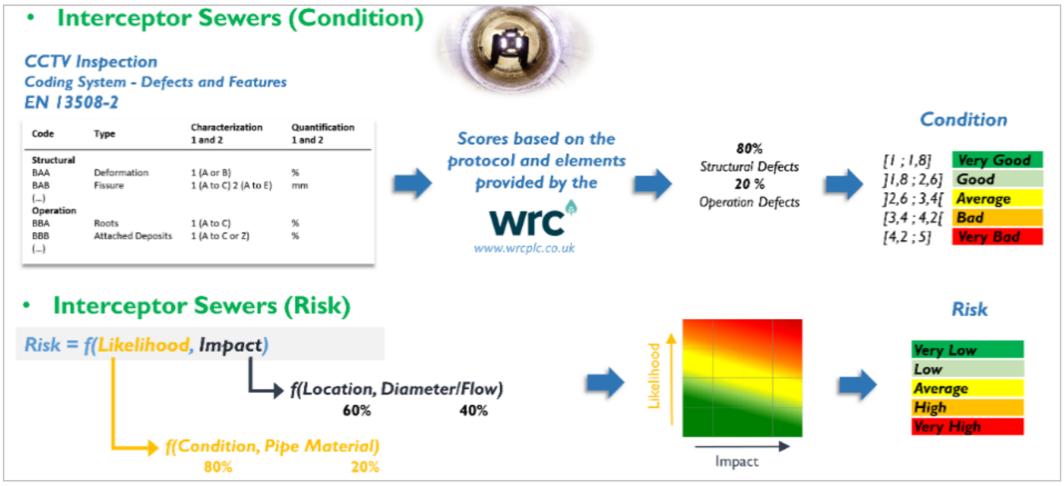


**Figure 1** Short summary of the procedure followed to calculate the condition and risk of interceptor sewers. Source: elaborated by the authors.

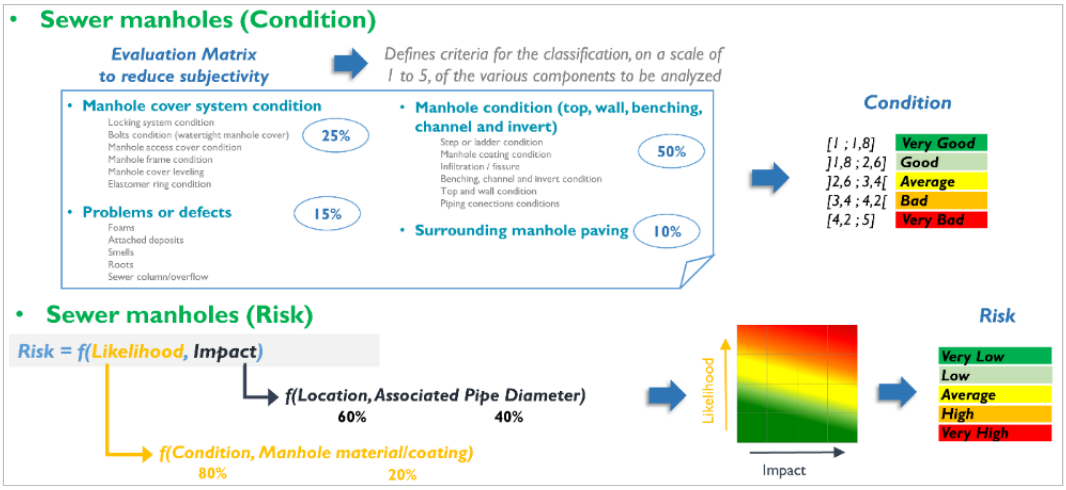


**Figure 2** Short summary of the procedure followed to calculate the condition and risk of sewer manholes. Source: elaborated by the authors.

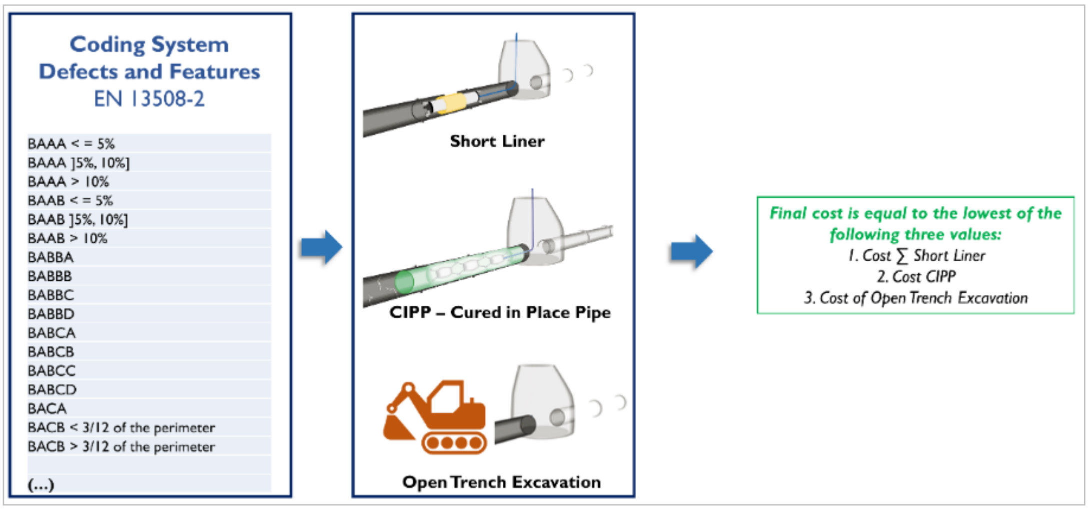


**Figure 3** Short summary of the procedure followed to calculate the rehabilitation costs of interceptor sewers. Source: elaborated by the authors.

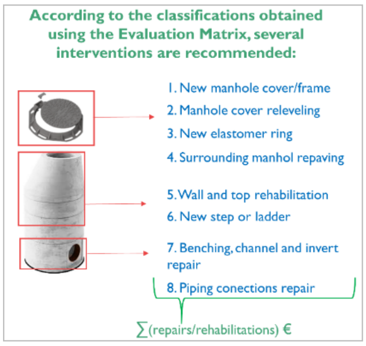


**Figure 4** Short summary of the procedure followed to calculate the rehabilitation costs of sewer manholes. Source: elaborated by the authors.

But the changes in the world of utility entities and the explosion of data demand more sophisticated ways of managing, examining, and communicating utility information. Since assets are spatial, their exchange of influence is not only reciprocal, but determined by their criticality and location. It was important optimize these asset management process with spatial intelligence and the adoption of Esri technology was our next step and the right choice, since it allowed enables a holistic approach with fresh insights about performance, risks, resources, and costs.

The second stage consisted in integrating into the organization's GIS the whole model used to calculate the condition, risk and rehabilitation costs. This made it possible to drop the use of Excel spreadsheets to calculate and store the data. Using GIS, and with the creation of thematic maps, we were able to obtain a spatial interpretation of the condition and risk of each pipeline section and manhole; the severity of both the condition and risk were represented through a colour scheme. The tool also enabled us to get performance priorities through ordered listings according to condition or risk, and the respective associated costs of rehabilitation. In the process of transitioning to a proactive managing strategy, this GIS tool became a central one in decision-making at Águas do Norte, SA – both in the creation of priority intervention plans and in the definition of investment and financial strategies, due to the enhanced predictability of the interventions to be made.

Within this context, this work addresses the difficulties and options taken in each step of the process, namely regarding the adoption of the Water Research Centre's protocol and the integration into the organization's GIS. We also identified specific needs for future developments, particularly concerning a deeper analysis of the criteria to be adopted in the assessment of the risk and the evaluation on how to minimize the consequences that potential visual inspection data errors might have in the final condition and risk values.

## Creation of the GIS tool

The development of the GIS tool was based on ArcGIS Solutions for Water Utilities, which is provided by Esri (see Figure 5). The functionality "Import CCTV data" was based on the CCTV Manager application; the functionalities "Assessment of Condition and Risk" and "Cost Estimates" were developed using ModelBuilder, an application that allows to create, edit, and manage workflows that string together sequences of geoprocessing tools, feeding the output of one tool into another tool as input. This way, it was possible to automate the process using a visual programming language for building workflows made available by ArcGIS capabilities. The GIS user has access in the ArcGIS Pro's taskbar to three new options:

- "Import CCTV data": it allows for the import of the data directly from video inspections software to spatial data (geographical objects as interceptor sewers and manholes), as well as associated videos and photographs.
- "Assessment of Condition and Risk": it provides the state of condition and risk of inspected interceptor sewers according to the defects registered, following the EN 13508-2 standard and the Water Research Centre's protocol.
- "Cost Estimates": it provides the cost estimates of the rehabilitation of interceptor sewers and manholes, allowing for the creation of several intervention scenarios.

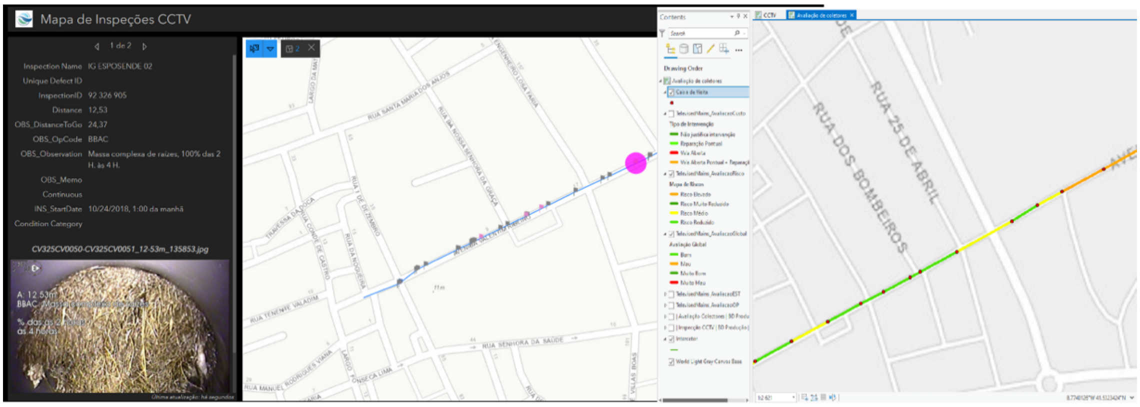

**Figure 5** Some screenshots of the GIS tool. Source: Águas do Norte, SA.

The GIS tool is flexible and allows for the adjustment of several fields related to the calculation of condition, risk and cost estimates. The number of inspections made is still limited and the flexibility of the GIS tool is thus fundamental for calibrating the model used as one conducts more inspections:

- Condition and Risk: adjustment of the scores attributed to which code from EN 13508-2 and values associated with the risk matrix (likelihood x impact);
- Cost Estimates: adjustment of the market prices associated with each type of intervention (Short Liner, Cured in Place Pipe (CIPP), Open Trench Excavation and each element of the rehabilitation of manholes).

This way it was possible obtain greater insight into our network, both in relationship to its surroundings and its threats. Visualization plays a strong role in effectively managing assets. The spatial analysis tools of ArcGIS sharpen your understanding of where the network is most at risk. Besides that, the functions to visualize on map and share results are easily accessible to the entire organization. Links to digital pictures and videos of observations are preserved and can be accessed via a map. Spatial analytics can be applied to the data providing additional asset management insights.

## Conclusion

The implementation of this GIS tool has brought a number of benefits to Águas do Norte, SA, namely the optimization of resources (both human and financial); the georeferencing of the defects detected and its presentation in thematic maps; the possibility to store historical data associated with a specific network element, before and after a rehabilitation intervention; and the definition of several reparation options and respective rehabilitation cost estimates. All these advantages facilitate decision-making regarding the prioritization of investments on the rehabilitation of sanitary sewer systems.

The recent application in Águas do Norte, SA of an Asset Management System and the respective certification according to ISO 55001 greatly contributed to the process of researching and developing the GIS tool presented in this work.

# A logistic network approach for optimizing sludge management under a circular economy perspective

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**Abstract:** This work presents a framework for the optimization of a logistic network for sludge management. It represents a relevant tool to be used under a circular economy paradigm. The logistics network was designed for a system of activated sludge wastewater treatment plants and anaerobic digestion in some of the plants. By applying this framework, efficiency in energy consumption is achieved, alongside an increase in energy recovery from the wastewater. The logistic network can integrate co-digestion of substrates from nearby relevant industries. These features are aligned with the operational principles of the circular economy, which can be an enabler of the sustainable development of the water sector.

**Keywords:** Sludge management optimization; Logistic network framework; Anaerobic digestion.

## Introduction

The effort made to extract more energy from wastewater (WW) results in a decreasing dependency on external energy sources, which has positive economic and environmental impacts. This suggests an enhanced water management to the fulfilment of basic needs associated with the quality of sanitation services, a requirement of quality of life. The WW has an embedded energy that is 5 to 10 times higher than the energy needed for its treatment [1]. As such, recovering more energy from the WW involves innovative thinking to, eventually, achieve net positive energy wastewater treatment plants (WWTPs) and generate income that can potentially be channelled elsewhere within the urban water cycle management systems.

Many research efforts have been made in terms of innovative solutions toward the positive energy balance target of WWTPs [2], [3]. However, in general, the approaches taken are single-WWTP focused. As highlighted by [4], in the scope of energy management systems such as those framed by the ISO 50001, the authors recommend to consider a unit-process as a basis for energy management rather than individual assets. The authors gave the example of the network-based infrastructure of the WW system and the need to tackle some major problems, such as overflows, yet the same can also be applied to the energy production processes.

Energy production at WWTPs, either directly from WW, i.e., energy recovery [3], or from the on-site exploration of other renewable energy sources [2], is comprised in the energy management strategies that should be considered in any energy management system in the scope of WW management [4]. Moreover, the same authors argue that an energy management system within the

WW management cannot be decoupled from other WW utilities' management processes, being the infrastructure asset management (IAM) one of the prominent ones since either energy efficiency and energy production are all linked to infrastructural aspects of the WW system. In addition, a key goal of asset management (AM) is primarily to extract value from the assets in use. Therefore, innovative ways to rethink WWTPs processes so as to improve any of the energy management related aspects constitutes a relevant contribution in terms of AM.

In this context, we present an innovative strategy for enhancing the energy production at a system of several WWTPs that was inspired in the work of [5] to highlight its suitable application under the circular economy paradigm as well as a means for energy management, which is associated to the correspondent IAM. This innovative strategy, developed by [6], is based on a logistic network for sludge transfers among WWTPs. The goal is to optimize the sludge management at the system level and increase the amount of biogas that is produced for energy recovery as well as decreasing the system's energy consumption. Furthermore, co-digestion is also considered at the parameters level of the model developed.

## Description of the logistic network

The logistic network (LN) is the result of a mixed-integer linear programming (MILP) model aiming to maximize the economic benefit from connecting two types of WWTPs that use activated sludge as the secondary treatment technology, via logistics transportation of sludge and adjustment of operational parameters (Figure 1). One type of WWTPs uses extended aeration (EA), so that the sewage sludge is completely stabilized via aerobic digestion. The other type of WWTPs uses conventional aeration (CA) and the sludge is further stabilized by anaerobic digestion (AD) before it is dehydrated and transported to be disposed. Some of the plants that undertake AD have available capacity in the anaerobic bioreactors, which constitutes an opportunity to optimize the percentage utilization of the installed capacity both in terms of volumetry and mass. This is factor helps improving the biogas production rate and, in some cases, to enable the combined heat and power (CHP) systems to be economically sustainable.

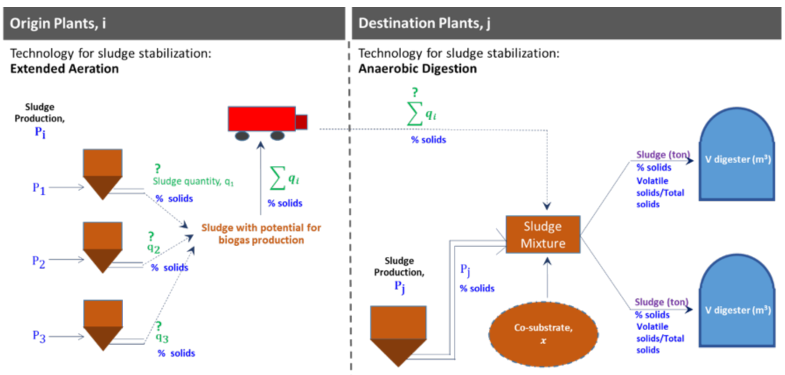


**Figure 1** Schematic representation of the problem to be tackled with the LN MILP model (source [1]).

Both costs and economic benefits associated with the LN are mostly related to energy, either electricity, thermal energy or other end-use energy forms. Therefore, even if there might not exist a standard unitary price for all types of energy forms involved, a positive result from the MILP model application indicates a positive energy balance. More precisely, to enable the LN functioning, it is assumed a reduction of at least half of the current electricity consumption at the plants that use EA (the origin plants), so that the sewage sludge retains its biogas potential.

Dehydration is an operation that is desirable due to the further need of sludge transportation, but this is already conducted in the current system. In addition, sewage sludge from this type of plants is already subject to transportation to the disposal destination, and so the transportation within the logistics network changes the sludge's destination. Nonetheless, there can be an increase in the transportation frequency along with a potential increase in the distances, depending on the configuration of the system of plants that are to be used for selection by the model. Regarding the plants with anaerobic digesters (the destination plants), the major requirement is the existence of a mixing tank to receive all the transported sludge so that the proper level of solids is achieved to guarantee the stable operating conditions within the anaerobic bioreactors.

Furthermore, there is the possibility of integrating additional organic substrate from nearby relevant industries, which can also be used to manage both the total solids amount and the percentage of volatile solids in the sludge mixture before entering the digesters. The so-called process of co-digestion, which integrates additional types of substrate to be digested with the sewage sludge, further enables a better rate of organic compounds degradation, so that an increased biogas production rate can be achieved [7]. With this expected result, a further reduction on the final volume of digested sludge to be dehydrated and disposed is attained, so that the associated costs will not increase in proportion to the additional sludge and co-substrates entering the digesters.

## Conclusion

The above explanation prompts the conclusion that the LN framework can be viewed as a contribution to the circular economy (CE), particularly through lowering resource consumption (e.g., energy) and increasing resource recovery (e.g., energy). These aspects are in accordance with the operational principles proposed in the CE study developed by [8]. An improved energy management, including an optimized recovery of the WW embedded calorific potential (a renewable energy source), corresponds to a partial internalization of negative externalities associated with the WW treatment activity, which is also fostered in the CE paradigm [9]. In doing this, the system of WWTPs can even become either energy self-sufficient or energy producer. These are concepts already explored elsewhere (e.g., [3]).

Furthermore, the CE paradigm can be implemented at different levels (i.e., micro, meso and macro), depending among other aspects, on the number of participants [9]. The LN, under a CE perspective, is implemented at the micro- and meso-level. The micro-level results from the effort made within the system of plants that belong to the same company, and the meso-level, results from the effort made to incorporate co-digestion of organic by-products of nearby industrial activities into the WWTPs system. This latter level of application can be gathered through industrial symbiosis [10] to enhance the enough trust and engagement from all stakeholders involved, which constitutes an opportunity for cooperation among companies, whilst promoting increased value of materials.

According to the projections made in the World Energy Outlook [11], by 2040 the electricity produced from WW can cover more than 55% of the electricity demand from municipal WW treatment in the 450 Scenario, which assumes the full exploitation of the energy efficiency improvement potential. In the particular case of sludge treatment, the improvements are expected through improved methods of dewatering. However, although it is also referred an increase in electricity generation from sewage sludge in the same scenario, there is still room for innovative ideas, such as the LN here mentioned, to enable covering an even higher level of electricity demand. This constitutes a broader context under which the LN can be asserted as a tool for sewage sludge treatment management improvement following the CE paradigm.

The design and implementation of the LN may be further seen as part of asset management strategy for enhanced energy efficiency results. This is because the WWTPs constitute the assets that need to be revised in their operational parameters to integrate the LN. This may also have implications in terms of slight investments needed (e.g., mixture tank at the destination plants) and further strategic prioritization of technology investments (e.g., more efficient dehydration and CHP technology), as the sludge management optimization model is designed with the objective of maximizing the economic benefit derived from the system energy balance. Also, the integrative perspective taken upon the WWTPs within the LN framework allows a better utilization of the installed capacity of the anaerobic digesters at some of the plants, which is one of the requirements to improved biogas production as well as enhanced feasibility of the energy recovery process with CHP systems.

As to the social benefits that can be accrued with the implementation of the LN, it is expected an increased quality of the WW service provision due to the economic and environmental benefits directly accomplished. Moreover, additional internal social benefits can also be obtained as a driving mechanism for the effective gathering of the economic and environmental benefits if the LN framework is to be implemented in parallel with increased valorisation, motivation, and preparation of individuals toward a better-trained and collaborative work force. Finally, when considering industrial symbiosis, the social benefits would be translated through thorough accountability of the interests of all stakeholders involved.

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# Asset management platform and decision support "OTIMA"

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**Abstract:** Águas do Norte, a public water and wastewater facility, was in the need for a better solution in an asset management platform and decision support tool. Based on the interconnection of data, inventory, energy management, operation, maintenance software and additional information supported by inspections and studies of the behavior of all water and wastewater infrastructures and their assets.

Allowing to improve the knowledge of the assets and thus be able to have a more sustained decision, based on accurate data in real time. The aim is to achieve the practice of managing infrastructure capital assets to minimize the total cost of owning and operating these assets while delivering the desired service levels.

**Keywords:** Asset management; OTIMA; decision; knowledge

## Asset management platform

In 2019, Águas do Norte, SA got its asset management system certified. The goal was to achieve an integrated strategy to manage capital assets, O&M tasks, costs, and long-term financial planning to provide appropriate levels of service. A fundamental principle was to help the organization with critical information on capital assets and investments timing. Effective decision-making requires a comprehensive approach that ensures the desired performance at an acceptable risk level, taking into consideration the life cycle costs of the assets. The focus naturally began on data quality control.

We grasped the need to gather, in a single IT platform with all the relevant information to decision-making about infrastructure and their assets. The creation of this platform follows the requirements that we have to achieve the most accurate and real-time information of all our infrastructures and their assets. In this context, we are creating/developing an asset management platform with Reporting /Dashboard functionalities, based on a sustainability policy (supported by efficiency /innovation) and a behavioural revolution supported by digitization at all stages of the asset lifecycle.

The construction of the location structure and uniform coding on all platforms, allowed us to think about a platform that, in addition to collect the information that we´ve consider crucial to our assets management should help us to create "OTIMA" based on our assets management tool and inspections. This way we can follow in real time our main variables and KPIs, thanks to the interconnection with other tools/platforms. By doing the inspections through the platform and following the location structure, we are able to update information about our assets condition anytime anywhere.

The actions resulting from inspections can be monitored in "OTIMA" regardless of the software in which they are registered and treated.

With all the information combined, we managed to accomplish our goal, which is to have the entire life cycle of the assets updated allowing us to be able to make a more sustained decision, based on more accurate data in real time.

We aim to standardize the location structure as well as the equipment records.

The platform is able to update equipment technical characteristics, or to eliminate deactivated equipment or locations.

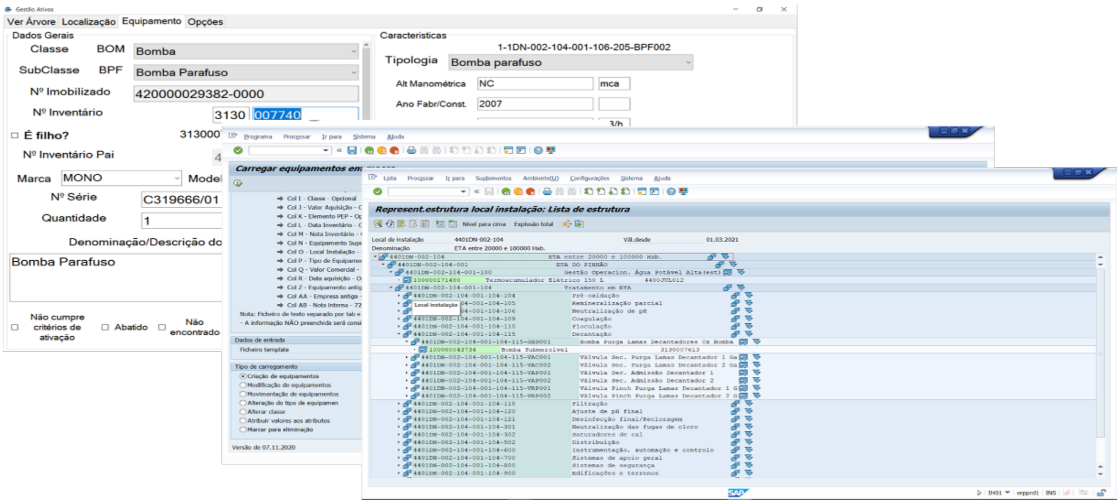



**Figure 1** this is a SIA and SAP example

After the inventory it was necessary to keep it updated. For this, we have at our disposal a series of tools, among which "SIGAME" stands out.

"SIGAME" is a GIS mobile software allowing changes/improvements to our inventory at any location with the help of GPS and photography.

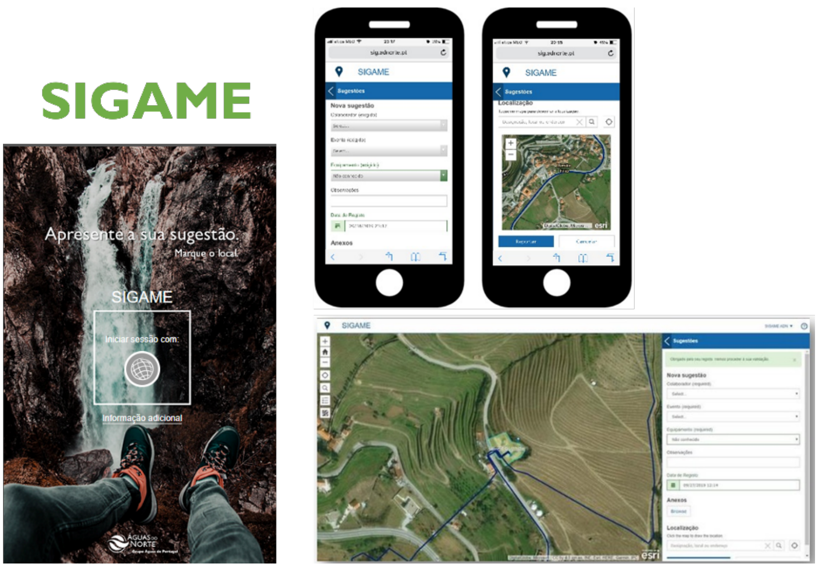



**Figure 2** SIGAME (ESRI)

From the assets location structure we can access a wide range of Infrastructures information as the picture below.

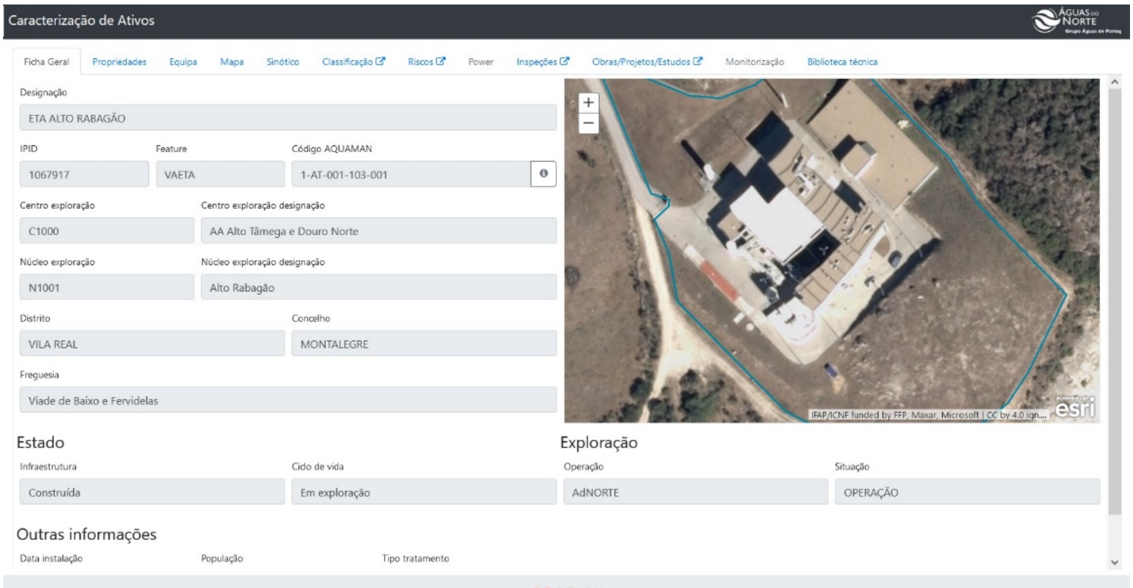
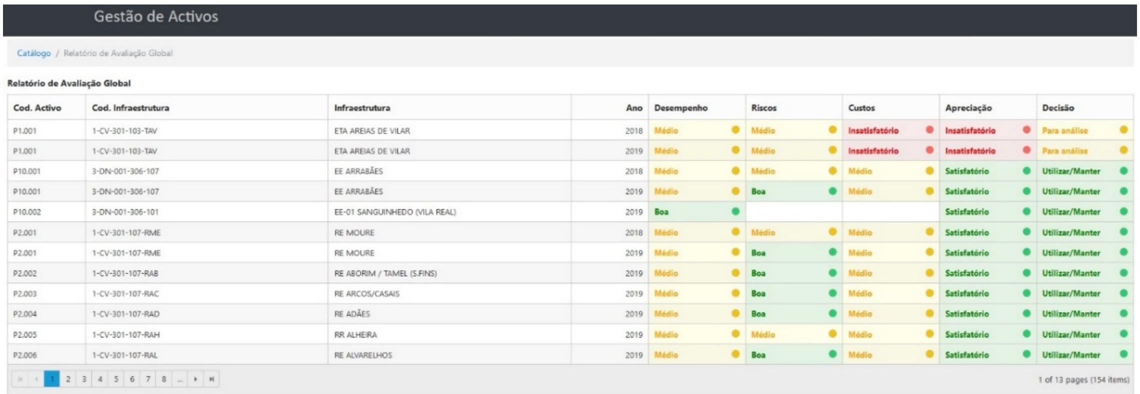



**Figure 3** Asset information

Based on the analysis of the key data, we will be able to build a matrix that compiles all the information and our KPIs, that will help us to define our actions and inspection priorities.


Gestão de Activos

Catálogo / Relatório de Avaliação Global

Relatório de Avaliação Global

| Cod. Activo | Cod. Infraestrutura | Infraestrutura | Ano | Desempenho | Riscos | Custos | Apreciação | Decisão |
|---|---|---|---|---|---|---|---|---|
| P1.001 | 1-CV-301-103-TAV | ETA AREIAS DE VILAR | 2018 | Médio | Médio | Insatisfatório | Insatisfatório | Para análise |
| P1.001 | 1-CV-301-103-TAV | ETA AREIAS DE VILAR | 2019 | Médio | Médio | Insatisfatório | Insatisfatório | Para análise |
| P10.001 | 3-DN-001-306-107 | EE ARRABÃES | 2018 | Médio | Médio | Médio | Satisfatório | Utilizar/Manter |
| P10.001 | 3-DN-001-306-107 | EE ARRABÃES | 2019 | Médio | Boa | Médio | Satisfatório | Utilizar/Manter |
| P10.002 | 3-DN-001-306-101 | EE-01 SANGUINHEDO (VILA REAL) | 2019 | Boa | | | Satisfatório | Utilizar/Manter |
| P2.001 | 1-CV-301-107-RME | RE MOURE | 2018 | Médio | Médio | Médio | Satisfatório | Utilizar/Manter |
| P2.001 | 1-CV-301-107-RME | RE MOURE | 2019 | Médio | Boa | Médio | Satisfatório | Utilizar/Manter |
| P2.002 | 1-CV-301-107-RAB | RE ABORIM / TAMEL (S.FINS) | 2019 | Médio | Boa | Médio | Satisfatório | Utilizar/Manter |
| P2.003 | 1-CV-301-107-RAC | RE ARCOS/CASAIS | 2019 | Médio | Boa | Médio | Satisfatório | Utilizar/Manter |
| P2.004 | 1-CV-301-107-RAD | RE ADÃES | 2019 | Médio | Boa | Médio | Satisfatório | Utilizar/Manter |
| P2.005 | 1-CV-301-107-RAH | RR ALHEIRA | 2019 | Médio | Médio | Médio | Satisfatório | Utilizar/Manter |
| P2.006 | 1-CV-301-107-RAL | RE ALVARELHOS | 2019 | Médio | Boa | Médio | Satisfatório | Utilizar/Manter |

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**Figure 4** Asset matrix results

"OTIMA" is a platform that helps decision-making, in a context of many types of infrastructures and a tremendous geographical dispersion.

*An internal project, developed our own way.*

Having a custom platform, tailored especially to meet our specific business requirements. Modular (can be changed without excessive impact). The customization experience is linked to its innovative nature. It is valued by its adaptability.

We can help other utilities sharing knowledge and experience.

# Assuring Long-term Sustainability via Asset Management for the EU Financed Infrastructure – The Romanian Case

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**Abstract:** In the last 20 years the Romanian water sector has implemented major investment in infrastructure mainly with EU funds leading to significant pressure on the operating costs and on future maintenance and replacement investments. In order to assure a sustainable operation and maintenance, a series of reform measures are intended to be implemented including the requirement for development of proper asset management systems. The proposed reform measures consider obligations for the operator to develop asset management plans and changes in the tariffing and affordability regulation system in order to assure also proper financing for asset maintenance and replacement. The present paper presents the proposed reform measures and offer an overview on the progress of implementation.

**Keywords:** Asset management; full cost recovery; tariff strategy; affordability; economic regulation.

## General Context

Regionalization of the water services, planned to overcome excessive sector fragmentation and to achieve economies of scale, is on-going. There are currently 43 regional operators in Romania, as well as two large private operators in Bucharest and Ploieşti. As a result of the regionalization process over the past decade, more than two-thirds of the Romanian population (about 13.3 million people in total) is served today by large public utilities.

The main investment programmes in the Romanian in the last 30 years were driven by the European Commission requirements in relation with grant funding. Compliance with the relevant EU Directives remained the main goal of the largest investment programmes. About EUR 7 billion were invested in the water and wastewater infrastructure over the past 20 years; due to this, about 12.6 million people benefit of water and sanitation services provided by large water utilities.

The overall cost assessment for compliance with the EU water and wastewater standards shows an investment need of EUR 24.5 billion, without taking into account the increasing costs associated with further delays or with the foreseeable infringement (for EU non-compliance). Out of the total EUR 24.5 billion, an amount of EUR 9 billion is estimated in relation with the water supply and EUR 13.2 billion for wastewater collection and treatment. The reinvestment needs are also higher for the wastewater, reaching EUR 1.5 billion.

Most of the investments required by compliance are necessary in the area of the regional operators (~70%) and more specifically in the rural area. The implementation capacity and operating sustainability is very different from one operator to another as well as the financing capacity from own sources. Application of solidarity principle between the urban and the rural areas is the only feasible solution for a sustainable operation in the area of the regional operators. However, the solidarity principle should be seen in connection with the consistent application of the regional tariff policy (that takes into account affordability and other social policies for the poor), factors that have an impact on the financial viability of the regional operators.

The Regional Operators have currently under preparation and partially under implementation long-term investment plans and feasibility studies for an overall investment value of approximately 9 billion Euro which are planned to be financed from the Large Infrastructure Operation Program (2014-2020 EU programming period) with an allocated amount of 2.5 billion euro, from the Sustainable Development Operational Program (2021-2027 EU programming period) with an allocated amount of 2.6 billion euro, National Recovery and Resilience Program and state budget.

In the cases of most of the operators, the size of the operated infrastructure has doubled in the last 10 years and it expected to double again in the following 10 years with significant pressure on the operating costs (this are mainly compliance investment that generated additional operating costs) and on future maintenance and replacement investments. In order to assure a sustainable operation and maintenance, a series of reform measures are intended to be implemented in the Romania water sector including the requirement for development of proper asset management systems.

**Proposed Reform Measures**

The Romanian Government has issued in 2019 the report "Water Sector Development in Romania. Strategic Directions - 2019-2035" developed under the Technical assistance project to consolidate the water and wastewater sector in Romania coordinated by EBRD considering a series of important reforms for the water sector in order to assure medium and long-term sustainability.

One of the main reform measure considered is referring to strengthen the role of ANRSC (the Regulator) including capacity and resources to effectively regulate the sector on quality, tariffs and efficiency, and report transparently on the sector performance; ANRSC should review the future business plans of ROCs and closely monitor investment plans for compliance. ANRSC needs to gradually undertake the role of economic regulator of the sector.

One of the main measure considered as part of the future economic regulation system is the focus on proper asset management by the operators. The development of asset management plan will become an explicit requirement of the tariff approval and business planning process which should lead to development of proper asset monitoring and recording, maintenance plans and replacement investment programs. The asset management will be part of a broader set of measures focusing on improvement of efficiency of operation for the utilities as shown in the following figure:

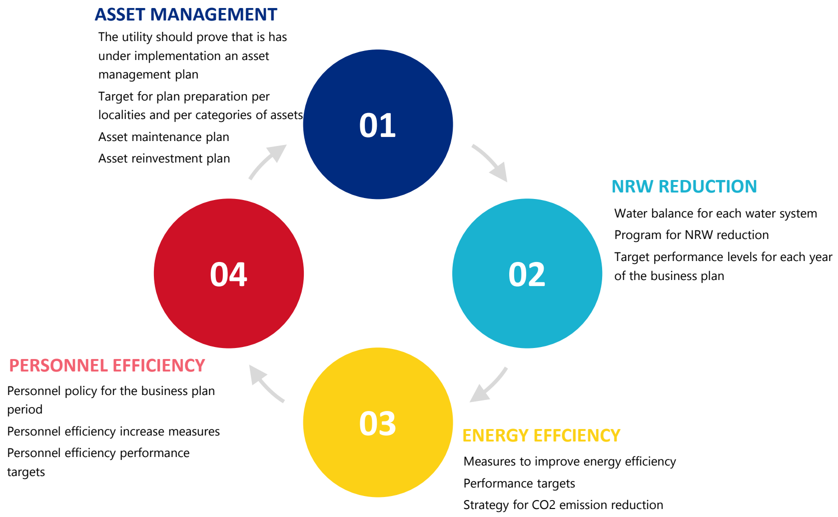


**Figure 1** Efficiency improvement measures to be imposed to the water utility companies.

An asset management system can be effective only if there are available financial resources to assure the proper implementation. In order to assure the proper financing, there are a series of other reform that are planned to be implemented such as:

- Including gradually the depreciation of the public infrastructure into the tariff considering the affordability constrains. In this way, by increasing every year the share of capital elements into the tariffs until the full depreciation is recognized, the water utilities will have increasing funds available for proper maintenance, replacement, and developments. The availability of increasing funds will require proper asset management plans for prioritization of spending.
- In order ot assure sufficient funding for the first measure (the introduction of depreciation into the tariff), there will be set a minimum level for the affordability ratio at 2.5% for the average household until the full depreciation is introduced into the tariff. Considering that the actual affordability rate (the percentage of water and wastewater invoice into the household revenues) is around 1.7-1.8%, the expected tariff increasing in the following year with focus on capital components will be important.
- The utility companies will have to prepare tariff strategies for medium terms (4-7 year) based on business plans and considering the two principles mentioned above in order to assure predictability of available financial resources and to decrease the political intervention into the activity.

**Status of Implementation**

Part of the reform measures mentioned are already started ot be implemented mainly via pilot projects. During the period 2019-2020, there were selected 6 pilot utilities for an asset management basic project under the coordination of EBRD as part of the Technical assistance project to consolidate the water and wastewater sector in Romania.

The purpose of the pilot projects was to demonstrate that, irrespective of the current situation, asset management can be improved using the framework presented during the workshops of the project. Each participating ROC explored and developed ways in which they could improve the manner in which they managed their assets, bringing benefits to both ROC and its customers.

The team of consultants have developed a "Guidelines for Development of a Good Asset Management Framework" and the pilot utilities participated to workshops and on the job training session with representatives of a water utility from Denmark (VCS) in order to start developing their own asset management systems.

Some of the pilot water utilities are continuing with the development of the assets management systems such as:

- The Regional Operator from Iasi County (ApaVital Iasi) has contracted a technical assistance with the support of EBRD for developing a customized asset management system for the entire water asset data based including performance indicators and a customized software. The project already started in January 2021 and the progress until the date of the study are important.
- The Regional Operator from Arges County (Apa Canal 2000 Pitesti) has contracted a technical assistance in April 2021 with the support of EBRD for assisting them with a detailed analysis and strategy for the asset management system and preparation of the tender documents for purchasing a customized IT software for asset management that should be integrated with the GIS and SCADA.
- There are a lot of other large public operators from Romani that are considering to focus in the near future on the development of proper asset management systems so this is only the beginning of the journey.

On another level, the Regulator (ANRSC) has contracted a technical assistance for developing the economic regulation system for the water and wastewater sector from Romania. The key principles mentioned above (introduction of depreciation into the tariff, minimum affordability ratio, imposing operation efficiency improvement measures, medium term tariff strategies, etc.) will be the key pillar of the future economic regulation system that is planned to be enforced to all operator via changes in legislation. The goal is to have this new regulation into force until the end of 2022.

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# Benchmarking: a multi-stakeholder tool to continuously improve water services

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**Abstract:** Benchmarking is a management instrument, developed by Rank Xerox company in the 1970's, to improve business processes by measuring and comparing performance and learning from peer companies.

Since the early 1990's benchmarking is increasingly used in the global water and sanitation sector. Several documented cases from Europe show that the instrument -when used properly- can lead to significant service- and efficiency improvements.

Over time, also stakeholders like governments, regulators and customer organisations have discovered the benefits of benchmarking and use it for policy making, regulation and public communication about service levels.

Today, society today calls for effective, efficient, sustainable and resilient water services. Benchmarking can play an important role in meeting this demand, provided utilities feel the sense of urgency to continuously improve and join the benchmarking efforts.

**Keywords:** Benchmarking; governance; improving water services.

## Introduction

The concept of benchmarking was developed by Rank Xerox company in the 1970's as an answer to increased competition by Japanese copier manufacturers. By measuring performance, comparing with others and searching for industry best practices, Rank Xerox improved its business processes and created a better cost/service ratio.

Since the early 1990's the benchmarking instrument is increasingly used in the global water and sanitation sector. Documented cases from countries like Denmark[1], Germany[2] and the Netherlands[3] show that benchmarking -when used properly- can lead to significant service- and efficiency improvements. Additionally, cross-border initiatives like from EBC Foundation[4] fill the gap in countries without national initiatives and facilitate knowledge exchanges between utilities from different countries.

Despite the increasing number of benchmarking programmes in the sector, many utilities are not yet involved in any benchmarking effort at all. This especially disadvantages smaller sized utilities, with -generally speaking- fewer improvement planning capabilities. Participating in a benchmarking programme could provide them with performance references and give access to a network of experts from colleague utilities to exchange on concrete improvement actions and learn for instance about practical financing options.

## Stakeholder use

Next to the water sector, stakeholders like governments, regulators and customer organisations have also discovered the benefits of benchmarking for purposes like policy making, regulation and public communication about service levels.

Though benchmarking is primarily developed to improve business processes, the information that is generated for management purposes can also be used by stakeholders for their specific goals. For example, water volume data which is collected for operational purposes and is aggregated to utility level for management purposes, like financial planning, demand management, benchmarking water losses etcetera is also used by stakeholders, though usually at a more aggregated level, like for national statistics or -policies.

For other types of information this works in the same way. The number of lead connections that need to be removed for reasons of public health for instance is used by utilities for operational purposes, for decision making and benchmarking. The same information is used by governments to understand regional differences and to decide about national clean-up policies.

The so-called information pyramid shown in the figure below illustrates that benchmarking information can be used for different purposes:

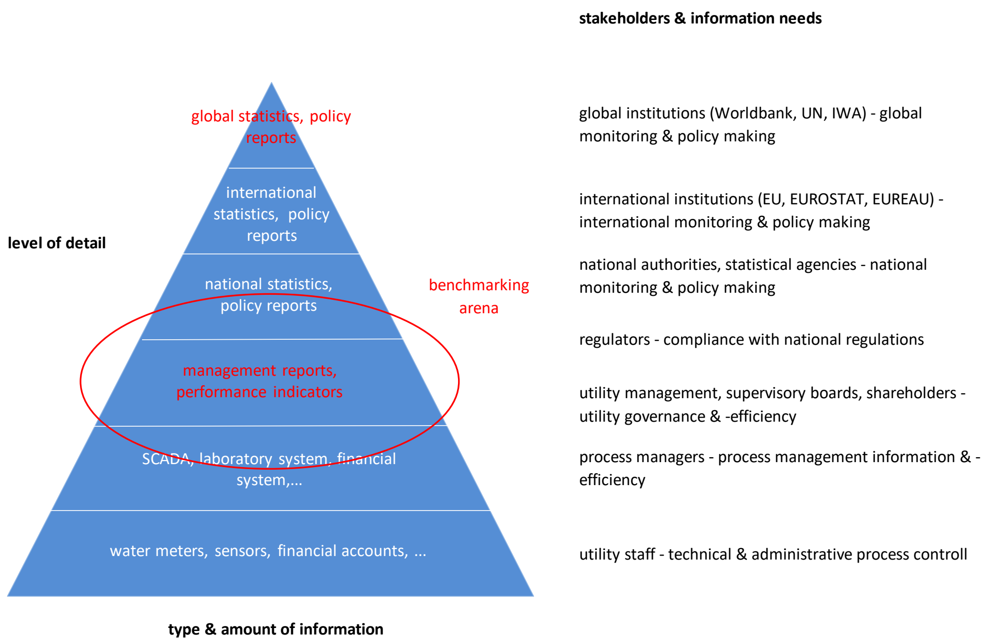


Figure 1 Information pyramid

## Increased expectations

Today, society today calls for effective, efficient, sustainable and resilient water services. Benchmarking can play an important role in meeting this demand. Despite the large benefits for utilities and the sector as a whole, many utilities are not yet involved in benchmarking efforts, due to a lack of urgency and stakeholder pressure. Society may expect from water utilities that they do their utmost to provide a good service and continuously work on improvements; joining a benchmarking effort is a relatively easy and proven measure to reach this goal.

