Schematic and structural optimization of group water supply systems

Chupin V. R.[1], Dushin A. S.[2]
[1]irkutsky national Research Technical University, 664074, Irkutsk, Lermontov str., 83
[2]community with limited liability "Network company "IRKUT", 664020, Irkutsk, aircraft Manufacturers str., 28 A

Annotation. Group water supply systems (GWSS) are designed for centralized water supply of settlements located in waterless areas and remote from drinking water sources. GWSS are an object of increased attention, have a great social and environmental significance, require significant capital investments and financial resources for operation, ensuring the required reliability and manageability. Therefore, the issues of optimization of design solutions for the structure and parameters of structures are relevant and require improvement and development of methodological and software solutions to these problems. The paper proposes a method of redundant design schemes and a method of schematic and structural optimization based on a sequential and iterative solution of two problems: for a fixed value of flows in the graph of the redundant scheme, network parameters are optimized (pipeline diameters, heads, and the composition of pumping stations); with fixed network parameters, the problem of the distribution of water flows is solved in the GWSS.

1. Introduction

Group water supply systems (GWSS) are designed for centralized water supply of settlements located in waterless areas and remote from drinking water sources. GWSS are an object of increased attention, have a great social and environmental significance, require significant capital investments and financial resources for operation, ensuring the required reliability and manageability. Therefore, the issues of optimization of design solutions for the structure and parameters of structures are relevant and require improvement and development of methodological and software solutions to these problems. The analysis of existing GWSS indicates that many systems today do not meet the requirements of efficiency, reliability and manageability. The main reasons are insufficiently justified decisions at the design level on the choice of structure of structures, pipeline routes, and their parameters. Increasing reliability by backing up and ringing networks requires additional investment. It is proved that taking into account reliability in the form of parallel laying of pipelines, installation of emergency water storage tanks on the network and in localities leads to an optimal solution of the network structure in the form of a tree for new networks, and in the presence of existing pipelines-in the form of a dominant graph with ringed sections of the network [1-16]. The creation of an extensive network with the strengthening of the graph tree trunk makes it possible to increase the speed of water movement in pipes, reduce the formation of stagnant zones, preserve water quality, and reduce the immediate threat of bacterial and chemical contamination. In addition to improving water quality, capital costs for the construction of reserve sites are reduced, the probability of accidents is reduced, and so on.

At the same time, we need to develop a method that allows us to optimize the structure of this tree and the ring sections of the network.

2. Methods

Many approaches and methods have been developed to find the optimal network structure in the form of a tree [12-18]. However, all of them are reduced to a purposeful and limited search of variants of trees of the redundant design scheme and do not view the ring graphs of the network. Traditionally, in project practice, this task is solved as follows [17-25]:
- several variants of routes are planned;
- for each option, the parameters of the pipeline, pumping stations and control structures are determined;
- each option is evaluated for reliability, manageability and economic costs of its implementation. The best one is selected. Almost no optimization of design solutions is performed.

At the same time, the task of optimizing the structure and parameters of the GWSS is to find such a pipeline route, places where water intakes, reservoirs, and pumping stations are installed that would correspond to the minimum of the total reduced costs.

From a mathematical point of view, this problem has a multi-extreme character, is difficult to formalize and implement [13]. In most cases, the available approaches and methods for solving this problem are reduced to a step-by-step and iterative procedure for optimizing the route and parameters of transport structures.

This paper proposes to solve this problem in a single iterative process based on the methodology of coordinate minimization. One coordinate is the vector of distribution of expenses in the network, the other is the vector of losses of pressure in pipelines and pump stations, which determines the composition of transportation structures. This is done algorithmically as follows:
- assigned all sorts of connections between the possible sources of consumers (in the General case this can be a complete graph).

