Digital Twin in Water Distribution Networks

Marta Ferrà Mesquida
martafm6@hotmail.com
Instituto Superior Técnico, Universidade de Lisboa, Portugal

February 2021

New generations of hydraulic networks and their management are emerging to increase the efficiency of the water network. With the incorporation of new technologies, the aim is to evolve towards intelligent hydraulic networks with the incorporation of Information and Communication Technologies (ICT).

The digital twin of a water distribution system implies the integration of virtual engineering models with city-scale reality models and GIS data. They are continuously updated with virtual operational data from SCADA, sensors, meters and other measurement sources, to replicate the network in real time, providing precise and reliable data that can be used and control for analysis throughout the life cycle of a water system.

The current paper aims to develop two main parts. The first, is a theoretical study on the incorporation of Digital Twin technology in Water Distribution Systems (WDS), detailing the main requirements and involved technologies. The second part consists of a case study where, after examining the current water system in Lisbon, the progress that would be made by incorporating Digital Twin in a district metered area of the city is analyzed. The improvements in water losses and pressure control are studied in order to attain a better optimization of available or wasted energy. The incorporation of Digital Twin in water distribution networks contributes to creating a more sustainable, efficient and smart water grids.

Key-words: Digital Twin, water distribution network, Smart Water Grid, Smart Water Management System, real time.

1. Introduction

Lisbon is located in the Southern Europe, due to its Subtropical-Atlantic climate, the city generally has mild winters and hot summers. It is a reason why the city has to pay attention to its water efficiency. Reducing the leakages from the water distribution network and the amount of ‘non-revenue water’ can significantly help to increase the city’s water use efficiency and improve the customer experience. An additional factor on the water distribution system has been the growing demand for drinking water due to the constant growth of population. Today, the network supplies water to around 350,000 domestic and commercial customers within the inner city and around 2,500,000 people in the Greater Lisbon area [1].

The main problem is to identify the faults in the pipeline due to the old existent infrastructure, that is why a detection of leakage program is essential to track down them in real-time and act as soon as possible to reduce the damages and losses. To comply it a new Water Distribution Network is needed, one purpose is to introduce new technologies as Internet of Things (IoT), Blockchain, Cyber-physical system or Digital Twins to become a Smart Water System. The Smart Water Systems can lead to more sustainable water services, increasing the leak detection and reducing financial losses with a constant monitoring of water energy quantity and quality. The Portuguese company EPAL, Empresa Portuguesa das Águas Livres S.A., is an example of application of smart water management. In Lisbon, the company has focused worldwide attention, due to the high level of efficiency obtained in Lisbon, namely in the reduction of water losses and, consequently, in the reduction of costs that will be analyzed for the water supply system in Lisbon.

The adoption of a supply system monitoring policy to control losses and water quality requires a deep knowledge of the intervened network and its characteristics and mode of operation. Therefore, the following key tools are necessary for the implementation of a monitoring system that does not jeopardize the supply, in quantity and quality [2]: Geographic Information System (GIS), Customer Management Information System (CMIS), Digital Land Model (DLM), Hydraulic System Model (HSM).

Currently the conventional water networks are large and centralized, with limited control and management, typically based on one-preferential flow. Traditional water supply is focused on pumping water at high pressure to reach high distances, causing over-pressures and pipeline bursts. Another important urban water management problem is between the supply and the demand. Water consumption is higher during day than during the nighttime. With conventional WDS an oversupply of water and/or shortage problems happen due to different peaks of demand cannot be controlled. The main boundaries of the actual systems are the low efficiency of operations, the loss of water, the number of leakages and pump bursts and the low treatment efficiency. In order to improve all the limitations commented before a new concept of water distribution systems is created [3].

In addition to greater efficiency in loss control, prevention and rapid detection of leaks, smart water system also allows the development of best practices in asset management by improving the efficiency of the system in emerging areas such as demand-driven distribution. Instead of simply following existing practices that pump high pressure into the water supply system to reach customers further away, a more intelligent system that use real-time data, decentralized systems, variable speed pumps, dynamic control valves and smart metered areas in order to balance demand, minimize overpressure, will ensure a better water quality and reduction of losses, meaning, save water and energy.

2. Smart water management system

Smart Water Grids (SWG) is proposed as a new generation of water management with the integration of ICT to increase the efficiency of all the elements of the water network [3]. The Smart Water System promotes the security of the water supply considering uncertainties but significant future risks such as population growth, hydrological variability, extreme events and the intensification of demand in water supply systems, agriculture, industry and ecosystems. Strategic and transparent decision making in the exploitation of water resources is fundamental to achieve sustainability in the water use.

