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WATER AGE IN THE WATER SUPPLY NETWORK AS HEALTH RISK FACTOR ASSOCIATED WITH COLLECTIVE WATER SUPPLY

WIEK WODY W SIECI WODOCIĄGOWEJ JAKO CZYNNIK RYZYKA ZDROWOTNEGO ZWIĄZANEGO ZE ZBIOROWYM ZAOPATRZENIEM W WODĘ

Abstract: The correct operation of collective water supply system requires continuous monitoring of water quality at various stages (collection, treatment, pumping and distribution). An important parameter associated with water quality is water age – the time from the moment of pumping the water into water supply system to its collection by people. In the case of water contamination at the exit of the water treatment plant, water age is exual to contamination time spread in the water supply network. The length of contamination time spread determines how many people will be affected by the bad water quality which can affect health or life. The paper presents a methodology for determining the risks associated with the appearance of water contamination using hydraulic model, as well as application case for selected collective water supply system.

Keywords: water supply network, water quality, contamination

Introduction

The lack of drinking water supply or inadequate quality water supply are the main cause of threats for consumers using the collective water supply system (CWSS). As a result of a more rational use of water (*eg* as a result of rising prices and metering of water consumption and the use of sealed and water-saving fittings) the problem of lack of water supply is mainly caused by failures of pipelines and fittings. On the other hand, the quality of drinking water is one of the hottest topics covered also by the International Water Association (IWA). The IWA president, Glen Daigger, at the World Congress on Water, Climate and Energy in 2012, in Dublin, in his plenary speech opening mentioned above Congress pointed to 2050 as the date when the accumulated problems with the delivery of safe water, food and energy will appear.

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The collective water supply system is a set of technical objects whose purpose is to provide customers with water of the required pressure, the right quantity and quality, in accordance with the valid regulation on the quality of water intended for human consumption. The scheme of the CWSS is shown in Fig. 1.

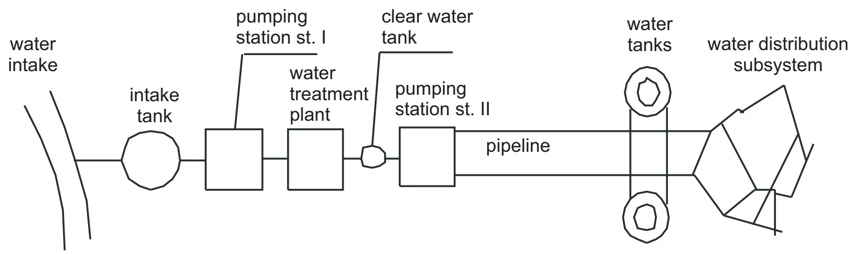

Fig.1. Collective water supply system

Water distribution subsystem (WDS) is one of the most important subsystems of the CWSS, whose aim is to provide customers with water of appropriate quality (in accordance with applicable regulations), in the right quantity and at the appropriate pressure, as well as an acceptable price. Comprehensive management of the WDS operation requires the collection of certain information relating to the operation of system's individual elements, transfer the data in real time to the operator of the system, archiving these data and alerting appropriate maintenance services about any disturbances in system operating. The subsystem operator should receive current data about potential failures, by what the time of his reaction to failure decreases [1–3].

Risk management involves three areas of studies: risk analysis, risk evaluation. risk control [4]. Risk identification generally means an analysis of risk factors, their sources, determination of the so called weak points and consequences (effects) of their occurrence. The most often this analysis concerns the undesirable events that can appear in system with a certain probability and cause certain losses, which can result in loss of the WSS safety. Analysis of the results for the possibility of a crisis can be performed on the basis of risk maps, *ie* the distribution of negligible, tolerable, controlled, unacceptable, inadmissible risks [5].

