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DYNAMIC MODEL OF THE WATER DISTRIBUTION SYSTEM AS AN ANALYSIS TOOL IN THE MANAGEMENT OF THE ŁAPY WATER SUPPLY NETWORK

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ABSTRCT: The subject of this paper is the analysis of a very common problem of water distribution systems of cities in Poland, which is the concentration of chlorine in water supply networks and the economic aspects of electricity consumption for the supply of pumps. As an example of the analysis, the water distribution system model of Łapy and the available data from the years 2015-2017 was used. As part of the work, an assessment of the existing state of the city water distribution system of Łapy was presented (lying in the Bialystok poviat), conducted with the help of the EPANET computer program, and aimed at improving the efficiency of the examined network. This allowed us to avoid errors during the investment and to assess the condition of the water supply network. This program was chosen because it is publicly available, as well as used by many companies to solve problems with water supply systems in a friendly and clear way.

KEY WORDS: mathematical model, water tower, water supply, dynamical model, computer modeling

JEL: C610, C630

Introduction

Having information about the operation of the water supply system is the basis for the proper functioning of the water company. Therefore, it seems advisable to use the water supply model as a tool supporting the process of water supply system operation.

The use of all computer software packages and their implementation as an application allows for organically operating costs of water and sewage systems, increasing the efficiency of business management and supporting the investment process. System modeling is currently the most reliable reproduction of real working conditions, taking into account the variability of water distribution and distribution (Fernandez et al., 2009).

The introduction of more data allows for the reconstruction of the water supply network operating conditions for random events such as water abstraction for fire-fighting purposes, failures as well as their impact on other recipients of the water supply network.

The ability to make the right decisions without a thorough knowledge of the facts, which is commonly used in engineering practice, will be partially enriched in terms of information and model, which will definitely ensure the developed and presented technique, on the behavior of individual elements in dynamic conditions (Boulos, et al., 2009; Darsono, Labadie, 2007).

The analysis was performed for the water distribution system of Łapy lying in the Bialystok poviat. An attempt was made to recreate the actual operating conditions of the water distribution system in a virtual environment.

The demand of Łapy for drinking water and other social, living and economic purposes is covered by three water intakes located in various parts of the analyzed area.Deep water intakes are found in:

- water supply station on Spółdzielcza street (production 523 m^3/d, pressure 3.8 bar),
- water supply station on Płonkowskiej street (production 173 m^3/d, pressure 3.8 bar),
- water supply station on Długiej street (production 667 m^3/d, pressure 3.8 bar).

The obtained results gave a picture of the functioning of the water distribution system and made it possible to improve the existing working conditions.

The problem of distribution and concentration of chlorine in SDW model

Chlorine dissolved in water prevents the growth of bacteria in water supply networks. It acts as a preservative and guarantees the sanitary properties of water supplied to consumers. To maintain quality up to the collection points and to prevent the risk of secondary contamination, it is essential to add chlorine to the treated water as it leaves the water treatment station (Studziński, 2014). In accordance with the requirements set out in the Regulation of the Minister of Health of March 29, 2007 the admissible concentration of free chlorine in drinking water is in the range of 0.1-0.3 mg/l, and the maximum acceptable concentration in stored water is 0.5 mg/l.

The classic method of introducing chlorine into water is based on the dosage of pure or sodium hypochlorite solution. Methods of generating sodium hypochlorite directly on the aqueduct, using kitchen salt or natural chlorides contained in water are also becoming more and more popular. Despite the undisputed technical advantages, these methods are, however, quite expensive today and therefore have to be used in waterworks with a higher capacity.

In this context, there are methods for the classical dosing of hypochlorite, with particular emphasis on the selection of disinfectant dosing pumps.

Thus, in the model chlorine with a concentration of 0.3 mg/l was introduced into the network and a simulation lasting 10 days (240 h) was started. Following this, a report was generated. The medium concentration map is shown in figure 1.

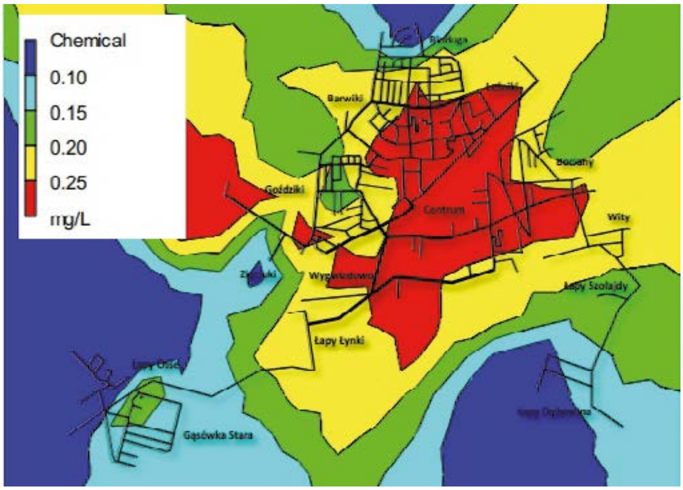

Figure 1. A map showing the average concentration of chlorine of the water distribution system of Łapy created in the program EPANET on a scale of 1:25 000.

