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Research paper

Optimization of City Water Supply Networks on Their Structural and Functional Analysis Base

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Abstract

Based on the research results on the operation of urban water supply and distribution systems, the most rational ways of their improvement are identified in order to improve water supply and energy saving.

Keywords: *water supply networks, pumping stations, systems of water supply and distribution, water losses, water leakage, overpressure*

1. Introduction

Water supply systems of cities in their territories should provide high-quality water to all consumers and especially the population. At the same time, the operation of water supply systems must be reliable, economical and efficient in terms of rational use of water, environmental protection and other urban planning requirements [1, 2, 3, 4].These requirements primarily concern the most costly, large-scale and technologically complex part of the city's water supply system - a complex of hydraulically interconnected water supply and distribution facilities as part of water supply networks, pumping stations and pressure-regulating tanks [3, 5, 6]. As the technological structures of the water supply and distribution system are characterized by structural complexity, dynamism of the state and work imperfection (even for small objects, these are hundreds of kilometers of water pipes and water pipelines from pipes of various materials and diameters, built in different years, several powerful pumping stations, pressure-regulating structures, with ten thousand cubic meters capacity).

The existing shortcomings in the operation of water supply and distribution systems and their main part - water supply networks, are caused not only by the unsatisfactory state of facilities (deterioration and failure of networks, water leakage, etc.), which is usual, but also by the mismatch between their parameters and constructive schemes for new conditions of functioning. This leads to unsatisfactory provision of water to consumers, an increase in the construction cost of water supply networks and facilities and maintenance costs, a surcharge of electricity to supply water and its loss due to leakage.

The conducted studies [5..15] indicate that the functioning of water supply and distribution systems under current conditions has its own characteristics associated with permanent changes in their parameters, requires a detailed analysis of trends in these changes, improvement of structures and operating conditions in order to stabilize water supply and resource conservation

Among the main features of the functioning of the existing water supply and distribution systems in the settlements of Ukraine, the following [5, 6] are identified:

• decrease in the volume of supplied water (due to a reduction in water consumption by industry, water metering introduction and a constant increase in the electricity cost, as the main energy source);

• increase in unaccounted losses of water (leaks, irrational water consumption, as a difference between actual costs and calculated according to water consumption norms, unauthorized water withdrawals);

• increase in the accident rate of pipelines and equipment due to their aging, low level of planned preventive maintenance, untimely repairs and replacement (sometimes almost complete lack thereof);

• deterioration of water lines and water supply networks hydraulic characteristics (growth of pipes hydraulic resistance, non-constructive changes in distribution networks schemes, etc.);

• reduction of the general, but increase in the specific electricity consumption, mainly due to aging and pumping units deterioration;

• decrease in reliability indicators due to aging and deterioration of structures, pipelines and equipment, low replacement level or restoration.

In recent years, water saving technologies have been spreading in all sectors of the Ukrainian economy. This is due to both low reserves of local water resources, and the significant specific costs of water and electricity for its supply, as well as their high prime cost. On average, one inhabitant of Ukraine has about 1100 m3 of total runoff per year 95% of the provision, and the local - 580 m3 per year. This is one of the lowest indicators in Europe (Norway - 97000 m3 per year, Sweden - 24000, European part of Russia - 5900, France - 3500, Germany - 2500, Belgium - 940, Hungary - 810, Netherlands - 780). In Ukraine, the volumes of water consumed in various sectors of the economy in recent decades have declined in 1.5 ... 2 times, and compared to the period of the largest water consumption (late 80s of the last century) - more than three times [6, 7, 9].

