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Optimization of developing district water supply systems taking into account variability of perspective water consumption

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Abstract. The issues of development and reconstruction of district water supply systems are considered and new techniques and methods for optimizing their structure and parameters are proposed, which allow the complex to optimize installation sites and performance of water intake and treatment facilities from surface and underground water sources, methods of transporting water from sources to consumers, including the selection optimal use of road and pipeline transport. The developed methods are based on the construction of redundant design schemes of possible options for the intake, water treatment and transportation of water and the search for the maximum flow of the minimum cost. This takes into account the capacity of existing systems and structures, optimized methods for the reconstruction of existing pipeline systems. Separately, the issues of increasing seismic resistance and the influence of seismic effects on the structure of structures and on the choice of the method of transporting water are considered. The technique and method allowed to substantiate the scheme and logistics of water providing to three districts of the Irkutsk region.

1. Introduction

The Russian Federation has enormous water resources. However, due to their uneven distribution throughout the territory, in many regions there is an acute shortage of water, and where it does exist, its quality does not always meet the requirements of SanPiN 2.1.4.1074-01 and GOST R51232-98. Every year, as a result of technological impacts, the hydrological situation worsens, water sources are polluted with untreated sewage. Due to significant fluctuations in the level of surface and groundwater, due to unsystematic drilling of wells, many water intakes operate on the brink of failure or become bare. One of the ways to solve this problem is the construction and development of district water supply systems (DWS) - systems serving several large facilities located at a considerable distance from each other [1,4]. A sufficiently large number of such systems have already been built in the southern and central zones of Russia. Some of them are complex, capital-intensive water systems designed to transport and supply water over long distances to heterogeneous and dispersed consumers over a wide area. However, at the present stage, due to insufficient funding, many DWS are in emergency condition, the wear and tear of networks and facilities is close to 80%, automation and scheduling does not meet modern requirements. The transition to market mechanisms of functioning and control of the DWS did not solve these problems. Although there were small investments that could be directed to the rehabilitation and development of networks and facilities. This raises the problem of where to invest these limited investments: in the construction of new or reconstruction of existing water supply networks, in the construction of new local water sources or in the expansion of existing ones, in the construction of new centralized water treatment plants (WTP) or in local WTP. There are many new tasks, namely [2, 3, 4]:

- justification of the locations and performance of water intake and treatment facilities, parameters of pumping stations and control tanks;
- justification of the methods and logistics of water transportation to consumers (automobile, pipeline, rail, water)
- selection of the optimal route and diameters of the pipeline system with regard to improving the reliability, controllability and seismic resistance of individual structures and the DWS as a whole;
- optimal allocation of investments in the reconstruction of existing and construction of new group water supply facilities;
- optimal reconstruction of water supply systems in conditions of decreasing water consumption.

As a criterion for choosing the best option are the costs of the life cycle [5,6]. With constant operating costs, life cycle costs can be represented as follows:

$$ЗЖЦ = K + T \cdot Э_З\,, \tag{1}$$

where T is the service life of the water supply system in years, is assumed to be equal to the service life of the most durable of the water supply system elements, K is an investment equal to one-time costs, plus the cost of restoring individual elements of the system whose life expectancy is less than the calculated one (multiple costs), thousand rubles, are determined on the basis of enlarged standards of prices for the construction HSC-81-02-14-2017; $Э_З$ - annual operating costs (thousand rubles/year), calculated on the basis of recommendations on the rationing of labor of workers in the water supply and sanitation sector (Order of the RF State Construction Committee of March 22, 1999, №66).

Based on the above standards, it is not difficult to obtain the dependence of operating costs on the consumption of transported water in a section of 1 km in length:

$$Э_з = 0{,}116 \cdot K + C_{элк} + 1{,}125 \cdot ЗП_{ср} \cdot x^{0,3} + 31536 \cdot C_{н,ст} \cdot x\,. \tag{2}$$

Where $ЗП_{ср}$ - the average salary for the enterprise, $C_{н,ст}$ - water tax. Taking into account the hydraulic characteristics of the pipeline, the dependence of investment on flow and speed (v) of the transported water per 1 km length is obtained:

$$K = (34796{,}4 \cdot x \cdot v^{-1} + 8346{,}6 \cdot x^{0,5} \cdot v^{-0,5} + 2537{,}9) \cdot L\,. \tag{3}$$

Formula (3) is presented for polyethylene pipes, when developing dry soil to a depth of 3 m (which is typical for the Irkutsk region). The cost of electricity is given to the section of the pipeline network with a length of 1 km and is expressed as a function of the flow rate and water velocity:

$$C_{элк} = 108 \cdot Z_{элк} \cdot \left(0{,}000642 \cdot x_i^{0,387} \cdot v_i^{2,387} \cdot L_i \cdot 1000\right) \tag{4}$$

where $Z_{элк}$ - the cost of 1 kW hour.