The aim of the study is to present the methodology for determining the risk associated with water age in the WDS, as a parameter affecting the safety of water consumers. A basic definition of risk, the way of determining the water age in the water pipe network, with the use of the hydraulic model, point scale for the risk parameters, are presented. The work contains an application example for the exemplary CWSS, assuming the appearance of the primary water contamination in WDS.

Water contamination in the water supply network

Generally, contaminations in the water pipe network are divided into:

– primary – contamination occurs in the source of water (river, lake, groundwater reservoir) and despite of the treatment process the contamination enters the WDS,

– secondary – water drawn from the source is effectively treated and uncontaminated flows to the WDS, contamination occurs in the water supply network.

An example of the primary contamination in the water network is the situation, which took place at the turn of June and July 2003 in Tarnobrzeg, where in the WDS coliform bacteria was detected. The message about contamination was given to the public only after 3 days and contained the information that the water is safe for consumption after boiling. In opposition to this information commented District Sanitary Inspector, who found the water to be completely unfit for consumption. The confused residents began to buy the bottled water. The CWSS operator decided to increase the dose of chlorine in the WDS, but due to low water consumption, chlorine was not able to reach the entire water supply network. After 16 days the city authorities appealed to the residents to drain 1 m^3 of water on a designated day and within a specific time period. State of emergency lasted for another 4 days and then it was allowed to consume water after boiling. During the whole incident about 100 cases of poisoning were recorded.

The main mechanisms causing secondary pollution of water in the water-pipe network include [6, 7]:

– corrosion and oxidization (susceptibility of the material of the pipes),

– significant changes in speed of flow (sludge is washed out),

– low speed of water (stagnant water in water pipes, the increase in water temperature),

– rapid change in pressure resulting in local vacuum (sludge is washed out),

– poor technical and sanitary condition of pipes (corrosion of pipes, a large quantity of bio-film, pipes leak),

– corrosion caused by aggressive water,

– lack of chemical instability of the water,

– inappropriate water treatment process (causing chemical instability of water in network),

– high doses of unused disinfectant remain in water (an increase of corrosion),

– accumulation of sludge in the network,

– presence of biochemical processes in the network,

– contamination of the network during repairs, replacement of pipes and fittings (the possibility that pollutants from the ground will pass into water in water-pipe network),

– household and industrial devices directly connected to the network (pollution from the installation is sucked into water-pipe network).

An example of the secondary contamination in the water network is the situation that happened in June 2014 in Dabrowa Gornicza. Because of the momentary loss of power in Water Treatment Plant in Bedzin and Maczki, caused by the energy supplier, on June 2 the direction of water flow in the main water pipe changed and it caused that loose mineral compounds of iron and manganese have been broken off the walls of the pipeline. The consequence of these disturbances in water supply has been the secondary water contamination in several districts of the city.

The method for determining the risks associated with the water age in the water network

According to the basic definition of risk, it was assumed that it is the product of the point weights related to the probability of threat and the consequences of threat:

$$r = P \cdot C \tag{1}$$

where: r – risks associated with the consumption of the primary contaminated water,
P – point weight associated with the likelihood of an event involving the appearance of the primary water contamination in the WDS,
C – point weight related to the water age in the WDS.

In the proposed method the parameter C associated with water age in the WDS should be equated to the time that passes between the moment when the contaminated water flows into the WDS and the moment when consumers take that water.

On the basis of own studies [8] and literature [9–21] the following point weights for the parameters P and C were proposed (Table 1 and 2).

Table 1

Weights point for the parameter P

Likelihood	Weights point	The incidence of threat
Very low	1	every ten years
Low	2	once every five years
Average	3	every two years
High	4	once a year
Very high	5	once in six months

Table 2

Weights point for the parameter C

Weights point	The water age in WDS
1	> 24 h
2	from 12 to 24 h
3	from 6 to 12 h
4	from 2 to 6 h
5	< 2 h

The shorter residence time of the contaminated water in the water supply network the greater threat to residents. Longer time gives the opportunity to inform residents through local media or text messaging from Regional Warning System, etc.

