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Strategic Engineering for Enhancing Efficiency and Effectiveness of Water Management Systems

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Abstract

The paper proposes the creation of an innovative strategic water management system based on Strategic Engineering approach through the combined use of Artificial Intelligence, Modeling and Simulation, Data Analytics in closed loop with data from the field in order to be able to reduce water waste on the entire water distribution network. In fact, despite the progress made in the field of sensors and data analysis, as well as the greater awareness from the users on the importance of reducing resources and water waste, losses on the water distribution network are still very high in many countries. Therefore, to turn be crucial to identify a new holistic approach based on trans-disciplinary technologies in order to identify most promising strategies for water management.

Keywords: Water Management; Water Losses; Strategic Engineering; AI; Modeling & Simulation (Three to five keywords representing the main content of the article)

1. Introduction

Water is a fundamental primary resource for humans: the Society, Agriculture, Industries and individuals need fresh water and drinkable water is crucial to support human life on daily use, but also to guarantee personal and general Sanitation & Hygiene (Leto, 2019). Indeed, since the rise of first civilization the water management was one of principal signs of advanced technology and superior quality of life; it is possible to see some of such examples which lasted until present time – famous Roman aqueducts, Greek channels and cisterns, reservoirs and piping in the city of Petra as well as channels and locks constructed by Sumer (Mays et al., 2007; Wilkinson, 2013; Ortloff, 2005). Water demand nowadays is mostly generated by Agriculture, Family Users, Industrial Activities et cetera. This fresh water is often taken for granted, however, it is a scarce resource that could lead to a crisis due to the growing consumption rates affected by demographics, industry and climate changes. In facts, worldwide attention to this issue is growing recently in relation to the current situation as well as to climate change and there is crucial need to develop Water Strategies as well as improvements in Water Management. Water losses from the pipe distribution network has long been a critical feature even in Countries with a high-developed infrastructures. According to the literature for example, water losses in the distribution network in France have been estimated at an average of 26%, in England at 19% (Metropolitan Consulting Group) and by a recent study conducted in Italy (ISTAT Report, 2020) water losses reach average value of 42%. By the way, Italy is one of the first European Countries for water availability, but despite this, its supply, purification, distribution, consumption and waste remain a very hard challenge; within this context, water strategic management results into a crucial issue to be addressed by innovative enabling technologies such as AI (Artificial Intelligence) and Simulation.

Water is probably the most strategic and critical resource for our sustainability, so this research aims to improve drastically its management in terms of reducing water waste, improving management policies and saving resources.

This paper introduces an innovative solution based on a Strategic Engineering using models of the water network that uses existing controls more appropriately, associating them with new instruments capable of detecting leaks. This study proposes to adopt Strategic Engineering by using AI to process available data from multiple sources and heterogeneous networks, fuse them, resolve inconsistencies and extract valuable information to be further elaborated by the use of simulation models integrated with machine learning and pattern recognition techniques. In this way, it turns possible to define how to increase efficiency, reduce water waste as well as to improve the infrastructure Safety and Security, which are the most valuable investments and most promising technologies to be introduced.

2. State of the Art

Water losses occur in all distribution systems; this depends on the characteristics of the pipe network, level of control, level of technology etc. Apparent losses from water distribution networks are often the result of local customs, combined with low tariff structures or inadequate metering policies (Farley and Trow 2003). Thus, it becomes crucial a better understanding of the reasons for the water losses in order to develop the most suitable water strategy. For our purpose it is suggested to subdivide Water losses in two terms: real losses and apparent losses, in which the first expression could be replaced with physical losses, while the second expression could be replaced by management losses. The main goal of this paper is to detect and find a solution to real losses. In facts, the infrastructure naturally deteriorates with time, but because of the high costs it becomes difficult to renew or replace pipe networks at a rate that produces significant results and improvements in water management compared with real losses. Thus, it becomes crucial to find new strategies to monitor the water network in order to intervene faster and locally; it is important to outline that in this context, due to the very large dimension of the networks, their location and related historical evolution, the intensive use of sophisticated automation components and integrated instruments could turn not sustainable in terms of installation and maintenance costs. The deterioration of the water distribution infrastructures and the consequent losses and malfunctions of the water network represent a complex system in which the individual parameters cannot be analyzed in a univariate manner. The interaction between several factors (materials, pressure, temperature, flow rate, etc.) represent a dynamic system in which the structural condition assessment condition of water mains and decision making for the most suitable line of action involves several elements (Rajani, B. and Kleiner, Y. 2004):