A SWG system implements the ICT into the WDS management. The transmission and distribution of water is monitored and controlled through sensors, meters, digital controls and analytic tools, in order achieve greater efficiency with a better quality and operation controls. Digitalization and automation enable the collection and transmission of data remotely, when this advances in ICT are applied in the water management enable the collection and storage of big data that can perform powerful and predictive analysis, such as artificial intelligence and Digital Twin, to contribute towards greater effectiveness and efficiency in water management. The operational processes that traditionally are done manually, such as leakage, water quality and overpressure controls, redesigning work processes by automating these tasks and reducing the reaction-time will contribute significantly to the whole system efficiency [4].

Smart Water Management (SWM) aims at the sustainability and self-sufficiency exploitation of water systems. A SWM leads to a reduction of water losses, water quality assurance, better customer experience, reduction of leakage and operational optimization [4]. The advance information technologies that are used in the Smart Water Management systems lead to the following benefits:

- Better understanding of the water system
- Early detection of leaks and efficient control of water losses.
- Constant monitorization of water quality
- Economic benefits to water and energy conservation
- Reduction of financial loses and enabling innovating business
- Improvement of the efficiency of the system
- Improve of customer service, reducing the water bill until a 30%.

2.1. Smart Water Management technologies

A SWM system is composed of the following technologies, explained briefly below:

- **Smart pipe and sensor:** the smart wireless sensor network is a viable solution for monitoring the state of pressure and loss of water control in the system. The main advantage compared to other methods of water loss control is the continuous monitoring of the network without local operator intervention and with low energy consumption of the wireless sensor, allowing to remain operational for long periods [4].
- **Smart Water Metering:** intelligent water metering essentially offers the opportunity to improve the balance between providing access to drinking water, the right of a management entity to receive payment for services rendered, as well as the joint responsibility of all to preserve scarce water resources [5]. It is a support tool to make real-time decisions based on registered database and helps to manage a better balance between satisfy demand and to increase the efficiency of Water distribution networks. To achieve it, a smart water meter includes the follow components: flow detection hardware, a transmitter and memory to store data and compensate for the disadvantages of traditional water meters.
- **Geographic Information System (GIS):** provides a complete list of the components along the network and their spatial locations. GIS allows the inclusion of the spatial components in an oriented model improving planning and management through a clear evolution of components in the network. The simulation of real features is the main advantage of GIS, based on a data system designed to collect, store, receive, share, manipulate analyze, and present information that is geographically referenced [4]
- **Supervisor, control and data acquisition (SCADA):** is referred to the use of memory and storage capacities and calculation of computers and servers shared and linked through the internet. It typically uses the collection of historical sensor readings to centrally control spatially distributed assets. SCADA system architecture is composed by computers, data communication systems from sensors to human-machine interfaces (HMIs) and graphical user interfaces (GUI) for supervisory management. In addition, contains programmable logic controllers (PLCs) and other interfaces to aid the WDS operation and management [6]. SCADA systems are designed to collect field information, transfer it to a central computer facility, allowing the operator to monitor or control from a central location in real time. In this way, control of any system, operation, or task can be automatic, or can be performed by operator commands [7].

2.2. District Metered Areas (DMAs)

Nowadays, multiple procedures and methodologies for water distribution system partition into district metered areas (DMAs) have been developed. Water network partitioning is the process of dividing the water system into independent DMAs, formed by placing gate valves and flow meters along boundary pipes to connect on DMA to another [8]. Thanks to the DMAs water losses are reduced and burst detection is simplified, since critical areas can be identified, and consequently, the interventions are prioritized reducing action time and increasing benefits.

Operational control problems include optimization-based pump scheduling and valve operation. For a network with given demand patterns, control sequence for pumps and valves is determined over a certain period into the future (often 24 hours). This is done in order to minimize pumping costs and reduce leakage while customers demand is satisfied with sufficient hydraulic pressure. In most water distribution systems, the mostly energy budged is consumed in the pumping of treated water from reservoirs to supply zones and storage tanks [9]. To design the DMAs of a water distribution system implies to identify how to allocate the nodes along the network in districts in such a way that each district is of adequate size. Each DMA has to include an adequate number of users and determine which pipes need to be closed off to delimit the area and which need to be open with the flow meters placed. With reference to this latter aspect, it is thus worth pointing out that while on the one hand partitioning a water distribution system into districts can bring significant benefits in terms of leakage reduction and real-time system management, on the other hand it can give rise to problems with respect to the reliability and efficiency of the system itself [10].