Source: author's own work.

Areas where chlorine breaks down and its concentration decreases are the final sections of the network, especially in the North, South and South West. The average concentration for the whole network after 240 h is 0.26 mg/l.

Predictably, the section of the W258 water supply network in Łapy Osse is characterized by the lowest concentration. This is closely related to the stagnation of water. The rate of concentration increase in selected sections is illustrated by graphs of time courses (figure 2).

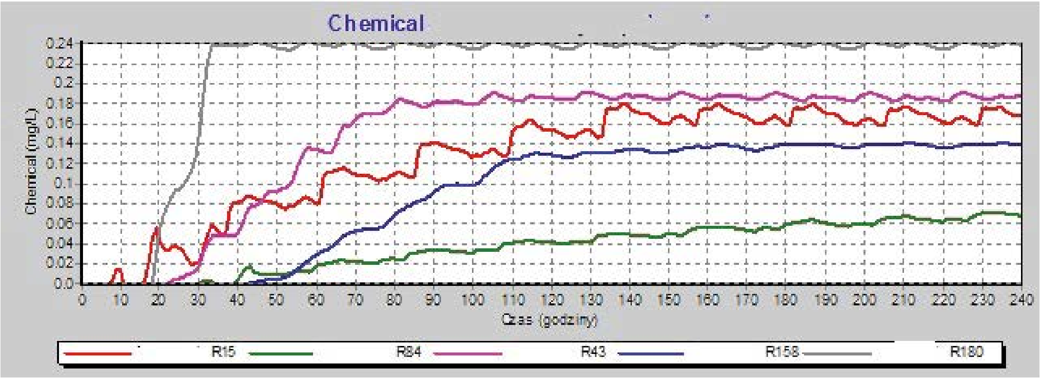

Figure 2. Increase in the concentration of chemicals and the range of variations for the sections of the model: R15, R84, R43, R158, R180

Source: author's own work.

The rate of increase in concentration for R180 is much higher than for the R84 tube. In the first case, the course stabilizes after 40 hours, while in the second case, until the end of the simulation the concentration increases without reaching a clear uniform level.

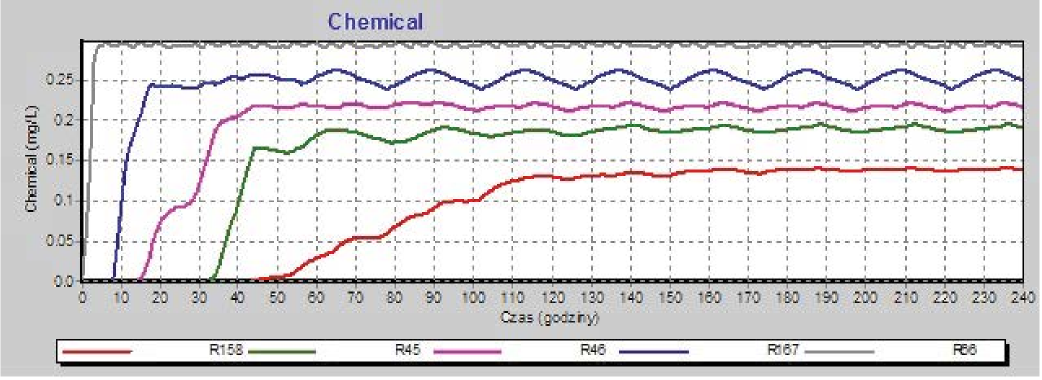

Figure 3. Increase in the concentration of chemicals and the range of variations for the sections of the model: R158, R45, R46, R167, R66

Source: author's own work.

Particular attention should be paid to the characteristics of changes in value after reaching the optimal concentration. In the R66 combination, the size changes several times a day, while in the R167 pipe, it changes only twice.

However, in the R158 connection, the concentration characteristic after reaching the optimal level has a course similar to a continuous line (figure 3).

Based on the obtained results, it can be concluded that the concentration of chlorine on the extreme sections of the model threatens the development of pollution.

The cost of electricity for powering the pumps in the system

Another very important problem that arouses many queries is the cost of electricity to power the pumps in the system. The analysis concerned three pumps located on the tested model of SDW and representing respectively water intake:P – on Spółdzielcza street, S – on Płonkowska street, D – on Długa street. Using EPANET it is possible to calculate this energy with great precision. Thanks to this, each network modification can be compared in terms of energy savings, which will document the legitimacy of the actions taken (Machón, López, 2007). For the calculation of energy consumption, the average energy price of PLN 63.00 per 1 kWh was adopted and the results were obtained as in the table below (table 1). The daily cost of energy used to pump water is PLN 130.80.