- inspection of the pipe network through different sensors
- characterization of the pipe failure
- development of mathematical and physical model
- scheduling pipe renewal

Thus, the initial and critical aspect in order to create the correct strategy for the water management of the pipe network, is the condition assessment through the right sensors or sensor networks. The-state-of the-art of sensors for water inspection is characterized by the use of a large number of different technologies (visual, acoustic, X-ray, etc.) and several new researchers are ongoing in this sector. Most relevant methods are presented in this section. Visual inspection through the use of Closed-circuit television is widely used for the inspection of pipe's surface (Liu & Kleiner, 2012) but it is obviously impractical due to the vastness of the water distribution network. In facts, this system is time-consuming as it does not allow the exact location of the leak to be identified immediately until after the entire inspection of the pipe or section of pipe in which a loss of pressure is observed and AI are investigated in order to automate as much as possible this process. Another method used for the inspection of water pipe's system is the Laser scan. This type of technology is usually used for medium and long distance range. The distance typically is obtained measuring times elapsed between two pulses or between two wave trains. Another method is based on structured light, which makes use of a ring of laser light projected onto the pipe inner surface (Duran et al., 2002). The magnetic flux leakage method uses magnets to induce a magnetic field around the wall of a ferrous pipe. The damaged areas do not support as much magnetic flux as undamaged areas, resulting in an increase of the flux field at the damaged areas (Marlow et al., 2007). Many variations of this method are often implemented for the inspection of pipes, such as for example Broadband electromagnetic (BEM) (Hazelden et al., 2003), Ground penetrating radar (GPR) (Costello et al., 2007). Other inspection technologies are based on the use of acoustic methods. Among these methodologies the most used technology is the Sonar profiling system. A sonar system consists of an underwater scanner unit, a sonar siphon float, sonar processor/monitor, skid set, and all necessary inter- connect cables (Cues, 2008). There are different technological solutions for pipe inspection through acoustic methods such as Impact Echo (Sack & Olson, 1998), Smart Ball (Liu & Kleiner, 2012) and Ultrasounds (Rose et al., 2008). Many studies have also been conducted related to the problem of leaks through the use of neural networks in predicting leaks in oil pipelines (Caputo & Pelagagge, 2003) and water distribution networks (Salam et al., 2014). Many other technologies, such as thermography and intelligent robots are used less frequently. However, all the technologies mentioned remain useful tools but not sufficient for a quick complete inspection of the distribution network if taken individually. The aim of this project is therefore to use a complex network of sensors, merge relevant information and process it through AI and M&S to obtain management and optimization models of the distribution network.