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# Biochar as a sustainable particulate electrode in a 3D electrochemical process to remove carbamazepine from aqueous solutions

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**Abstract:** In the present work, a 3D electrochemical process was applied to the degradation of carbamazepine (CBZ). Biochar (produced by pyrolysis of vineyard pruning) was used as the particulate electrode, and the influence of pre-treatments of the biochar was studied. Adsorption studies indicated that, when hydrated, the biochar had a higher adsorption capacity than when dry biochar was used. However, in the 3D electrochemical experiments the use of different biochar's pre-treatment - hydrated (overnight), dry, and saturated biochar (overnight with a 10 mg/L CBZ solution) - influenced in a different way the CBZ removal, obtaining better results for the dry and the saturated biochar.

**Keywords:** Adsorption; Advanced-oxidation; Carbamazepine.

## Introduction

Carbamazepine (CBZ) is one of the pharmaceuticals that is ubiquitously present in raw urban wastewaters (ranging from ng/L to μg/L) and is poorly removed by conventional wastewater treatment plants (WWTP) [1]. CBZ is an anticonvulsant and mood-stabilizing drug, primarily used to treat epilepsy and bipolar disorder, consumed in substantial daily amounts [1]. In this context, CBZ has been proposed as an anthropogenic marker of sewage contamination in freshwater bodies due to its persistence and presence in waters [1].

Adsorption is one of the most promising advanced treatment processes due to its efficiency, simple design, and low cost. Furthermore, it does not lead to the formation of toxic intermediate compounds [2]. One of the most crucial factors in this process is the adsorption capacity of the material [2], and, therefore, commercial activated carbon is the most used because of its high adsorption capacity. Nevertheless, it is necessary to overcome the restrictions associated with the high price of activated carbon and the limitations associated with its regeneration [3]. Recently, biochars have drawn attention as alternative adsorbents to activated carbon due to their physicochemical properties and widespread availability [4].

Besides adsorption, electrochemical systems offer several advantages, such as simple operation (at room temperature and pressure), robust performance [5], and viability in degrading non-biodegradable pollutants [6]. In comparison with the two-dimensional (2D) electrochemical process, in which two electrodes (cathode and anode) are employed, in a three-dimensional (3D) process, a third (particulate) electrode is used. Recently, Correia-Sá *et al.* [1] reported the removal of CBZ from aqueous solutions using a 3D process, comparing the performance of biochar particulate electrodes obtained from Touriga Nacional (TN), with different granulometries, with activated carbon. These authors concluded that the TN biochar with a size between 1-2 mm had a similar performance than the activated carbon. In this context, the present work aimed to optimize the 3D electrochemical process for the degradation of CBZ, considering the influence of biochar (TN, 1-2 mm) pre-treatments such as saturation and hydration.

## Materials and Methods

### Reagents and materials

CBZ was purchased from Sigma-Aldrich (St. Louis, Missouri, USA). A Boron-Doped Diamond electrode (BDD) (DIACHEM® electrode type 100×20×2 mm, niobium substrate, both sides coated, multilayer – from CONDIAS, Itzehoe, Germany) was used as the anode, and stainless steel (STS) (AISI-304, austenitic grade, 100×20×2 mm) was used as cathode in the 2D and 3D electrochemical experiments. An HQ DC power supply, model PS3020 (Velleman®, Gavere, Belgium) with an adjustable potential output of 0-30 V and an adjustable current output of 0-20 A was used to carry out the electrochemical processes. A centrifuge (Heraeus Fresco 21 Microcentrifuge, Thermo Scientific, Waltham, Massachusetts, USA) and a Multistirrer 15 (Velp Scientifica) were used. The supernatant was vacuum filtered through nylon membrane filters with 0.22 µm pore size (Filter-Lab®, Barcelona, Spain). CBZ analysis was performed using a high performance liquid chromatography (HPLC) system equipped with an SPD-M20A diode-array detector (Shimadzu Corporation, Kyoto, Japan) [1]. An air pump ELITE 802 with two 1500 $cm^3$/min outputs (Hagen, Yorkshire, United Kingdom) was used as the air supplier. Vineyard pruning residues from Touriga Nacional (TN), gently provided by Sogrape Vinhos, S.A. (Porto, Portugal), were used to produce the biochar (1-2 mm) as previously described [1,7]. The hydrated and saturated biochar were prepared by immersing 150 mg in 25 mL of ultrapure water and 25 mL of a 10 mg/L CBZ solution, respectively, for 24 h.

### CBZ adsorption experiments

In these tests, 150 mg of each biochar sample (with different pre-treatments) and 25 mL of a 10 mg/L CBZ solution were magnetically stirred at 370 rpm at room temperature (21°C). At the end of the assays (60 min), an aliquot of the final solutions was immediately centrifuged at 14,500 rpm for 10 min at 4°C. Then, the supernatant was filtered and analyzed by HPLC. In parallel, blank assays were prepared with the same CBZ concentration without adsorbent. The assays were performed in duplicate.

## 2D and 3D electrochemical experiments

The 2D electrochemical experiments were carried out in a single compartment electrochemical cell, using an acrylic reactor (2×15×8 cm) built with a rectangular base with a total volume capacity of 240 mL (Cromotema, Vila Nova de Gaia, Portugal). The submerged area of the used electrodes (BDD and STS) was 15 $cm^2$. An aqueous CBZ solution (150 mL), containing NaCl as electrolyte (0.1 M) and a pH value adjusted to 7, was transferred to the electrochemical cell, maintaining an airflow of 3000 $cm^3$/min and an interelectrode distance of 3.5 cm. The current intensity was maintained at 0.1 A, corresponding to a current density of 6.67 mA/$cm^2$. For the 3D electrochemical experiments, 150 mg of the biochar were placed in the electrochemical cell between the anode and the cathode. Aliquots were taken at regular periods, and each aliquot was filtered using a nylon microfilter (0.22 μm pore size) before HPLC analysis. All experiments were performed in triplicate.

## Statistical analysis

Statistical analyses were performed with IBMS SPSS for Windows, version 26 (IBM Corp., Armonk, N.Y., USA). Removal in % was represented as mean ± standard deviation. For each 3D treatment, comparisons between groups were made using the Mann-Whitney test, at a significance level of $p<0.05$.

# Results

## Adsorption experiments

In the adsorption assays, two tests were performed with dry and hydrated biochar. A 1.6-fold increase of the adsorption capacity was observed for the hydrated biochar (Figure 1).

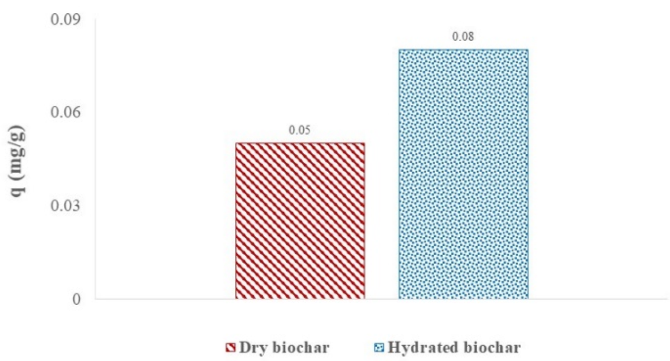


Figure 1 Adsorption capacity of the dry and hydrated biochars after 60 min.

## 2D and 3D electrochemical experiments

The results obtained for the removal efficiency of CBZ when using the 3D electrochemical process and a comparison with the results from the 2D process can be seen in Figure 2.

The experiments show that in the first 3 min, the biochar pre-treatment significantly influenced the CBZ removal ($p<0.05$), showing an increase in the removal of CBZ compared with the 2D process. This was not expected according to the results of the adsorption experiments for the hydrated biochar. After 4 min, the dry and the saturated biochar presented a removal efficiency higher than 95%, significantly different from each other (*p<0.05*) and from the hydrated biochar and 2D process. Under an electric field, biochar particles are polarized, forming charged microelectrodes, delivering higher electrocatalytic efficiency [6], suggesting that this polarization is higher when this material is saturated. Therefore, the use of dry biochar can be more advantageous for application in real situations.

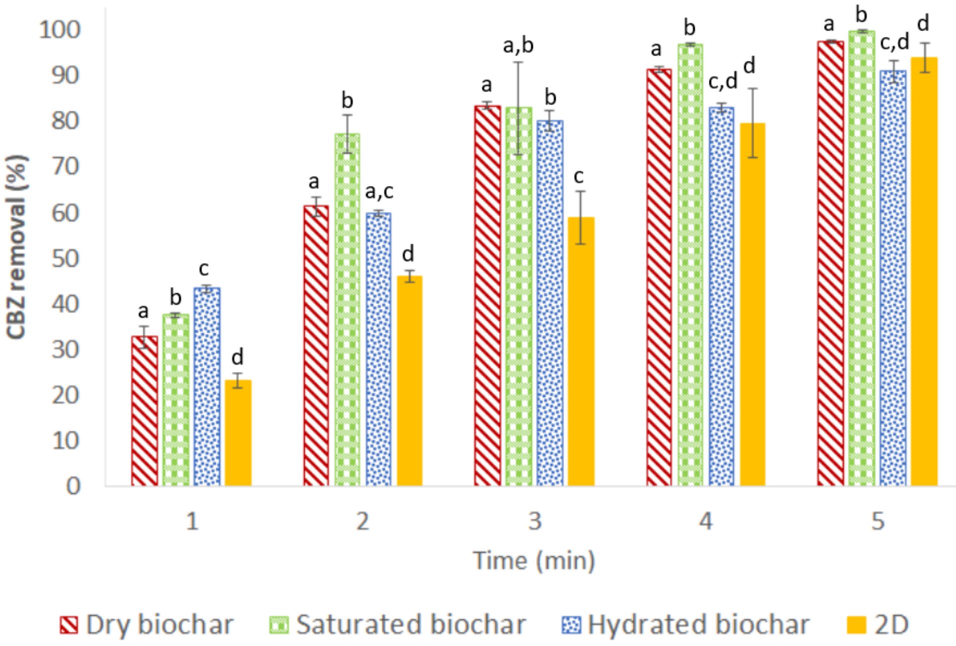


Figure 2. CBZ removal efficiencies obtained in the 3D (using dry, saturated and hydrated biochars) and 2D electrochemical processes. For each experiment, distributions with different letters (a-d) are statistically different at $p < 0.05$.

## Conclusion

The 3D process presented higher CBZ removal compared to the 2D process. The use of dry biochar can be more advantageous for application in real situations. The polarizability of the particulate electrodes of the 3D system is of higher importance than the adsorption capacity of the materials. Applying the 3D process to wastewaters will the next step of this study.

The application of the 3D process, as tertiary treatment in WWTP, will enlarge its useful lifetime when facing future legislation demands concerning pharmaceuticals discharge limits. Also, the increase of the water reuse potential allows a better and more efficient water resources management. Moreover, the waste valorization achieved by using biochar as a particulate electrode follows the principles of the circular economy.

**Acknowledgements**

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# Circular economy in water management: facing the problem of nitrates pollution in groundwater bodies

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**Abstract:** Nitrate presence in groundwater cause many social and environmental problems due to their widespread use. Groundwater is an invaluable resource to ensuring long-term water demand, which quality need to be monitored and guaranteed. The EU-funded project LIFE LIBERNITRATE proposes the construction of filters to remove nitrates using rice straw as raw material, ensuring water supply of study area. LIBERNITRATE is an innovative solution to nitrate problem which is based on circular economy principles. This approach is used to quantify the social costs of nitrates in groundwater and demonstrate the relevance of non-action costs, which are considered as a reference value of the importance to develop new technologies in order to address the problem of nitrates in the water cycle.

**Keywords:** nitrate; groundwater; non-action costs.

## Heading

A part of drinking water supply comes from groundwater sources. Many groundwater bodies are currently polluted because the influence of human activities. One of the main pollutants are nitrates, which are widely used in agriculture and livestock. The main characteristic of nitrates is that are highly soluble in water, easily penetrate groundwater bodies through soil. Groundwater is an invaluable resource to ensuring long-term water availability, but its biogeochemical characteristics (inaccessibility, size of the water body and low mobility of the stored volume) make it necessary to monitor its quality level to know its pollution level. For this reason, the presence of nitrates in groundwater bodies used for human consumption is a serious problem that need to be managed by competent authorities through using innovative technologies.

In this framework, the EU-funded project LIFE LIBERNITRATE proposes a synergic application of efficient rice waste management to treat nitrate problems in areas with groundwater consumption (Figure 1). This is achieved through the controlled combustion of rice straw and the successive production of silica-based adsorbents from ashes, which are used to construct a filters to decrease the high concentration of nitrates in water [1]. Through LIBERNITRATE filter the nitrate concentration can be reduced up to 30% allowing to use groundwater to supply the demand of urban areas. The filter is an innovative technology with low manufacturing and operation costs due to the use of harvest rice as main filter material. Specifically, this is an innovative approach focused on circular economy that put in value harvest rice as a raw material to remove nitrates of groundwater sources. Furthermore, LIBERNITRATE filter allows to water management authorities to use groundwater sources in urban areas complying with legal quality requirements.

The municipality of *Alginet* (Valencia, Spain) has been selected as study area due to its nitrate concentration problems, according to the Nitrates Directive. Currently most wells have been abandoned or closed because the quality requirements to be used for drinking water sources are not meted. The aquifer considered is the *Plana de Valencia Sur* (080,142), located in the southern part of l'*Albufera*. The report of Jucar Hydrographic Confederation (authority responsible of river basin management) highlights the poor quality of this aquifer in 2018, proving the influence of agricultural activities in nitrates pollution as well as the type of soil in area, causing the aquifer's typology to be permeable to pollution. This situation, together with the influence of overexploitation and water scarcity, show the importance of LIBERNITRATE project to ensure the long-term water availability, as well as the public health and the ecosystem sustainability.

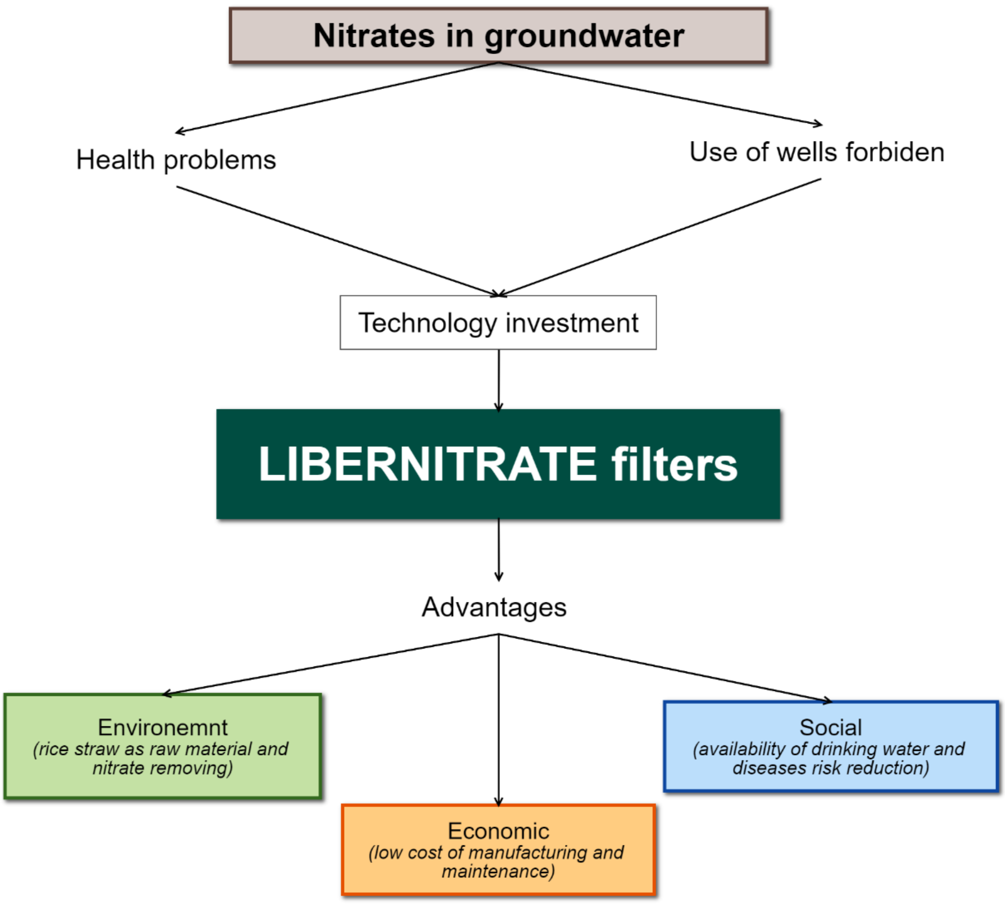


**Figure 6**. Approach of LIBERNITRATE project. Source: own elaboration.

Rice is one of the most consumed crops worldwide and Spain is the second-largest rice producer in Europe (117,000 ha) [2]. The main by-product of rice harvest is rice straw which cause an environmental and economic problems for farmers. Rice production in the Valencia Region represents approximately 14% of national rice production, where cultivation areas are mainly located in the Albufera Natural Park. Specifically, there is around 15,087 hectares which means that around 75,000-90,000 tonnes of rice straw are generated each year. Rice straw is a waste that is difficult to manage, not only because of the large amount generated, but also because its production is concentrated in a short period of time (a few weeks). Until now, rice straw has been managed by burning it in rice fields, as has been considered that burning destroys fungal spores, bacteria and weed seeds, as well as facilitating reintroduction of nutrients into the soil. This practice causes problems in the surrounding areas and environmental impacts, as rice burning is the main source of carbon monoxide ($CO_2$), methane ($CH_4$), nitrogen oxides ($NO_x$), sulphur oxides ($SO_x$), hydrocarbons, dioxins, and particulate matter emission in these areas. As has been mentioned, this situation is focused on a short period of time where high concentration of these emissions can cause local pollution problems, increasing the risk of respiratory problems in population. In the case of LIBERNITRATE, using rice straw as a raw material is an additional advantage for farmers, as the waste is revalued to reduce nitrate pollution in groundwater. This situation generates a positive environmental impact and is in line with the principles of the circular economy.

Focusing on the social and water supply point of view, the damage caused by nitrates in population health need to be considered. This scenario allows to obtain the non-action costs in the study area. The non-action costs are interpreted as the costs of the presence of nitrates in the water under public health point of view. The filters avoid these costs because remove nitrates of groundwater; hence obtaining the non-action costs scenario, the social benefit of LIBERNITRATE project can be obtained. The presence of nitrates in groundwater directly affects human health. Consumption of nitrate-containing water has direct effects on red blood cells and oxygen transport in blood and is particularly serious for children. In addition, long-term exposure to nitrate concentrations above 5 mg/L increases the risk of various types of cancer, as well as fertility disorders [3]. Specifically, the health problems related to water consumption with nitrates are [4]: (i) methaemoglobinaemia, (ii) stomach and colorectal cancer, (iii) thyroid conditions, and (iv) reproductive problems.

The most significant health problems are methaemoglobinaemia and stomach and colorectal cancer. According to data from the US National Cancer Institute, the direct cost of cancer treatment related to nitrate consumption is quantified at between $250 million and $1.5 billion. However, not only direct costs need to be considered but indirect costs related to both loss of life years and quality of life must be obtained. This is where the DALY indicator (Disability Adjusted Life Years) is used, which is a combination of the years of life lost with the years lived with disability. In other words, the DALY is an indicator that makes it possible to measure the loss of health because of premature mortality and disability related to get different diseases. Through DALY, assessing the indirect costs of nitrate consumption is more complete. Table 1 (adapted to Temkin et al. [5]) shows the loss of life years attributable to nitrate due to premature disability and death, as well as the economic costs of treatments and the loss of productivity due to incapacity for work in USA.

**Table 1**. Cancer cases and medical costs attributable to water consumption with nitrates in 2014 [5].

| Cancer type | Total attributable cases to nitrates consumption | Economic lost due to loss of productivity (billions) | Medical costs of cancer treatment (billions) |
|---|---|---|---|
| Colorectal | 10,379 | 4.9 | 1.33 |
| Colorectal | 6,176 | 2.92 | 0.79 |
| Colorectal | 4,007 | 1.89 | 0.51 |
| Colorectal | 2,684 | 1.27 | 0.34 |
| Colorectal | 1,233 | 0.58 | 0.16 |
| Ovarian | 580 | 0.47 | 0.11 |
| Ovarian | 110 | 0.09 | 0.02 |
| Thyroid | 1,047 | 0.85 | N/A |
| Thyroid | 369 | 0.30 | N/A |
| Kidney | 454 | 0.25 | 0.06 |
| Bladder | 134 | 0.03 | 0.01 |

*There are recurrent cancer types because the authors have considered different areas of USA (obtained through literature revision) with high nitrates exposures in drinking water.*

Results of Tempkin et al. [5] highlight that nitrate exposure may be responsible of 1-8% colorectal cancer cases. The 12-24% of these cases are caused by private wells users exposition, where in many cases concentration values are, at least, 5 mg/L. According to authors, medical costs of colorectal cancer treatment range between $157 million to $1.3 billion. Given the ageing population and advances in medical treatments, annual cancer treatment costs are expected to increase by 27-39% in the coming years.

These data demonstrate the need to implement specific strategies to remove nitrates from groundwater to provide safe water source to urban areas, such as LIBERNITRATE project proposes. Data presented here approximates non-action costs of nitrate presence in groundwater, which has been developed currently through data provided by partners. LIBERNITRATE has the aim to achieve a positive impact in study area (allowing small towns to use wells) and create a filter capable to remove nitrates using rice straw as raw material (according to circular economy principles). This is an innovative approach which makes LIBERNITRATE as leading solution to nitrate problems in the water cycle and reinforces the advantage of implementing the circular economy and economic analyses of social and environmental aspects in decision-making processes.

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# Condition assessment and risk analysis for decision support on rehabilitation investments in water systems. Application to Águas do Douro e Paiva water tanks.

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**Abstract:** Assets' condition in water systems may have serious implications on supply reliability, water safety and public health. Thus, there is a need for early detection of assets' degradation, and accurate characterization of the potential consequences of a failure, under a risk analysis frame. Therefore, condition assessment is fundamental for prioritizing and forecasting maintenance and rehabilitation efforts. It can be used to understand asset's deterioration and support risk analysis, namely allowing for a better quantification of the probability of failure. In this context, the present paper will present the main methodology followed in the condition assessment and risk analysis program applied to the Águas do Douro e Paiva's water tanks for decision support in rehabilitation investments.

**Keywords:** water tanks´ condition assessment; risk analysis; asset management.

## Introduction

When undertaking condition assessments, inspection data are collected, which can also count with the support of complementary tools (e.g., field tests), that provide information on the presence of defects and their severity. However, even when a defect, such as a crack or corrosion is identified, a main question remains regarding the significance of the findings [1].

In fact, the level of severity could be a very subjective matter. On the other hand, data collected during inspection of assets must be interpreted in terms of the operating demands placed on the asset and/or the relevance of the asset for the water/ wastewater system.

One way of comparing assets for definition of renewal priorities is through risk analysis. It correlates a probability of failure (related to assets' condition) with the potential consequences (related to assets' criticality). Typically defined as a matrix, for definition of risk classification, this could support the decision process, namely balancing the importance of moderate degradation on critical assets when comparing to small scale assets, even if in worse conditions.

Although the potential consequences are usually easier to characterize and assess, failure probability should be based on solid information of real assets' condition.

Condition and performance assessment programs may, then, provide many benefits but can also be expensive and time-consuming activities. Ideally, the expenditure on assessment programs should be balanced against the anticipated benefits.

Therefore, performing field technical inspections for visual identification of potential defects, whenever possible and relevant, can be cost-effective. Nonetheless, it must be performed regularly and through a predefined and common frame. This could support risk analysis for asset management and identify those cases where a deeper and specialized assessment should be performed.

Águas do Douro e Paiva water tanks' condition assessment and risk analysis program.

Águas do Douro e Paiva, S.A. (AdDP) is a Portuguese water utility responsible for the construction, management and concession of the multi-municipal water supply system in the south of Porto Metropolitan Area. The main activity is to abstract, treat and supply water for public consumption to 1.7 million inhabitants in 20 municipalities, covering an area of 2,715 km$^2$.

Within its facilities there are 36 water tanks for storage of drinking water, from which 34 are in operation. The total capacity is of about 210,000 m3, with an average age of around 20 years.

It was considered the development of a condition assessment and risk analysis program that could support the decision on rehabilitation investments in these infrastructures. Thus, with the support of H2OPT consultancy company, the program was framed in four main stages:

- **Phase 1:** inspection and assessment of condition of these infrastructures.
- **Phase 2:** risk analysis performed for every infrastructure using information collected from Phase 1, jointly with other design and operational characteristics.
- **Phase 3:** needs for investment in rehabilitation were assessed, identifying the interventions needed, and carrying out the respective budget estimate.
- **Phase 4:** systematization of all the information, collected, or developed in this project regarding these assets, including its organization in a Database.

The Phase 1 was based on the realization of Visual Technical Inspection (VTI) which main purpose was to survey the condition of the various components of the asset (Exterior, Roof Cover, Maneuver Chamber and Cells). These inspections allowed the identification of situations that should be subject to follow-up or require some type of preventive or curative interventions. Moreover, level decay tests were also performed to complement visual inspections.

For each of these components, was carried out an identification of the main pathologies that could occur, and the definition of specific classification scales, measured according to the degree of severity of the problems, as well as with the potential consequences that could result.

For the definition of the classification scales, a variation of 1 to 5 was considered, 5 being the most serious, and 1 being the best condition, without special occurrences. However, considering the relevance of the problems, for some components (e.g., fencing, hydraulic equipment, vents, etc.) was considered a limitation of the classification scale, leaving the 5 classification to those problems that could more seriously impact water tank's function or be more difficult to repair (structural problems, water losses, disseminated pathologies, etc.).

Finally, the overall classification of water tank condition (Figure 1) was given by the equal weighting average of the various components' condition (Figure 2), since the most severe classification of each component was already adjusted to the severity and possible consequences of the potential problems.

| Water tank | Exterior | | Roof cover | | Maneuver Chamber | | Cells | | | | | | | Classification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fencing | Walls | Vents | Water proofing | Building | Pipes and equipments | Lining (walls, floor) | Structural elements | Joints | Ceiling | Pipes | Other metal equipment | Water losses | Overall |
| R21 | | Deg. | Deg. | P. Deg. | | Deg. ; Oxi. | Deg. | | | Carb., Dest.; Inf. | Oxi. | Oxi. | C.E.E. | |

Figure 1 Condition classification for each component of the water tanks' assessment – example.

| Final Condition Classification | | | |
|---|---|---|---|
| 1 | | More than half components at green or maximum yellow classification | Very Good |
| 2 | | 4 or more components at yellow or 1 at orange classification | Good |
| | | 2 components at orange classification | |
| 3 | | 1 component at red or 3 at orange classification | Reasonable |
| 4 | | 2 components at red classification | Bad |
| | | At least 3 components at red classification | |
| 5 | | 5 or more components at red classification | Very Bad |

Figure 2 Overall condition classification developed for AdDP water tanks' assessment.

At Phase 2, a multicriteria risk matrix was developed, considering inputs from former and similar works ([2]; [3]), but adapting to the information collected in Phase 1, and to AdDP water tanks' characteristics. Thus, it sought to respect the following assumptions:

- different criteria and sub-criteria were considered, distinguishing the probability of failure of the infrastructure (functionality) and the consequence of this failure (criticality), and the weighting of the different criteria, in each of these components, making up 100%;
- the final classification for probability or consequence is given by multiplying the score assigned to each indicator (from 1 to 5) by the respective weight.

For this matrix, the criterion considered to assess functionality were: (i) the overall condition of each water tank, (ii) the years of operation of the infrastructure. On the other hand, criticality was divided into 3 sub-criteria, namely: (i) the potential impact of anomalies downstream, (ii) the level of difficulty for intervention (existence, or not of redundancy, and the dimension of the water tank) and (iii) the strategic importance of the infrastructure for the subsystem.

Based on previous phases, in Phase 3 the needs for investments in water tanks rehabilitation were assessed. It should be noted, however, that some pathologies, currently, do not affect the operation of the water tank and should mostly be monitored for the future.

Thus, the criterion was to act on the anomalies with a higher degree of severity, classified with level 4 or 5. In this sense, the rehabilitation interventions considered for budget estimation were those ensuring an overall Very Good condition classification, although some pathologies with level 3 (yellow) may remain for future monitoring.

Finally, in Phase 4, was ensured the organization of information into 2 main elements, namely:

- An infrastructure technical sheet, by water tank, gathering the most relevant information in relation to: (i) main characteristics, including the condition (last inspection), (ii) the criticality, (iii) the resulting risk level and (iv) the history of interventions;
- An overall database, where, in the form of a list, aggregates, for all water tanks, simplified information in relation to the main characteristics, overall condition (last inspection), automated quantification of the criticality level and definition of the risk level. Moreover, it compiles the necessary information for automated quantification of the Infrastructure Value Index (IVI) [4].

## Concluding Remarks

One of the most important findings was the relevance of setting a unique and adequate frame for condition inspections, to reduce, as much as possible, the inherent subjectivity of the inspector sense that is visually detecting defects and classifying its severity. This frame also provides a good support to assess evolution of pathologies in future inspections.

On the other hand, the risk analysis performed, that should, on the consequences side, reflect the operational importance of the assets, but also the difficulty of performing an intervention, allowed for the identification of the main infrastructures to intervene.

Complementary, the estimation of costs for those interventions is a very important support to plan and define from short, to long-term budgets, and the collection and organization of all the related information, is fundamental to make information available for future updates and comparisons.

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# Discussing improvements to an indicator-based approach for the capital investment planning of infrastructure assets.

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**Abstract:** All companies have limited capital available to make investments in their infrastructures. Consequently, it is imperative that investments are as smart as possible, to ensure proper assets' functioning and high service levels, at a manageable risk level and at the lowest possible cost. These dimensions are quantified through multiple financial and operational indicators. This article proposes a more pragmatic approach to the calculation of one of these indicators, the Infrastructure Value Index (IVI), which is being tested in the Portuguese water sector. It discusses a revised formulation for the IVI and illustrates its application with an empirical case study consisting of water infrastructures managed by the Portuguese Company Águas do Douro e Paiva (AdDP).

**Keywords:** Infrastructure Value Index; Investment Planning; Asset Management.

## Introduction

Asset Management is a holistic concept that is transversal to several areas. It is focused on the use of assets to generate value and achieve the goals of the organization. Businesses with mature asset management approaches may gain competitive advantages, as this can enable achieving better financial performance, more assertive decision-making, and improvements in the services provided.

Asset management is an area of particular importance in the water supply and sanitation sector, given its intensive capital nature (Covas, Cabral et al. 2018). High investments must be continuously performed by the utilities, often involving irreversible decisions. Consequently, it is imperative that investments are as smart as possible, so that the proper functioning of assets and high service levels can be achieved, at a manageable risk level and at the lowest possible cost. This involves the design of strategies in a context of informed decision making that requires the integration of asset management approaches into planning and management processes, in order to generate benefits both for service users and stakeholders.

To achieve the best execution of these strategies, a trade-off between the dimensions 'Risk', 'Cost' and 'Performance' becomes essential. These dimensions are quantified through multiple financial and operational indicators. This research contributes to the literature on asset management by proposing a different approach to the estimation of the Infrastructure Value Index (IVI) aligned with companies' practices and financial/accounting procedures. This indicator is already in use within the water sector in Portugal, and intends to reflect the three key dimensions of asset management.

The IVI indicator was first introduced by Alegre (2008) and was subject to improvements by Alegre, Vitorino et al. (2014) . Although organisations have already started using this indicator, its calculation depends on subjective information, as its components can be interpreted in different ways. More recently, Vieira, Cabral et al. (2020) presented a methodology to forecast the evolution of the IVI in future years, as a function of planned CAPEX investments. This approach makes the indicator useful in a company context and allows it to be embedded proactively in the capital investment planning process.

Although the IVI is being mostly used in the water supply and sanitation sector, the aim of this paper is to present a tool that can be extended to other areas, making this indicator truly impactful in asset management. For example, Salvado, Marques de Almeida et al. (2020) have adapted and tested this methodology for managing large portfolios of building assets.

The aim of this paper is to build upon previous efforts and test a new approach for long-term investment planning focused on the annual capital expenditure and asset deactivation. Relatively to previous studies, the novel contributions of this paper include a methodology where the useful life of the assets is adjusted to their age and real condition. This is an advancement in comparison with the common practice of using only the state of condition. Another contribution is a more objective approach to the long-term IVI calculation proposed by Vieira, Cabral et al. (2020). The methodology developed was applied in a Portuguese water supply company. A dashboard was also constructed to enable the visualisation of the information obtained, such that the results can be presented to the company's collaborators, allowing to validate the methodology with the contribution of enterprise knowledge.

## Methodology

The original IVI formula was proposed by Alegre (2008), and it remains unchanged in the latest ERSAR Guide (Covas, Cabral et al. 2018). According to this proposal, the calculation should be based on replacement value, technical lifetime and year of installation of each asset.

$$IVI_t(\%) = \frac{\sum_{i=1}^{N}(\frac{cs_{it} \times vr_{it}}{vu_i})}{\sum_{i=1}^{N} cs_{it}} \tag{1}$$

In expression (1), $N$ is the number of assets that compose the infrastructure, $cs_{it}$ is the cost of replacement of asset $i$ ($i$ = 1,...,N) in year $t$, expressed in monetary terms (e.g., in euros), $vr_{it}$ is the residual useful life of the asset $i$ in year $t$, and $vu_i$ is the total technical useful life of asset $i$ (expressed in number of years).

The most appropriated way to calculate assets replacement costs, according to EPA (2005), is through the Modern Equivalent Asset (MEA) method. This method assigns to the replacement cost what the company would currently have to pay for the project specifications.

To correctly determine the residual life of an asset, it is suggested a revision of the previous proposals (that only account for the current condition of the asset) in order to also account for its age, as shown in expression (2).

$$vr_{it} = vut_i - (\frac{vut_i}{5} \times c) \times \left(\frac{i_t}{vut_i}\right)^{\frac{1}{c+1}} [years] \quad (2)$$

In expression (2), $\boldsymbol{vut_i}$ is the theoretical technical useful life of the asset $\boldsymbol{i}$, $\boldsymbol{c}$ is the condition coefficient (ranging from 1 to 5), and $\boldsymbol{i_t}$ is the asset age in year $\boldsymbol{t}$. The revised formula is based on the linear variation of the useful life with the infrastructure age. This methodology considers a significant reduction of the expected useful life if the condition state is classified with the most severe levels, or an extension of that life if the condition state is favourable, for the age of the infrastructure at the time of the assessment.

Once the IVI for the current year has been obtained, it is also important to make projections for future years. This task requires a comprehensive knowledge of the infrastructure, and the involvement of technical teams to obtain correct data. Over the years, renovation, replacement and expansion operations will be carried out on the infrastructures. To calculate the IVI, CAPEX investments for these interventions must be estimated, as well as the percentage of assets in operation at the current date. Therefore, expressions (3) and (4) are proposed, which represent the residual useful life and replacement value in year t.

$$\mathrm{cs_t} = \mathrm{cs_{t-1}} \times (1 - \beta) + \mathrm{CAPEX} \quad (3)$$

$$\mathrm{vr}_t = \mathrm{vu} \times \frac{\mathrm{cs_{t-1}} \times (1 - \beta) \times (\frac{\mathrm{vr_{t-1}} - 1}{\mathrm{vu_i}}) + \mathrm{CAPEX}}{\mathrm{cs_t}} \quad (4)$$

In expressions above, β is the abatement coefficient ranging from 0 to 1. It is important to pay attention to the parameter β (Vieira, Almeida et al. 2020, Vieira, Almeida et al. 2020). A β value close to 1 means that the asset under study will be almost totally dismantled, whereas a β value close to 0 means that the existing assets will not be deactivated with the CAPEX investment. Due to the subjective nature of the β coefficient, it is important to interact in detail with technical teams, such that its value represents a good estimate of the reality.

**Results and discussion**

The methodology described in the previous section was put into practice in an AdDP group infrastructure, the Jovim pumping station. The IVI estimates obtained for the current year are shown in Table 1.

**Table 1** Total and by category IVI

| Category | Present Value | Replacement Cost | IVI |
|---|---|---|---|
| Civil Work | 810,281.25 | 1,290,000.00 | 0.63 |
| Equipment | 942,055.87 | 2,222,944.44 | 0.42 |
| Electrical facilities | 279,655.91 | 1,004,000.0 | 0.28 |
| Total | 2,031,993.03 | 4,516,944.44 | 0.45 |

The overall IVI is 0.45, and as this value is in the range [0.4;0.6] it means that the condition of the infrastructure is acceptable. A closer analysis by category shows that despite the acceptable value of the overall IVI score, the IVI of the electrical installations is only 0.28, which is under the acceptable lower limit. As the relative weight of electrical installations is lower than from the construction and equipment, the overall IVI does not drop much. Note that the weight that each category used for the calculation of the overall IVI score is proportional to the total replacement costs of that category (as shown in Table 1). These costs are estimated based on asset reports, the knowledge of the technical team and the relative weights proposed in the ERSAR guide (Covas, Cabral et al. 2018).

For a better understanding of why this value of the IVI for the electrical facilities is so low, it is necessary to analyse the IVI of the assets that make up the electrical facility to see if there is any specific asset pulling the value down or if it the assets' condition within the group is homogeneous. The electrical installation is the same since the electrical facility was built. Despite being in good conditions, as a result of a good maintenance policy, the useful life of electrical installations is relatively short. Consequently, the information provided by the IVI signals an urgent need for CAPEX investments in the electrical facilities.

Figure 1 shows the IVI value for future years based on CAPEX investments planned by the organization. The overall IVI value for the infrastructure varies between 0.45 and 0.4, indicating that it is at the lower limit of the acceptable condition. A more detailed analysis at the categories level reveals that the IVI for the electrical installations will decline from 0.28 to 0.18 in future years, which is not desirable. This shows that the investments planned for this infrastructure in the coming years are not sufficient, and more CAPEX investments in electrical installations would be recommended.

Civil construction will not be subject to investments in the period considered, as the building is recent and this category of assets depreciates very slowly. In fact, during the period under analysis the minimum IVI for this category is 0.54, which corroborates this statement. The category subject to the largest CAPEX investment is equipment. The group condition will remain approximately constant over the 5 years analysed, with values between 0.42 and 0.37.

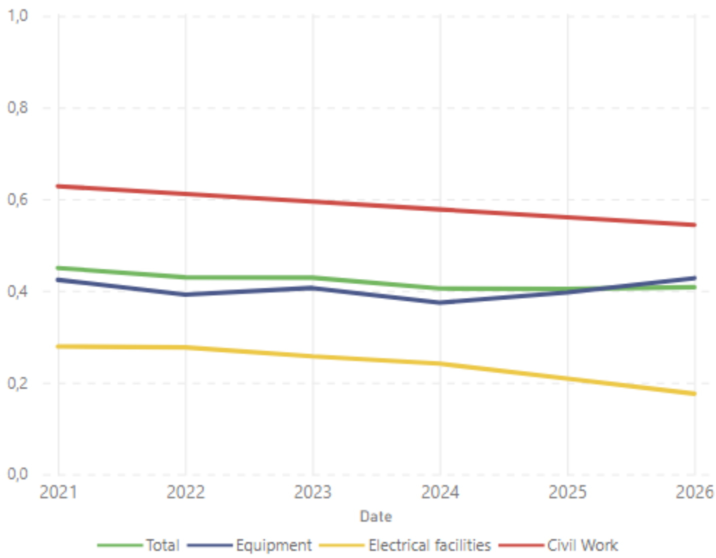


**Figure 1:** Total and by categories IVI.

## Conclusion

AdDP has considered this project a relevant contribution to guide asset management procedures in the company. A feature especially appreciated in this project was the ability to communicate the results in a simple way to the collaborators of different teams. This was possible due to the development of a dashboard that enables an intuitive visualization of the IVI indicator and its evolution over time for different CAPEX investment levels. This project allows the company to see in real time the assets' condition and the impact of alternative CAPEX investment decisions on the condition of the infrastructures.

Future work could extend this research to a longer time period and explore other types of infrastructures. We recommend considering periods up to 10 years, as longer time horizons can become subjective and lose credibility.

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# Efficiency of Water Sanitation Service Investments vis-à-vis Universal Access.

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**Abstract:** The objective of this research is to analyze the efficiency of investments by State Water and Sanitation Companies in Brazil vis-à-vis the increase in universal access to services. The approach uses the Data Envelopment Analysis methodology applied to the sample of companies responsible for the operation of the Water and Sanitation Services for 153 million people, 73% of the national population. The practical implication is to identify the efficiency of investments and benchmarking companies. This research is innovative in the efficiency evaluation of the investments to expand coverage and its impacts on the universalization of the services with the corresponding benchmarks which is still an unexplored topic and represents a contribution to this research field.

**Keywords:** Water and sanitation services in Brazil; universal access; investments.

## History of investments in WSS and universal access in Brazil

Brazil has undergone considerable improvements in the coverage of the Basic Sanitation Service - WSS since the implementation of the National Basic Sanitation Plan - PLANASA in 1971. Among the initiatives taken, one of the main measures was the creation of State Water and Sanitation Companies – SOE's [1, 2]. Since then, these regional companies are the main operators in the sector, being responsible in 2019 for more than 70% of WSS in Brazil. The initial progress towards universalization has stagnated, partly due to the end of investment incentives from PLANASA and the Financial Sanitation System - SFS, resulting in low levels of investment and governance in the sector [3]. With the Federal Constitution of 1988, the universalization of the WSS became a consolidated right, but its standardization occurred only twenty years later, with Law 11.445 / 2007 - National Basic Sanitation Law - LNSB. Universal access was assumed to be the first of its fundamental principles, responsible for guiding the sector's strategies and public policies, with a focus on the progressive expansion of access to all occupied households [4].

The low historical level of the investments, aggravated by the fiscal limitations of the public power, the insufficient performance of SOE's and the difficulty of fulfilling the WSS universalization goals are among the main factors determining the revision of the regulatory framework of the sector, updated by Law 14.026 / 2020. The aim of this norm is to boost investments in the sector to achieve the universalization goals through the adoption of instruments that stimulate competition and the private initiative participation in WSS concessions. The new concession contracts will have universalization targets that guarantee the supply of drinking water for 99% of the population and sewage collection and treatment for 90% by the year 2033. In projects where the economic feasibility for meeting the targets is not possible, the universalization period will be extended until the year 2040 [5].

The database used in the study is available at the National Water and Sanitation Information System - SNIS, a system of the Federal Government that has maintained a sector database since 1996, with which it is possible to verify that the sanitation deficit has made little progress in the past years. In 2019, the total water service index with water supply networks was 83.7% and the sanitation service was 54.1% [6]. There has been a disorderly city growth for many decades and in regions with more developed indicators, such as the state of São Paulo and Rio de Janeiro, the deficit tends to be concentrated in the poorest neighborhoods, mainly in the favelas [7]. The WSS universalization considers the right to equality, in which everyone must have access to services of general interest, considered as essential to human life, public health, the environment, the competitiveness of the economy and the general well-being of society [ 8].

**Findings and research results**

Although the projections of necessary investments are based on laws and programs that align WSS plans at the national, state and municipal levels, the execution of these instruments has not been methodically carried out and Brazil has not reached the universalization goals projected in the National Plan of Water and Sanitation - Plansab. Factors related to investments in the sector are directly related to the maintenance of this deficit, highlighting three potential reasons: i) the historical underfunding of the sector; ii) the inefficient allocation of financial resources; and iii) the low prioritization of investments for actions related to universalization. In recent years, the resources invested have been below 50% of the goals stipulated for achieving universal WSS [9]. The federal government has been reducing its resource contribution year after year, with no compensation for private sector investments. In addition to the value being below what is necessary, it has been directed towards the maintenance of existing systems. The priority of investments tends to be disconnected from coverage and contributes little to universal access to WSS. This difference in performance between what is provided for in legislation and planning (de juris) and what is actually carried out (in fact) can be conceptualized as isomorphic mimicry and is a barrier to universalizing access to the WSS [10].

This work analyzed a set of 23 SOE's presented in Table 1, responsible for WSS in 23 states and for 73% of the national population. Information on the population, coverage and investments made was analyzed, calculating the variation in the WSS coverage indexes for the years 2015 to 2019. As for the investments made by the providers, the total and the value per capita in the period were calculated. The results show the structural limitations of the sector, since the states with the best WSS coverage are the ones that invest the most, in contrast to the states with the least access, notably those in the North and Northeast regions, with investments well below the national average.

The total investments made by the provider correspond to the inputs while the total population served with water supply, the number of active water connections, the extension of the water network, the total population served with sanitation, the volume of sewage collected, the volume of treated sewage and the number of total sewage connections are the outputs. The results indicate that solid companies, with good governance and in line with international benchmarks, remain at the edge of efficiency in terms of investments for universalization.