Taking into account the values of operating costs (2), the life cycle costs (in thousand rubles) can be represented:

$$ЗЖЦ = K + T \cdot \left(0{,}116 \cdot K + C_{элк} + 1{,}125 \cdot ЗП_{ср} \cdot x^{0,3}\right) \tag{5}$$

If we take the partial derivative of the life cycle costs by speed and equate zero, and then solve the resulting equation with respect to speed, then we can obtain in each particular case the optimal values of the water velocity. For example, for the Irkutsk region, v is 2.8 m/s, for the Novosibirsk region - v = 2.07 m/s.

Based on the analysis of prices offered by manufacturers, the following dependencies were obtained:

1. For underground water intakes from artesian wells with a depth of 100 m with a maximum flow rate of 40 m^3/hour, in thousand rubles.

$$ЗЖЦ = 31500 \cdot x_i + T \cdot \left(6300 \cdot x_i + C_{элк} + 15 \cdot ЗП_{ср} \cdot x_i^{0,3}\right) \tag{6}$$

2. For treatment facilities for deferrization and softening (removal of calcium and magnesium salts) from the producers of CJSC “Rosa” - typical water treatment stations based on pressure filters for deferrization and softening (catalytic oxidation and filtration of impurities in the loading layer):

$$ЗЖЦ = 178085 \cdot x_i + T \cdot \left(35617 \cdot x_i + C_{элк} + 15 \cdot ЗП_{ср} \cdot x_i^{0,3}\right). \quad (7)$$

3. Underground water intake with water treatment plants:

$$ЗЖЦ = 209585 \cdot x_i + T \cdot \left(41917 \cdot x_i + C_{элк} + 30 \cdot ЗП_{ср} \cdot x_i^{0,3}\right) \quad (8)$$

4. Pumping stations:

$$ЗЖЦ = 48053 \cdot x_i + T \cdot \left(9610 \cdot x_i + 15 \cdot ЗП_{ср} \cdot x_i^{0,3}\right). \quad (9)$$

5. Water transportation by road:

$$ЗЖЦ = 10800 \cdot \frac{x \cdot (C_м + C_г)}{V_e} \cdot \left(1 + \frac{2 \cdot L}{45}\right) + T \cdot 6307200 \cdot \frac{x \cdot L}{V_e}. \quad (10)$$

where $C_м$ and $C_г$ are the cost of a tank truck and a garage (thousand rubles), V_e is the capacity of one tank truck in m^3.

For all the listed structures and for various methods of their construction and operation, you can obtain the corresponding functions and their linear approximations. Figure 1 shows such functions for pipeline and road transport, from which it follows that up to costs of 0.0015 m^3/s (130 m^3/day), an efficient transport of water delivery is road transport (with a volume of 8m^3 tank), more than that - pipeline. With a tank volume of 20 m^3, the volume transported by road increases to 446 m^3/day. (see figure 1a).

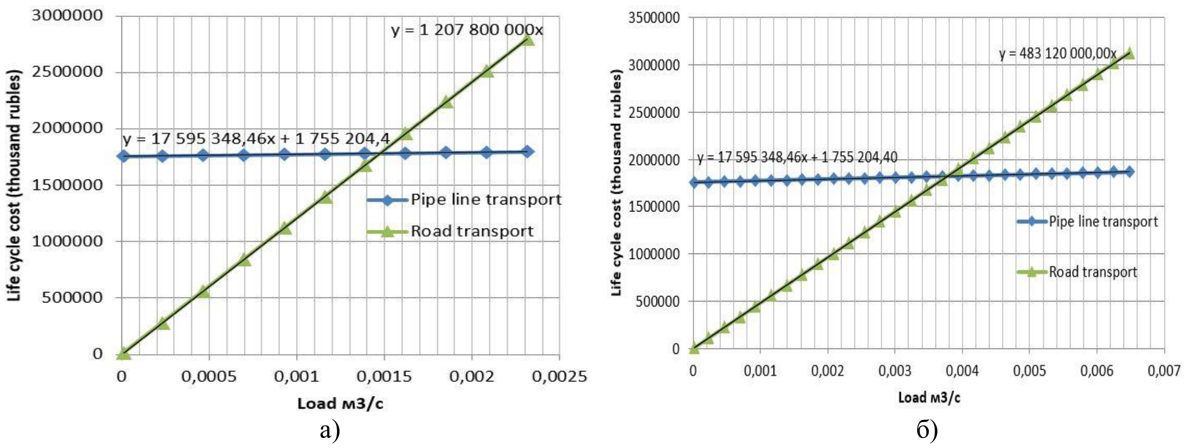

Figure 1. Determination of the optimal boundaries of the road and pipeline water transport.