A survey of water pipelines in Ukrainian cities has shown that water lines and water supply networks are constructed, mainly, from cast iron (up to 55%) and steel pipes (up to 42%). In general, pipes (more than 82%) have on the inner surface deposits of corrosive nature, which lead to an increase in the hydraulic resistance of the pipes in 1,5 ... 5,0 and more times [6, 9, 10]. The degree of increase in the pipes resistance, in addition to their material and chemical water composition, is significantly affected by the modes of water supply through pipelines and the operation period. At the same time, the location of the pipeline section in the system, the speed of water movement, the nature of their change over time, and the like are important

2. Main Body

Studies argue that one of the most influential factors in the failure rate of networks and the magnitude of water leakage from them is the pressure of water [7, 11, 12]. Therefore, in many countries of the world, the maximum permissible pressure in water supply networks is normalized. In particular, in Italy it makes up 61.2 meters of water, in Russia 60, in Great Britain, Ireland - 30, in the Netherlands - 20, and in Ukraine - 45 meters. Compliance with these standard values of pressure significantly reduces the accident rate of pipelines, reduces leaks and irrational water distribution.

In the work of modern water supply and distribution systems, secondary pollution of water is observed when it is transported through water pipes. As a result, qualitatively prepared drinking water at water treatment facilities does not meet modern regulatory requirements in the areas of its distribution. Secondary pollution is associated with the condition of the water supply networks and their operating modes. Factors affecting secondary water pollution - the time of water in the pipes, the formation of a vacuum in them, the corrosive properties of water, the quality of the pipe material, and suchlike.

This situation of water supply networks and facilities indicates the need for their full renovation, which involves not only a massive replacement of pipelines and equipment, but also changes in the conditions for designing their reconstruction and modernization, taking into account existing problems and development trends, changing the main parameters during operation, and accounting resource-saving requirements.

For this purpose, on the existing water supply and distribution systems diagnostic, debugging and optimization works are carried out. These works are carried out in a complex, in a certain sequence, providing [6, 9]:

- ➢ analysis of the status and operating modes (expert evaluation of information on the facilities parameters and verification of the pumping stations status, clean water tanks, water lines, networks and equipment on them, analysis of the water supply balance and consumption, identification of constructive flaws in the scheme and water networks operation, etc.);
- ➢ parameters research and their work (manometric survey, actual characteristics of pumps and pipelines determination, revealing the reasons for their changes in time);
- ➢ simulation and calculation on the computer all structures joint operation of water supply and distribution systems in order to determine the most rational ways to improve them, improve reliability and cost efficiency;
- ➢ adjustment of water supply and distribution systems (elimination of identified bottlenecks, pumping re-equipment stations, phased reconstruction, rehabilitation and pipelines renovation, etc.).

Such works were carried out with the participation of authors in many settlements of Ukraine (more than 50 cities and townships). In recent years, optimization schemes have been developed for the cities of Ternopil, Zhitomir, Khmelnitsky, Ivano-Frankivsk, Gorodenka, Verkhovyna, Kosiv, Korets and others.

The implementation of these works provides for a structural and functional analysis of existing urban water pipelines. It should be interpreted as a comprehensive analysis of the structural diagrams of water supply networks in the conditions of permanent changes in their parameters during operation and taking into account the stochastic nature of the influencing factors. The purpose of structural and functional analysis is to justify constructive water pipes schemes based on optimization of their operational parameters, oriented to resource saving and improving economic and technological indicators.

The works on optimization of water supply and distribution systems provide for the definition of the most expedient option for improving their schemes, parameters and operating modes under standard technical constraints, in particular, providing all consumers with water at pressures not exceeding permissible, cost efficient and reliability conditions of water supply. To do this, modeling of systems individual elements and joint operation modes of their facilities is carried out, and on their basis all calculations, both in the design of new or reconstruction of existing water supply networks and structures, and for assessing their effectiveness in the process of operation. The main issues of modeling and calculation of water supply and distribution systems are classified into three groups [6]:

• water consumption and formation of water distribution from water supply networks (setting the design load on the system);

• hydraulic calculations of water networks and facilities and their joint work (so-called "verification" calculations)

• technical and economic calculations (establishment of schemes for water supply networks, pipeline diameters, size of structures, etc.).

