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WATER LOSSES IN THE WATER SUPPLY PROCESS – IDENTIFICATION AND CONTROL

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Abstract: Large losses in the water supply system are a significant problem for water supply companies in our country. In a significant number of water supply systems, more than half of the drinking water is lost during use. There are many reasons for this, the most obvious being an outdated water supply network and leaks in the network. In addition to the loss of a large amount of water, leaks in the system can also lead to water pollution in the network, damage to buildings and equipment, etc. Proper leakage management is one of the most important ways to tackle the problem of water loss. Leakage management is usually associated with pressure control and leakage localization. Various software solutions are used, with input data including the volume of water supplied, billed and metered consumption and average working pressure. Such software solutions cannot replace comprehensive monitoring, but they are a good way to start a control program, as the software calculates various actual and apparent water losses and performance indicators based on the data entered by the user. The automation of water supply and wastewater systems enables optimal distribution based on real-time data and ensures more efficient water use, especially in water-scarce regions. Predictive maintenance features reduce operating costs by identifying potential problems before they lead to costly repairs. This proactive approach increases the lifespan of the infrastructure. Simple and convenient mobile applications allow users to access water consumption data, raise awareness and encourage responsible consumption behavior. By minimizing water loss and increasing the efficiency of water use, the innovative methods contribute significantly to environmental sustainability and help preserve natural resources and ecosystems.
Key words: water losses, leakage, location, pressure control

INTRODUCTION

Today's technological challenges in urban water supply and sewerage require integrated approaches, including advanced methods of water purification, monitoring and management of water resources, and the active involvement of smart buildings and urban residents in this process. These innovations and technologies improve the quality and efficiency of water supply and wastewater systems and ensure a sustainable future for the urban environment [1]. In today's conditions, urban water supply and sewerage are crucial, as they not only ensure the comfort and hygiene of the population, but also the preservation of public health and compliance with environmental standards. The development and maintenance of these systems is a complex process that involves many technological challenges and requires innovative approaches and solutions [2]. New technologies offer the opportunity to improve the efficiency and reliability of urban water and wastewater systems, but also place new demands on management and adaptation. The main challenges are: outdated infrastructure, the need for sustainable management of water resources, the preservation of drinking water quality, the integration of smart management and monitoring technologies, and financial and operational constraints. Global events such as urbanization, climate and demographic change are putting increased pressure on water resources and infrastructure, further exacerbating the above challenges. Infrastructure obsolescence in the water and wastewater sector is a complex problem that affects many aspects of management. Many of the existing water and wastewater systems were planned and built in the post-war period and have only been partially renovated and modernized since then. This leads to an increased frequency of breakdowns, water losses due to leaks, reduced efficiency of treatment plants and ultimately an increased risk of pollution of water resources and the environment. Over time, the materials that make up pipes and other system components are subject to wear and corrosion, which reduces their reliability and increases the likelihood of breakdowns. Many systems that were designed in earlier times to meet the needs of settlements and industry are no longer sufficiently efficient today. Growth and urbanization lead to an overload of the existing infrastructure. At the same time, leaks in the old infrastructure are the cause of considerable water losses, which not only increase operating costs but also reduce the efficiency of the entire system. Solving all these problems requires an integrated approach that includes both technological innovation and strategic planning. SCADA and IoT (Internet of Things) monitoring of water and wastewater systems through continuous pressure and flow monitoring registers losses and simultaneously sends alarm alerts to dispatch centers. The combination of these methods provides a non-destructive approach to locating leaks with high accuracy and minimal cost. Implementing smart IoT sensors and monitoring systems helps to detect leaks and failures in real time, enabling faster and more efficient intervention. Remote control and automation also offer opportunities to optimize work and reduce water loss [3-5]. On the other hand, establishing long-term programs to renew and replace old infrastructure is critical to improving the reliability and sustainability of water supply and wastewater systems. Informing and engaging the public about the importance of investing in water infrastructure can also support efforts to secure the necessary funding and support for reform. Water resource management is another important aspect as water scarcity becomes an increasingly pressing issue in many regions of the world. Technologies for the efficient use and recycling of water as well as innovations in this area offer solutions to this problem, but also require considerable resources and adaptation to local conditions. The modern management of water resources requires a complex and integrated approach, especially against the backdrop of increasing global demand for water, climate change and urbanization. In this regard, technological innovations and digital capabilities play a key role in optimizing the use, monitoring and management of water resources [4, 5]. Digital twins, IoT technologies, automation, data collection and analysis offer new opportunities to increase the efficiency and sustainability of water supply systems. Digital twins as virtual replicas of physical systems enable the simulation, analysis and optimization of their work in real time. They can be used to model water networks, treatment plants and other key components, providing useful information on potential efficiency improvements and reducing the risk of failures. Through continuous monitoring and analysis, digital twins help predict system behavior under different conditions, making management and maintenance easier. IoT technologies are transforming the management of water resources by enabling the continuous collection and analysis of data from multiple sensors in the water network, treatment plants and other critical points. This gives a detailed overview of the status of the system in real time, including leak detection, water quality monitoring and optimization of pumps and other devices. The integration of IoT with automated management facilitates the implementation of effective strategies to allocate water resources, reduce water loss and improve overall operational efficiency. Automation, supported by advanced data analytics, enables water utilities to optimize their decisions based on in-depth analysis and predictions. Machine learning and artificial intelligence algorithms can analyze vast amounts of data for trends, anomalies and potential threats and make suggestions for effective management. This includes automatically regulating water flow based on demand, predicting maintenance needs and optimizing the treatment process [2, 4-8].