- on this graph, the initial flow distribution is assigned (for example, using the proportional flow division method);
- for fixed flow distribution, the optimal diameters and parameters of transport structures are determined and the cost of the option is determined.
- with known diameters and parameters of water pumping stations, the problem of flow distribution in the network is solved (for example, by the method of nodal pressures [1]);
- next, the diameters and parameters of the pumping stations are selected again for the newly obtained water flow values;
- such procedures are performed for new networks until the water flow rate and, accordingly, the pipeline diameters are close to zero in some parts of the network. The number of such sections will be: n-m+1, where n is the number of sections of the redundant scheme, m is the number of nodes.
- as a result, we get a variant of the network in the form of trees. This tree (or network route) will be the solution to the problem. If there are already built sections and structures in the network, then the computing process will end on some solution that will correspond to the graph with the ring sections of the network.
For simplicity and clarity of the proposed approach, we accept the speed of water movement in pipelines equal to 1 m / s. Although this parameter also requires optimization and depends on the cost of electricity in the design area (for example, for the Irkutsk region, the optimal value of water speed in pipelines is 2.7 m / s). With this in mind, the diameter (d) of the pipelines is determined by the following formula:

$$d=(1/30)\sqrt{Q}$$

(1)
where Q is the water flow rate on the pipeline section of the network.

The costs shown $З_i$, taking into account (1) calculated using the following formula:

$$З_i=\sum_{i=1}^{n} K_{уд}(D_i)*L_i*E+\frac{\gamma*365*24*m}{102*\eta}*Q_i*H_i$$

(2)
where γ - specific weight (for water =1), number of hours per year 365*24, Hi-head of pumping stations, mV.
Q_j - consumption in the node l / s, m-unit electricity costs = 1.067 rubles/KWh (for Irkutsk), η - pump efficiency 0,7
E= the coefficient of comparative efficiency of capital investments is the inverse of the payback period, which is recommended to be determined on the basis of forecast tariffs for utilities; $K_{уд}(D_i)$ - specific capital investments, RUB/m, L_i - the length of channel, m.
On the basis of (2) level of each iteration, the optimal scheme structure and its parameters are evaluated
The computational process ends if there is no decrease in the value of the reduced costs during the transition to subsequent iterations.
Thus, the option in which the value of the reduced costs will have the smallest size and will be optimal.

3. Results and discussions

Let's illustrate this approach using the example of a redundant network shown in figure 1, containing 12 nodes and 17 network sections. The source information for network of nodes is shown in table 1, and the source information for network of sections is shown in table 2