Estimation of water consumption regimes as random processes is carried out on the basis of two main methods - probabilistic and statistical. However, the requirements [1] in the norms do not allow to reliably estimate the load on the system for different levels of reliability, which is important both for the system as a whole and for its individual elements. In addition, reliability levels are generally not standardized.

Hydraulic calculations of water supply networks have been carried out since the 30s of the last century. Modern computer technology makes it possible to effectively carry out high-performance hydraulic calculations of the joint operation of water supply networks and the structures interacting with them, that are part of the water supply and distribution systems, taking into account their features and service to the maximum. Computer programs are geared towards GIS technologies, create conditions for high-quality and rapid generation of input data by importing files from other GIS-models. These are WaterCAD®6.0 software packages from HaestadMethods, EPANET Lewis A. Rosman, ZuluHydro LLC Polyterm and others [3, 6].

Along with the significant positive aspects, these computer programs do not take into account the changes in the values of water distribution in the nodes, they have difficulties in determining the changes in hydraulic resistances in time. When using them, problems arise with the accuracy of optimization calculations due to the lack of a proper mathematical apparatus and for modeling changes in the influencing parameters during operation.

Technical and economic calculations, during which economically advantageous parameters of water supply networks are determined, are usually carried out without sufficient consideration for the other structures mutual influence of water supply and distribution systems and indicators of their reliability. But the biggest drawback of existing methods is that they do not take into account changes in the parameters of structures and pipelines during operation, the stochastic nature of the factors affecting the operating modes, the interrelations between the operating parameters of water supply networks and structures.

Optimization of city water supply networks requires consideration of many factors that determine their condition, the relationship with other structures of the water supply and distribution system and should be based on a modern mathematical apparatus, allowing to model a large number of elements and operating system modes. The existing methods for calculating water supply and distribution systems when optimizing them do not take into account changes in the influencing parameters during operation, and the dependence of water withdrawals on nodes. In addition, there are no methods for determining the estimated water discharge depending on the given levels of availability and categories of water supply and distribution systems; calculations of economically viable pipeline diameters and constructive schemes determination of water supply networks are carried out without taking into account their reliability indicators and stochastic changes in their operating modes.

This research provides for the determination the most effective ways of solving these issues and the justification for the possibility of applying the results obtained earlier in the water supply networks optimization in the city.

All factors affecting the optimization of water supply and distribution systems are determined by the construction conditions and water lines operation, water networks, pumping stations and other elements, can be divided into three large groups: constructive, technological and economic (Figure 1).

Constructive indicators of the influencing factors depend on the size of the water supply object, the category of the water supply system and the adopted scheme for supplying water to consumers. They affect the reliability level of the water supply and, in most cases, determine the number of water lines threads and the change in the relative values of the estimated water flow in certain areas.

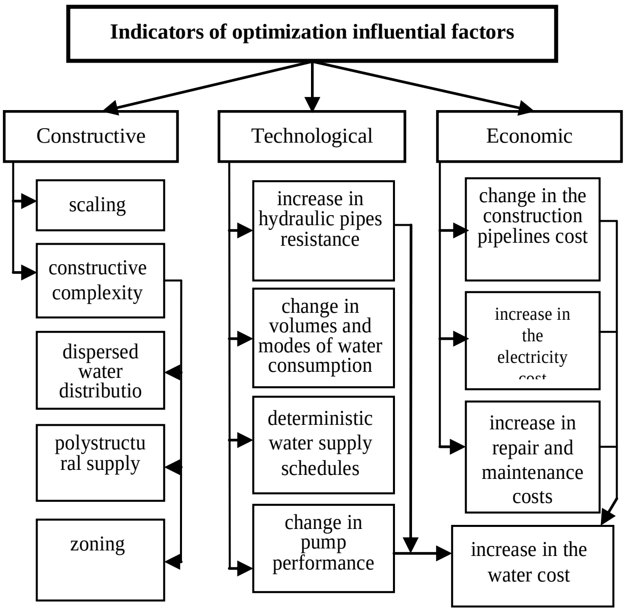

Fig. 1. Influencing factors of water supply networks optimization and structures

Technological indicators are determined, mainly, by the operating conditions of water supply networks and the structures interacting with them. They depend on changes in pipes hydraulic resistance, power parameters of pumping units, water consumption and water supply volumes and modes.

