Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2018.23103

128 (2018) 442–449
October

Protection of water resources for sustainable development

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Received 5 June 2018; Accepted 28 August 2018

ABSTRACT

Poland, like other European Union countries, is committed to the rational use and protection of water resources in accordance to the principle of sustainable development. The strategic activities in this area undoubtedly include, for example, reduction of rainwater discharge from urban areas and saving or rationalizing water consumption. Actions in the field of water resources protection should focus on the management and use of rainwater at the place of its creation, promoting the concept of minimization of water consumption and water loss, and the development of new ways of collecting and using water and protection against its pollution. In their paper the authors analyzed in detail the possible reduction of water losses in the Cracow water supply system.

Keywords: Green infrastructure; Saving water; Loss of water; Measurements

1. Introduction

Water as a priceless raw material covers 72% of our planet's – Earth, which due to this fact is known as a blue planet. Unfortunately, more than 97% of water resources are sea and ocean waters, which due to salinity are difficult to be used as water supply resources. Fresh water resources, which comprise of surface, ground, and atmospheric water, are very unevenly distributed. About 40% of areas on the Earth's surface has a limited access to drinking water and about 20% of the world's population has no access to clean drinking water. The deficit is most acutely felt by the countries of northern and central Africa, South America, and Central Asia. It is estimated that some European countries such as Spain, Italy, Belgium, Germany, and the United Kingdom will face a shortage of drinking water in the near future. According to the World Health Organization, over 100 million people in Europe do not have access to clean drinking water, and by 2050 the demand for drinking water will increase by 55%. Poland's water resources are small compared with European countries. Their average amount is about 62 km and about 16 km^3 of this volume accounts for hard to recover groundwater resources. According to the European Commission, annual amounts of water available per capita in Poland in 2009, was 1,580 m^3 – three times less than the European average (4,580 m^3) and 4.5 times less than the world average [1].

Due to various factors (climatic and hydrological conditions, increasing pollution of water resources) our country, although it may seem unlikely, is threatened by a water deficit. Hence, we are talking about a century of water.

Poland, like other European Union countries, is committed to the rational use and protection of water resources in accordance to the principle of sustainable development, that is, by improving the quality of life and at the same time preserving the natural environment, in particular water resources [2].

Existing drinking water supplies are extremely vulnerable to pollution. 1 L of sewage pollutes about 8 L of clean water. It is estimated that the total amount of polluted water in the world is 12,000 km^3; this is more than the total amount of water from the 10 largest river basins in the world. If the

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Presented at the XII Scientific Conference "Membranes and Membrane Processes in Environmental Protection" – MEMPEP 2018 13–16 June 2018, Zakopane, Poland.

degree of pollution increases, following a population growth, the world will lose 18,000 km^3 of clean water by 2050; this number exceeds nine times the amount of water used annually for irrigation throughout the world, and irrigation consumes the largest amount of water [3].

In Poland, the sewage volume discharged from households was 938.1 hm^3 in 2016 and it increased by 12 hm^3 compared with 2015. Meanwhile, the water treatment process is very expensive and a water quality deteriorates with every treatment round [4].

Therefore, the first objective is "do not pollute," while the next is to stop diminishing water resources and use them rationally. The strategic activities in this area undoubtedly include, for example, reduction of rainwater discharge from urban areas and saving or rationalizing water consumption.

2. Limitation of rainwater outflow from urbanized areas

Drinking water resources are renewable: river water is renewed every 18–20 d, water in an atmosphere after 12 d, in lakes after 10 years; groundwater gets renewed in over 5,000 years, while it takes about 8,000 years to renew glaciers. This process is regulated by a hydrological cycle that depends on the amount and intensity of atmospheric precipitation [5].

The Water Law Act of July 20, 2017 (OJ 2017, item 1566) clearly defines water management obligations and declares rainwater as a water resource. The concept of waste rainwater has disappeared; what goes into the sewage system remains rainwater. In Poland, atmospheric precipitation as the main water resource accounts for 97% of the total water supply; the remaining 3% comes with tributaries from abroad [6, 7]. Atmospheric precipitation is not evenly distributed on Earth, nor in Poland.

