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NUMERIC MODELING OF THE RESIDUAL CHLORINE CONCENTRATION EVOLUTION IN A WATER DISTRIBUTION NETWORK

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The supply of quality potable water to the customers' branch pipe of the distribution network represents a major responsibility for the water supply system operators. There are circumstances when the quality of the water produced in the water treatment plant is palatable, but the same water distributed to the consumers might be altered (from quality point of view) due to its transport through the distribution network. For that purpose, the present article describes the analysis application to the way the residual chlorine concentration evolution is performed in a regional water distribution network. The numerical model of the distribution network was carried out through the program EPANET 2.0, and the simulation of the network's performance was performed for a 72 hours period, with the aim at control the residual chlorine concentration in terms of flows passed through.

Keywords: *chlorine concentration, distribution network, water quality, EPANET.*

MODELAREA NUMERICĂ A EVOLUȚIEI CONCENTRAȚIEI DE CLOR REZIDUAL ÎNTR-O REȚEA DE DISTRIBUȚIE A APEI

Furnizarea unei ape potabile corespunzătoare din punct de vedere calitativ la branşamentele consumatorilor arondați rețelelor de distribuție reprezintă o responsabilitate majoră pentru operatorii sistemelor de alimentare cu apă. Există situații pentru care apa produsă în stațiile de tratare poate fi de o calitate acceptabilă, dar apa care ajunge la robinetul consumatorilor să prezinte modificări calitative în procesul de transport prin rețelele de distribuție. În acest sens, în prezentul articol se prezintă posibilitatea de analiză a modului în care se realizează evoluția concentrației de clor rezidual în cadrul unei rețele regionale de distribuție a apei potabile. Modelul numeric al rețelei de distribuție este realizat cu programul EPANET 2.0, iar simularea funcționării rețelei de distribuție, cu scopul de a urmări variațiile concentrației de clor rezidual în funcție de debitele tranzitate, a fost efectuată pentru o perioada de 72 de ore.

Cuvinte-cheie: *concentrație de clor rezidual, rețea de distribuție, calitatea apei, EPANET.*

Introduction

High attention in the water distribution systems of the localities is given to the activities for continuous control and keeping track of the water quality indicators. For that purpose, the major responsibility for the healthcare of the population is the permanent measurement of the main water quality indicators to both the inlet and the furthermost points from the supply source of the distribution network (reservoir or pumping station). The water quality intended for human needs consists of organoleptic tests, chemical, physical, biological, microbiological and bacteriological indicators, which values are regulated by the Law 458/2002 [3] amended and completed in December 2011.

The removal of bacteria and viruses in water is carried out through chlorine disinfection at both the outlet of the water treatment plant and the reservoirs upstream the inlet of the distribution network. According to the in force regulation, the free chlorine concentration in the disinfected water by chlorination is 0.50 mg/l [3] at the inlet of the distribution network and 0.10 mg/l at the end of it [3]. The evolution of the residual chlorine concentrations in the water distribution network can be studied and analyzed by numerical models for the simulation of the efficiency and exploitation of the water distribution network, models achieved by way of computing programs fit for the under pressure hydraulic systems.

The numerical model of the distribution network

Generally, the distribution network form a complex functional unit, developed all over the locality, for which the design, the execution and the exploitation consist of numerous restrictions and conditionings that one should attend to in the numerical modeling. Thereby, the researchers have directed their work on the development of software programs that represent a modern and useful tool for the simulation of the water distribution network performance, thus giving the ability to carry out study analysis of the quality indicators variation in various exploitation scenarios.

For the numerical modeling of the water distribution network in cluster Călan, the graphics interface of the EPANET 2.0 program was used, developed by the Environmental Protection Agency USA and intended for hydraulic design and for water quality analysis in water distribution network [2]. The reviewed distribution network ensures the potable water demand for both Călan town and the neighboring areas (Crişeni, Strei Săcel, Strei Sângeorgiu, Ohaba Strei, Ceangăi), such as to build a regional distribution network that serves for much 13,000 inhabitants, as described in Fig. 1.

