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Characteristics of water supply network zoning

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Abstract. ***Relevance.*** The original studies of water supply network and network exploitation data, as well as international experience, applied in similar conditions, and the data of existing literature, data of works on water supply zoning, which were carried out in the networks of various settlements in the Republic of Armenia, have been improved and are now being implemented effectively through the clear procedure developed by us. In our case, zoning is carried out under the conditions of the existing system, therefore the methods developed during design and reconstruction work consider the features of the existing system. ***Aim.*** To develop a technique to enhance the efficiency of water supply systems by implementing network zoning. It involves transforming the network into hydraulically separated zones isolated from each other. Within each zone, water supply can be regulated based on consumption requirements. ***Objects.*** The article discusses issues related to design and reconstruction procedures of existing water supply network zones. It defines the priority of zoning implementation for the current stage and proposes a method for assessing the permissible level of losses, taking into account the technical condition of the water supply network. ***Methods.*** The calculations for this study were performed using well-known hydraulic principles and laws. Experimental studies were conducted directly on the water supply network under production conditions. ***Results.*** The actual implementation of these measures in various urban locations revealed that reduction in water usage in a service zone was only 8–10%. However, analysis of the functioning of the reconstructed zones led to the conclusion that the already constructed zones now offer suitable conditions for productive work on leak detection and elimination. In the given example, during the operation of the study zone, 4300 m (about 25%) of the existing 17400 m pipelines in the reconstruction zone were decommissioned, along with 13 of 22 pumping stations. Over two years of work, the cost of electricity at the existing yard pumping stations was reduced by more than six times, the total cost of electricity in the zone was reduced by more than twelve times, and the amount of water entering the zone was reduced by 44% as a result of the water supply system reconstruction presented in the example.

Keywords: water supply network zoning, leakage, zone hydraulic isolation, reduction of electrical energy consumption

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Характеристики зонирования сети водоснабжения

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Аннотация. ***Актуальность.*** Результаты оригинальных исследований водопроводной сети и данные эксплуатации сети, а также зарубежный опыт, применяемый в аналогичных условиях, и данные изученной литературы, работ по районированию водопровода, которые проводились в сетях различных населенных пунктов Республики Армения, были усовершенствованы и в настоящее время эффективно реализуются посредством разработанной нами четкой процедуры. Поскольку в нашем случае зонирование осуществляется в условиях действующей системы, методы, разработанные при проведении проектно-реконструкционных работ, учитывают особенности существующей системы. ***Цель:*** разработка методики повышения эффективности функционирования систем водоснабжения путем зонирования сети, т. е. преобразования сети в гидравлически разделенные зоны, которые изолированы друг от друга, где подача воды регулируется в зависимости от потребления. ***Объекты.*** Рассматриваются вопросы, связанные с проектированием и проведением реконструкции существующих зон водопроводных сетей. Определена очередность выполнения работ по зонированию на текущем этапе, и предложен метод оценки допустимого уровня потерь с учетом технического состояния водопроводной сети. ***Методы.*** Расчеты для данного исследования проводились с использованием известных гидравлических принципов и законов. Экспериментальные исследования проводились непосредственно на сети водоснабжения в производственных условиях. **Результаты.** Фактическая реализация этих мероприятий в различных городских населенных пунктах показала, что сокращение водопотребления в зоне обслуживания составило всего 8–10 %. Однако анализ функционирования реконструированных зон позволил сделать вывод о том, что в уже построенных зонах созданы условия для продуктивной работы по обнаружению и устранению утечек. В приведенном примере за время эксплуатации исследуемой зоны было выведено из эксплуатации 4300 м (около 25 %) из существующих 17400 м трубопроводов в зоне реконструкции, а также 13 из 22 насосных станций. За два года работы в результате реконструкции системы водоснабжения, представленной в примере, стоимость электроэнергии на действующих дворовых насосных станциях снижена более чем в шесть раз, общая стоимость электроэнергии в зоне снижена более чем в двенадцать раз, уменьшено количество воды, поступающей в зону, на 44 %.

Ключевые слова: зонирование водопроводных сетей, протечки, зональная гидроизоляция, снижение потребления электрической энергии

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Introduction

To increase the controllability of water supply distribution networks, it is necessary to implement effective zoning of a network, i. e. to transform the network into separate zones that are hydraulically isolated from each other. The isolation must be carried out by installing the existing or new valves, which will be closed during normal operation of the water supply network, but can be opened if necessary.