Design variability is the main tool for finding a rational investment in the development and reconstruction of water supply systems. Designers, taking into account the accumulated experience and their own intuition, have always used this tool. But always, due to lack of time and money, they were limited to considering two, three, and on the strength of five options. Although they may be much more, especially in justifying the structure of the supply of water to settlements located at considerable distances from each other. There may be the following options:

- water intake is carried out from an open source, water is purified to the required indicators to drinking water and is supplied to populated areas by pipeline transport (group water pipelines);
- water intake is carried out from an open source, water is not cleaned and is supplied to settlements by pipeline transport, where it is cleaned only for the purposes of drinking water supply;
- water intake is from an open source, with water quality that meets the requirements for drinking water, and is supplied by the consumer.
- in each settlement, water intakes from open and underground sources are possible, but water may not be suitable for drinking and it needs to be cleaned;
- every possible open and underground water intake may have a limit on the volume of water supplied;
- Various combinations of the listed options are possible.

Such possible options are presented in Figure 2 a, b, c, d.

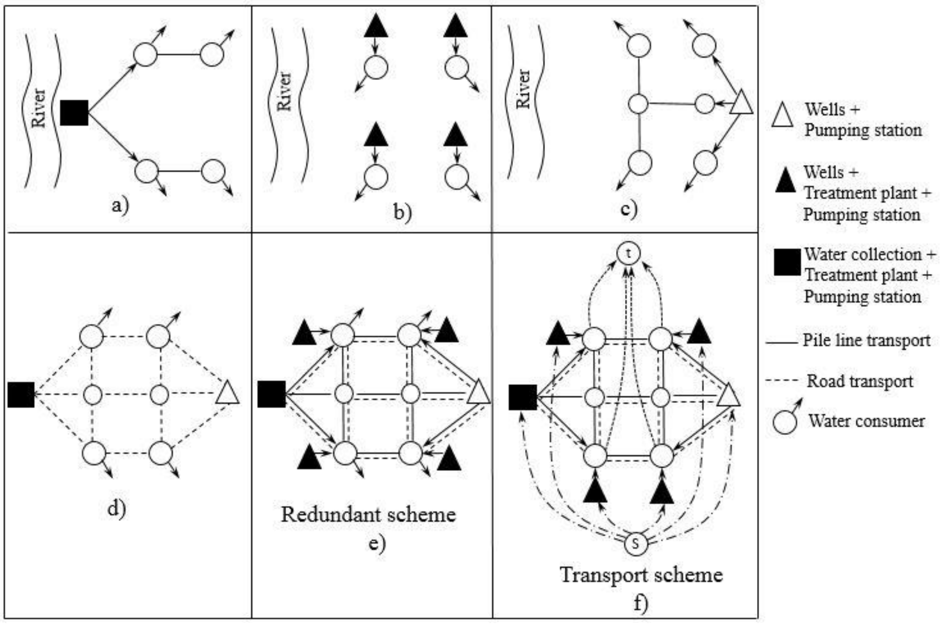

Figure 2. Design options, redundant and transport schemes of district water systems.

Figure 2 presents the graph, which was obtained as a result of the imposition of options 2a, b, c, d. This graph reflects all possible options of the projected district water supply system and is commonly called the "redundant design scheme" [7,8]. This column already contains not four, but several dozens and even hundreds of options.

