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Proposal of water intake location in a rural area – case study

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ABSTRACT

The location of water intakes in agricultural areas is extremely important due to the possibility of microbiological contamination of source water. The main factors causing pollution are both agriculture and uncontrolled discharge of domestic wastewater into the environment. Therefore, it is essential to delineate an appropriate protection zone around the water intake. The main aim of the study was to locate water intakes with a connection of several local water supply systems into one. Three intake locations were proposed: on hills, in forests, and away from agricultural areas. The selection of the best localization was preceded by the analysis of the water supply network operation carried out via simulation studies based on the numerical model created in the EPANET software. Out of the proposed locations of water intakes, only one met the requirements for intakes in terms of possibility of supplying water to all consumers under the conditions of domestic water demand and fire flow.

Keywords: Water intake; EPANET; Water supply network

1. Introduction

In rural water companies, the drawn water is frequently untreated, non-disinfected and not monitored periodically. Due to the lack of funds for repair and modernization, rural water intakes are usually in poor technical condition. Various types of pesticides are used on the farmlands near the intakes, which affect the chemical composition of the water. In addition, uncontrolled discharge of domestic sewage directly into the environment contributes significantly to the contamination of water intakes [1–3]. Only during a month, that is, September 2021, there were more than 40 incidents of water supply system contamination with the *Escherichia coli* bacteria in the Lublin Province, which resulted in their exclusion from service as well as the need to carry out flushing and disinfection. These factors pose a threat to the health of water consumers. Therefore, proper location of water intakes in rural areas and maintaining a protection zone are very important.

When selecting a water intake location, proximity to potential sources of pollution, such as agricultural fields, landfills, wastewater treatment plants and existing sewage systems, leach fields and septic tanks, should be considered. All these elements may have a negative effect on the water quality. Rural, small water intakes very often do not meet the criteria for adequate water quality. Due to the lack of financial resources of local water companies, the water is not properly treated and monitored. The solution to this problem may be to combine several local water supply systems into a group water supply system supplied from one or two water intakes. In that case, before making a decision to carry out hydrogeological tests of the area where the water intake is to be located, it is necessary to determine whether the location of water intake will meet the requirements for providing water to all its recipients. For this purpose, simulations of network operation are carried out together with determining appropriate working parameters of a water supply pumping station [4]. These

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simulations allow to identify places where there is a risk of lack of water supply under appropriate pressure, both in the conditions of domestic water demand and fire flow. Basing on the results obtained, it can be determined which location of the water intake is the most optimal in terms of ensuring the water supply. In the next step it is necessary to check whether water of adequate quality and quantity is available in the selected area. Depending on whether surface or underground water will be drawn, once the intake site has been selected, it will be necessary to conduct appropriate analyses and field studies. Their aim is to establish the water relations in the vicinity of the planned intake, to analyze the possibilities of meeting the water demand for the supplied towns and villages as well as determine the profitability of the investment.

When planning the location of surface water intakes, the accumulation of sediment before the intake constitutes a crucial problem [5–7]; thus, determination of the optimal location of the intake is preceded by the modeling of water circulation conditions [8,9]. Groundwater intakes usually consist of several wells. It is important that the distance between them should take into account the occurrence of the depression funnel caused by water pumping for the wells not to interact with each other. In addition, it is important to maintain an optimum distance between the well and the river. For this purpose, this distance should be determined taking into account infiltration and retention of water from the river and the length of its flow paths [10].

Choosing a site for a water intake is a key element in making decisions about designing or expanding water networks. The practice so far shows that at first a place with groundwater aquifers is searched for. However, that is a wrong approach, because not in every place will it be possible to supply water under the right pressure, or it will be very expensive. Therefore, it is important to conduct computer simulations to assess which location will meet the requirements set by the investor. Thanks to such solution, you can easily analyze several potential locations of water intakes, and then look for water resources.

The paper presents a proposal for the location of a water intake linked with connecting several local water supply networks into a group system supplied from one or two water intakes. Five variants of water intake locations were analyzed. The network operation was simulated in order to check the possibility of supplying water to all recipients in adequate quantity and under appropriate pressure. Additionally, it was checked whether the water intakes would meet the fire safety requirements in terms of supplying an adequate amount of water in case of fire. According to the polish requirements [11], a rural group water supply system should provide water for fire fighting – the required hydrant capacity should be at least 5 dm^3/s at a pressure of 10 mH_2O.

The choice of location was also related to the analysis of indicators characterizing the analyzed water supply systems. In all cases, the range of pipe diameters and pipe lengths, the number of water supply stations, pumping stations, and of zone valves were taken into account. The location of the water intake determined in that way will allow further research to verify the presence of an appropriate amount of water in the indicated area.