## The importance of this work for the event and the topic "Water supply and urban and rural sanitation"

The research is in line with the theme "Water supply and urban and rural sanitation - Financing the urban water cycle". Its innovative aspect consists in the use of DEA to measure the efficiency of investments and their impact on universal access, an approach that is still little explored and which represents a contribution to the field of research. Although the number of studies using DEA has increased since the 1990s, such research focuses on analyzing the productivity and efficiency of public interest services, emphasizing technical and operational efficiencies, considering dimensions such as the ideal size of companies, economies of scale, comparison between services provided by public and private companies and other analysis lenses [11]. Another review on the use of DEA for WSS identified 190 quantitative studies focusing on sectoral performance, of which 71 used non-parametric methods [12]. A third review analyzed 46 studies on the performance of WSS operators, mainly from developing countries, and identified the predominance of non-parametric methods (54.4%), with the variables most used as inputs were work, extension of the water network, operating costs, electricity, water losses, number of connections and others. The most used output variables were water supplied, number of customers, total revenue, water production, service coverage, number of connections, volume of sewage collected, volume treated, and others [13].

| Region | State | Total population in 2020 | State Basic Sanitation Company - CESB's | Municipalities where CESB's operate WSS | | WSS indicators in municipalities served by CESB | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Total resident population of the municipality with water supply, according to IBGE | Total state poplation served by CESB's (%) | Total population served by water supply (%) | | Total population served sanitary sewage (%) | | Investimento pelo Prestador | Investiment Per Capta |
| | | | | | | 2015 | 2019 | 2015 | 2019 | 2015 à 2019 | 2015 à 2019 |
| North | AP | 861.773 | CAESA | 845.731 | 98,14% | 30,83% | 34,40% | 3,44% | 7,04% | 2.233.860 | 2,64 |
| | RO | 1.796.460 | CAERD | 1.235.512 | 68,77% | 44,70% | 38,34% | 1,70% | 2,30% | 91.118.494 | 73,75 |
| | RR | 631.181 | CAER | 605.761 | 95,97% | 66,79% | 81,67% | 30,00% | 57,95% | 14.787.726 | 24,41 |
| | PA | 8.690.745 | COSANPA | 5.210.320 | 59,95% | 40,82% | 38,20% | 3,41% | 5,29% | 44.620.276 | 8,56 |
| Northeast | AL | 3.351.543 | CASAL | 2.645.130 | 78,92% | 73,29% | 70,82% | 14,46% | 19,33% | 139.710.646 | 52,82 |
| | BA | 14.930.634 | EMBASA | 13.015.392 | 87,17% | 79,21% | 79,20% | 32,62% | 35,93% | 2.387.816.684 | 183,46 |
| | CE | 9.187.103 | CAGECE | 7.789.769 | 84,79% | 58,00% | 53,06% | 22,66% | 23,53% | 948.469.544 | 121,76 |
| | MA | 7.114.598 | CAEMA | 4.883.359 | 68,64% | 48,49% | 46,38% | 11,98% | 13,01% | 387.544.158 | 79,36 |
| | PB | 4.039.277 | CAGEPA | 3.804.386 | 94,18% | 73,41% | 74,91% | 29,00% | 31,85% | 382.902.682 | 100,65 |
| | PE | 9.616.621 | COMPESA | 9.229.495 | 95,97% | 74,55% | 81,23% | 16,91% | 21,71% | 2.976.363.760 | 322,48 |
| | PI | 3.281.480 | AGESPISA | 2.847.285 | 86,77% | 75,46% | 47,58% | 8,53% | 6,18% | 108.244.407 | 38,02 |
| | RN | 3.534.165 | CAERN | 3.314.679 | 93,79% | 73,85% | 82,88% | 19,65% | 23,50% | 2.203.706.092 | 664,83 |
| | SE | 2.318.822 | DESO | 2.088.593 | 90,07% | 85,18% | 87,58% | 16,83% | 21,50% | 459.679.056 | 220,09 |
| Southeast | ES | 4.064.052 | CESAN | 2.852.264 | 70,18% | 77,18% | 77,74% | 36,24% | 46,23% | 1.059.390.637 | 371,42 |
| | MG | 21.292.666 | COPASA | 14.816.174 | 69,58% | 75,75% | 76,46% | 51,22% | 54,70% | 3.094.556.432 | 208,86 |
| | RJ | 17.366.189 | CEDAE | 14.173.816 | 81,62% | 85,56% | 86,67% | 46,11% | 39,15% | 1.060.663.950 | 74,83 |
| | SP | 46.289.333 | SABESP | 30.689.431 | 66,30% | 85,25% | 95,80% | 76,66% | 88,02% | 19.992.769.701 | 651,45 |
| South | PR | 11.516.840 | SANEPAR | 10.637.128 | 92,36% | 90,55% | 94,69% | 64,67% | 74,22% | 4.475.180.802 | 420,71 |
| | SC | 7.252.502 | CASAN | 3.319.614 | 45,77% | 82,68% | 84,28% | 15,58% | 20,76% | 1.248.857.409 | 376,21 |
| | RS | 11.422.973 | CORSAN | 7.510.122 | 65,75% | 81,74% | 81,70% | 9,83% | 13,46% | 1.516.319.820 | 201,90 |
| Midwest | MS | 2.809.394 | SANESUL | 1.747.901 | 62,22% | 75,13% | 78,80% | 24,53% | 36,58% | 581.745.839 | 332,83 |
| | GO | 7.113.540 | SANEAGO | 6.516.423 | 91,61% | 82,27% | 88,03% | 45,45% | 56,80% | 1.866.432.438 | 286,42 |
| | DF | 3.055.149 | CAESB | 3.015.268 | 98,69% | 95,68% | 99,00% | 81,69% | 89,48% | 1.176.263.011 | 390,10 |
| Population 23 States | | **201.537.040** | | **152.793.553** | **75,81%** | | | | | | |
| Total Population Brazil | | **211.755.692** | | | | | | | | | |

**Table 1**– Analysis of CESB's investments in view of universal access to WSS.

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# Improving the Investment Planning in a Water Supply System

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**Abstract:** Water is an essential asset for all humanity, which must be managed effectively and rationally. The principles of asset management, focusing on improving decision-making and reasoned prioritization of investments, promote the sustainability of water and wastewater services and improve the management of the life cycle of its infrastructures. This work presents a methodology developed for a water utility to optimize its investment plan for five years, being the main objective to maximize the creation of value for the company. The methodology proposed and the results obtained support and show the advantages of rethinking treatment and water services in general with asset management tools.

**Keywords:** Value; Optimization; Investment Planning.

## Introduction

The water and wastewater services are a capital-intensive activity, and a rational management of infrastructures is essential for its sustainability. The utilities should effectively control and manage the assets to improve value throughout their life cycle. It involves making decisions throughout the asset's life cycle, which aims to minimize the total cost without compromising security and optimize performance [1].

In this kind of organization, most investments are irreversible, and they commit for an extended period. In addition, the financial resources available in the organizations for the maintenance and rehabilitation of their assets are scarce. For these reasons, it is crucial to make informed asset investment decisions.

Asset management is an integrated process of decision making, planning, and control of the company's assets, operation, maintenance, rehabilitation and replacement, to perceive and produce value to achieve the desired balance between cost, risk, and performance [2]. Thus, it is necessary to evaluate all investment proposals with clear criteria and at various levels, namely: strategic, technical, economic, political, social, environmental.

According to the objective of each investment, these can be classified according to several types: replacement, modernization, expansion, innovation, and strategy. In the particular case of this study, the investment plan of the Portuguese water utility *Águas do Douro e Paiva* (AdDP) was divided into two large groups: IT investments (for example, software licenses, acquisition of computer material, application developments, among others) and investments in assets, belonging to one of AdDP's five infrastructure groups: pumping stations, water treatment stations, pipelines (also known as water mains), reservoirs and water catchments.

Currently, water utilities are increasingly concerned about proper management of the investment plan, and, to this end, they use several criteria in order to prioritize these investments. In addition to prioritizing investments, the proposed methodology also optimizes the investment plan allowing better asset management. Moreover, this model returns the most appropriate time to make each investment in the considered planning horizon.

## Methodology

The methodology developed is based on the utility's mission –"*To manage the water supply system ensuring efficiency, reliability, service quality, product safety and respect for the highest social and environmental values*"- and the vision -"*To be recognized for our efficiency, competence, sustainability and value creation for the region*"- from AdDP. In this way, the proposed optimization model maximizes the assets´ value realization, indicating the investments that must be made in each of the next five years (each investment only needs to be made, at most, once throughout the five years).

Consider the parameters $wa_i$ e $wt_j$, which correspond to the classification of the value that investment in assets i and IT investment j have for the organization, respectively, in the interval [0;25], and the parameters $Ninva$ and $Ninvt$, which represent the total number of investments in assets and IT, respectively. Also, consider the binary decision variables $x_{k,j}$, and $y_{k,j}$ that take the value 1 if the asset investment i is made in year k and the IT investment j is made in year k, respectively. As such, this model has the objective function:

$$\text{Maximize}\left[\sum_{k=1}^{5}\sum_{i=1}^{Ninva}\left(x_{k,i}\times wa_i\right)+\sum_{k=1}^{5}\sum_{j=1}^{Ninvt}\left(y_{k,j}\times wt_j\right)\right] \tag{1}$$

The value classification attributed to each investment ($wa_i$) is obtained based on a set of criteria, meeting AdDP's mission and taking into account the current state of the asset and the advantages that this investment will bring to the management entity. The current state of the asset is assessed through its level of risk, its remaining life (determined from the year of construction of the asset and its recommended useful life), and the history of failures in the last four years, ensuring safety and efficient assets [3]. Regarding the return on investment, each is analyzed for their possible technological update/innovation, energy efficiency/production, supply reliability, water losses/leaks, and economic gains. It is indicated if any of these five factors will occur with the investment. These last evaluated criteria allow to increase the reliability of the supply and to emphasize the positive environmental consequences through the valorization of the energy production, leading to a better quality of all the service provided by the water utility.

Regarding IT investments, the classification of its value ($wt_j$)considers whether it is new for the water utility, whether it is currently obsolete, and the advantages that the investment may bring when done. The benefits considered fundamental for this evaluation are: process automation, digital transformation, economic gains, renewal support, and technological update/innovation. After determining the objective function, some fundamental restrictions were established that meet AdDP's mission. Firstly, a budgetary constraint was created. The total amount used each year to make investments in assets and IT cannot exceed the budget available for each year by the water utility.

$$\sum_{i=1}^{Ninva} (x_{k,i} \times za_i) + \sum_{j=1}^{Ninvt} (y_{k,j} \times zt_j) \leq budget_k, \quad k = 1, \dots, 5 \tag{2}$$

Where $budget_k$ corresponds to the budget available to invest, in year k. The parameters $za_i$ e $zt_j$ represent the amount, in euros, of investment in asset i and technological investment j, respectively.

In addition, it was imposed that, each year, the average risk and performance in asset investments not yet made cannot exceed 7 and be less than 3, respectively.

$$\sum_{i=1}^{Ninva} risk_i - \sum_{m=1}^{k} \sum_{i=1}^{Ninva} (x_{m,i} \times risk_i) \leq 7 \times \left[ Ninva - \sum_{m=1}^{k} \sum_{i=1}^{Ninva} x_{m,i} \right], \quad k = 1, \dots, 5 \tag{3}$$

$$\sum_{i=1}^{Ninva} performance_i - \sum_{m=1}^{k} \sum_{i=1}^{Ninva} (x_{m,i} \times performance_i) \geq 3 \times \left[ Ninva - \sum_{m=1}^{k} \sum_{i=1}^{Ninva} x_{m,i} \right], \quad k = 1, \dots, 5 \tag{4}$$

where $risk_i$ corresponds to the risk of asset investment i, and $performance_i$ represents the performance of the investment in asset i. The risk has a scale of [0;25], where the value 25 means that the risk is unacceptable, whereas the performance has a scale of [0;5], where value 5 represents the excellent performance's asset.

After analyzing all investment proposals, it was found that approximately 35% of the total amount of these proposals were intended for IT investments. Consequently, there is no significant disparity in investments in assets and technology made; a restriction has been established where the funds used each year to make technological investments do not exceed 35% of the available annual budget.

$$\sum_{j=1}^{Ninvt} y_{k,j} \times zt_j \leq 0.35 * budget_k, \quad k = 1, \dots, 5 \tag{5}$$

Finally, when an investment plan is drawn up, it is common for them to be mandatory investments to be made in the next 5-year period as they constitute a legal obligation or due to the concession contract. This way, two restrictions were established: one for investments in assets and another for IT investments, to comply with this condition.

$$\sum_{k=1}^{Nanos} x_{k,i} \geq obligationA_i, \quad \mathrm{i} = 1, \dots, \mathrm{Ninva} \qquad (6)$$

$$\sum_{k=1}^{Nanos} y_{k,j} \geq obligationT_j, \quad \mathrm{j} = 1, \dots, \mathrm{Ninvt} \qquad (7)$$

where $obligationA_i$ and $obligationT_j$ indicate whether the asset investment i and IT investment j, respectively, is mandatory for the next 5-year period.

## Results and discussion

According to AdDP's current investment plan for the next five years, the value created corresponds to about 73% of the V value. The V value represents the entire value created if the water utility could afford to make all investments proposed in the plan.

With the implementation of the optimization methodology developed, (i) the budget K, that represents the total budget to be invested in the next 5-year periods in AdDP's current plan, allows creating 82% of the value V, i.e. there is an increase of 12 percentual points of the value V; (ii) in turn, to achieve 73% of the value V, only 77% of the budget K is used. In other words, there is a reduction of approximately 23 percentual points of the budget K.

shows the results of alternatives: (i) same investment, higher value created; (ii) same value created, lower investment. The same figure also shows the optimized value created with half the budget K to be approximately 56% (alternative iii).

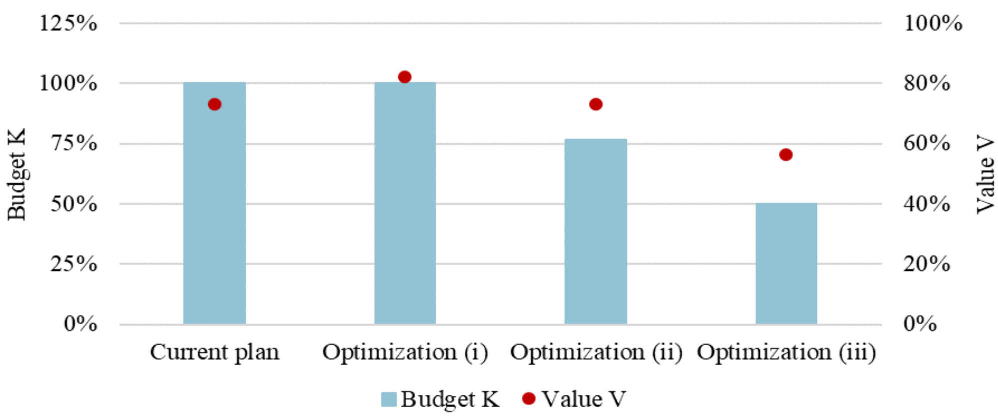


**Figure1** Results of the optimization developed concerning AdPD's current investment plan

## Conclusion

The implementation of this methodology brings several advantages, such as establishing a better decision-making process, allocate investments to the right asset at the right time and improve the financial efficiency of the organization. In addition to fulfilling the main objective of maximizing the value created from the assets intervened by the investment plan, other inherent goals are also achieved: ensuring the proper performance of the assets; increasing the remaining useful lives of the assets; managing the risk of asset failure. These achievements ultimately lead to the sustainability of water supply and treatment services and to the improvement of the assets' life cycle management.

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# Incentives for the development of water supply and sanitation systems for poor families

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**Abstract:** This research investigates the incentives for the development of water supply and sanitation services for poor families, presents the challenges that politics, institutions and regulation must achieve the goals of coverage and equity in access. It highlights the actions developed in Brazil and the integration of the National Public Policy for universal access to services and the development of vulnerable areas. A defined incentive is the expansion of the participation of the private sector as an alternative to universal access to water and sanitation services.

**Keywords:** Incentives; universalization; pro-poor.

Public water and sanitation services (WSS) are understood as a public good and, for a long time, managed by public entities. The development of society demanded from providers better results in increasingly larger operations, transforming public providers into large corporations, needing to expand production capacity and coverage in cities. The transformation of the sector configured a service that could be commercial and since the 1980s, especially since the 1990s, the WSS had the participation of the private sector [1]. However, it is still an essential public service that every citizen has the right to use [2], in a sector that demands high standards of quality and performance, resulting in constant investments. In addition, vulnerable areas face a number of constraints on the provision of WSS, often related to the general deficit of public services [3].

The economic and financial sustainability of the WSS is ensured by means of remuneration for the collection of services, and, when necessary, by other additional forms, such as subsidies or subsidies, always maintaining the priority for meeting essential health-related functions, in theory, focused on in expanding access to citizens, with special attention to low-income locations. In Brazil, despite the advances promoted by Law 11,445 / 07, the Brazilian population still faces serious problems of access to WSS [4]. Added to the service's low attendance, high rates of operational losses and the need for significant investments, estimated at more than R$ 700 billion to reach the goal of universalization by 2033 [5]. The expansion of coverage indices should be defined in the contracts and the water supply coverage targets are 99% and 90% for sewage treatment [6]. The universalization of WSS will provide enormous benefits, direct and indirect, to the country. The benefits brought about by universalization are expected to reach around R $ 1.5 trillion across the country in the next twenty years through direct and indirect effects [7]. In order to increase investments in the sector and achieve these benefits, the participation of the private sector is paramount.

Incentives are motivating influences or stimuli that incite people and, therefore, encourage institutions, companies and other actors involved in the WSS sector to pursue certain goals or to behave in a certain way. Incentives for the universal access of WSS can be political, institutional and regulatory (PIR) [8] and are fundamental to ensure that actors adopt the reform and enable within the dynamics to implement institutional reform. The incentives that allow actors to commit to agreements are, therefore, crucial for the formulation and implementation of effective policies. Furthermore, stronger incentives increase the accountability of institutional actors as they strengthen voluntary compliance through the successful execution of commitments which, in turn, help to build trust in institutions.

The policy inspires WSS actors and creates incentives for performance can be through the promulgation of formal political statements, as well as through governments announcing WSS development strategies supported by enough funding for the goals to be met. Inclusive institutions can encourage sustainable service delivery management as they shape and apply accountability mechanisms that create incentives for actors across the service delivery chain to accept and respond to their responsibilities and the desired actions to achieve sustainability. A regulatory framework can directly impact the efficiency of the sector through the creation of incentives, such as performance requirements in tariff concessions or the more informal national benchmarking approach that encourages the emulation of the best performing concessionaires.

The WSS production chain is directly connected to the use of modern and efficient technologies, which must be stimulated to increase the required levels of quality, continuity and security in the provision of services, associated with the incentive to the efficiency of the service providers. Tariff and non-tariff subsidies may be adopted for users who do not have enough payment capacity to cover the full cost of the services can access it.

In Brazil, we highlight the Sustainable and Inclusive Water and Sanitation Program developed by the water and sanitation company of the State of São Paulo, strongly related to water security, linking social inclusion, environmental preservation and technical and contractual innovations. In 2016, in the metropolitan region of São Paulo 300,000 households were diagnosed in vulnerable areas and with low family income without regular access to WSS. That same year, the Água Legal Program began, whose purpose is to regularize the service provided to these areas, through contracts with an incentive clause for performance and remuneration, with the possibility of bonuses, linked to the established goals of measured recovery of water volumes [9].

This program aligns the various incentives highlighted by specialists in the sector [10; 11 e 8], as the contracts involve a strong relationship with the population, with a view to solving the problem with regularization of access through an intense work of diagnosis and environmental awareness, with the participation and consent of the local government regarding the opportunity of the enterprise, social work to raise awareness and diagnosis of the population to adhere to the program. The gains were significant, ranging from improved public health, regular water supply, social tariff, tangible and intangible benefits of formalizing access. After the first edition, in 2019 a new project was started, with a cost of US$350 million, to contribute to the expansion of safe access to the WSS in areas of high social vulnerability to around 190,000 families by 2024, with the execution of 152 thousand connections of water and 38 thousand new sanitation connections.

Among the main options and changes that have taken place with the new regulatory framework for the WSS, the focus is mainly on the commitment to the private sector for the provision of the WSS, either through privatizations, through concessions or PPPs and the end of contracts between public institutions (PuP) [12], which will necessarily lead to a very significant number of tenders related to the municipalities that have delegated the WSS to state companies. It appears that the new law reinforces contractualization and regulation by contract, through the process of private competition, with clear incentives for universalization.

This article will present contributions to the literature regarding the universalization of WSS for poor families in vulnerable areas, reinforcing the role of incentives for better governance, regulation and institutional structures, since only with a better alignment of the PIR can adequate incentives be provided for a universal and sustainable WSS.

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# Increasing the Competitiveness of Sanitation Services with an Intelligence Process

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**Abstract:** Sanitation companies are commonly considered a natural monopoly with captive customers in the area in which they operate. However, consumers today are more aware of their demands and rights, and there is a subtle but growing competition from companies in the sanitation area aiming at new markets and pressuring legal and regulatory changes for this access.

Observing and analyzing the environment has been a recurring concern in companies that seek competitiveness in the market and advances in their performance and positioning.

Therefore, this work will demonstrate the importance of competitive intelligence in the area of sanitation, which means the ability of companies to monitor environmental information to anticipate and respond satisfactorily to the challenges and opportunities that present themselves.

**Keywords:** Competitive intelligence; Monitor Information; Adaptive Strategy.

## Introduction

Competitive intelligence is a systematic process of collecting and analyzing information from the business environment, collaborating to achieve the goals and objectives, intelligence, therefore, it is a collection of prioritized and analyzed information, that is, intelligence is knowledge (Kahaner, 1996). Tarapanoff (2006) describes that a competitive intelligence system makes it possible to organize the collection of information and process its treatment and analysis, aiming to create knowledge with strong added value, which will collaborate for strategic decision-making.

In this context, the importance of considering the entire macro environment, that is, the external environment (political, economic, technology and legal) and internal factors such as corporate knowledge, human resources, financial resources and, finally, the strategy. Vieira and Oliveira (2006) emphasize that the main objectives of Competitive Intelligence must be issues related to the analysis of competition, in order to generate knowledge or variables to favor decision making with the objective of expanding the market and profit.

Competitive Intelligence (CI) also enables the association with risk management. The CI process uses several sources, which after analysis produces the knowledge to answer specific questions and it is possible to identify possible business risks. This approach allows the CI process to forecast risks and provide for actions resulting from the analyzed scenarios (Gilad, 2001). Risk management, therefore, must be seen as a component of CI in the face of economic reality, as it integrates business security and management demands, generating contributions to decision making, considering the risks involved (Kempfer, 2002).

With regard to the competitive aspect, there is a need to anticipate the movements of competitors and market opportunities to systematically nourish internal customers with information to support decision making and route corrections. Figure 1 indicates the environmental forces in the sanitation area that deserve special attention so that there is success and anticipation of external and internal trends.


Figure 1 - Strengths of the Macro Business Environment – Sanitation – Source: Authors

## Methods

This research uses exploratory research as a method. With this method it was possible to achieve greater familiarity with the problem, with a view to making it more explicit and developing applicable solutions.

The exploratory research involved the bibliographic, documentary, and analysis of the examples [1]. The bibliographic research was developed based on books and scientific articles. Through this research methodology, a broader coverage was possible than that which could occur in direct research and this was important because the information of the research object is dispersed in space and time (geographical dispersion and historical information).

In the documentary research, documents that did not receive analytical treatment were observed. In this category are the documents kept in archives of public agencies and private institutions. Included are documents such as, memos, regulations, letters, bulletins and internal reports. Documents were also used, which in some way have already been analysed, such as: research reports, company reports, and statistical tables.

In this study, the main sources of information are public data in the form of the law and available for access on the Internet or in specialized publications, in this category are management reports, balance sheets, and literature specialized in business management and planning.

Qualitative research can be used to "discover and understand what is behind phenomena about which little is still known or to obtain new points of view about things about which much is already known" [2]. Your submission should include the background and nature of issue or problem, your findings and results, and the significance and impact of your presentation on the topic of the conference.

## Results

In order to migrate from strategic planning to a strategic management process, that is, to adopt a new strategic posture, it is important to implement a competitive intelligence process that includes, among other activities, the diagnosis of the current information flow, definition of the architecture of the Competitive Intelligence system best suited to the company, the planning of the implementation, the definition of the information collection process, the selection of the analysis methodologies to be carried out, the reports to be produced, the team training (collectors, analysts and users) , the definition of the communication platform, the elaboration of a code of conduct for the collection of information and the monitoring of the implementation. Figure 2 presents the main processes involved in the operationalization of competitive business intelligence.

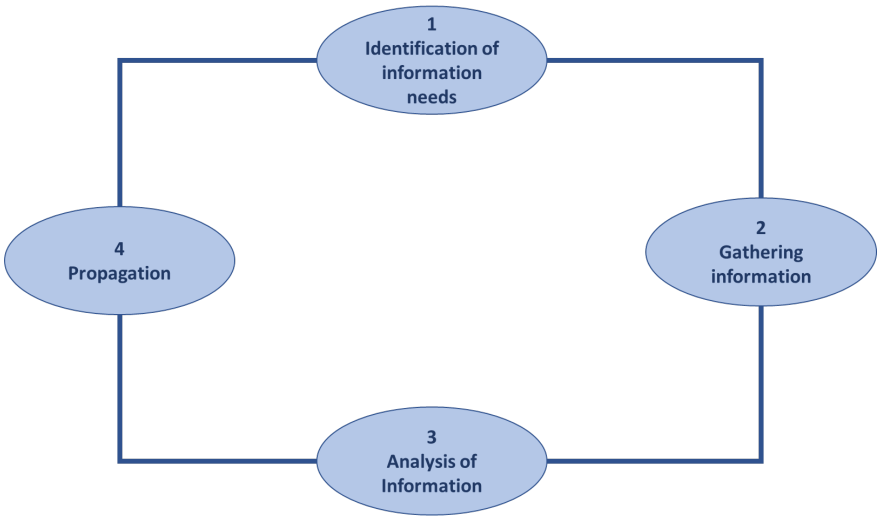


Figure 3 – Main processes of the intelligence cycle – Source: Authors

Due to the importance of sanitation companies to thrive in an environment that is becoming more and more competitive, questions arise regarding the costs of implementing and maintaining the CI process. A recent survey carried out with SABESP's Competitive Intelligence process suppliers indicated that the implementation of a process with diagnostics, training, acquisition of technological platform, use licenses and subscriptions to information bases in Brazil and worldwide has an estimated cost of 0.003% annual revenue. With respect to the effort required for this implementation and its importance for strategic management, figure 5 shows the relationship between resource consumption and the strategic impact of some alternatives for the performance of competitive intelligence.

The strategic impact considers the importance of the product generated for the planning area and for the company itself. The consumption of resources considers the need for execution time, difficulty in obtaining information and difficulty in analysis. It should be analyzed only as a relative position, not an absolute one.

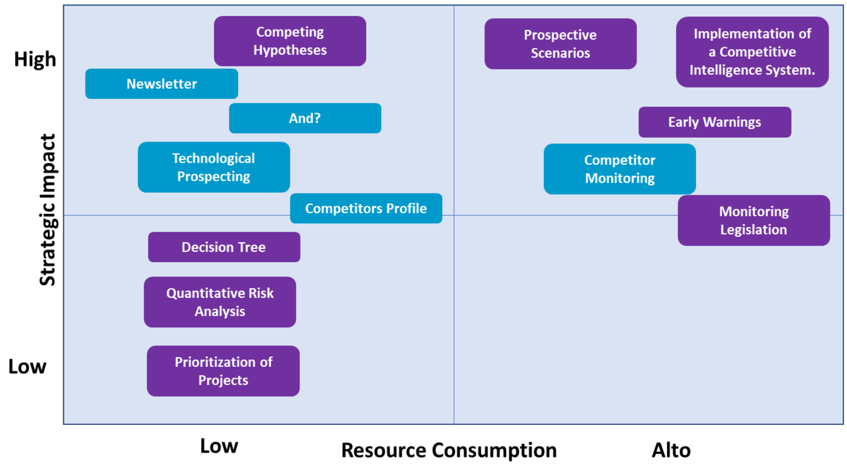


Figure 5 - Impacts vs. Resources Matrix – source: Authors

The resources required to operate in a competitive environment are variables that must be defined after analysing the macro environment of the sanitation company, so for different markets and regions the diagnosis must define which important Competitive Intelligence resources should be used.

## Conclusions

For a sanitation company to become competitive in the markets in which it operates, it must insert competitive intelligence in its management by anticipating political, regulatory, technological, market, social and economic changes, in order to anticipate competitive decisions.

The creation and maintenance of a process focused on competitive information has a low cost in relation to the possible return and proactive actions to develop new services and businesses and face the actions of competitors.

Even with a reaction to the use of Competitive Intelligence in sanitation, it appears that there is a vast field of opportunity that can be taken advantage of by those who more quickly adopt the practice, since a quick adaptation will bring different results because it is a sector not yet exposed to market competition practices and the change to the legal framework in the short term.

Another benefit worth mentioning is the development of the company's ability to identify and protect information considered strategic, enabling the definition of actions that can restrict the flow of information to unauthorized people. Thus, the company can become more competitive and develop other markets or businesses in a sustainable way.

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# Infiltration and Inflow Reduction Master Plan – Small systems at Northwest Portugal Case Study

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**Abstract:** Sewage systems have been facing complex challenges, as a result of the political, economic, social and technological changes of the current society. Management of wet weather flows in the wastewater systems has remained one of the most intractable problems for wastewater managers. These flows can result in sewer backups, system overflows, health risks, environmental damages, treatment efficiency problems and increased operational costs. The main objective of this paper is to develop a methodology for access the prioritization of the investments for reducing inflow and infiltration throughout the Northwest Region of Portugal. Following data collection and intensive data treatment and validation, dry and weather analyses and KPI developed were combined and resumed in a Inflow and Infiltration Reduction Master Plan.

**Keywords:** Sewage systems; infiltration; inflow; Prioritization KPI.

## Introduction

Although Europe water policy has successfully contributed to water protection over the past three decades according to the European Commission (EC) (2012) the challenge of water protection is still one of the great challenges for the EU principally in wet weather (WW), because of polluted overflows. Wet-weather (WW) events and periods have a large impact on the sewage systems and Water Resource Recovery Facility (WRRF) behaviour and on its capability to comply with regulations.

During WW events, frequent flooding can occur, associated with sewers' surcharge combined with large quantities of sand and grit, which contributes towards operational failure of drainage and treatment of systems. In the case of WRRF, the substantial amount of stormwater inflow generates bypasses of untreated or partially treated wastewater and could washout the biological secondary process [3,4]. These uncontrolled urban floods and direct discharges into receiving waters (combined sewer overflows, CSO) will remain big challenges for the wastewater utilites and municipalities for the next years [3].

Moreover one of the key aspects mentioned in the Blueprint to Safeguard Europe's Water Resources (EC, 2012) is related to the implementation of Article 9 of the Water Framework Directive that requires cost-recovery (including environmental and resource costs) for water services, taking into account the polluter-pays principle. At a utility management financial level there is still a lack of proper set-up of water pricing modelling regarding dry weather (DW) and WW periods and therefore estimation of the exact impact in operating expense cost (OPEX) of the DW and WW period remains an important issue.

In the current case study at the Northwest of Portugal the wastewater servicing is multi-jurisdictional based on a two-tier municipal governance structure. Sewage from most of the communities in the Region is collected through a combination of local multi-municipal (Águas do Alto Minho. SA) and multi-municipal company (Águas do Norte, SA) for large sewer systems and WRRF.

In order to overcome these limitations, the authors developed a methodology to access the prioritization of the investments for reducing inflow and infiltration for the wastewater systems of Northwest Region of Portugal. This methodology could be used to identify the investments in the drainage and the WRRF in a holistic and integrated perspective based on specific KPI developed for short term and long term and therefore for fine tuning the predicted investments.

**Material and Methods**

The work was carried out at the Viana do Castelo Municipality located at Northwest Region of Portugal. The sanitation system of the industrial zone of Viana covers a total area of approximately 1493 ha belonging to the municipality of Viana de Castelo, divided by the parishes of Castelo da Neiva, São Romão de Neiva, Chafé, Anha, Darque, Vila Fria, Mazarefes, Vila Franca, Subportela, Deocriste and Deão. The system is confined to the North by the River Lima, to the West by the Atlantic Ocean, to the South by the River Neiva and to the East by the summit of the drainage basin of the River Neiva, which corresponds to the municipality of Viana de Castelo and Braga. From the point of view of system management, the system consists of: small diameter networks, including collectors and pumping stations (Águas do Alto Minho); Large diameters networks, including interceptors and pumping stations (Águas do Norte); and WRRF (Águas do Norte).

One of the major challenges related with the performed work is related to the lack of data for the measurement of sewage flows in the system, with no data available of wastewater flows in the drainage system. This led to the assessment of the availability of existing operational data, namely, i) WRRF flow and quality data, ii) water demand data, iii) GIS and iv) number of pumped hours per pump in each pumping station.

Based on this data extrapolation methods were applied to define wastewater base flow, infiltration and stormwater inflow, which served as a basis for the development of the methodology, namely:

a. Firstly the analysis of rainfall in the region was performed, based on the national weather institute (IPMA) climatological normal, namely, the annual values and frequencies.

b. Subsequently, the drinking water consumption and its relationship with produced wastewater, in dry and wet weather, were analysed on a daily, monthly and annual basis, with the following aspects taken into account in the analysis:

   - Evolution of wastewater volumes over the past few years treated in the WRRF;

- Definition of wastewater and infiltration base flows, with decay identification after precipitation events in dry and wet weather;
- Influence of rain assessment on the pumping station, drainage network and WRRF
- WRRF Wastewater Quality data – Variations, evolution and particular situations
- Sewage pumping stations data analysis (individual and flow balance):
    - DW: estimated pumped volume vs theoretical water consumption.
    - WW: estimated pumped volume vs theoretical water consumption.

c. According [1] a performance assessment enables to quantifying objectively the systems' strengths and weaknesses, providing support for the adoption of corrective rehabilitation measures, in addition to allowing independent and standardized comparisons to be established. In this context after the data treatment and analysis which lead to a first assessment of the hydraulic and environmental performance of the sewage system, a benchmarking analysis of existing specific performance indicators for the infiltration and inflow was performed. Performance indicators from the International Water Association (IWA), ERSAR [1], WSAA Guidelines and I&I York Region [2] were analysed. In this way, the performance indicators developed in the current work are presented in Table 1.

**Results and Conclusions**

From the Figure 1a and 1b example for one of the ten pumping stations evaluated it is possible to observe that the estimated wastewater flow rates based on water consumption are much lower than the flow rates estimated by the hours of operation of the pump flow rates. This situation should be validated by carrying out a flow measurement campaign, or by installing a flow meter in the pumping station. If the estimated pumped wastewater flow is correct, it will be necessary to understand the difference to the water consumption values, which may include illegal connections, measurement errors, groundwater pumps or permanent infiltration flows.

As can be seen in Figure 1c, for the various precipitation events between 10/30/2015 and 12/20/2015, immediately after the decrease, or cessation of precipitation, there is a sudden decrease in the flow rate affluent to the WRRF. Despite the occurrence of weak precipitation events between 7/11/2015 and 11/15/2015, the flow influent to the WRRF decreases, on those days, from 5000 $m^3$ / day to values below 3000 $m^3$ / day. For this period, it could be assumed that the system has strong stormwater inflow influence but with low infiltration flows. This type of analysis was performed for a four-year period and with different behaviors of the system which could be also observed in Table 2 for the several months.

As mentioned previously one of the key aspects in the management of sewage systems corresponds to the need for integrated management (drainage, treatment and disposal) from the point of view of quality and quantity. In particular during WW events significant stormwater inflows entering the systems provides levels of dilution which require lower levels of treatment and even at sometimes with quality parameters lower than the discharge compliance values. The analysis performed and presented in Figure 1d reveals that could be possible in some periods of WW periods, to have effluents discharged compatible with the discharge permit with efficiencies of wastewater treatment compatible with chemical primary treatment (80-50%) and conventional primary (50% - 30%) treatments TSS and COD/BOD removals efficiencies, respectively. As can be seen for the parameters analyzed (COD, BOD and TSS), situations of compliance with the discharge license for treatment efficiencies below 20% are not uncommon. Therefore, an integrated approach combining on-line monitoring based on spectrophotometric or NTU probes located in strategic locations could support the decision for by-pass the WRRF treatment and enable current situation optimization among other CAPEX related with infiltration and inflow control.

In terms of application of the developed KPI the infiltration flow, calculation was based on the minimum value of the dry period, considering the previous analysis presented, as it is considered that it represents an adequate approximation. In Table 2 is presented the results of the KPI ID7 where it could be seen a general increase in all sub-basins from year to year, reflecting a direct effect of precipitation on the volume of wastewater affluent to the different pumping stations, possibly due to an increase in direct connections or by deterioration of the drainage network. Nevertheless it is possible to address that the sub-basin of the pumping station n.º 9 and n.º 10 corresponds to the worst cases in terms of direct influence of stormwater inflow.

Finally after defining and applying the performance indicators, an action plan was proposed, defined by short-term and medium-term measures, with identification by basin, namely:

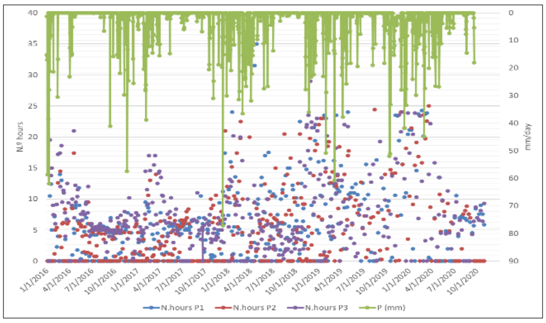
- Definition of priorities for rapid implementation interventions: corrections in the system, recommendations from the point of view of operating the system, topographic surveys, cleaning, among others.
- Definition of the measurement points of the level and / or flow and precipitation of the areas under study

For the medium-term measures it was proposed the definition of subsequent studies, whose relevance is deemed relevant for the continuation of the work, with a view to the elaboration of projects and the improvement of the knowledge of the systems behavior.

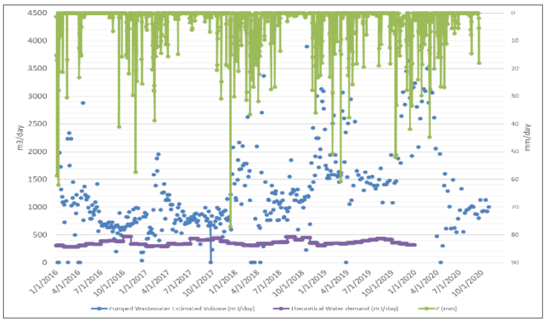
**Table 1** KPI developed for accessing infiltration and inflow.

| ID | Objective | Name | Key Factors for Prioritization | Frequency | Units | Rank | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Low | Medium | High |
| ID1 | Infiltration | Theoretical water demand | Mensal Water Consumption Volume / Population /30 | Monthly | l/hab.day | <100 | | >200 |
| ID2 | Infiltration | Real Water demand | Wastewater volume / 0,8 / Population /30 | Monthly | l/hab.day | <100 | | >200 |
| ID3 | Infiltration | Infiltration flow vs Number of manhole | Minimum mensal wastewater flow / n.° manholes | Monthly | m3/month .n.° camaras | <10 | | >20 |
| ID4 | Infiltration | Infiltration flow vs vs pipe wall | Minimum mensal wastewater flow / (Hydraulic radius x network extension) | Monthly | m3/(m DN/4) x m | <2 | | >4 |
| ID5 | Infiltration | Infiltration flow vs Network extension | Minimum mensal wastewater flow / network extension | Monthly | m3/month.km | <100 | | >200 |
| ID6 | Inflow | Volume Wastewater / Volume Water Consumption | Wastewater volume / (Water consumption volume x 0,8) | Monthly | NA | <2 | | >4 |
| ID7 | Inflow | Volume wastewater Wet weather / Rainfall | [(Wastewater volume - Minimum wastewater volume) / (Mensal rainfall x basin area )] x 100 | Monthly | % | <5 | | >20 |

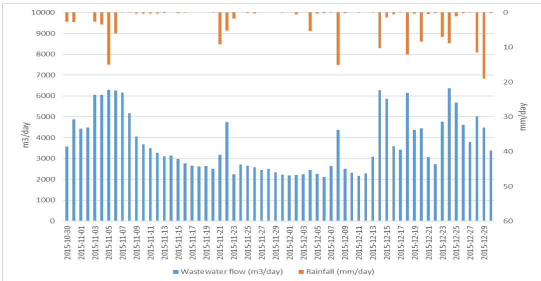
(a)




(b)



(c)




(d)

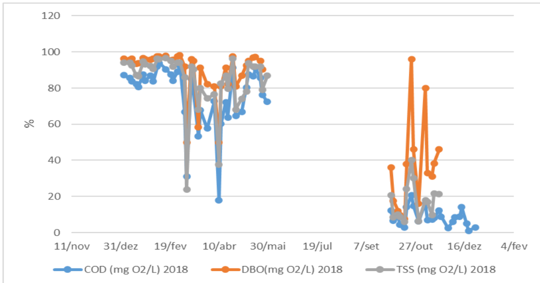



Figure 1: (a) Pump station hour analysis vs rainfall; (b) Estimated pump flow vs rainfall; (c) WW Event infiltration decay analysis (30/10/2015 - 30/12/2015); (d) WW WRRF treatment minimum efficiency

**Table 2** KPI results example.

| Date | P (mm/dia) | Volume wastewater Pumping station 1 / Rainfall Pumping station 1 basin | Volume wastewater Pumping station 2 / Rainfall Pumping station 2 basin | Volume wastewater Pumping station 3 / Rainfall Pumping station 3 basin | Volume wastewater Pumping station 4 / Rainfall Pumping station 4 basin | Volume wastewater Pumping station 5 / Rainfall Pumping station 5 basin | Volume wastewater Pumping station 6 / Rainfall Pumping station 6 basin | Volume wastewater Pumping station 7 / Rainfall Pumping station 7 basin | Volume wastewater Pumping station 8 / Rainfall Pumping station 8 basin | Volume wastewater Pumping station 9 / Rainfall Pumping station 9 basin | Volume wastewater Pumping station 10 / Rainfall Pumping station 10 basin |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan-16 | 383 | 1.42 | 0.28 | -0.79 | 0.48 | -0.86 | 1.17 | 0.28 | 1.00 | -1.04 | 2.19 |
| Feb-16 | 396 | 0.02 | 0.28 | 0.45 | 1.16 | 1.35 | 1.30 | 0.38 | 1.32 | 2.87 | 1.89 |
| Mar-16 | 269 | 0.98 | 0.57 | 0.81 | 1.29 | 1.95 | 1.60 | 0.46 | 0.91 | 8.19 | 3.08 |
| Apr-16 | 209 | 1.46 | 1.14 | 0.32 | 1.50 | 1.82 | 2.17 | 0.49 | 1.50 | 5.13 | 2.82 |
| May-16 | 146 | 2.04 | 1.08 | 2.24 | 1.60 | 2.50 | 1.36 | 0.13 | 0.36 | 5.16 | 3.17 |
| Oct-16 | 82 | 0.00 | 0.00 | 0.00 | 0.87 | 1.25 | 0.00 | 0.04 | 0.21 | 4.33 | 0.33 |
| Nov-16 | 171 | 0.62 | 0.19 | 0.73 | 0.77 | 1.41 | 0.18 | 0.13 | 0.41 | 5.70 | 0.76 |
| Dec-16 | 48 | 0.00 | 1.18 | 1.30 | 0.00 | 0.00 | 1.82 | 0.20 | 1.09 | 13.71 | 2.60 |
| Jan-17 | 137 | 1.34 | 0.62 | 0.84 | 0.25 | 0.35 | 0.00 | 0.00 | 0.00 | 4.91 | 0.95 |
| Feb-17 | 285 | 5.33 | 0.44 | 0.89 | 0.57 | 0.91 | 0.45 | 0.18 | 0.79 | 3.59 | 1.36 |
| Mar-17 | 153 | 9.97 | 1.05 | 2.57 | 1.16 | 2.25 | 0.42 | 0.15 | 0.68 | 7.37 | 1.90 |
| Apr-17 | 36 | 5.76 | 0.89 | 1.58 | 2.09 | 4.18 | 5.81 | 0.35 | 1.91 | 15.11 | 4.62 |
| May-17 | 36 | 7.29 | 2.13 | 5.61 | 3.03 | 4.81 | 2.42 | 0.53 | 1.45 | 18.25 | 5.17 |
| Oct-17 | 64 | 4.12 | 0.82 | 0.83 | 1.08 | 2.13 | 0.74 | 0.25 | 1.37 | 14.55 | 0.18 |
| Nov-17 | 118 | 0.82 | 0.07 | 0.90 | 0.54 | 1.24 | 0.43 | 0.27 | 1.48 | 6.92 | 0.15 |
| Dec-17 | 229 | 0.34 | 0.00 | 0.55 | 0.72 | 1.45 | 0.57 | 0.17 | 0.76 | 3.86 | 1.07 |
| Jan-18 | 145 | 1.93 | 1.31 | 0.66 | 1.50 | 5.24 | 1.46 | 0.00 | 0.00 | 12.02 | 3.45 |
| Feb-18 | 109 | 0.00 | 1.00 | 0.48 | 1.60 | 6.51 | 1.63 | 0.03 | 0.80 | 12.76 | 1.71 |
| Mar-18 | 337 | 1.48 | 1.16 | 0.00 | 0.33 | 0.00 | 1.71 | 0.38 | 1.86 | 8.26 | 2.14 |
| Apr-18 | 165 | 3.28 | 2.34 | 0.58 | 0.93 | 1.17 | 1.38 | 0.39 | 2.53 | 10.97 | 4.03 |
| May-18 | 48 | 9.03 | 3.92 | 5.17 | 4.03 | 7.79 | 2.84 | 0.39 | 2.88 | 5.58 | 4.18 |
| Oct-18 | 7 | 85.03 | 8.84 | 43.47 | 13.37 | 61.59 | 0.46 | 0.87 | 2.39 | 96.25 | 11.01 |
| Nov-18 | 174 | 4.62 | 1.58 | 0.36 | 2.74 | 4.68 | 1.85 | 0.73 | 2.80 | 8.81 | 3.08 |
| Dec-18 | 145 | 4.40 | 2.67 | 1.00 | 4.41 | 7.62 | 2.80 | 0.48 | 3.01 | 12.02 | 4.46 |
| Jan-19 | 103 | 3.83 | 2.24 | 9.56 | 3.74 | 4.95 | 2.62 | 0.56 | 2.89 | 9.53 | 5.62 |
| Feb-19 | 66 | | 2.34 | 7.19 | 3.97 | 3.88 | 3.79 | 0.92 | 5.05 | 9.09 | 6.14 |
| Mar-19 | 102 | 8.89 | 8.20 | 5.59 | 2.78 | 4.03 | 1.87 | 0.40 | 2.21 | 6.07 | 3.18 |
| Apr-19 | 211 | 1.12 | 0.56 | 4.11 | 1.14 | 1.62 | 0.32 | 0.26 | 0.58 | 5.87 | 5.17 |
| May-19 | 29 | 6.42 | 1.55 | 13.95 | 3.87 | 10.40 | 8.22 | 1.00 | 10.35 | 16.56 | 13.08 |
| Oct-19 | 208 | 0.63 | 0.29 | 3.35 | 0.47 | 0.12 | 0.61 | 1.00 | 1.34 | 2.11 | 2.29 |
| Nov-19 | 134 | 2.22 | 1.81 | 0.00 | 5.12 | 8.31 | 2.83 | 0.88 | 4.03 | 12.84 | 9.29 |
| Dec-19 | 252 | 4.47 | 2.99 | 0.99 | 4.27 | 3.53 | 3.40 | 1.15 | 3.11 | 1.05 | 4.02 |

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# Linking safe water supply to catchments' risk assessment and water treatment – a case study based on Águas do Douro e Paiva asset management.