3. Digital Twin for Water Distribution Networks

A digital twin is a virtual representation of a physical asset, process or system. A water system's digital twin involves integrating virtual engineering models with city-scale reality models and GIS data (Figure 1). Additionally, digital twins are continuously updated with virtual operational data from SCADA, sensors, meters and other measured sources. A digital twin system is used to reproduce a real-time model from the water network that supports planning, design, construction and operations for smart water networks. Digital twin provides accurate and reliable data that utilities can use to perform analysis throughout the lifecycle of a water system [11]. The aim for digital twins' models of water distribution system is to reproduce disruption scenarios for resilience assessment purposes, to analyze asset prognosis and health-status to determine proactive maintenance models [6].

A big platform is needed to filter, normalize and integrate information to be useful and develop Digital Twin. The main sources to create the platform are: (i) GIS, to provide information of spatial locations; (ii) Sensors, to receive the information from the hydraulic network; (iii) SCADA, to supervise, monitor and control the data collected; (iv) Smart Metering, to control the network operation and customer service in independent metered areas; (v) Computerized Maintenance Management System (CMMS), to track and maintain stationary assets. As a result of the integration the hydraulic model with all the information sources, using artificial intelligence algorithms and Information and Communication Technologies (ICTs) [12]. A virtual twin model must contain three main parts, as presented in Figure 1.

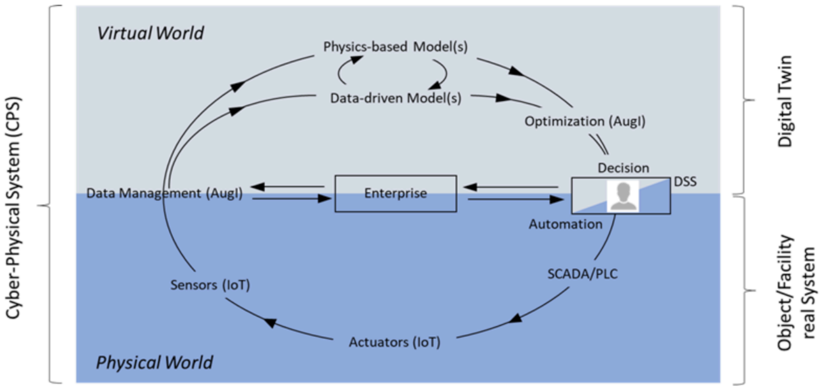

Figure 1. Data-streams, decision-making and implementation in a Cyber-Physical System powered by a Digital Twin [13]

Offline models do not represent the actual operations over a longer period of time, many inputs have to be estimated as pump and valve settings. With an online model these inputs don't have to be estimated, are taken from real-time field measurements. Data from field instruments are fed to the model via SCADA, the model uses these readings as boundary conditions to run a simulation, the results of these are used to run an optimization simulation. The output of that second model are pump and valves set points that can be sent back to SCADA. The set points allow the network to be operated in the most optimum manner in an automated closed loop way [14].

Thanks to the online model that repeats the process every hour the costumer status is constantly updated giving information about which are receiving low pressure and which will have supply disruption later.
There are four main optimizations of using real time model Digital Twin [14]:

- The pressure optimization calculates and send a pressure set point to valves or pumps to ensure the minimum pressure needed in the zone at all time steps. The reduction of excess pressure in the network reduces the water losses, extends asset lifetime and reduces energy usage.
- Pumping optimization provides the optimum pumping flow that leads to energy costs reduction and extending asset lifetime.
- Demand forecast uses historical demand, and the model is able to predict future demand and the operator will be able to take precautionary steps to alleviate low pressure zones.

- Asset condition assessment prioritize pipeline rehabilitation by taking into consideration dynamic variables given by real-time simulation results and static variables from field survey.

The platform is formed by a set of models, depending on the sector or industry it contains different models. In the water sector a Digital Twin should include: (i) water process models, physics-based models or data-driven models that are forced by boundary conditions; (ii) asset model, a record of the physical assets and infrastructure, used to setup and configure the water process models; (iii) performance models, generates the metrics required to make the decisions.

The Digital Twin infrastructures are able to precisely monitor asset health and performance, and timely recognize potential anomalies. The simulation of the operation of assets, their surrounding environment and the interact in real-time enable users to test possible futures scenarios, view and compare outcomes in other to optimize asset performance. The result is a better take of decisions that lead to an improvement of the system efficiency by the reduction of losses, the pressure control, the leak detection, system repairs, among others. In the Figure 2 it is represented the process of optimization thanks to the proactive Digital Twin Model proposed by Paul Boulos [15].