2. Materials and methods

The study area, for which water intake location is chosen, is located in the south-eastern part of Poland. The area of the site covers about 208 km^2. Most of the area is occupied by agricultural land (65%) and woodland (27.6%). The differences in ground elevations in the study area exceed 170 m (Fig. 1). The average annual temperature is about 6.7°C, the average cloudiness approximates 62% and is one of the lowest in the country. The total annual precipitation in 2021 is about 700 mm, with a national average of 650 mm [12]. Higher precipitation in comparison with adjacent regions and a favorable geological structure constitute a significant underground water reserve and a source area for many rivers; there are numerous karst springs whose flow rate reaches 100 l/min. The study area is situated entirely within the Bug river basin, with the Sołokija, Prutnik and Łukawica rivers flowing through it. The main usable aquifer is associated with the Late Cretaceous formations. The groundwater table level is free, whereas in the zones of less fractured rocks it is confined. The Cretaceous layer is characterized by good hydrogeological conditions. The water-bearing formations are 60–90 m thick and are found at a depth of 15–50 m. The potential capacity of drilled wells depends on the conductivity of the aquifer and in most of the area it reaches 30–50 m^3/h. The water is of good quality and only locally does it require treatment due to increased contents of iron and manganese.

There is a dispersed water supply system in the study area, comprising about 30 km of water supply network in several villages. Residents commonly use dug and drilled wells located on private land. Some parts of the area lack water supply systems. In view of the efforts to connect several local water supply systems into one system and in order to supply water to all inhabitants of the study area (Fig. 1), a new water intake location had to be determined.

The choice of location for a new water intake was linked with preparation of a project of connecting several local water supply networks into one water distribution system. For this purpose, a numerical model of the water supply system was developed basing on the provided geodetic and cartographic documentation as well as water law acts. Preliminary location of water intakes (Fig. 2a–c) was indicated by the investor. It assumed that the intake will be

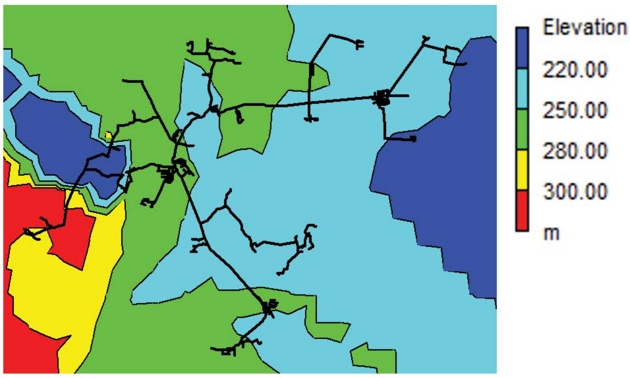

Fig. 1. Elevation scheme of the area with proposed water supply network routes.