Nearly half of the annual rainfall comes from high intensity or even torrential rains, which result in a rapid surface runoff. Poland has one of the lowest in Europe percentage (on average 18%) of waters penetrating deeply into the ground, that is, stored for a longer time.

A proper water management must comply with two principles, namely:

- maintaining as much water as possible for as long as possible in the ground; it can be done by minimizing a water discharge beyond the basin through surface and ground retention as well as prolonging in time the discharge from the basin,
- enhancing transport of water from the soil to the atmosphere via plants and reducing a transport through a direct evaporation from the soil.

The problem of poor retention particularly affects urban areas, where there are always natural hazards generating social, economic, and environmental losses; they are related to the prevailing climate, natural conditions, and human activity. Currently, these threats are becoming more intense, both in Poland and in the world, due to ongoing climate warming, which is associated with the intensification of extreme atmospheric phenomena, including natural disasters [8,9].

Cities are ecosystems, where people, infrastructure, and nature should co-exist in a harmonic way. The challenge, however, is to develop the city in such a way, so that it has a positive impact on all areas of life, including the quality of the natural environment. The handling of rainwater and snowmelt in urbanized and industrialized areas is an extremely important element of a sustainable development in cities. Rainwater should be protected from pollution and then managed and used on site.

It should be ensured that rainwater drainage from urban areas passes through sustainable drainage systems, which guarantee infiltration, retention, and evaporation. As alternative solutions, they can serve as separate systems replacing a sewage system or elements of systems supporting the work of traditional technical infrastructure [10].

A very good way to deal with adverse effects of climate change are solutions based on natural forces, for example, green and blue infrastructure; they can support the work of traditional technical infrastructure. Blue–green infrastructure is a key element in many strategies, for example, National Strategy of Regional Development 2010–2020, Europe 2020: European Strategy (Brussels, 03.3.2010 COM (2010) 2020, or National Development Strategy 2020, adopted on September 25, 2012, by the Council of Ministers.

Green and blue infrastructures work closely together: vegetation is a biological reservoir of water, while water is essential for a vegetation growth. Green and blue infrastructures reproduce natural processes occurring in the environment, such as: infiltration, by increasing a proportion of permeable and absorbent surfaces; retention, by increasing the share of open waters, use of ground and underground retention reservoirs and application of appropriate bioretention-based solutions, and uptake of water from a root zone and evaporation to the air (evapotranspiration) [11,12].

Green infrastructure, integrated with spatial planning includes: green gardens, green roofs, or green walls (Fig. 1), basins with vegetation as well as green streets and passages; they are modern systems of rainwater and floodplain management, integrated with a spatial planning.

In water management, green and blue infrastructures in urbanized areas become a part of a future eco-engineering, regardless whether there is a water excess or shortage.

Fig. 1. Green wall (authors' own work).

Cities are doing more and more in this matter and also local communities are more and more interested in greening urban spaces. Łódź can be a good example of the city that stimulates the residents' activity and involvement in green area expansion (Green Łódź program). As a part of the program, the residents get familiar with existing green areas in the city, where they can participate in numerous events (photo-workshops, bicycle trips, runs, cognitive walks, yoga classes, concerts, etc.); thus they can spend time in an active way. Following the example of Łódź, the Board of the City Greenery in Cracow initiated a similar project "Cracow in Green." Both programs are very popular among the city residents. Actions encouraging residents to spend time in an active way in city parks are very valuable, since they change perception of greenery, showing it as a very beneficial and desirable asset. Such events also raise awareness and knowledge of residents on a common cultural and social space [13].

3. Rational water consumption and saving

Technologies that save water and introduce appropriate economic incentives can reduce water consumption in industry, agriculture, and households by up to 40%. With a free access to running water, most people do not think about how to manage it, and how much water they use to do their daily household chores. It turns out that the easiest way to save water is to change our everyday habits. Within 1 min, about 9 L of water runs from the tap to washbasins, hence one should turn off the water while brushing teeth, shaving, and performing similar activities. The bath in a bathtub requires 115–150 L of water, while taking a shower can reduce water consumption by up to 25%.