DRINKING WATER QUALITY

The quality of drinking water is of crucial importance for public health. Problems such as pollution from industrial and agricultural sources require the development and application of advanced treatment and monitoring methods to ensure the safety and quality of water. Advanced treatment and monitoring methods provide the opportunity to explore innovative approaches and technologies that are critical to maintaining high drinking water quality and protecting public health. These methods include physical and chemical processes as well as biological technologies and are supported by advances in sensor technology and real-time water quality monitoring data. Drinking water treatment methods are costly solutions and their use is only justified in the presence of certain contaminants [1, 2]. Therefore the availability of adequate information on potential contaminants is crucial for the efficient operation of drinking water treatment plants. In this regard, modern sensors enable continuous monitoring of water quality by measuring chemical, physical and biological parameters in real time. Sensors can detect a variety of contaminants such as heavy metals, organic compounds and microorganisms, enabling a rapid response when problems are detected. The integration of IoT devices and cloud technologies into water monitoring systems enables remote monitoring and analysis of data from multiple locations, contributing to efficient resource management and water pollution prevention [1, 2]. Artificial intelligence and machine learning offer the ability to analyze large water monitoring data, detect patterns and predict potential risks to water quality. These technologies can improve the accuracy of monitoring and the efficiency of water quality management solution. Technological innovations offer new opportunities to solve today's water supply challenges and provide access to clean and safe water for population on a global scale [3, 6].