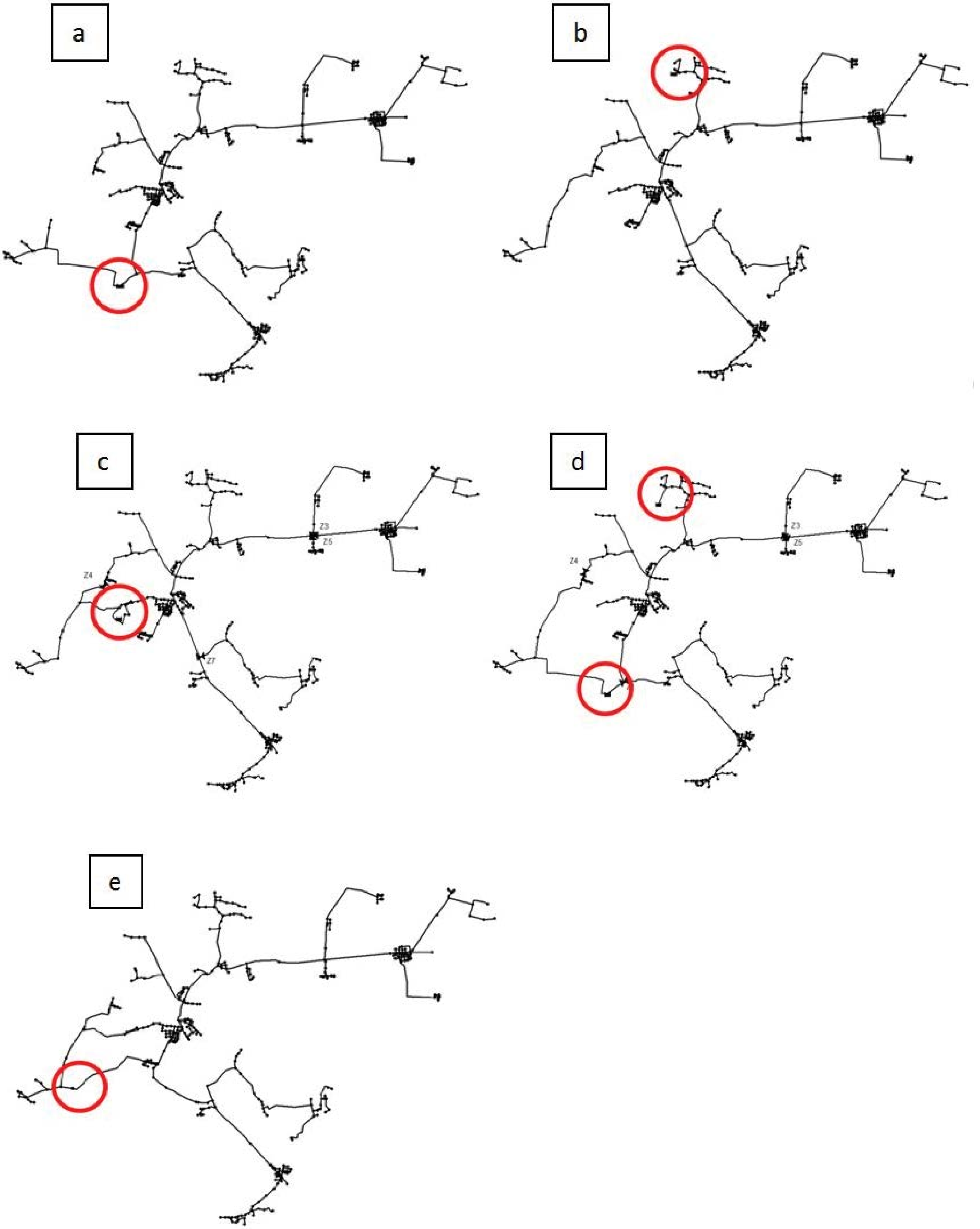

Fig. 2. Diagram of the designed water supply system (a) Variant 1, (b) Variant 2, (c) Variant 3, d) Variant 4, and (e) Variant 5. The colored circles indicate the location of intakes and water supply stations.

located on a hill, away from buildings and farmland, and that the area will not belong to private owners.

The concept of developing the water supply system for the study area was prepared in five variants, differing in the number and location of water intakes. Variants 1–4 included the water intake locations indicated by the investor (Fig. 2a–d), whereas Variant 5 was proposed by the author (Fig. 2e).

For all variants, it was necessary to lay new pipes to the water intakes and to carry out a water demand balance for the perspective period. It was assumed that the water supply system would cover all the inhabitants residing in the study area (6,220 people) and that the water demand for agricultural production, increasing due to climate change, would be covered from domestic wells. On the basis of water meter data on water consumption of all consumers, a total water demand indicator was determined as 145.2 dm^3/(d·M). The results of calculating the characteristic water demand rates for the study area are summarized in Table 1.

Variant 1 assumes the location of the intake in the southern part of the study area, in woodland. The designed station will pump water in two directions, that is, eastwards and westwards. The advantages of the location include a high ground elevation, allowing the use of gravity runoff in an easterly direction. In the event of power failure, water will flow by gravity to the consumers in nearby lower-lying towns, albeit at a reduced pressure. The disadvantage is the necessity to pump water uphill, towards the village located in the western part of the area. The advantage of that location is the distance of the intake from agricultural fields and buildings – the nearest fields are about 2 km away from the proposed water intake. In Variant 2, the water intake is located in the northern part of the study area, 400 m from buildings and farmland, and 600 m from the river. The designed station will pump water in one direction. The advantages of the location include the ground elevation allowing to use partially gravitational runoff towards the villages located to the east and south of the intake. As in Variant 1, the disadvantage of this location is the necessity to pump water uphill, towards a higher-located village in the western part of the area.

The water intake in Variant 3 is located on the border of the forest, in the vicinity of farmland, about 500 m from the nearest buildings. It is planned to pump water in two directions, that is, eastwards and westwards. The advantage of the location is the central position of the station in relation to the entire water supply system. In turn, the disadvantage corresponds to the necessity of pumping water uphill, in a westerly direction.

Variant 4 entails supplying water from two intakes: northern and southern. The use of two stations in the indicated locations combines the advantages of Variants 1 and 2, that is, gravitational support of water supply is possible, the likelihood of contamination of intakes by fertilizer run-off from fields is limited and the distance between the stations and the final water recipients is shortened. An additional advantage is that in case of failure there is a possibility of partial replacement of one station by the other.

Table 1
Summary of estimated water demand after completion of water system expansion

Number of residents	$Q_{d\text{ av}}$	$Q_{d\text{ max}}$	$Q_{h\text{ av}}$	$Q_{h\text{ max}}$
	m^3/d	m^3/d	m^3/h	m^3/h
6,220	903.1	1,670.8	69.6	165.0

Variant 5 uses a single water intake located in the highest area, in the woodland of the western part of the study area. The station will feed water in two directions: by pumps in the western direction and by gravity to the rest of the area. The advantage of that location is that the intake is located close to the edge of the study area, which will decrease the water retention time in the system.

The particular variants of the designed network differ not only in terms of the location of the water intake, but also in regard to network length, pipe diameter, the presence of network pumping stations as well as the number of reduction valves. A summary of these elements is presented in Table 2.

The required water intake capacity (Table 3) for particular variants was calculated basing on the estimated water demand. Variants 1–3 and 5 assume construction of one water intake, whereas Variant 4 assumes supplying the network with water from two water intakes.

The necessary hydraulic calculations and analyses of the working conditions of the designed water supply system were performed using the computer simulation method. For that purpose the EPANET software provided by the U.S. Environmental Protection Agency (US EPA) was used. The flow velocity, pressure and water age in the water supply system were analyzed. In addition, according to the polish requirements [11], a rural group water supply system should provide water for fire fighting. The required hydrant capacity should be at least 5 dm^3/s at a pressure of 10 mH$_2$O. In order to verify these requirements, the possibility of supplying water to the farthest hydrants under fire flow conditions was simulated (Fig. 3).