In order to determine the average water age in the given area of the water supply network the mean time for the area is calculated:

$$t = \frac{\sum_{i=1}^{5} t_i \cdot LM_i}{LM} \tag{2}$$

where: t – the average water age in the studied area of water supply network,
i – the time interval,
t_i – the assumed average water age in the water supply network in the time interval i,
LM_i – number of people at risk of water supply in i-th period of time,
LM – the number of residents of the studied area of the water supply network.

For a set weight points of P and C in accordance with (1) risk measures were determined.

Table 3

Risk measures

		C				
		1	2	3	4	5
P	1	1	2	3	4	5
	2	2	4	6	8	10
	3	3	6	9	12	15
	4	4	8	12	16	20
	5	5	10	15	20	25

Based on the Table 3, the following categories of risk were proposed:
- negligible for $r \in [1–3]$,
- tolerated for $r \in [4–6]$,
- controlled for $r \in [8–10]$,
- unacceptable for $r \in [12–15]$,
- impermissible for $r \in [16–25]$.

Application case

The public water supply is Wislok river. The water treatment is on two water treatment plants – Zwieczyca I and II, located in the south-western part of the city. Water supply network (Fig. 2.) with a total length of about 878 km consists of:
- the main network – 49.8 km,
- distribution network – 504.1 km,
- house connections – 324.4 km.

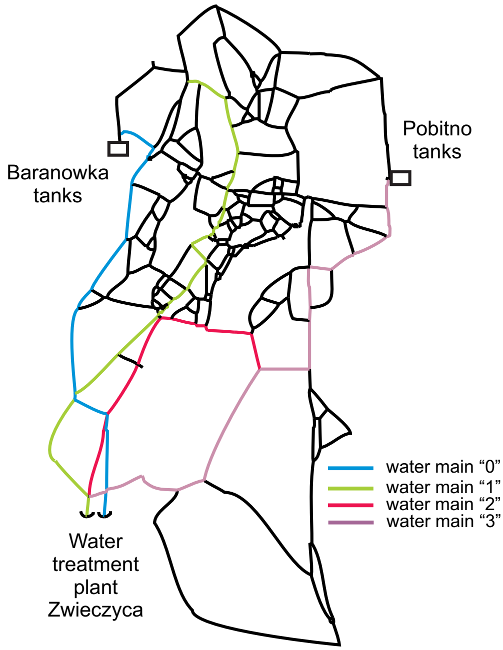

Fig. 2. CWSS of Rzeszow

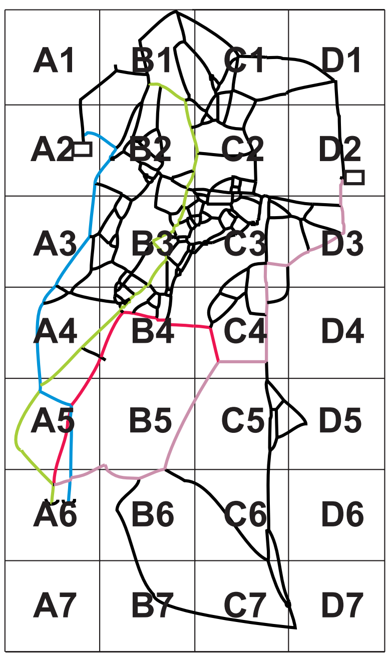

Fig. 3. Division of the CWSS of Rzeszow into areas

Main network is made of cast iron and steel pipes. The WDS was built with iron wires, steel and PE and PVC. House connections are made mainly of galvanized steel, cast iron, PE and PVC.

In order to conduct the analysis of the water age in the water supply network the city was divided into 28 areas, in accordance with Fig. 3.