When constructing redundant schemes, it is possible to avoid deliberately non-optimal solutions in advance and to ensure the ability to generate many acceptable options for the structure and parameters of drainage systems that differ from each other in reduced costs. It is also possible to designate in advance on various existing sections of the network possible ways for their reconstruction (parallel installation, re-laying, installation of a new pipeline, installation of pumping stations, sewage treatment plants, etc.). The task is only to reject non-effective links and nodes in this column. For these purposes, a method [9–12] is proposed, based on the construction of a transport network and the search for a maximum flow of minimum cost (life cycle costs) on it. To build a transport network, all nodes - water consumers are closed using fictitious branches to a common node t - flow output (see Figure 2e), and water source nodes are closed to a common fictitious node entering flows S. For each section of the transport network restrictions on their carrying capacity (upper and lower) are assigned. For fictitious flow entry branches, the upper limits correspond to the maximum possible water withdrawals from water sources, and for fictitious flow exit branches, the upper limits correspond to the water needs of settlements or subscribers. Restrictions on the flows of the projected pipeline sections of the network and on the routes by road are not assigned. For existing sections of the network, the upper limit on flows is determined on the basis of the optimal values of the water velocity:

$$\overline{\overline{в}} = V_{onm} \cdot \frac{\pi \cdot d^2}{4} \tag{11}$$

The optimal speeds are presented in table 1. For each network segment, the cost of the flow unit is determined and assigned. For the fictitious branches, the input flow is cost of collecting and water treatment one m^3 of water, for real new pipeline sections of the network this is the cost of building and transporting one m^3 of water per 1 km of pipeline, for road transport this is the cost of transporting m^3 of water per 1 km of road length. For the fictitious sections of the output stream, the cost is not assigned, or are taken as the cost of the further transportation of one m^3 of water to specific subscribers. For existing parts of the network, the flow unit costs correspond to the operational costs. Taking into account the transport network constructed in this way, the problem of finding the maximum flow of the minimum cost is solved. As a result, the optimal locations and performance of water intakes and sewage treatment plants, the type of water transport (pipeline, road), the route of the pipeline system and its parameters are determined. In this case, the options are fully centralized or decentralized water supply system.

Taking into account the obtained dependencies (1) - (11), we can formulate a mathematical problem of optimizing the structure and parameters of district water supply systems as the task of minimizing linear cost functions on a set of allowable values of the costs of the water transported:

$$\sum_{i=1}^{n} C_i \cdot x_i \to min \text{, where } \underline{\underline{в}}_i \le x_i \le \overline{\overline{в}}_i, \quad A \cdot x = q'_{cp} \qquad (12)$$

where x_i is the desired flow on the branch of the redundant or transport network; $\underline{\underline{в}}_i$, $\overline{\overline{в}}_i$ - lower and upper limits on the flow x_i; A - matrix of connections of nodes and network branches; q'_{cp} - vector of estimated water consumption of human settlements, m^3/s.

If the value of the allocated investment in the construction of new and reconstruction of existing networks and structures is known, the following restriction is introduced:

$$\sum_{i=1}^{n} C_i \cdot x_i \le \overline{C} \qquad (13)$$

$\overline{C}$ - allocated investments in the construction and reconstruction of the water supply system. When solving problem (11) - (12), an algorithm for finding the maximum flow of minimum cost is used. The method begins with the selection of the shortest route from S to t, which corresponds to the minimum value of the sum of the specific stream cost values, multiplied by the length of the branch. The magnitude of the flow is then increased by systematically searching all possible routes from *S* to *t*. As soon as one of such chains is found, the flow along it increases to the maximum value. The algorithm finishes the work and gives the maximum flow, if no chain can be found that increases the flow. Moreover, the graph splits into two disconnected subgraphs. As a result, the allocated investment is optimally distributed to the construction of new and reconstruction of existing water supply facilities, the remaining fictitious branches will indicate the optimal water sources, and the remaining parts of the redundant scheme will indicate the optimal route and type of water transport.

As a result of the optimization, the route and parameters of the new network sections, options for the reconstruction of existing collectors (by the open method, channelless re-routing, laying of a parallel pipeline, etc.), the productivity of the treatment plant are determined. Figure 3 presents such options.

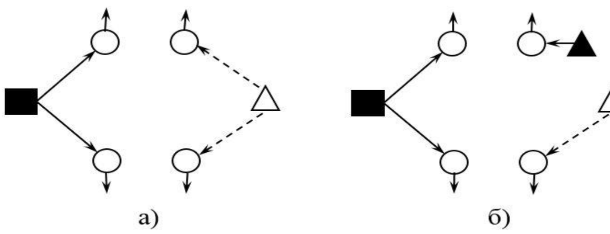

Figure 3. Optimal solutions

For seismically hazardous areas, the reliability of district water supply systems should be given special attention. Since during strong earthquakes, underground communications are first of all destroyed. The territory of the city is filled with sewage, hot water, water mains are destroyed and it is impossible to extinguish fires. It is for this reason that many large earthquakes in Japan, in Central Asia, had disastrous consequences. It is known from the theory of earthquake-resistant construction that pipelines located parallel to the seismic impact are most susceptible to destruction. The more deeply the pipeline is, the more clamped it is and is subject to seismic effects. The greater the seismic impact, the greater the failure rate. The most susceptible pipelines are made of cast iron, the most seismic resistant ones are made of polyethylene. In [13, 14], the dependences of the increase in the failure rate depending on the orientation of the seismic impact and the score on the MSK -64 scale were obtained based on statistical material. Given the arbitrary angle of inclination $0^0 \le \alpha \le 90^0$ of the seismic impact with respect to the location of segment *i*, you can get the following dependency:

$$K^{\alpha} = 0{,}08418 \cdot \sin(74{,}709 + \alpha) \cdot Б^{2{,}6} \tag{14}$$

It should be noted that when the scaling is less than 4 seismic effects on the pipelines do not appear. This factor increases the failure rate of pipeline sections of the network. For example, for the network sections located parallel to the seismic impact (near 9, which is typical for the Irkutsk region), the failure rate increases by 24.6 times, and for the sections located perpendicular to the seismic impact - by 6.7 times. The failure rate (the number of failures per year per 1 km length) is determined on the basis of statistical data using the formula $\lambda = a / D^b$ [15], where, depending on the pipe material and pipeline laying conditions, a = 0.307 - 0.229, and b = 0.6-1, D is the diameter of the pipeline in m. Therefore, the number of accidents on the pipeline for 1 year will be: $\lambda * L * K^a$, and the cost of eliminating emergency situations will be: $З^{ав} = \lambda * L * K^a * З^1$, where $З^1$ is the cost of eliminating 1 accidents, which according to water utilities vary from 50-150 thousand rubles depending on pipe diameters. Thus, depending on its orientation, each section will have different specific (per unit of flow and length) life cycle costs.

$$ЗЖЦ = K + T \cdot \left(0{,}116 \cdot K + C_{элк} + 1{,}125 \cdot ЗП_{ср} \cdot x^{0{,}3} + K^{\alpha} \cdot (-10{,}174 \cdot x^{1{,}5} + 36{,}36 \cdot x^{0{,}5} + 5{,}49 \cdot x^{-0{,}5}) \cdot L\right)$$

Figure 4 shows the dependences of life cycle costs on the magnitude of earthquakes and the flow rate of transported water. The figure shows that the use of road transport in areas with high seismicity will be more effective even with a tank capacity of 8m^3.

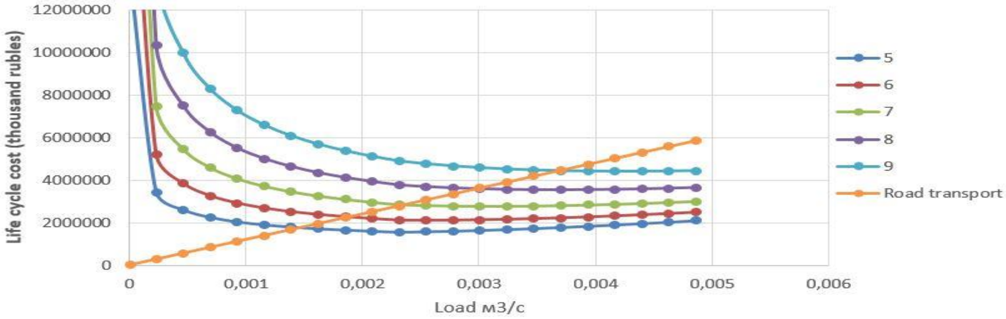

Figure 4. Dependence of the life cycle costs on the earthquake intensity of the territory.

The seismic effects can be taken into account when drawing up redundant design schemes due to the orientation of the pipeline sections of the network. As for road transport, we can assume that the seismic effects on it do not affect. As an example, we will consider the problem of justifying the structure and parameters of a district water supply system consisting of one water source and 11 settlements located at a distance of 30 km from each other. Figure 5a shows a redundant scheme of options for transporting water to consumers (solid lines - pipelines, dashed lines - automobile). If you do not take into account the seismic effects factor, then the option presented in figure 5b will be optimal, for which 6 sections will be pipeline transportation and 5 sections will be road transport. But if seismic effects are taken into account with the direction indicated in figure 5a, then the option presented in figure 5c, which differs significantly from figure 5b, and already has 2 pipeline sections and 9 road transport, will be optimal.