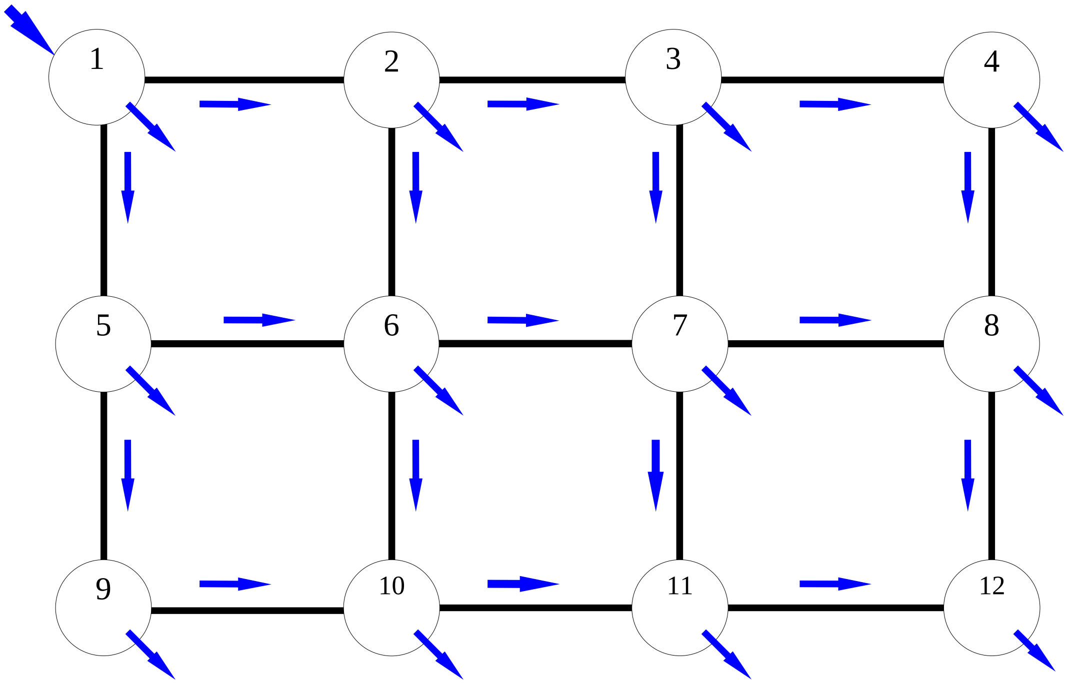

Figure 1. Redundant (ring) scheme of the group water supply system

Table 1. Source information for nodes

node number	mark in node, m	selection in node Q, l / s	node number	mark in node, m	selection in node Q, l / s
1	400	30	7	400	30
2	400	30	8	400	30
3	400	30	9	400	30
4	400	30	10	400	30
5	400	30	11	400	30
6	400	30	12	400	30
in total		**180**			**180**

Table 2. Source information for sites

node number		the length of the DL, m	tube material	node number		the length of the DL, m	tube material
the beginning of the segment	the end of the segment			the beginning of the segment	the end of the segment		
1	2	1000	new	7	8	1000	new
2	3	1000	new	5	9	1000	new
3	4	1000	new	6	10	1000	new
1	5	1000	new	7	11	1000	new
2	6	1000	new	8	12	1000	new
3	7	1000	new	9	10	1000	new
4	8	1000	new	10	11	1000	new
5	6	1000	new	11	12	1000	new
6	7	1000	new				

The results of iterative calculations to determine the optimal parameters of the group water supply system are summarized in tables 3.1, 3.2, and 3.3.

Table 3.1. The result of the iterative calculation of diameterм

node number	the number of the iteration

the beginning of the segment	the end of the segment	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	2	500	472	472	477	484	491	499	507	515	523	531	539	545	547	548	548
2	3	400	370	370	378	386	395	404	411	415	416	414	413	411	409	409	408
3	4	250	260	260	268	278	289	300	308	314	317	316	316	316	316	316	316
1	5	400	379	379	373	364	355	344	332	319	306	291	276	265	259	258	258
2	6	250	229	229	228	227	227	228	233	243	259	277	295	307	314	316	316
3	7	200	191	191	193	196	198	200	201	201	199	196	192	188	185	183	183
4	8	200	185	185	197	210	224	237	248	256	259	258	258	258	258	258	258
5	6	250	219	219	210	199	186	171	155	137	116	91	63	35	14	3	**0**
6	7	200	176	176	159	138	112	83	53	28	12	3	0	0	0	0	**0**
7	8	150	128	128	114	95	73	49	27	12	3	0	0	0	0	0	**0**
5	9	250	250	250	248	245	241	236	230	223	216	207	197	188	183	183	183
6	10	200	191	191	194	197	200	203	205	209	217	228	240	250	256	258	258
7	11	150	132	132	128	122	115	106	96	87	79	71	60	46	30	16	**0**
8	12	150	131	131	135	141	149	159	171	180	183	183	183	183	183	183	183
9	10	200	170	170	167	163	157	149	139	128	115	98	75	46	16	5	**0**
10	11	200	179	179	179	179	177	173	168	164	164	168	172	177	180	182	183
11	12	150	127	127	123	116	105	89	65	32	14	6	0	0	0	0	**0**

Table 3.2. Result of iterative calculations on expenses, l / s

node number		the number of the iteration															
the beginning of the segment	the end of the segment	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	2	197	201	205	210	217	224	231	238	246	254	261	267	270	270	270	270
2	3	120	123	128	134	141	147	152	155	156	155	153	152	151	150	150	150
3	4	53	61	65	70	75	81	86	89	90	90	90	90	90	90	90	90
1	5	133	129	125	120	113	106	99	92	84	76	69	63	60	60	60	60
2	6	47	47	47	46	46	47	49	53	60	69	78	85	89	90	90	90
3	7	38	33	34	34	35	36	37	36	36	34	33	32	31	30	30	30
4	8	23	31	35	40	45	51	56	59	60	60	60	60	60	60	60	60
5	6	47	43	40	36	31	26	22	17	12	7	4	1	0	0	0	**0**
6	7	38	28	23	17	11	6	3	1	0	0	0	0	0	0	0	**0**
7	8	23	15	12	8	5	2	1	0	0	0	0	0	0	0	0	**0**
5	9	56	56	55	54	52	50	47	45	42	39	35	32	30	30	30	30
6	10	26	33	34	35	36	37	38	39	42	47	52	56	59	60	60	60
7	11	23	16	15	13	12	10	8	7	6	5	3	2	1	0	0	**0**
8	12	15	15	16	18	20	23	26	29	30	30	30	30	30	30	30	30
9	10	26	26	25	24	22	20	17	15	12	9	5	2	0	0	0	**0**
10	11	23	29	29	29	28	27	25	24	24	25	27	28	29	30	30	30
11	12	15	15	14	12	10	7	4	1	0	0	0	0	0	0	0	**0**