IMPACT OF SMART BUILDINGS

With emergence of smart buildings, prerequisites are created for optimizing and increasing the quality of water supply and sewage systems in urban areas. Smart buildings use advanced water management systems that include sensors and automated consumption control. These systems can identify and prevent leaks, regulate consumption in real time and direct the use of recycled water e.g. in toilets, for watering green areas, etc. This reduces the total consumption of water in the city and increases the efficiency of the city's water systems. Smart buildings can reduce their dependence on central water systems by integrating rainwater harvesting and recycling technologies, which reduces pressure on urban water and sewer networks, especially during drought or high consumption, and enables sustainable management of urban water resources. Smart buildings can also include water pretreatment systems that improve water quality even before it is used in the building. This not only ensures a higher quality of life for residents, but also reduces the burden on the city's treatment plants, because the wastewater returned to the system is less polluted. Systems in smart buildings can be integrated into a wider network of smart city systems, sharing data and information about water consumption and quality, thereby enabling city governing bodies to obtain useful information for resource planning and emergency response in real time, leading to more efficient and sustainable management of city water supply and sewage systems. By optimizing water consumption, reducing pressure on infrastructure, improving water quality and integrating with smart city systems, smart buildings contribute to sustainable development and improvement of life in urban areas. City dwellers have a very important role in the sustainable management of water resources, as their daily habits, awareness and engagement can have a major impact on water consumption and quality. Citizen participation in water conservation, recycling and waste water management programs is important for reducing pressure on city water systems. User awareness of the impact of their actions on water resources and support for investments in smart technologies and sustainable practices can help improve the quality of water supply and sewage systems. Modern cities are increasingly resorting to intelligent solutions for monitoring water supply and water distribution to ensure that citizens and industrial enterprises have access to the required quantities of water. The goals of intelligent water resource management are twofold: minimizing losses and wastage due to leakage, as well as rational management of consumption. Although various strategies and programs to reduce water losses and water supply management are implemented in many places around the world, losses due to inefficient distribution and leakage are still a serious problem in the water sector. The European Environment Agency predicts that by 2030, global water needs will increase by as much as 40 percent. Modern smart technologies and mobile applications provide powerful tools for involving city residents in water management processes, promoting sustainable habits, raising awareness and improving the overall efficiency of city water systems. Mobile apps allow users to monitor their water consumption in real time providing useful information that can help identify unnecessary consumption or leaks. The aforementioned applications can send alarm messages when consumption is extremely high, encouraging a quick response and preventing water loss. Also, applications and platforms that send notifications about emergencies or planned water outages help residents prepare and manage their resources more effectively [3]. A block diagram of a complex intelligent system of water supply and sewerage, which is connected to a cloud platform, is shown in Figure 1 [9].