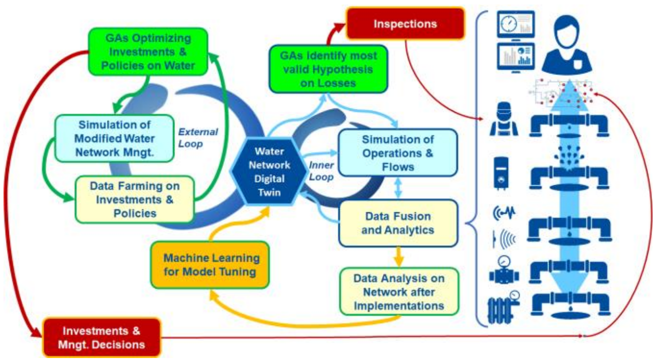

Fig.1 General Architecture

This study aims to create Digital Products and Solutions able to identify and reduce water waste over networks and to support development of effective and efficient Water Strategies. As expected results it is possible to expect the capability save millions of cubic meters of water, energy and money, improving the quality and allowing to be more effective in maintaining and managing Water Resources. Indeed, the possibility of integrating the information deriving from an extensive and diversified sensor networks and the fusion of such data could offer an innovative solution in which simulations guided by AI and Genetic Algorithms create virtual scenarios in which it is possible to identify the losses as well as possible solutions. In this case, the role of the Digital Twin is to provide high fidelity model of the real system, suitable for both identification of problems as well as assessment of efficiency of proposed solutions (Bruzzone et al., 2019a). The scenarios are expected to give life to a virtual environment on which it turns possible to test the actual consequences of the actions taken to mitigate the problem. Furthermore, the scalability of the solutions proposed on multiple XR devices offers the advantage of changing the virtual world according to the user. The on-site operators are expected to be guided to the real points of the losses over the virtual scenario, directing them in most suspect places.

For instance, the approach of integration of industrial plant data, data fusion and analysis solution as well as Mixed Reality systems was tested in real-life cases ad demonstrated to have high potential (Bruzzone et al., 2020).

The decision makers, on the other hand, has the possibility of interacting with the Decision Support System at high Level in order to be able to understand the situation and evaluate the consequences of possible alternative actions to improve the network, such as restoring various links and nodes of the network or introducing new automation systems. The Availability of a simulation environment allows also to test different "What if?" scenarios, hence, to evaluate engineering solutions as well as to increase efficiency by modification of existing water distribution networks (Bruzzone et al., 2018).

3. Conceptual Model and Architecture

The general architecture proposed in this paper is based on two nested loop based on Strategic Engineering as proposed in figure 1. Data Fusion driven by AI on data collected by different sensors, instruments allows to combine different data source and interact with fluid dynamic and plant simulation to extract correct information about the status of the water networks. By this approach, it is possible to identify most probable causes of water losses and to locate them in much more efficient way respect to use of each single data source independently. In this way it is possible to create a real Digital Twin of the water network dynamically updated based on the information extracted from big data by AI from multiple sources and instruments.

AI and Simulation of the network are used to evaluate the different actions and to recombine them in order to identify most promising and more effective to achieve multiple target functions (e.g. water saving, energy saving, cost reduction, service improvement, time to achieve the goal, return of investments). In this sense the use of AI could be also devoted to optimize the possible alternative actions as well as to recombine investment proposals by the users to be tested virtually on the Digital Twin at higher level by using Modeling & Simulation: the analysis of these virtual experimentations support the identification of best strategies able to improve water management. The AI allows to recognize Development of systems based on machine learning to correlate data from different sources (Bruzzone et al., 2019b; 2013a; 2012). The Simulation Models are able to evaluate the physical evolution of water networks in terms of pressure, flow and quantities under specific hypotheses on water losses and other boundary conditions respect the scenario obtained by Data Fusion of instruments, automation systems and sensor. This comparison by using Genetic Algorithms allows to investigate the most suitable hypotheses in order to detect water losses and locate them, will be carried out. Extensive use of fluid dynamic models and discrete event simulation based on continuity and Bernoulli equations provides a reference to test hypotheses and consistency respect collected and fused data.

$$Q_j^{Tot} = \sum_{jk=1}^{n_j} \left(Q_{jk}^{th} + Q_{jk}^{ww}\right)$$

$$p_j + r \cdot \left[\frac{1}{2} v_j^2 + g \cdot \left(h_j + Dh_j^{pd}\right)\right] = p_m + r \cdot \left[\frac{1}{2} v_m^2 + g \cdot \left(h_m + Dh_m^{pd}\right)\right]$$