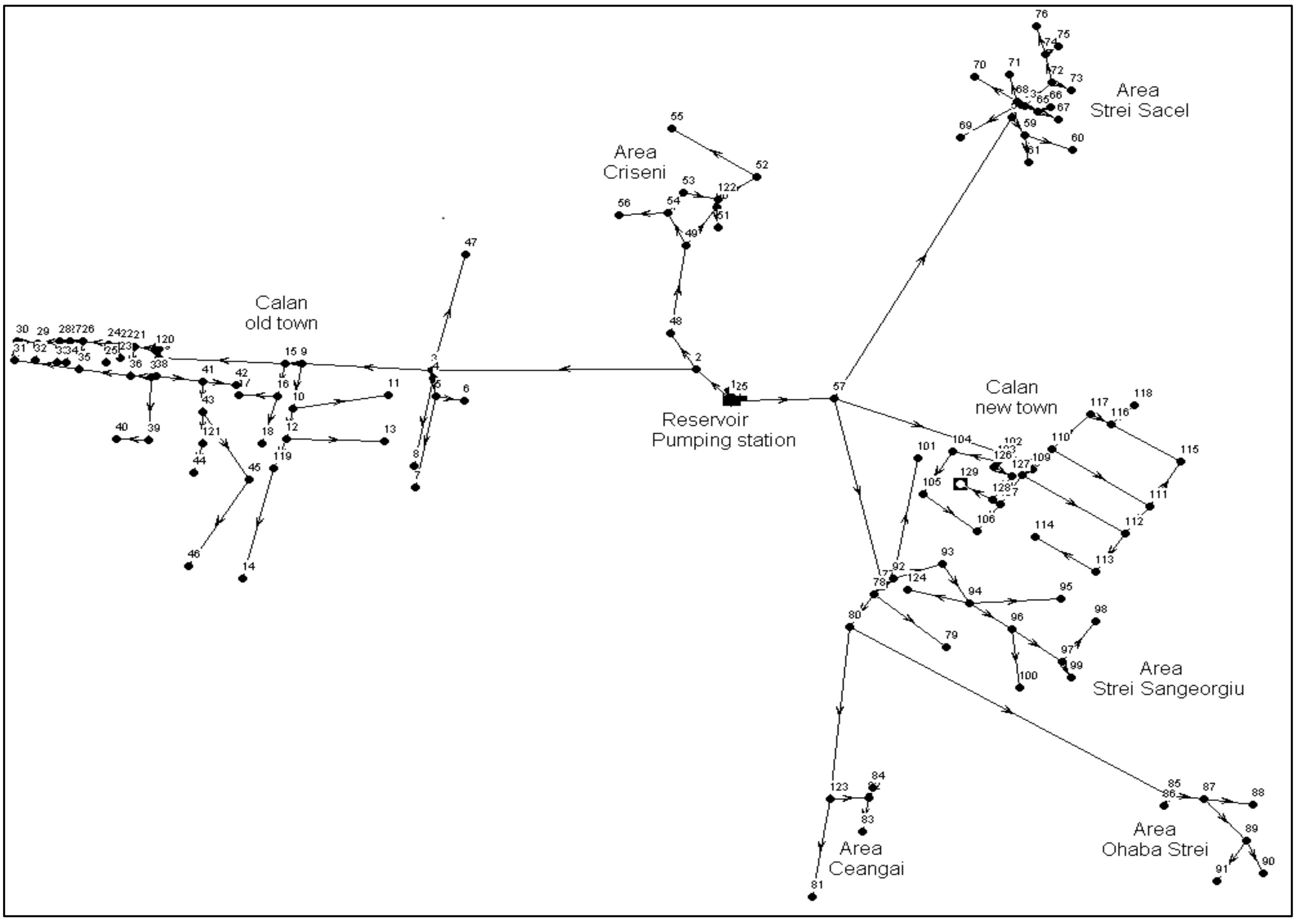

Fig.1. The diagram of the distribution system (the junctions and the service areas).

The configuration program and the construction of the numerical model were established based on the network architecture, wherefore the initial and the final junctions of the pipes and their connections into the network had been defined. For pipe line, the representative elements were referred to: units length, diameters, roughness coefficient, pressure loss, and for defining the junctions, the geodesic heights, the junctions input, X and Y coordinates were ascribed to graphical diagram of the distribution network. The numerical model of the distribution network is built up of 133 junctions and 133 pipes, one intake reservoir for the pumping station that provides the transport of the water into the distribution network, as well as a pumping station for the highest area in town.

The simulation of the pumping and the boosting station that provides the flow demand and the pressure into the network's junctions was accomplished by the insertion of the representative curves in the program EPANET (Fig. 2).

In order to simulate the variation of the water hourly consumption during a day, the EPANET program allows the user to introduce the hourly variation coefficients via the instruction Pattern Editor. The diagram for the hourly variation of the water consumption in every junction, in relation to the daily average flow is presented in Fig. 3, according to the variation curve of the consumption for an average town [4].