Table 1. Energy consumption report

Pump	Percent wear	Average eficiency	KWh/m^3	Average KW	Peak KW	Cost/Day
P	77,5	52,10	0,24	1,24	2,93	14,95
S	100	68,28	0,15	4,76	16,48	74,30
D	75	72,36	0,15	3,55	5,3	41,55
Total cost						130,80

Source: author's own work.

Degree of mixing of water from various sources in the simulation over time

Using the EPANET program, an analysis of the common problem of water distribution systems concerning the mixing of water from several sources were made. The source node can be any node in the network, including the tank. Simulation in time determines the percentage of water from an indicated source in remote places of the network. Internally, EPANET treats the source node as a permanent source without chemical reactions. Water is treated as an ingredient that is introduced into the network at a concentration of 100%. The traceability is a useful tool for analyzing distribution systems built from two or more water systems. Thanks to this situation, it became possible to indicate the degree of mixing of water from a given source with water from other sources and to observe how the spatial model of this mixing changes over time (Abe, Peter, 2010).

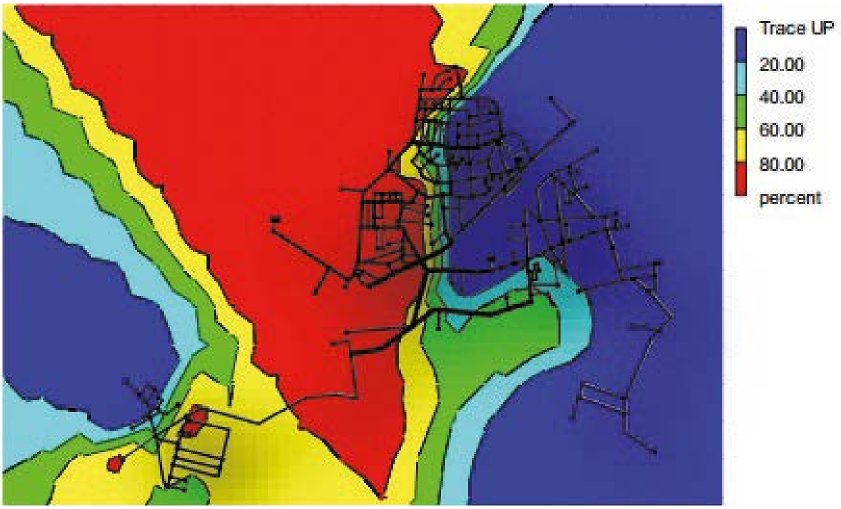

Figure 4. Percentage of water from the water intake on Płonkowska street. in relation to the remaining water intakes in the city of Łapy created in the program EPANET on a scale of 1:25 000

Source: author's own work.

In figure 4 there is one of the simulations carried out with the range of water coming from the intake on Płonkowska street. The water flows to the Łap Osse district. Generally, the pumping station on Płonkowska powers the western part of the city. Figure 5 shows the range of water distribution from the intake of the river Długa. Despite the smaller distance between the river Długa and the district of Łapy Osse, the water pumped there comes from the intake on Płonkowska street. The reason for this situation may be large housing estates with multi-family housing in the south of the network. High demand in this region makes it possible to redirect most of the mass of water from the Długa intake to these areas, giving space in the South-West part of the network to water originating from a more distant angle which is the Płonkowska intake.

Figure 5. Percentage of water coming from the intake on Długa street in relation to the remaining water intakes in the city of Łapy created in the program EPANET on a scale of 1:25 000

Source: author's own work.

The third source – the intake of Spółdzielcza street.The cooperative fills the rest of the network, that is the north and north-east region (figure 6).

Figure 6. Percentage of water coming from the intake on Płonkowska street relation to the remaining water intakes in the city of Łapy created in the program EPANET on a scale of 1:25 000

Source: author's own work.

The percentage of the largest number of connections is served by the shot in Spółdzielcza – on average 34.7% of the entire network; in second place, the entry in Płonkowska 31.6%. The intake on Długa Street is fed by 28% of calls in the catchment network.

The simulation proved that switching the network from three intakes to one can not take place without the modernization of the transmission pipelines.

Conclusions

The simulations carried out make calculations of important parameters of the network operation that have previously been impossible, for example the mixing of water from various sources, the distribution of chlorine concentration in water supply networks and economical aspects of electricity consumption for powering the pumps. The developed and presented technique definitely ensured the most reliable information on the behavior of individual elements in dynamic conditions, where problems were diagnosed and proven, among others, that the concentration of chlorine, so far difficult to study at extreme sections, threatens the development of pollution, and switching networks from three intakes to one can not take place without the modernization of transmission waterworks (Walski, Chase, Sawicki, 2011).

Making the right decisions without knowing the facts is a valuable skill commonly used in engineering practice. Currently, it is becoming more reliable thanks to information and model enrichment, through the variant and mathematical modeling used in the study. The simulations and the construction of the model reflecting the real conditions of SDW Łapy required obtaining a number of data, which ensured correct reproduction in the system machine and brought invaluable benefits in the form of reliable results, indicating problematic network parameters and at the same time enabling new concepts of engineering solutions.

Acknowledgements

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