Economic indicators depend on the construction conditions (pipelines construction cost) and the functioning of water supply networks and facilities (primarily the cost of electricity for supplying water) and are determined by appropriate analytical expressions or specific calculated indicators.

Among the regulatory requirements [1] that affect the optimization indicators, it is necessary to note the reliable supply of all the consumers with water of the required quality, in a given amount, with the right pressure and with the least expenses for the construction and operation of water supply networks and structures.

The reliability of water lines and water networks is determined by their design schemes, material and class of pipes adopted in accordance with the conditions of construction and operation of individual sites. In this case, the contact of water with the pipes surface should not degrade its quality [1].

The specified amount of transported water by water lines is determined by the estimated costs, which should be the same when considering alternative water supply schemes and different diameters of water pipes. The values of estimated costs, as well as the parameters of the water supply modes and analysis, are predetermined external factors [3, 4].

The necessary pressure, as a rule, is different for water lines located in different parts of the water supply networks. Their values affect only the class and thickness of the pipe walls, which must be taken into account at appropriate stages of calculations by correcting the internal pipe diameters [1].

The lowest costs for the construction and operation of water supply networks and facilities in accordance with the approach discussed above are determined in conditions that allow obtaining the maximum values of net discounted income [3, 5, 6]. Therefore, the criterion for optimizing the city's water supply network in order to determine the most appropriate option for its improvement when the network parameters are matched to the standard technical constraints and reliability conditions is the discounted amount of the total financial costs for the construction and maintenance of the network and the structures interacting with it, that is, the entire water supply and distribution system [3 6].

$$Bn = \sum_{t=0}^{T} \frac{K_t + Bmain_t}{(1+e)^t} \to \min, \qquad (1)$$

where ***Kt***- the cost of construction works in the t-th year;

B_{maint} - operating costs in the t-th year;

T - term of the project, year;

e - discount factor.

The search for optimal parameters of the network or its scheme is reduced to finding the minimum values of B_n discounted before the start of the project. To do this, we compare several technically equivalent options or find the extremum of the goal function. In the first case, for example, when considering network schemes, numerical values of B_n for various variants are determined. In the second case, all the quantities in the formula (1) are considered as mathematical dependencies, and conducts studies of their general expression (goal function) on the extremum. Based on this method, analytical expressions are determined for finding economically advantageous pipe network diameters, parameters of pumping stations, supplying a water supply network, pumping stations and the like.

To determine the economically advantageous diameters of the pipes of the network and water conduits we need to calculate the formula:

$$d_{ec} = E \cdot k_{qt} \cdot Q_{av.SP.o}^{\frac{\beta+1}{\alpha+m}}, \qquad (2)$$

where ***E*** is a parameter that takes into account the construction cost and pipeline operation (economic factor); for the conditions of Ukraine can be taken equal to: E = 0.8 ... 1.1;

k_{qt} - generalized coefficient of the network section relative load;

Qav.SP.o - average (per year) water supply to the network in the initial period, m3 per second;

α, β, m - the exponents, depending on the pipe material, are given in Table. 1.