Our original research showed that by creating zones using the existing developed, constructed, reconstructed and fragmented network, some additional challenges have arisen:

- defects in the design task;
- comprehensive investigation of the network;
- application of incorrect zoning and pressure management principles.

The aim of the study is to increase the efficiency of existing water supply systems, improve zoning methods, and develop clear procedures for the systematic implementation of reconstruction works on the existing systems. Of course, to increase the manageability and reliability of the water supply distribution network, it is necessary to develop appropriate schemes that allow for the efficient use of limited human and financial resources and save time.

To achieve this aim, the following objectives are accomplished:

- to develop a procedure for reconstructing the existing water supply networks;
- to create specifications for determining the priority of system zoning.

The studies carried out for reconstructing the water supply network, including the analysis of available data, original research, foreign experience, and the study of existing literature, have improved the zoning and reconstruction of the water supply network in different settlements of the republic of Armenia (RA) and are currently being applied according to a clearly defined methodology.

Special approaches were raised to overcome these issues. This study presents the results of the approach in Lower Zeytun district in Yerevan.

The requirement for zoning the distribution network arises in mountainous conditions when there is a significant difference in levels within the boundaries of a settlement. Both gravity and pressing systems (reverse zoning) may require zoning. When high-rise multi-residential buildings are constructed in areas where low-rise buildings are already present or when the high-rise buildings absolute height exceeds that of the low rise buildings within the water supply zone's boundaries, zoning becomes crucial. Therefore, to increase the controllability of the distribution network, it is necessary to implement effective zoning of the network, i. e. to transform the network into hydraulically separated zones that are isolated from one another.

Literature review and problem statement

In the existing literature, there are various options for water network zoning principles. Recently, with the use of specially developed computer programs, various methods of automatic network zoning have been widely used.

Different models were proposed, based on classic optimization methodologies or on meta-heuristic approaches [1, 2]. Some authors proposed hybrid approaches for the automatic partitioning of a water distribution network, based on both meta-heuristic algorithms and on applications from graph theory [3–5]. The analysis of the functioning of the reconstructed zones, however, led to the conclusion that the already constructed zones now offer suitable conditions for productive work on leak detection and elimination.

Many attempts are made to follow the known methods, but due to many circumstances mentioned in this article, improvements in the water supply network efficiency for reconstruction and zoning of existing systems should be carried out on the basis of experimental data. We find that the use of calculation programs in such works has low accuracy.

The proposed models mainly focus on preservation of hydraulic reliability of the network, while less control is allowed on the costs of the provided solutions [6–8]. Spatial analysis of zoning approach based on the METIS graph partitioning tool was developed in [9]. More recently [10, 11], an approach for automatic creation of district metered areas (DMAs) based on the hierarchical community structure of the water distribution networks (WDN) was introduced.

A comprehensive description of the possible objective functions for the problem can be found in [6]. The two-step approach proposed by the authors consists of a preliminary partitioning of the WDN into suitable DMAs through the application of the design criteria and graph theory concepts. Although there were satisfying results, the global optimality of the solution is not ensured by the Simulated Annealing (SA).

The distribution network should be zoned in complex terrain conditions when there are differences in levels between residence boundaries. In this case, there is excess (unacceptable) pressure in the network before zoning and pressure management. This regulation reduces leaks and improves the conditions under which plumbing equipment and reinforcement operate, reducing water consumption and the amount of electricity consumed in pumping systems.

Since in our case, zoning is carried out under the conditions of the existing system, the methods developed during the design and reconstruction work consider the features of this system: a great difference in the levels, dictating the levels of the daily regulating reservoir, location and volumes, diameters of the existing pipes, the stores of the buildings, population density, etc.

Our original research showed that some additional problems arise when creating zones using existing weathered, prefabricated, reconstructed, or fragmented networks.

Materials and methods

This research presents the studies of the zoning problems of the water supply network, considering various local conditions. It is obvious that the water supply distribution network controllability and efficiency can be achieved through system zoning. However, the known methods cannot be used while reconstructing already operating, technically poor, elementally constructed systems. Based on the above, developing unique techniques for solving problems and overcoming defects is necessary. Many attempts are made to follow the known methods, but due to the many circumstances mentioned in this article, improvements in the water supply network efficiency for the reconstruction and zoning of existing systems should be carried out on the basis of experimental data. We find that the use of calculation programs in such works has low accuracy.

The calculations related to the studies were performed by the following well-known hydraulic principles and laws. The experimental studies were conducted directly on the water supply network under production conditions. The zoning developed principles can be successfully applied during reconstruction of the water supply networks of other settlements.