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**Abstract:** Provision of safe water is indispensable for life and its management must be rational and sustainable. Most of the technical and managing efforts to ensure this mission have been addressed to water treatment and related distribution system. Yet, catchments represent an essential part of Water Treatment Plants (WTP) and their characteristics can incorporate significant vulnerabilities that may compromise system's performance. An asset management system promotes periodic risk assessment procedures to estimate assets' performance and evaluate renewal needs. Extending this proven methodology to catchments, identifying and adapting their particular characteristics and organization´s specificity, can represent a drive for decision making and investment strategies. The present research follows this approach evaluating a case study with eight catchments in a Portuguese utility.

**Keywords:** Water catchments; Asset management; Risk management.

## Introduction

Water catchments are critical infrastructures to water supply systems. They are decisive to abstract raw water from a water body into a treatment process, whose design and performance is deeply associated to the origins' water quantity and quality.

The study and understanding of the corresponding water bodies is vital to the performance of the infrastructure, while the study and understanding of the impacts on the treatment processes is critical for the related WTP. A decrease of raw water quality will raise subsequent problems in the WTP or even in the whole supply system [1]. Therefore, water catchments must be included in a risk assessment, under an Asset Management (AM) system developed for a water supply system [2].

The present study will consider eight catchments of Águas do Douro e Paiva (AdDP), a Portuguese operator that is responsible for the bulk system that supplies 20 municipalities in Porto region, of around 1,7 million people. The abstractions are located in rivers, dam reservoirs and aquifers. In 2019, the more important catchments of AdDP were two water intakes in Lever Compound, near the Douro River, extracting around 90% of the volume delivered by the company's eight catchments. Specific treatment is provided to these two catchments' water. The other six catchments are much smaller. In addition, AdDP system has evolved along the years to have redundancy- some areas are supplied from more than one origin [3]. In 2019, an AM system was implemented and certified by the ISO 55000 standard.

Though, the operation has demonstrated that such infrastructures' management can´t use an isolated approach, and that it was necessary to implement Risk Assessment tools for AdDP's catchments.

The research that supports this paper, comprises a performance and Risk Assessment process that was implemented for these eight catchments, developed in a two step process: seeking relevant information for each catchment; and developing risk matrices to estimate the risk level of each catchment. Based on the results, corrective actions are proposed and future investments are prioritized.

## Methodology and Case Study

As a base component of AdDP AM system, a performance assessment of all infrastructures is done periodically, giving information that contributes, namely, for risk assessment [4] of such infrastructures. The company also uses its own methodology for assets' risk of failure assessment, adapted from the one [5] developed together with other companies of Águas de Portugal Group – the holding which AdDP integrates. This methodology is based on risk matrices where both probability and consequence of failure are estimated in a scale from 1 to 5, in order to identify the risk level of an infrastructure. The estimation of these two parameters is based on the weighting of different indicators, that are related to specific characteristics of each infrastructure [6] (e.g. Survey results or Anomalies to address Probability's values, and Volume or Supplying alternatives available to address Consequence's values). The main objectives on the implementation of this research were to improve the relation between the catchments' analysis and evaluation, and the corresponding WTP, under an AM process, and to provide significant insights for treatment processes.

The proposed methodology considers an asset management system that analyses catchments separately from WTP, although following the same generic approach of the methodologies commonly implemented in AM systems. Different indicators and weights are proposed for five infrastructures' typologies: Catchments, Water Treatment Plants (WTP), Pipes, Reservoirs and Pumping Stations. This methodology also distinguishes, within each typology, the risk level estimation for Electromechanical Equipment and for Civil Construction, mapping infrastructures on two separate risk matrices. Infrastructures risk levels are confronted against the risk matrix accepted by the organization's top management, in order to decide if and what actions are needed to meet acceptable risk levels.

The initial step of the performance assessment involved studying the way the infrastructure was conceived and how its functioning was foreseen. Note that AdDP has 7 different superficial water origins and 1 underground abstraction, imposing a special attention to their operating conditions. This initial step is a comprehensive phase, that enables gathering, and periodically updating, a range of data that is very important for the following risk assessment step [2] [3]. This important information is the bases of the Report and Assessment Files (RAFs), which has specific samples for the company's five typologies of infrastructures previously referred. It greatly follows a model [5] developed by Águas de Portugal Group, that compromises a platform that can be utilized in different water and wastewater types of infrastructures [6]. AdDP's adaptation of the document added three sections[2]: *Report*; *Impact's severity* and *Infrastructure's evolution*. The other five (initial) sections are: *Cover info*; *Framework*; *Fitness diagnosis*; *Performance summary* and *Improvement suggestions*.

Table 1 presents the criteria for catchments risk assessment, for Equipment. For the subsequent risk analysis, the Risk Matrix adopted by the organization follows a typical approach [7], involving a 1 to 25 risk level, as depicted in Figure 2. RAFs have a clear connection to punctuation of three indicators that contribute to probability of failure estimation, that can be seen in table 1. Nevertheless, the whole information of the document indirectly helps reaching a sound global understanding of the infrastructure.

**Table 1** –Risk analysis of Catchment's Equipment –criteria, indicators and weights.

**Equipment**

| | Criteria | Indicator | Weight | Metrics | Ponctu-ation | Data Source |
|---|---|---|---|---|---|---|
| Probability | Real Performance | Obsoles-cence Degree | 10% | No problems | 1 | RAF |
| | | | | Dificult to obtain spare parts | 3 | |
| | | | | Descontinued, no spare parts | 5 | |
| | | Level of Utilization of Installed Capacity | 20% | Level < 0,6 | 1 | "Operation" |
| | | | | 0,6 ≤ Level < 0,7 | 2 | |
| | | | | 0,7 ≤ Level < 0,8 | 3 | |
| | | | | 0,8 ≤ Level < 0,9 | 4 | |
| | | | | Level ≥ 0,9 | 5 | |
| | | Number and Severity of Anomalies | 30% | Reduced Impact | 1 | Mainte-nance Software |
| | | | | Medium Impact | 3 | |
| | | | | High Impact | 5 | |
| | | Fitness for Operation | 30% | Suitable | 1 | RAF |
| | | | | Suitable with Limitations | 3 | |
| | | | | Unsuitable | 5 | |
| | | Survey's Procedure | 10% | Very Good | 1 | RAF |
| | | | | Good | 2 | |
| | | | | Tolerable | 3 | |
| | | | | Bad | 4 | |
| | | | | Very Bad | 5 | |
| Consequence | Relevance | Annual Volume Pumped (1000 x $m^3$) | 75% | Volume ≤ 100 | 1 | "Operation" |
| | | | | 100 < Volume ≤ 1.000 | 2 | |
| | | | | 1.000 < Volume ≤ 5.000 | 3 | |
| | | | | 5.000 < Volume ≤ 10.000 | 4 | |
| | | | | Volume > 10.000 | 5 | |
| | Redundancy | Pumping Alternative | 25% | Total | 1 | "Operation" |
| | | | | Total / Partial | 2 | |
| | | | | Partial | 3 | |
| | | | | No Alternative / Partial | 4 | |
| | | | | No Alternative | 5 | |

The three new sections accelerate the risk assessment process. For instance, the *Report* of Catchments' RAFs, collects information like the years of construction and rehabilitations, the pumping capacity installed, the pumping height, a brief description of the operating mode and more. Also, information about the main actions to develop, and related costs and deadlines, is detailed in this section too, while it also registers the more valuable photos of the assets, collected during each survey. Figure 1, bellow, shows excerpts of a *Report and an Infrastructure evolution* of a catchments' RAF.

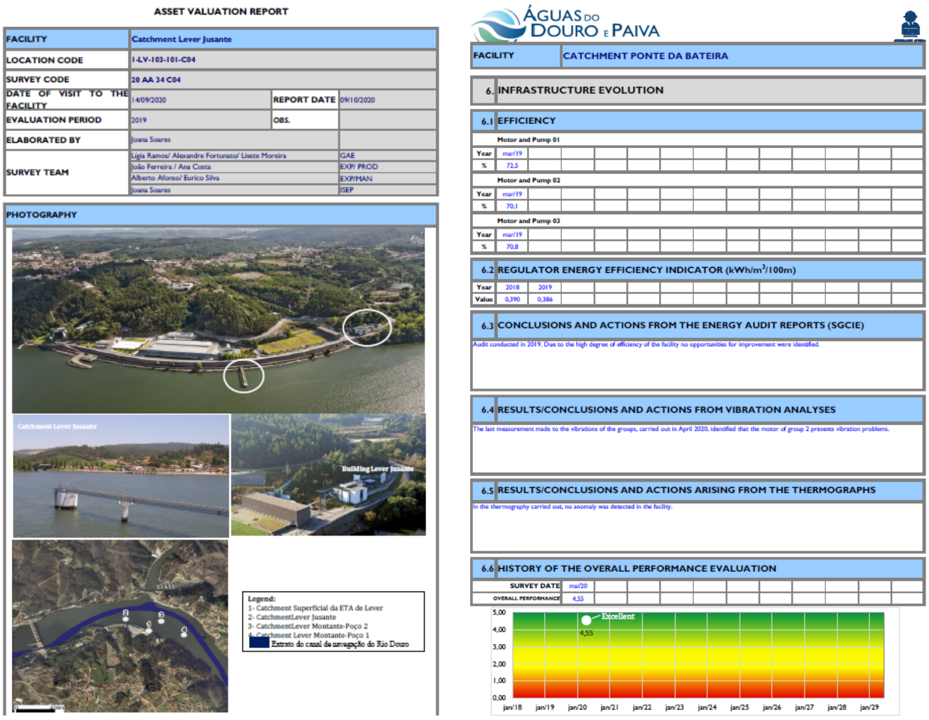


Figure 1 – RFA excerpt (Report and Infrastructure evolution sections).

Section *Impact's severity* of Catchments' RAFs shows severity of anomalies spotted on surveys, to support defining the "real performance". Lastly, section *Infrastructure's evolution* shows historical data on global performance of the infrastructure, as well as the global energy efficiency of the infrastructure and of each pump. The conclusions of external energy audits, vibrations and pump's thermograph surveys are also included. The remaining information follows the initial model disseminated by AdP, allowing to assess three main areas: performance, condition evaluation and security.

At AdDP, surveys are done by multidisciplinary teams, with agents of each phase of the asset's life-cycle and the AM process targets Functional Evaluation five-year reports required by the Regulator.

## Results and discussion

The two Risk Matrices for the 8 catchments, depicted in Figure 2, clearly identify the infrastructures with higher risk level, whose assets need actions in the short term, and the ones with acceptable risk level, whose assets replacements can be planed for the long term.

These results were jointly analysed, by AM Department and by Operation and Maintenance Department, for validation and future actions, which are passed to the company's investment planning. In the present case, actions were drawn to reduce the Equipment's risk level of catchments C4 and C6 and the Civil Construction's risk level of catchment C8.

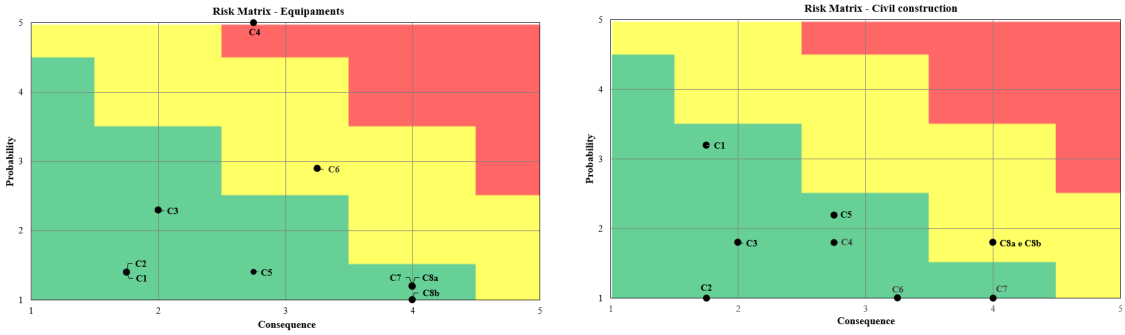


Figure 2 – Risk matrix for AdDP`s water catchments.

For example, in terms of Equipment, catchment C4 fell in the higher risk zone. Risk assessment showed that the installed pumping capacity is not enough, during seasons of higher water consumption. Also, original catchment's studies showed that the flow constraint resulted from the initial dimensioning of pumps, which was based on the water availability of the river. Demand increased since then (more than 20 years ago) and forecasts don't reveal decreasing trend. So, replacement by new pumps is not an option. Furthermore, future climate change's impacts, during hot summers, may occur given the location, although this additional problem wasn't deepened, being unnecessary. The solution adopted was to plan investments for a new water origin, in a river nearby, and a new pipeline to the existing WTP, whose installed treatment capacity is enough. Still, future developments will give further information on eventual adaptations of treatment process, to meet the new origin's water characteristics. By reducing probability of failure (consequence remains the same), risk level decreased to around 4.

## Conclusions and future developments

An effective AM, and associated risk assessment, can provide valuable information for the water supply systems' management, and contribute not only for high efficiency, but also to increase their resilience to unexpected pressures, as those related to climate changes. However, these methodologies do not often consider the catchment characteristics and future changes.

The knowledge of all existing assets is an essential part of a comprehensive risk assessment, justifying the inclusion of water abstraction catchments. In fact, the catchments specific characteristics and future changes should be taken into account, when identifying risks and forecasting the system's evolution (e.g. on demand, climate change effects, and raw water parameters), so that AM delivers alerts to the other company's areas, namely Operation, but also Maintenance, Project Management, Planning, etc., allowing the utility to timely take actions to increase capacity and adaptation availability [3].

Based on a case study of eight catchments, risk matrices were built to support decision making, while giving insights to the prioritization of future investments. Decisions are based on RAFs contents, and include the calculated risk level, bringing objectiveness to the process. Such transversal approach, involving different company's areas, derivates from AM strategies and is a gain for the company.

Conversely, the methodology systematized the information related to perimetral delimitation for the catchments. This wasn't implemented in the utility's AM System. The risk assessment addressed the study and understanding of the water body where catchments are located, hence enhancing the existing methodology and contributing to a basic AM requirement, as it maximizes infrastructure's knowledge.

The importance of the results has led the water utility to target the integration of such approach, adapting RAFs to include this information, in order to continuously monitor water characteristics versus AM processes. The main contents of protection's perimeters are: the characterization of the water basin, existing punctual sources of pollution and the risk assessment of the water body's pollution.

Results also demonstrated that the proposed methodology is an excellent way for catchments' owners to master water origins, to ensure safe water distribution, increase the resilience of the water system, while providing inputs that allow to prioritize risks and associated investment plans.

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# Moving towards energy neutrality by optimizing the energy mix in the water sector: the INOVA case study

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**Abstract:** As energy costs continue to increase, reducing energy costs is rapidly becoming a major priority for water utilities. There is an evolving paradigm shift from the use of fossil fuels to the integration of on-site renewable energy sources in the energy mix of water utilities. Regardless renewables are becoming increasingly attractive financially, without an integrated approach based on water and energy forecast and optimization, it becomes difficult to move towards "energy neutrality", where energy needs from water utilities are entirely satisfied with their own generation. This paper aims to present the results of the SCUBIC implementation in the energy mix optimization thus reducing energy costs from INOVA-EM water company.

**Keywords:** Renewable energy sources; real-time water management; forecast and optimization;

## 1. Introduction

Water is a crucial resource to human life and to provide a global sustainable development. Without additional efforts to achieve the Sustainable Development Goals, by 2030 the amount of energy consumed by the water sector would increase by around 50% and the dependence of these systems on fossil fuels will still be notorious. As energy costs rise, population grows and regulations become more stringent, electricity demand and costs associated with water supply will increase [1]. Futhermore, to accomplish the European Green Deal climate-neutrality goal for 2050, energy-intensive industries, such as water facilities, need to place an emphasis on decarbonizinh their processes by increasing the shares of on-site renewable energy production and improving the energy efficiency [2], [3]. The integration of these two approaches will lead the water companies to improving the efficiency of water supply systems (WSS) but also contributing to mitigation on climate changes.

The best way to make WSS energetically sustainable is through the introduction of renewable energy sources (RES) [4]. As seen, WSS are energy-intensive infrastructures that are composed of water storage tanks and energy components (pumps) for delivering water to the end consumers. This kind of systems is an excellent candidate to integrate electricity produced from intermittent sources (such as RES) since these have the ability to often choose when to consume energy. Furthermore, RES contribute to mitigate GHG emissions, reduce dependence on the energy grid, and consequently energy price fluctuations effects [5]. However, due to the randomness and volatility of renewable generation, it is necessary to develop an integrated approach that allows water suppliers to forecast and take full advantage of renewable energy production in order to achieve energy neutrality.

Nevertheless, real-time management of WSS associated to RES, is a highly complex task that requires advanced tools considering water and energy forecast to effectively manage WSS operations. A clear demonstration of this intricate problem is the reduced number of reported real case-studies (in addition to the interest in the topic being fairly recent) [6]. The most efficient operation is the one that, on a daily basis, pumps the exact volume of water needed to satisfy the population at the lowest possible energy cost . However, achieving the optimal operation requires that WSS engineers have to calculate and change the operation on a daily basis and this is unfeasible. More, as water demands and renewable energy production vary from day to day, accurately predicting has proven to be very difficult [7]. Therefore, to reduce the operational cost of a WSS it is necessary to:

1. Accurate forecast water demands, and renewable energy production;
2. Dynamic optimization algorithm;

Over the years, many solutions and algorithms were proposed to optimize the operation of a WSS [4], [6], [8]–[12]. SCUBIC has developed a method based on a dynamic optimization algorithm that is composed by three interlinked stages [13]. The first consists in the development of a virtual hydraulic model that represents the real operation of the WSS. This model describes how all the assets of the WSS interact with each other based on the pre-defined operational constraints. The second stage calculates on a daily basis the boundary conditions of the virtual model, which includes the water demand, the renewable energy available, and tank levels at the beginning of the simulation. In contrast to water demand forecasting, which considers the history of water consumption, renewable energy forecasting should consider meteorological parameters. In the third stage, an optimization algorithm solves the hydraulic model for different inputs to find the combination that originates the best operational management results (lower cost).

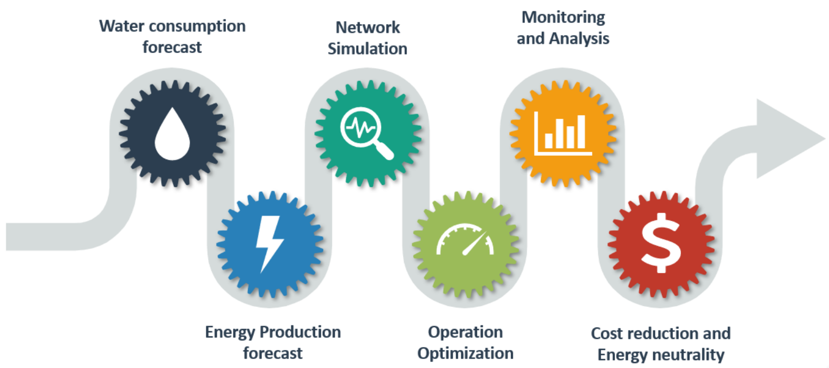


Figure 8 – The phases involved in the operational optimization process promoted by SCUBIC

The final output is made available on the platform developed by SCUBIC, with the objective of making operating orders available (on/off pump status) to achieve the daily optimal operation of the WSS with the integration of the energy mix thus minimizing the WSS operating costs. To the best of our knowledge, not many tools are known on the market and applied in a real water management operation that include forecasting the availability of renewable energy in their pumping schedule optimization models. Additionally, another innovation of the optimization models designed by SCUBIC is the use of continuous real valued variables.

## 2. Case Study

SCUBIC is currently installed in a water supply system in the Municipality of Cantanhede, being the company INOVA-EM the managing utility in charge of the collection, treatment, regularization and distribution of water in the Municipality. Despite some dispersion of population agglomerations, the resident population is served by the system based on Olhos de Fervença intake and water treatment plant, being the pumps the most energy consumers.

Since September of 2018, the utility has a solar PV system installed at the Olhos de Fervença WTP (Erro! A origem da referência não foi encontrada.). Solar PV has an installed capacity of 62,5kWp on a self-consumption basis, with the possibility of selling the energy surplus to the electricity grid. This solar PV system supplies the pumping system, as well as the water intake. Given that the installed capacity is not large, currently, only Mira pumps (pumps 4.2 and 4.3) have the capacity to absorb the power produced without requiring extra energy from the electricity grid. The Mira water tank, which is supplied by pumps 4.1, 4.2 and 4.3, has constraints on the operation between the operational limits of 55-95% of the tank capacity.

**Figure 2** - Solar PV system installed in the water treatment infrastructure of Olhos de Fervença.

The main goal of this project is minimizing the WSS operating costs taking into consideration the combination of the renewable energy production available and the adjustment of the pumping schedule to cheaper electric tariff respecting the several constraints, especially the clients' water demand, pressure and water quality.

## 3. Results

In this chapter, the results of this case study are presented. Figure 3 and Figure 4 show the result of the operational management of Mira pumping system (operation with pumps 4.2 and 4.3) on May 4, 2021 representing the normal operation without cost optimization, and on May 7, 2021 representing the operation with SCUBIC energy cost optimization. The background colors correspond to the energy tariffs applied to the installation. Four tariff periods are presented, from the cheapest, the super-off peak (€/kWh) to the most expensive, the peak (€/kWh). Other information available in the figures are the 4.2 and 4.3 parallel pumps power (kW), the solar PV power produced (kW), the level tank variation (%) during the day and the operational levels constraints. As can be seen in both figures, the maximum solar PV system power production is obtained in the two most expensive energy tariff periods (peak and half-peak). For the pumping system to take advantage of the "free" renewable energy available, the tank level must be kept to a minimum, complying with operational constraints, when the solar energy starts to be sufficient to exclusively supply the pumps. Otherwise, if the water tank was close to the maximum limit, it would not be possible to turn on the pumping system. Figure 3, representative of operation management without SCUBIC, the maximum power of renewable energy production reached this day is 53.5 kW. It's important to highlight that water pumped between 8:30 am and 10:00 am, a part of the energy consumed derives from the power grid because there is not yet enough solar power to fully supply the pumping systems. Furthermore, the water tank is already at the maximum operational level when the energy produced in the solar PV system becomes sufficient to fully supply the pumping systems. It appears that there is a potential for energy cost optimization on this day, given that it could have avoided consuming energy from the power grid between 8:30 am and 10:00 am, turning on the pumps only after 9:15 am when the pumps could be powered only from renewable energy and consuming "free" energy in the most expensive period, the peak.

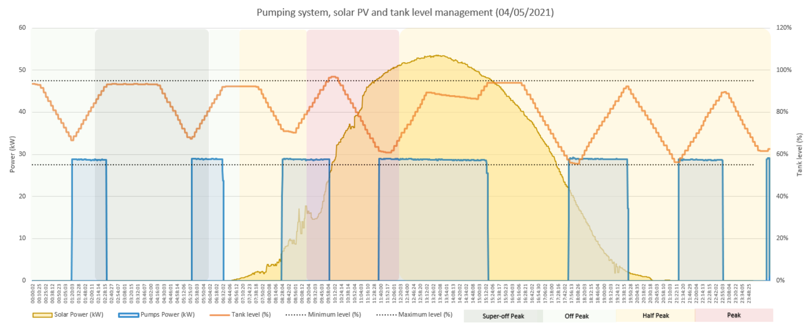


Figure 9 – Operational management without cost optimization on May 4, 2021.

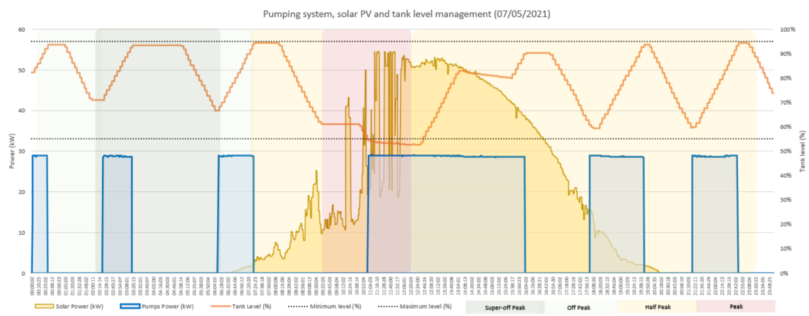


Figure 10 – Operational management with SCUBIC cost optimization on May 7, 2021

Figure 4 is representative of optimized operational management with SCUBIC during May 7, 2021. The maximum power of renewable energy production reached this day is 54.6 kW, which is enough to supply both 4.2 and 4.3 pump's energy consumption. In order to take advantage of the cheapest tariff periods (the super-off peak and the off-peak), the pumping system is turning on during these periods to fill the water tank. After the off-peak period, the pumps are turned off since the tank is already full, thus avoiding consuming energy during the half-peak period. At the beginning of the peak period, the tank is near the minimum level. As soon as the power produced from the solar PV panel is sufficient to absorb the power of the 4.2 plus 4.3 pumps, the pumping system is switched on, restoring the water tank levels. In an operation without solar PV panels, it's desirable to avoid pumping water during peak periods, whenever possible, to reduce energy costs. However, in water utilities that have solar PV systems installed, operational management changes its paradigm, given that renewable energy production reaches its maximum potential in the period corresponding to the most expensive electric tariff provide from grid power. In Figure 4, Mira pumping system achieves the energy neutrality of the electricity grid between 11am and 16pm on May 7, 2021.

For this operational and energy management to be optimized together with the renewable energy available, it is essential to use tools that make it possible to forecast water consumption and the energy that will be produced daily, the simulation of the water supply network behavior and the use of optimization algorithms that make it possible to maximize the use of renewable energy for self-consumption and thus reduce energy costs and decrease GHG emissions. Consider only Mira pumping system in the two days represented, there was a reduction in the specific energy cost from 0.1215 €/kWh on May 4th to 0.1201 € /kWh on May 7th. This represents a saving of 1.2% when just compared these two days. It should be noted that in the examples presented, the Mira pumps did not absorb all the solar energy produced, allowing solar energy during peak production periods to also be consumed in the intake pumps, for example.

## Acknowledgments

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# Non-Thermal Plasma Treatment for Pharmaceuticals Removal from Municipal Wastewater

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**Abstract:** Pharmaceuticals compounds (PC) were analyzed in the Municipal Wastewater effluent of a Portuguese Wastewater Treatment Plant. Atorvastatin, caffeine, carbamazepine, and venlafaxine (algae) are responsible for a potential "high" environmental risk, while acetaminophen, diclofenac, fluoxetine, trazodone, sulfamethoxazole, sulfapyridine, and venlafaxine (fish and *Daphnia magna*) for a "medium" environmental risk for at least one representative organism of three trophic levels of the aquatic ecosystem. The minimum removal efficiency required for guaranteeing no harmful effects in the environment must be tailored regionally, according to the local peak concentrations of critical PC, and monitored along time. Carbamazepine was identified as the critical contaminant. If a Non-Thermal Plasma unit is implemented for PC removal, the estimated electric energy consumption is 2.38 kWh/m$^3$ treated water with an associated treatment cost of 0.23 €/m$^3$.

**Keywords:** Pharmaceutical Compounds; Non-Thermal Plasma, Wastewater Treatment.

## 1. Introduction

Pharmaceutical Compounds (PC) have been detected usually at concentrations between ng/L to μg/L in Municipal Wastewater (MWW) of several Portuguese Wastewater Treatment Plants (WWTP) [1]. The presence of these PC in MWW and the environment raises environmental concerns due to their bioaccumulation potential, endocrine-disrupting effects on animals and humans, and inhibition potential of photosynthesis and plant growth. The detected PC include non-steroidal anti-inflammatory drugs, antibiotics, regulators of liquids, cholesterol-lowering compounds, stimulants, laxatives, and psychiatric drugs. Some of these are included in the European Commission watch list, but no official regulation about the maximum acceptable emission limits for any of these PC has been adopted by any European Union member-state. The only reference currently in Europe is provided by the Swiss Federal Office for the Environment (FOEN), which has selected 12 PC as reference indicators; among them, carbamazepine, diclofenac, and venlafaxine can be identified. For these PC, the Swiss regulation requires 80% removal at the WWTP outflow, independently from the initial concentration they have in the influent. When adopting the environmental risk approach, the protection of ecosystems can be ensured if the detected contaminants are kept with a risk quotient (RQ) <0.1 for representative organisms of three trophic levels of the aquatic ecosystem (algae, *Daphnia magna*, and fish). Under these circumstances, the associated environmental risk can be considered "low".

Among the different technologies for PC removal from MWW, the Non-Thermal Plasma (NTP) has raised increasing interest in the last decade, due to its simplicity, robustness, and potential high efficiency. NTP is generated by the ionization of a gas (generally, air or oxygen) through an electric field. The formed plasma can be composed of reactive oxygen and nitrogen species, free radicals, ions, atoms, and molecules, in the excited or ground state, coexisting at near ambient temperature. These species have high oxidative potential and can break PC molecular bonds, causing their partial or complete degradation. One of the most effective NTP discharge systems for PC removal from MWW is the dielectric discharge barrier, in which the plasma is generated in the presence of an insulating (dielectric) material located between the electrodes, favoring the plasma diffusion. This work includes (i) the preliminary study of PC removal from MWW by NTP, (ii) the assessment of the expected electric energy consumption for the operation of an NTP unit designed to ensure a "low" environmental risk at the WWTP outflow, and (iii) a preliminary estimation of the NTP treatment cost. Moreover, some considerations about the recommended quality standard required by FOEN, which represents the only regulation currently proposed for PC removal, are provided. The outcomes of this work develop a new asset management approach oriented to emerging pollutants' impacts and provide solutions for future water reuse.

**Material and Methods**

The PC concentrations in the treated MWW of the Portuguese WWTP were obtained from a sampling campaign performed in November 2020 following the developed methodology base on solid-phase extraction (SPE) preparation and liquid chromatography coupled with tandem mass spectrometry (UHPLC-MS/MS) [1]. The chemical characterization of the MWW effluent was based on an internal report. The data considered for this study are as follows: Chemical Oxygen Demand (COD) 64.0 mg $O_2$/L; Biological Oxygen Demand ($BOD_5$) 49.0 mg $O_2$/L; Total Suspended Solids (TSS) 29.0 mg/L; Total Nitrogen (TN) 60.0 mg N/L; Total Phosphorus (TP) 1.00 mg P/L; 10,11-epoxy carbamazepine 58.7 ng/L; 2-hydroxyibuprofen 1868 ng/L; acetaminophen 215 ng/L; atorvastatin 1994 ng/L; azithromycin 72.3 ng/L; bupropion 84.9 ng/L; caffeine 405 ng/L; carbamazepine 567 ng/L; diclofenac 4502 ng/L; fluoxetine 22.2 ng/L; gemfibrozil 119 ng/L; ibuprofen 384 ng/L; ketoprofen 429 ng/L; naproxen 160 ng/L; *O*-desmethylvenlafaxine 15697 ng/L; ofloxacin 64.1 ng/L; salicylic acid 177 ng/L; sulfamethoxazole 341 ng/L; sulfapyridine 635 ng/L; topiramate 1271 ng/L; trazodone 85.8 ng/L; trimethoprim 86.5 ng/L; and venlafaxine 865 ng/L. For each detected PC, the RQ coefficient was calculated through ECOSAR predictive model (v1.11) according to Eq. 1:

$$RQ = MEC/PNEC \qquad \text{Eq (1)}$$

where MEC is the highest concentration of PC found in the treated MWW (ng/L) and PNEC is the lowest acute toxicity value (median effective or lethal concentration, $EC_{50}$ or $LC_{50}$) divided by the pertinent assessment factor (generally 1000). The environmental risk of the detected PC was classified as "low"

(RQ < 0.1), "medium" (0.1 < RQ < 1) or "high" risk (RQ > 1). For PC that showed "high" and "medium" risk, the removal efficiency required to achieve the "low" risk level was calculated according to Eq. 2:

$$\eta_i = (c_i - MEC_{lowrisk}) / c_i. \qquad \text{Eq (2)}$$

where $\eta_i$ is the removal efficiency for the $PC_i$ (dimensionless), $c_i$ is the concentration of $PC_i$ detected in the treated MWW (ng/L), $MEC_{lowrisk}$ is the maximum $PC_i$ concentration to keep RQ < 0.1.

For this study, the NTP unit configuration and experimental results obtained by Back *et al.* [2] with carbamazepine, sulfamethoxazole, and diclofenac have been considered. These results were integrated with the preliminary experimental data obtained within the "Farmasense" project at similar, but more conservative, pilot-scale operating conditions. In the present work, a fixed voltage of 16 kV, 96W for the plasma generation unit, and a reference volume (V) of 0.41 $m^3$ were considered. The NTP treatment time, *t*, was calculated through the pseudo-first-order kinetic reaction for a concentration decay from $c_i$ to $c_f$, according to Eq. 3:

$$\ln (c_i / c_f) = k' * t \qquad \text{Eq (3)}$$

where $c_i$ is the NTP inflow concentration of PC (ng/L), $c_f$ is the desired final concentration of PC to achieve a "low" risk level (ng/L), k′ is the pseudo-first-order reaction constant ($min^{-1}$), and *t* is the reaction time (min). The time dependence of concentration was defined by *k′* through the global fitting of the experimental results [2] with Eq. 3 by using Solver, MS Excel, applying the Fit Standard Error minimization. Moreover, the removal efficiency obtained by Back *et al.* [2] was divided by a conservative Matrix Correction Factor of 5, as the treated MWW used in Back's work is characterized by a COD of 12.6 mg $O_2$/L, which is 5-times lower than that observed in the treated outflow of the Portuguese WWTP used as case-study (64.0 mg $O_2$/L). The energy analysis was performed through Eqs. 4 and 5. Eq. 4 represents the figure-of-merit proposed by the International Union of Pure and Applied Chemistry (IUPAC), of Electric Energy per Order ($E_{E0}$) (kWh/$m^3$.order), which gives the number of kWh of electric energy required to reduce the concentration of a pollutant by 1 order of magnitude in 1 $m^3$ of contaminated water in batch systems; Eq. 5 provides the expected specific electric energy consumption ($E_E$) (kWh/$m^3$) of the NTP unit at the studied WWTP.

$$E_{E0} = (P * t * 1000) / (V * \log (c_i / c_f)) \qquad \text{Eq (4)}$$

$$E_E = (P * t * 1000) / V \qquad \text{Eq (5)}$$

where P is the rated power (kW), t is the reaction time (min), V is the volume (L) of the water in the reactor, and $c_i$ and $c_f$ have the same meanings as for Eq. 3). The NTP treatment cost was assessed based on the current Portuguese electric energy price (0.096 €/kWh).

## Results and Discussion

Figure 1 shows that in the WWTP effluent atorvastatin is responsible for a potential "high" environmental risk for the representative organisms of three trophic levels of aquatic ecosystems, while caffeine, carbamazepine, and venlafaxine are only responsible for such a "high" risk for algae. Diclofenac is responsible for "medium" risk for algae, *Daphnia magna,* and fish, while fluoxetine for algae and *Daphnia magna,* and trazodone for algae. Acetaminophen, sulfamethoxazole, and sulphapyridine are responsible for "medium" risk levels for *Daphnia magna,* and venlafaxine for *Daphnia magna* and fish. All the other detected PC are characterized by "low" environmental risk (RQ < 0.1).

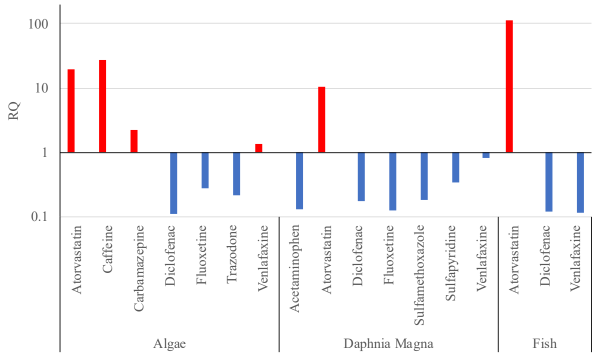


**Figure 1** RQ values for the pharmaceuticals characterized by "high" (red bars) and "medium" (blue bars) environmental risk.

These results showed that not all the PC detected in the WWTP outflow are harmful to the environment since most of them provided RQ<0.1 for the representative organisms of the three trophic levels of aquatic ecosystems.

The removal kinetic analysis, extrapolated from the results obtained at pilot scale by Back *et al.* [2] on carbamazepine, sulfamethoxazole, and diclofenac provided pseudo-first-order rate constants, *k'*, of $3.75\times10^{-3}$ $min^{-1}$ (sulfamethoxazole), $5.25\times10^{-3}$ $min^{-1}$ (carbamazepine), and $5.42\times10^{-3}$ $min^{-1}$ (diclofenac), which resulted in NTP treatment times ranging from 122 min (diclofenac) to 611 min (carbamazepine) (Table 1). Based on the preliminary results obtained within the "Farmasense" project, it is highly reasonable to assume that, at the selected operating conditions, the treatment time, *t*, required to lower RQ < 0.1 for all the other PC at "high" to "low" risk (atorvastatin, acetaminophen, fluoxetine, sulfapyridine, trazodone, and venlafaxine) is always lower than or equal to the time required for carbamazepine. On the contrary, the caffeine treatment time required for achieving "low" risk is expected to be similar or higher than that of carbamazepine, since the final target concentration required for caffeine is very low (1.35 ng/L). Further insights are needed on the removal of caffeine, being excluded from the energy consumption calculation. Based on the information available, if the NTP technology is applied, the design of the NTP unit may be tailored according to the peak concentrations of the most resistant PC, which in this case study is carbamazepine. The estimated electric energy consumption to achieve RQ < 0.1 at the studied WWTP is 2.38 $kWh/m^3$ treated wastewater (Table 1), with an associated cost of 0.23 €/$m^3$, which must be added to the current MWW treatment cost of 0.13 €/$m^3$.

**Table 1** Pseudo-first-order kinetic constant (k'), Electrical Energy per Order ($E_{EO}$) Electric Energy consumption (EE) of the Carbamazepine, Diclofenac, and Sulfamethoxazole.

| PC | $c_i$ | $c_f$ | Removal efficiency (1) | Trophic level (2) | k' | $E_{EO}$ | t | $E_E$ |
|---|---|---|---|---|---|---|---|---|
| | ng/L | | % | | (min$^{-1}$) | kWh/m$^3$.order | min | kWh/m$^3$ |
| Carbamazepine | 567 | 23.0 | 96 | algae | 5.25×10$^{-3}$ | 1.71 | 611 | 2.38 |
| Diclofenac | 4502 | 2318 | 49 | *Daphnia magna* | 5.42×10$^{-3}$ | 1.66 | 122 | 0.48 |
| Sulfamethoxazole | 341 | 168 | 50 | *Daphnia magna* | 3.75×10$^{-3}$ | 2.40 | 187 | 0.73 |

(1) Removal efficiency required for the achievement of "low" risk; (2) Trophic level that required the most severe removal efficiency for achieving an RQ < 0.1.

Finally, the comparison of the results obtained with the requirements of the Swiss regulation suggested that a removal rate of 80% does not guarantee the achievement of "low" environmental risk for some of the detected PC, such as carbamazepine and caffeine. The minimum removal efficiency required for guaranteeing the absence of harmful effects in the environment must be tailored regionally, according to the local peak concentrations of the site-specific PC, keeping into consideration the specific conditions of the receptor water body.

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# On the use of machine learning algorithms to model and reduce energy costs of water supply systems

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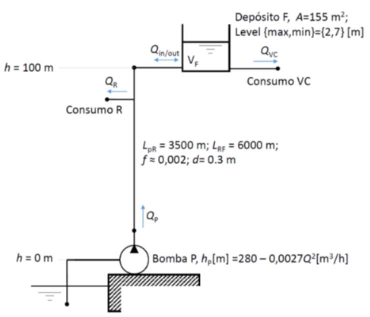
**Abstract:** Providing water in adequate quantity, quality, and pressure to the entire population has been one of the challenges of human history. Being critical systems to the society, water supply systems (WSS) have focused on the effectiveness of transporting water to all homes and industries, not giving due importance to energy costs resulting from this process. However, with the continuous population growth in recent years and the consequent increase in water demand, it has become essential to optimize the system [1]. Currently, in the majority of the WSS, pumps start when the tanks reach the minimum, and switch off when the maximum value is reached. This operation is inefficient, as it does not consider the energy cost tariffs variations throughout the day nor any water demand forecasting. However, to predict the most efficient operation of WSS and considering that these are critical systems, it is necessary to model and calibrate these systems. However, even using well-recognized hydraulic simulators, the calibration of these models can be cumbersome. Much of this difficulty is due to pre-established formulations, which do not present enough flexibility to real data.

In this work, a possible solution to the problem is presented using machine learning methods for simulating water supply systems and subsequently optimizing the system to ensure an optimal operation of the pumps, resulting in the lowest possible energy consumption and subsequent cost reduction. For this, two algorithms with different architectures are used: artificial neural networks and a decision tree-based algorithm (XGBOOST). Two different models are also tested: a differential and total time-updated model.

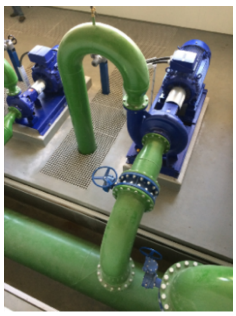
**Keywords:** Water supply systems; Machine learning; Reduce operational costs.

## Case studies and results

In this work, two case studies will be used to demonstrate the application of machine learning in the modeling and cost efficiency of WSS: the Fontinha system and the Richmond benchmark. The Fontinha system is illustrated in Figure 1 and further details can be seen in [2]. The Richmond water system is a well-known benchmark for the analysis of hydraulic systems and a scheme of this system can be seen in Figure 2.




(a)



(b)

(c)

Figure 1 (a) Schematics and (b-c) equipments/sensors of the Fontinha case-study.

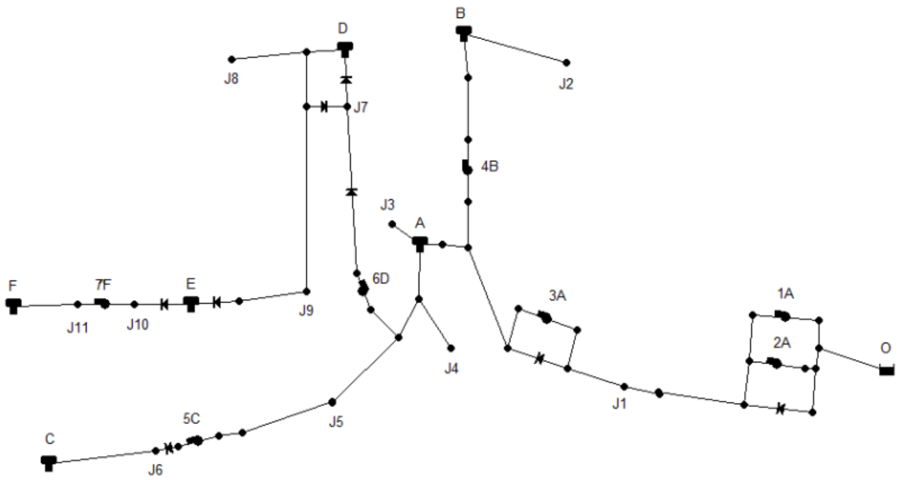



Figure 2 (a) Schematics of the Richmond.

For both models, virtual water syppply systems were used as reference for training the ML models. Random operations and time increments were created as data-base for training. Different architectures and algorithms were used, however, artificial neural networks and a decision tree-based algorithm algorithm (XGBOOST) seemed to produce the most promising results. The Keras ML library was used. Considering that the goal is to model hydraulic (flow rates and water levels) and energy (pump power) characteristics of the system, these were used as features, as can be seen in Figure 3.

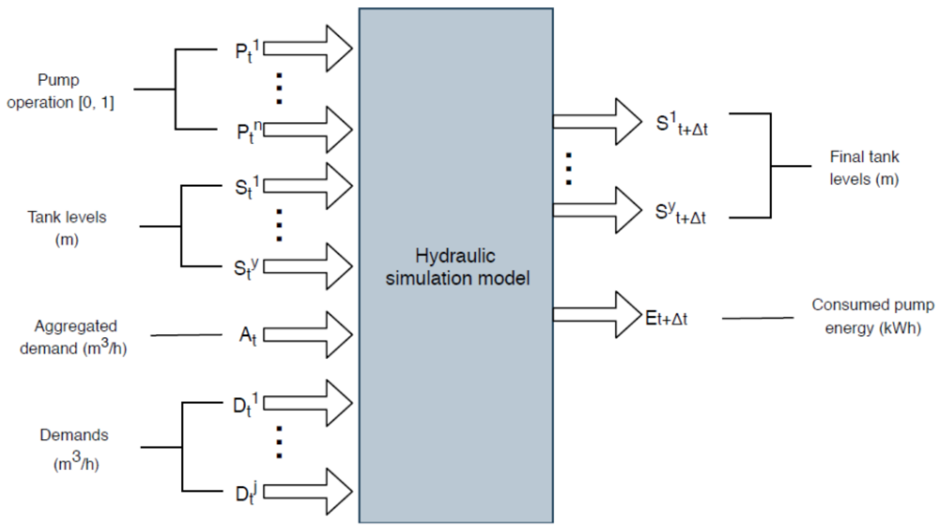



Figure 3 Representation of the input-output features of the model.

Figures 4 and 5 illustrate some results obtained using machine learning, validating the technique in comparison with the conventional hydraulic modeling. Figure 4 present the power prediction using the XGBOOST model. As can be seen, the prediction of the energy feature is quite well. Figure 5 present the comparison between the hydraulic simulator EPANET and the ML model produced in this work. Altough some differences can be observed, the overall results are good, validating the developed model.