Where

Q_j^{tot} Total flow of water at j-th node

Q_j^{th} Theoretical flow of water at j-th node

Q_j^{ww} water wast flow at j-th node

n_j number of branches from j root

p_j pressure at j-th node

v_j speed at j-th node

p_j pressure at j-th node

h_j altitude at j-th node

$\boxtimes h^{pd}_j$ delta pressure at j node due to pressure drops

Indeed, the simulation models could be also used to update dynamically the configuration and status of the Digital Twin to keep it up-to-date respect the real Water Network. The Genetic Algorithms (GAs) could produce multiple configurations respect the hypotheses on the losses to be experimented virtually on the simulation models and compared with fused data to conduct a reverse engineering on the localization of the water losses. In similar way on a high-level loop, it could be possible to use the GAs also to conduct optimization respect the alternative investments and strategies to be implemented to improve water management. In fact, the use of Artificial Intelligence allows to explore the possible solutions and their effects on the system by the Digital Twin and to get a feedback from real effect measured on the reality.

The idea in this project is also to use the innovative MS2G (Modeling, interoperable Simulation and Serious Games) paradigm combining it with the use of Extended Reality (combining Augmented and Virtual Reality) to represent intuitively the situation and its critical elements, as well as the impacts of alternative actions respect the Digital Twin; this could be a support for operators looking for losses as well as for engineers and decision makers. These uses could enhance the efficiency of the network not only reducing water waste, but also respect multiple target functions to be optimized by the GAs that could include energy saving, quality of the service and resilience. In facts, even respect recent events on 2021, cyber-attacks to Florida water network (Bergal, 2021; Bruzzone et al., 2016; 2013b), the water networks are critical infrastructures and it is necessary to work to reduce vulnerabilities over multiple layers, including cyber-attacks; indeed the use of Modeling, Simulation and AI allow also to reproduce cyber-attacks and carry out virtual experiments on different scenarios to improve these aspects

4. Materials and Methods

This First step of the development is related to the identification of available data sources, including analysis of data, its completeness, presence of noisy and/or erroneous data entries, as well as definition of criteria for its filtering and pre-processing. At this point, it turns possible to proceed with identification of correlations and features, most suitable for design of the AI-based analytical algorithm. The AI proceed to the fusion of the data and to a qualification of the related sources through algorithms that highlight inconsistencies assessing also the reliability of different sources based on the achievements obtained in identifying the water wastes. At this point, with reverse engineering techniques starting from fluid dynamic models integrated with discrete event simulators, the most probable conditions that generate the overall losses on the water distribution network could be identified. Obviously, this identification phase requires to explore a very large number of variables, so the authors decided to use genetic algorithms in order to find the causes and positioning of the losses among the many variables involved. This process involves hypothesizing many parameters related to missing data which will have to be based on different evaluation criteria, these may initially be set by analysts and/or users, but the overall architecture is structured so that they are progressively corrected on the basis of the revelations. This component use Machine Learning for fine tuning of these parameters, while the Genetic Algorithms continues to define configuration of the network to be evaluated by simulations to find the losses. This process responds to the principle of Strategic Engineering which in the proposed study provides for two loops nested in each other: the first internal one allows to merge the information and hypothesize the configuration of the water network and its problems through genetic algorithms that test then on the simulators the most probable conditions underlying the losses. In this paper it is proposed the initial part of this research as well as the scenario to be investigated to identify losses and the most effective lines of action to monitor, measure and mitigate water waste by innovative automation, mitigation and management policies. One of the main advantages of this approach is minimization of additional sensors and instruments, required to detect and localize losses. Indeed, while the brute force solution is based on installation of as much instruments and sensors as possible, at least in every critical point, the proposed approach based on AI and M&S allows to reduce costs and maximize the value extracted by already available equipment, with only minimal additional investments, much easy maintenance and improving energy saving, safety and security of water networks

5. Case Study

The In order to validate the current approach the authors propose a case study where to apply the mentioned approach. The present paper includes just preliminary results.