Aim and objectives of the study

Roadmap for reconstructing the existing water supply systems

To assess the water balance within the boundaries of separate zones, to determine the quantity of unaccounted water, and subsequently determine the nature and location thereof, it is proposed to temporarily turn the cyclic network existing within the zone into a dead-end network using valves. To divide the zone into separate sections, magnetic flow meters and pressure recording sensors should be installed on the supplying pipes. The study aims to estimate the amount of water entering each zone and compare it with the calculated amount of water received by the number of subscribers. By creating water supply sections with a one-way supply and a precise number of subscribers, it is possible to estimate the unaccounted volume of water in a given zone. Before starting the zoning work, it is necessary to examine the issues and operational data, set registration guidelines, form a working group, purchase the required monitoring and measurement equipment, and avoid obvious (visible) leaks.

The following work sequence was developed for zone design and implementation (construction):

- The existing water supply distribution network designed in the plan is divided into separate zones by valves. This separation should consider the possibility of creating optimal pressure regimes in the zones and exclude the dead-end sectors in the pipelines. Designing sectors with a limited number of subscribers is essential to enable the controllability of the pressure zone. According to the results of the studies, it is desirable that the zone include 500–3000 subscribers, depending on the level of leaks, construction features of the district, methods used to control leaks, and hydrological conditions. In densely populated areas, such as in the central parts of settlements, the water zone may include more than 3000 subscribers. In this case, it is difficult to identify small failures and their locations from the data recorded at night, and it takes a long time to find them. However, by temporarily closing the valves, the water supply areas can be divided into subsectors of two or smaller sizes. In this case, additional valves may need to be installed during the design phase of water supply areas.

- The power source is determined based on the case of providing an uninterrupted water supply to the facility in the most dangerous (critical) conditions in the specified area. In design practice, the following zone-supplying options are possible:
  1) the zone may have one or two power sources: an aquifer or a reservoir;
  2) zoning can be carried out sequentially: here, the second zone receives water from the first zone in a transit way (Fig. 1).
- It is planned to close off the valves on all boundary feeding lines during the hydraulic isolation of the separated zones, leaving only the planned feeding line. To guarantee total isolation, it is sometimes required to install new valves. Small-scale maps of the distribution water lines, information from the staff about them, and current hydraulic data are all employed at this stage of the contour demarcation of the water supply zone design.
- “Zero tests” are used to ensure that the design is in accordance with the completed reconstruction works. The requirements are as follows:
  1) inspecting the installed flow meter for accuracy;
  2) checking the functioning (hermetic) of the boundary valves;
  3) detecting the hydraulic connections between neighboring zones;
  4) evaluating and assessing the changes in the quality of water supplied to customers in the reconstructed zone and neighboring zones;
  5) inspecting for excessive pressures:
- decommissioning redundant pipes;
- control of pressure in the isolated zone and regulation of excess pressures;
- detection and elimination of hidden failures and leakages;
- recording the parameters of the reconstructed zone and creating the zone passport.

Because of the formation of sectors within the borders of a separate zone, the existing ring network turns into a dead-end having a one-way supply. Hydraulic calculations are required to verify the transmittivity and pressure losses of the sections to maintain the water supply of the dead-end network. For this purpose, a calculation scheme for the dead-end network was created. It is divided into calculation sections, where the directions of water flow are noted, and the actual outputs in the sections are measured.

In contrast to the well-known method for calculating the dead-end network, during the conducted studies, the outputs obtained through the experimental measurements are taken as the calculation output for each section based on the maximum actual water demand. When choosing the endpoint for the constructing pressure lines based on the measured outputs, not only the distance and relief but also the required pressure at that point, considering the height and location of the buildings, are considered.

The optimal design of water distribution systems is a widely explored research area, which still faces many barriers and practical challenges [12], such as the difficulty of defining the objective functions and constraints, the variability of flow in the network, the design optimization difficulties related to the fact that these systems are not typically constructed at once, and the fact that solutions of optimization problems directed at cost minimization often lead to under-sized networks. Composed of pipes, pumps, valves and other components, the water distribution networks are modeled and simulated based on the laws of mass conservation (the hydraulic balance between the provided and consumed flows) and energy conservation (which relates the hydraulic heads and losses over the network). The flows in these laws are governed by complex, non-linear, non-convex and discontinuous hydraulic equations [13]. The classical and extensively described model of water distribution network design optimization has as an objective function the minimization of network deployment costs, which are used to define the smallest pipe diameters that meet the hydraulic requirements in terms of the pressures and flows [14–17].