To determine the water age in the WDS the hydraulic model of the Rzeszow CWSS, made in the program Epanet, was used. The input data for the model were, in addition to the spatial schema, junctions ordinates, water consumption in junctions, diameters, lengths and roughness of pipes, operating parameters of the pumping station, water tanks dimensions, daily distribution of water consumption.

The water age in the water supply network was analysed for the average daily water consumption. In Fig. 4 a stratified graph from program Epanet, showing the residence time of water in the WDS, is presented.

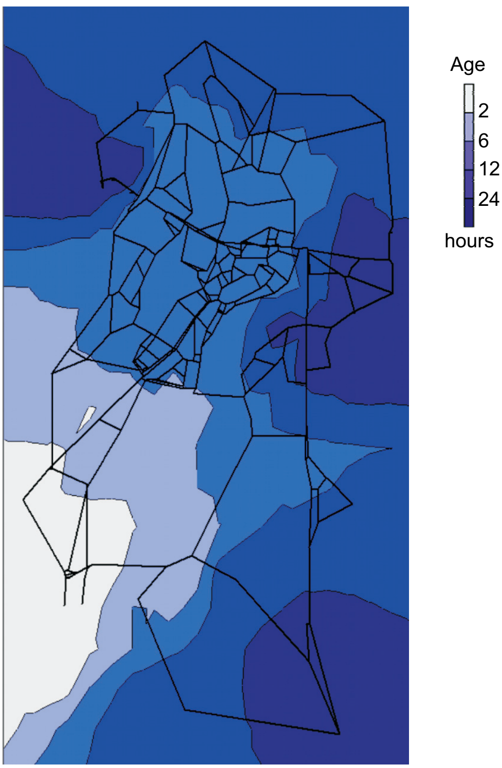

Fig. 4. A stratified graph of the water age in the water supply network

Based on the results of simulation of water age in the water supply network, for particular areas of WDS, the number of residents exposed to consumption of contaminated water for the assumed intervals, was defined. (Table 4). In the calculation of the values of t according to (4), for the subsequent time intervals, successively values

t_i = 1, 4, 9, 18, 36 were assumed. In the last column the point weight of the parameter *C* was defined in accordance with Table 2.

Table 4

Parameter *C* calculation

Area	Number of residents with getting water:					*t* [h]	*C* [-]
	< 2 h	from 2 to 6 h	from 6 to 12 h	from 12 to 24 h	> 24 h		
A1	0	0	2 690	1 770	1 050	17.0	2
A2	0	0	0	4 220	4 080	26.8	1
A3	0	8 220	3 260	520	0	6.0	4
A4	0	15 340	160	0	0	4.1	4
A5	2 240	460	0	0	0	1.5	5
A6	5 630	70	0	0	0	1.0	5
A7	1 190	530	1 770	0	0	5.5	4
B1	0	0	1 180	320	0	10.9	3
B2	0	0	6 900	880	570	11.8	3
B3	0	100	15 400	0	0	9.0	3
B4	0	9 410	1 940	0	0	4.9	4
B5	660	10 940	0	0	0	3.8	4
B6	30	200	270	0	0	6.5	3
B7	0	10	50	240	0	16.0	2
C1	0	0	790	610	0	12.9	2
C2	0	0	900	0	0	9.0	3
C3	0	40	5 950	570	330	11.0	3
C4	0	3 370	2 420	1 300	250	9.2	3
C5	0	2 730	7 100	11 980	0	13.3	2
C6	0	70	860	4 360	310	17.4	2
C7	0	0	0	1 750	4 050	30.6	1
D1	0	0	40	1 560	0	17.8	2
D2	0	0	320	1 250	40	16.7	2
D3	0	0	30	3 530	2 740	25.8	1
D4	0	0	0	5 960	2 840	23.8	2
D5	0	0	0	10	5 790	36.0	1
D6	0	0	0	1 760	2 340	28.3	1
D7	0	0	0	0	5 800	36.0	1

Based on many years' observation of the studied CWSS and the nature of water source the weight of the parameter *P* was adopted as 2. On the basis of the value of the parameter *C* from the Table 2 and the adopted value of the parameter *P* the risk value was calculated and risk categories were defined. The results are presented as a map (Fig. 5).