3. Results

On the basis of simulations of pressure distribution in the designed network at the hour of minimum (2:00 a.m.) and maximum (8:00 p.m.) water demand, it was noticed that

Table 2
Summary of indicators describing the analyzed variants

Variant	1	2	3	4	5
Diameter range (mm)	63–225	63–250	63–225	63–200	63–250
Length of pipes (km)	114	110	114	118	111
Number of water supply stations	1	1	1	2	1
Number of secondary pumping stations	2	1	2	3	1
Number of network pumping stations	1	3	0	0	0
Number of reduction valves	2	0	4	4	11

in Variants 1–4 the pressure in the night hours exceeds, in many places, the value of 60 $m\mathrm{H_2O}$ – considered to be the limit for water supply networks. In Variant 5, the maximum pressure is not exceeded. In all variants, the age of water is similar. The fire protection requirements are met only in Variant 5. Table 4 presents a summary of the simulation results for all variants.

Figs. 4–8 show the distribution of flow velocity and pressure in the designed network for all variants during the hour of minimum (2:00 a.m.) and maximum (8:00 p.m.) water demand. Simulation calculations were performed on a day of maximum water demand.

In this study, the selection of a target variant of water intake location was based on the simulation results and calculated indicators characterizing the analyzed water supply systems. In all cases, the hydraulic conditions of network operation were considered, that is, flow velocity, pressure and water age. The range of pipe diameters, pipe lengths, number of water supply stations, pumping stations, number of zone valves, as well as fulfillment of fire protection requirements at all analyzed hydrants and the degree of protection of intakes from contamination associated with field run-off were also taken into account. Additionally, the reliability aspect was considered, that is, the possibility of at least partial replacement of one station by another and the possibility of gravitational water supply, which limits the failure rate of the designed system.

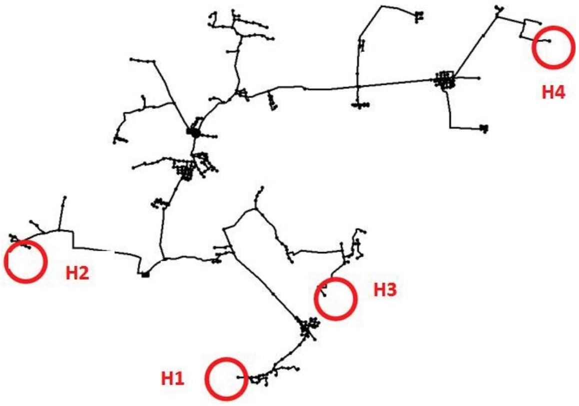

Fig. 3. Location of the studied hydrants.

Table 3
Well capacity depending on the adopted variant

Variant	Number of water supply stations	$Q_{d\ \mathrm{av}}$ (m^3/h)	$Q_{d\ \max}$ (m^3/h)
1	1	56.8	104.4
2	1	56.8	104.4
3	1	56.8	104.4
4	2	31.6	75.1
		24.4	43.7
5	1	56.8	104.4

Table 4
Summary of the simulation results for all variants

Variant	Maximum pressure ($m\mathrm{H_2O}$)		Average water age (h)	Firefighting capacity			
	2:00 a.m.	8:00 p.m.		H1	H2	H3	H4
1	84	58	320	yes	no	yes	yes
2	73	52	312	no	no	yes	yes
3	64	53	322	yes	no	yes	yes
4	61	59	315	yes	no	yes	yes
5	60	58	290	yes	yes	yes	yes

Taking into account the above-mentioned factors, Variant 5 was found to be the most advantageous, because no exceedance of pressure above 60 $m\mathrm{H_2O}$ was noted, which is considered as the limit for water supply networks. This variant has almost the shortest total pipeline length, it has only one second-stage pumping station and no network pumping stations. In addition, this variant meets both fire requirements at all hydrants analyzed and reliability requirements due to the gravity water supply to customers. The large number of pressure reducing valves should not contribute to operational difficulties, as these devices operate in an unmanned mode and require only periodic maintenance.

4. Discussion

Location of water intakes is a complex issue. Many factors affecting the choice of optimum location make the decision difficult, and sometimes even impossible, to take. Therefore, it is essential to determine the parameters that maximize the objective function. Taking into account high investment costs of building a new water intake, we assume that indication of its optimal location should be preceded by adequate analyses and simulations facilitating decision making. Mathematical models are used for this purpose. Since the solution is conditioned by many decision variables and many variable parameters, it is necessary to employ multi-objective optimization methods. They allow to compare many variants and choose the best one.

Most mathematical models map groundwater and surface water flows to determine the optimal locations of water intakes. Mądrala and Wąsik [13] used the MODFLOW program to simulate the surface water flow of the Jamielnica River. They assumed three different intake locations and three well capacities. The main objective of their work was to test the possibility of using water of better quality by reducing the inflow of polluted surface water. A similar study was conducted by Dinesh Kumar et al. [14], who examined the possibility of using water from the Maharashtra basin to enhance the existing water supply systems and to develop new water supply systems.