Table 3.3. Result of iterative calculations based on reduced costs

the number of the iteration	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Amount of reduced costs, RUB.	58 115,08	57 817,68	55 690,35	55 554,14	55 290,46	54 697,32	53 588,77	52 042,02	50 361,29	49 261,08	48 377,92	47 007,39	45 646,41	44 346,30	43 611,20	43 257,75

The diagram of the group water supply system corresponding to the most optimal structure is shown in figure 2.

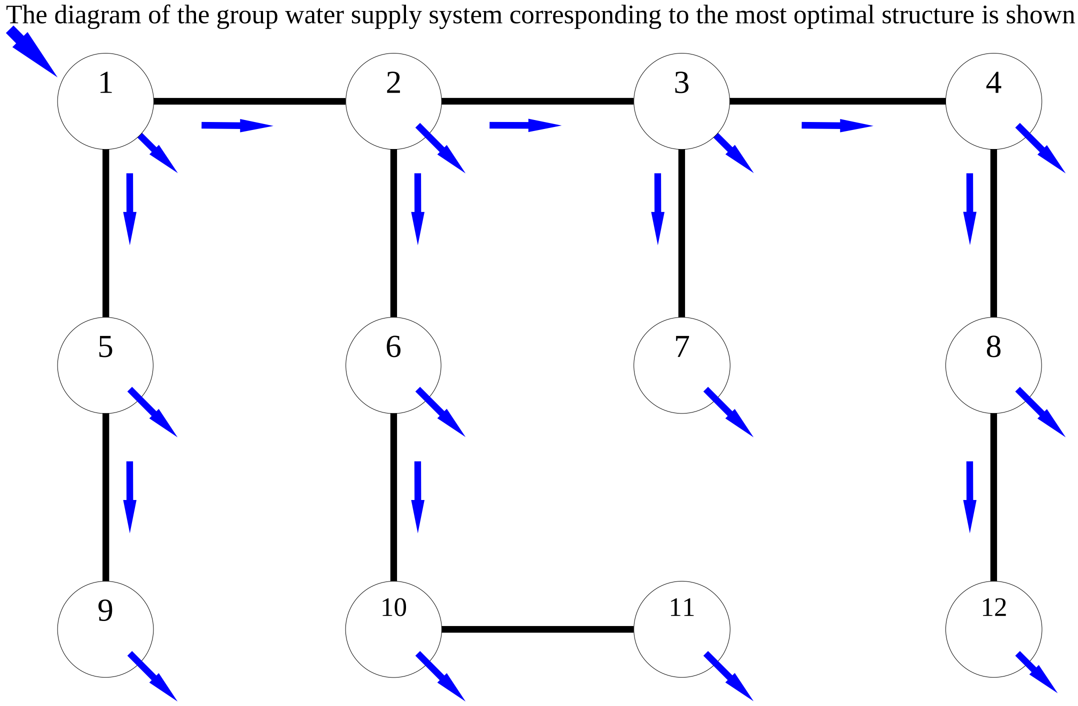

Figure 2. Optimal (branched) scheme of the group water supply system

Figure 2, as a result of the above example, shows that the redundant (ring) circuit has become a branched network as a result of optimization. Part of branches (5-6, 6-7, 7-8, 7-11, 9-10, 11-12) it will be rejected, and the remaining cost values will correspond to the optimal distribution of flows in the network.