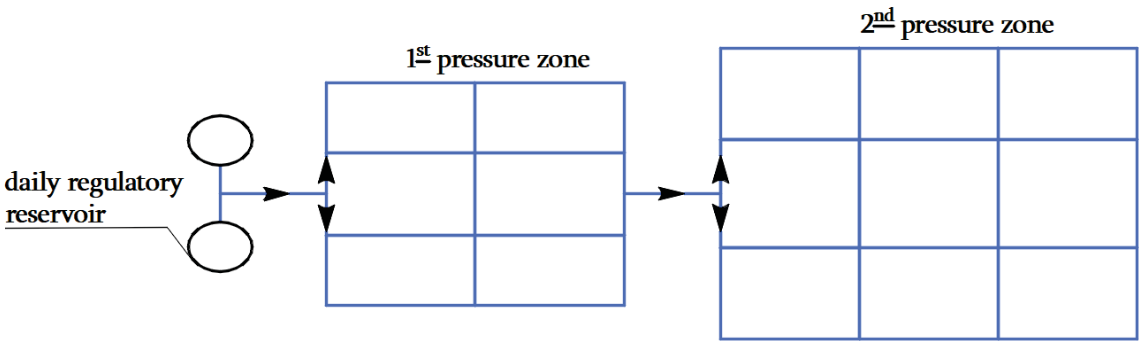

Fig. 1. Sequential zoning scheme
Рис. 1. Схема последовательного зонирования

After measuring the outputs of the designed dead-end network segments, the network transmittivity condition is checked. For this purpose, the pressure losses, occurring in the sections, are determined by the formula $h_l=SQ^2$, using Shevelev's Tables. Based on the Tables the free pressure lines of the network are built to have the pressure magnitude at all points of the selected calculation direction. The free pressure lines are installed in every possible direction to assess the pressure at the examined network points. The circular network temporarily turns into a dead-end network until the end of the studies (recording of the defined result). The mentioned operation is carried out using valves installed in the necessary sections of the network, which can remain open after the completion of studies and relevant reconstructions.

Within the established water supply zones, the effective pressure management is crucial to ensure the reliable and sustainable provision of water to consumers. The use of pressure control is a cost-effective measure to reduce leakages in water distribution systems [18]. Leakages are considered to be pressure-driven demands in the hydraulic analysis and modeling of water losses [19–21]. To prevent excessive or insufficient pressures in the network, it is essential to use modern computer programs for hydraulic calculations of the water supply network. The program enables the identification of critical and vulnerable parts of the water supply network, as well as the determination of appropriate diameters for pressure regulators and installation points.

In case of pressure providing problem in the subzone of the designed dead-end network, based on specific conditions, it can be solved by:

- over-correcting the pressure regulators or opening the compressed valves on the supplying water pipe (if available);
- excessing pressure regulation increased the pressure in the initial part of the considered subzone in the neighboring sub-sector;
- changing the power source of the zone that will provide the required pressure or apply another zone scheme;
- pressure losses in the specified sections revealing the significant leaks by finding and fixing leaks in any section(s). Therefore, it may be found that the cause of the pressure loss is a hidden local resistance (unknown compressed valve, presence of a gasket, or blockage);
- increasing the diameter of a specific network section if the pressure line in that section has a steep slope;
- installing local pumps if the pressure is insufficient for a few high-rise buildings.

The last two options are advisable to use in case of economic feasibility. It should be added that when performing zoning, the need to increase the diameter or install a pump arises in rare cases because the diameters of pipelines built in the Soviet era are chosen with a high stockage.

The priority of network zoning distribution

Because of zoning financial and technical requirements, it is impossible to carry out operations simultaneously in all planned zones. Instead, priority is given to the zones with the highest leakage levels. Based on the technical condition of the Yerevan city distribution network, it is recommended to use the following expression of specific losses of flow:

$$q_{\text{leak}}=(Q_{\text{night}}-Q_{\text{cons}})/L_{\text{w}}(\text{l/hour m}),$$

where q_{leak} is the specific loss of flow, l/s m; Q_{night} is the average night flow recorded by the zone flowmeter, l/h; $Q_{\text{const.}}$ is the average consumption of subscribers during the night, l/h; L_{w} is the length of pipelines of the zone, m.

In the sector of own residences, the accepted average consumption per subscriber during the night was 1.7 l/h, while in multi-apartment buildings, it was 0.6 l/h. These values were adopted based on the data recorded during the experimental studies performed in various pressure zones.