When determining the location of water intakes for water networks that are planned to be connected, we should check whether the supply of water will be ensured to all consumers at an appropriate pressure. For this purpose, simulations of network operation are carried out, for example, in the EPANET program. The studies carried out by Kruszyński [15] prove that the pressure distribution in the network varies, depending on the number and location of

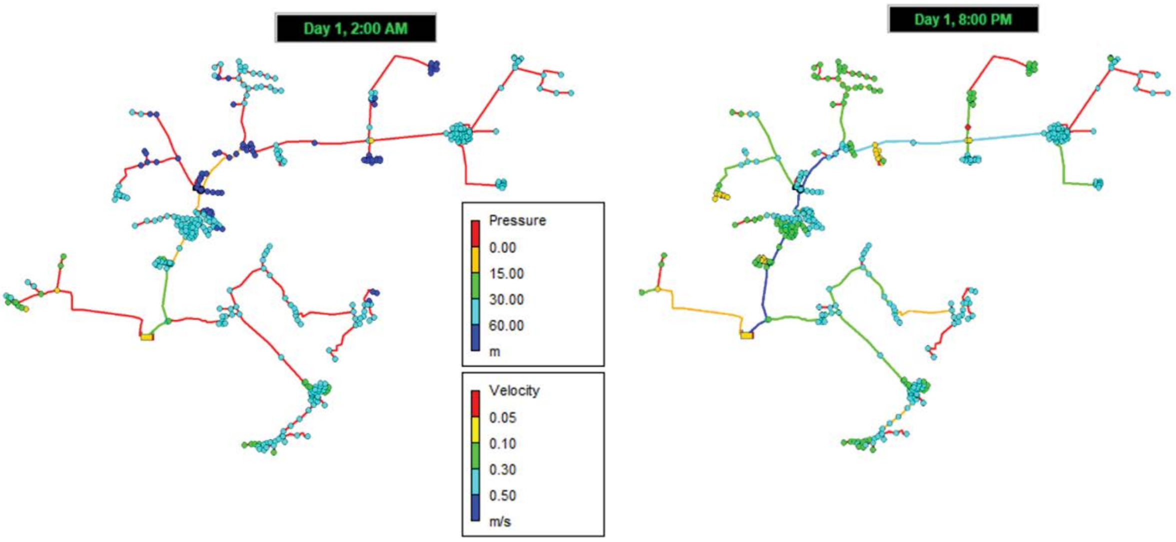

Fig. 4. Flow velocity and pressure in the designed network during the hour of minimum (2 a.m.) and maximum (8 p.m.) water demand – Variant 1.

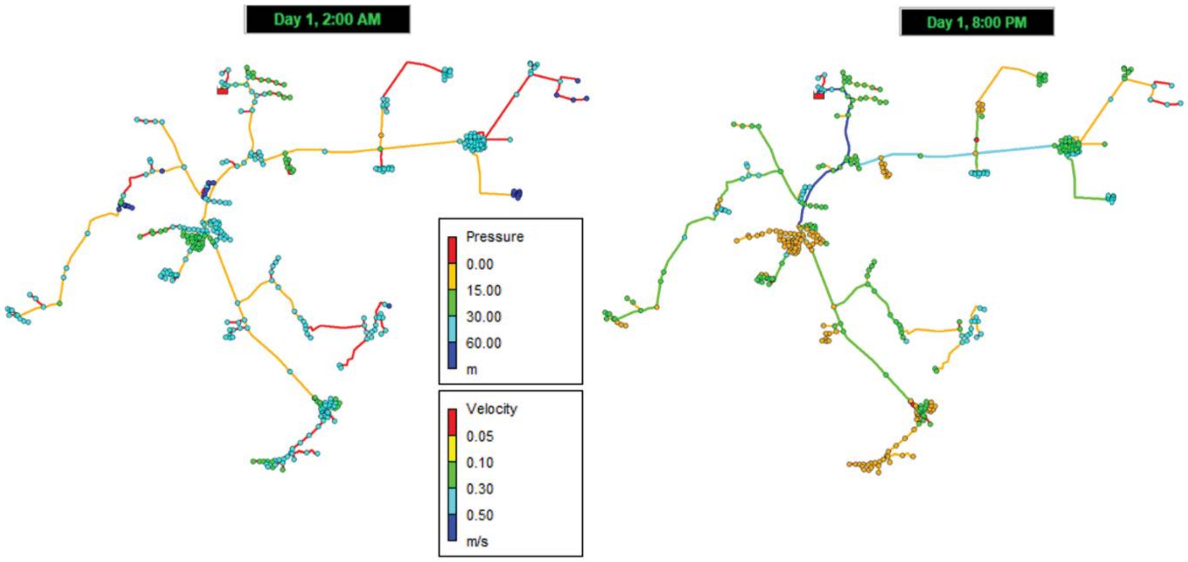

Fig. 5. Flow velocity and pressure in the designed network during the hour of minimum (2 a.m.) and maximum (8 p.m.) water demand – Variant 2.

water intakes and on the ways of connecting several local water supply systems into one. Similar results were obtained by Jia et al. [16], who, basing on EPANET and GIS modeling programs, developed an integrated hydraulic model of the network which experienced problems connected with excessive pressure. By analyzing scenarios in different subzones, he corrected some of the pipe diameters in the network and showed the possibility of reducing the network pressure. A similar study was also conducted by Zdechlik et al. [17], who used the GIS technology to determine the optimal location of groundwater intakes. Having prepared the input data, the research team attempted to develop a multi-criteria analysis system methodology as well as to determine an appropriate selection of criteria and weights. The results obtained indicate the degree of suitability of the selected areas for potential location of groundwater intakes in geological and environmental terms.