Table 1. Values of the coefficients and degrees exponents for pipes of various materials [3-6]

Pipes	*k*	*β*	*m*	*α*
Steel	0,00148	1,93	5,08	1,1/1,15
Iron	0,00163	1,81	4,90	1,6/1,5
Reinforced concrete	0,00169	1,85	4,89	2,05/2,4
Plastic	0,00105	1,774	4,774	1,8/1,5

Notes: **1.** The coefficients ***k*** are taken for ***q***, m^3/s, and ***d***, meters;

2. Above the line are the values of the parameter α for the water lines, and below the line for the water networks.

The generalized coefficient of the section relative loading $\boldsymbol{k_{qt}}$ is determined by the formula

$$k_{qt} = \left(\frac{k_S^{\beta}}{n} \right)^{\frac{1}{\alpha + m}} \cdot k'_{qt}, \quad (3)$$

where $\boldsymbol{k_s}$ - coefficient of site relative loading, which is defined as the ratio of the water flow amount in the area before filing by the pumping station for the settlement case for average water consumption in the initial period;

n - number of pipelines threads in the cross-section of the network on this section;

$\boldsymbol{k'_{qt}}$ – coefficient taking into account changes in influencing factors [5, 6] and is determined by the formula 4 or its analytical counterparts 5 ... 8.

The parameters ***E*** and $\boldsymbol{k_{qt}}$ depend on a number of influencing factors, namely, the cost of electricity, kWh, the rate of profit (the discount factor), the pipe material, the unit cost of laying pipelines, the share of normative deductions from construction costs, the efficiency of pumping aggregates, the change coefficients the relative supply of the pumping station and the network section, the coefficients of the sites role in the energy costs for the water transportation, the project timing.

$$k'_{qt} = \left(\frac{1}{8760 \cdot Set} \cdot \sum_{t=0}^{T} \left(\frac{1 + a_{\sigma} \cdot t}{(1+e)^t} \cdot \sum_{\tau=1}^{8760} \left(\frac{\left(1 + a_t \cdot t^{\gamma}\right)^{\beta+1}}{1 - a_{\eta} \cdot t \cdot \tau} \cdot K_{h.\tau}^{PS} \cdot \left(K_{h.\tau}^{S}\right)^{\beta} \right) \right) \right)^{\frac{1}{\alpha+m}}; \quad (4)$$

$$\boldsymbol{k'_{qt} = k_{q\sigma} \cdot k_{q\eta} \cdot k_{qt} \cdot k_{qK}^2 \cdot k_{qe} \cdot k_{qT} = k''_{qt} \cdot k_{qe} \cdot k_{qT} = k'''_{qt} \cdot k_{qT}}, \quad (5)$$

where $\boldsymbol{k_{q\sigma}}$, $\boldsymbol{k_{q\eta}}$, $\boldsymbol{k_{qt}}$, $\boldsymbol{k_{qK}}$ are the coefficients of changes influence in the electricity cost, the pumps efficiency, the size of water consumption, which are determined by the respective parameters aσ, aη and at,, and the unevenness of water supply, depending on the coefficients for the pumping station $K_{h.\tau}^{PS}$ an d site $K_{h.\tau}^{S}$;

$\boldsymbol{k_{qe}}$ - influence coefficient of the loan rates values, depends on the parameter k''_{qt} and is determined by the formula 7;

$\boldsymbol{k_{qT}}$ - the influence factor of project implementation terms, depends on the parameter k'''_{qt} and is determined by the formula 8;

$\boldsymbol{k''_{qt}}$ - coefficient that takes into account the change in the multiplier $\boldsymbol{k'_{qt}}$ with the value of the credit rate e = 0.16 at T = 25 years;

$\boldsymbol{k'''_{qt}}$ - the same, with the actual value of the loan rate

$$k''_{qt} = k_{q\sigma} \cdot k_{q\eta} \cdot k_{qt} \cdot k_{qK}^2 = \left(1 + 0{,}654 \cdot a_{\sigma}\right) \cdot \left(1 + 4600 \cdot a_{\eta}\right) \cdot \left(1 + 2{,}548 \cdot a_t\right) \cdot$$
$$\cdot \left(0{,}961 + 0{,}034 \cdot K_{h..\max}^{S} + \left(0{,}05 \cdot K_{h.\max}^{S} - 0{,}033 - 0{,}01 \cdot \left(K_{h.\max}^{S}\right)^2 \right) \cdot K_{h.\max}^{PS} \right)^2; \quad (6)$$