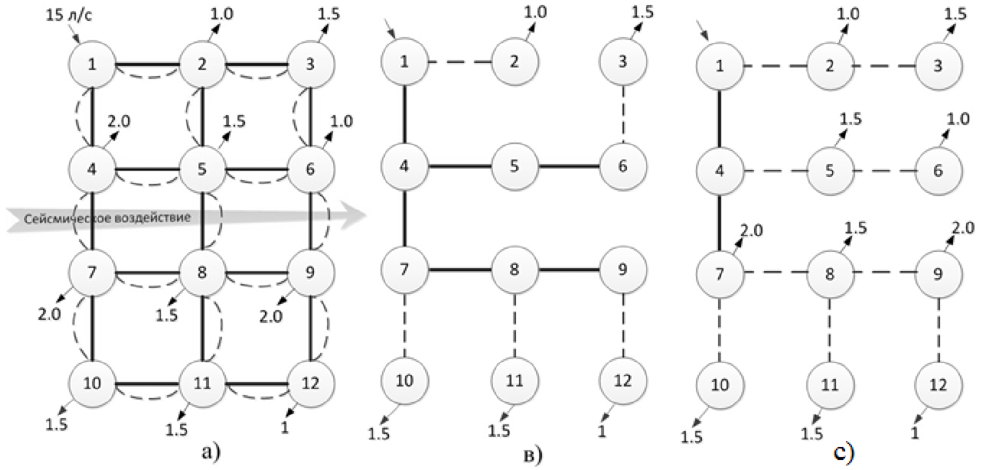

Figure 5. Accounting for seismic loads in the optimization problems of district water systems.

For many years, unshakable, the indicators of specific water consumption in the cities of the Russian Federation have declined significantly over the past ten years. For example, for the city of Irkutsk in 2000, the specific water consumption was 300 l/person per day, now 194 l/person per day. At the same time, in the joint venture 31.13330.2012, the following values are still recommended: 220-280 l/person per day and there are no proposals as to which of the expenses to be taken when designing water supply systems for the future. There is a problem of forecasting and forming specific water consumption values that could be used to justify promising schemes for water supply systems. Traditionally, the apparatus of the theory of probability and mathematical statistics was used for these purposes. However, when justifying the development parameters of water supply and wastewater systems for a period of 15-30 years, perspective information is not always sufficient to establish the adequacy of the probabilistic model chosen to describe the situation.

New and effective, in this regard, are models and methods based on the use of fuzzy sets and interval mathematics. Their essence lies in the fact that the characteristic function (membership function) can take any value in the interval (0; 1), and not just the values 0 or 1. Initial membership functions, as a rule, are formed by experts and specialists. Using models of fuzzy sets, the representation of the specific water consumption rate for household needs of the population in the form of even 220 ÷ 280 l/person per day recommended by the joint venture 31.13330.2012 can be expressed by a fuzzy set using the membership function μa (x): X → [0.1] in the form of linearly triangular, trapezoidal and rectangular shapes (see Figure 6).

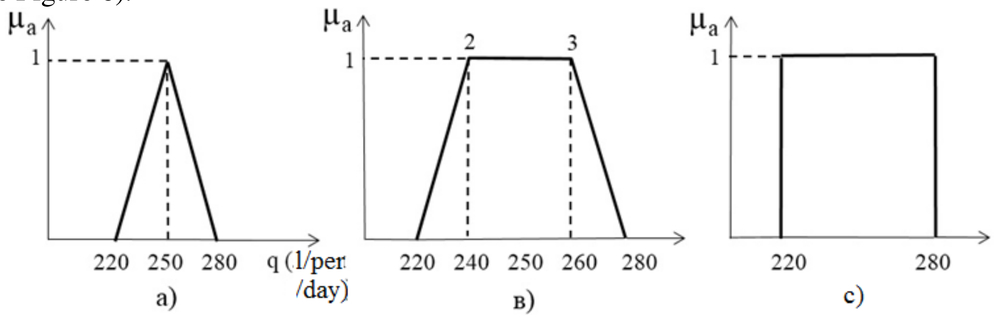

Figure 6. Fuzzy representation of perspective water consumption a) triangular; b) trapezoidal; c) interval (rectangular) shape