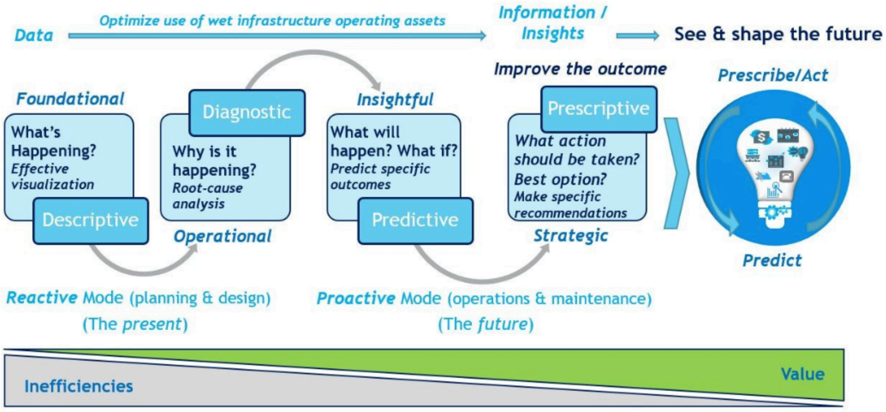

Figure 2. Proactive DT model Proposed by Paul Boulos [15]

Digital Twin technology provides a complete picture of the water infrastructure allowing a better understand the water network behavior, predict, plan and prepare for future events. The access to accurate and complete information in real-time permits the management of the assets, the reduction of lifecycle costs, the optimization of asset performance and lifespan and the improvement of service levels. Digital Twin platform permits to automate routine, repetitive and manual operations and maintenance tasks, enhancing their accuracy. It has many applications across the water infrastructure as well as potential business benefits and improved costumer's service.

The continuous access to real-time water network information enables to monitor, predict, and react to disruptions or emergencies, gaining complete control over resilient infrastructure operations. Digital twin provides a 360-defree view of all the infrastructure, helping to perform diagnostics, build models, establish ideal maintenance schedules, conduct predictive and prescriptive analytics, test and evaluate scenarios, and generate actionable insights in real-time for critical and efficient decision making [16].
Finally, longer-term benefits include: (i) improved planning and preparedness; (ii) enhanced infrastructure resilience and sustainability; (iii) ensured continuity of service without incident; (iv) prediction of future renewal needs; (v) achieve permanent reduction in production, maintenance, emergency, financial and operational costs [15].

Some examples of the application of DT in WDN are the cities of Valencia, Oporto and San Diego. In Valencia, a digital transformation was carried out with the result of a complete overview of the network in real-time, with informative actionable dashboards 24/7. Allowing the simulating of the past, present and future scenarios under all kind of operating conditions [17].

In Oporto the public company uses DT to integrate information across multiple software systems. The utility is focused in managing the water supply, wastewater, two wastewater treatment plants, water quality and stormwater drainage. The platform is used to forecast flooding and water quality issues, improving services and ensuring a resilience of the water infrastructure [18].
Finally, San Diego is using DT to improve commissioning and long-term operations as an operator training platform for a water purification facility. The model is used to verify control points as to when pumps should start and stop and how they should adjust speed in relation to other process operations and online instrumentation [19].

4. Methodology

A methodology has been defined in order to reduce losses and leakage (Figure 3). The reduction losses' methodology is the one studied in the case thus is the part that can improve in better percentages the efficiency of the network and provide a greater cost reduction.

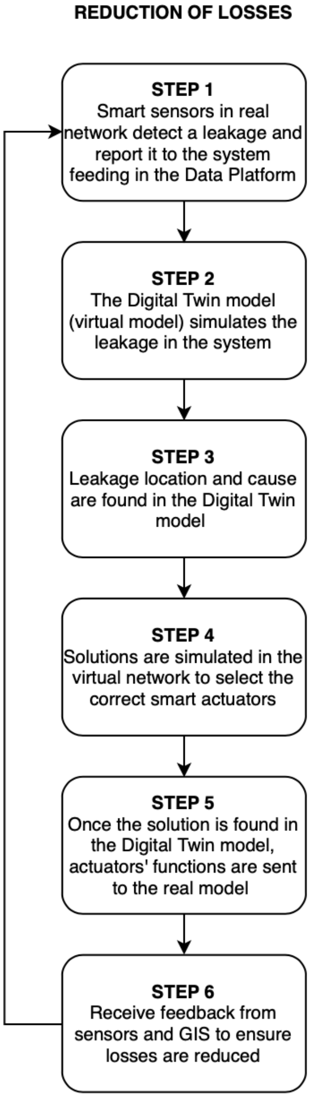

Figure 3. Methodology proposed to reduce losses

STEP 1: The water distribution network has different smart sensors distributed along the water network that detect an anomaly, such as a leak or an abnormal loss of water. These sensors report the alert to the Digital System and feed the data platform. Thus, the data collection for future events is increased and the virtual model receives the necessary information to be able to process and identify what kind of problem there is in the network.