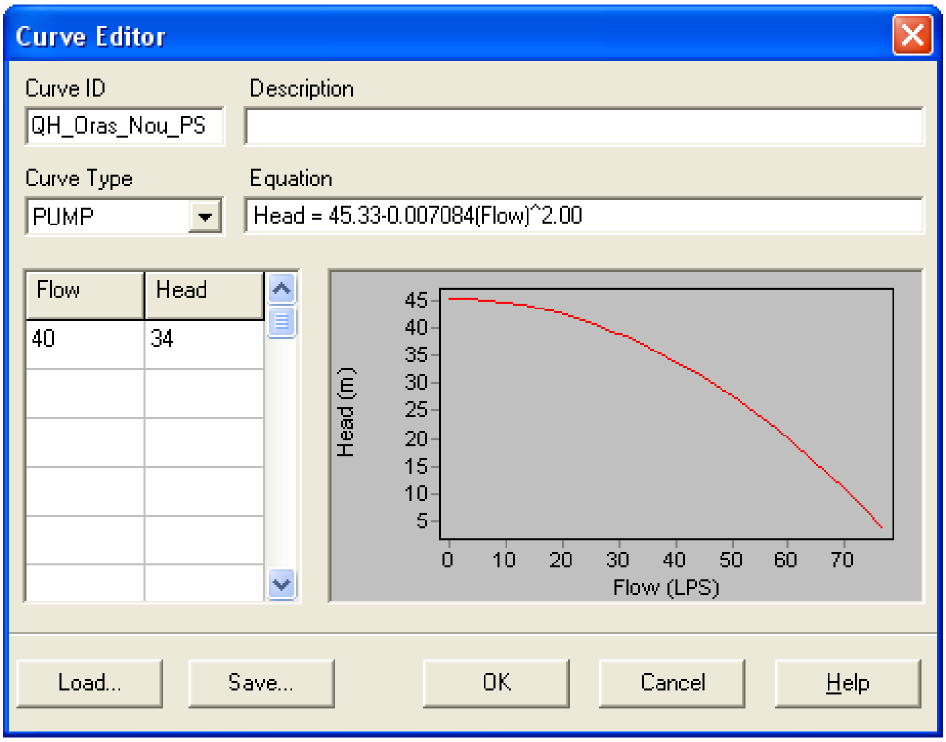

Fig.2. Pump's curve.

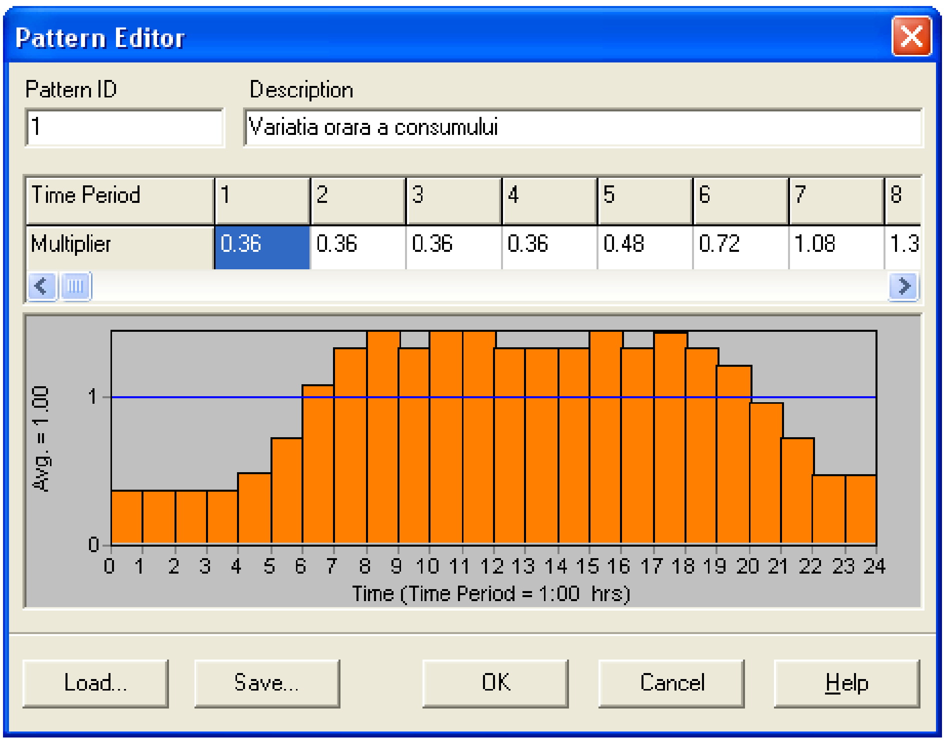

Fig.3. Hourly variation diagram for water consumption.

For the study of the chlorine concentration into the distribution network, at the inlet of the distribution network in the pumping station's intake reservoir, it is considered a free chlorine concentration of 0.50 mg/l, which value remains constant in time. After running the numerical model, that simulates the performance of the distribution network, the variation in time of the residual chlorine concentration in each of the network's junctions is acquired.