The nighttime price for many customers is calculated separately based on actual measurements, as it can significantly affect the zone nighttime loss estimate.

Analyzing the results of multi-year studies and considering the current technical situation of the distribution network, it is recommended to continue the accident detection and elimination work for the current phase until the nighttime consumption of the zone is less than a half of the daytime consumption:

$$Q_{\text{night}}\leq Q_{\text{day}}/2(\text{l/s}),$$

where Q_{night} and Q_{day} are the average water volumes given to the zone during the night (100–500 period) and daytime.

The mentioned expression was defined after studying the zones with the lowest water losses in Yerevan city (Davtashen, South West, and other districts).

Discussion of the results for water supply network zoning on the example of Yerevan Inner Zeytun district

The zoning work of the district started back in 2008. The scheme of the separated water supply zone of the district is given in the section of the cadastral map (Fig. 2).

Pressure monitoring and transmission devices were installed at different points within the network to check the hydraulic distribution scheme of the district water supply network.

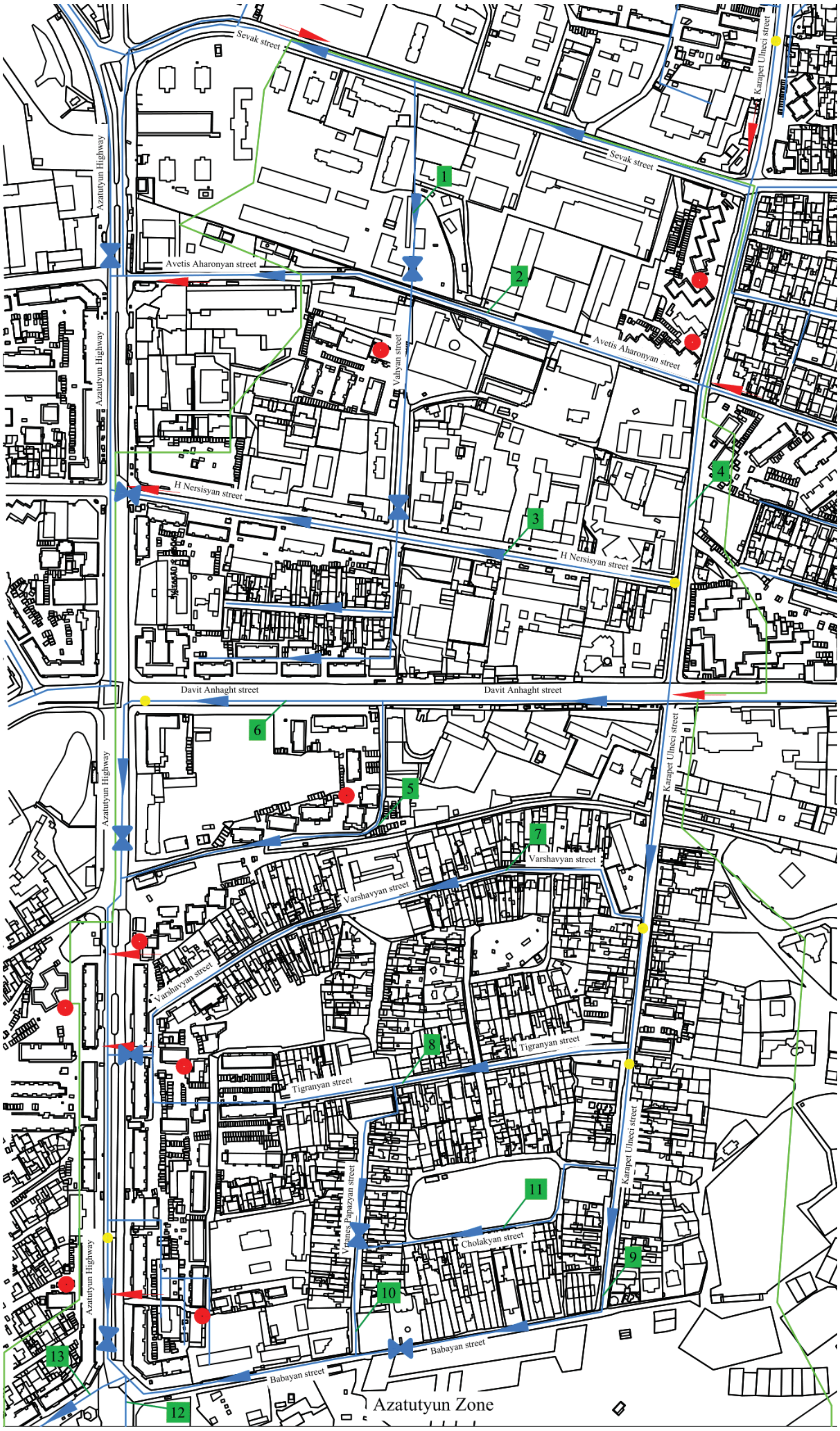

Fig. 2. *Scheme of water supply zone in Inner Zeytun district:* – *eliminated hydraulic connection;* – *water flow direction;* – *pump station;* – *PRV;* – *closed valve;* – *zone initial boundary;* – *pipelines*