Water transported through the water supply system from the water treatment station to the farthest recipient should meet the quality requirements for drinking water. Unfortunately, the composition of the water pumped into the network often differs in quality from the water supplied to consumers. Although initially its parameters comply with the applicable standards, it is affected by various pipeline materials, mixed with water stored in tanks and with water from other pipelines. Deterioration of water quality in the

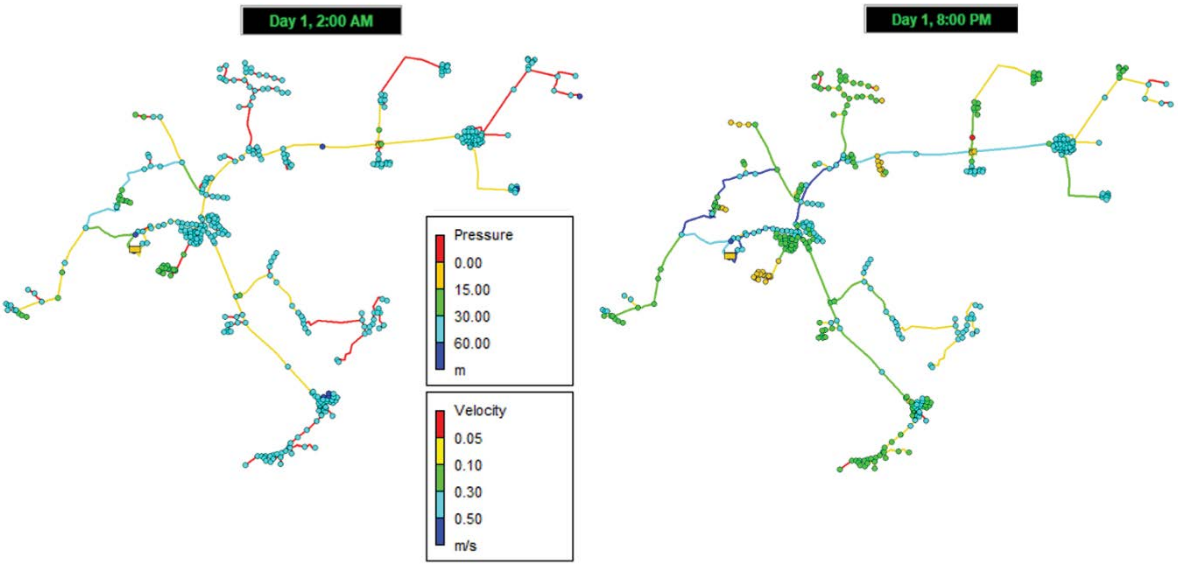

Fig. 6. Flow velocity and pressure in the designed network during the hour of minimum (2 a.m.) and maximum (8 p.m.) water demand – Variant 3.