Aspects regarding the modelling of the distribution network using the program EPANET 2.0

Intended as an instrument for the simulation of the pressure pipes network performance, the software package EPANET 2.0 was conceived on the purpose to allow for the in time simulation of the hydraulic conditions and of the water quality through the distribution network. EPANET monitors the variation of the water flow parameters through pipes (rate, flow, pressure-loss), the variation of the piezometric heads and the pressure into the network junctions, the water quantities into the reservoir and the chemical substances concentrations during the simulation periods of the distribution network performance [1].

Running in Windows, EPANET represents an integrated media for editing the data required for building the numerical model of the network, for the running of the hydraulic and water quality simulations for a certain period of time of an hydraulic system, and to envision the results in different forms that might include maps of the colored codified network, data, diagrams and variation curves. The layout and the dimensioning of the pumps, pipes and valves, the minimization of the power demand for pumping, the flow analysis, the study of the vulnerability and the operator's training for different scenarios in exploitation, represents one of the capabilities of EPANET program.

The advantages that EPANET brings in, include the following aspects: the size of the explored network is unlimited; the definition of the pressure loss is accomplished using the relations Hazen-Williams, Darcy-Weisbach or Chezy-Manning (on the users choice); modeling the pumps running with constant or variable speed (based on an algorithm required by the user); calculates the power needed for pumping and its costs (in USD, based on a price assessed by the user); simulates different types of valves (for pressure control, flow control, and for the input of some local pressure losses); simulates the clack valves; affords the simulation of some different categories of customers (each to their own in time variation model of the parameters), allows the introduction of some elementary or complex conditions in the operation system.

The results of the hydraulic computation obtained by running the numerical models that are drawn up, are separated for pipes and junctions. For pipes, there are: the water flow Q (in l/s), the water rate (m/s), the pressure losses (m/km) and the Darcy coefficient λ. For junctions, there are: the pressure, (m.c.w.), the piezometric height (m), the geodesic head (m), the water flow required by the customer connected to that junction (l/s), the chemical substances concentration (mg/l).

In order to access the computation module that simulates the chlorine concentration variation when water flows through the distribution network, the instruction „quality options" is selected and the word „chlorine" is introduced for parameters; to the instruction „reaction option", for the global coefficient in the flowing center, the value -1.0 is introduced (the value indicates the chlorine degradation rate, due to the reactions that occur in the settled time; this rate will be applied to the whole pipe network); in the junction where the reservoir is set out, the option „initial quality" is selected and the value 0.50 is introduced (C_0=0.50 represents the chlorine dose, in mg/l, continuously added to the network). In the first stage, at the time t=0, the values of chlorine concentration in all junctions are zero. Choosing a time step of 1 minute, the values of chlorine concentration can be determined dependent on the water flow variation through the water distribution network. To simulate the chlorine degradation rate after the reactions have occurred during the water flow, it is necessary to know the rate the substance reacts and its dependence upon the concentration. For example, the chlorine introduced for disinfection reacts, leading to hydrochloric acid (a very corrosive acid) that acts both as disinfectant for water and as oxidizer, but when carried through the limit layer of the pipe causes corrosion or may even increase the risk of microbiological membrane formation along the pipes wall. The herein paper considers only the mass reaction (in the center of the flow).

The relation that describes the momentary rate of the reaction depends on the concentration is presented below (Eq. 1):

$$R = K_b C^n \tag{1}$$

where K_b is the reaction coefficient in the center, C is the reactant concentration, and n is the reaction order. A first order reaction $(n=1)$ and a rate coefficient reaction $K_b = -1$ are considered. Using this algorithm, a linear graphical representation of the natural logarithm of the in time concentrations ratio (C/C_0) is obtained, where C_0 is the concentration upstream the moment zero $t=0$, and C is the concentration downstream, at the time $t>0$.

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The coefficient K_b is determined as a gradient of the line (generally it increases once the water temperature is increased). In this way the law of the chlorine concentration decreasing can be determined as (Eq. 2):

$$C = C_0\, e^{K_b t} \tag{2}$$

And for the values: $C_0 = 0.50$ and $K_b = -1$, it becomes (Eq. 3):

$$C = 0.50\, e^{-t} \tag{3}$$

The results of the calculations for the network junctions give the chlorine concentration values $C = C(t)$, or the ones of the chemical constituents considered.

The analysis of the residual chlorine concentration

The simulation model of the residual chlorine concentration evolution in the existing distribution network was carried out for a 3 days period (72 hours) starting to time 0. The variation of the daily flow pumped from the reservoir into the distribution network, meets the variation curve of the consumption pertain to an average town, with a maximum hourly flow of 48.83 l/s, as it can be seen in the diagram below, Fig. 4; it can be noticed that the coordinate values are negative because the water flows out the reservoir.