The tests were conducted over the following water network proposed by Figure 2 that outlines in big circles the demand of users and small circles the bifurcation of different lines; the scenario configuration is reported in table I and include information about average demand and prevalence, therefore it is important to outline that the demand is variable over time and characterized by stochastic behavior that is coupled in the simulation by analyzing historical data and characterizing the best fitting distribution of probability; considering the specific nature of the process in this simulation empirical distribution generated from the time series based on predefined consumption classes over the different timeframes of the day and of the week are adopted to be used by the Monte Carlo technique embedded into the Simulation Models. In this case, apart from the most probable decision, thanks to statistical data used in stochastic simulation it could be possible to obtain also intervals of confidence (Bruzzone et al., 2021a). One of very useful concepts in this regard could be utilization of Modeling and Simulation as Serious Game approach (MS2G), in which the user is able to learn behavior of the system in an interactive and immersive way (Bruzzone et al., 2021b; 2014).

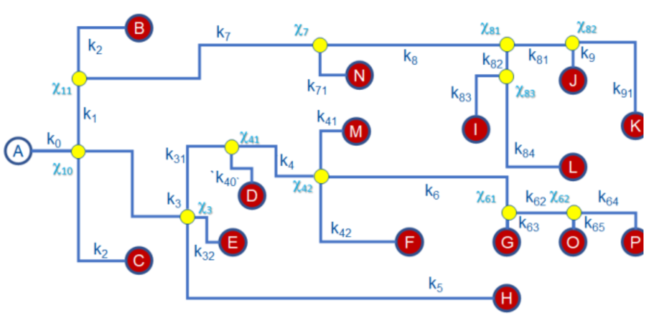

Fig.2 Configuration of the water network

Table I – Water Network																												
Demand		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	χ10	χ11	χ3	χ41	χ42	χ61	χ62	χ72	χ81	χ82	χ83
Flow	[m3/h]	-	100.8	44.0	30.3	66.0	495.0	1,045.0	550.0	176.0	205.3	192.5	154.9	205.3	88.0	1,045.0	1,320.0	5,718.2	917.6	4,756.6	4,140.6	4,110.3	3,410.0	2,365.0	829.6	728.8	397.8	330.9
H	[m]	400.0	300.0	200.0	180.0	110.0	50.0	50.0	20.0	190.0	50.0	40.0	30.0	200.0	180.0	20.0	20.0	420.0	380.0	220.0	210.0	210.0	70.0	70.0	190.0	120.0	120.0	120.0
Pressure	[bar]		4.6	6.1	4.6	4.8	5.7	3.8	8.4	4.2	4.2	6.6	5.0	4.2	8.4	4.0	4.2	22.8	10.6	13.2	10.0	8.4	9.7	5.2	3.0	9.0	5.8	6.2

Table 1 Water network data

6. Results

The experimentation was carried out just over the inner loop based on GAs devoted to identify losses respect the proposed network. In this case, the number of variables to identify the loss are 26 that were coded based on 12 bit over a chromosome composed by 312 bits and a population of 1000 individuals with reproduction rate equal to 0.4 and mutation rate at 0.1.

The target function was to measure the errors respect available measurements of pressure and flow over the network by the automation system plus a component related to the reliability of the prediction. In this case the reliability is expressed as

$$RC = \sum_{k=1}^{m} \left(\frac{Q_k^{ww}}{\sum_{u=1}^{m} Q_u^{ww}} - \frac{R_k \cdot Sr_k}{\sum_{f=1}^{sn} Rf \cdot Sr_f} \right)^2$$

RC Reliability consistency R_k Suspect emersed on k-th nodes

m total number of nodes sn total number of sensor networks and data sources

Sr_k Sensor Reliability used on k-th node

The Sr_k are hypothesized a priori, to be corrected based on effective detection of water wastes based on inspections. Just a preliminary result is proposed in the following graph on Fitness Function related to identification of most consistent water losses respect the comparison of water network simulation and collected data over the generations; in similar way the external loop allows to optimize investments and management policies.

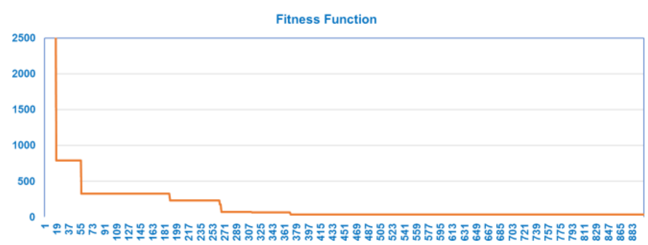

Fig.3 Preliminary result

7. Conclusions

This paper proposes an innovative approach based on Strategic Engineering to the reduction of losses in water networks able to guarantee improvements in their design, refurbishment and management respect energy, water and economical savings as well as vulnerability reduction.