Conclusions

A new method of optimization of GWSS based on the reduced costs of their construction and operation is proposed. This method is an effective tool for justifying the structure of the network and structures of water supply systems and can be useful for decision-makers to optimize the structure and development of a promising water supply scheme for urban area

Bibliographic list

1. Merenkov A. P., Khasilev V. Ya. Theory of hydraulic circuits. – M: Nauka, 1981 - 320.
2. Chupin R. V., Melekhov E. S. Development of the theory and practice of modeling and optimization of water supply and sanitation systems. - Irkutsk: Irstu publishing House, 2011.-323 s.
3. Methodology for assessing the capacity of existing water supply networks and developing measures to intensify the Methodology for assessing the capacity of existing water supply networks and developing measures to intensify their work using computers. - M., AKH im. K. D. Pamfilova, 1972.
4. Mints D. M. on technical and economic calculation of water supply networks. Moscow: Scientific works of AKH. 1951. Vol.1. Pp. 48-52.
5. Moshnin L. F. Choice of diameters of water supply lines / / water Supply and sanitation. technic. - 1940. - No. 2/3. - Pp. 48-55.
6. Moshnin L. F. Improving the efficiency of water supply and distribution systems. //Water supply and sanitary equipment.- 1995, no. 11, P. 23-26.

7. Nechaev A. P., Moshnin L. F. Optimization of water supply and distribution systems. //Water supply and sanitary equipment.- 1998, no. 8, Pp. 12-14.
8. Sirotin V. P. Economic calculation of water pipes/ / Construction industry. 1951. No. 5. Pp. 8-12.
9. SNiP 2.04.02-84. Water supply. Outdoor networks and structures/ Gosstroy of the USSR. Moscow: Stroizdat, 1985. 136 PP.
10. SNiP 2.05.06-85. Main pipelines /Gosstroy of the USSR. - Moscow: stroizdat, 1988 -56 p.
11. Modern methods for calculating water supply and distribution systems/ L. F. Moshnin [et al.] / / water Supply and sanitary engineering. 1984. No. 10. Pp. 7-9.
12. Sumarokov S. V., Khramov A.V. Questions of optimal synthesis of water supply systems taking into account reliability / / Questions of reliability of water supply systems. - M.: MISI im. V. V. Kuibysheva, 1978. - Pp. 36-44.
13. Sumarokov S. V. Mathematical modeling of water supply systems. Novosibirsk: Nauka, 1983. 167 PP.
14. Surin A. A. Choice of water supply scheme. L.: State science.- land reclamation Institute. Willow.Fedorova, 1927. 126 PP.
15. Chupin V. R. Optimization of developing water supply and distribution systems. Abstract. the dessert. on the job. academic step. d-RA tekhn. sciences'. Moscow: VNIIVODGEO, 1991. 41 PP.
16. Chupin V. R., Maizel D. I., Chupin R. V. Modeling and optimization of utility pipeline systems. Vestnik Irgtu. 2008. Vol. 1. No. 1. Pp. 169-180.
17. Shevelev F. A. Tables for hydraulic calculation of steel, cast iron, asbestos-cement, plastic and glass water pipes. - Moscow: Stroizdat, 1973. -114 p.
18. Hasilev V. ya. Questions of mathematical modeling in optimization of hydraulic systems using computers / / Methods of mathematical modeling in power engineering. Irkutsk: East.-Nib. kN. ed., 1966. -- From 343-348.
19. Alekseev M. I. Urban engineering networks. Textbook, L., L. O. Stroizdat, 1990.
20. Abramov N. N. Water Supply. Moscow: Stroizdat, 1974. 480 p.
21. Abramov N. N. on problems of reliability of water supply systems / / Tr.MISI im. V. V. Kuibyshev. Moscow: MESI Publishing house 1973. 138 PP.
22. Dushkin S. S., Kraev I. O. Operation of water supply and sanitation networks. - K.: ISIO, 1993. - 160 p.
23. Evdokimov A. G., Dubrovsky V. V., Tevyashev A.D. flow Distribution in engineering networks.- Moscow: Stroizdat, 1979. 200 PP.
24. Evdokimov A. G., Tevyashev A.D. Operational control of flow distribution in engineering networks. Kharkiv: Vyshcha SHKOLA, Ed. at Kharkiv University, 1980 , 144 p.
25. Evdokimov A. G., Tevyashev A.D., Dubrovsky V. V. Modeling and optimization of flow distribution in engineering networks. -M: Stroyizdat, 1990.-368 PP.