If tap water drips with a frequency of one drop per second, in a year even 11,935 L of water can be wasted and gone to the sewer.

The use of eco-fittings, savings programs in washing machines, and dishwashers guarantees significant savings in water consumption. One of the most interesting solutions is contactless fittings. Thanks to the mounted photocell, it automatically switches off water after the preset time. This type of battery works well in public institutions and shopping malls as well as in individual housing. An alternative solution is models equipped with economical ceramic regulators that allow for setting the economic flow of the water. By adjusting water temperature, water flow is reduced rather than increased. A toilet and its reservoir consume the most water in households. Recently, a compact toilet with a mechanism, allowing for only half of the tank volume to be used for flushing, becomes a standard.

The economic use of rainwater is becoming more and more popular in Poland. It reduces the direct outflow of water into the ground, but also reduces consumption of drinking water. Depending on a pattern of water consumption in a given household, up to 60% of water demand can be covered with water coming from atmospheric precipitation [14].

Gray sewage, beside rainwater, can be an alternative source of water (often used in combination with rainwater). Gray sewage as a source of water of inferior quality, which after appropriate treatment, can be used for flushing toilets, watering gardens, and even washing, in case of industry. The potential role of sewage as a source of water supply was presented in the Strategic Plan of Implementation of the European Innovation Partnership for Water, in the Plan for the Protection of European Water Resources. Among EU countries, Malta reuses up to 90% of sewage, Cyprus 60%, while Greece, Spain, and Italy only from 5% to 12% [15].

Saving water also means taking care of sanitary installations. Small leaks and damaged gaskets can result in hundreds of cubic meters of water losses. A regular check-up of technical conditions of fast-wearing elements will not only guarantee a lower water consumption, but also avoid a serious breakdown. The problem arises particularly in multifamily housing, where many minor leaks from installations and taps in the building (faulty tap, leaky flush) still occur, especially when residents are charged with a lump sum for water.

Another issue is the loss of water within a water supply system. It can occur at any stage of a water supply system (intake, treatment, transmission, distribution, and retention). The subsystem of water distribution is particularly sensitive, since its losses are caused by water leaks (leaking pipes and fittings) or failures of water pipes.

An intelligent water metering system (readings from water meters), which automatically collects water meter readings in periods much shorter than a billing period, is a very good tool to minimize irretrievable water losses [16].

In this paper, the authors analyzed in detail the possible reduction of water losses in the Cracow water supply system.

4. Characteristics of the test site

The Cracow water supply system is one of the largest in Poland. The system takes water from four surface water sources; the largest one is the Dobczyckie Lake. The water is treated in four treatment plants and then transported through over 2,200 km of the water distribution network. The water supply to the residents is metered by 59 thousands main water meters installed throughout the city. The city of Cracow is constantly growing and more than 1,500 new sites are connected to the water network every year. However, despite the intensive development of both the city and the water supply network, water consumption by Cracow's residents has been systematically declining, until 2015. In 2017, the Cracow Waterworks sold over 50 million m^3 of water, and the actual sales trend is shown in Fig. 2.

5. Methods and results

There is a strategy developed to limit water losses and to optimize costs incurred by a water supply company, including environmental costs. These activities are carried out simultaneously and involve organizational, investment, modernization, and renovation actions. The strategy of searching for leaks (constant network monitoring, hydrodynamic models of the network) is combined with optimization of metering (verification and adjustment of a water meter class and size to current needs, remote reading). A diagnostic system linked with a calibrated water network model, operating in a real time, helps to precisely detect, locate, and determine a leakage rate.

The precise measuring system, operating in real time, is a very important element of diagnostic system operation.