The approach proposed is under development by the authors that currently are creating the models devoted to address these issues and to validate the approach by initial experimentation phase; currently the author are extending this research to include a real water network and combine new sensors and digital solutions to provide the data to demonstrate the benefits on the field. This is intended as a preliminary research activity devoted to investigate the potential of this approach in this area and currently the authors are further developing the models in order to be used in different real cases in synergy with major players in the sector.

References

Alegre H., Hirner W., Baptista J.M. and Parena R. (2000) *Performance Indicators for Water Supply Services. IWA Manual of Best Practice*. ISBN 900222272

Boschert, S. and R. Rosen. 2016 Digital twin—the simulation aspect. In Mechatronic Futures pp. 59-74. Springer, Cham.

Bruzzone A.G., Sinelshchikov K., Tarone F. & Grosso F. (2021a). Risk Analysis by Monte Carlo Simulation over Large Offshore Projects. Proc. SESDE, pp. 70-74

Bruzzone A.G., Leto A., Massei M., Pernas-Álvarez J., di Bella P. & Turi M. (2021b). Serious Game for Project Management applied to Large Constructions Plants in Africa. Proceedings of the 9th SESDE 2021, pp. 75-79.

Bruzzone, A.G., Sinelshchikov, K., Massei, M., Fabbrini, G. & Gotelli, M. (2020) Extended reality technologies for industrial innovation In Proceedings of 32nd European Modeling and Simulation Symposium, EMSS 2020, pp. 435-443.

Bruzzone, A. G., Cianci, R., Sciomachen, A., Sinelshchikov, K., & Agresta, M. (2019a). A digital twin approach to develop a new autonomous system able to operate in high temperature environments within industrial plants. Proc. SCSC, Berlin, Germany, July, pp. 22-24

Bruzzone A. G., Massei, M., Sinelshchikov, K., Fabbrini, G., Gotelli, M. & Molinari., A (2019b). Machine learning to support industrial digitalization and business transformation. Proc. EMSS, pp. 390-393.

Bruzzone, A.G., Massei, M., Sinelshchikov, K. & Di Matteo, R. (2018). Population behavior, social networks, transportations, infrastructures, industrial and urban simulation. EMSS, c, 401–404.

Bruzzone, A. G., Massei, M., & Poggi, S. (2016). Infrastructures protection based on heterogeneous networks. International Journal of Simulation and Process Modelling, 11(1), 24-35.

Bruzzone, A G, Massei, M., Tremori, A., Longo, F., Nicoletti, L., et al. (2014). MS2G: simulation as a service for data mining and crowd sourcing in vulnerability reduction. Proceedings of WAMS

Bruzzone, A. G., Massei, M., Poggi, S., Dallorto, M., Franzinetti, G., & Barbarino, A. (2013a). Quantitative simulation of comprehensive sustainability models as game based experience for education in Decision Making. Proc. of I3M, Athens

Bruzzone, A. G., Merani, D., Massei, M., Tremori, A., Bartolucci, C., & Ferrando, A. (2013b). Modeling cyber warfare in heterogeneous networks for protection of infrastructures and operations. Proc. of I3M.

Bruzzone, A. G. & Bocca, E. (2012). Innovative solutions based on simulation combined with optimization techniques for maintenance service management within complex systems. International Journal of Modeling, Simulation, and Scientific Computing, 3(02)

Bruzzone, A.G., Gambardella, L.M., Giribone, P. and, & Merkuryev, Y. A. (2000). Proceedings of the International Workshop on Harbour, Maritime & Multimodal Logistics Modelling and Simulation. In SCS Europe

Caputo, A.C. and Pelagagge, P.M. 2003. Using neural networks to monitor piping systems. *Process Safety Progress*. 22(2): 119-127.