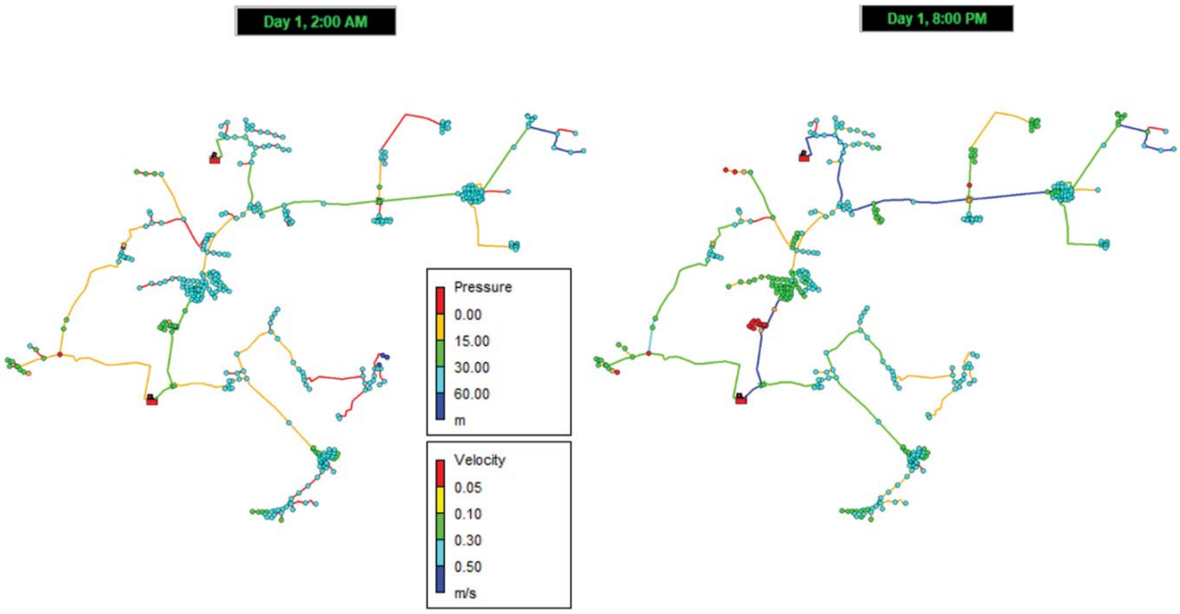

Fig. 7. Flow velocity and pressure in the designed network during the hour of minimum (2 a.m.) and maximum (8 p.m.) water demand – Variant 4.

distribution system may occur both during its storage and transport [18,19]. The result of water contamination may be not only its change in color, taste, sediment or water turbidity. The worst possible qualitative changes are the deterioration of microbiological and chemical parameters of water, which may be dangerous to human health. The prolonged water residence time in the system leads to its secondary contamination. This is especially visible after the water stagnation at night and at the dead-end of the network.

To eliminate the causes of secondary pollution of drinking water is very difficult due to a variety of factors influencing its occurrence. Most often these are activities related to cleaning and rinsing the network which allow to remove accumulated sediments, corrosion products of pipes, growing biofilm. They are also related to water disinfection in the network, which is aimed at killing or inactivating pathogenic microorganisms (viruses, bacteria, parasites) as well as preventing their secondary development: by adding disinfecting and oxidizing chemicals to the water (e.g., Cl_2, ClO_2, O_3) or using physical methods (irradiation with UV rays, ultrasound) [20].

The above-mentioned studies prove that numerical modeling is essential in making decisions related to water

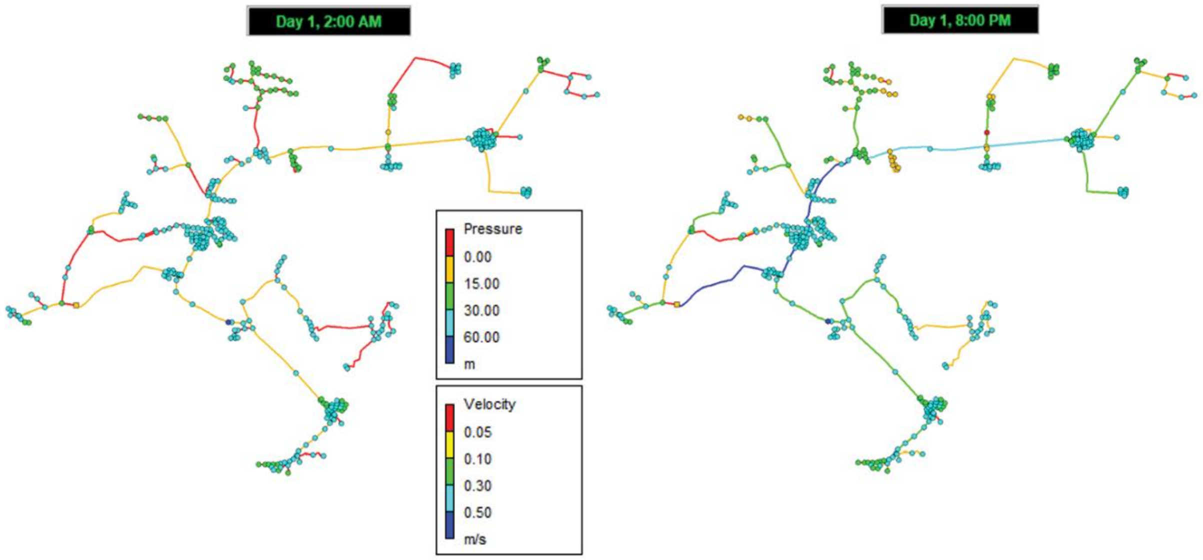

Fig. 8. Flow velocity and pressure in the designed network during the hour of minimum (2 a.m.) and maximum (8 p.m.) water demand – Variant 5.

intake design. Both at the stage of locating an intake for a new water supply network and in the case of extending an existing network, computer simulations are a source of valuable information. Analysis of different variants of solutions allows to understand the issue better and to reach a decision on the optimal location of water intake.

5. Conclusion

The first stage of locating a water intake should always be preceded by carrying out simulations and analyses concerning the possibility of supplying water in appropriate quantity and under appropriate pressure to all users. It is essential especially when considering the possibility of supplying water to a newly designed water supply system.

The proposed methodology for selecting the best location for water intakes can be used for all new water supply systems, as well as for the existing ones. The use of computer simulations facilitates decision-making at the stage of planning the location for new water intakes.

In this study, Variant 5 is considered the most advantageous. There is no pressure excess over 60 $m\mathrm{H_2O}$, and the water age is the lowest – 290 h. Moreover, this variant needs building almost the shortest length of pipelines (110 km), and is the only one that meets the fire requirements in all analyzed hydrants.