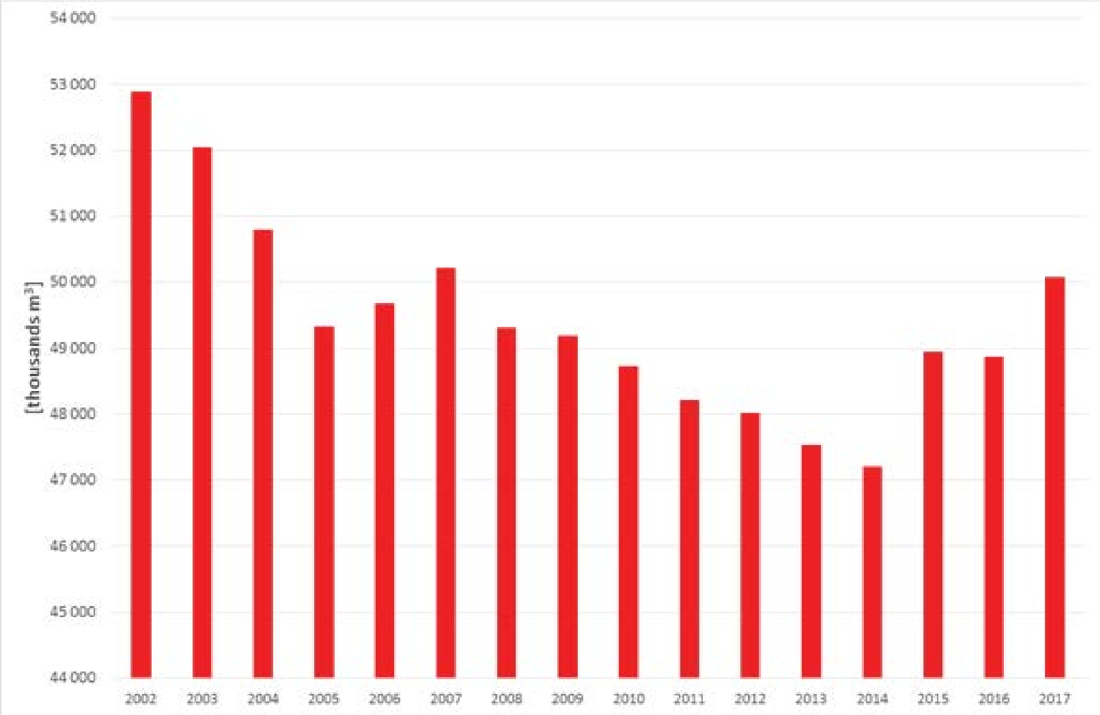

Fig. 2. Water sales at the Cracow Waterworks in the years 2002–2017 (authors' own work).

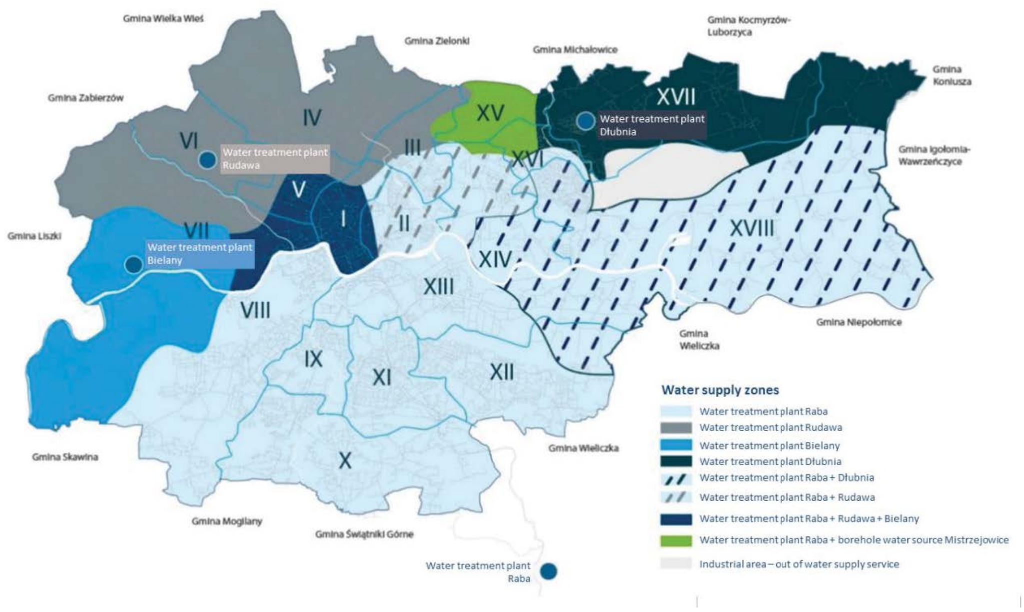

Fig. 3. Water supply source zones within the Cracow water supply system (authors own work).