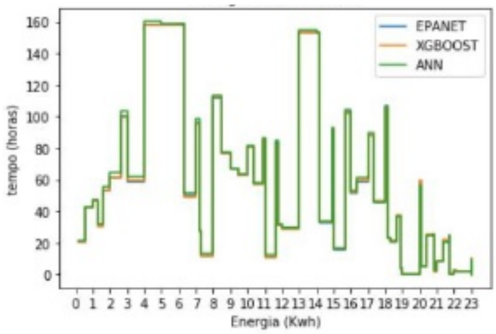



Figure 4 Machine learning results for time prediction and comparison of different approaches for the Fontinha case-study.

## Conclusions

Diferent architectures for a ML model were developed during this work and, particularly the features definitions. It was observed that the time, and consequently the time increment, has a large influence on the model and its training. This fact has given advantage to the differential ML model, in which the outputs are rate values.

The advantages of ML models in comparison to classical hydraulic models were presented and discussed in this work. These models do not require cumbersome calibration tasks and can be used to solve pump scheduling problems and reduce energy costs of water supply systems, as shown in Figure 6.

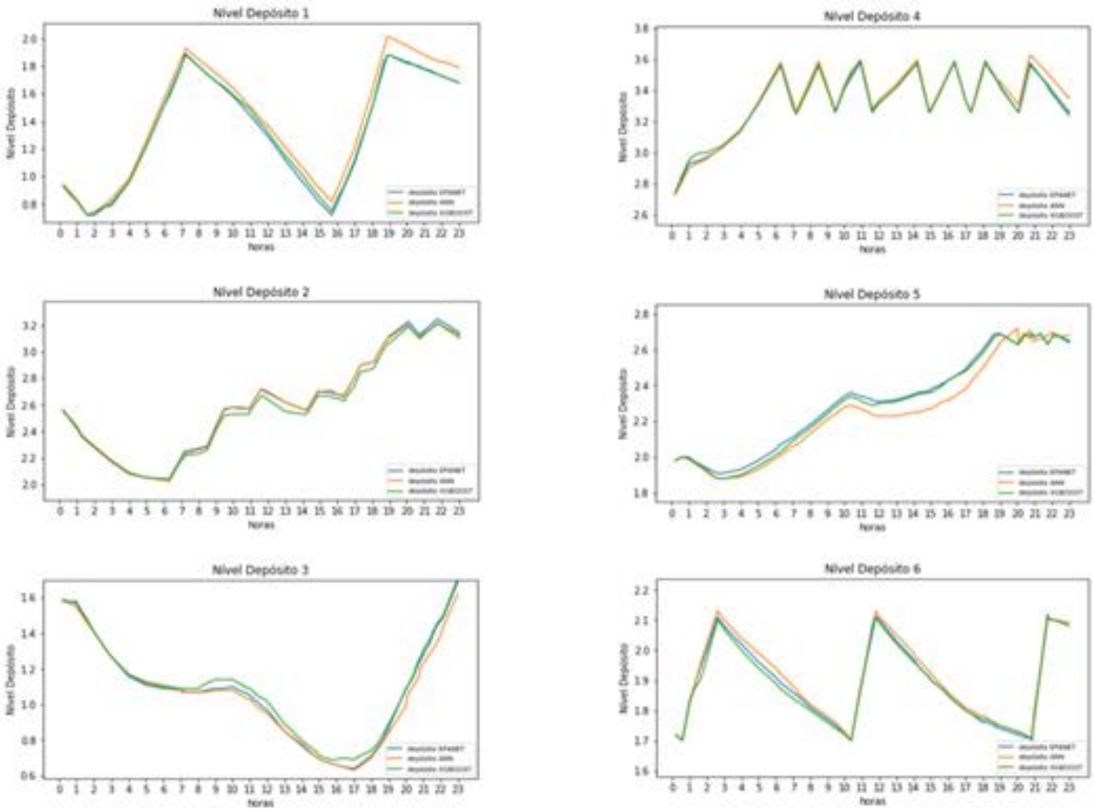


Figure 5 Machine learning results for the Richmond case-study. Comparison with the hydraulic simulator EPANET.

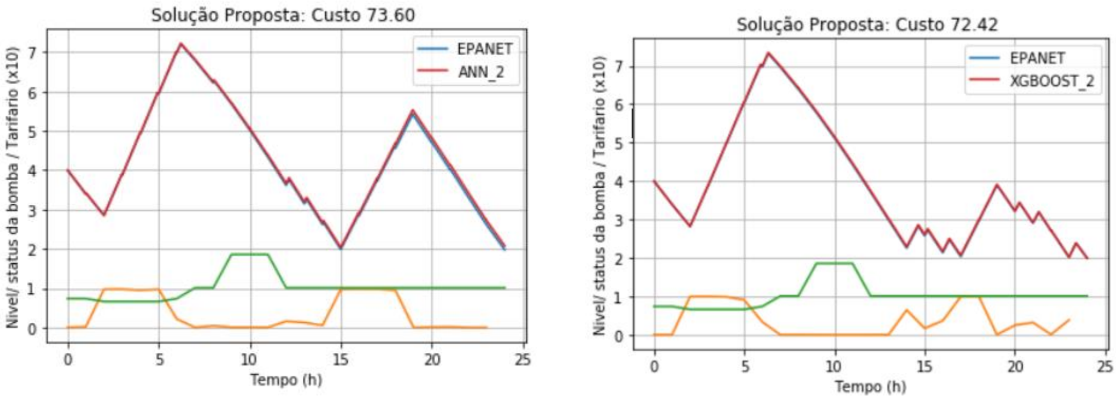



Figure 6 Machine learning model used together with optimization techniques to obtain the most efficient pump schedule for the Fontinha case-study. Comparison with the hydraulic simulator EPANET. (a) The use of a ANN and (b) XGBoost ML model to reproduce the behaviour of a single pump-tank water supply system.

**Acknowledgments**

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# Optimal number and location of pressure sensors in water distribution networks using a multi-objective optimization methodology

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**Abstract:** The current paper presents a practical application of a multi-objective optimization methodology to determine the optimal number and location of pressure sensors in a real water distribution network. An optimization problem is formulated with two objective functions and solved for different number of sensors, providing the optimal locations of pressure sensors. Results are used to characterize the total benefit of installing different number of pressure sensors using a quality indicator, namely the Hypervolume. Finally, the optimal number is determined by analyzing the variation of the Hypervolume with the number of sensors.

**Keywords:** Multi-objective; Pressure sensitivities; Pressure sensors.

## Introduction

Pressure data plays an important role in the real-time monitoring of water distribution networks by water utilities. It is widely used in the calibration process of hydraulic models [1,2] and by pipe burst detection techniques [3,4]. The number of installed pressure sensors is usually limited due to budget constraints. Therefore, the number and location of these pressure sensors should be optimally defined in order to maximize the total benefit.

Over the past decades, some methodologies based on different principles have been developed to optimally locate pressure sensors in water distribution networks [5,7]. In a smaller scale, some methodologies also provided the optimal number of sensors to be installed [8]. Nonetheless, most of these techniques were applied to the context of synthetic networks and have not been tested for real complex networks.

This paper presents a practical application of a multi-objective optimization methodology to determine the optimal number and location of pressure sensors in a real water distribution network. The methodology is applied to a real water distribution network located in Lisbon's metropolitan area, Portugal.

## Methods

The general framework of the methodology is depicted in Figure 1.

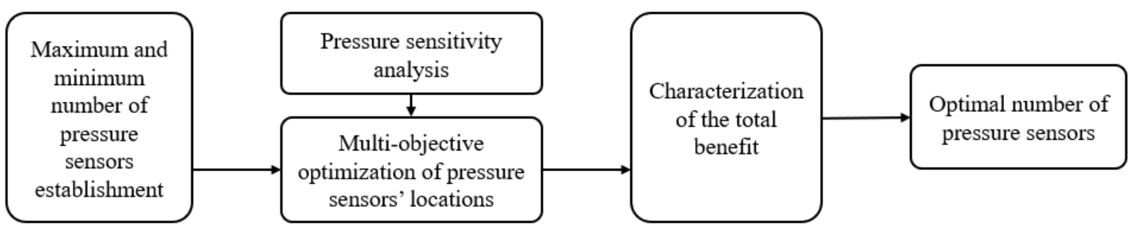



Figure 1 General framework of the methodology.

The maximum possible number of sensors in the network should be firstly established, for instance, based on the size of the water distribution network or on the number of possible locations. It is assumed that the minimum possible number of sensors is one. These limits define the range of values in which the optimal number of sensors will be searched for.

Then, a multi-objective optimization problem is formulated and solved for each number of sensors in the previously defined range, providing the optimal combinations of sensors (i.e., optimal locations) for each number of sensors. By considering two distinct objective functions, the locations of pressure sensors are optimally defined in such way that maximize the nodal pressure sensitivities to both pipe roughness coefficient variations (f1) and pipe burst events (f2). To this end, a pressure sensitivity analysis [9] should be previously carried by assessing changes in nodal pressure-head due to variations in both pipe roughness coefficients and pipe burst (simulated using an emitter coefficient).

The characterization of the total benefit of installing each number of sensors is not a trivial task. Since two objectives are considered, the benefit of each combination of sensors is described by two distinct values. Due to the trade-off between considered objectives, multiple optimal configurations might exist for the same number of sensors and, thus, Pareto Fronts are obtained. The Hypervolume indicator [10] is used to quantify with a single value the total benefit associated to each number of sensors.

The optimal number of pressure sensors is determined by analyzing the relationship between the total benefit (characterized by the Hypervolume) and the number of sensors. Since the marginal benefit decreases when considering additional sensors, the optimal number is defined as the "knee" of the Hypervolume curve. Finally, a "knee" detection technique based on the works of Satopaa et al. [11] is used to determine this optimal number of sensors.

## Case study results

The case study is a real water distribution network located in Lisbon's metropolitan area, Portugal, and serving a total population of about 14,000 inhabitants. The distribution network is about 36 km long, with about 2,180 service connections. The hydraulic simulation model includes a storage tank, 967 pipes and 1,261 nodes.

A pressure sensitivity analysis was carried by considering a variation on the Hazen-Williams's pipe roughness coefficient of 20 and by generating a burst of fixed size for every node of the hydraulic model with a single emitter coefficient of 0.2 (leading to an average burst of 1 m3/h).

The minimum and maximum number of sensors were defined as 1 and 20, respectively. The multi-objective problem was formulated and solved twenty times using the NSGA-II algorithm [12], one for each number of sensors between 1 and 20. Every node of the model was considered as a possible location for installing the pressure sensors. The obtained results are presented in Figure 2. The obtained Pareto Fronts are depicted with different colors. Each dot represents a possible combination of a given number of sensors between 1 and 20.

The Hypervolume indicator is calculated for each Pareto front, leading to a single value for each number of sensors. This value characterizes the total benefit of installing each number of pressure sensors and is presented in Figure 3(a). Note that the marginal benefit decreases when considering additional sensors.

As previously referred, the optimal number of pressure sensors is defined as the "knee" of the Hypervolume curve and is detected using the technique presented in Satopaa et al. [11]. The method works by assessing the point of maximum curvature, leading to an optimal number of eight pressure sensors, as depicted in Figure 3(a).

Once the optimal number of sensors is defined, an optimal configuration can be chosen from the Pareto front related to that number of sensors. Figure 3(b) presents a possible optimal configuration of 8 sensors highlighted in white circles.

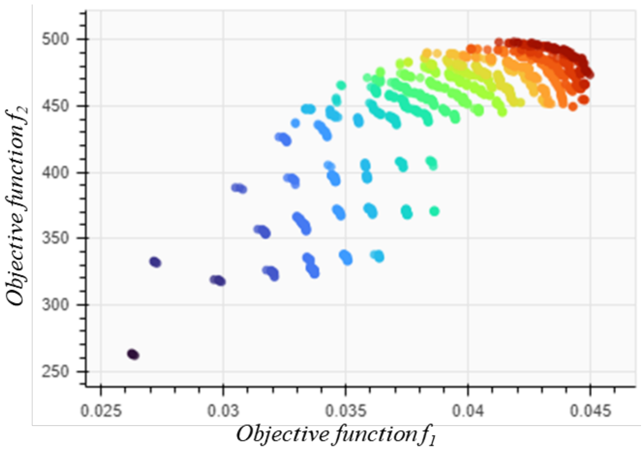
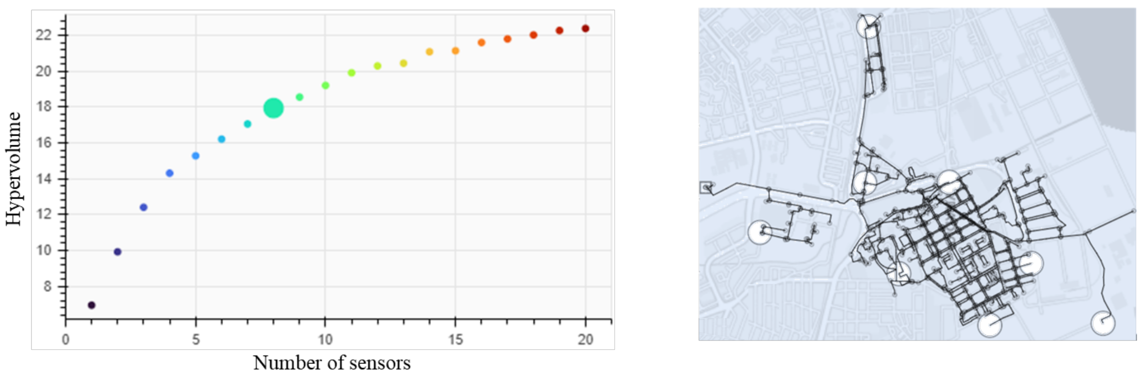



**Figure 2** Obtained Pareto fronts.




(a) (b)

**Figure 3** (a) Hypervolume for the different number of sensors and optimal number of sensors identification; (b) Optimal location of the pressure sensors.

## Conclusions

This paper presented a practical application to a real water distribution network of a methodology to determine the optimal pressure sensors number and its location.

The methodology can be easily applied and provide robust solutions of sensor locations for an optimal number considering real-time monitoring. This real-time monitoring should consider at least the two-objectives of pipe roughness calibration and pipe burst or leakages detection. The former is important to ensure a continuous calibration process with real-time measurements of the hydraulic model. Such model will be used to detect and to locate pipe burst events.

As such, two distinct objective functions were formulated, maximizing nodal pressure sensitivities to both pipe roughness coefficient and pipe burst events. This ensures that pressure sensors are optimally located to generated pressure-head data to be used in the calibration of the hydraulic model and for pipe burst detection. Furthermore, a quality indicator, the Hypervolume, was used to characterize the total benefit of installing a given number of pressure sensors with a single value. The optimal number of sensors is found by assessing the evolution of the quality indicator as a function of the number of sensors.

Finally, the results demonstrate the importance of using tools, such as optimization techniques, to help water utilities addressing real-life problems, which are often be too complex to be solved solely by engineering judgment. The use of such tools allows utilities to explore a higher number of solutions and, ultimately, increase the benefit of installing pressure sensors. Nonetheless, the experts' judgement is crucial for the correct use of such tools, not only in the problem formulation, but also for in the critical analysis of the obtained results .

## Funding

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# Prioritization method based on risk in a Water Supply System

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**Abstract:** Based on the abundant availability of data, namely the data characterizing the company's assets, the intention is to develop a decision support methodology, which enables the prioritization of a list of actions, previously elaborated. The prioritization methodology uses one Multicriteria Decision Analysis method (MCDA) called Simple Additive Weighting (SAW), and it will be based on the level of risk related to each asset. The theme of risk and its management is a fundamental criterion of asset management, which enables the various decision-makers to be supported.

**Keywords:** Prioritization; Risk; Decision making.

## Introduction

Asset management is a critical area regarding corporate management and has been increasingly valued. All kinds of decisions related to asset management (maintenance, rehabilitation, decommissioning, etc.) should be based on an adequate evaluation of alternatives taking into consideration three fundamental criteria: the costs, the benefits over the asset´s life (performance), and the achievement of an acceptable level of risk [1]. Decision-making is intended to be informed, prioritized and the result of weighing up different alternatives. [2]. Considering the three criteria mentioned above, it will be possible to develop a holistic, integrated, and structured approach to maintaining, updating, and operating physical assets, contributing to improved processes and the company´s overall value and assets

The Portuguese water utility *Águas do Douro e Paiva S.A*. (AdDP) manages a water supply bulk system, responsible for the abstraction, treatment, and distribution of water to the reservoirs of 20 municipalities located in the Porto region and partners of AdDP. The system supports a public consumption of around 1.7 million inhabitants, covering an area of 2.715 km$^2$. Bulk systems are composed of a wide range of infrastructures, that include components for the abstraction, treatment, and water storage, such as Water Treatment Plants (WTP), Reservoirs, Pumping Stations, and Pipelines [3].

The considerable size of the flows treated, and the essential nature of the service provided reinforce the absolute need to guarantee high-performance standards. The multiplicity and complexity of facilities and equipment also means that AdDP permanently has many actions that it intends to implement. The technical and time constraints associated with each action, and the inevitable limitation of the financial resources available at any given time, demand particular attention in identifying which actions are of real interest to be implemented. Assessing and quantifying the impact that each action may represent in altering or maintaining the value of the company's assets is the question that arises.

## Methodology

The company AdDP has abundant data records regarding the level of risk of the assets that make up its water supply system. Data organization, analysis and visualization processes are fundamental for supporting decision-making. Using Microsoft Power BI, dashboards were created to visualize the data on asset risk levels and thus contribute to knowledge acquisition.

To prioritize the list of actions considered, the following methodology was developed, consisting of the steps:

1) Analysis and validation the set of actions to be prioritized.

2) Defining and weighting the criteria.

3) Characterization of the actions according to the established criteria.

4) Applying of the multicriteria method.

5) Adjusting the priority levels.

### 1) Analysis and validation the set of actions to be prioritized

The asset management system implemented in AdDP allows, among others, to identify several actions of direct intervention in its assets or others that, despite not doing it directly, enable the creation of value from them to the organization.

Several actions are detected during routine inspections of assets and include, for example, improvements in terms of technical and geographical registration of assets, whose implementation does not impact asset risk management, but are important for asset management on a day-to-day basis. These types of actions will not be considered in the work presented here.

Thus, firstly, a rigorous reading of the company's set of actions is required to consider those that can improve the current or future performance of the asset or impact its level of risk.

Thorough knowledge of the risk assessment implemented in the organization is required to perform this step effectively.

### 2) Defining and weighting the criteria

To develop a prioritization methodology, it was necessary to establish prioritization criteria. The first criterion relates to the level of risk of the asset, a value that can vary between 1 and 25. The action´s priority is directly related to the risk level of the associated asset. The higher the level of risk of the asset, the higher the priority of the action. The second criterion relates to the capacity of reducing the risk level of the associated asset, the value of which may vary between 0 and 24.

Once the criteria have been defined, the weight associated with each one must be estimated. With the company´s support, a weight of 60% was defined for the criterion "Level of Risk" and 40% for the criterion "Capacity to Decrease the Level of Risk". The weighting attributed values actions whose associated assets have a high level of risk. It is considered preferable to carry out actions capable of reducing, even slightly, the level of risk of high-risk assets, rather than reducing, the risk level of risk of low-risk assets.

Table 1- Defining and weighting the criteria

| Criteria | | |
|---|---|---|
| **Nº** | **Designation** | **Weight** |
| 1.º | Level of Risk | 60% |
| 2.º | Capacity to Decrease the Level of Risk | 40% |

3) Characterization the actions according to the established criteria

Before the characterization itself, it is necessary to specify each action about its location. Then, according to the risk assessment methodology used by the *Águas de Portugal* Group, it´s possible to correspond for each asset the respective risk of failure, and characterize each asset regarding the first criterion.

For assessing the second criterion, a detailed understanding of the impact of each action on the asset is required. A rigorous interpretation of each of the actions is then initiated, it is fundamental to understand in what aspect a given action acts in concerning to the risk.

To assist this analysis, inspection reports and risk assessments were consulted for each asset in question.

4) Applying the multicriteria method

Once the characterization of the actions is completed, which in this work covered 118 actions, the multicriteria method Simple Additive Weighting (SAW), is applied [4].

Some popular MCDA methods are ELECTRE (Roy, 1968), PROMETHEE (Brans & Vincke, 1985), AHP (Saaty, 1990), TOPSIS (Hwang & Yoon, 1981), VIKOR (Opricovic & Tzeng, 2004), among others. The advantage of the Simple Additive Weighting (SAW) is the proportional linear transformation of the raw data, which means that the relative order of magnitude of the standardized scores remains the same [4].

This method is considered immediate and consists of the following phases:

First phase: Construct the decision matrix.

The matrix is composed of 118 rows (one for each action) and 2 columns (one for each prioritization criteria), represented as follows:

$$X_{118\times 2} = \begin{bmatrix} x_{1,1} & x_{1,2} \\ \vdots & \vdots \\ x_{118,1} & x_{118,2} \end{bmatrix} \quad (1)$$

Second phase: Normalize the decision matrix.

Both criteria determined are benefit criteria, i.e., that priority is given to actions whose ratings are of higher value. Therefore, the normalized matrix is created by dividing each value present in the decision matrix by the maximum value existing in that column.

Third phase: Calculate the preference value of each action, according to the criterion established.

Fourth phase: Sort the actions in descending order of preference value and create priority thresholds.

5) Adjusting the priority levels

Given that we considered two criteria and the number of actions to be prioritized is relatively high (118 actions), many of them obtained equal preference values (i.e., were in the same priority level). Therefore, a "tie-breaker" was established between actions in the same priority level. After analyzing various alternatives, the following procedure was implemented:

- 1st Give preference to actions associated with assets of higher criticality.

If even so there are cases of a "tie", then:

- 2nd Give preference to actions associated with assets of worst functionality.

If even so there are cases of a "tie", then:

- 3rd Give preference to actions associated with assets with higher volume.

To automatize steps 4) and 5) of the methodology, a code was developed in Python considering any set of classified actions (input), a prioritized list is generated based on the risk (output).

## Results and Discussion

After analyzing the results obtained, some conclusions were made:

- The highest priority action is action 111 and refers to the rehabilitation of *Ramalde-Pedrouços´s* pipeline, whose risk level is 25 and the capacity to decrease the risk level is 24. It is estimated that the risk level will change to 1.
- Considering the first 10 actions on the prioritized list, 8 relate to reservoir interventions. In fact, reservoirs have a higher level of risk, and the interventions that concern them are related to state/condition assets improvements, which are quite effective in decreasing asset risk levels.
- There are 100 priority thresholds and, given that 118 actions were prioritized, it´s concluded that the small number of actions with equal levels of priority refers to the same infrastructure.

It was considered pertinent to compare the methodology developed in the project with the company's current execution plan. In this sense, the list of actions prioritized concerning the systems' Pumping Stations was compared with the prioritization proposed empirically by the asset management team.

This comparison showed that, overall, action priority levels were similar to those obtained in this project. However, many actions with the same execution scheduled date were found, despite being characterized at different risk levels and presenting quite different risk reduction capacity. In other words, the set of actions lacks effective prioritization.

## Conclusion

Prioritization models are a tool in the risk management context. Organizations do not have the capital, time, or resources to address all risks, and it is necessary to know how to prioritize them. With a model capable of prioritizing projects/investments, the risk of investing wrongly is reduced and the probability of success is increased. Global risk management is therefore truly important when it comes to the process of choosing and deciding which projects to execute. Therefore, global risk management is essential when it comes to choosing and deciding which projects to execute

Through this methodology, organizations make decisions based on risk management, managing the overall risk associated with their assets in a more robustly way.

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# Probabilistic Intraday Wastewater Treatment Plant Inflow Forecast Utilizing Rain Forecast Data and External Flow Measurements

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**Abstract:** Energy efficiency of wastewater treatment plants can be further improved by using forecasts of wastewater inflow, supporting the implementation of proactive control schemes and clarifying the need for structural changes for appropriate handling of precipitation events. Here, especially the prediction of days with rainfall is still challenging. In this research, a seasonal probabilistic time series model is proposed for modeling the intraday wastewater inflow accurately, especially in case of rain events. Rain forecasts as well as data from sensors inside the sewer system are incorporated as exogenous variables. Non-linear effects are approximated by piecewise linear functions, accounting for the flow-rate dependent temporal correlation structure of precipitation quantity. The model is applied to and evaluated on quarter-hourly data from two German wastewater treatment plants of different size.

**Keywords:** time series analysis; wastewater treatment; inflow forecasting

## Introduction

Increasing availability of internal and external data allows to further improve the efficiency of wastewater treatment plants. In recent years, forecasts of the intraday wastewater inflow into a wastewater treatment plant have been proven to be of high value to practitioners, enabling smoother operation of treatment processes. In particular, the prediction of inflow patterns arising from future rainfall can provide valuable information for enhancing the energy efficiency of the wastewater treatment process, enabling the implementation of proactive control schemes [1,2,3]. Furthermore, support for decisions on structural changes to improve the handling of heavy precipitation events associated with climate change can be provided. However, it has been shown that especially the prediction of days with rainfall is still challenging [4].

In order to utilize inflow forecasts efficiently within the scope of existing control structures at wastewater treatment plants, the ability to quantify the underlying uncertainty is crucial [1,2].

In case of dry weather periods, the inflow rate measured at the wastewater treatment plant is dominated by daily seasonal patterns. Flow and water level measurement data from inside the sewer system can provide information on non-seasonal effects. Each sensor provides information on the effect of the wastewater discharge throughout the respective sewage water catchment area for a time horizon of at most the dwell time with respect to the sensor's position [5].

In case of rain events, vastly increased flow rates result in a significant decrease of dwell time [5], so that the exogenous variables only provide information for an insufficiently short forecasting horizon. To realize a sufficiently long forecast horizon and suitable accuracy, precipitation forecast data can be utilized.

Whereas the propagation of wastewater throughout the network at low flow rates, where dwell-times are approximately constant, is reflected well by the lag structure of an autoregressive model, non-linear effects arise from the sewer system's hydrodynamic properties as flow rates increase. Beneath flow rate dependent dwell times, water can be buffered and removed from the system by detention basins if the sewer system's hydraulic capacity limit is reached.

An exemplary time series of inflow with the corresponding measurement data of rain is shown in Figure 1b and 1d. As it can be seen, the inflow remains at a high level even hours after the rainfall event has occurred.

## Dataset

The research has been performed on datasets from two German wastewater treatment plants. The data covers the years 2017 to 2019 with a frequency of 15 minutes. The dataset consists of the wastewater treatment plant inflow measurement, rainfall depth measurement from a location within the sewage water catchment area and water level and flow sensor measurements from multiple locations spatially distributed throughout the sewer system. In addition, series of rainfall radar raster images covering Germany with a sampling frequency of 5 minutes, provided by the DWD opendata service [6], are used to construct rainfall forecasts.

## Methodology

We propose a linear seasonal probabilistic time series model to estimate the time-dependent complete predictive distribution of wastewater treatment plant inflow.

Using the framework of Generalized Models for Location, Scale and Shape (GAMLSS) [7], the Probability Density Function is modelled as a Johnson's SU distribution (JSU) [8]. The distribution's parameters are conditioned on the past plant inflow, measurements from sensors in the sewer system, historical rain measurements and rain forecast data.

The distribution's parameters are formulated as a sum of seasonal effects and an autoregressive process, incorporating the effects of the exogenous variables. A piecewise linear approximation of the system's non-linear effects is realized using linear splines for each regressor, representing distinct sets of lags for different value ranges. This way, flow-dependent dependency structures caused by flow-dependent dwell times, hydrodynamic and buffering effects of water throughout the system are represented.

Rain forecast data was constructed by spatial summation of values near the sewer system's location in forecasts of raster radar data. Our simple baseline radar forecast was obtained by temporal extrapolation of movement in the radar raster data using the Robust local optical flow algorithm [9], in analogy to the RADVOR forecasts of Deutscher Wetterdienst [10]

Lasso Regularization [11] is utilized for feature selection and regularization during parameter estimation to account for the high-dimensional parameter space.

## Results

We calibrated the model using data from a time window of two years and performed out-of-sample forecasts with a forecast horizon of 150 minutes for the following six months.

To investigate the influence of thresholding and the incorporation of external measurements as well as rainfall forecast data on the prediction accuracy, we calculated Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Energy scores (ES) and Pinball scores for different sets of exogenous variables and thresholds. RMSE and MAE assess prediction accuracy regarding the mean and median, respectively, and the Energy and Pinball scores represent strictly proper probabilistic evaluation measures, assessing the predictive distribution [12]. Statistical significance of model performance differences was evaluated using the Diebold-Mariano-Test [13].

**Diebold-Mariano-Test [13].**

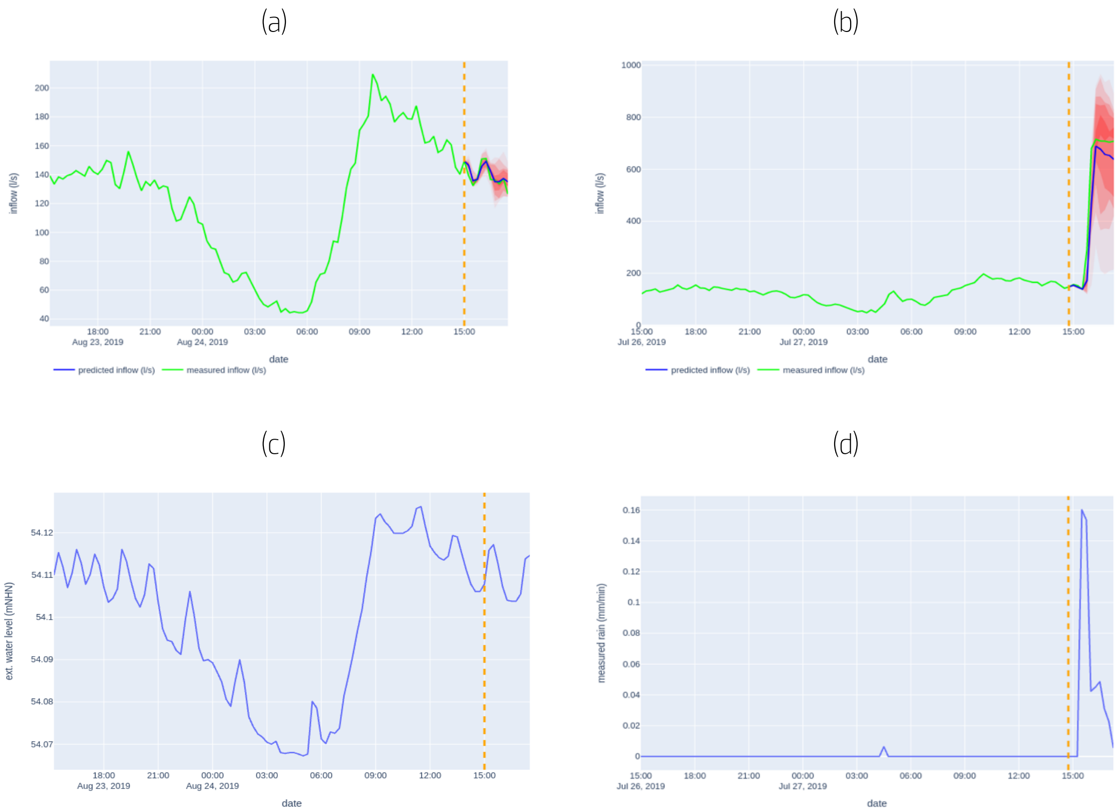


Figure 1: Inflow forecasts for a dry weather period and a future rain event. Red bands: Quantiles of prediction samples. The dashed line indicates the beginning of the forecasting time point. External flow

and historical rain data (right to the line) are not available to the model. (a) Inflow, dry weather; (b) Inflow, future rain; (c) External water level measurement, dry weather; (d) Rain measurement, future rain.

Our results indicate that forecasts without utilization of thresholds and exogenous variables show good reproduction of dry weather periods, where the process is dominated by seasonal and autoregressive effects of the inflow rate.

Utilization of exogenous measurements from within the sewer system leads to an increase of forecast accuracy by 14 % regarding the RMSE for dry weather periods, confirming that those measurements provide usable information on flow contributions that will arrive at the wastewater treatment plant (Figure 1a, 1c).

For the successful prediction of rising inflow after rain events, our results show that information on future rain is mandatory. The corresponding model, without using thresholds, yields an improvement over the model with flow and exogenous measurements of approximately 55 % regarding the ES. The transition from rising inflow to near-constant high inflow levels is not predicted accurately due to the non-linear behaviour. Here, using 10 threshold levels for all regressors to model the non-linear effects results in a further improvement of 45 % regarding the ES.

Benchmarks against a recurrent artificial neural network for different subsets of the data show equivalent performance, with statistically significant improvement especially after rainfall.

## Conclusion

We propose a probabilistic forecasting model for predicting wastewater treatment plant inflow. The forecasting model parameterizes the predictive distribution using a thresholded autoregressive exogenous process. In addition to external sensor data from within the sewer system, the influence of rainfall events is modelled by incorporation of historical rain measurements as well as rain forecast data. We find that integration of the external measurements improves the forecasting performance especially for dry weather periods. Significant improvement on prediction of rainfall-induced flow changes can be achieved utilizing rain forecasts. Here, flow-dependent non-linear effects can be approximated well using linear splines. However, the prediction accuracy depends strongly on the rain forecast quality. In conclusion, our results demonstrate that, using linear models, probabilistic wastewater treatment plant inflow forecasts can be produced with sufficient accuracy for application in future research on wastewater treatment process optimization.

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# Probabilistic short-term water demand forecasting with application in water storage optimization

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**Abstract:** Focusing on water storage optimization the prediction of the expected water demand allows to reduce energy costs, improve the energy efficiency, and better balance demand peaks to ensure a higher security of supply. Here, especially the control of pumps can be optimized by using the expected demand and the expected storage level as basis for decision making. However, in this context existing water demand forecasting models are rather inadequate as crucial properties as the underlying uncertainty are not sufficiently modelled.

In this research a high parameterized time series model is introduced, which allows for simulating the mean, the marginal properties, but also the correlation structure between hours within the forecasting horizon. Such complete probabilistic forecasts are of considerable relevance as they provide additional information about the expected aggregated demand, so that a statement can be made whether a storage capacity can guarantee the supply over a certain period of time.

**Keywords:** Probabilistic multi-step ahead water demand forecasting, storage optimization, path-dependencies, improving energy efficiency

## Introduction

The expected demand is crucial to control pumps more efficiently and to improve the balancing effect of storages. Hence, an adequate forecast of the expected water demand is needed to optimally control the given assets (e.g., storages and pumps). However, most water demand forecasts are not sufficient as the underlying uncertainty as well as the time dependency is not adequately considered to derive e.g., the expected water level in a water storage for the upcoming period.

Hence, the quantification of the underlying uncertainty and time dependence of future demand forecasts is of great importance as emphasized by [1]. In this regard, [2] noted that a distinction must be made between prediction uncertainty and emulation uncertainty. The former denotes the uncertainty associated with the natural variability of the true water demand process and describes the actual quantity of interest for practitioners. The latter denotes the uncertainty which arises and cascades within the data collection and modelling procedure (e.g., measurement/-data uncertainty, parameter uncertainty, or model structure uncertainty), as outlined by [3]. In contrast to prediction uncertainty, emulation uncertainty must be quantified but marginalized, so that the probabilistic forecaster issues only the expected natural variability of the true water demand process. Here, [2], and [4] have published promising approaches.

However, to date the need for modelling the correlation structure between single hours in a multi-step-ahead forecast has not been addressed. The same applies to the need for appropriate evaluation criteria, which should likewise be able to penalize errors in the mean, the marginal properties, and the correlation structure.

The practicality of providing a complete probabilistic multi-step-ahead forecast can be illustrated by the planning and management of storage capacities. Here, decision makers are interested in the aggregated demand, so that a statement can be made about the probability with which a water storage capacity can guarantee the supply over a certain period of time. This information forms the foundation to better balance demand peaks and to better schedule the pumping arrangements to take advantage of the electricity price structure.

**Model and estimation method**

To appropriately account for the high-dimensional complexity of the water demand process, the authors propose a model which is characterized by a huge feature space. However, by applying an automatic shrinkage and selection estimation method, the feature space can be tuned, so that a sparse, simple interpretable and fast computable forecasting model is obtained.

As inputs, the authors consider autoregressive effects, multiple seasonal patterns, and calendar effects. The proposed model can be defined as

$$Y_t = \mu(t) + \Phi(\mathbb{Y}_t) + \Psi(t, \mathbb{Y}_t) + \varepsilon(t) \,,$$

Whereby $Y_t$ is the water demand at hour $t$ and $\mathbb{Y}_t$ = (Y_{t-1}, Y_{t-2}, …) denotes the past realizations. The model contains a deterministic component $\mu(t)$, an autoregressive component $\Phi(\mathbb{Y}_t)$, a time-varying autoregressive component $\Psi(t, \mathbb{Y}_t)$ and a zero mean noise process, so that $\mathbb{E}$ [$\varepsilon(t)$]=0. The $\varepsilon(t)$ component accounts for the stochastic nature of the process, especially for the time-dependent variance structure.

To handle the proposed parameter space the authors, use the lasso estimator and its properties for handling huge feature spaces to obtain a parsimonious and efficient model. The lasso algorithm can distinguish between relevant and irrelevant features with the so-called selection ability. Moreover, the lasso algorithm is also able to weight the features in accordance with their explanatory power for the independent variable. This is denoted as the shrinkage ability. Hence, irrelevant features will be fully excluded, and less important features lose influence, as outlined by [5]. The lasso is the standardized version of the well-known ordinary least squares (OLS) estimator, extended by a penalty term.

**Probabilistic forecasting framework**

As noted by [6] the quantity of interest in probabilistic forecasting is the natural variability of the true water demand process and not the uncertainty arising and cascading in the modelling procedure. Based on this, complete probabilistic multi-step-ahead forecasts are constructed, which consider beside the mean and the marginal properties, especially the correlation structure between each issued hour $h \in H$, so that a joint distribution rather than a marginal distribution is issued. This implies that the expected water demand for a fixed forecasting horizon $H > 1$, can be seen as a multivariate random variable $\boldsymbol{Y} \in R^H$, where $\boldsymbol{Y}$ follows an unobservable distribution $G$ so that $\boldsymbol{Y} \sim G$.

To appropriately model the multivariate random variable $\boldsymbol{Y}$, ensemble forecasts reveal preferable properties. In the water demand forecasting literature, ensemble forecasts are commonly used, for example by [10] and [11]. However, these forecasts have predominately been applied to account for uncertainties arising in the emulation process.

In this research study, ensemble forecasts are used to model the prediction uncertainty. As forecasting horizon, $H = 24$ is chosen and an ensemble is created by recursively solving the corresponding forecasting model in a Monte-Carlo simulation with a total of $M = 1{,}000$ sample paths.

## Results and discussion

Besides the mean and the marginal properties is the dependency structure of probabilistic multi-step-ahead forecasts of considerable relevance with respect to time-dependent optimization problems in the field of water planning and management. For illustration, the proposed time series model and a manipulated version with assumed independent path dependency are considered. They are identical in the mean and the marginal properties but differ in the simulated path-dependency structure as displayed in the upper right corner of Fig. 1 and Fig. 2. It is obvious, that only the standard model simulation in Fig. 1 covers the true dependency structure of the water demand process reasonably well as shown on the right side of Fig.1 and Fig. 2. To verify the practicality, the water storage optimization as an actual operative management is considered. Here, decision makers are especially interested in the expected aggregated or cumulative demand, so that a statement can be made about the probability with which a water storage capacity can guarantee the supply over a certain period of time.

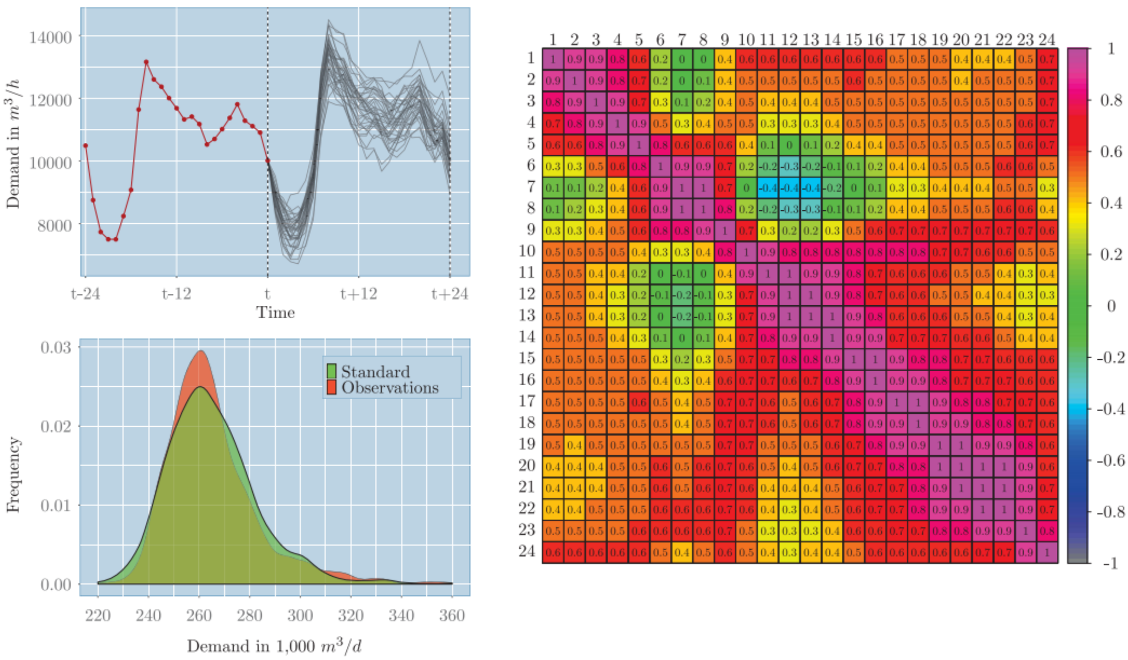


Figure 11: Illustration of standard model simulations, on the right side: the corresponding simulated 24 x 24 correlation matrix (lower triangular) in comparison to the true correlation matrix (upper triangular);

in the lower left corner: the density of the cumulative sample paths of simulated and true water demand; and in the upper left corner the simulated sample paths for an example day.

The impact of the dependency structure on the cumulative water demand is illustrated on the lower left corner of Fig. 1 and Fig. 2. Here, the density of the cumulative sample paths of each model simulation is compared with the true density of the cumulative water demand process.

Moreover, assuming a hypothetical water storage tank with a capacity of 290,000 $m^3$ and a considered time period of 24 hours, the actual expected probability for both model simulation versions is computed and compared with the true probability, as shown in Table 1. Here, the true cumulative water demand exceeds with a probability of 0.0935 the storage capacity within the corresponding 24 hours. The standard model simulation predicts a probability of 0.0934 and the independent model simulation a probability of 0.0000. Although both model simulations are simulated with identical mean and marginal properties, their expected cumulative water demand distributions differ distinctively.

**Table 2**:Probabilities that the true and the simulated cumulative water demands exceed the water storage capacity of 290,000 $m^3$ within a time period of 24 hours.

| Models | Standard Model Simulation | Independent Model Simulation | Observations |
|---|---|---|---|
| Probabilities | 0.0934 | 0.0000 | 0.0935 |

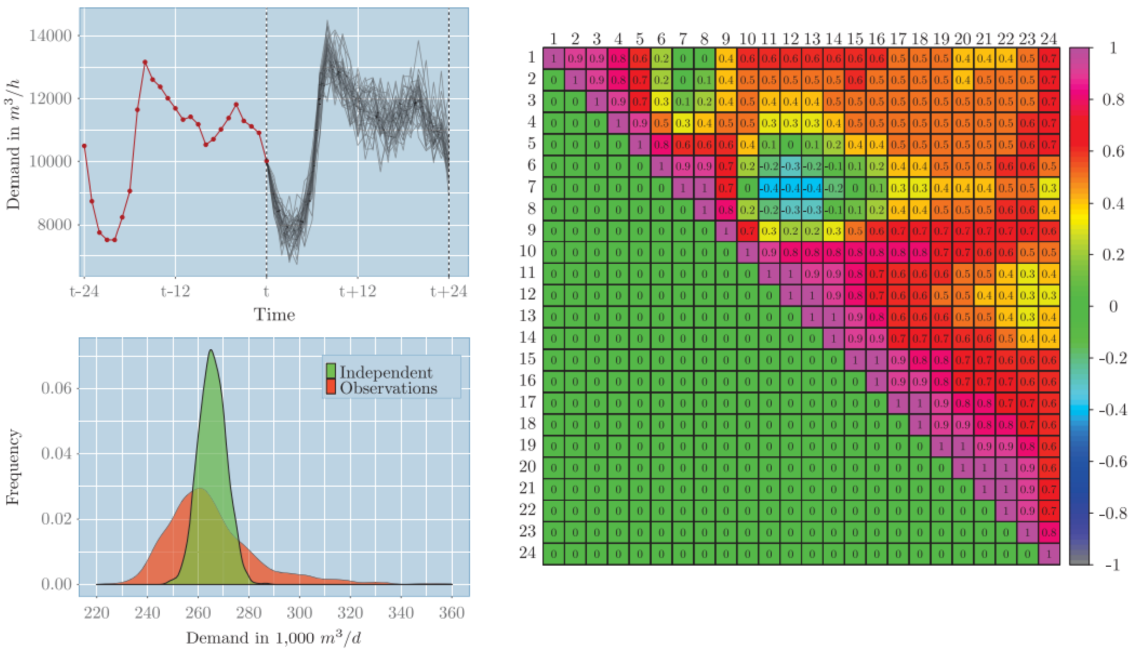


**Figure 12:** Illustration of independent model simulations, on the right side: the corresponding simulated 24 x 24 correlation matrix (lower triangular) in comparison to the true correlation matrix (upper triangular); in the lower left corner: the density of the cumulative sample paths of simulated and true water demand; and in the upper left corner the simulated sample paths for an example day.

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# Project risks influence on water supply and sanitation sectors' financing: a case-study on the World Bank database

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**Abstract:** Focusing on water storage optimization the prediction of the expected water demand allows to reduce energy costs, improve the energy efficiency, and better balance demand peaks to ensure a higher security of supply. Here, especially the control of pumps can be optimized by using the expected demand and the expected storage level as basis for decision making. However, in this context existing water demand forecasting models are rather inadequate as crucial properties as the underlying uncertainty are not sufficiently modelled.