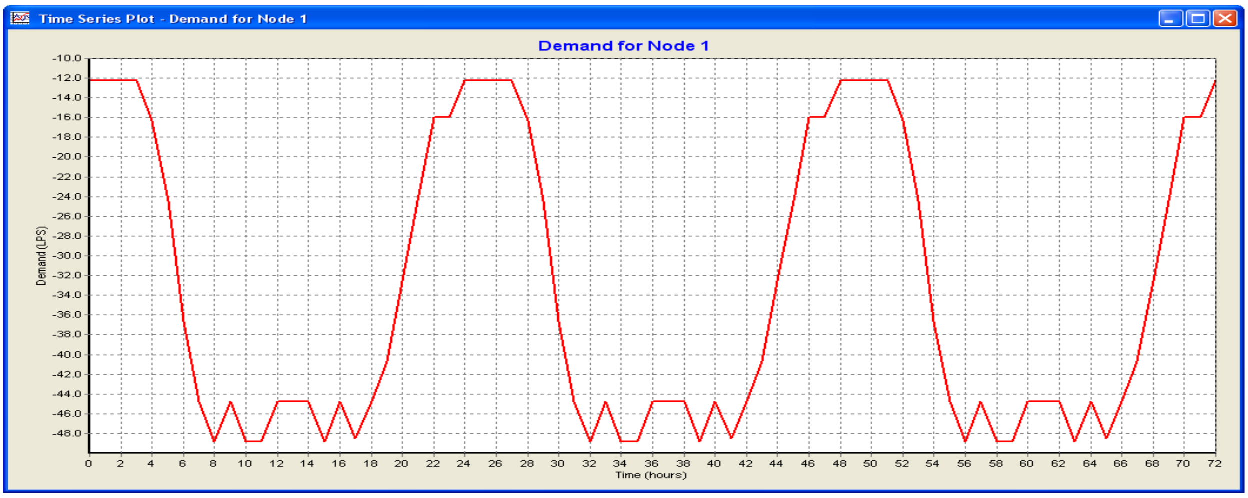

Fig.4. Water flow variation along the distribution network.

The analysis of the residual chlorine concentration distribution showed that after a running time of 20 hours from the beginning of the simulation, the residual chlorine concentration value is partial present in the service areas. It can be noticed that in Ohaba Strei district the residual chlorine concentration is zero (the blue colored junctions). The presence of chlorine in this area is observed starting with the time 21:00 (0.22 mg/l in junction 85). Fig. 5 describes the evolution of the residual chlorine concentration in junction 85 (inlet junction for Ohaba Strei area).

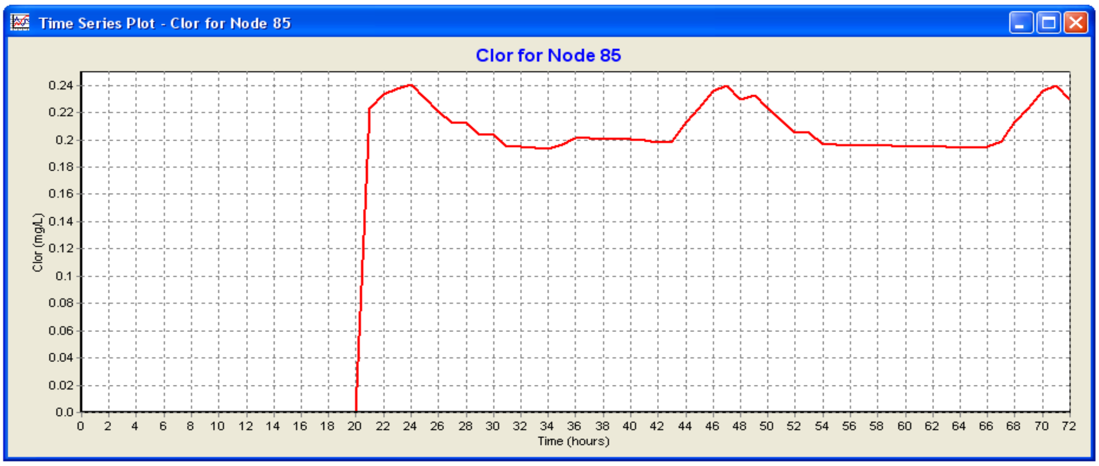

Fig.5. Residual chlorine concentration in junction 85 (Ohaba Strei).

The distribution of the residual chlorine concentration variation through the network's junctions after 20 hours is presented in Fig.6.