Costello S.B., D.N. Chapman, C.D.F. Rogers, N. Metje, Underground asset location and condition assessment technologies, Tunnelling and Underground Space Technology 22 (2007) 524–542.

CUES, Sonar Profiler System for Submerged and Semi-Submerged Pipes, 2008, <http://www.cuesinc.com/Sonar-Profiler.html>.

Doorn, N. (2021). Artificial intelligence in the water domain: Opportunities for responsible use. Science of the Total Environment, 755, 142561.

Ejah Umraei Salam, A., Tola, M., Selintung, M. & Maricar, F., 2014. *on-line monitoring system of water leakage detection in pipe networks with artificial intelligence*. ARPN Journal of Engineering and Applied Sciences.

Farley, M., Trow, S., Losses in Water Distribution, IWA Publishing, 2003

Hazelden G., G. Ragula, M. Roubal, The use of broadband electromagnetic technology for integrity inspection of a 760 mm (30 in.) cast iron and steel line, in: Proceedings of the 22nd World Gas Conference, Tokyo, Japan, 2003.

ISTAT (2020), Censimento delle acque per uso civile, Technical Report, Rome

Lambert A. and Hirner W. (2000): Losses from Water Supply Systems: Standard Terminology and Recommended Performance Measures. IW A Website, www.iwahq.org.uk/bluepages

Leto A. (2019) "From Sustainability to Responce Sustainability up to Resilience", P.Loffredo Editions, Naples

Marlow D., S. Heart, S. Burn, A. Urquhart, S. Gould, M. Anderson, S. Cook, M. Ambrose, B. Madin, A. Fitzgerald, Condition Assessment Strategies and Protocols for Water and Wastewater Utility Assets, Tech. Rep., Water Environment Research Foundation, 2007.

Mays, L. W., Koutsoyiannis, D., & Angelakis, A. N. (2007). A brief history of urban water supply in antiquity. Water Science and Technology: Water Supply, 7(1), 1-12.

Metropolitan Consulting Group (2006). VEWA survey – Comparison of European water and wastewater prices.

Ortloff, C. R. (2005). The water supply and distribution system of the Nabataean city of Petra (Jordan), 300 BC–AD 300. Cambridge Archaeological Journal, 15(1), 93-109.

Rajani B., Y. Kleiner, Non-destructive inspection techniques to determine structural distress indicators in water mains, in: Evaluation and Control of Water Loss in Urban Water Networks, Valencia, Spain, 2004, pp. 1–20.

Rose, J.L., Mu, J., Cho, Y., Recent advances on guided waves in pipe inspection, in: Proceedings of World Conference on Nondestructive Testing, Shanghai, China, 2008.

Schlosser, C. A., Strzepek, K., Gao, X., Fant, C., Blanc, É., Paltsev, S., et al. (2014). The future of global water stress: An integrated assessment. Earth's Future, 2(8), 341-361.

Sack D.A., L.D. Olson, Impact echo testing of in situ precast concrete cylinder pipe, in: Proceedings of the 1998 Pipeline Division Conference: Pipelines in the Constructed Environment, American Society of Civil Engineers, San Diego, CA, USA, 1998, pp. 250–259.

WHO, & Unicef. (2000). Global Water Supply and Sanitation Assessment 2000 Report. Water Supply, 87.

Wilkinson, T. J. (2013). Hydraulic landscapes and irrigation systems of Sumer. The Sumerian World, 33-54.

Xiang, X., Li, Q., Khan, S., & Khalaf, O. I. (2021). Urban water resource management for sustainable environment planning using artificial intelligence techniques. Environmental Impact Assessment Review, 86, 106515.

Yasin, H. M., Zeebaree, S. R., Sadeeq, M. A., Ameen, S. Y., Ibrahim, I. M., Zebari, R. R., ... & Sallow, A. B. (2021). IoT and ICT based smart water management, monitoring and controlling system: A review. Asian Journal of Research in Computer Science, 8(2), 42-56.