In this research a high parameterized time series model is introduced, which allows for simulating the mean, the marginal properties, but also the correlation structure between hours within the forecasting horizon. Such complete probabilistic forecasts are of considerable relevance as they provide additional information about the expected aggregated demand, so that a statement can be made whether a storage capacity can guarantee the supply over a certain period of time.

**Keywords:** financing; risk; water supply.

## Introduction

Historically, it has not been easy to mobilize private sector investments in the water supply and sanitation (WSS) sectors. According to OECD [1], only 1% of the total private finance mobilized by official development finance interventions, between 2012 and 2017, occurred in this sector. This means that from the USD 157.2 billion mobilized across sectors, only USD 2.1 billion took place in the water and sanitation sectors.

According to Rees et al. [2], the achievement of a self-financing water and sanitation sectors, which are not so dependent on public budget funding and are able to attract finance (loan, bond or equity), faces practical barriers, such as lack of administrative capacity, opposition to rate and revenue raising, and lack of incentives for providers to embark on a financial reform process. Also, OECD [3], stated that the gap between current financing and future needs is due to a number of factors, such as: undervaluation of the water resource; insufficient cost recovery for investments due to water services underpricing; need for high initial investment followed by a very long pay-back period; difficulty to monetize the water management benefits, which undermines potential revenue flows; lack of analytical tools and data to assess and track investments; small dimension and specificity of water projects, which raise the transaction costs and hinders scaling-up; prioritization of bankable projects over the maximization of social and environmental benefits; and failure to support operation and maintenance efficiency.

However, it needs to be understood that financiers have diverse needs and expectations when investing in the sector. Different financiers will react differently to different types of barriers, since, according to OECD [3], financiers have different mandates, investment objectives, liquidity needs and risk appetites. So, similarly to any other type of project, in the WSS sectors, risks need to be identified and mitigation plans drawn, to attract commercial lending.

Risks can occur in a variety of forms. They can be political, regulatory, macroeconomic, technical, and so on. Thus, risk mitigation is a concern, as excessive risk limits investments in public service infrastructures, which are extremely important both economic and socially [4].

This paper aims to understand how perceived project risks could be influencing the financing of the water and sanitation sectors, through the analyses of the risk profiles of all water and sanitation projects that were financed by the international financial institution World Bank since 2015 (the year the United Nations Member States launched the Sustainable Development Goals – SDGs – including the SDG6 dedicated to the clean water and sanitation sectors, with the main goal of ensuring the availability and the sustainable management of water and sanitation for all [5]).

## Methodology

The applied methodology aimed to identify, retrieve, and analyse data from all relevant projects that benefited from commitments from the World Bank which is composed of two institutions: the International Development Association (IDA) and the International Bank for Reconstruction and Development (IBRD).

It was retrieved, from the World Bank database, all the projects specifically from the "Water Supply" and/or "Sanitation" sectors, which had an "Active" or "Closed" status, were financed by "IBRD" and/or "IDA", and had been approved by the bank's board between January of 2015 and April of 2021. This allowed the retrieval of data from 185 projects.

The collected data was submitted to a systematic quantitative review, which enabled the determination of key aspects of the sample, such as: year of project approval; number of projects per region and country; the amounts committed (in USD) by each entity per project; the different types of risk ratings of the projects; and others. The data analysis of the collected projects allowed to draw parallels between the types of projects, the types of financing, the amounts disbursed, and the identified project risks ratings.

## Results

Through the data analysis it was observed that, between 2015 and 2020, the average number of projects financed annually by IBRD and IDA was, respectively, 11 and 20. In total, the number of projects approved for financing increased from 24, in 2015, to 37, in 2018, but decreased again in 2020 to 27. Also, it was found that in the first trimester of 2021, only one WSS project was financed, contrasting with the previous 5 years average of 10 projects approved in the first trimester of each year. The amounts committed each year and their decreasing tendency line can be observed in the following figure.

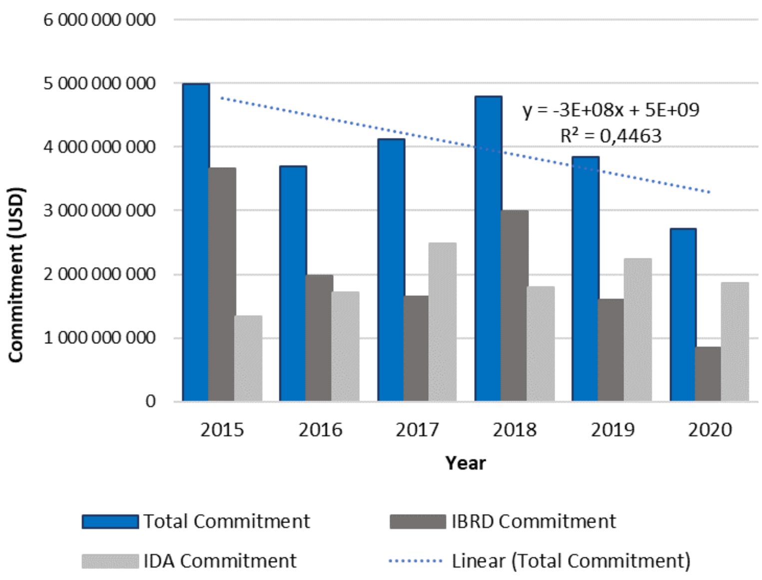


Figure 1 IDA and IBRD commitment from 2015-2020 (in USD).

The following figure shows the different types of risks that were identified and rated by the World Bank, during the 5 year period, in all the 185 projects. Through its analysis, for example, it is possible to observe that the World Bank has a higher tolerance for the "institutional capacity for implementation and sustainability" risk (from all the projects with this risk, 20% rated it high and 3% low), than the "macroeconomic" risk (from all the projects with this risk, only 11% rated it high and 16% low)

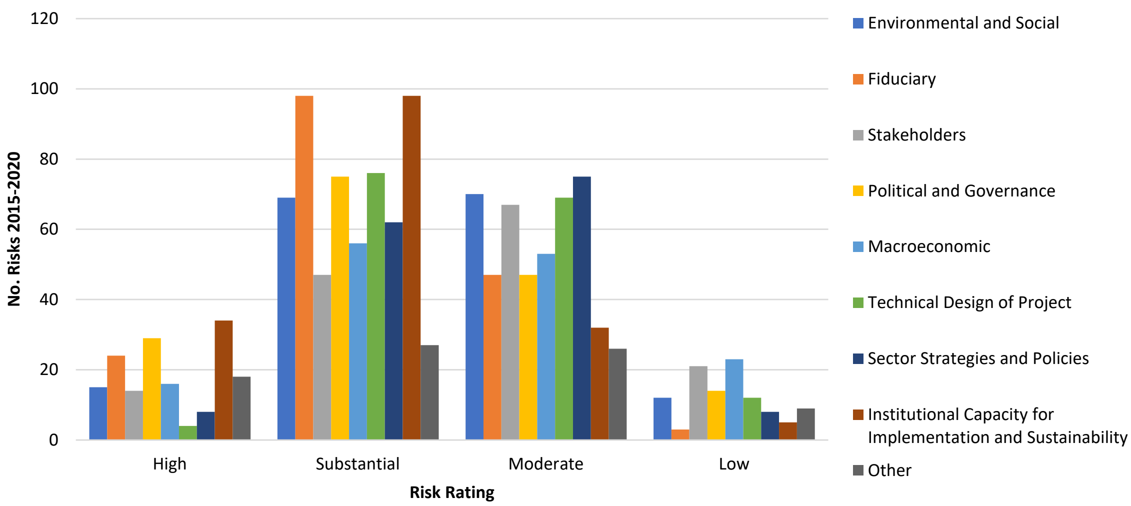


Figure 2 Identified risks per risk rating – 2015-2020.

The number of risks identified per rate, each year, are shown in the following figure. It can be observed that, while the amounts committed each year have been decreasing (as previously mentioned), the number of project risks rated as "high" and "substantial" has been increasing since 2015.

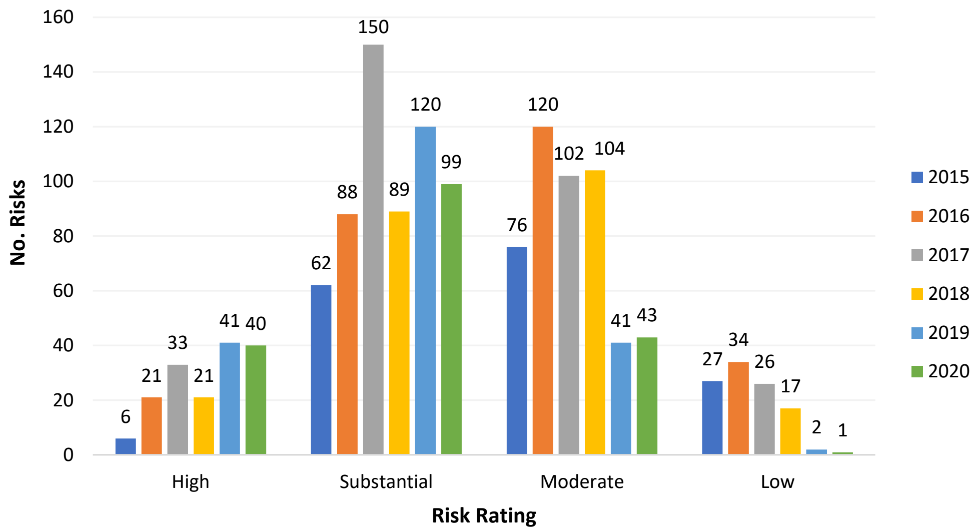


Figure 3 Annually identified risks per risk rating.

The overall risk profile of each project was also determined, which allowed, for example, the identification of the annually amounts committed by IDA and IBRD, for each of the four different types of project risk ratings, and, also, according to each of the three types of lending instruments (i.e. Development Policy Lending, Investment Project Financing and Program-for-Results Financing). In addition, it was also possible to create historic profiles, for each region and country (e.g. based on the number and types of projects financed, the type of lending instrument, the amounts committed, and the types of risks and risks ratings of the projects).

## Concluding Remarks and Next Steps

This paper contributes to the financing literature because it provides an in-depth analysis of the World Bank's WSS financed projects, since the launch of the SDGs, in 2015, while identifying the risk profile of the projects through the years and presenting parallels between different types of project risks ratings and the different lending instruments and amounts disbursed. This analysis is significant for borrowers and academia alike.

Moving forward, it would be interesting to assess the influencing power of the various types of risks that are measured in WSS projects, through the creation of a ranking, according to the capacity of each risk to discourage the financing of these types of projects, with the help of a panel of experts of financiers and borrowers.

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# Public-private partnerships – a risk approach in the water sector

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**Abstract:** This study provides a contribution on how public-private partnership arrangements can more efficiently address risk. The perception of risk management by different stakeholders is presented.

The results are based on semi-open interviews performed to public-private partnership experts. Literature suggested five risk categories, namely financial, context, technical and operational, commercial and infrastructure.

Twenty-five risk factors with high impact were established as a result of the semi-interviews. The top-five critical risk factors are related to political interference, no baselines for measurement performance, unfavourable global private investment climate, non-payment of bills and water asset condition uncertainty.

The traditional risk management approach in public-private partnerships contracts have space to improve. Study results supported that risk category context ranked first, nevertheless, emergent topics such infrastructure risk category are equally relevant.

**Keywords:** public-private partnerships; water sector; risk management.

## Introduction

Public-private partnerships (PPP) are a type of strategic alliance characterised by being long-term contracts signed between the public sector and a private party (finance and/or industrial contractor), with programmed payments over life as a consequence of the use of the facility by the public sector or the users of the facility [1]. It can be considered as the vehicle to perform complex infrastructure projects with flexible negotiation, maximizing efficiency and improving monitoring [2]. Evidences from the literature support that risk management in PPP contracts is a hot topic [3]–[6].

The risk assessment phase can include risk categories, risk factors identification, risk analysis, evaluation and critical risk identification [7], [8].

The purpose of the current study was to provide a comprehensive, holistic approach to risk management perception in PPP. More specifically, the present research focused on answering these questions:

1. What is the most relevant risk category?
2. How to mitigate the critical risk factors?

## Research design

The research design was based on a semi-open interview protocol and its results. The research method used in this thesis was a hybrid methodology: content analysis, narrative and semantic analysis. The semi-open interview protocol was designed and has already been successfully used in previous studies [9], [10].

## Results

Five risk categories were identified by using literature contributions and Word Clouds programme, data outputs, synonyms, antonyms and similar words were aggregated. This was performed based on visual observation. From 37 studies, totalling 158,801 words, the five identified risk categories (30,559) represent 19.24%. Five risk categories were identified: financial, context, technical and operational, commercial and infrastructure.

These previous results were integrated into the semi-open interview protocol. Experts provided their opinion regarding the possible risk factors (risk assessment phase) and risk treatment or mitigation measures for all risk categories. Results are presented allow to identify 25 risk factors (184 answers) and 38 risk treatment or mitigation measures (148 answers).

*Risk management aggregated results*

The risk categories that ranked higher were context with 53 (29%) frequencies and financial with 47 (25%) frequencies. Commercial ranked third with 35 (19 %) frequencies and in fourth and fifth with similar results ranked infrastructure with 25 (14%) frequencies and technical and operational with 24 (13%) frequencies.

*Critical risk factors*

The top five risk factors were identified, hereinafter referred as critical risk factors. Table 1 shows the critical risk factors.

Table 1: Critical risk factors

| Critical risk factors | Risk factor top frequency | Top risk category |
|---|---|---|
| Political interference | 26 | Context |
| No baselines for measurement performance | 19 | Commercial |
| Unfavourable global private investment climate | 18 | Financial |
| Non-payment of bills | 14 | Commercial |
| Water asset condition uncertainty | 10 | Infrastructure |
| **TOTAL** | **87[a]** | |

Note: [a]Total of 87 frequencies, from the initial 184.

The 'water asset condition uncertainty' risk factor emerges on fifth and is relevance was equally confirmed by scholars [11], [12]. Service targets of a PPP project can fail due to obsolete technology, equipment defects, and poor maintenance and asset condition [13].

The participants indicated 'the introduction of mandatory clauses in the contracts passing the responsibilities of the maintenance of the infrastructure to the private partner', 'the creation of mechanisms that allow an adequate registration of assets during the contract preparation phase' and '. . . mechanisms that allow an external evaluation of the accuracy of the infrastructure records' as possible mitigation measures for the critical risk factor. The 'water asset condition uncertainty' critical risk factor is closely connected to this thesis definition of the infrastructure risk category, which is the impact that a good or bad preservation and awareness of PPP assets can have in the success of the project's outcomes. The water infrastructure is complex to project, construct and maintain. It is characterised as having high sunk costs, and poor infrastructure management can have a relevant impact in the project's outcomes.

## Conclusions

The authors' results supported that risk management has space to improve. Risk management in PPP contracts is a compelling concern [14], [15]. From the initial five risk categories suggested by the literature, it was possible to allocate critical risk factors to all risk categories, except for the technical and operational risk category. The infrastructure risk category emerges has and less obvious category, were results showed that it there is space to improve, with the 'water asset condition uncertainty' critical risk.

Pro-poor measures, updated customers and assets databases, and the application of alternative collection solutions, such as pre-paid water meters, could emerge as possible solutions to address the 'non-payment of bills' and 'water asset condition uncertainty' critical risk factors.

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# Roadmap of the renewal of Vila Real WWTP towards energy neutrality

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**Abstract:** The main objective of this project is to increase energy efficiency and reduce operating costs by optimizing or changing its assets, promoting an increase in the sensing and automation of the Vila Real WWTP, in order to obtain energy neutrality. Energy neutrality is being developed in three stages: first to reduce energy consumption and then to increase energy production through biogas for self-consumption. Finally, achieving self-sufficiency in the installation with the integration of energy consumption control taking into account the instantaneous energy consumption and production capacities. Reducing the consumption of energy purchased from the grid as well as increasing the production of energy generated through biogas will be possible by turning this installation into a Resource Generating Unit towards energy neutrality.

**Keywords:** asset management; efficiency; energy neutrality.

## Business context of the project

The management of energy associated with asset management is one of the strategic priorities of the company Aguas do Norte, SA in the context of promoting levels of efficiency that guarantee the eco-efficiency and sustainability of the exploitation of its assets in relation to water supply and water sanitation. With more than 50% of the operating costs related to electricity consumption, the company is constantly studying new alternatives with the assumption of maximizing the energy use of its assets and the rationalization of consumption and aiming to improve its energy performance.

## Vila Real WWTP

The Vila Real WWTP treats effluents from the municipality of Vila Real city and some neighboring parishes. Dimensioned for a population of 84,321 inhabitants, the treatment line consists of the liquid phase, the treatment of sludge and, also, the treatment of odors and the reuse of treated water. It foresees the admission of an average flow of 12,281 m3 / d, with a peak flow of 1,208 m3 / h, it has tertiary treatment, thus complying with what is established in the Water Resources Utilization Title in force, in view of the rehabilitation / remodeling process occurred in the year 2010.

Figure 1 Aerial view of the entire extension of the Vila Real WWTP

The treatment line consists of:

· Liquid line: entrance work with harrowing and sieving, sanding / degreasing and primary decanting, biological treatment by Hybas process (plastic biosupport has been removed), with air supply by blowers, microtamming and disinfection by ultraviolet rays. The service water is used for cleaning and / or internal stages and made available for use by third parties.

· Sludge line: sludge treatment consists of gravity thickening of primary sludge, thickening tables for biological sludge, a mixture of these two types of sludge, anaerobic digestion and dehydration by centrifuges;

· Deodorization: the installation is equipped with a chemical washing deodorization system consisting of two washing towers with sulfuric acid, sodium hypochlorite and caustic soda. It also has an Activated Carbon deodorization system for Equalization Tanks.

**Motivation for project development**

The Vila Real WWTP was one of the first infrastructures of Águas de Norte (AdNorte) in the implementation of the Energy Management System by the standard NP EN ISO 50001: 2012 and has been certified since 2018. The Vila Real Wastewater Subsystem, where it is located including the WWTP, it was also one of AdNorte's first infrastructures in the implementation of the Asset Management System by the standard NP EN ISO 55001: 2016 and has been certified since 2019. The specific consumption of electricity, kWh / m3, is one of the most used indicators to measure the energy efficiency of an infrastructure, as it relates the consumption of electricity to the treated flow. [1]

Figure 2 Second view of the part of the Vila Real WWTP

**The path of energy neutrality**

With the implementation of the Energy Management System at the Vila Real WWTP as of 2017, the installation has gradually become more energy efficient, as shown in the table taken from the Energy Assessment of Energy Management:

| Year | TOTAL energy (kWh) | Volume collected (m3) | Specific Consumption in Treatment (kWh / m3) |
|---|---|---|---|
| 2017 | 2 167 407 | 2 252 321 | 0,962 |
| 2018 | 1 915 366 | 2 521 757 | 0,760 |
| 2019 | 1 774 451 | 2 638 095 | 0,673 |
| 2020 | 1 899 613 | 2 991 148 | 0,635 |

**Table 1** Evolution of the energy assessment of Vila Real WWTP energy management.

Since 2017, the energy management team and recently the asset management team have been implementing a modeling of the WWTP's operating conditions. In this 1st phase, it is noteworthy that the operating conditions were optimized without major investments by monitoring consumption in real time.

The circular economy is also promoted when the biogas produced in the anaerobic digestion of sludge is converted into energy for self-consumption. Through an Energy Assessment, the stages / equipment with significant energy uses (USE) were identified and the Energy Performance Indicators (IDE) were then defined. The objectives and goals were defined based on energy policy, legal requirements, USE and other opportunities for improving energy performance.[1]

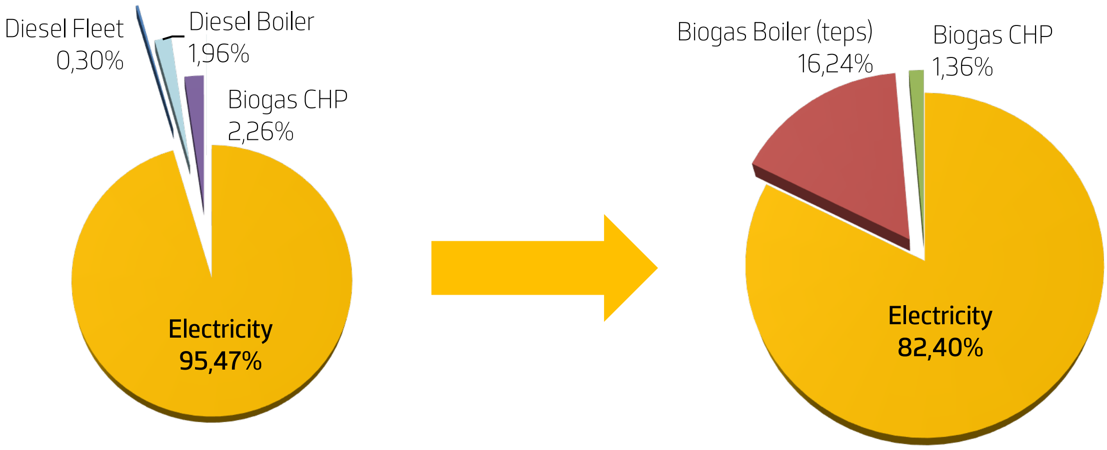


**Figure 3** Evolution of energy sources in Vila Real WWTP from 2018 to 2020

A set of actions were developed in the direction of the WWTP's energy neutrality. First, the plastic biosupport was removed alternately from each line of the biological reactors, with the repair of the air distribution network as well as the structural conservation of the tanks. In parallel, for examples, the potential of primary decantation was increased with the determination of ferric chloride upstream of this stage. The mechanical thickening was optimized by changing the polyelectrolyte, replacing screens and installing static mixers. The two digesters were cleaned and the state of the internal condition was evaluated, with surgical repairs. The thickening optimization resulted in changes in the quantity and concentration of primary and biological sludge, making it possible to progressively increase the production of biogas and decrease the amount of sludge produced. Energy production was restarted with the recovery of 2 cogenerators (CHP), currently corresponding to 10% self-sufficiency.

As a result of the actions that AdNorte has been carrying out with a view to fully optimizing the treatment of the WWTP, a consultancy was contracted with DHI- Water & Environment. The evaluations of this Danish consultant, through experts and the hydraulic-procedural simulator WEST, concluded that this facility is able to be energy self-sufficient, if a roadmap of surgical and sustainable investments is implemented, especially in the most demanding stages in terms of energy consumption and in the production / reuse of biogas. Thus, based on several studies for the implementation of various measures to reduce energy consumption and for energy production, the following objective was outlined:

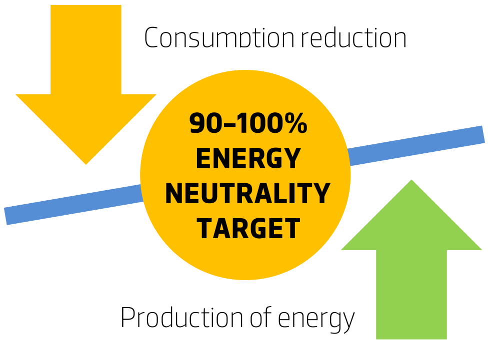


**Figure 4** Objective defined for the balance of measures between reduction of energy consumption and energy production

After the various phases of the project, it was concluded that it was technically and economically viable to increase the overall energy efficiency of the WWTP in Vila Real and, consequently, reduce the operating costs of the installation. In order to achieve the proposed objective, a roadmap of the new structural measures aimed at:

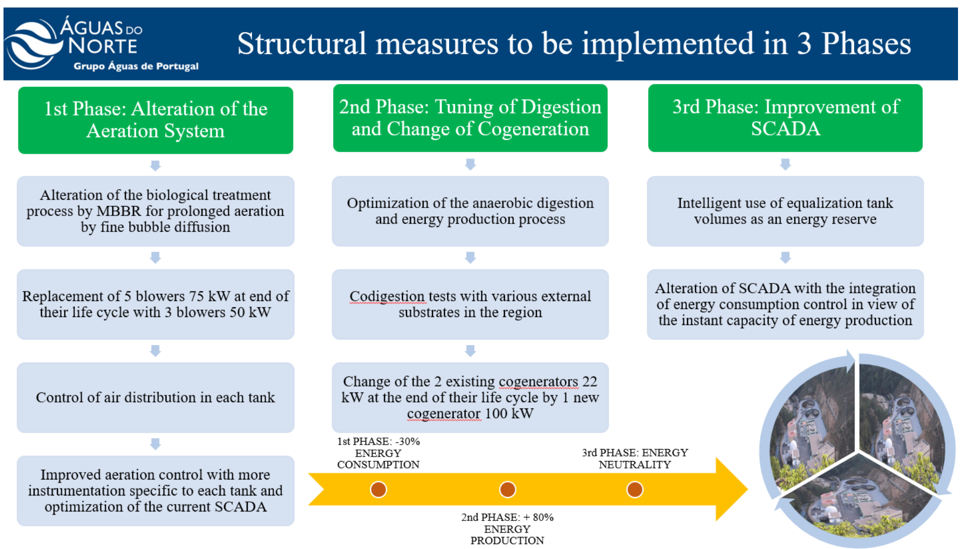


**Figure 5** Structural measures to be implemented in 3 phases at WWTP Vila Real

Reducing the consumption of energy purchased from the grid as well as increasing the production of energy generated through biogas will be possible by turning the WWTP into a Resource Generating Unit (UGR) towards self-sufficiency. The Energy Management Team made up of elements of energy management, operation and maintenance of the system as well as corporate sustainability is essential to the pursuit of the objective of neutrality. Knowledgeable, motivated, participatory and attentive teams of the process are the key to this challenging process.

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# SIGAME – an application that allows dynamic and always up-to-date knowledge of water supply and sanitation assets

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**Abstract:** Águas do Norte, a public water and wastewater utility, was in need of a better solution to keep the information of your assets up to date and reliable. With Esri's ArcGIS technology, the entity easily provided their employees with a solution to obtain better infrastructural knowledge of their assets. SIGAME application became the Águas do Norte's primary organizational tool for both internal and external (in the future) communication. The solution arises from the need for Águas do Norte to have an inventory of assets permanently updated, as its failure makes any asset management strategy that is to be implemented unfeasible.

**Keywords:** Digital Mapping; Collecting Data; Knowledge.

## Introdution

Águas do Norte had begun considering how it could help your employees to know their assets and provide tools that can contribute to the correction of gaps in information detected by them. We had heard about geographic information system (GIS) technology and knew that it was a strong tool for supporting an asset management program. The GIS needed to provide increased efficiencies, be affordable, and be of good quality. It also needed to be easy to use. Águas do Norte needed a tool that would support them now and into the future, which led to the decision of using Esri's ArcGIS.

Without updated information, it is impossible to implement any asset management strategy. Despite all efforts underway, namely the elaboration of work instructions and dedicated internal procedures, all of them with references to updating and inventorying any and all operational assets existing in Águas do Norte infrastructures, the entity recognizes the weaknesses of these processes, and for this reason, it provided employees with digital tools based on GIS for consulting and sending information about assets.

The solution provided is called SIGAME, to enhance the dynamic and updated knowledge of the assets and, above all, involve and hold people accountable for their contribution in the entire process.

## Solution

Águas do Norte implemented a SIGAME site through ArcGIS Enterprise. ArcGIS Enterprise allowed company to create a tailored web page experience for your users to help them share GIS data more easily. Águas do Norte Map Portal (https://sig.adnorte.pt/portal) is a collaborative platform that gathers geographic information (maps, applications and other diverse contents associated with assets). Home site has links for easier access a two different web apps for staff less familiar with

ArcGIS navigation. Each web app show information map, one dedicated to the network water supply and another to the wastewater sanitation network.

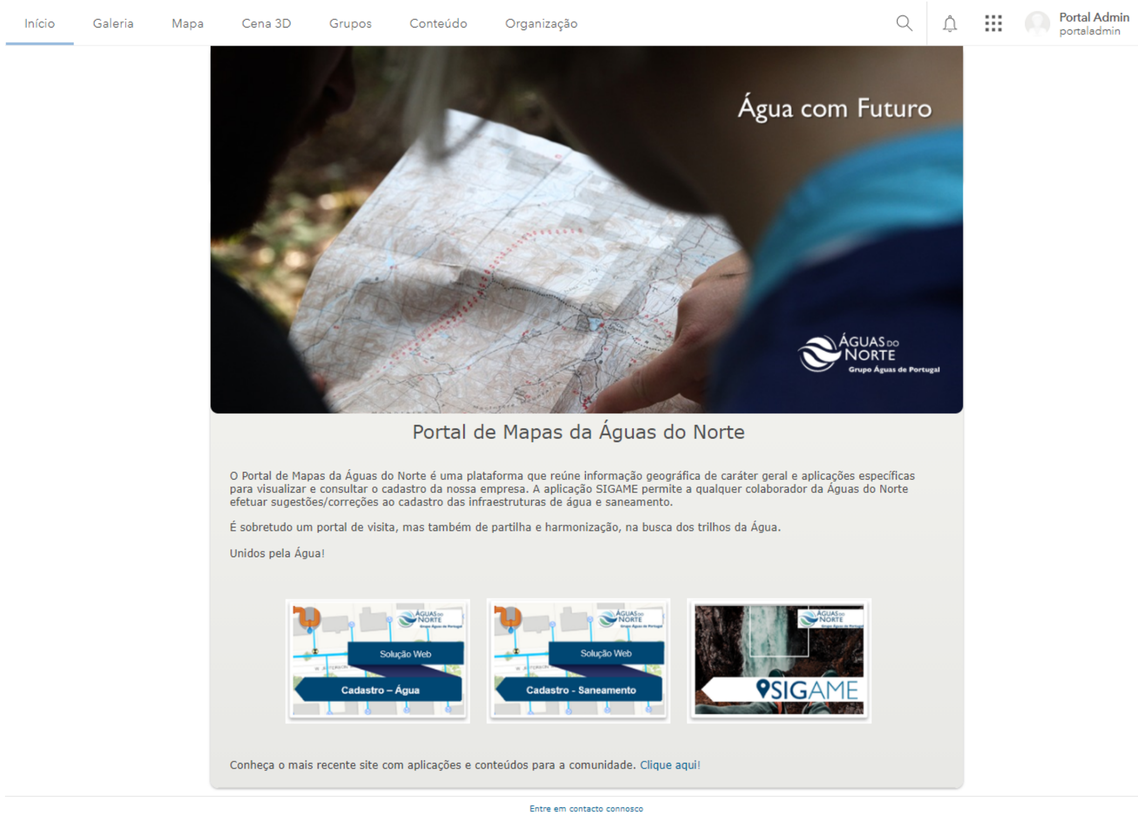


Figure 1 ArcGIS Home page of Águas do Norte Map Portal.

Through the ArcGIS Explorer app, available on the App Store or Google Play, whether for iOS or Android, respectively, it is possible to access the asset inventory map from mobile equipment.

The maps are useful, but not all information has up to date. SIGAME app is a crowdsource reporter that allows users to submit problems or observations about incorrect location or characterization of assets network. The application has been optimized for smartphones but is responsively designed to be used on smartphones, tablets, and desktop computers. Users can submit new reports, review existing reports, and comment and vote on reports or observations submitted by other users.

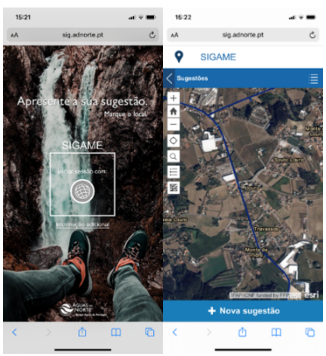


Figure 2 SIGAME application.

The managers of Águas do Norte can review problems or observations submitted through the SIGAME application, and review problem details, update status, and assign responsibility for the correction of the asset inventory.

**Results**

Águas do Norte employees can use the apps easily and with little training. What really helped us to decide was that Esri allowed company employees to collect data in the field and see it appear on their map instantaneously. There was no waiting for weeks or involvement from some other location to add the data to the map. Seeing the fruits of their labour, having the ability to edit data, and creating a map as they work help staff feel accomplished and encourages them to be successful. They know that their work is making a difference and contributing to the future prosperity of their system.

Having a digital map that can be accessed via smart devices makes it easier for Águas do Norte to do his job. It is continually improving information about the systems, and it helps to get relevant information about assets by being accurate and easy to reference.

The big win with SIGAME is the ability to use it in the web and mobile environmental with applications to collect and update information from the office or field.

**Conclusion**

This approach improves the quality of information in assets inventory and reduces long-term asset maintenance costs.

Our next challenge will be to extend the use of the solution to the public, promoting a more effective proximity with the community and our customers, whether direct or indirect.

For Águas do Norte, this is not just an application. Has become an investment for entity and community that serves with. Each employee is gaining intimate knowledge of water and wastewater networks: locating assets, identifying maintenance needs, creating a view into work that we didn't have before. At the end of a day of working in the field, users can see what they have accomplished. We believe that Águas do Norte is helping to make a difference in a better infrastructural knowledge of its assets.

# The use of variable speed drives to reduce energy and costs in water supply systems – analysis, discussion, and validation

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**Abstract:** The control of water supply systems (WSS) is performed daily using pumping stations and water volume deficits of the reservoirs. Some progress developed in this area, employing energy tariffs that vary throughout the day and water-demanding forecasts with computational resources, have increased the efficiency and decreased the cost of these systems [1]. The use of pumps with variable speed drives (VSD) can contribute positively to the improvement of this process, as well as the implementation of parallel pumps in elevation stations. However, there is still a lack of confidence in the use of VSD due to the difficulty of the selection of the adequate operational point, *i.e.* the adequate frequency speed.

This work has the main objective of proving the full potential of the use of variable speed drives in pump installations, including parallel pumps. For that purpose, a computational tool able to simulate accurately the pump behavior for a real case study was developed (see Fig.1). The tool is used to compare different scenarios of pumping operation, including pump scheduling and variable speed. An optimization algorithm is also used to drive the best operational controls for a 24h operation of the WSS (Fig. 2-3). This work demonstrates that VSDs contribute to both energy and cost savings. However, it is also demonstrated that the operation of VSD cannot be made manually by an operator but require automatic control software for effective energy and cost savings.

**Keywords:** Water supply systems; Variable speed drive; Energy and costs reduction.

## Introduction

In both the scientific and industrial communities, the efficient use of variable speed drives (VSD) together with parallel pumps is still an open question. VSD are mainly used for smooth starts due to a general unknown of efficient management of its set points and due to scarce resources to real-time management of these equipments. Therefore, this communication has the goal of illustrate an efficient operation of VSD in an elevation group of parallel pumps and contribute to the increasing confidence of the water sector in the use of VSD.


(a) (b) (c)

Figure 1 (a) Schematics and (b-c) equipment of the Fontinha case study.

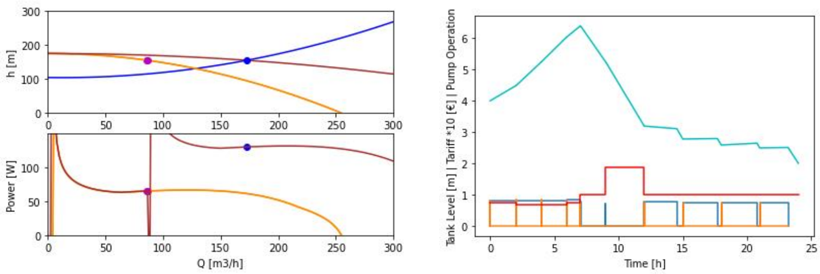
## Case studies and results

In this work, one case study will be used to demonstrate the application of VSD pumps in a water supply system (WSS): the Fontinha system. The Fontinha system is illustrated in Figure 1 and further details can be seen in [2].

Figure 2 (a) shows the hydraulic curves for two similar VSD parallel pumps working together for a time instant. The yellow curve characterizes the pump's hydraulic curves and the brown characterizes the overall parallel curve. The blue point indicates the operation, being the interception point of the system with the pump curves. The red point indicates the functioning of each pump.

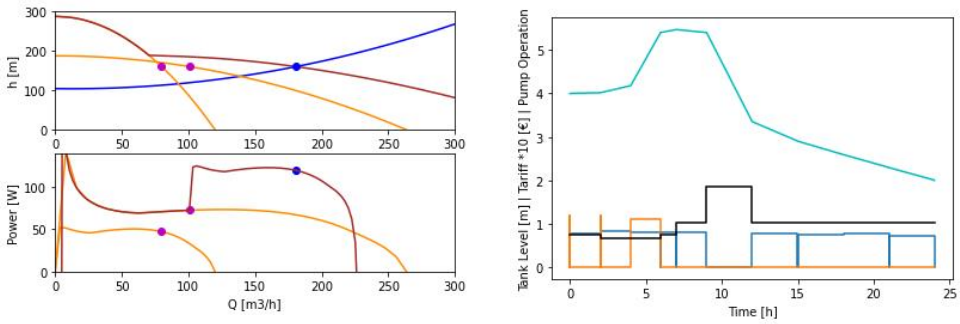
Figure 2(b) illustrates the evolution of the tank level during the day (turquoise blue) and the optimum operation of the two pumps for a power tariff represented by the brown lines. As can be seen, the pump mainly works when the power costs are lower and at low relative speeds. However, it is rather interesting that, during the afternoon, the use of a single pump reduces the slope of the tank level, allowing it to reach the day-end at the minimum level.

Figure 3 present the optimum operation for two dissimilar pumps in parallel. The results are rather interesting and show that the two pumps only work in parallel in the most cheap tariff period. Additionally, the most used pump only works at the most reduced relative speed, as shown in Figure 3 (b) by the dark blue line.




(. a) (b)

Figure 2 Pump operation using VSD: (a) hydraulic and power curves for similar pumps working in parallel; (b) optimum pump operation using both scheduling and speed control.




(a) (b)

Figure 3 Pump operation using VSD: (a) hydraulic and power curves for dissimilar pumps working in parallel; (b) optimum pump operation using both scheduling and speed control.

## Conclusion

The most important conclusion of this communication is that the use of VSD contribute to energy and cost reduction. However, the efficient operation of VSD pumps requires real-time software for smart water utilities or digital twins.

## Acknowledgments

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# The Water Safety Plan of the municipality of Porto as a new framework for managing the utility's water supply operations and assets

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**Abstract:** Safe and readily available water is essential for public health, quality of life, environmental protection, economic activity and sustainable development. Water Safety Plans are globally recognized as an important utility's tool to accomplish those goals. The Municipality of Porto implemented its first Water Safety Plan in 2014/15. Five years later, the lessons learned from the experience and the strategy of Águas e Energia do Porto, EM, were combined into the Plan's revision, leading to a much more detailed, practical and reliable Plan that became one of the most important management tools for daily operation and assets management. This paper presents the transformation's achievements and the benefits and challenges of having such a tool implemented in the organization.

**Keywords:** Water Safety Plan; Water Supply System Operation; Assets Management.

## The Water Safety Plan of Porto: framework and goals

The Water Safety Plan (WSP) of the Municipality of Porto was first developed and implemented between 2014 and 2015, following the World Health Organization (WHO) recommendations [1] and the utility's strategic guidelines for drinking-water quality. Águas e Energia do Porto, EM, (AEdP) was one of the first utilities to develop this kind of Plan in Portugal.

The strategic goal of the WSP is to "systematically ensure the Safety and Acceptability of the drinking-water supply in terms of Quantity and Quality in the Municipality of Porto". Its scope covers the entire water supply system, from the supplier's delivery points, on field, to the consumer's tap. Furthermore, AEdP is responsible for supplying 160.000 costumers and for the management of six municipal water tanks (with 125.450 cubic meters of total capacity) and a pipe network with a total of 800 km (where 50 km are main pipes).

In 2020 AEdP started a comprehensive review of the WSP in order to adjust the risk assessment to the changes in the water supply infrastructures, organization and management modifications in the system and in the utility, as well as to include the analysis of new hazardous events and possible hazards.

With this review, a fresh attitude was also reflected in the WSP: it is now a dynamic and practical tool and not merely another operating procedure. Closely articulated with the utility's assets management strategy, the WSP works both ways: on one hand, assets management data is enclosed in the WSP, whether in the description or in the risk assessment; on the other hand, risk assessment outputs are integrated in the assets management strategy helping to define and rank the investments. The same happens with the operations management: the WSP is fed by operations know-how and, as a result, procedures are evaluated and updated as needed.

The successful implementation of this WSP version intends to improve the understanding of the water supply system and its main structure, the stakeholder collaboration, as well as operational efficiencies of the utility. At the same time, it also aims to provide a robust framework to better target more sustainable long-term capital investments.

**WSP Structure**

The WSP of Porto was totally improved to match the utility's needs. In its revision process some documents were simplified, others were turn into dynamic, always up-to-date files, and others, like the risk assessment sheets, were expanded to include a detailed and thorough analysis of the system and new hazardous events.

Hence, the WSP was structured in the following documents:

1. WSP actual responsibilities flowchart
2. Water Supply System Description – "Water Supply System Description" report ("static" part of the document) and Annexes ("dynamic" part of the document, updated whenever necessary)
3. Risk Assessment – Risk Matrices (Quality & Quantity); List of Hazardous Events and Hazards; Risk Assessment File; Improvement/ upgrade plan actions; Memorandum of Risk Assessment Criteria
4. Planning Support (WSP monitoring, revision and auditing procedures)

**Risk assessment methodology**

As risk assessment is the "heart" of the WSP, it is the most elaborated and crucial stage of the Plan, incorporating a set of important, very sensitive and highly detailed information, which supports its entire functional structure and purposes. This part of the Plan is only unblocked to the WSP team, to ensure the total confidentiality of the data.

The risk assessment covers all the infrastructures of the water supply system that are in service or that, being out of service, work as a system's redundancy. The hazardous events were assessed by process step: General (overall events that can arise anywhere, like atmospheric or seismic phenomena), Transmission (main pipes), Storage Water Tanks, Pumping Stations, Distribution Lines and Internal Consumers' Networks.

Hazards were typified as: Microbiological Contamination and Physical-Chemical Contamination, in terms of quality; Water Shortage & Low Pressure, High Pressure and Water Loss & Flood in terms of quantity.

The risk assessment approach involved three semi quantitative matrices: one for quality and two for quantity issues. The risk associated with each hazard or hazardous event was evaluated by defining the likelihood of occurrence (e.g., certain, possible, rare) and the severity of consequences if the hazard occurred (e.g., insignificant, major, catastrophic). For the quality matrix, the risks were assessed for each contaminant parameter's severity, following the national regulation and the WHO guidelines. For the quantity matrices, the risks were assessed by determining the number of consumers affected by each event (for Water Shortage & Low Pressure and High Pressure hazards) and by the impact of the location of the Flood & Water Loss if occurred.

The aim is to distinguish between important and less important hazards or hazardous events and to prioritize risks in terms of their impact on the supply system's ability to provide safe water and the trust of AEdP's customers.

In the end, 6908 assessments were carried out on the total of the system, each corresponding to one line in the Risk Assessment spread sheet. The WSP team established a rigid cut off-point, above which risks are considered critical points, with need for special attention and immediate action. The initial risk assessment detected 2512 critical points in the water supply system.

For each risk, the existing control measures on the system were identified and validated, one by one, and after this, the risks were recalculated in terms of likelihood and severity, considering the effectiveness of each control measure or the lack of it. At this stage, it was extremely important to consider not only the medium- and long-term performance of the measures, but also their potential to fail or to be ineffective in a short period of time.

As a result of this first reassessment, 2245 critical points were identified, which represents about 11% reduction, on total. Looking only to the quantity related part, the critical points decreased about 59%, from 393 to 230 through the existing control measures (Figure 1).


Figure 1 Main risk assessment numbers of the WSP of the Municipality of Porto.

### Improvement/ upgrade plan actions

Improvement or upgrade plan actions were developed to address all uncontrolled and prioritized risks, mainly to resolve critical points, but also all the other issues, encompassing an overall improvement of the system. Upgrade plan actions identify who is responsible for the improvements, together with an appropriate time frame for the implementation of the controls.

There were 174 improvement plan actions identified, which means a total of 174 opportunities to enhance and reinforce the water supply system's structure and the quality of the service daily provided by AEdP. These actions may range from minor and specific repairs, at the level of simple assets logistics, or the creation of internal procedures, to more complex and costly measures such as the execution of large-scale works or the development and implementation of strategic plans. These plans and actions are budgeted and support the operation and assets management strategy of the utility and are affected by it, in a continuous improvement cycle, that seeks for ensuring, constantly, the safety of the drinking-water supply.

With all the 174 actions becoming effective control measures, it is expected to reduce from 2245 critical points to 1780 – about 21% decrease. Focusing only on the quantity aspects, the reduction is from 230 to 58 critical points, resulting in an effective decrease of 75% (Figure 2).

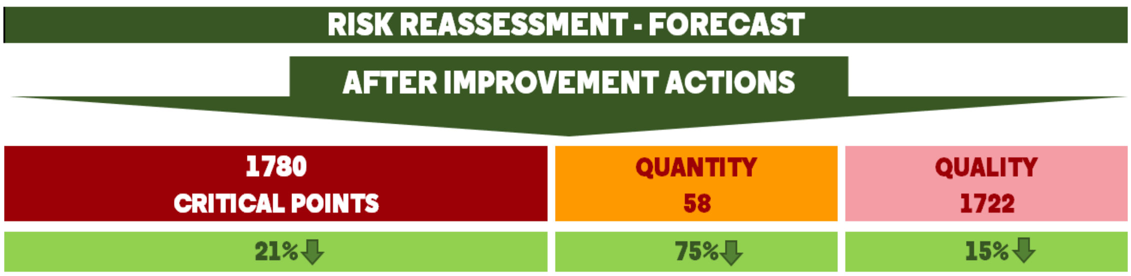


Figure 2 Major risk reassessment numbers: a forecast on the completion of all the improvement WSP actions.

## Benefits and challenges

The effective implementation of an integrated, always up-to-date, Water Safety Plan that is, at the same time, in line with the utility's goals and strategies, brings multiple benefits, internal and to the consumers, but also some challenges.

The main challenges to this approach are related to the commitment of keeping the WSP initiative embedded in the utility's operations and management procedures, that may be impaired by governance or organizational changes, or, on the other hand, the time and workload requirements of maintaining the plan up to date, in between daily operation tasks of the teams.