$$k_{qe} = 1{,}372 \cdot k''_{qt.i} - 0{,}386 \cdot \left(k''_{qt.i}\right)^2 + \left(5{,}806 - 7{,}945 \cdot k''_{qt.i} + 2{,}21 \cdot \left(k''_{qt.i}\right)^2 \right) \cdot e; \quad (7)$$

$$k_{qT} = 2{,}065 - 1{,}37 \cdot k'''_{qt.i} + 0{,}325 \cdot \left(k'''_{qt.i}\right)^2 - \left(0{,}05 - 0{,}064 \cdot k'''_{qt.i} + 0{,}016 \cdot \left(k'''_{qt.i}\right)^2 \right) \cdot T. \quad (8)$$

The analysis of the changes influence in the main factors on the determination of economically viable water supply pipelines diameter shows that they can be accounted for by direct calculations or by correction factors, which is more suitable for practical application [3-6]. For this purpose, a service program module TEP_dec.xls was created in the Microsoft Excel environment, which allows to quickly and efficiently take into account permanent changes in the main influencing factors, obtain calculated values of economicallyprofitable pipe diameters, and analyze pipeline operating conditions.

Comparison of the calculations results by the numerical method (formula 4) and analytical (formulas 5..8) shows that the latter is quite suitable for practical use. For various values of the influencing parameters, the value of the multiplier determined by the analytical method practically does not exceed the deviations limits of its magnitude in the calculations series of these coefficients by the numerical method and does not exceed ± 2% (Fig. 2).

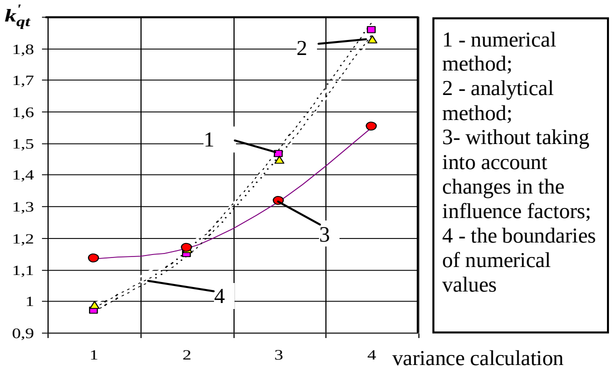

Fig. 2. Comparison of the calculations results by numerical (1) and analytical (2) methods

To calculate the increase coefficients in the pipes hydraulic resistance, the formula was got [3-6]

$$K_S = 1 + a_2 \cdot \left(1 + \frac{0{,}02554}{d_p}\right) \cdot \lg\left(1 + a_1 \cdot t\right), \quad (9)$$

where $\boldsymbol{a_1}$ is a parameter that takes into account the continuity of the pipeline operation in the "main mode", 1 / year;

$\boldsymbol{a_2}$ - coefficient, taking into account the influence of the main factors on the hydraulic resistances growth;

$\boldsymbol{d_p}$ - design value of the pipe inner diameter (equal to the diameter of the new pipes $\boldsymbol{d_p = d}$), meters.

Computer programs (UWM, GRS, PWS others) and program modules in the Microsoft Excel environment (TEP_dec.xls, kfQ.xls, Пог_витр.xl others) have been created for ease of use [3, 4], allowing to automate these calculations.

For the simulation of water consumption in operating water supply networks, an analytical function of the integrated distribution of water flow has been obtained, which establishes an adequate dependence of the water distribution probability P on the coefficients of its unevenness K, taking into account the most characteristic local factors in the modes of water supply and analysis

$$P = \frac{e^{\alpha \cdot (K-a)} + c}{e^{\alpha \cdot (K-a)} + e^{b/K}}, \quad (10)$$

where ***α***, and ***b*** and ***c*** are the parameters that depend on the variance ***σ2*** of the water discharge distribution function, the form of its integral curve, its displacement (asymmetry) are determined by approximating the statistical data (Fig. 3).