The Cracow's water supply system is divided into zones under the pressure occurring in the network and in terms of water supply sources Fig.3.

In order to assure an active control of water losses, there is a need to distinguish smaller subzones within the existing pressure zones. Cracowian water system implements gradually this strategy, according to its technical and economic capacities. The ultimate goal is to develop a power tree structure, in which individual branches represent water flow measurements. Such a structure will be even more effective, if it helps to identify metered zones, containing up to several hundred water meters in individual zones. The system performs a successive analysis of water balance and trends for individual recipients for each zone.

Water network failures or a leakage in a household installation, that is, downstream from the main water meter, occur both in old and exhausted networks/installations and in newly built ones. Sometimes their effects are ignored, because the water gets into the sewage system or soaks into the ground under the building. The presence of such a failure can be verified only by thorough diagnostic tests or a pressure test within the internal installation of the building. Online measurements of the flow rate in the network provide information on any possible irregularities (see Fig. 4). The initial flow rate in the water network corresponds to the actual water consumption (during normal operation) followed by a rapid increase in water demand, caused by a leak from the network zone; once the failure has been repaired the flow returned to the previous value.

Figs. 4 and 5 present values of instantaneous flow rates in the network zone in two different states. The blue graph shows the flow during normal operation, while the red one

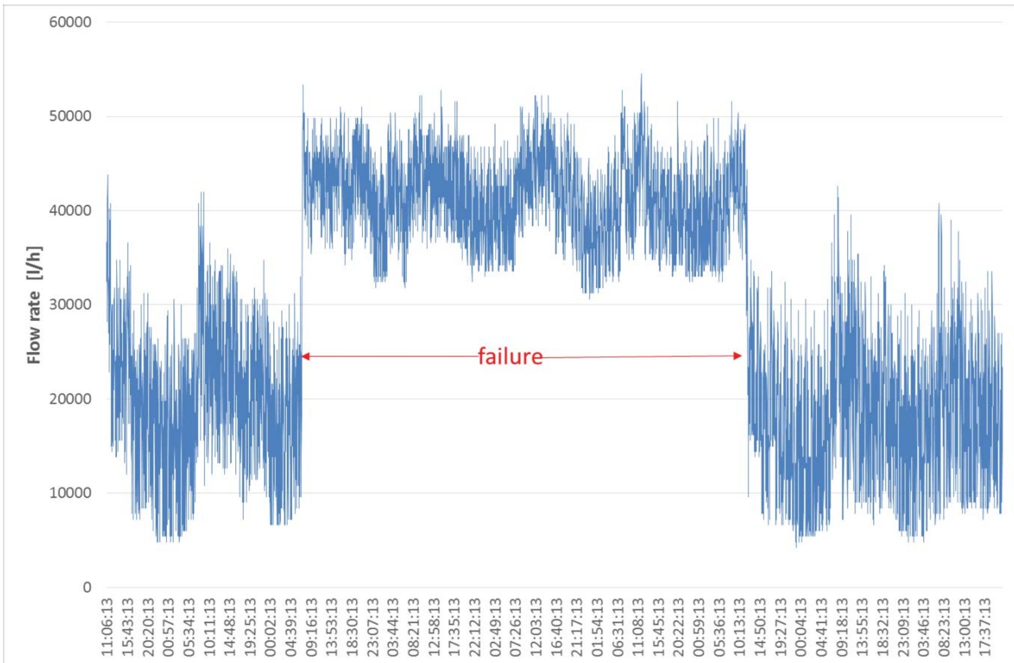

Fig. 4. Flow rate in the water supply network during normal operation and during a breakdown (authors' own work).