Still, the outcomes of putting the WSP in practice and overcoming those challenges come with a few major benefits:

- Protection of public health, by ensuring high quality and safe drinking-water with an increased level of consumer trust and acceptability of tap water;
- Water efficiency enhanced strategy, supported by the quantity part of the WSP, that looks into water loss and non-revenue water aspects;
- Proactive identification of all potential hazardous events, in order to validate the existing control measures and, consequently, outline the improvement plans needed;

- Focus on the critical and sensitive points of the water supply system, to eliminate or minimize the magnitude of its risk;
- Improved reliability of the system by ensuring water supply alternatives, to minimize the risk of water shortage and/ or pressure drop to the costumers;
- Optimization of procedures and resources for operation, maintenance, control and management;
- Decision making support in the prioritization of the utility's investments, adjusting them to the current and future needs of the system;
- Continuous improvement mindset - "today better than yesterday & tomorrow better than today".

## Closing remarks

The new WSP of Porto, implemented and in daily operation since the beginning of 2021, is a paradigm shift on the safety of the drinking-water supply, headed for a more effective management of the system, with a preventive attitude instead of the traditional post-supply control. This involves understanding the entire system as a whole, identifying where, when and how problems could arise, putting control measures and management practices in place to stop the problems before they really happen and making sure all parts of the system continue to work properly, ensuring efficiency and continuity of customer service.

The Plan's revision, undertaken between January 2020 and March 2021, turned it into a new risk management strategy that influences the utility's whole way of working towards the continuing supply of safe water. Significant risks that are not currently controlled need to be mitigated. This may involve short, medium or long-term steps for improvement, that may range from low-cost operational and maintenance solutions to more capital-intensive infrastructure improvements.

Finally, and in accordance with European Union legislation, regarding the sustainable and integrated water use – Drinking Water Directive – this line of analysis is considered an essential foundation for achieving the social purposes of universal accessibility of safe water, present and to come, in a frame where AEdP is a key agent.

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# Towards energy and costs efficiency: the analysis and control of discharge pumps in wastewater pumping stations

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**Abstract:** Hydraulic pumps are responsible for a large portion of the energy costs in wastewater pumping station; thus, it is important to reduce them. With this work, an accurate model that reproduces the energy consumed and the flow rate delivered by the set of discharge pumps present in the pumping station IS8 of Ílhavo's wastewater treatment plant was build. For this, data from sensors installed were used and hydraulic equations were applied. More cost-efficient setpoint plans were also found using the Nelder-Mead optimization algorithm; however, they may lead to higher maintenance costs. The tools developed and results obtained are critical for future improvements of similar systems and for reducing energy consumption and costs.

**Keywords:** Wastewater pumping stations; setpoints management; model calibration.

## Problem framework

Currently, energy costs can represent a significant share of the global operational costs in a wastewater pumping station and, since a growth in the world population is expected for the next years, these costs will increase to these facilities [1]. As pumping is the largest consumer of electrical energy in these stations (around 80%), the optimal control of pump units can help the utilities to decrease operational costs by minimizing energy consumption [2, 3].

This work starts with the modelling of the energy consumption and pumped flow by the pumping station IS8, which receives the treated effluent from Ílhavo wastewater treatment plant, managed by Águas do Centro Litoral, S.A. (AdCL) company. This pump set is responsible for the discharge of the treated effluent to the sea. It consists of 3 parallel pumps, each one equipped with one Variable Speed Drive (VSD). However, due to pressure constraints, only two of them can work simultaneously. This pump set can work in 3 different configurations: these can be all turned off, only one working or two of them working.

Two models were developed: one for simulating the energy consumed by the pumping set and another for simulating the pumped flow, both of them using as input the percentage of the maximum frequency (50Hz) of the pumps' VSDs. For the definition of the models, the pump hydraulic curves and affinity law equations were used in combination with the system working points and Darcy-Weisbach Equation to obtain the system hydraulic curve. This procedure is illustrated in Figure 1. Then, using these curves it is possible to obtain the pumped flow and the head loss for a certain working point and obtain the energy and volume pumped by that set of pumps.

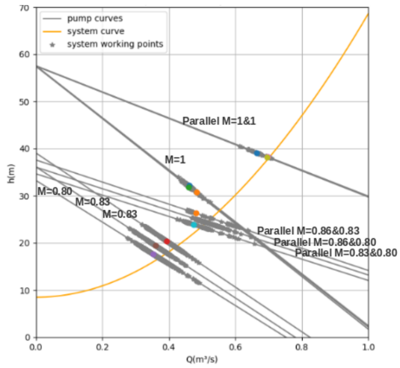


Figure 3: Pump and system curves from pumping station IS8.

The data used was acquired through the facility's supervisory control and data acquisition (SCADA) system and covered the operation of the pumping station during February of 2021, with a time resolution of 5 minutes. Moreover, real measures of the energy power and volume pumped by the pump set for each day were provided.

Then, an improved operational setpoint plan was sought. To this end, a simulator was first created using the calibrated model to replicate the behavior of the automatic pump operation: it decides the start/stop of the pumping sets along with the increase/decrease of the VSD frequency according to the level of the tank, with the aim to maintain it at the stable level.

Afterwards, the simulator was used to search for an improved operational setpoints plan. Over time, AdCL improved their setpoint plan based on their experience. The Nelder-Mead algorithm was used to find this new plan with the objective of minimizing the energy consumption of the pump set. The optimization decision variables used were the level of the tank at which the first and the second pumps start and stop working and the stable level. Approximately 95 days from February 2020 to February 2021 were used for the search of the decision variables and different initial guesses were tried, comprising periods of low and high effluent volume subject to pumping.

## Results

After the model's development, a simulation was done. The results can be seen in Figure 2 and 3 and the metrics are presented in Table 1.

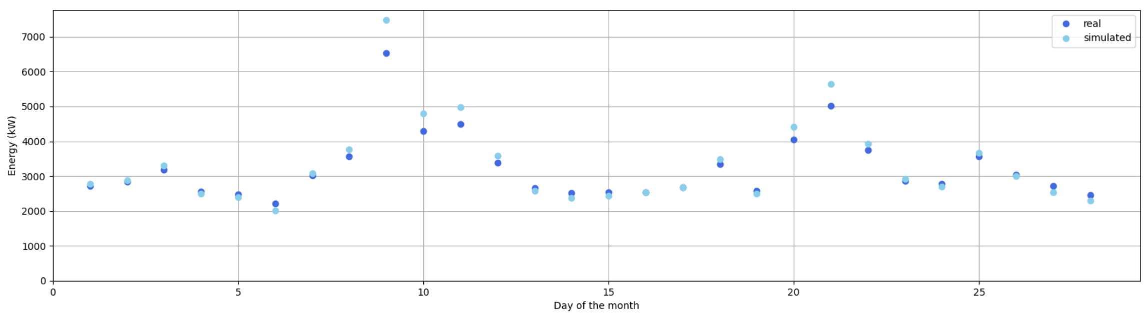


Figure 2: Real and simulated energies consumed per day by the set of pumps.

Figure 3: Real and simulated pumped volumes per day by the set of pumps.

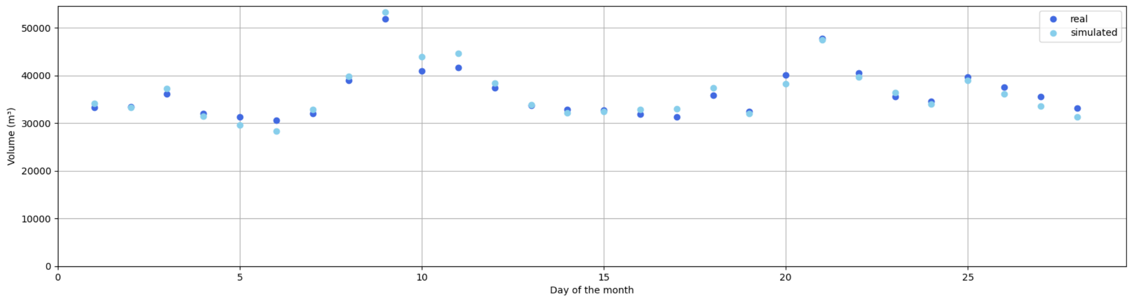


Table 4: Metrics for the calibration of the models for the set of pumps in terms of volume and energy.

| | Volume | Energy |
|---|---|---|
| Coefficient of Determination ($R^2$) | 0,906 | 0,919 |
| Mean Absolute Error (MAE) | 190 $m^3$ | 1173 kWh |
| Mean Absolute Percentage Error (MAPE) | 5,093% | 3,240% |

Observing the charts present in Figures 2 and 3 and the calibration metric $R^2$, it is evident that the model that replicates the energy and the flows produced by the pumps can reproduce the variability of the data: the simulation produces lower energy and lower pumped volumes when the real energy and pumped values are also low and vice-versa.

The difference between the real and the simulated values is minor for both simulations, as it can be checked on the figures and by the low values of the MAE and MAPE metrics, which indicates that these models are accurate. The small differences in terms of energy can be explained by Figure 4, which shows the percentage of time that none, one or two pumps of the system are working. Comparing the days 9, 10, 11 and 12 of Figure 4 with Figure 2, it is evident that the difference between the real and the simulated values is larger when two pumps are working during more time, which indicates that the modelling still has space for improvements.

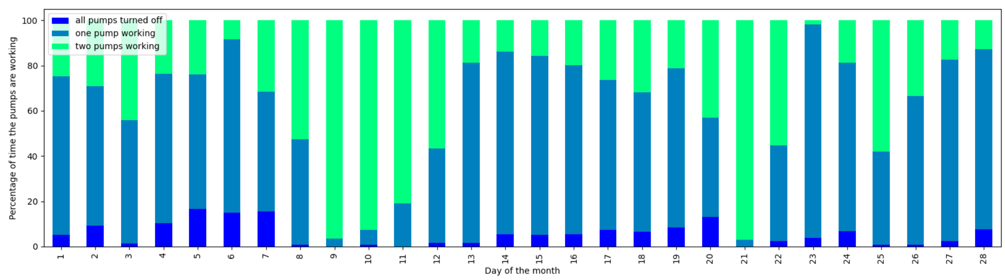


Figure 4: Percentage of time that all pumps are turned off, one or two pumps are working per day of the month.

Then, the simulator was used to search for the best operational points. Table 2 lists the setpoints currently used by AdCL (scheme A) and two local minima setpoints found using the process described above (scheme B and C). Some statistics related to each setpoint applied to the data from February 2021 are present in Table 3.

**Table 2:** Setpoints plans: the AdCL (scheme A) and two optimized (scheme 2 and 3), in meters.

| | Start 1st pump | Start 2nd pump | Stop 1st pump | Stop 2nd pump | Stable level |
|---|---|---|---|---|---|
| Scheme A | 1,85 | 2,05 | 1,50 | 1,85 | 2,00 |
| Scheme B | 1,81 | 2,07 | 1,52 | 1,94 | 1,93 |
| Scheme C | 1,64 | 2,07 | 1,50 | 2,05 | 1,97 |

**Table 3:** Total energy consumed and number of starts and percentage of time the first and the second pumps were on.

| | Total energy consumed (kWh) | 1st pump | | 2nd pump | |
|---|---|---|---|---|---|
| | | Start-up cycles | Percentage of time the pump was on | Start-up cycles | Percentage of time the pump was on |
| Scheme A | 89290 | 280 | 96,30 | 20 | 15,83 |
| Scheme B | 88293 | 331 | 96,23 | 106 | 6,58 |
| Scheme C | 88184 | 668 | 96,33 | 613 | 6,49 |

Observing the total energy consumed when using the different setpoints, the optimization procedure was successful, since the total energy consumed by scheme A is larger than the one consumed by scheme B and C.

Although scheme C has the lowest energy consumption, the number of starts of the first and second pumps increased greatly compared to the scheme A. This happens due to the lower level for the first pump to start working and to the start and stop level of the second pump being close to each other. This causes the pumps to wear out faster, which increases maintenance costs in the long run.

Scheme B has an intermediate cost. When comparing with scheme A, it reduces the time the second pump is on and, therefore, the total energy consumption, but an increase on the number of starts of both pumps is verified. A more in-depth study should be conducted to see if the benefit of changing the setpoint plan to scheme B does not cost more in the future.

## Final Remarks

In this work, the modelling of the set of pumps applied in the IS8 pumping station using hydraulic equations has been carried out with success, showing that it is possible to model the energy consumed and flow pumped by a set of pumps accurately, even if these have several years of effective use. The optimization of the setpoint management was also achieved and advantage was taken from the VSD to reduce the energy consumption. However, the long-term impact should also be taken into account, since improving the energy consumption today may lead to higher maintenance costs in the future. It would be interesting to reformulate the optimization process to include long-term costs.

The developed model in combination with the simulation and the optimization of the setpoints are crucial to make further studies and consequently more efficient decisions about the management of this and other pumping stations to achieve energy and cost efficiency.

**Acknowledgments**

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# Undue inflows approach for systems prioritizing

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**Abstract:** Undue inflows are a recurring urban water drainage system problem. Following the Águas do Vale do Tejo Undue Inflow Control Plan, a performance assessment system was developed, intended to be applied throughout its 411 systems. This assessment system itself revealed to be insufficient to evaluate the issue properly, thus a complementary diagnosis approach was developed. This approach combines incoming wastewater *Quality* and *Quantity* features at WWTP. A priority matrix was further developed, intended to combine Quantity and Quality factors, allowing for a final priority ranking for all systems regarding undue inflows. Thus setting the operational and investment agenda for where to look and what to do next. Combining the best Asset Management practices and the developed approach, which is an innovation as regards an integrated undue inflows control, it is intended to provide an efficient and sustainable management for WWTP.

**Keywords:** undue inflows; I&I; asset management.

## Introduction

Undue inflows are a common problem amongst urban water utilities. Having different characteristics and diverse consequences, they tend to bring serious implications to wastewater system efficiency and sustainability (Ellis, 2001; Beheshti *et al.*, 2015). These inflows can be from either a quantity (volume) perspective like undue rainfall, infiltration and illegal connections, or a quality perspective such as industrial undue inflows (David *et al.*, 2017).

From an operational perspective, undue inflows have consequences in terms of reduced efficiency and effectiveness, with either transport or treatment systems, which may lead to a lower service quality. Regarding financial impacts, these mostly relate to higher operation and maintenance costs. Fines may also be a consequence due to non-compliance of legal discharge values. Alternatively, these undue discharges may also have consequences from an environmental perspective, such as watercourse pollution, as well as from the utilities' public image perception.

Águas do Vale do Tejo is the utility responsible for managing the wastewater systems of 54 municipalities, collecting wastewater from each municipality and conveying it for adequate treatment. The geographic area managed is expansive and diverse, in terms of topography and morphology. As a result there is a large variety of wastewater systems. Overall, the combined total of systems consist of 895 km of sewer pipes, 311 pumping stations, 411 wastewater treatment plants (WWTP).

Given the overall system dimension, diversity and general complexity of undue inflows, it was necessary to establish a starting point as regards where to go and what to do. Therefore, an Undue Inflows Control Plan was developed following the iAFLUI methodology (Almeida *et al.*, 2017). The main objective is to determine, from a strategic point of view, which systems are subject to the greatest stress with these issues. Subsequent to this and from a tactical point of view, assessment of these problems should be undertaken in a meticulous manner and provided with suitable solutions. However, from the strategic viewpoint, a complementary diagnosis approach was developed intended to assist with prioritizing which systems to address first.

## Methodology

Given the overall dimension of the company infrastructure, systems are addressed independently by WWTP, to be further assessed from an undue inflows perspective. Overall there are a total of 411 systems, combining WWTP. These are divided in four distinct areas: *Beira Alta, Beira Baixa, Alentejo, Alentejo – Sistemas Mistos*.

Following the Águas de Portugal (AdP) Strategic Commitment Board, EPAL's strategic pillars and the ERSAR quality assessment plan (ERSAR, 2021), an assessment system was developed in order to assess undue inflows at a strategic planning level. This system is based on strategic objectives and each has particular assessment criteria, which are further evaluated through specific metrics. Respectively, metrics have reference values intended to allow to performance assessment over time (Almeida & Cardoso, 2010).

However, even having this assessment system on its own was not enough to perceptibly address the undue inflows subject. Therefore, a complementary diagnosis approach was developed, being intended to supplement the previous methodology and assess undue inflows from two different perspectives (Figure 1). These are: *Quantity* - undue inflows from a quantity perspective, such as Inflows and Infiltration (I&I) - and *Quality* - undue inflows from a quality perspective, such as Non-Domestic-Inflows (NDI).

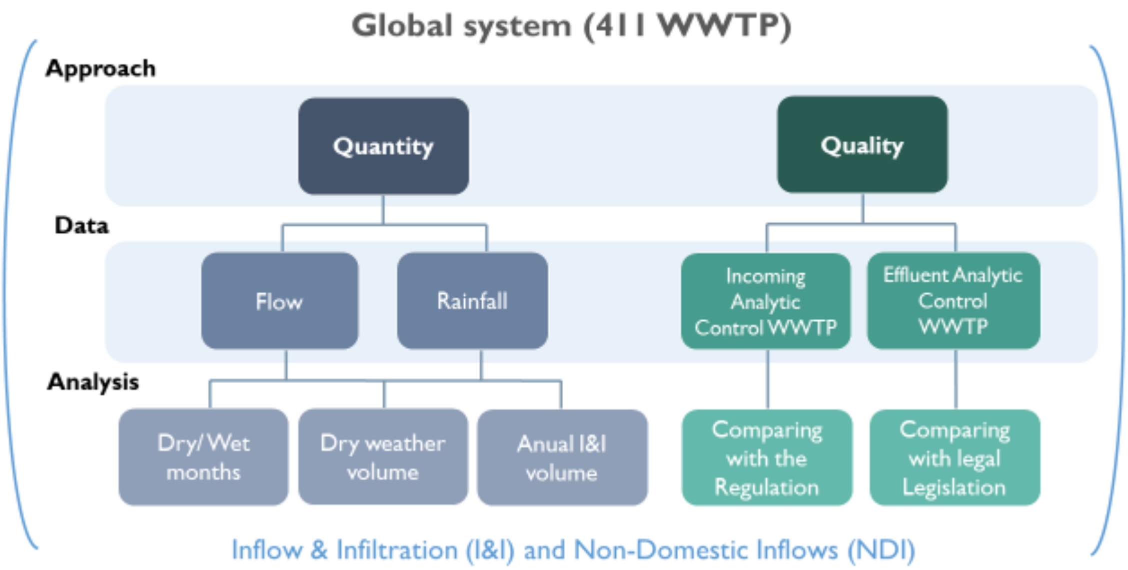


Figure 1 Methodology to assess undue inflows form a quantity quality perspectives

Having systems ranked from a quantity point of view (I&I) and from a quality perspective (NDI), is was necessary to combine these two scales to determine which systems were a priority to address regarding general undue inflows, hence a matrix was developed for this purpose (Figure 2).

This matrix combines three different factors regarding *Quality*, these are: incoming legal compliance, directly related to the legal limits established in utility's Systems Regulation; effluent legal non-compliance, related to effluent legal compliance; and legal discharge non-compliance, related to the each WWTP legal licence. Whereas the other axis corresponds to a single factor related with *Quantity*, which is I&I calculated taking into account WWTP capacity, volume incoming and I&I estimated volume. By combining these two points of view we get a priority level (from 1 – low to 5 – high), within the matrix, for each treatment facility regarding undue inflows.

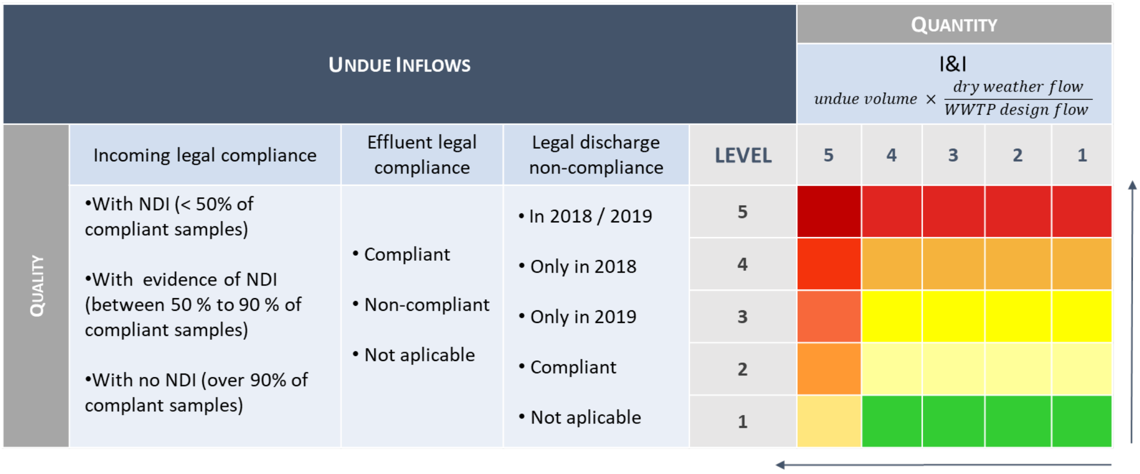


Figure 2 Undue inflows priority matrix

## Results and Conclusions

Combining data and information between 2017 and 2019 with the proposed method, it was possible to rank all 411 systems from an undue inflows perspective, combining *Quality* and *Quantity* type, from a high-priority level (5), to a non-priority level (1). This resulted in the identification of 26 priority systems at level 5.

This approach proved to be a valuable and robust tool since it allowed Águas do Vale do Tejo to determine where to initiate dedicated studies in those systems which were subject to the most significant levels of undue inflows, providing results for practical use. Following implementation of the Undue Inflows Control Plan, actions plans are intended to be developed and established for each of the 26 priority systems identified, which will be further developed at a tactical decision level. The main goal is to further conclude in determining suitable solutions for each of the identified undue inflows problems as well as providing an investment plan for its reduction, supported in an Asset Management global strategy. By ensuring control of these inflows, an improvement of the quality of the incoming water to the WWTP's is expected, as well as a decrease of I&I, contributing to an overall improvement of the quality of water available in the basins.

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# Water data management: a fit-for-purpose approach

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**Abstract:** The water sector is highly heterogenous when it comes to data collection and data management procedures. As a consultancy company operating worldwide, DouroECI deals with very diverse utilities - in terms of size, organizational culture, and level of digitalization. Moreover, providing different services to its clients, DouroECI constantly takes part in projects with a wide range of scope, timeframe, and budget, in what constitutes a call for pragmatism and flexibility. This submission introduces the approach to data collection and management, focusing on establishing a clear baseline, and creating and implementing structured procedures, supported on a strategy to overcome existing challenges. Case studies from projects in different geographies will be discussed: Qatar, Portugal, Angola, and the United Arab Emirates.

**Keywords:** data management; data quality; ETL

## Introduction

Started in 2013, DouroECI is a Portuguese company operating exclusively in the water sector. It provides services that blend engineering and technology, from detailed design of hydraulic infrastructures, to hydraulic modeling, software development and implementation, aiming for the continuous improvement in performance and sustainability of water utilities. With an enthusiastic view of technology and science, DouroECI works to bridge the gap between utilities and the latest advances in the fields of hydraulics, data analysis, and engineering.

In a context of high heterogeneity of utilities and projects, DouroECI has been establishing a fit-for-purpose approach, which attempts to create value from the existing data at each utility while identifying both the weaknesses stemming from each simplification (and their implications on the attainment of the established goals) and the opportunities for improvement.

This approach attempts to collect all data relevant to the project by making use of the available sources:

- Utility and public databases;
- Documents and records;
- Observations;
- Forms and questionnaires;
- Oral testimonies;
- Meta-data.

Backed by a broad view of the technological solutions in the market, the data pre-processing and data validation steps are designed to fit both the format and quality of the data and each client's needs. When data is not available, a strategy, that may include software deployment, is established to reach the intended goals. Depending on the project, having a clear definition of the goals to be achieved and the necessary data, this step may encompass the design of adequate data pipelines, the implementation of a project database and the manual depuration of data inconsistencies. Likewise, in most situations, the creation and maintenance of a GIS project, which aggregates all the geographic information collected, is essential for understanding the problem at hand and the possible constraints to the design process.

As examples of the real-life application of this approach, 2 case studies will be introduced.

## Case study 1: Hydraulic modelling and odour risk assessment – Phases 1 and 2 (Qatar, 2018 – 2022)

Promoted by Qatar's Public Works Authority (Ashghal), the initial aim of this project was to perform an odor risk assessment on known hotspots across Qatar (Phase 1). The study scope involved extensive onsite survey works to assess the characteristics and condition of the sewerage networks and benchmark odor levels using H2S as an odor surrogate. A total of eight key 'hotspot' areas which had been linked to public complaints were assessed in the Priority 1 study and 105 individual discharge chambers assessed in Priority 2 study under Phase 1 across Doha [1].


**Figure 1** Phase 1 areas of concern and monitored discharge chambers [1].

Started in 2020, Phase 2 of the project includes extensive hydraulic modelling of the Doha South Catchment (> 1 200 m of network pipes and 40+ pumping stations). Initial data for the project included: the infrastructure registry, the history of complaints associated with each hotspot and daily flow data for a number of pumping stations. The additional data collected at both Phases 1 and 2 is summarized in Table 1.

Table 1 Collected data and used tools.

| Phase | Date | Data collected | Tools used for collection and pre-processing |
|---|---|---|---|
| 1<br>Risk Assessment | 2018 - 2019 | Visual inspection reports of the assets, including sensitivity analysis of the surroundings | KoBoToolbox (web-based forms and questionnaires application); MS Excel; QGIS |
| 1<br>Risk Assessment | 2018 -2019 | H2S monitoring at multiple assets | Portable H2S Gas Monitors (PPM); MS Excel; MySQL; QGIS |
| 2<br>Hydraulic Modelling | 2021 - 2022 | Flow monitoring | Portable flow /depth monitors; MS Excel; MySQL; QGIS |

Besides the geographic location of the clients, which raises scheduling and communication constraints, the main challenges faced during data collection and pre-processing were the massive transformation undergone by the city of Doha in recent years, which impacts on the quality of the infrastructure registry, and the difficulty to get access to data on short notice, which results from the data security procedures in effect at Ashghal, even when advanced software packages were in place and renowned platforms were in use. To overcome the challenges related with the available data and to support the development of the project, there was the need to implement structured procedures related with data collection and treatment, promoting, overall, quality assurance and control on the initial data provided.

**Case Study 2 – Infrastructure Asset Management and Business Intelligence software implementation in Portugal, Angola, and the UAE**

Infrastructure Asset Management (IAM) processes developed by DouroECI intend to leverage today's technological landscape in order to provide a holistic approach to operation, management and rehabilitation of urban water and wastewater systems, thus focusing on the daily challenge of consolidating a sustainable increase of the utilities levels of service (LoS).

The developed processes, based on context knowledge and each utility particular characteristics, are implemented as part of a structured and broad IAM policy framework along all different planning to management levels, from the strategic to the operational level. This vision can be magnified when combined with a thorough asset management perspective within the ISO5500X international guidelines [2].

The initial aim of the platform implementation always takes into consideration the data baseline that exists at each utility, and, supported on the local requirements, existent processes and workflows, draws a path for robust data collection, thinking on the long-term vision while addressing daily needs from O&M teams to management.

In this article, it will also be discussed the basic principles and ideas that led to the development of a software platform - in a first phase regarding data collection for urban infrastructure systems management and operation, from planning to execution, gathering all intervention data (ION) and in a second phase the development of a data framework to connect all existing data systems of an utility (OBI), thus creating a unified reference information layer for a more transparent view on the existing data, increasing KPIs precision and quality and empowering all users with the ability of performing simple yet powerful self-service data analysis [3].

The article will reference several implementation projects, such as for Plainwater SGPS, SA utility group (including Águas de Barcelos, Águas de Paços de Ferreira e Águas do Marco) in Portugal in 2019, Penafiel-Verde, EM utility in Portugal in 2020, EPAS Huíla in Angola in 2017 and Park Water Limited in the UAE in 2021, describing different challenges encountered as well as the different custom-made modules that were necessary.

ION was built with the purpose to be an agile maintenance and asset management system that would allow utilities to have a simple and intuitive data collection tool providing increased data quality assurance. The system improves operations efficiency and effectiveness, contributing for an extended asset lifetime and allowing operational teams to make quick and better data-driven business decisions.

The way this is approached is by considering the need to collect baseline data to support infrastructure asset management, adapted to the level of the entity and the users, in an interface that allows any user, with a given profile, to collect and complete the necessary data following a clear path along the software, being built around a robust structure that limit errors and promotes data quality assurance and control. For this to happen, several layers are relevant to provide the ground for the platform, from ETL processes bringing in data from support systems (such as CMS, ERP or SCADA), to the structure of the platform itself, with desktop and mobile instances designed for specific uses.

This system includes full integration with GIS systems for a reliable and updated asset inventory and synchronization with external databases such as the materials and parts inventory with ERP systems in order to provide automated processes for intervention management and therefore data quality assurance to utilities. Other modules allow for further integration, including accounting/billing systems for customer tracking, SCADA systems for readings update and events or HR systems to manage operational team's performance.

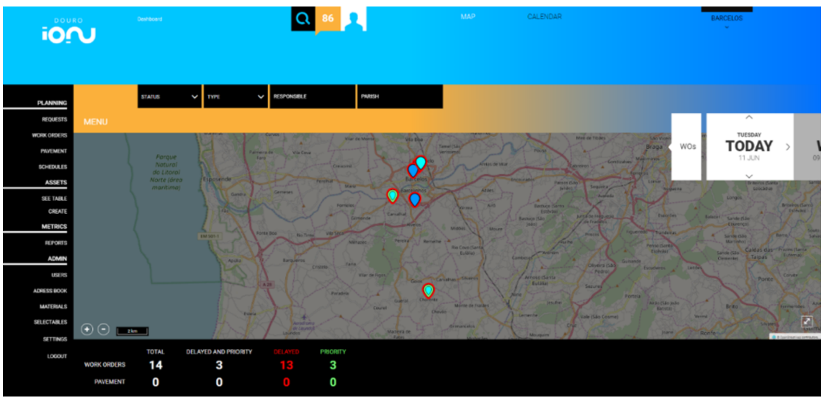

Figure 2 ION's user interface.

On the other hand, OBI is an open-source based platform developed for consolidation and exploration of existing utilities data sources (GIS, SCADA, CRM, ERP, ION…) aiming to provide interactive and intuitive data knowledge from the existing data to all teams, from technical to commercial, with different data schemes, from billing indicators, water meters management to operation and management KPIs and asset management. More than analyzing the utilities data it is increasingly important to allow users to develop knowledge from existing data with transparency and confidence on the quality of the accessible data.

OBI has also evolved from a standard Business Intelligence cloud webservice for the water sector to a full-fledged data platform with the development of particular modules for water utilities like the automated extraction, transformation and load (ETL) module, the data testing, documentation and profiling module, optimization algorithms for water meters management and advanced statistical analysis for water loss detection in district metered areas (DMA's).

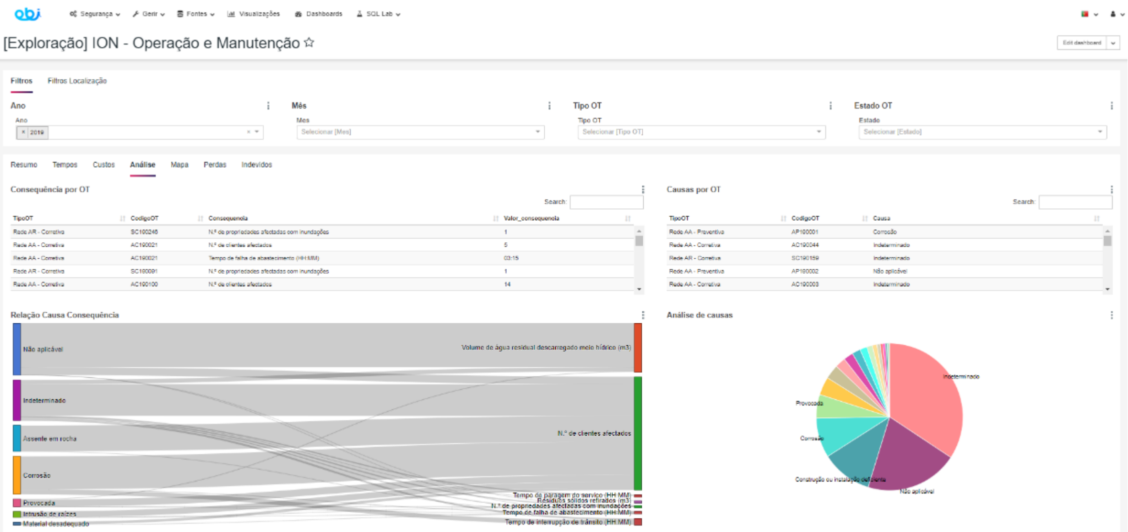


**Figure 3** Dashboard in OBI.

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# Water quality prediction based on Naïve Bayes algorithm

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**Abstract:** This paper aims to test the efficiency of the application of the classical machine-learning method - Naïve Bayes in predicting water quality. The Naïve Bayes model for classification is based on nine water quality parameters which are defined within the Serbian Water Quality Index methodology. These are temperature, pH, electrical conductivity, oxygen saturation, biological oxygen demand, suspended solids, nitrogen oxides, orthophosphates, and ammonium. The parameters were taken from five measurement stations (on the Danube, Tisza, Begej, and two on the Danube-Tisza-Danube canal network) in the period 2013-2019 in each April and August, 68 samples in total. The model predicted correctly 64 out of 68 cases.

**Keywords:** Naïve Bayes; Serbian Water Quality Index; Water quality class' prediction.

## Introduction

Prediction of water quality is a difficult task because of numerous influence factors some of which can be changed easily and quickly, but also because of the consequences that may occur due to incorrect prediction [1].

One of the models which are in use for prediction in many different domains is the Bayesian Network (BN). The core of BNs is Bayes' Theorem [2]. BNs are direct acyclic graphs that are representing the cause and effects of systems' components through a conditional probability distribution [3]. The use of BN in the modeling of environmental systems is expanding because of the possibility of integration of different components, handling missing data and uncertainty, etc. [4, 5]. BNs are widely used also in the field of water management [6, 7].

Traditional machine-learning algorithms assume that data are precise, but for uncertain data Naïve Bayes (NB) classifier is favorable to use [8,9]. In this paper, NB algorithm is used for water quality class' prediction. The paper aims to test the efficiency of its application with the goal of possible management changes - more efficient use of fewer resources (economic, time, human, etc.) compared to the traditional way of water quality assessment.

Some previous research in water quality class prediction using NB [1] showed promising results and this work attempts to expand the input data and check the output accuracy. Thus, nine water quality parameters that are defined within the Serbian Water Quality Index (SWQI) methodology [10] are included in the model. Also, the quality of water samples at five measuring points in Serbia is assessed – classified and used for the model testing, including the points at the Danube River, Tisza, Begej, and two sections of the Danube-Tisza-Danube (DTD) canal network. Training input includes the data from 2015 to 2019, but the data for testing covers two years more.

## Material and method

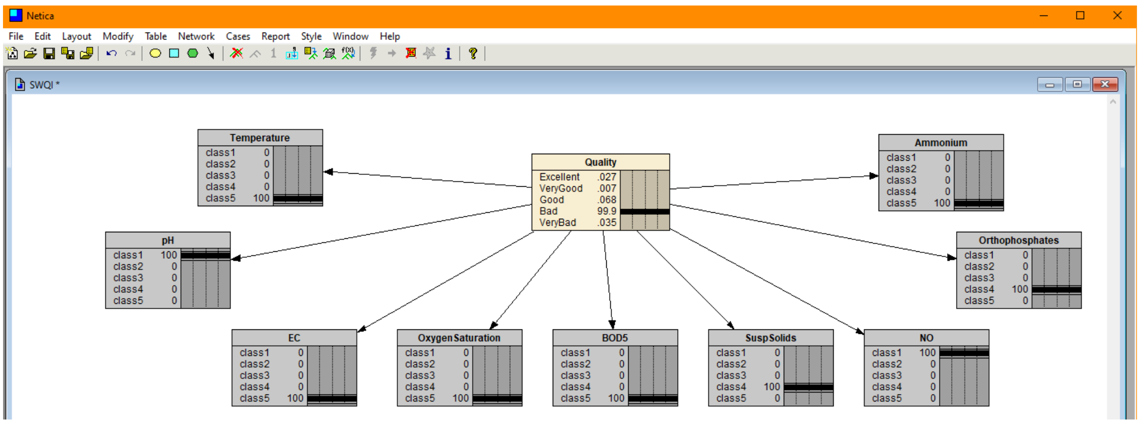
NB classifier belongs to the probabilistic family of classifiers based on Bayes' Theory with the main assumption that all the variables are conditionally independent. Because of that, the parameters can be learned separately, simpler and quicker [11]. NB classifier calculates a posterior probability of the class given predictor *P(c/x)* as in Equation 1 [12]:

$$P(c|x) = \frac{P(X|C) * P(c)}{P(x)} \tag{1}$$

where *P(c)* is the prior class' probability, *P(x/c)* is the probability of predictor given class, and *P(x)* is the prior probability of predictor.

Here, the BN is constructed of 10 nodes: one parent node ("Quality") and 9 child nodes that represent nine water quality parameters in the software Netica [13] (Figure 1). The parameters are defined within the SWQI methodology [10]. These are temperature, pH, electrical conductivity, oxygen saturation, biological oxygen demand, suspended solids, nitrogen oxides, orthophosphates, and ammonium. The data were taken from the database of the Serbian Environmental Protection Agency for the period 2013-2019 in each April and August, 68 samples in total. The samples are taken for five measurement points: Novi Sad (on the Danube), Titel (Tisza), Hetin (Begej), and Melenci and Bač (on the Danube-Tisza-Danube canal network).

First, SWQI index is calculated [14] using the data from 68 samples (Table 1). Within the SWQI methodology, five water classes are defined: excellent, very good, good, bad, and very bad, and these classes represent the states of the "Quality" node. To train the network, parameters from 2015-2019, 48 learning cases in total, are selected. The input file is.txt in the corresponding form for the software Netica and then incorporated into the BN.




## Results and Discussion

In table 1, calculated indexes and corresponding classes are presented, as well as predicted classes by the classifier. The number of samples from 1 to 14 represent the quality of the Danube water, 15-28 of the Tisza River, 29-42 the Bega Veche, 43- 54 DTD canal (Melenci), and from 43 to 68 DTD canal (Bač).

The classifier predicted correctly 64 out of 68 cases. Ten of these 64 cases were selected in a different class but it is not wrong because it is the threshold value of the previous or the next class or very close to it (for 3 samples). Also, two samples are allocated to the contiguous class but the probabilities for both classes were almost equal and the value of the index is also almost on the border of the classes (samples No. 31 and 46). The reason for the misclassification of sample no. 17 is a small number of learning cases for "excellent" quality class (only one).

**Table 1** Serbian water quality index (SWQI), corresponding SWQI class, and NB estimation of quality class

| No. | SWQI | Class | NB class estimation | No. | SWQ index | Class | NB class estimation |
|---|---|---|---|---|---|---|---|
| 1 | 88 | Very good | Very good (90%) | 35 | 74 | Good | Good (83%) |
| 2 | 80 | Good | Good (69%) | 36 | 58 | Bad | Bad (99.8%) |
| 3 | 90 | Excellent | Very good (84%)* | 37 | 82 | Good | Very good (63%)** |
| 4 | 81 | Good | Good (96%) | 38 | 60 | Bad | Bad (75%) |
| 5 | 85 | Very good | Very good (91%) | 39 | 77 | Good | Good (70%) |
| 6 | 84 | Very good | Very good (57%) | 40 | 58 | Bad | Bad (75%) |
| 7 | 88 | Very good | Very good (97%) | 41 | 84 | Very good | Very good (74%) |
| 8 | 82 | Good | Good (63%) | 42 | 51 | Bad | Bad (87%) |
| 9 | 83 | Good | Very good (75%)* | 43 | 68 | Bad | Bad (86%) |
| 10 | 77 | Good | Good (97%) | 44 | 69 | Bad | Bad (84%) |
| 11 | 88 | Very good | Very good (84%) | 45 | 90 | Excellent | Very good (87%)* |
| 12 | 74 | Good | Good (99%) | 46 | 70 | Bad | Good (49%) / Bad (45%)**** |
| 13 | 83 | Good | Very good (81%)* | 47 | 85 | Very good | Very good (65%) |
| 14 | 85 | Very good | Very good (59%) | 48 | 70 | Bad | Bad (74%) |
| 15 | 78 | Good | Good (90%) | 49 | 88 | Very good | Very good (90%) |
| 16 | 72 | Good | Good (66%) | 50 | 75 | Good | Good (97%) |
| 17 | 92 | Excellent | Very good (74%) | 51 | 89 | Very good | Very good (82%) |
| 18 | 74 | Good | Good (74%) | 52 | 78 | Good | Good (97%) |
| 19 | 85 | Very good | Very good (65.1%) | 53 | 82 | Good | Good (91%) |
| 20 | 85 | Very good | Good (57%) /Very good ( 41%)** | 54 | 78 | Good | Good (96%) |
| 21 | 86 | Very good | Very good (72%) | 55 | 83 | Good | Very good (86%)* |
| 22 | 77 | Good | Good (97%) | 56 | 42 | Bad | Bad (99.9%) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 23 | 83 | Good | Very good (58%)* | 57 | 80 | Good | Very good (87%) |
| 24 | 82 | Good | Good (83%) | 58 | 59 | Bad | Bad (99.5%) |
| 25 | 78 | Good | Good (87%) | 59 | 78 | Good | Very good (82%) |
| 26 | 75 | Good | Good (99%) | 60 | 55 | Bad | Bad (99.9%) |
| 27 | 91 | Excellent | Very good (78%)** | 61 | 68 | Bad | Bad (93%) |
| 28 | 81 | Good | Good (98%) | 62 | 73 | Good | Good (97%) |
| 29 | 74 | Good | Good (76%) | 63 | 64 | Bad | Bad (84%) |
| 30 | 64 | Bad | Bad (71%) | 64 | 47 | Bad | Bad (99.9%) |
| 31 | 80 | Good | Very good (56%) / Good (43%)*** | 65 | 66 | Bad | Good (43%) |
| 32 | 51 | Bad | Bad (97%) | 66 | 59 | Bad | Bad (99%) |
| 33 | 84 | Very good | Very good (90%) | 67 | 83 | Good | Very good (75%)* |
| 34 | 56 | Bad | Bad (95%) | 68 | 72 | Good | Bad (68%)** |

*threshold value of classes; **very close to the threshold value of classes; ***index is close to class "Very good"; **** index is close to class "Good"

The prediction may be done correctly even if some parameters are unknown. For example, for sample no. 1 the probability of the "Very good" class is still high (77%) when we have data for just four parameters (grey nodes on Figure 2).

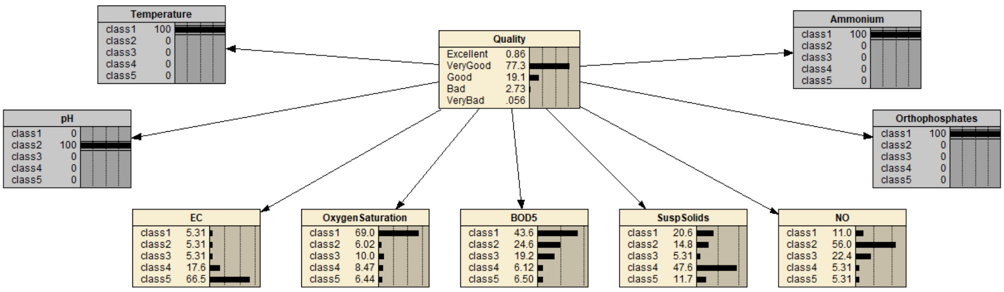



**Figure 2** Example of the prediction with missing data (sample no. 1)

## Conclusion

Water quality prediction is an important issue for efficient water management. Very often some parameters are missing or are expensive to measure. It is a challenge to predict it precisely because of many influence factors some of which can be changed easily and quickly, but also because of the consequences that may occur due to incorrect prediction. The NB classifier is conducive for this purpose because the final decision can be made based on a probability distribution, i.e. on known uncertainty. Further, in the BN model, the parameters are conditionally independent, thus it is easy to manipulate with the data (add, delete, change) within the network. Finally, the model in this work predicted accurately 64 out of 68 cases and gives correct results when some data are missing.

**Acknowledgment**

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# Water reuse for vine irrigation – from research to full-scale implementation

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**Abstract:** From this 2021 summer, 80 ha of vine will be irrigated with tertiary treated municipal effluent in the French Languedoc region. This was made possible thanks to a collaborative research project conducted between 2013 and 2018 to address all potential health and environmental risks associated with this process. This paper aims at presenting an overview of the research project and its main conclusions, as well as the technical, financial and administrative solutions implemented for its up scaling.

**Keywords:** vine irrigation; water reuse

## Context

With 1.2 billion liters of wine produced annually, the Languedoc-Roussillon wine region is the largest in France and one of the largest in the world. The Mediterranean-type climate is characterized by hot and dry summers and rare and concentrated precipitation during the winter period.

Between 2000 and 2006, summers have been particularly hot and dry in the area, resulting in an estimated loss of production of 9%. One of the consequences from these hot and dry events is that a law was voted in 2006 to enable the previously prohibited irrigation of vine under certain conditions, in order to support, but not to increase, the productivity of wine per ha according to their respective rules of appellation of origin.

Water reuse for irrigation of cultures or green spaces has been regulated in France since 2010, with an amendment in 2014 [1]. This regulation defines 4 classes of water, from A to D, depending on the intended use and method of irrigation (sprinkler or drip).

## The Irrialt'eau research project

Between 2013 and 2018, Veolia led a collaborative research project in partnership with the INRAE research institute, the Grand Narbonne public authority, AQUADOC and La Cave Coopérative de Gruissan, to assess the potential impacts of irrigating vine with tertiary treated municipal effluent, in comparison with surface water and potable water.

Two tertiary treatment lines (Figure 1) were investigated to produce class B and class C (which is the quality required for vine irrigation) water according the French regulation. The project specific objectives were to remove existing barriers:

- Technical: reinforce competencies and know-how in terms of design and operation of the treatment scheme; demonstrate that health and environmental risks could be effectively managed.