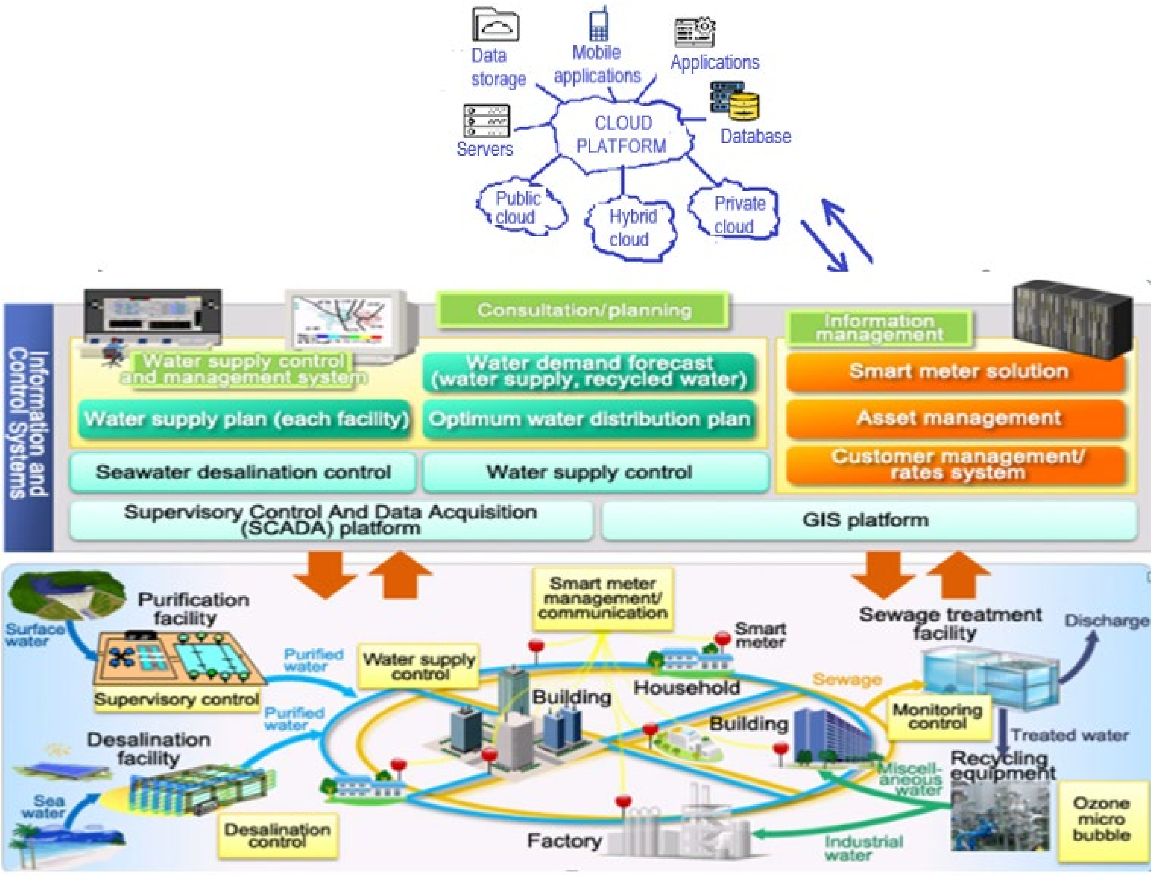

Fig. 1. *Water management system technology*

An intelligent water supply network is a fully integrated set of components and solutions that, based on a large amount of collected data, enable water companies to optimize all aspects of water distribution, waste water collection and treatment systems [9]. The 5-layer model of intelligent water networks is most often considered. The first layer includes physical components-springs, dams, reservoirs, pipelines, pumping stations, well facilities, reservoirs, break chambers, etc. In the second layer are devices and equipment in the field: sensors that measure various parameters such as flow, pressure, level and quality of water, as well as remotely controlled devices such as pumps, various electric drives, regulation and on/off valves. These automation elements are installed in the aforementioned plants of the first layer. In the third layer, data acquisition and communication are performed. There are included systems for storing and transmitting data from remote locations, and this data is forwarded to the layers where it is analyzed and processed. Using two-way communication channels, commands are sent back to the second layer requesting the sensors to collect certain data and commands to the executive bodies (actuators). Part of this layer are e.g. fixed cable network, radio, mobile, Wi-Fi and other communication technologies used for data transmission. The fourth layer includes data management and visualization, whereby collected data is processed and displayed on an operator-friendly interface Supervisory Control And Data Acquisition (SCADA), geographic information system (GIS) or other network visualization platforms. This layer also interacts with systems and tools related to cybersecurity and to support business functions such as order management and customer information systems. The last, fifth layer applies tools that integrate software for data analysis and modeling using communication channels and sensors in the network. As a result, water companies can automatically remotely manage the network, including monitoring the quality of water in the network, automated leak detection, optimization of pump plant operation, and more. To solve the tasks in this layer, the capabilities of Artificial Intelligence - AI, management and analysis of Big Data, real-time monitoring, Soft Computing that uses fuzzy logic, artificial neural networks, genetic algorithms in the field of evolutionary computing and techniques based on the application of rough set theory can be additionally used [3-6]. These solutions are introduced to enable assessment of the potential impact of changes in the network, to react in time and to consider likely scenarios. To illustrate, an example of modern water resource management in the city of Indore, India is given. By applying edge computing, IoTstar series ICP DAS intelligent controllers, and IIoT cloud infrastructure management software, data on water supply systems located in the aforementioned city can be wirelessly transmitted in real time to a central monitoring and control system via a 4G network, enabling remote management and monitoring of water supply throughout the city [10]. Status of the water supply system can be monitored at any time through operator panels, and the information obtained can be used as a reference for preventive maintenance of the water supply system (Figure 2) [10].