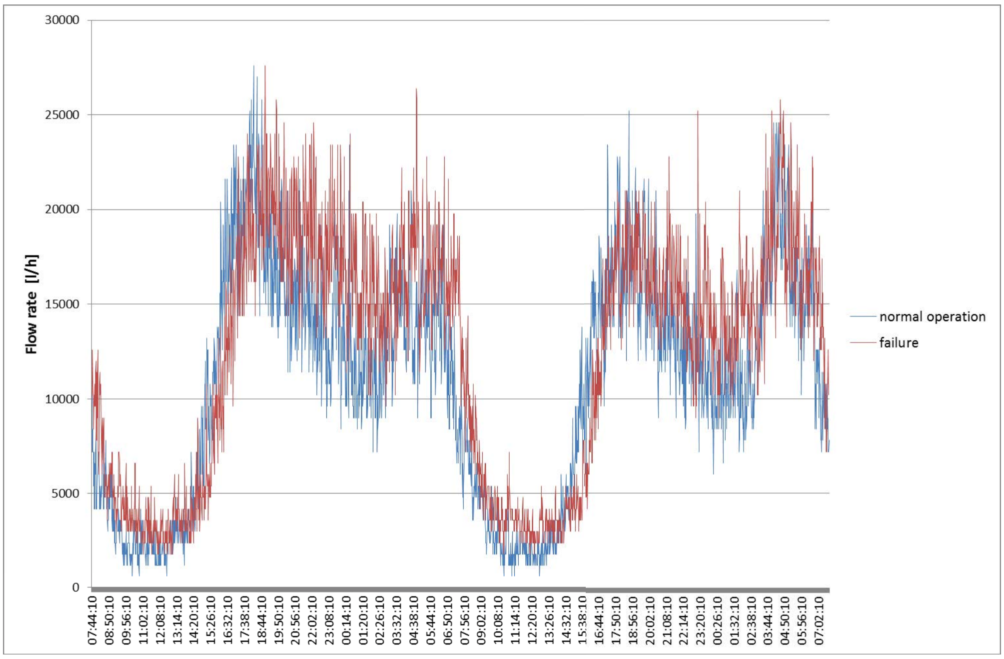

Fig. 5. Instantaneous flow rates in the network zone during normal network operation and during a breakdown (authors' own work).

shows the flow to the zone, when an emergency water leak took place. Much higher water losses were observed at night due to higher working pressures in the network.

A professional application tool is required to successively estimate water losses in individual zones and point out the ones that require diagnostics. The Infrastructure Leakage Index (ILI) together with some empirical data, resulting from technical experience, should provide such a tool. Based on the latest measurement data a water balance can be calculated in individual zones as well as in the rest of the system (not divided into zones).

The daily flows at the zone supply points and at outlets from the water treatment plants play the key role in a water balance. According to the IWA methodology, it is necessary to enter the parameters essential for calculation Unavoidable Annual Real Losses (UARL) for each zone, that is, length of the network in the zone, number of connections, length of connections, and water pressure in the zone. Based on the long-term analysis of historical water losses in the zone, both during regular and emergency operations, the acceptable water losses for each metered zone of the water network are determined [17,18]. The network efficiency in the zone can be estimated by a comparison of the actual daily flow delivered to the zone with the total consumption, complemented by unavoidable or permissible losses. The application algorithm is shown in Fig. 6.

Fig. 7 shows the ILI in the analyzed zone of the water network in subsequent days, which include both a normal network operation status and the failure incident. The ILI = 2 was assumed as an acceptable limit of losses in the zone (doubled inevitable losses). In practice, when this value is exceeded, it means a zone's failure or failure of any of the measuring devices used. Once the failure is removed and the network is rinsed, the value of the infrastructural indicator of leaks in the zone returns to the value of ILI < 2.

International benchmarking studies show that water losses occur in all water supply systems and their magnitude vary between systems. The volume of water losses per kilometer of the network were reported for western Europe waterworks, gathered under the European Benchmarking Co-operation (waterbenchark.org) for 2016. They ranged daily from 0.7 to 14.4 m^3/km of the network. The median value for the group was 6.34 m^3/d [20,21].