STEP 2: The virtual system, reproduces all the information received from the sensors in order to make an approach and try to localize the leakage from the real network. The parameters used in DT are the differences in the flow, pressure and head losses given in different points of the network.

STEP 3: Once the Digital Model has simulated the leakage, thanks to the different parameters, the cause of the leakage is studied to find the better solution. Some of the causes such as a burst in a pipe, some illegal connection and defects in supply point are analyzed.

STEP 4: In order to find the best solution and reduce as soon as possible the losses, different solutions are simulated in the virtual model to analyze the effects on the network and choose which are the actions to proceed.

STEP 5: The DT model send the orders to the actuators of the real model to proceed with the solution chosen. This step can be really different depends on the type of solution it has been selected, in some cases can be a really simple or a complicated and long procedure, so the time of the action changes depending on the type of.

STEP 6: Once the actuators has realized its function, a feedback is needed to ensure the problem is solved and to feed the platform with new data to increase resources and thus improve the efficiency in future anomalies. This is a continuous learning and improvement.

5. Case Study

The network simulated in the EPANET is a representative model of a part of the districted metered area 320 in Lisbon, near Benfica neighborhood. Not all of the DMA has been selected as it was not necessary to observe the changes and improvements made with the incorporation of DT. A model of actual network is simulated with the EPANET (one simulation with normal behavior and another with a leakage induced) and then in that network will be applied the changes that DT would predict it. Comparing these conclusions about the improvements of DT in WDS are extracted. The main objective is to study the behavior of the network during the night, when the demand is 55%, when most of this demand is due to losses (Figure 4).

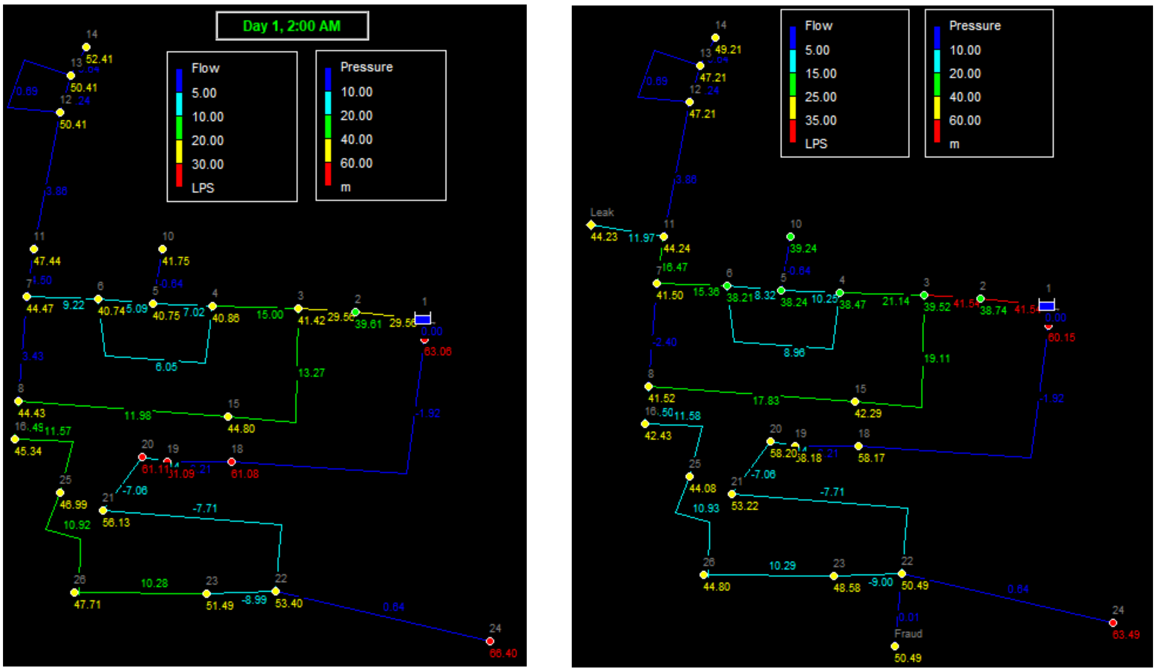

Figure 4. Graphs of the network simulated without DT at 2am (a) without leakage and fraud (b) with leakage and fraud

The second step is analyzing the parameters with the DT model applied. A set of hypotheses and methodology that would affect the current network were chosen, in case of implementing a DT model, in order to analyze the values of the new parameters and the improvements.
Finally, all the results of different simulations (with and without DT) have been studied, compared and analyzed in order to draw conclusions about the benefits of a smart water network with DT technology.