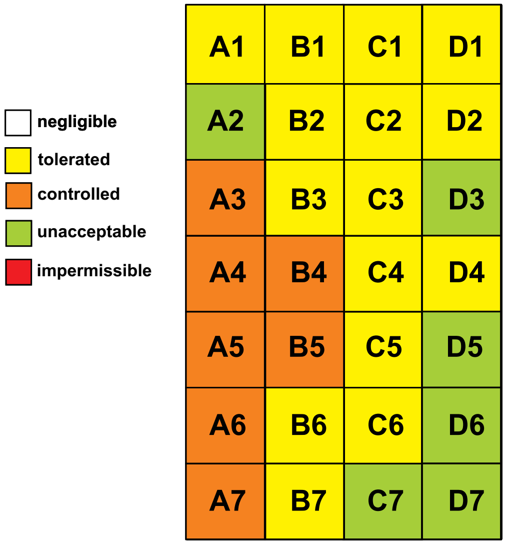

Fig. 5. Map of the risk associated with the water age in WDS

On the basis of Fig. 5 it was found that:

– in 6 areas (5 of them in column D) the risk associated with the water age in the WDS is on a negligible level,

– in 7 areas (5 of them in column A) the risk associated with the water age in the WDS is on a controlled level,

– in 15 areas (mainly columns B, C and a whole line 1) the risk associated with water age in the WDS is on a tolerable level,

– the risk associated with the water age in the WDS is closely related to the hydraulics of the WDS (flow, speed, the demand for water in particular junction).

Conclusions

The water age in the WDS is an important factor for the safety of water consumers. A short time of water inflow to the recipients can cause threat to health or life if primary water contamination appears in the WDS. A key role in ensuring water consumers safety plays water quality monitoring, from the intake through the water treatment plant until the WDS. Although the possibility of the appearance of primary contamination in the water network is small, the consequences of such an event can be tragic. Fast information to residents about the vulnerable areas quickly should be a priority for the water supply network management services. The presented methodology gives the possibility to undertake the information actions in the right order, starting with the areas with the highest threat. Information about threat can be conveyed indirectly through local media, the water supply company website, Sanitary Inspection, text messaging from the Regional Warning System or directly through stationary and mobile megaphones.

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WIEK WODY W SIECI WODOCIĄGOWEJ JAKO CZYNNIK RYZYKA ZDROWOTNEGO ZWIĄZANEGO ZE ZBIOROWYM ZAOPATRZENIEM W WODĘ

Zakład Zaopatrzenia w Wodę i Odprowadzania Ścieków
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Abstrakt: Poprawna eksploatacja systemu zbiorowego zaopatrzenia w wodę wymaga ciągłego monitoringu jakości wody na różnych etapach (ujmowania, uzdatniania, pompowania, dystrybucji). Istotnym parametrem związanym z jakością wody jest wiek wody, czyli czas od momentu wpompowania wody do sieci wodociągowej do jej pobrania przez odbiorców. W przypadku skażenia wody na wyjściu ze stacji uzdatniania wody wiek wody jest tożsamy z czasem rozprzestrzeniania się zanieczyszczenia w sieci wodociągowej. Od długości czasu rozprzestrzeniania zależy, ile osób korzystających z wodociągu będzie narażonych za spożycie wody o jakości zagrażającej zdrowiu lub życiu. W pracy przedstawiono metodykę określania ryzyka związanego z pojawieniem się w sieci wodociągowej zanieczyszczonej wody wykorzystującą model hydrauliczny, a także przykład aplikacyjny dla wybranego systemu zbiorowego zaopatrzenia w wodę.

Słowa kluczowe: sieć wodociągowa, jakość wody, zanieczyszczenie