In practice, water supply companies often encounter failures of installations downstream also from the main water meter. The failures (anomalies) in the installation of the monitored property are signaled by a continuous operation of the main water meter, also during the night; the flow does not drop below 50 L/h. Such flow is usually not measured by a low-accuracy residential water meter. However, it is measured by the main water meter, class R160.

Figs. 8 and 9 show flow recordings in the household, where high water consumption was caused by a sprinkler used in the garden after the vegetation period.

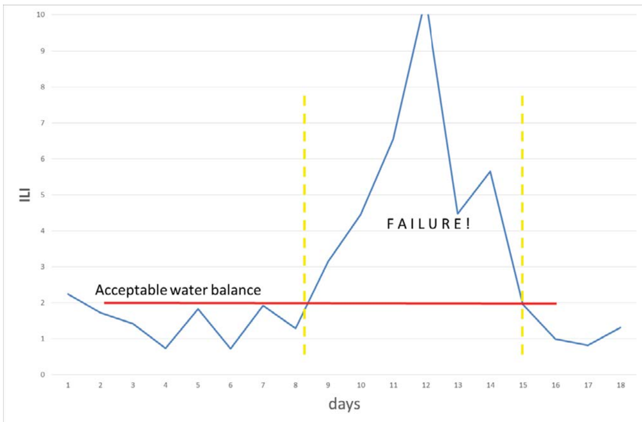

Fig. 7. The Infrastructure Leakage Index (ILI) in the zone of the water supply network (authors' own work).

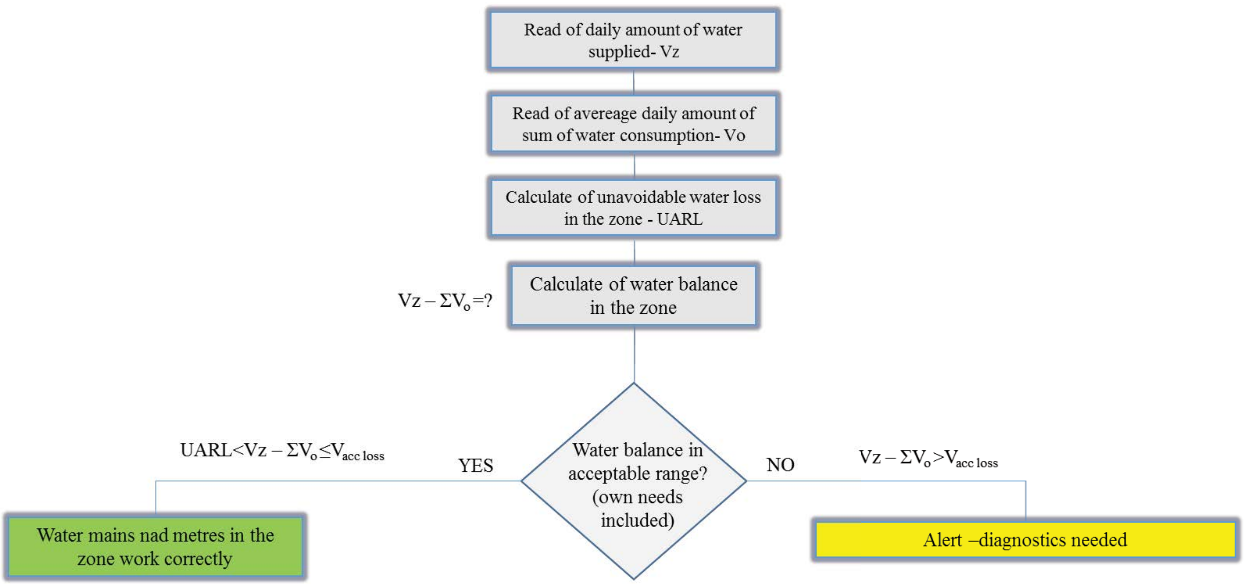

Fig. 6. Algorithm of successive evaluation of the network zone with respect to water loss [19].