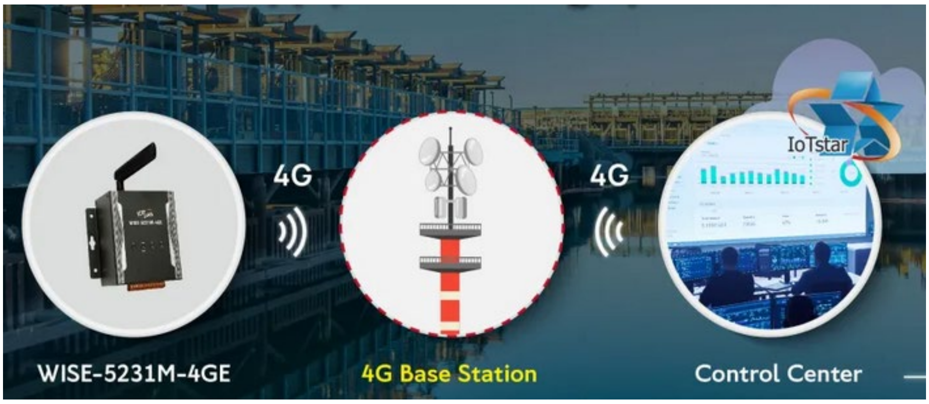

Fig. 2. *Illustration of supervision and control of the water supply system of the Indore city, India*

WATER LOSSES CONTROL

Main reason for large losses is usually an outdated water supply network and numerous breakdowns. However, replacing the water supply network requires significant financial resources, which the water supply companies could hardly provide on their own. In order to overcome the problem of large water losses, in addition to replacing the outdated pipeline network and performing the necessary repair work, it is necessary to undertake other measures related to the management of leaks in the system. Performance and profitability of the water transportation system depends to a large extent on transporting the water with as little loss as possible. Leaks in pipelines mean not only the loss of potable water that has been treated at high cost, but also the potential economic loss caused by possible consequential damages, especially due to the collapse of buildings. Therefore, the goal is to detect and locate leaks in transport pipelines. Leaks can cause serious financial losses to the water supply system. For example a breakthrough of 5 mm at a pressure of 5 bar generates annual losses of about 12.000 m3. With an average consumption of 160 liters per day, this amount is enough to provide the annual drinking water needs of around 200 people. Leak management activities are related to pressure management and finding leak locations. One method used to estimate the amount of water lost through the network is to measure the minimum night flow. In this case, the hourly amount of water delivered to the network is measured during the period when there is the least demand, usually between 1 and 4 at night. Consequently, in parts of the network where leaks are well controlled, the value of the measured minimum night flow would not be much above zero. The higher the minimum night flow, the higher the leaks in the system.

LOCALIZATION AND LEAKS DETECTION

Bearing in mind that the preliminary analysis provides an overview of the leakage in the network as a whole, the most efficient approach from an economic point of view is to identify and locate the 20% of the largest leaks, since in principle they account for 80% of the losses. A common strategy is to zone the water supply system, which allows the most serious leaks to be isolated to a specific area, which can then be more accurately assessed using appropriate leak detection equipment. Strategically installed flow meters divide the network into specific sectors or zones that can be analyzed independently. Leak detection equipment includes basic and relatively simple technologies as well as more sophisticated ones. One of the simplest devices is a sound detector (microphone). In practice, it is a microphone that is placed on the ground. Microphone amplifies the noise created when pressurized water comes out of a damaged pipe. Finding the location with the loudest noise indicates where the leak is most likely. Advantage of digital microphones is that they distinguish the actual leak noise from the surrounding noise. There are electronic sound detectors for recording and amplifying sound oscillations of all kinds that arise in the very structure being examined. Such a detector is Stethophon 04. Oscillatory sensor enables sound reproduction without distortion even when the noise is barely audible. A ground microphone can be connected to the Stethophon 04 detector to listen to sounds below the ground. The filtering function allows users to listen to the sound at a frequency that best suits their hearing and the noise being heard. Filters make it easier to listening certain noises such as the deep sounds characteristic of leaks from plastic pipes and the higher frequencies from metal pipes. The operator's hearing protection function automatically ensures that the headphones are turned off when loud noises suddenly occur. To facilitate the leak location process, the digital display shows not only the current lowest noise, but also the lowest measured noise from the previous location, so the operator can see if he is moving closer or further away from the sound source [11]. In addition, to measure an accurate digital value in real time, the noise level is represented graphically. By recording noise levels for several locations, the location of the leak can be determined with high precision. There are more complicated devices - noise correlators. In principle, correlation is the detection of leaks based on a computational process for underground pipelines with flow. Noise caused by the leak propagates along the pipe and reaches the two fittings (valves, hydrants, fire hydrants, etc.) at different times depending on the distance from the leak to the contact points. Highly sensitive sensors are used that detect the resulting noise from the fitting, and the radio transmitter forwards them to a receiver (correlator) that determines the location of the leak by calculating the time difference based on the different distance between the contact points and the leak. In order to more precisely determine the location of the leak, it is necessary to take into account the material, diameter and length of the measured part of the pipeline. With use of a correlator, the leak can be located with a precision of up to a few centimeters. Intensity of the background noise has no influence on the measurement results.