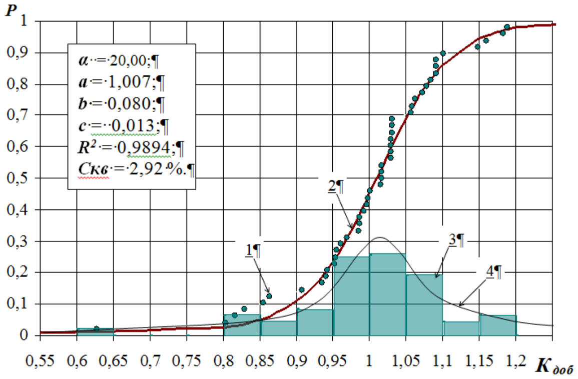

Fig. 3. A characteristic graph of the integral distribution coefficients of the daily water cumulative distribution:
1 - experimental; 2 - analitic distribution function (according to formula 10); 3 - experimental dependence of the distribution density function; 4 - the same, theoretical

The ***α*** value in formula 10 is determined from the statistical data of water consumption, depending on the type and size of the settlement, the composition of water consumers in it, local conditions, and the like.

If the distribution of water flow is approximated to normal, then in formula 10, the values of the exponents are taken equal to: a = 1, b = c = 0, and α - according to the formula 11. In this case, the probability dependence of water distribution on the coefficients of its unevenness is determined only by the parameter α, which, in turn, depends on the value of the variation coefficient Cv and can be calculated by the formula

$$\alpha = \frac{1{,}8}{C_v}. \tag{11}$$

For practical use, the method of water distribution statistical analysis in the range of its security calculated values Po = 0,95..0,999 with the calculation of the maximum coefficients of the water consumption unevenness by the formula

$$K_{\max} = 1 + \frac{1}{\alpha} \cdot \ln\left(\frac{1 - P_o}{P_o}\right), \tag{12}$$

Based on the assessment of the accident rate flows impact and the technical condition of the water supply networks on the reliability of the water supply networks as a whole and their design schemes compliance with the specified levels of water availability, the numerical values of the availability factors and security levels were determined (Table 2).

Table 2. The proposed reduction in the water supply T_{rp}, the availability factors K_r, and the availability levels of P_o

Category of water supply system	Duration of water supply reduction				P_o levels of availability for water consumption	
	to 30 %		on 30..100%			
	$T_{rp(30)}$, day	K_r	$T_{rp(>30)}$, hours	K_r	daily	hour
1	3	0,90	6	0,99	0,01	0,005
2	10	0,75	12	0,98	0,03	0,01
3	15	0,60	24	0,97	0,04	0,015

To account the increase in water costs due to water leaks and unproductive water costs, with an increase in free pressures, analytical dependencies were determined

$$q_{zag} = q_н \cdot k = q_н \cdot \left(\frac{P}{Pn}\right)^{\chi}, \tag{13}$$

where q_n is the total discharge of water at a pressure equal to the normalized $P = P_n$; P - free pressure in the network, m; χ is an exponent that depends on the technical condition of the pipelines, the fittings and the local conditions of the water withdrawal from the grid.

χ determines the nature of the change in costs from the pressure in the network, is in the range χ = 0.5 ... 2.6 and is determined on the basis of field studies. χ at a pressure greater than the normative N is determined by the formula

$$\chi = 0{,}95 \cdot K_m^{0{,}65}, \tag{14}$$

where is the regression coefficient, which depends on the conditions of water distribution, common water sources and its losses in the consumer, and can be determined by the formula

$$K_m = 6{,}36 \cdot \alpha \cdot \gamma + 0{,}26, \tag{15}$$

where ***α*** and ***γ*** are coefficients that take into account the ratio of total sources and total water analysis and losses in buildings (consumers) to the total sources, respectively.