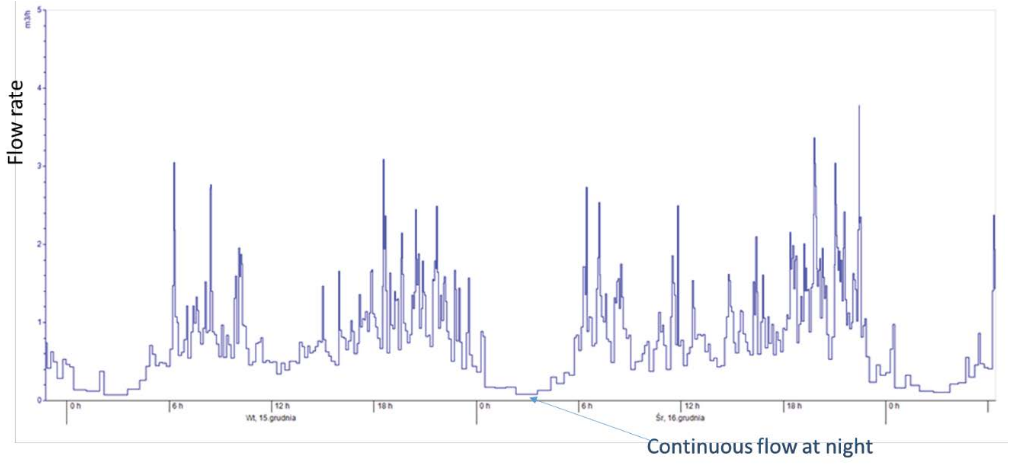

Fig. 8. Flow rate diagram in the household with a continuous water flow at night (authors' own work).

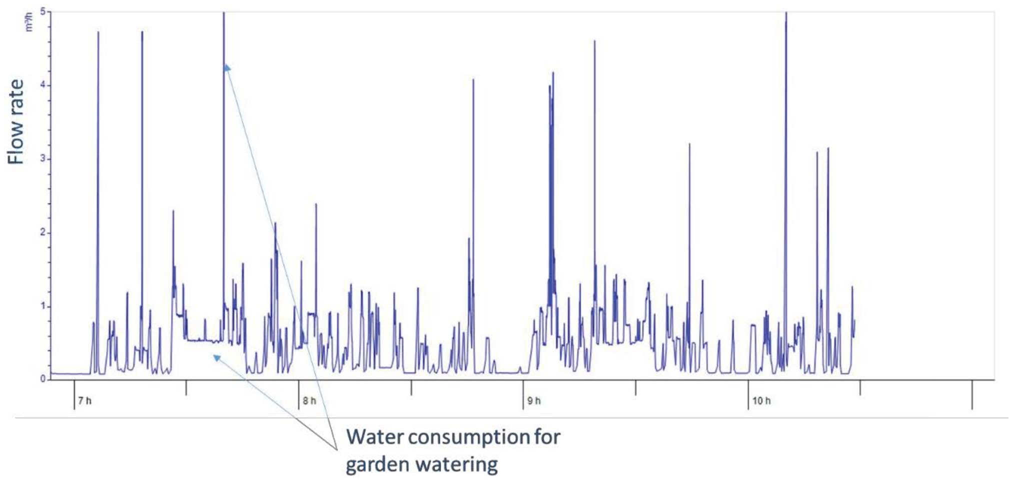

Fig. 9. Temporary flow rate in the household with an automatic garden sprinkler (authors' own work).

6. Summary

About 6,000 children die each day as a result of diseases associated with scarcity of drinking water. It means that one child dies every 15 s. Water requires a strategic and balanced approach and water resources should be efficiently managed at every stage of their handling, beginning from clean water supplies to their final use. Actions should focus on propagation of a concept of minimization of water consumption and water losses and discovering new ways to collect and use water and to protect it from contamination.

Measurements within the zones of the water supply system combined with data from integrated information systems offer a possibility to calculate indicators to assess water losses. Analysis of the daily water flows allows to set alerts for diagnostics of a network or water meters in the zone. The small changes in a volume of sold water allow to use the average daily flows to estimate water losses in the zone.

The indicators used in the water loss analysis give a fairly accurate picture of the operating conditions in the water distribution subsystem. An automatic system of stationary readings can ensure collection of water meter reading database at least once a day. The database from readings should be used not only to charge customers, but also to analyze water losses in the distribution network.

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