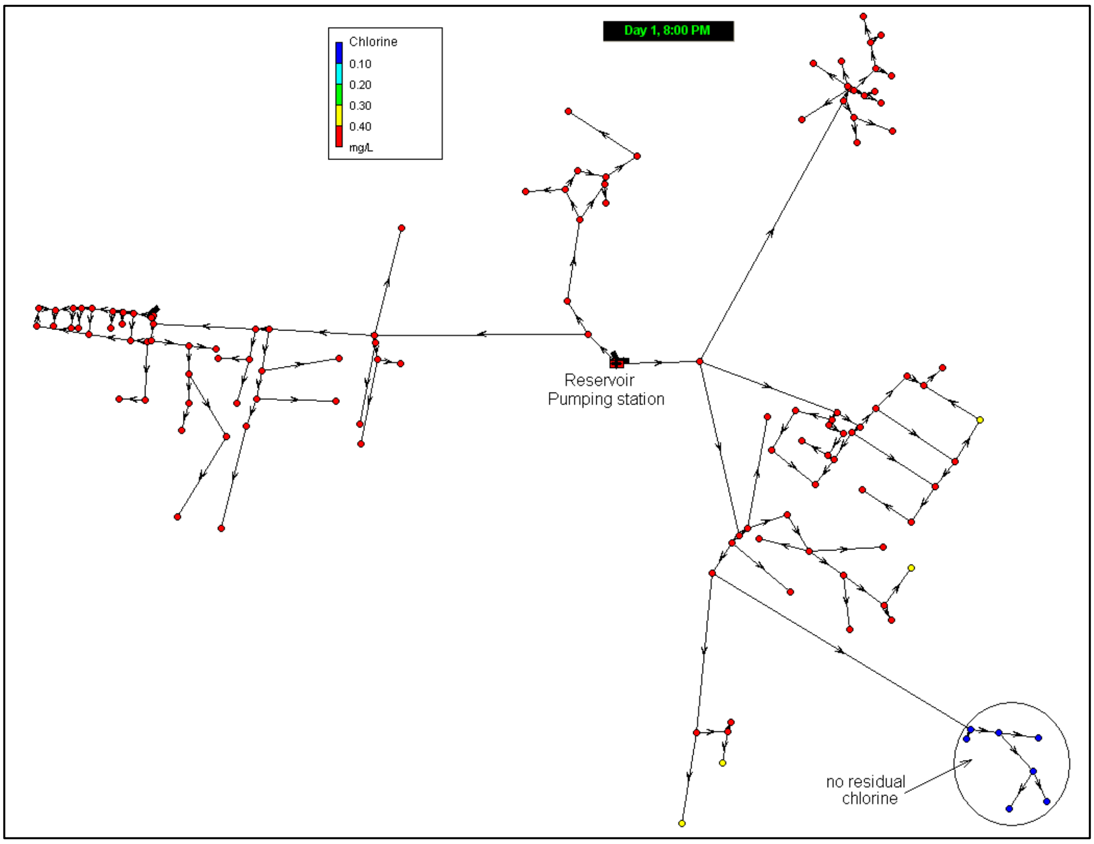

Fig.6. Residual chlorine concentration after 20 hours.

At the same time, due to reduced water consumption in this area, the water flow rates through the network are very low, the reason why there might be a risk for a microbiological film development on the pipes' wall of the network. This appears from the residual chlorine concentration values, obtained for the junctions 88, 90 and 91 (that characterize the distribution network sector in Ohaba Strei area). The diagram presented in Fig. 7 shows that for this part of the network, during simulation, the presence of the residual chlorine is delayed, while values of less than 0.1 mg/l (the minimum value accepted according to the in force regulation) are registered.