The coefficient K_m is zero for dependencies that do not take into account the increase in water flow rates with the growth of water pressures, and for ***α*** from 0 to 1 are within 0.26 ... 6.62.

The values of the coefficients α and γ are theoretically in the range 0 to 1. Under real operation conditions of water supply networks their values vary: α - from 0,1 to 0,9; γ is from 0.4 to 0.8. To estimate leaks only in residential buildings, the value of γ should be taken equal to 1, and in case of leaks only from external water supply networks γ = 0.

Based on the results of the research, the analysis made it possible to determine the main economic feasibility of water distribution and distribution systems using the most common schemes. In particular, it is established that when justifying the schemes of water lines and water supply networks, it is always advisable to arrange the main part of water pipelines with the minimum permissible diameters, and the most important lines - with increased economically justified minimum length. The most economical option is the one in which the ratio between the diameters of the water lines laid in one direction is more different from single value. This provides a basis for the design of supply systems and distribution of the new type - with the regionalization of water supply networks [3-6]. When determining water supply networks, first of all, regulatory requirements and technical limitations should be taken into account, and optimization calculations take place only if the technical equivalence of possible water supply options is considered with the most complete consideration of the influencing factors and local conditions (network plans, location of water users, relief, etc.).

Such approaches to optimization of existing water supply networks allow maintaining free pressures in each area of the network as close as possible to the necessary ones. As a result, it is possible to minimize overpressures and, as a result, reduce water losses due to leaks, reduce network failures, and reduce energy costs for water rising .

Application expediency of the conducted studies results is confirmed by the analysis data of the existing water supply and distribution systems functioning (more than 50 cities) with changes in their zoning schemes [4..14]. Such water supply and distribution systems are resource-saving, have high levels of reliability and water supply to consumers. The application of the proposed methods in the reconstruction and intensification of the water supply networks operation and facilities allows stabilizing water supply, reducing water consumption and losses, and is confirmed by calculations and real results on existing water supply and distribution systems.

3. Conclusion

1. The majority of water supply networks in the cities of Ukraine are in a state of intensive aging and deterioration, permanent changes in their parameters and require the use of optimization

measures to stabilize water supply, resource conservation and improve the reliability of water supply in cities.

2. To substantiate the feasibility of structural changes in water supply networks and facilities and optimize their parameters a mathematical model of their technical and economic calculations based on minimizing the values of the discounted costs for construction and operation was constructed. It allows you to take into account the changes in the main influencing parameters during the whole period of the project implementation: the discount factors, the electricity cost, the pumping units efficiency and the unevenness of water supply and water consumption.

3. Analytical formulas were proposed for determining economically advantageous pipe diameters, the use of regional water supply and distribution systems is justified, and the boundary conditions for their application to modern cities are determined.

4. On the basis of water distribution statistical analysis, the analytical function of the water costs integrated distribution was determined, which made it possible to establish an adequate probability dependence of water distribution on the coefficients of its nonuniformity, taking into account the most influential local factors.

5. To assess the impact of accident rates and the technical condition of water supply networks and structures on reliability and compliance with their design schemes, numerical values of availability factors, daily and temporary water supply levels, are proposed for specified levels of water consumers. They allow scientifically justify calculated values determination of the coefficients of uneven water consumption in accordance with local conditions, the object and the category of the water supply system.

6. The proposed analytical dependencies allow to take into account the increase in water costs from the values of free pressures due to water leaks and non-productive water consumption.

7. The application of the proposed calculation methods and improvement of water supply networks and structures allows for the design stage to take into account changes in their parameters in the process of operation, peculiarities specific to specific cities, and determine the compliance of their schemes to standard indicators of reliability and security. This creates the right conditions for stabilizing water supply and resource saving while optimizing water supply networks.

8. The proposed approaches to the optimization of water supply networks are implemented on the water pipelines of more than 50 cities. Their use has allowed to stabilize water supply, to reduce water consumption and losses, is confirmed by calculations and real results on operating water supply networks and structures

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