Рис. 2. *Схема зоны водоснабжения в районе Внутренний Зейтун:* – *устраненное гидравлическое соединение;* – *направление потока воды;* – *насосная станция;* – *клапан регулирования давления;* – *закрытый клапан;* – *начальная граница зоны;* – *трубопроводы*

The planned zone hydraulic linkages to nearby zones were discovered through interdisciplinary research, and their effects on the zone operation were identified. According to the operation data, the zone was supplied from Zeytun day regulator reservoir (DRR) at the crossroads of P. Sevak-Ulnetsi streets and considered the zone boundaries for P. Sevak, Ulnetsi, Babayan Streets, and Azatutyun Avenue.

The research revealed that the zone is hydraulically connected to all surrounding zones, and four additional points supply the mentioned district, receiving around 90 l/s of water (Table 1).The figures in the Table 1 show that the amount of water entering the zone is 320 l/s, but before the studies, we knew only one power source: an aqueduct with a diameter of 400 mm with a capacity of 230 l/s, powered by Zeytun DRR.

Table 1. *Characteristics of supply sources in Lower Zeytun district*

Таблица 1. *Характеристика источников водоснабжения района Нижний Зейтун*

Zone supplying points Зональные точки водоснабжения	Aqueduct Водовод	Output, l/s Производительность, л/с	Pipe diameter, mm Диаметр трубы, мм	Mark, m Отметка, м
Zeitun DRR ДРР Зейтун	Katnaghbyur 3 Катахбюр 3	230	400	1285
Crossroads of Hasratyan–Avetisyan streets Перекресток улиц Асратян–Аветисян		25	250	1279
Crossroads of Tbilisi highway –Sevak street Перекресток Тбилисского шоссе и улицы Севака	Arzaqan Арзакан	10	400	1281
Crossroads of D. Anhaght–Ulnetsi streets Перекрёсток улиц Д. Анахт–Улнеци	Katnaghbyur 2 Катахбюр 2	30	200	1211
Crossroads of Ulnetsi–Aharonyan streets Перекрёсток улиц Улнеци–Агаронян	Katnaghbyur 3 Катахбюр 3	25	200	1236

For proper zoning, it was necessary to disconnect all additional connections found to supply the district, leaving only the main one, and check the possibility of increasing the amount of water provided by it to maintain the water supply level. The presence of hydraulic connections from one area to the other was investigated. Along Azatutyun Avenue, seven connections were found, connecting the zone to the adjacent lower-pressure zones, and a certain amount of water was flowing into these zones (Table 2).

Table 2. *Estimation of the amount of water directed to other zones*

Таблица 2. *Оценка количества воды, направляемой в другие зоны*

Zone leak points Зона точек утечки	Pipe diameter, mm Диаметр трубы, мм	Output, l/s Производительность, л/с	Mark, m Отметка, м
Crossroads of Aharonyan–Azatutyun Streets Перекресток улиц Агаронян–Азатутюн	250	5	1221
Crossroads of Nersisyan–Azatutun streets Перекресток улиц Нерсисян–Азатутун	150	10	1208
Crossroads of Zaryan–Azatutyun streets Перекресток улиц Зарьян–Азатутюн	400	15	1186
Near Azatutun 11 building Рядом со зданием Азатутун 11	50	9	1180
Near Azatutun 8 building Рядом со зданием Азатутун 8	125	8	171
Near Azatutun 3 building Рядом со зданием Азатутун 3	80	1.5	1157
Crossroads of Azatutyun–Babayan streets Перекресток улиц Азатутюн–Бабаяна	250	12	1149

It can be seen from the Table 2 that about 60 l/s of water flowed from the designed zone to neighboring zones, so to regulate the pressure in the designed zone, it was necessary to disconnect them or add the service areas of the specified connections to the area of the zone.