CORRELATION FUNCTION

Conventional correlators require a highly skilled operator to search the required data in the software, including the material, diameter and exact length of each pipe segment between the sensors. The quality of the results depends largely on the operator's ability to obtain a clean correlation peak using manual adjustment of the filter range. The decision as to whether or not a leak is present is up to the operator and in many cases is an art, not a science. If the correlation is unsuccessful, the user has no way of reproducing the results (or lack thereof) later, and there is no way to put them in context in the entire environment; the results are essentially individual and independent. There are also modern intelligent leak locators such as the EASYSCAN system. Eliminating the need for manual distance measurement: the operator automatically receives the GPS position of the two sensors, which can be manually adjusted via the device's street map (Figure 3).

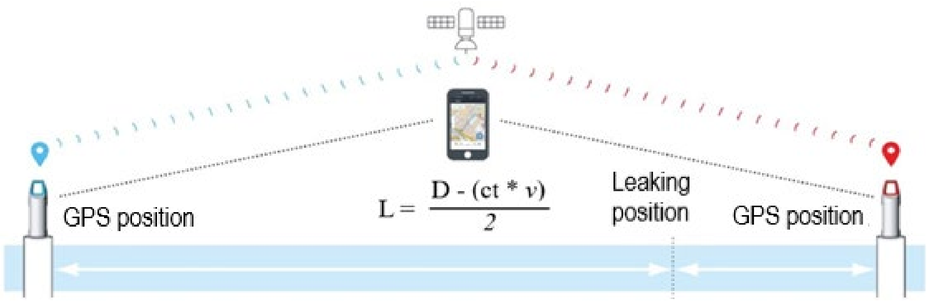

Fig. 3. *Illustration of leak location determination using the EASYSCAN system*

Any leaks detected will be automatically displayed at a precise geo-location on a street map. EASISCAN features an "auto filter" developed for high-quality Gutermann correlators. As soon as the sensors are programmed and positioned, the correlation result appears automatically, with no ambiguity in the results. At the end of the measurement, EASISCAN concludes whether or not a leak is present. If there is one, the operator activates the listening function by pressing a button and can listen to the noise of the leak at the indicated position. All measurements, whether there is a leak or not, can be recorded in the device's memory for later review [12]. After pinpointing the location of the leak with the help of the correlation function, acoustic listening is used to confirm the exact location above the earth's surface. Using GPS coordinates, the EASYSCAN application guides the operator to the expected location of the leak. The exact location can be seen on the street map. All information containing sound recordings can be saved on the map, and can be reviewed and listened to again later. The exact position is located with the help of GPS and displayed on the street map of the application. If a leak is found, it can be recorded on the map, along with the original search sound. The EASYSCAN application has an easy-to-understand and intuitive interface with which the entire leak detection process can be managed. It is connected to all sensors that are available by radio connection via the EASYSCAN link so that no additional cables are needed for connection. The application combines GPS and street map data, and thus enables an extensive overview of the locations and distances of all possible leak sites [12]. Measurements that are recorded can be saved for later review and playback. For advanced listening while working with a ground microphone, there are optional headphones that can be connected to a smartphone. Software uses automatic frequency filters to set the best parameters to get accurate results. Application works on all Android OS tablets and smartphones. Even in the heaviest road traffic, the correlation is performed successfully. Factors such as pipe depth, surface, soil type, different weather conditions cannot affect the correlation detection of leaks. Other devices used are acoustic loggers. They measure noise intensity over a period of time when looking for the lowest levels of noise or possible interference. Very low levels (measured values around 0) do not indicate a leak. In the case of leakage, the noise is constant and ideally it is the only noise that is measured. Loggers are usually mounted on surface equipment such as fire hydrants and can be permanently installed or used as needed for short periods of about two days.