The final decision of choosing the variant of water intake location does not have to coincide with the optimal result obtained during the modeling. This result is only a guideline helpful in decision-making process that should take into account other, for instance economic, factors.

References

[1] K. Dragon, D. Drożdżyński, J. Górski, R. Kruć, The migration of pesticide residues in groundwater at a bank filtration site (Krajkowo well field, Poland), Environ. Earth Sci., 78 (2019) 593, doi: 10.1007/s12665-019-8598-0.

[2] G. Premazzi, G. Ziglio, Regulations and Management, E. Funafi, M. Vighi, Eds., Pesticide Risk in Groundwater, CRC Lewis Publishers, Boca Raton, 1995, pp. 203–240.

[3] M.A. Dalvie, E. Cairncross, A. Solomon, L. London, Contamination of rural surface and ground water by endosulfan in farming areas of the Western Cape, South Africa, Environ. Health, 2 (2003) 1–15.

[4] J. Hyung, J. Seo, K. Kim, T. Kim, J. Koo, Optimal water intake and supply pump scheduling considering water quality safety in multiple water intake system, Desal. Water Treat., 182 (2020) 49–60.

[5] M. Fawzia, R. Khaled, S. Abbas, B. Mohamed, K. Yousra, The optimum location of water intakes in Nile river Basin, Water Energy Int., 64 (2021) 24–28.

[6] F. Michell, R. Ettema, M. Muste, Case study: sediment control at water intake for large thermal-power station on a small river, J. Hydraul. Eng., 132 (2006) 400–449.

[7] S.F. Daly, R. Ettema, Frazil ice blockage of water intakes in the Great Lakes, J. Hydraul. Eng., 132 (2006) 814–824.

[8] E.H. Na, S.S. Park, A hydrodynamic modeling study to determine the optimum water intake location in Lake Paldang, Korea, JAWRA J. Am. Water Resour. Assoc., 41 (2005) 1315–1332.

[9] A. Krutov, B. Norkulov, F. Artikbekova, P. Nurmatov, Optimal location of an intake at a reservoir prone to salt diffusion, IOP Conf. Ser.: Mater. Sci. Eng., 869 (2020) 072020.

[10] T. Grischek, D. Schoenheinz, Ch. Ray, Chapter 14 – Siting and Design Issues for Riverbank Filtration Schemes, C. Ray, G. Melin, R.B. Linsky, Eds., Riverbank Filtration, Part of the Water Science and Technology Library Book Series (WSTL, Vol. 43), Springer, Dordrecht, 2002, pp. 291–302.

[11] Regulation of the Minister of Internal Affairs and Administration of 24 July 2009 on Firefighting Water Supply and Fire Roads. (in polish)

[12] Z. Ustrnul, M. Marosz, D. Biernacik, D. Kopaczka, A. Chodubska, K. Wasielewska, K. Kusek, Climate monitoring bulletin of Poland, year 2021. Institute of Meteorology and Water Management – National Research Institute, 2021. (in polish)

[13] M. Mądrala, M. Wąsik, Improvement of water intake location at Zawada near Opole using fictive groundwater flow models, Bull. Polish Geol. Inst., 451 (2012) 177–184.

[14] M. Dinesh Kumar, N. Bassi, S. Kumar, Locating Water for Augmenting Rural Water Supply Schemes, M. Dinesh Kumar, N. Bassi, S. Kumar, Eds., Drinking Water Security in Rural India, Part of the Water Resources Development and Management book series (WRDM), Springer, Singapore, 2022, pp. 81–95.

[15] W. Kruszyński, Influence of the change of the amount and the location of presentations on flows of water in water supply systems, Ecol. Eng., 26 (2011) 171–177.

[16] H. Jia, W. Wei, K. Xin, Hydraulic model for multi-sources reclaimed water pipe network based on EPANET and its applications in Beijing, China, Front. Environ. Sci. Eng. China, 2 (2008) 57–62.

[17] R. Zdechlik, K. Kukuła, G. Nikiel, GIS as a Supporting Tool for Selecting Optimal Localization of Groundwater Intakes, 17th International Multidisciplinary Scientific GeoConference SGEM 2017, 51 Alexander Malinov blvd, Sofia, 1712, Bulgaria, 2017, pp. 395–404.

[18] M. Zhang, M.J. Semmens, D. Schuler, R.M. Hozalski, Biostability and microbiological quality in a chloraminated distribution system, J. Am. Water Works Assn., 94 (2002) 112–122.

[19] J. Chudzicki, M. Kwietniewski, M. Iwanek, P. Suchorab, Secondary Contamination, Drinking Water, Urban Water II, S. Mambretti, C.A. Brebbia, Eds., WIT Press, United Kingdom, 2014, pp. 15–26 (in Polish).

[20] I. Winkler, A. Choban, Drinking Water System of Chernivtsi: Current Condition, Vulnerability Assessment and Possible Ways of Threat Mitigation, Risk Management of Water Supply and Sanitation Systems, NATO Science for Peace and Security Series C: Environmental Security, Springer, Dordrecht, 2009, pp. 135–141.