The presented studiy analysis results serve as a basis for drawing up the final design task for changing the network boundaries, and it was decided:

- to disconnect four of the five supply lines and leave the pipe supplied from the Zeytun DRR at the highest level. The selected zone supply scheme follows the zoning principles: the network is supplied by the daily control tank, which provides the required pressure throughout the zone;
- to disconnect four of the seven connections going to other zones (Azatutyun–Aharonyan, Nersisyan, Zaryan crossroads, and near the Azatutyun 8 building) and provides water supply to deprived customers from the other zones. It was considered to include the areas supplied by the remaining three connections within the project zone boundaries (near the buildings of Azatutyun 11 and 3, and the crossroads of Azatutyun–Babayan streets).

During the zone border adjustment studies, it was also discovered that several structures within the specified area (in this example, enterprises such as the Institute of Biochemistry, Armentel, and Relay Factory) are fed by the adjacent zone. Fig. 2 displays the predicted zone with adjusted borders. Further research to improve zone performance continued within the adjusted area.

The results of the study once again confirm that the water supply network of Yerevan was developed simply without proper justification and zoning. A dead-end network was developed and rebuilt into a cyclic network to supply water to new regions of the city.

After putting into operation the pipelines constructed or reconstructed at different stages, the existing technically worn-out water supply network was not decommissioned. The consequence was a hydraulically interconnected "spider" or "chaotic" system. It is evidenced by the examples of control unit photos in Fig. 3. It was challenging to determine, which pipes were supplying which users. It is obvious that, under such circumstances, network operation is seriously hindered.

The project scheme was being redesigned and changed at the same time. During this time, it was vital to include in the projects the decommissioning of redundant water lines and to connect the inputs of the subscribers fed from these pipes to the protected pipelines, as well as to simplify unnecessarily complicated units. During the operation, 4300 m (about 25%) of the existing 17400 m pipelines in the reconstruction zone were decommissioned, and the control units that were part of them were reconstructed. The performed activities contributed to reducing the probability of water losses and accidents. To measure water volumes and detect hidden accidents and illegal connections, it was necessary to temporarily convert the existing cycle network into a dead-end by installing valves.

In the area under reconstruction, the water supply network was divided into 13 dead-end sections (Fig. 2). During the design phase, portable magnetic flow meters should be provided at the start points of all dead-end networks. They should be installed in wells, away from the compression valves, on a rectilineal pipe section, the length of which depends on the pipe diameter.

To constantly monitor the quantity of water entering the Lower Zeytun zone, a magnetic flowmeter with a data transmission system is installed at the beginning of the supply pipe in the sanitary zone of the DRR (the quantity of water is monitored every 5 min).

The next step in the district zoning is a zero pressure test. The positive results of the experiment in the Lower Zeytun zone were obtained after about three months.

After waterproofing and delineation of the water area, cost and pressure measurements show that there was a significant change in the parameters compared to the measurements taken at the initial stage.

To regulate the pressure in the isolated zone and avoid excessive pressures, as well as to use position energy efficiently, the next step is to determine the needed pressures in the sectors created in the zone. Based on the regulatory requirements and operational experience, the following values for the required pressure are defined in Yerevan city: up to 20 meters in districts built with 1–2-story private houses; 27–30 meters for 5-story multi-apartment buildings; in higher-rise buildings, it is advisable to supply the required pressure with local pumping stations because with higher pressures, the emergency of the network increases.

A problem of pressure management in the water supply area is the decommissioning of local pumping stations. Because of the construction activities, 13 out of 22 pumping stations in the reconstruction zone were disabled. The remaining pumps were replaced with contemporary, reliable, high-efficiency pumps (Table 3).

a

b

Fig. 3. *Water supply network management units before reconstruction: a) network; b) chamber*
Рис. 3. *Узел управления сетью водоснабжения до реконструкции: a) сеть; b) камера*

Table 3. *Characteristics of reconstructed pumping stations*

Таблица 3. *Характеристики реконструируемых насосных станций*

Pumping station address Адрес насосной станции	Number of served buildings Количество обслуживаемых зданий	Number of subscribers Количество абонентов	Monthly energy consumption, kWh Ежемесячное потребление энергии, кВтч		Saved energy Сэкономленная энергия	
			Before reconstruction До реконструкции	After reconstruction После реконструкции	kWh кВтч	%
Azatutyun, 12/1 Азатутюн, 12/1	4	144	3600	810	2790	77.5
Azatutyun, 6 Азатутюн, 6	1	66	4080	540	3540	86.7
Tigranyan, 4 Тигранян, 4	1	75	3840	594	3246	84.5
Tigranyan, 3 Тигранян, 3	1	75	3480	594	2886	82.9
Zeitun 8, 113 8-я ул. Зейтун, 113	6	288	3648	900	2748	75.3
Aharonyan, 2/1 Агароняна, 2/1	2	96	4440	432	4008	90.2
Ulnetsi, 49 Улнеци, 49	2	121	4200	486	3714	88.4
Aharonyan, 7 Агароняна, 7	2	114	1800	378	1422	79.0
Ulnetsi, 66 Улнеци, 66	3	180	3840	648	3192	83.1
Total/Всего	22	1159	32928	5382	27546	83.6