PRESSURE CONTROL

A convenient method to reduce water losses due to leakage is to control pressure in the water supply network. It is a known fact that there is a direct relationship between pressure and water losses. Reducing the water pressure in the network reduces the amount of water escaping through any existing openings or leaks in the pipes. Measures to maintain pressure within optimal limits at low consumption are considered very effective and pay off quickly, as they also contribute to extending the life of pipes. This enables the pressure to be balanced within the network, so that a larger number of customers can be served with very little increase in incoming water. A suitable method to reduce water losses due to leakage is A good solution is to use automatic pressure reducing valves and connecting equipment so that the pressure can be adjusted flexibly taking into account fluctuations such as e.g. change in inlet pressure, which can be further reduced at night when there is low consumption. In situations where underground pipelines have multiple leaks, pressure management can be among the most cost-effective methods of reducing losses, barring, of course, large leaks that require intervention. Siemens offers a solution that continuously monitors the value of the flow in different branches of the water supply network, which significantly reduces the time to detect leaks, the costs associated with this process, as well as water losses. The Siemens Siva LeakControl monitoring system is based on a three-step solution concept. During the first step, measures are taken to automatically detect leaks by continuously measuring the flow in defined parts of the network. The method is based on a complex monitoring system that measures flow using ultrasonic flow meters for non-invasive installation-Sitrans FST020. High accuracy and repeatability of measurements are of primary importance. The flow meter FST020 allows accurate measurement even at low speeds. Easy to assemble and disassemble, the converters have no contact with drinking water and can be installed in the ground even without a shaft. Data from the flow meter are transmitted to the central unit, where they are collected and estimated, and in case of suspected leakage, an alarm signal is generated. In the second step, the leak is located by temporarily placing additional acoustic sensors. The last step is to accurately determine the location of the leak using the correlator [13].

CONCLUSION

Water losses have socio-economic and environmental aspects. The fight against water scarcity and water resource management is increasingly relevant due to climate change. In addition to human needs, water is also needed to maintain natural ecosystems. Water prices are already causing tension in some regions, and water scarcity could lead to pressure to withdraw more water from natural ecosystems, some of which are already suffering from scarcity. Technological and digital innovations offer significant opportunities to improve water resource management. Implementation of digital twins, IoT technologies, automation and data analytics can significantly improve the monitoring, analysis and optimization of water supply systems. These approaches not only increase efficiency and reduce operational costs, but also help in the sustainable management of water resources in the future, ensuring their availability and quality for current and future generations. Integration of IoT devices and cloud technologies into the water monitoring system enables remote monitoring and data analysis at multiple locations, which contributes to efficient resource management and the prevention of water pollution. Artificial intelligence and machine learning offer opportunities to analyze big water monitoring data, identify patterns and predict potential risks to water quality. Advanced purification and monitoring methods are essential to ensure the safety and quality of drinking water. Technological innovations offer new opportunities to solve today's water supply challenges and enable access to clean and safe water for the population globally. Various software tools have been developed to determine the likelihood of leaks as well as possible sources, however, they all require the availability of some basic data about the water supply system, such as the amount of water supplied, billed and metered consumption, as well as the average operating pressure. Typically, such software solutions are not intended to and cannot replace performing a thorough due diligence, but they are a good way to start a leakage management program, as the software uses the input to calculate different types of actual and apparent losses as well as efficiency metrics. Losses of water distribution companies can be controlled by an annual audit of water supply activities and implementation of programs to identify and limit those that function poorly. Such programs include leakings management, water meter accuracy testing, and measures to combat water resources misuses. Commercial losses arise from inaccurate customer meters, billing system data inconsistencies, or unauthorized use. These losses cost the utility revenue and distort data on customer consumption patterns. Losses are also physical, including water that leaves the water supply system due to leaks or overflows. To overcome the problem of large water losses, in addition to replacing aging piping and performing necessary repairs, other measures related to managing leaks in the system are also required. Leak management activities are associated with pressure control and leak location.

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