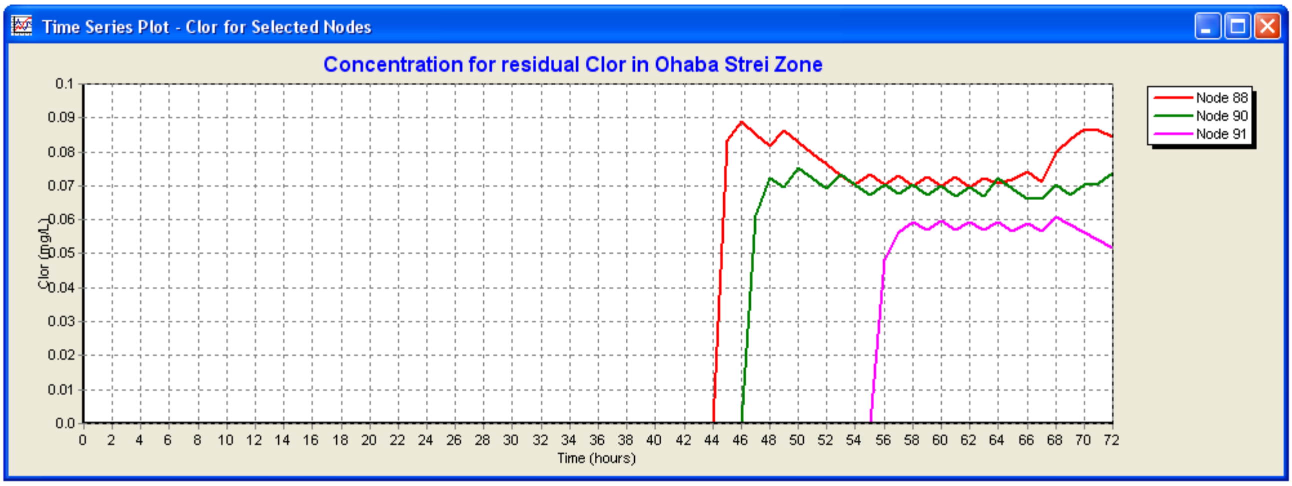

Fig.7. Variation of the residual chlorine concentration in Ohaba Strei area.

To avoid this inconvenience (the absence of the residual chlorine), a numerical simulation of the network's performance in the circumstances of re-chlorination process in junction 85 (the one that represents the inlet junction in Ohaba Strei area) has been developed. The simulation was performed with extra chlorine dose by 0.2 mg/l in junction 85, as it can be noticed in Fig. 8. In this context, the variation of chlorine concentration records values between 0.50 mg/l at the reservoir in junction 1 and 0.11 mg/l in junction 91 in Ohaba Strei area, (Fig. 9), values that are within the in force law.

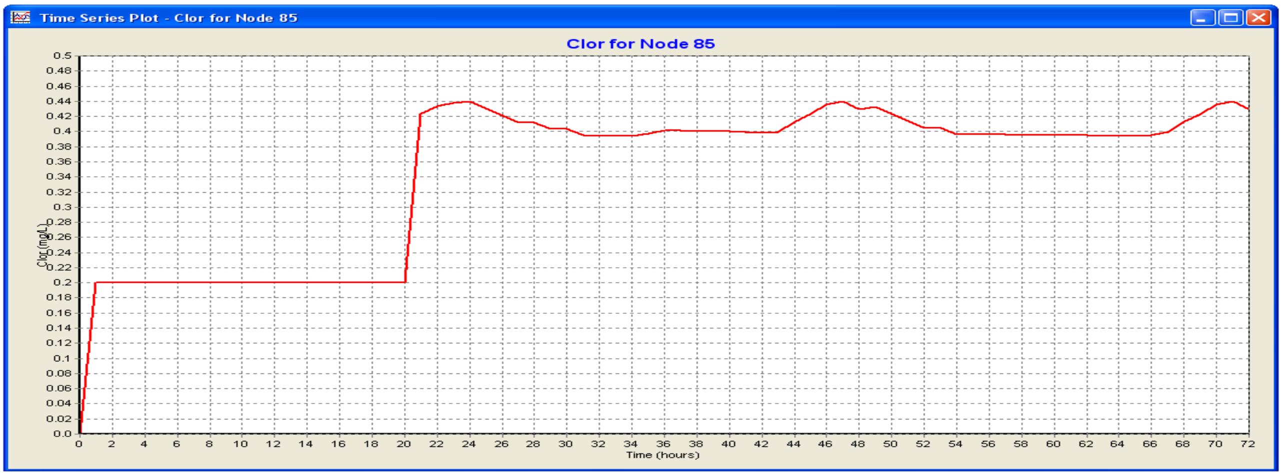

Fig.8. Variation of residual chlorine concentration in junction 85 after re-chlorination.