The considerations and hypothesis that it have been assumed to analyze how DT acts for a new leakage occurrence are the following:

- The new leakage appears in the real network at midnight.
- As the monitoring of the network occurs practically in real-time, with a gap between 60 seconds and 5 minutes, it is verified that the DT model detects at the moment the increasing of water consumption due to the leakage.
- The monitoring control is due to SCADA, AI and GIS. The combination of these technologies allows the control in real-time of the WDS.
- It is considered that during the nighttime the actuation time is higher. The process of analyzing the situation of DT model, select actuators and apply the solutions in the real network is estimated in 3h.
- The reduction of the leakage can't be 100%, because there is a minimum value when the smart sensors can't detect the loss of water, estimating that the 10% of the leakage is still active.
- The demand in each point decreases a 15% due to:
  - Control of patterns demand with AI and big data platform (SACADA, GIS and Smart sensors in the nodes)
  - Control of peaks demand
  - Control of pressure and flow along the network of DMA under study

Figure 5 shows the difference between demand with and without DT technology.

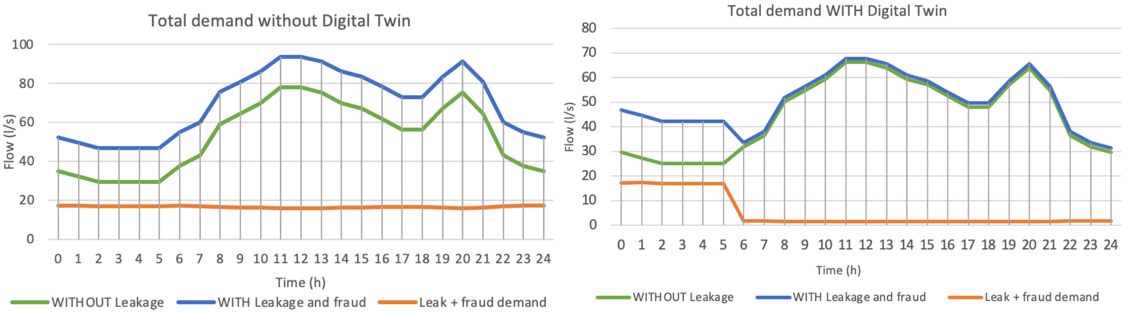

Figure 5. Daily water demand curve: (a) Without DT (b) With DT

The orange line is the water wasted in the leak; due to the action of the DT model a different pattern occurs along time in the second graph. The first period is when the leakage is detected, and operations are carrying on reducing the leakage. The second period, between 5 and 6 am is when the smart actuators reduce the leakage. Finally, the last period, from 6 am to the end of the day, the leakage has been fixed and only 10% of the water is lost due to the minimum undetectable amount for smart sensors be able to distinguish.

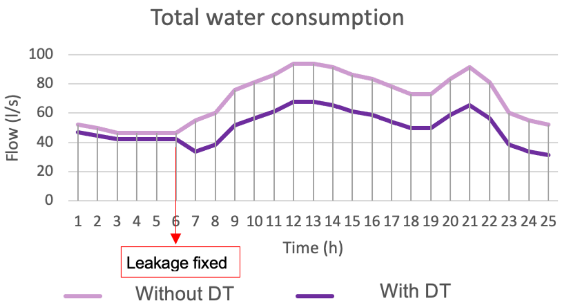

Figure 6. Daily water consumption comparison

In Figure 6 the comparison of total water consumption is shown. due to the application of DT in the under-study DMA of this WDN the water consumption has been reduced and almost 30% of the water can be saved when unexpected leakages appear in the network. Moreover, thanks to the data collection of SCADA and AI the patterns of demand in the nodes can be accurately predicted, ensuring a better supply efficiency towards future smart water grids. In the Table 1 the amount of water saved can be seen.