- Social: support the acceptance of water reuse for vine irrigation by opening the project site to visitors and broadly communicating the results.
- Financial: assess the costs and benefits of the various irrigation scenarios.

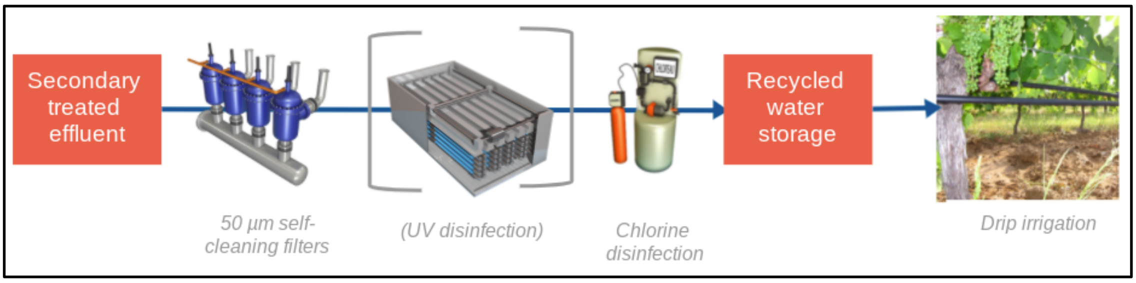


**Figure 1** Schematic diagram of the 2 tertiary treatment lines.

Between 2013 and 2016, 2 characteristic grapes of the region (Viognier and Carignan) were irrigated over 3 consecutive summers on testing parcels with the 4 different waters (reclaimed class B and C, surface and potable). Extensive monitoring was conducted on:

- Water quality: microbiological indicators, physic-chemical parameters and micropollutants.
- Aquifer and soil: microbiological indicators and physic-chemical parameters.
- Wine: microbiological indicators, pesticides and carbamazepine
- Plants/grapes/must: agronomic monitoring

Results of this research project were previously presented at water professional events [2]. As an example, Table 1 below provides a comparison of Sodium Adsorption Ratio (SAR) and key ions concentrations depending on the type of water.

**Table 1** Comparison SAR values for different waters.

| Parameter | Unit | Agronomic standard | Class B water | Class C water | Surface water |
|---|---|---|---|---|---|
| SAR | mmol/L | < 10 | 3.2 | 2.9 | 1 |
| Chloride | mg/L | 300 | 224 | 214 | 42 |
| Chloride + sulfate | mg/L | 400 | 275 | 272 | 90 |
| Sodium | mg/L | 450 | 124 | 111 | 33 |

The electrical conductivity of the reclaimed water varied between 1,450 and 1,900 µS/cm for the duration of the project. It was therefore concluded that the reclaimed water, while more mineralized than the surface water, was suitable for vine irrigation and soil stability.

Similarly, all results produced during the project demonstrated the feasibility of applying this process for vine irrigation while effectively managing health and environmental risks.

## Full-scale implementation

Based on these positive results, it was decided to roll-out the water reuse solution to a larger scale irrigation scheme covering 80 ha of vine for commercial production. In order to do so, several barriers had to be addressed.

- Technical

In June 2020, the European Union (EU) released a new regulation establishing minimum water quality standards for water reused across its member states [3]. This regulation that aims exclusively crops irrigation is again articulated around 4 classes of water quality depending on the type of cultures and method of irrigation considered.

Irrigation of vine by drip irrigation has to comply with class C water quality according to the EU regulation, which is more stringent on maximum concentration of *E.coli* than the French regulation (i.e. ≤1,000/100mL vs ≤100,000/100mL respectively for EU and French regulations), but has no additional requirement for the removal of other microbial indicators (such as coliphages for pathogenic viruses, or spore-forming sulfate-reducing bacteria for protozoa). The EU regulation does ask for a water reuse risk management plan to be implemented. The outcomes of the research project

While the results obtained during the research project demonstrated that it was not particularly challenging to meet the ≤1,000/100mL EU class C limit for *E.coli*, the tertiary treatment process was upgraded by replacing the 50 μm self-cleaning filters by a more robust automatic backwashing glass marbles pressurized filter. The complete tertiary treatment process developed as a standard solution for water reuse by Veolia Eau has a capacity of 50 $m^3/h$ and all equipment fits within a 20 ft. container labelled the REUSEbox (Figure 2).

**Figure 2** Pictures of a standard containerized 50 $m^3/h$ REUSEbox.

This REUSEbox as well as upstream/downstream flexible soft storage tanks and associated piping has been installed at the back end of the municipal wastewater treatment plant and is ready for its first season of irrigation during summer 2021.

In addition to the tertiary treatment unit, a 7.8 km network had to be installed along with 13 connected irrigation meters and valves to irrigate the 80 ha of vine.

- Administrative

In order to fully manage the risks associated with this water reuse scheme from production to use, an association of irrigators had to be created. This association is responsible for the distribution of the reclaimed water from the treated water storage tanks to the limit of the irrigated parcels and the irrigation valves that are controlled by winegrowers. It then becomes their responsibility to use this water for drip irrigation on their parcels.

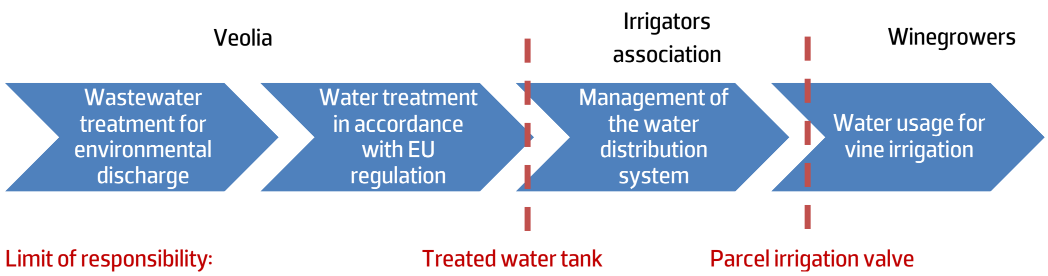


Figure 3 Chain of responsibility for the scheme operators.

A request for irrigation with reclaimed water had to be filed and has been approved by the competent authority (the Prefecture that is supported by the local health agency).

- Financial

The investment cost was heavily subsidized by local and European funds as described in the Table 2 below.

Table 2 Breakdown of investment costs and subsidies.

| Parameter | Investment costs | Subsidies | Funding agency | Remaining costs |
|---|---|---|---|---|
| Tertiary treatment | 532 k€ | 100% | Region Occitanie<br>Narbonne City | 0€ |
| Distribution system | 774 k€ | 80% | European fund FEDER | 154.8 k€ |

The cost to the winegrowers is ultimately of 0.65 €/m3 of water used for irrigation. This includes 0.38 €/m3 for the operations and maintenance costs of the tertiary treatment plant (manpower, maintenance, consumables, analytical) as well as 0.27 €/m$^3$ for the irrigators association (amortization of 20% of the investment costs and maintenance). This is shown in Figure 4 below.

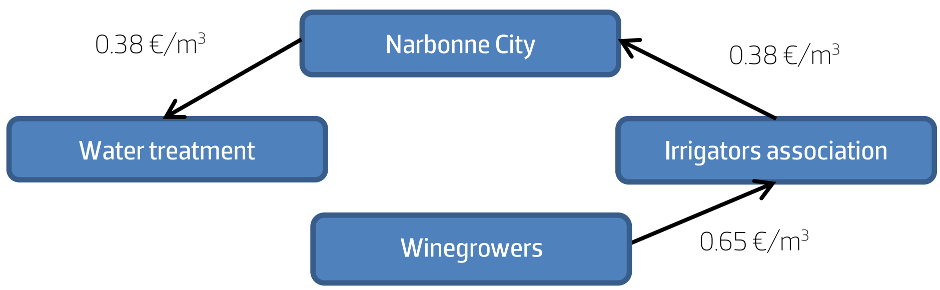


Figure 4 Repartition of the O&M costs.

The impact targeted for the winegrowers is a security on yield resulting in an net increase of income of 350€/ha.

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## A panoramic view of the recent Brazil´s sanitation framework

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**Abstract:** The recent review of Brazilian sanitation legal framework generated high expectations for the society and market. Besides an ambitious goal to cover over 90% of the population with water and waste services, and the more opportunities for private companies, it exposes a complex network of services and actor, increasing the challenge to regulate the sector in different scales and knowledge level. This article proposes a panoramic view of the key values to contribute to a comprehensive dialogue and to enhance the sector by an opportunities identification to specialize and fill gaps.

**Keywords:** Sanitation; System Approach; Values Mapping.

## A selection method to optimize preventive maintenance task in water facilities

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**Abstract:** Wastewater treatment processes require a lot of equipment. From an economic perspective one of the most important is centrifugal pumps since they require huge amounts of financial resources in acquisition, maintenance, and energy. In addition, these equipment are subjected to continuous wear and tear mainly due to the conditions in which they work, causing breakdowns and unplanned stops. To predict breakdowns, approaches based on artificial intelligence techniques have been used, such as neural networks, support vector machines, regression, fuzzy logic, or genetic algorithms. The present work determines, from a panel of experts, which are the maintenance tasks and their frequency, as well as other characteristics that can affect a greater wear and tear of the equipment. Next, a decision tree is used to optimize maintenance and thus reduce the probability of failure in the equipment analyzed.

**Keywords:** Maintenance; Water facilities, Machine learning, Centrifugal pumps.

## A well-tested approach for water-energy diagnosis to improve efficiency in urban water systems

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**Abstract:** Urban water systems (UWSs) need energy for abstraction, transport, distribution, collecting, treating and reusing water, and water-energy efficiency is a key performance objective of its strategic asset management towards its sustainability. Herein, the novel aspects of the recently proposed framework for a comprehensive assessment of UWS energy efficiency are presented, namely new performance indicators and reference values for wastewater systems and equipment (e.g., pumping stations). This framework is being applied to 13 Portuguese water utilities, the diagnosis results are herein summarised, and the sources of energy inefficiencies at each level of analysis. Examples are energy dissipated by water losses, layout or operation in drinking water systems, undue inflows and infiltrations in wastewater systems, and the lack of aeration adjustment to influent wastewater quality during treatment..

**Keywords:** Diagnosis, efficiency; energy; urban water systems.

## Alignment between the Urban Water Sector Mission and the SDGs: the Management Model Effect in Portugal

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**Abstract:** The 2030 Sustainable Development Goals (SDGs) reinforce the central role of organizations in the implementation of solutions that promote sustainability. Similarly, there is a direct link between society's well-being and the management of water resources. Thus, water companies have a central role in defining targets and programs focused on achieving these goals. This research aims to analyze the incorporation of the SDGs in the Portuguese water sector and evaluate whether their incorporation varies with the management model of each organization. Likewise, it is also intended to compare these results with those observed at international level. By examining the existence of a management model effect in the integration of the SDGs, the paper contributes to the formulation of adoption policies.

**Keywords:** Water management; water sector; sustainable development goals.

## Assessing unacceptable intermittent saline inflows in urban water systems

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**Abstract:** Urban water drainage systems are designed to transport either sanitary or stormwater, and are usually not designed for saline waters. In coastal areas, saline undue inflows increase the risk of bypass and may compromise the structural condition of concrete structures, wastewater treatment, and reuse for irrigation. Using asset management to better understand the constraints to service levels compliance in treatment facilities, implies considering the behavior of the upstream drainage system and its interconnections with the surrounding surface waters. The paper presents a procedure for diagnosing the presence of undue saline inflows, namely to determine its magnitude, acceptance levels, and contribution to the system's performance, namely wastewater treatment. The need to use asset management when considering these inflows is also highlighted. Application to a case study, discussion of results, and replicability opportunities are presented.

**Keywords:** Assessment; undue inflow; saline water; sewer systems.

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## Assessment of Sustainable Drainage with Detention Pond System for Peak Flow Attenuation

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**Abstract:** Conventional stormwater management removes runoff from developed areas as quickly as possible. It does not consider possible reduction of runoff at source or water pollution control, and sustainability aspects cannot be incorporated in the management of stormwater by following this practice. This article describes the design, hydraulic simulation and appraisal of a sustainable stormwater management system in a new urban housing development. The post-development peak stormwater discharges achieved were considerably smaller than the pre-development discharges.

**Keywords:** Stormwater management; urban residential development; sustainable drainage system; life cycle economic evaluation; regional control SuDS technique; water sensitive urban design.

## Asset Management and circular economy: a perfect binomial

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**Abstract:** Although the main target of the application of circular economy in the wastewater treatment sector has been waste management, the current research intends to extend its application to other aspects: the equipment and facilities. Circular economy should be applied at all levels in order to guarantee the sustainability of wastewater services. To this end, the research will demonstrate how asset management could help to achieve this circularity in wastewater facilities.

**Keywords:** Circular Economy; Deterioration; Wastewater.

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## CAN – Alerts and Notifications Center: a disruptive approach for water utilities

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**Abstract:** Águas do Norte operates around 1,150 water and wastewater facilities in northern Portugal. About 110 SCADAs monitor the equipment status, water and wastewater treatment processes and facilities supported in automation and Internet of Things systems.

Having different levels of maturity in terms of equipment diversity, supervision platforms, alarm solutions and alerts descriptions, any activity to maintain the existing alarm solutions becomes complex and expensive. Monitoring activities on multiple SCADAs becomes hard to perform.

As such, CAN was developed as a disruptive platform to centralize and manage alarms coming from multiple SCADAs, with additional information from other platforms on the organization. The result is to deploy online (web and mobile) democratized information combined with metrics and features for all operational staff.

**Keywords:** Alarm Management; Artificial Intelligence; Machine Learning.

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## Can Financial Inclusion Improve Water and Sanitation Policies? Empirical Evidence from Developing Economies

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**Abstract:** Access to clean drinking water and sanitation facilities remains a fundamental challenge in many developing economies even today. Achieving greater water and sanitation access has indeed been a global policy priority over the years, especially considering how these objectives are listed as an integral part of the United Nations' Sustainable Development Goals (SDGs). Despite notable progress made over the years, several international organizations still continue to devote significant funds towards developing the requisite infrastructure to facilitate access to drinking water and sanitation, especially in the rural areas which would translate into improved hygiene and living conditions of local communities.

The policy world has recognized the pivotal role of financial inclusiveness, through traditional financial instruments (e.g. small loans) as well as their digital counterparts (e.g. mobile money wallets) as a possible way to enable accessibility to water and sanitation infrastructure, primarily by reducing transactions costs and offering low-cost alternatives for water connections.

Yet however, there has been little academic research on the role played by financial inclusion to enhance the accessibility of developing economies to water and wastewater services (WWS). While much of the limited set of studies available on this subject are largely qualitative and case specific, there appears to be a significant gap in the literature when it comes to offering empirical evidence of WWS policy implementation and the role played by financial inclusion.

Given this context, our study aims to explore the role played by traditional and digital financial instruments in increasing the accessibility of WWS in developing economies. Our empirical approach will rely on estimating the impact of financial inclusion on access to WWS by factoring in the heterogeneity among regions and countries. To that end, we will employ panel data techniques to focus on a large number of middle income and lower-income countries over 1995-2018, cutting across all regions.

We also expect our findings to further consolidate the existing efforts (e.g. WASH programme) to improve WWS accessibility and relevant policies in developing economies through achieving effective financial inclusion among the local communities in selected study areas.

## Combining data clustering and stratified sampling for selecting customer's location for smart meter installation in drinking water distribution systems

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**Abstract:** In drinking water distribution systems, smart metering data of customers is crucial to enhance billing systems, network operation and maintenance of water losses. However, this equipment is expensive and technologically complex. Therefore, reducing the number of smart water meters is fundamental. A representative sample of customers, using stratified sampling based on billing consumption, was selected for smart metering installation. With around 50% of the customers sampled, the approximate error on the total billed consumption was 1%. Based on the customers' sample, essential information for real loss (water consumption patterns, domestic minimum night consumption) and apparent loss (volume distribution by the flow) analysis was obtained. The very trustworthy approximations achieved contribute to the economic, environmental, and infrastructural sustainability of water utilities.

**Keywords:** Customers' stratified sampling; Drinking water distribution systems; Time series clustering.

## Cost and Benefits of Green Stormwater Control Measures: taking into account the multifunctionality and the multi-actors maintenance

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**Abstract:** This article proposes a cost-benefit analysis of two green stormwater control measures scenarios with regards to the traditional sewer system in the Eurométropole de Strasbourg (France). As green stormwater control measures are not maintained only by the sewerage utility but also by other departments within the metropolis, we investigated the direct costs for these different actors. To assess the benefits for users, a survey on residents was conducted aiming at assessing their preferences and measuring their willingness-to-pay for the benefits provided by green stormwater control measures. At the end, all costs and benefits of the scenarios during the timeline of the programs were incorporated into the cost-benefit analysis. Results provide new insights for informed judgement and decision-making.

**Keywords:** Green stormwater control measures; cost benefit analysis; France

## Cost-benefit analysis of enhancing the control of pharmaceutical compounds in conventional wastewater treatment plants

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**Abstract:** Currently, in the European Union, there are no requirements to remove contaminants of emerging concern in urban wastewater treatment plants (WWTPs). Without the support of an adequate regulatory framework, it is difficult for water utilities to recover the costs incurred with the enhanced control of pharmaceutical compounds (PhC). However, there are other drivers that may support an investment from water utilities in treatment enhancement, such as, an aspiration to be a front-runner or an environmental commitment within the organisation. The objective of this paper is to present the results of the Cost-Benefit Analysis applied to existing treatment plants in order to evaluate the feasibility of the enhanced PhC control in conventional urban WWTPs.

**Keywords:** cost-benefit analysis; contaminants of emerging concern; enhanced wastewater treatment.

## Customer satisfaction in Portuguese drinking water services

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**Abstract:** Assessing the quality of services is mandatory for any enterprise's profit. Particularly, such a quality influences customer satisfaction and, inherently, brand loyalty (Srivastava and Kaul, 2016). Being part of quality, which is a broader concept, customer satisfaction plays, then, a central role in modern marketing theory and practice. This topic is not only important in competitive markets, but also for regulators and other public entities, whose objective is not profit maximization. For the case of regulators, policies might be influenced by the service quality and, then, by customer satisfaction (Hormann, 2016). For instance, tariffs for drinking water supply services may result from the operators' performance (Ferreira et al., 2020), which in turn depends on the quality and, naturally, the customer satisfaction (Ferreira and Marques, 2019). Thus, if the quality is poor, there must exist a penalty over such a tariff or the company delivering the service.

Ensuring access to safely managed drinking water, recognized as a human right by the United Nations General Assembly, has been a challenge for many countries, mainly those located in Africa, Central and South America, and Asia (Cetrulo et al., 2020). Particularly, there is the problem of waterborne diseases, whose containment constitutes a considerable burden for different governments worldwide. Even in developed countries, such a problem may exist, especially in the form of gastroenteric diseases (Ferreira et al., 2021a), resulting from poor quality and conditioning later the customer perspective and satisfaction. It demands a stronger regulation act upon drinking water operators.

In mainland Portugal, drinking water is a public service delivered by over three hundred suppliers serving more than ten million people. Although the drinking water transport to a general hydraulic system is done at the bulk level, the distribution to the end-consumers is made by retail operators (Hormann, 2016). Besides, there are three management models of the drinking water sector: direct management, delegation, and concession. In retail, direct management by municipalities is the most important model in terms of market share. The Portuguese Water and Waste Services Regulation

Authority (ERSAR), operating under the supervision of the Ministry for Environment, regulates the drinking water supply and other two public services (wastewater and waste). ERSAR's main goal is to ensure equal and safe access to those services, keeping all operations transparent, and promoting accountability. Because of the natural monopoly in the water sector, ERSAR plays a very important role in fixing and regulating tariffs, which, as claimed before, should account for the quality of the service, including customer satisfaction.

Customer satisfaction is a somehow difficult term to define (Stefanini et al., 2020). Perhaps the most accepted definition is the extension to which customer preferences and expectations are met (Sitzia and Wood, 1997). Thus, if at least one expectation or preference is not met by the service supplier, the customer cannot be fully satisfied. Naturally, criteria underlying satisfaction do not share the same weights (Grigoroudis and Siskos, 2002), nor do they have the same influence over the overall satisfaction. Customers can be more demanding regarding one criterion and less demanding regarding another criterion (Ferreira et al., 2018). In the same vein, the company's performance does not necessarily increase with satisfaction. For instance, the Kano model defines three types of criteria: must-be, one-dimensional, and attractive requirements (Suh et al., 2019). Must-be criteria are mostly associated with basic needs, like waiting time in a queue, and are taken for granted by the customer: he/she never gets satisfied even if the company performs well in those dimensions but becomes very dissatisfied in the case of poor performance. In opposition, attractive attributes or criteria are not necessary as customers never get dissatisfied even in the case of absence but tend to be satisfied if present in the service. In the middle, one-dimensional attributes lead to satisfaction if present (and being properly executed) and to dissatisfaction otherwise (Ferreira et al., 2021b). All these concepts must be considered whenever designing new strategies and legislation concerning the delivery of any service (Grigoroudis and Siskos, 2010), including the public ones, like drinking water.

In the case of the public sector, customer analyses tend to focus on healthcare (Ferreira et al., 2021b), while there are not many devoted to water (drinking water and wastewater) or waste. For instance, Kassa et al. (2017) studied the customer satisfaction in the case of urban water supply services in Ethiopia, using over eight thousand surveys based on SERVQUAL model. The authors verified that satisfaction was far below acceptable levels and detected a positive relationship between satisfaction and service quality. In Portugal, Hormann (2016) employed an ordered logit model to analyze the importance of specific service aspects for overall customer satisfaction and its main drivers. The author used a set of more than one thousand surveys obtained by ERSAR and, during the experiments, she faced several problems related to the categories used to classify the judgments made by customers in all satisfaction criteria. Recalling that surveys typically use ordinal scales for judgments, it is imperative to say that the classes or categories only obey to a pre-specified order, i.e., 2 (dissatisfied) is better than 1 (very dissatisfied), 3 (neutral) is better than 2, and so on. However, conducting mathematical operations over these numbers is not correct because they are just semantic representations of judgments and the effort spent going from 1 to 2 is not necessarily the same effort of going from 2 to 3, i.e., $3 - 2 \neq 2 - 1$. Following Stevens (1946), transforming the ordinal scale into a utility scale is an admissible and possible alternative for dealing with that problem.

Therefore, this study proposes to evaluate customer satisfaction in Portuguese drinking water services adopting the so-called MUSA model (Grigoroudis and Siskos, 2002, 2010), which constructs utility scales for satisfaction criteria, based on customer judgments. MUSA constructs a utility function per criterion which should represent an average customer. Using this model, we can assist the regulator on what are the main drivers of customer satisfaction and what is the expected behavior of customers beholding service performance improvement.

## Digital transformation in water and energy utilities – Porto Case

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**Abstract:** Águas e Energia do Porto is the water utility company that manages the entire urban water cycle and has been doing a portfolio of business transformation processes that have a clear and strong support of IT and innovation technologies. In this paper we'll try to expose the approach to innovation and IT that build the most part of business strategy.

**Keywords:** Management, technology, innovation, operations, clients, assets.

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## Economic impacts of Rainfall-Derived Inflow/Infiltration in sewage networks

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**Abstract:** This study aimed to estimate the costs of having excess water (rainwater and unauthorized wastewater) flowing into sewer systems. A calculation methodology based on management recorded values was developed and applied in eight case studies, with different characteristics and configurations.

Results revealed that around 50% (sometimes more) of the wastewater flowing in upstream wastewater management entities, is rainwater or unauthorized wastewater and, thus, not invoiced. Costs related with this excess water ranged from 0.3 M€ to 7.2 M€ per year. The results strongly justify an investment in the control and minimization of this problem to assure the financial sustainability of these systems, with clear associated environmental and social benefits.

**Keywords:** Rainfall derived inflow/infiltration (RDII); RDII impacts; sewage systems efficiency; sewage management.

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## Efficiency benchmark of drinking water service providers in Portugal

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**Abstract:** The analysis of technical-economic efficiency of the Portuguese drinking water service providers, from 2015 to 2019, reveals that water intake is the most efficiently managed resource followed by energy consumption and expenditures. On the other hand, the allocated personnel is the resource less efficiently managed. Regarding the outputs, the billed water attained the largest efficiency opposite, to the low energy production efficiency. The least efficiently managed output is the undesirable water losses. From 2015 to 2019 there was an overall gain in total efficiency due to a positive technological change. The service providers size, typology, governance model, mains length, supply failures and certifications impact the operators' efficiency.

**Keywords:** Water service providers; efficiency benchmarking; data envelopment analysis.

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## Energy Efficiency of Drinking Water Treatment Process and its Drivers Using the Stoned Approach

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**Abstract:** The evaluation of energy performance of water treatment facilities is critical to deliver potable water in an efficient and sustainable manner. Understanding how energy efficient is the drinking water treatment process could help managers to make informed decisions on how much energy should be used and what drives this behavior. Controlling energy consumption during the water treatment process could lead to lower production costs and lower levels of greenhouse gas emissions improving therefore economic and environmental performance of water companies.

In this paper we measure the energy efficiency of several drinking water treatment plants in Chile using a robust methodology called stochastic non-parametric envelopment of data (StoNED). This approach avoids the limitations of the widely used SFA and DEA approaches under an efficiency framework. We also include several environmental variables to see their impact on energy performance. The main findings of our study can be summarized as follows. First, it is found that the removal of pollutants from raw water significantly impacted energy use. In particular, cleaning water from total dissolved solids and sulfates pollutants were major drivers of energy consumption. Other factors that could affect the energy performance of drinking water treatment process were the type of water resource and the type of technology used. It is found that treating more water from mixed sources, both groundwater and surface, requires high use of energy. Coagulation flocculation processes and gravity pressure filters (CF-RGP) technologies could be more energy efficient than

other types of technologies that combine chemical processes and pressure filters. In terms of energy efficiency, the results indicated that the drinking water treatment plants on average are characterized by low levels of energy efficiency. The mean efficiency was 0.461 which means that energy savings of the amount of 54% could be obtained to generate the same level of water. The majority of the treatment facilities reported an efficiency score which ranged between 0.41 and 0.61 on average whereas there was only one treatment facility with an energy efficiency score greater than one. It is also found that DWTPs who use CF-PF technology could save energy up to 67.2%, whereas DWTPs who use CF-RGP technology could reduce energy by 52.4% to remove the same level of pollutants. On average the majority of the most energy efficient treatment plants are old and small facilities that operate under full private ownership. They use a combination of chemical processes and gravity pressure filters technologies mainly to remove high volumes of turbidity and sulfates pollutants from mixed water sources. By contrast, newer facilities were found to be less energy efficient. These facilities are large and treat higher volumes of turbidity and sulfates. They mainly use chemical processes and pressure filters to clean surface water from pollutants. From a policy perspective the findings of our study could be of great importance for several reasons. We provide robust energy efficiency scores using a methodology that overcomes any shortcomings of other parametric and non-parametric techniques. The low energy efficiency of the drinking water treatment plants suggests that managers need to act. Considerable savings in energy use could lead to a better economic and environmental performance, lower production costs and lower levels of greenhouse gas emissions released in the atmosphere. This could be done by adopting energy efficient technologies, maintaining the existing infrastructure, and treat water from mixed sources. We believe that managers could incorporate these aspects in their decision making process so that they can contribute to the enhancement of the economic and environmental sustainability of the water cycle.

## Excess inflow in wastewater treatment plants: environmental and economic aspects

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**Abstract:** The existence of rainfall derived inflow and infiltrations in sewage networks brings negative consequences, that are and will be highlighted by intense rainfall phenomenon (due to climate change) and by adverse economic contexts. This excess inflow compromises the performance of Wastewater Treatment Plants (WWTP), as well as the compliance of quality parameters and sustainability criteria applied by management entities. This study aimed to elaborate a methodology to determine the excess inflow admitted to a WWTP and estimate the associated economic and environmental impacts. A real case study was used to assess its application, and the results revealed the magnitude of this problem, and the necessity of implementing urgent mitigation procedures.

**Keywords:** Sewage networks; excess inflow; wastewater treatment plants (WWTP); efficiency of WWTP.

## Extracellular polymeric substances recovered from aerobic granular sludge – a natural material for different applications

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**Abstract:** Circular economy has been directing the water sector towards the recovery of added value bioproducts from wastewater. In this work, extracellular polymeric substances (EPS) were recovered from aerobic granular sludge (AGS) and were used as an immobilizing agent for a 2-fluorophenol degrader, *Rhodococcus* sp. FP1. The produced EPS granules exhibited a 2-fluorophenol degrading ability of 100%, preserving that after up to 2 months. The bioaugmentation of an AGS reactor with EPS granules led to the degradation of 2-fluorophenol and allowed for recovery of nutrients removal. Moreover, AGS can be used to enhance plant growth in soil adverse conditions. Recovery of EPS from AGS biomass in wastewater treatment plants can be used in a truly circular economy approach, integrating asset management in water treatment.

**Keywords:** Extracellular polymeric substances; microorganisms' immobilization; plant growth.

## From a Millennium to a Sustainable water and sanitation development: Were we there already?

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**Abstract:** The Sustainable Development Goals (SDGs) of the United Nations (UN) brought many countries closer to the best practices in several sectors. However, regarding water and sanitation services (WSS), the evolution from the original Millennium Development Goals (MDGs) is not yet understood. Therefore, analyzing whether low- and middle-income nations were able to converge in terms of WSS is fundamental for policy-making. Here, we propose a benchmarking exercise aimed at assessing the performance of 123 UN Member States regarding WSS development targets over the 2001-2015 period of MDG pursuance. In the end, we show that, on average, the assessed Member States were already fully convergent before the implementation of the SDGs, despite further improvements with the latter.

**Keywords:** Water and sanitation services; Millennium Development Goals; Convergence.

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## Guidelines to enhance infrastructural asset management in water utilities: the Portuguese regulator's perspective

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**Abstract:** The Portuguese water sector has made remarkable progress in the past three decades. The current challenge is to guarantee long-term sustainability, by ensuring that existing infrastructures are properly managed, with adequate levels of preventive maintenance, repair and rehabilitation.

In the last years, a growing interest in infrastructural asset management (IAM) principles has been observed in Portugal. However, there is still a long road ahead, and the regulator can play an important role in promoting the implementation of IAM best practices in the sector.

This paper aims to discuss how an asset management approach can help water utilities to develop sound investment plans in compliance with public service goals. On the other hand, it intends to present a model developed by ERSAR that will help water utilities to assess the condition of their infrastructural assets, based on a set of pre-defined and harmonized criteria.

**Keywords:** Infrastructural asset management; Investment plan; Public service goals.

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## H2Porto – from unstructured data to real time decision making central tool

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**Abstract:** Águas e Energia do Porto is the water utility company of the second largest city in Portugal. With infrastructures covering 41 km$^2$ of land on River Douro's mouth by the Atlantic Ocean, the company serves a population of 395,000 (45% of which is fluctuating), with significant pressure from tourism. Legacy data sources and numerous software systems and solutions, in multiple water networks can be a problem or a source of valuable information, online management and decision-making solutions.

**Keywords:** Data integration; technological platforms; digital twins.

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## How To Replace Inefficient Assets With No Investment Efforts. Now Water Companies Don´t Have To Take The Risk. They Just Have To Make a RISCA.

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**Abstract:** Many reasons contribute to the lack of efficiency of important assets managed by water companies. Replacement of those assets is usually expensive and demands intensive capital expenditures. Águas do Norte develop a new methodology based only in performance fee, giving water companies a new tool to replace old and inefficient equipment by new and highly performant one.

**Keywords:** Energy; efficiency; equipment replacement.

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## Implementing a circular economy model in the water sector at local level

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**Abstract:** The rapid demographic and economic growth has increased the demand of natural resources while increasing the production of waste and accelerating the degradation of natural resources putting at risk their sustainability. Water is a very vulnerable and valuable resource that should be managed optimally to guarantee its availability. Therefore, there is a strong need to implement strategies that allow the transition from a linear economic model to a circular one, particularly in this sector. To face this

situation the current research aims to develop a model to implement a circular economy model giving value to the products generated taking into account the local context.

**Keywords:** Water; Wastewater; Circular economy; Circular model.

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## Internal and integrated workforce for the water supply and wastewater treatment tariff: AdP – Águas de Portugal case

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**Abstract:** Portuguese water sector model demands an enormous ability to evaluate different future scenarios, involving not only demographic, technological, regulatory, financial, but also water consumption trends. To this need adds the rapidly changing economic cycles, together with technological improvements and regulation updates, to shown that predicting the future is, nowadays, more difficult than ever, and, at the same time, a total necessity

Modelling tools implemented by the AdP group allied with considerable technical, financial and regulatory knowledge resulting from several years of water systems exploitation have been the backbone of many studies and evaluations of with intention to provide evidence and guidance for strategic political decisions, such as future water sector configuration, but also for operational decisions concerning efficiency drivers and sustainable tariffs.

Though a workforce as gather in AdP Group in order to address to these challenges and to provide the answers needed by the stakeholders to make to best scenario decision always regarding the final tariff results.

**Keywords:** Energy; efficiency; equipment replacement.

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## Microalgae for Paper Industry Effluents Remediation

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**Abstract:** Microalgae are photosynthetic microorganisms with the capability to play the dual purpose of wastewater remediation and added-value bioproducts accumulation. This study evaluated the potential of the microalga *Chlorella vulgaris* for nutrients removal from a paper industry effluent and bioenergy production. Experiments were performed to assess the potential of this microalga to: (i) successfully grow in different concentrations of a paper industry effluent (from 20% to 100%); and (ii) treat the industrial effluent, reducing phosphorus concentrations. Then, a techno-economic assessment was performed to study the viability of a *C. vulgaris* biorefinery aiming the remediation of a paper industry effluent and bioenergy production, while extracting value from the existing wastewater treatment plant, targeting Asset Management goals.

**Keywords:** Microalgae production; Wastewater remediation; Biorefinery; Nutrients Removal.

## Microalgae-bacterial granular systems able to treat marine aquaculture water streams

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**Abstract:** This study aimed to evaluate the granulation of microalgae-bacterial biomass and its ability to treat marine aquaculture water streams. For this, a phototrophic consortium adapted to saline conditions was enriched from water collected from a marine aquaculture facility and then used to develop the microbial aggregates. Two lab-scale photo-reactors were used: one inoculated only with the enriched phototrophic consortium and the other with the consortium and activated sludge. Rapid granulation was achieved. High ammonium and organic carbon removals of about 100% and 80%, respectively, were quickly established and maintained in the long run. . This study demonstrates the rapid granulation of phototrophic biomass and its robustness and feasibility for nutrient and carbon removal from extremely low loaded water streams.

**Keywords:** Microalgae-bacterial granules; marine aquaculture water streams.

## Nitrogen treatment optimization and associated energy consumption reduction

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**Abstract:** Controlling aeration of activated sludge tanks based on online ammonium and/or nitrate measurements is a proven technology to optimize energy consumption, reduce carbon footprint, and guarantee high-quality water level. The water management board of Metz chose to implement an aeration optimization system based on ammonium online measurement. A reduction of 16% in electricity consumption dedicated to the aeration was successfully obtained. This reduction of electricity consumption was paired with a slight overall improvement of the total nitrogen removal rate.

**Keywords:** Aeration; nitrification; optimization; energy.

## Optimizing water infrastructure replacement: an approach from the circular economy

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**Abstract:** Wastewater treatment plants are very valuable urban infrastructures that should be maintained in order to guarantee the quality of the service. Nevertheless, this facilities age over time and their components degrade progressively, therefore they should be replaced. With the aim of helping operators and plant managers to establish a replacement strategy, the current research intends to analyze not only the economic aspects associated to the replacement of the equipment, but also the environmental impacts that it could generate.

**Keywords:** Maintenance; Water facilities, Machine learning, Centrifugal pumps.

## Pennies and Dimes: The Harder Way to Buckets

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**Abstract:** The definition of water affordability for urban water and wastewater systems is quite a challenging issue in developed countries and even more in developing countries. This study attempts to give an overview of the affordability status in 164 cities worldwide by using the Hours of Minimum Wage (HM) indicator as a metric. The HM indicator provides a benchmark for the affordability of the poorer members of society by analyzing consumption habits, water expenditures and household incomes. It is concluded that the monthly cost of a "basic" water consumption of 50-100 litres/capita/day should not exceed 4hours/month of minimum wage labor to maintain equity of financial burden between poor and wealthy households.

**Keywords:** Water; Affordability; Equity.

## Performance assessment of water services in Brazilian municipalities: an integrated view of efficiency and access

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**Abstract:** This study proposes a benchmarking approach to assess water supply and sanitation services' performance in Brazilian municipalities from an integrated perspective of efficiency and access. The regional differences and the impact of the governance models adopted by different municipalities (local public entities, regional public entities, and private entities) on efficiency levels are also explored. The results revealed significant heterogeneity in the efficiency levels of Brazilian municipalities, as the average efficiency score is relatively low (45%). The Southeast and Center-west regions stand out both in terms of efficiency and access dimensions. There is evidence that municipalities with services provided by local entities have higher efficiency than those with regional providers. On the other hand, efficiency differences between municipalities with public and private providers are statistically significant. Finally, the results suggest that municipal socioeconomic development significantly impacts performance, especially the access dimension.

**Keywords:** Data Envelopment Analysis; Efficiency; Access.

## Porto WWTP as resource factories, from a circular economy perspective

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**Abstract:** Águas e Energia do Porto, EM delineated a clear vision for decarbonisation of its activity and efficient use of resources. For that, it defined as a strategy the creation of a Complex for the Valorisation of Porto Wastewater, that aims to redesign their WWTP, positioning itself at the forefront of scientific-technological development and environmental sustainability.

In 2020, promoted a study of "Performance Evaluation and Proposal for Improvement of their WWTP", in order to analyse reuse of treated wastewater, compounds recovery, micropollutants elimination, energy efficiency and, even, bioplastics production.

It is intended that WWTP are part of the municipal ecosystem of circular economy, through the incorporation of innovative solutions, which will enable the use of treated water and energy to self-consumption.

**Keywords:** WWTP; factory resource; circular economy.

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## Procurement Model Selection for Water Public-Private Partnership Projects in China

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**Abstract:** Water public-private partnership (PPP) projects are critical to the life quality of the public worldwide. As the largest developing country, China has launched hundreds of water PPP projects. Selecting the best procurement model for these projects is vital to their operational performance. This article intends to conduct a descriptive analysis of the procurement model selection for water PPP projects in China. Specifically, the distributions of procurement mode by investment, duration, secondary sector, operation model, and region are examined. This research is helpful to better understand the procurement model selection for water PPP projects, further helps the government decide which procurement models should be selected for different kinds of water PPP projects.

**Keywords:** Procurement model; water; public-private partnership (PPP).

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## Reliability and energy performance assessment of two urban wastewater treatment plants

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**Abstract:** A performance assessment system (PAS) has been applied to wastewater treatment plants (WWTP) to assist in the optimization of global efficiency and improve global effectiveness. This work presents the results obtained from a detailed analysis on wastewater treatment reliability and energy efficiency evaluation of two WWTP. The results allowed to identify improvement opportunities for each WWTP in terms of aeration energy requirements and to determine the effluent concentration goal for different parameters to achieve higher reliability levels whilst potentially reducing running costs. Additionally, the PAS assists in the identification of the limiting stages or dysfunctions of WWTP, which affect both efficiency and effectiveness, in order to determine the investment needs and prioritization of rehabilitation or even retrofitting of facilities' assets.

**Keywords:** WWTP; factory resource; circular economy.

## Rethinking sewer condition assessment – the importance of expert-based evaluation and benefits of an action related approach

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**Abstract:** Sewer condition assessment provides the basis for a broad range of further planning and asset management approaches. However, although well established in practice, current assessment protocols appear rather stringent, rehabilitation orientated and thus not very objective. To contribute to the development in the field, this abstract introduces a novel approach of sewer condition assessment differentiating between structural and operational perspectives. It furthermore highlights the importance of expert-based evaluation in sewer condition assessment in contrast to un-scrutinized computer-based ones. The work clearly indicates that sewer assessment approaches considering very local-specific boundary conditions through expert judgement are more beneficial than those just based on stringent specifications.

**Keywords:** Sewer operation; sewer maintenance; CCTV inspection.

## Retrofitting of the Montemor-o-Velho wwtp: an integrated solution in the circular economy

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**Abstract:** The increase in water scarcity and the frequency of droughts is prompting a profound change in the water management system, which provides not only for the conscious consumption of drinking water, but also for the reuse of gray water and treated waste water for compatible uses.

Biological Membrane Reactors present a set of very interesting characteristics, especially for the discharge of wastewater in sensitive areas, where the quality requirements of the treated effluent are **more demanding, and where the production and use of reusable water is foreseen. The Montemor-o-Velho WWTP fits into the set of facilities that will benefit from this retrofitting, contributing to reducing operating costs, improving the water quality of the Mondego River and saving water.

**Keywords:** WWTP; factory resource; circular economy.

## The challenges of energy optimization in Águas do Centro Litoral, SA

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**Abstract:** This work aims to reflect the state of the art of Águas do Centro Litoral, S. A. (AdCL) regarding energy consumption and own production of electricity. It will also be part of this work the goals that are intended to be achieved, with a view to reaching the carbon neutrality goals and the measures that will be implemented and the projects in which the company is involved.

**Keywords:** Energy; carbon neutrality; anaerobic digestion; ZERO Energy Neutrality Program; Ecodigestion 2.0; SCUBIC

## The i-SMART Management Model

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**Abstract:** To tackle the challenges that the water sector faces, management models and technology pair along and are a fundamental piece of Indaqua's strategy. At Indaqua, an intelligent and smart concept to water management and a business model supported on the use of key performance indicators, organizational processes approach, and on the balanced scorecard methodology, all of which adapted to meet the industry's specificities, are the base for performance continuous improvement. Key performance indicators' monitoring and reporting, strategy execution analysis, and overall performance assessment are agile and effective due to the adoption of the i2WaterBoard system developed by Indaqua to meet water organizations' governance requirements and regulatory reporting obligations.

**Keywords:** SMART; Strategy; Performance.

## The Role of Policies, Institutions and Regulation in the Capverdean Water and Sanitation Sector

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**Abstract:** Under the impetus of its main development partners in the sector, Cape Verde launched, in 2011, substantial reforms of the water and sanitation sector, aiming to change the paradigm at the level of production, distribution, governance and tariffs, technical and financial sustainability of the sector and the improvement of service quality.

Public policies for the water sector in Cape Verde were designed to promote, firstly, universal access to water supply and sanitation and, subsequently, the sustainability of these services. The new institutional framework of the sector was designed, aiming at the extinction of some existing institutions and the creation of new institutions with broad powers. The framework also defined new strategies for water mobilization and new standards of service quality to be provided.

**Keywords:** Water; regulation; policy.

## Use of recycled water in the city of Lisbon

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**Abstract:** Water stress can affect public health, environmental quality, development and competitiveness. The use of recycled water is a sustainable alternative to other water sources, which does not depend, at least directly, on climate uncertainty, contributing to the transition to a more circular economy. Lisbon is implementing a recycled water distribution system using the water treated in its water resource recovery facilities (WRRF), in accordance with the green strategic objectives of the city, namely the creation of green corridors and urban farming allotments. This approach constitutes an important process of environmental valorisation and protection of natural resources, with the conservation of water and minimisation of effluent rejection into the Tagus estuary, and will contribute to increase the city resilience to climate change drought scenarios.

**Keywords:** Recycled water; Strategic Plan; urban resilience.

## Valuing urban drainage assets – aligning financial and technical procedures

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**Abstract:** The paper presents a procedure for determining drainage assets' current and replacement value, in a situation where real construction costs are mostly unavailable and technical and accounting records are misaligned. Current asset value is determined based on estimated construction costs and a reflection is made on accounting and technical useful lives. In the case study, the development of the urban drainage asset management plan and the requirement to standardize the accounting system triggered the need to update information exchange and align technical and financial procedures in Lisbon Municipality. In summary, the proposed update and alignment might greatly impact the average value of annual depreciation and the reasoning of the wastewater tariffs. Results, their implications and replicability opportunities are discussed.

**Keywords:** Current value; fixed assets; urban drainage; useful life.

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## Water distribution costs optimization with Smart Digital Twins: a Case study

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**Abstract:** Water is the most important commodity for human life. However, water distribution networks are energy-intensive infrastructures, meaning that energy efficiency plays a large role in the sustainability effort of water utilities. The application of a digital twin represents an opportunity for improving operations and significantly reduce electricity costs. Smart Digital Twin (SDT) technology consists of creating a virtual replica of a water network that simulates the behavior of the real system, connected with real-time data and optimization algorithms, to analyze and optimize the effectiveness or behavior of the real system. In this article, it is shown that the implementation of an SDT with the use of machine learning techniques for demand forecasting, together with optimization algorithms for real-time pump-scheduling, results in specific savings of 9,8% in kWh/m3 and 12,3% in €/kWh, and 21% in €/$m^3$.

**Keywords:** Smart Water Networks; Smart Digital Twin; Water-Energy Nexus.

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## Digital Water cybersecurity resiliency

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**Abstract:** Potable water supply is a fundamental foundation of a human healthy society. Water distribution systems have been evolving to incorporate digital technologies, the so called "Digital Water" transformation, with business advantages on one hand and increasing cybersecurity risk on the other. Digital Water led to a growing attack surface, due to the higher number and complexity of assets, automation, technologies and suppliers. Focusing on Digital Water infrastructure cybersecurity, the study proposes to analyze how the introduction of security best practices supports Digital Water resiliency and consequently the resilience of water distribution supply. The study conclusions are that using security best practices at processes, technology and human resources increases the cybersecurity Digital Water resiliency.

**Keywords:** Cybersecurity; Digital water resiliency; Risk management.

## A holistic approach to a balanced scorecard tool in the water sector

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## A new glance at water networks of Ductile iron pipeline. Born from earth, return-to-earth…Indefinitely

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## Asset Management, Strategic Tool for Performance Improvement of the Water Sector

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## H2OPTIMAL – A cybersecurity approach to water companies systems and solutions

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## Increasing the competitiveness of sanitation services with an intelligence process.

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## Using Edge Analytics to Optimize Pump Performance & Asset Management

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## Using WBS to manage sanitation assets

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