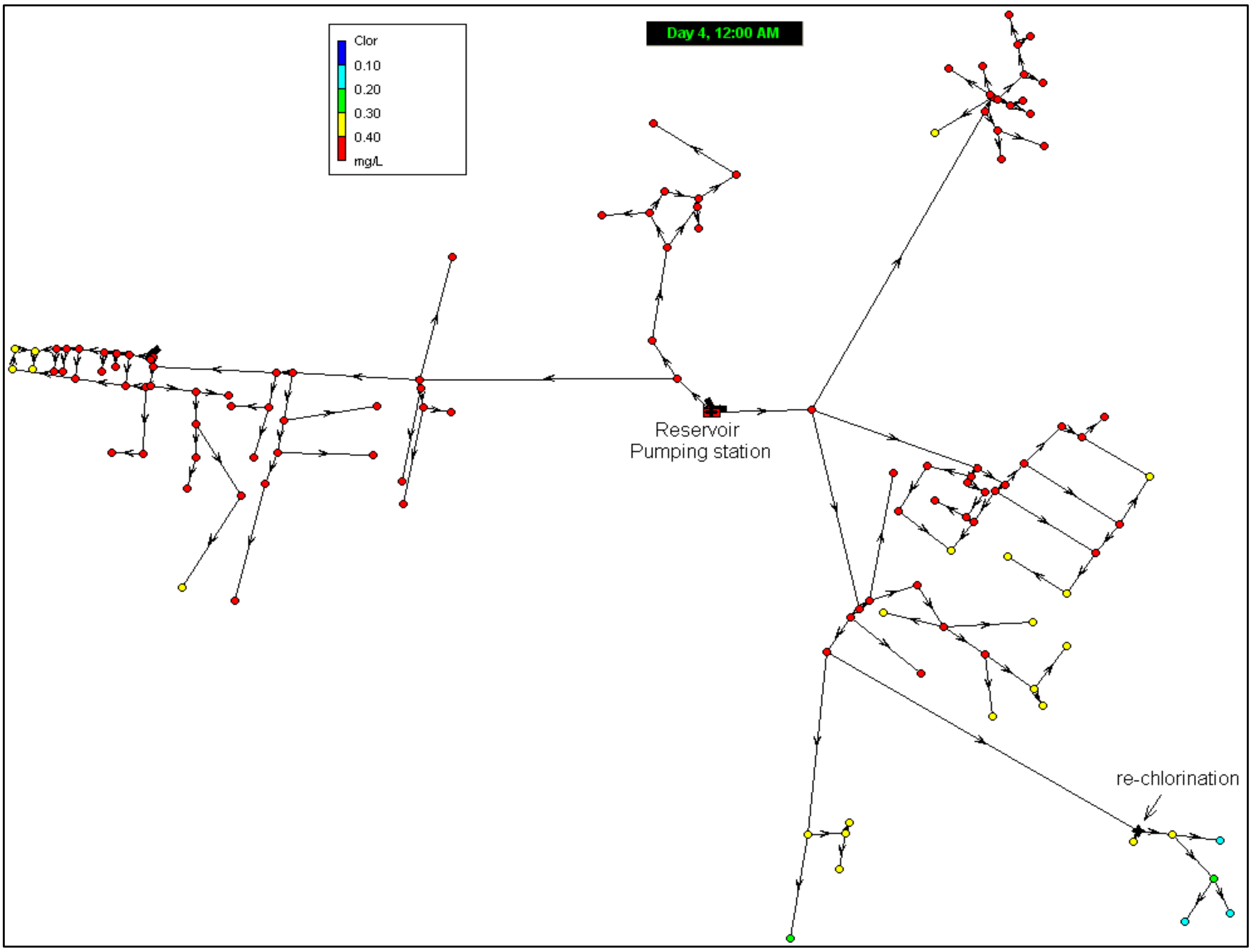

Fig.9. Variation of residual chlorine concentration in junction 85 after re-chlorination.

Results and discussion

The performed analysis aimed at the range of chlorine concentrations variation, simulating the distribution network performance for a dose of 0.50 mg/l added constantly into the water storage reservoir, that represents the uptake reservoir of the pumping station that serves the entire distribution network.

After analyzing the data presented above, it was determined that due to the length of the network, to reduced consumptions and by default to the low rates the water flow is characterized of, there is an adjacent area to the town (Ohaba Strei) where the residual chlorine concentration is below the limit accepted by the in force law (0.1 mg/l, [3]). The suggested solution in the study for handling this inconformity consisted of constantly introducing a chlorine dose of 0.2 mg/l in junction 85 (inflowing junction for Ohaba Strei area network). The acquired results after the simulation of the network's performance for this scenario, in which junction 85 is subjected to re-chlorination, showed that, for the entire distribution network, the water quality according to the residual chlorine concentration complies with the in force regulation for potable water.

Conclusions

The numerical study performed in this paper intended to analyze the variation of the residual chlorine concentration in the water distribution network from Călan town and its neighboring localities. The elaboration of the numerical model, the simulation of the network's performance, the analysis of the data and the graphical approach were developed with the program EPANET 2.0.

Considering that the distribution network is one of a regional type, with a considerable length, a simulation of the distribution network's performance for the study of the residual chlorine concentration in the distribution network's junctions within an extended time of 3 days, was accomplished.

Bibliography:

1. GEORGESCU, A.M., GEORGESCU, S.C., CIULACU, C., MOICEANU, A. (2006) – *Numeric modeling of chlorine transport through water distribution network for a locality of 10000 inhabitants*, The Fourth Conference of the Hidroenergetic Researchers in Romania, Bucharest.
2. ROSSMAN, L., (2000), *EPANET 2 Users Manual*, U.S. Environmental Protection Agency, 600/R- 00/057, Cincinnati, OH.
3. *Legea privind calitatea apei potabile*, nr.458/2002. În: Monitorul Oficial al Republicii Moldova, 2002, nr.552/29.
4. ***, STAS 1343-06, *Hourly variation coefficients for the diagram of the daily water consumption in inhabited centers.*

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