Table 1. Summarize of water losses with different models

	Without DT (m^3/day)	With DT (m^3/day)	Difference (m^3/day)	Percentage of water saved
Demand without leakage	4768,884	4053,55	715,33	15,00%
Water lost in leakage	1498,32	483,26	1015,06	67,75%
Total Demand	**6267,20**	**4536,81**	**1730,39**	**27,61%**

Besides studying the losses, monitoring and control the pressure of the water is one of the main purposes of the implementation of Digital Twin in a WDS, it is important keeping pressure constant and make sure that it does not exceed the limits established by the regulation (no higher than 600 kPa and the variation can't be greater than 300 kPa). The procedure followed was to identify the point of maximum pressure during the nighttime and analyze it behavior throughout the day. Thus, studying its variation and its maximums allow to see how a DT model would act in that case. Figure 7 shows the pressure change resulting from the reduction of losses, since by reducing the flow, the pressure increases.

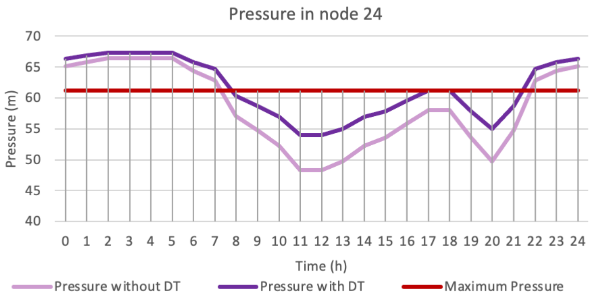

Figure 7. Pressure in node 24 when reduction of losses with DT is applied

Once the flow and pressure have been analyzed, they have to be linked as they are closely related. The pressure is inversely proportional to the flow, that is why, when reducing the flow, the pressure increases and vice versa. In Figure 8 is shown that the reduction of losses with Digital Twin leads to increase the pressure and decrease the flow.

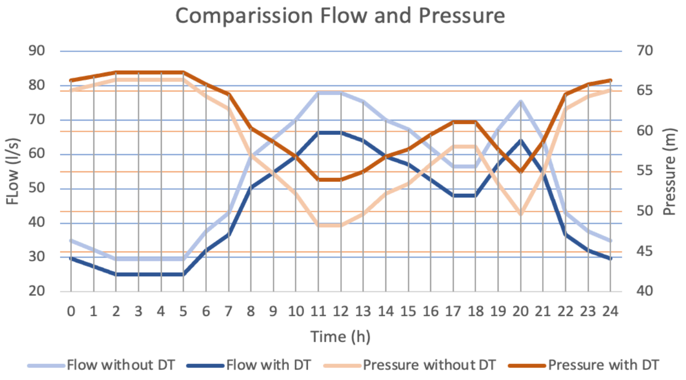

Figure 8. Comparison of flow and pressure, with and without Digital Twin

The monitoring and control of DT is key to regulate and establish a balance between the two parameters that ensure the most efficient combination of loss reduction and supply conditions. With the predictions of the digital twin, the losses are reduced, consequently, the flow decreases, since the amount of water demand is reduced. This leads to a pressure increase in points of the network that must be regulated. In order to adjust the demand and the pressure levels at every time instant, with the adjusted strategic model, the operators can simulate the real-time decisions, analyze the system behavior at any past time and program the actions to be carried out in the near future. In this way, a cyclical system is built to control and reduce losses through pressure value updates. Over time, this concludes with a stabilization of the water network parameters obtaining the flow and pressure values discussed in the two previous sections.

6. Conclusions

In this paper, the introduction of Digital Twin technology in a Water Distribution Systems is presented. To this end, a theoretical study has been carried out on the characteristics of Smart Water Management, which consists in the development of DT technology and its application in the field of hydraulic networks. Finally, to observe its benefits applied to a real network, a case study has been made based on the application of Digital Twin in a District Metered Area of Lisbon.

The real-time monitoring of Digital Twin, thanks to the incorporation of GIS, SCADA and smart sensors, means that in the event of a loss or burst, the control operation is much faster, and the problem can be solved in a few hours, thus saving a significant amount of water. This advantage has a direct influence on the reduction of costs, social and environmental impacts of these losses. In the case study these improvements resulting in 27% of water savings, equivalent to 1730 m^3/day.

The potential benefit of Digital Twin in the water sector is very extensive, directly impacting on water economy and wastewater management, passing throughout customer experience, better maintenance and environmental protection, as evidenced in the case study. It provides a better user experience, reduces operational costs, increases capital efficiency, allows the consumption predictions, during peak demands which can provide a better service managing of pressure, flow, system reliability, flexibility of operation and safety. Costs due to maintenance and energy operations are reduced, as well as costs from unexpected water main breaks. In addition, water saves due to losses and fraud control, as can be seen in the case study, evidencing a positive economic impact, both for the company and consumers.