For each of the forms, fuzzy sets can be written as follows:

$$q^{a} = \{220|\,0;\ 250|\,1;\ 280|\,0\};$$
$$q^{b} = \{220|\,0;\ 240|\,1;\ 260|\,1;\ 280|\,0\}; \quad (15)$$
$$q^{c} = \{219{,}9|\,0;\ 220|\,1;\ 280|\,1;\ 280{,}19|\,0\},$$

q^a , q^b, q^c - possible values of specific water consumption and their membership function in the representation of fuzzy sets. According to (14), water consumption up to a value of 220 l/person per day inclusive has a degree of ownership of 0, as well as expenses greater than 280 l/person per day. For expenses from 220 to 250, the degree of belonging increases from 0 to 1, and for expenses in the range from 250 to 280 decreases from 1 to 0. Obviously, each form of representation of an odd set will have its own time interval. For example, experts determined the specific water consumption interval for the future in the amount of 220–280 l/person per day, based on the fact that in the current year the actual specific water consumption mattered was close to 250 l/person per day. There is no certainty that in subsequent periods it will increase or decrease. Therefore, the membership function can be viewed as triangular (Figure 6a). If there is confidence that the prospective specific water consumption will be in the range of 240-260 l/person per day from a possible 220-280 l/person per day, the membership function can be viewed as a trapezium (Figure 6b). If there is confidence that the prospective specific water consumption will be in the range of 220-280 l/person per day from a possible 220-280 l/person per day, the membership function can be viewed as a rectangle (Figure 6c). Obviously, each form of representation of a fuzzy set of specific water consumption will correspond to a certain temporary stage in the development of a water supply and wastewater system. For example, if a prospective scheme is considered for a period of 15 years in three construction stages, then to justify the parameters of the first stage, the preferred form of a fuzzy set will be triangular, the second is trapezoidal, and the third is rectangular.

Assuming that due to ongoing energy and resource saving measures, specific water consumption will decrease and reach a rational (minimum) value, for example 150 l/person per day, fuzzy sets for three time intervals can be represented as the following sequence of triangular forms (Figure 7).

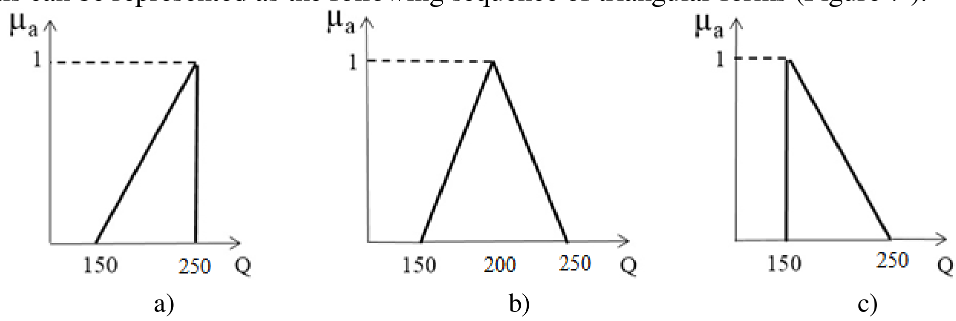

Figure 7. Fuzzy representation of the specific water consumption in terms of its reduction

2. Results and discussion

When evaluating and comparing options for the development of networks and facilities, the values of the membership function can be considered as follows. Formed many specific values of water consumption. For example, the interval of specific values of 220-280 l/person per day is divided in equal parts 220, 230, ..., 280 l/person per day and for each fixed value of specific water consumption a degree of belonging from 0 to 1 is assigned. Further, for each fixed value specific water consumption solves the problem of justifying the parameters of new and reconstructed network sections and determines the cost of this option. As a result, we obtain a set of values of the cost options with the corresponding membership function. The function of ownership in this case can be interpreted as trust, or distrust of the value values of the analyzed options. Distrust can be expressed in the form of the appreciation factor, which can be defined as follows:

$$k_y = 1+(1- \mu_a(x)). \quad (16)$$

Obviously, for the rectangular shape of the membership function (Figure 6c) for all options for the development and reconstruction of water supply systems, the rise in price ratio will be 1. From the set of options considered considering the membership function, it is necessary to choose the preferred one.

The choice of this option is proposed based on an assessment of possible risks. By risk we mean additional costs in the reconstruction of the water supply system if the designated specific water consumption turns out to be less than the actual at the time the project is implemented, and unnecessary costs (immobilization of investments) if the selected specific water consumption value is greater than it turns out to be in reality. The option with the least risks will be preferable.