Table 4. *Characteristics of pressure regulators in the zone of Inner Zeytun district*

Таблица 4. *Характеристики регуляторов давления в зоне района Внутренний Зейтун*

Location of regulators Расположение регуляторов	Installation mark, m Отметка установки, м	Pressure, m Давление, м		Regulator diameter, mm Диаметр регулятора, мм
		Before regulator До регулятора	After regulator После регулятора	
Ulnetsi–Sevak crossroads Перекрёсток Улнеци–Севак	1270	18	6	400
Ulnetsi–Vagharshyan crossroads Перекрёсток Улнеци-Вагаршян	1187	39	12	200
Ulnetsi–Tigranyan crossroads Перекрёсток Улнеци–Тигранян	1170	33	16	100
Near Azatutyun 8 Рядом с Азатутюн 8	1170	50	29	100
Near Lambada Bridge Рядом с мостом Ламбада	1198	40	28	100
Nersisyan–Ulnetsi crossroad Перекрёсток Нерсисян–Улнеци	1223	38	27	150

As a result, 1251 subscribers in 25 buildings received water by gravity, and about 61000 kWh of electricity per month was saved. Another 1159 subscribers in 22 buildings of the reconstructed pumping station service had a round-the-clock water supply instead of 8 hours (pumps operate on a round-the-clock schedule).

We should also add that before the zoning, the pumps worked on an 8-hour schedule, and the Table 3 shows the cost of electricity for 8 hours. After the reconstruction, they work around the clock, and the cost of electricity is also given for 24-hour work. Concurrently, the rebuilding reduced the zone overall electricity usage by more than 12 times and more than six times in the existing pumping stations.

Since the difference between the high (1252) and low (1130) levels of the reconstructed district is almost 120 meters, it was necessary to install six pressure regulators. The characteristics of the installed pressure regulators are shown in Table 4.

The zoning project, being the basis for the construction work, is not final. Numerous modifications and unexpected behavior are both possible. With this in mind, the construction company is often awarded a unit cost contract, which allows the zoning group to operate without restrictions and flexibility.

The actual use of zoning measures in various urban locations revealed that the water usage in the zone of service is reduced by just 8–10%. The analysis of the functioning of the reconstructed zones, however, led to the conclusion that the already constructed zones now offer suitable conditions for productive work on leak detection and elimination.

At our suggestion, in the Zeytun District, the implementation of such work began intensively. The operation lasted almost two years, where 175 hidden accidents with different water releases were detected and eliminated. It resulted in the district output of 268 l/s being reduced by 150 l/s, averaging 116 l/s during the day and 56 l/s at night.

We can say that the fluctuation of water consumption in this zone during the day was brought to the level set for Yerevan:

$Q_{night} \leq Q_{day}/2$ (l/s), 116/56≃2,

where Q_{night} and Q_{day} are the night (1^{00}–5^{00} period) and daytime average water volumes given to the zone.

Taking into account the current technical condition of the Yerevan water supply network, at the mentioned stage, it is recommended to confirm that the zone reconstruction works are considered completed. After performing these actions, the basic parameters of the operation received are recorded, which serve as a guide for the continued general operation of the zone. Reconstruction work began in all areas established in the Yerevan water supply network. Some of them were completed, and others are at various stages of implementation.

Conclusions

1. Zoning should be implemented to ensure the efficient operation of the water supply network. The studies showed that, using the existing distribution system and considering the position of the reservoirs, the distribution, the relief of the site, and the storeys of the buildings, the water network should be converted into hydraulically isolated zones. The creation of zone design and implementation procedures, which cover system management principles, the formation of sub-zones (dead-end networks), pressure calculation, leak detection, elimination, etc., became crucial. The network reconstruction (zoning) projects help to improve the following indicators: water supply reliability; regulation of environmental and social problems, reducing power costs; quality of supplied water; reduction of technical losses, adjustment and price.
2. It is necessary to define the priority of the distribution network zoning, to detect and eliminate losses at the current stage, considering the technical condition of the system.

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