In conclusion, the implementation of Digital Twin in WDN has relevant benefits in different sectors having social, economic, environmental and energetic positive impacts, thus positively and directly affecting the world as water is an essential life asset.

References

[1] Climate Adapt. 2021. [online] Available at: <https://climate-adapt.eea.europa.eu/metadata/case-studies/private-investment-in-a-leakage-monitoring-program-to-cope-with-water-scarcity-in-lisbon>.

[2] Epal.pt. 2021. EPAL - Empresa Portuguesa Das Águas Livres, SA. [online] Available at: <https://www.epal.pt/EPAL/docs/default-source/epal/publicações-técnicas/controlo-ativo-de-perdas-de-água.pdf?sfvrsn=30>.

[3] Seung Won Lee, Sarper Sarp, Dong Jin Jeon & Joon Ha Kim. Smart water grid: the future water management platform, Desalination and Water Treatment. 2015, 55:2, 339-346

[4] Ramos, H.M.; McNabola, A.; López-Jiménez, P.A.; Pérez-Sánchez, M. Smart Water Management towards Future Water Sustainable Networks. Water. 2020, 12, 58.

[5] Boyle, T., Giurco, D., Mukheibir, P., Liu, A., Moy, C., White, S., & Stewart, R. Intelligent Metering for Urban Water: A Review. Water. 2013.

[6] Giudicianni, C.; Herrera, M.; Nardo, A.d.; Adeyeye, K.; Ramos, H.M. Overview of Energy Management and Leakage Control Systems for Smart Water Grids and Digital Water. *Modelling* 2020, 1, 134-155.

[7] Stouffer, K., Falco, J., & Kent, K.; Guide to Supervisory Control and Data Acquisition (SCADA) and Industrial Control Systems Security. Recommendations of the National Institute of Standards and Technology. 2006. Gaithersburg: National Institute of Standards and Technology.

[8] Slideplayer.com. 2021. [online] Available at: <https://slideplayer.com/slide/16174921/95/images/4/District+Metered+Areas.jpg>.

[9] Kartakis, S.; Abraham, E.; McCann, J.; WaterBox: A Testbed for Monitoring and Controlling Smart Water Networks. 2015.

[10] Alvisi S.; Franchini, M.; A Procedure for the Design of District Metered Areas in Water Distribution Systems,Procedia Engineering. Volume 70. 2014.

[11] WaterWorld. 2020. Digital Twins For Managing Water Infrastructure. [online] Available at: <https://www.waterworld.com/water-utility-management/smart-water-utility/article/14173219/digital-twins-for-managing-water-infrastructure>.

[12] P. Conejos Fuertes, F. Martínez Alzamora, M. Hervás Carot & J.C. Alonso Campos. Building and exploiting a Digital Twin for the management of drinking water distribution networks. Urban Water Journal. 2020.

[13] Dr. Richard J. Vestner, G., 2020. *The Digital Twin: What Is It And How Can It Benefit The Water Sector? | DHI Reservoir*. [online] DHI Reservoir. Available at: <https://blog.dhigroup.com/2019/06/06/the-digital-twin-what-is-it-and-how-can-it-benefit-the-water-sector/>.

[14] Singh, K., 2019. Real Time Digital Twin Of Water Distribution Network. [online] Linkedin.com. Available at: <https://www.linkedin.com/pulse/real-time-digital-twin-water-distribution-network-keshvinder-singh> .

[15] Boulos, P., 2018. Digital Twinfrastructure: Delivering Maximum Value For The Water Industry. [online] Linkedin.com. Available at: <https://www.linkedin.com/pulse/digital-twinfrastructure-delivering-maximum-value-paul> .

[16] Digital Water Works. 2020. Access Accurate And Complete Information In Real-Time. - Digital Water Works. [online] Available at: <https://digitalwaterworks.net/digital-water-benefits/> .

[17] Conejos, P., Martínez Alzamora, F., Hervás, M., Alonso Campos, J.C. (2019) “Development and Use of a Digital Twin for the Water Supply and Distribution Network of Valencia (Spain)”. 17th Int. Conf CCWI 2019. Exeter (UK), Sept. 2019

[18] Digital Water Works. 2020. Oporto Water Utility Leverages Digital Twin For Integrated Management Of Urban Water Cycle. [online] Available at: <https://digitalwaterworks.net/oporto-water-utility-develops-technology-platform-for-integrated-management-of-urban-water-cycle/>.

[19] J.M. Curl, T. Nading, K. Hegger, A. Barhoumi, M. Smoczynski. Digital twins: The next generation of water treatment technology. Journal-American Water Works Association, 2019, pp. 44-50