Example. We will make a substantiation of the parameters of the water pipeline with a length of 1 km from polyethylene pipes through which water is supplied to the area of prospective development per 100 thousand people. In the current year, the actual specific water consumption in the city was 250 l/person per day. For the calculated values of specific wastewater take it in the range of 220 - 280 l/person per day. Therefore, for this example, the pipeline's estimated flow interval will be as follows: 0.173 - 0.324 m^3/s. Given the values of actual water consumption, the membership function has a triangular shape (Fig. 6a). To construct this function, the possible load range is divided into the following values: Q = (0.173 | 0.01; 0.211 | 0.5; 0.249 | 1.0; 0.287 | 0.5; 0.324 | 0.01). For each flow rate, we determine the collector diameters, the membership function values and the life cycle costs, at a speed of 2.8 m/s). The results of the calculations are presented in the table. one.

Table 1. Evaluation of options for laying the discharge pipe

№	**Flow load, $м^3$/с**	**Diameter, мм**	**Recuced costs,million rub. per year**	**Membership functions μ (x)**	**$К_у$**	**Recuced costs talk into account $К_у$, million rub. per year**	**Option of preference**
1	0,173	315	1.05	0,01	1,99	2,10	4
2	0,211	400	1.26	0,50	1,50	1,89	2
3	0,249	500	1.53	1,00	1,00	1,53	1
4	0,287	600	2.52	0,50	1,50	2,30	3
5	0,324	630	2.70	0,01	1,99	5,37	5

The preferred option is with a design flow rate of 0.249 m^3/s. However, before making a final decision, it is required to assess the risks. To do this, using the decision-making methodology and build a "risk matrix", which for the example under consideration is presented in Table 2. In this matrix, the values of the calculated costs under study are presented in the first row and first column. Zero values of additional costs are located on the diagonal, which means that the accepted value of expenses coincides with those that will be after the project implementation (100% match option). The values to the right of the diagonal indicate the risk values from the fact that the actual value of the costs after the project will be greater than their values assigned in the project. For example, a flow rate of 0.173 m^3/s was chosen and a collector d315 mm was designed, and at the time of completion of construction, the flow rate was 0.211 m^3/s, i.e. 0,027 m^3/s more. Consequently, it will be necessary to re-position the pipeline by d400 mm, or to expand or parallelly lay a new section, for example, d200 mm with a reduced value of 0.98 million rubles. per year (see table 2). If the flow rate is 0.324 m3 / s, the risk will already be 2.42 million rubles. in year. To the left of the diagonal in the matrix there will be risk values associated with overstatement of parameters and, therefore, with excessive investments. For example, a flow rate of 0.211 m^3/s was chosen, and after the project implementation, it turned out to be 0.173 m^3/s. For a flow of 0.211 m^3/s, the estimated diameter of the pipeline is d400 mm, and the cost is 1.26 million rubles. in year. For a flow rate of 0.173 m^3/s, the calculated diameter is equal to 315 mm, and its costs are 1.05 million rubles. in year. Therefore, the risk value is calculated as 1.26 - 1.05 = 0.11 million rubles. The last column of the "risk matrix" presents the maximum risks for each option for making the estimated expense. The last element of this column corresponds to the minimum value of the maximum risks (Savage criterion). Therefore, from the point of view of minimum risks, the option with a flow rate of 0.324 m^3/s will be preferable. Although this option is the most expensive at the stage of evaluation options (see table. 1).

Table 2. "Risk Matrix"

Load, м^3/c	0,173	0,211	0,249	0,287	0,324	Max, million rub. per year
0,173	0	0.98	1.43	1,95	2.42	2,42
0,211	0.11	0	0.85	1.46	2.21	2.21
0,249	0,48	0,27	0	1.14	2.03	2.03
0,287	1.47	1,26	0.99	0	1,87	1.87
0,324	1.65	1,44	1,17	0,18	0	1.65
Min						1,65

The developed approaches and methods are implemented in the Trace-BK software package as a subprogram for optimizing district water supply systems. On the basis of this program complex, promising schemes of water supply and wastewater systems in many cities and towns of the Irkutsk Region have been developed, including: Zalarinsky, Kuytunsky, Cheremkhovsky group water mains.

3. Conclusions

New dependencies of life cycle costs on the consumption of transported water by various types of transport were obtained. These dependences and their research allowed to substantiate the method of optimizing the search for the maximum flow of the minimum cost on a previously constructed redundant design decision scheme. It is proved that the determining factor in choosing the method of transporting water are the volumes of water transported. For the first time, methods for optimizing district water supply systems according to the criterion of life cycle costs were proposed and developed, taking into account the uncertainty of water consumption, the variety of methods for transporting water, and the reliability and seismic resistance of structures. This approach, in contrast to the traditional technology of designing water supply systems, significantly increases the validity and effectiveness of decisions made.

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