The issues of creating rational water supply schemes using desalination and recycling systems

I A Nechaev¹, P I Nechaev, E I Pleskač¹, R A Alexandrov²

¹ Joint Stock Company «Scientific-research institute of chemical technology», Kashirskoye sh., 33, Moscow, 115409, Russia
² National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoye sh., 31, Moscow, 115409, Russia

E-mail: inechaev@yandex.ru

Abstract. The topic of this article is a discussion of the prospects for using methods of recycling and desalination of waters of various composition that allow the implementation of schemes for the reuse of water in various production processes, while reducing both the total water consumption and the value of the resources received. Recycling itself is seen as an integral part - the addition of a single scheme of water supply, including, including the desalination stage.

The authors of numerous publications refer to the problem of water shortage as one of the global challenges of the present, pointing to this problem as a reason of the decline in the growth of economic development or even conflicts, both between different groups of water users and between individual countries. What can be called water deficit - is the shortage of water of the appropriate quality in the required amount. Indeed, the overwhelming number of water users use fresh water with a minimum amount of pollution of natural or anthropogenic origin, and therefore, first of all water shortage is a shortage of fresh water, the total amount of which is very limited and amounts to about 1% of the total water volume on the planet. In this regard, many developers of water treatment equipment and water treatment see the solution of the problem of water shortage by desalting salt or brackish water, which should lead to increasing the volume of fresh water and thereby eliminate water shortage.

However, this problem is becoming urgent today, both for countries traditionally experiencing a shortage of fresh water resources and for possessing seemingly significant reserves of natural fresh water. The reason for such an urgent problem is, first of all in the shortage of water, suitable for further use. It concerns the lack of fresh water and anthropogenic pollution of water sources, still used yesterday for water supply systems without any serious water treatment. According to the reports about the state of the environment in the Russian Federation, there is a steady tendency to maintain unsatisfactory state of a significant number of water sources [1]. Despite the fact that for the period from 1998 to 2015 in the country water consumption for various needs has decreased almost 2 times, the volume of pollution entering the environment with the discharging of insufficiently treated or untreated sewage remains at the same level. As a result, today the actual water shortage in a number of regions of the Russian Federation is observed first of all in Kalmykia, in a number of areas of the Astrakhan, Volgograd regions, the Stavropol Territory and the Crimea - where there is simply no natural fresh water in sufficient quantity, and a hidden water shortage is a lack of water of the appropriate quality in view of
the anthropogenic pollution of water sources, which is typical for the Central Federal District, where the main part of the population of the Russian Federation lives. Thus, in fact, a situation has been created where the shortage of water resources is exacerbated by the pollution of water sources by discharges of insufficiently treated sewage.

It is quite obvious that a number of specialists are offered a variety of technologies, technical and design solutions, including desalination and/or transfer/transportation of water over significant distances to solve the water supply problem. Most of the technologies listed are found and will be used in the field of water supply, however, before discussing the prospects of certain technologies or technical solutions, it is necessary to determine the feasibility of water treatment to certain standards, assess the possibilities of using water of various qualities, and introduce certain limitations in the cost of the product received, intended for various groups of consumers. Today, there is an unspoken, but well-established cost of water resources on the international market. This cost is not used for direct water trade between countries or individual consumers, it is a certain maximal cost of a water resource put into the cost of a product. So, the industry is ready to pay the highest price for water - within the limits of 1-3 US dollars/m3, the municipal services provide water supply services at the price of 0.4-0.7 US dollars/m3 (which generally corresponds to the average tariff for water supply in the Russian Federation - about 25-30 rubles per cubic meter). The largest consumer of water in the world is agriculture, ready to buy water at a price not more than 0.1 USD/m3. These prices are a certain guide for estimating the cost of water within the commodity output produced/consumed by different groups of water use and can vary within very significant limits in each specific case. However, for a general assessment and to determine the perspective for different methods of water treatment/treatment, these prices are very interesting.

Turning to the issue of water supply, it is necessary to avoid the misconception typical for the most population that tap water - initially is spring water taken from protected sources or thawed water of high mountain glaciers, today the realities are somewhat different. So, the population of Western Europe: Switzerland, some lands in France, Holland and Germany consistently use the same water, which according to experts four times succeeds in becoming both a source of water supply and the result of the vital activity of the population, living in certain areas. This is the basin of the River Rhine, one of the most densely populated and industrialized region of the planet. At the same time, the establishment and enforcement of water legislation both at the interregional and international levels made it possible to create and maintain a more complex water management system that provides comfortable and economically efficient living of tens of millions people in very harsh conditions of scarcity of resources and the highest anthropogenic load.

What is the key to the success of creating such systems? First in an effective, scientifically based approach both to the development of water legislation, and the creation of effective economic mechanisms that ensure the implementation of modern technological and technical solutions.

If we turn to the domestic legislation in the field of water quality regulation, we can see a number of requirements for the quality of water used for drinking water supply, technical water supply, irrigated agriculture, as well as the requirements for the quality of treated sewage before discharging them into water reservoirs for various purposes. Given the lack of domestic water management as a single industry, the requirements to water quality have become the result of interdepartmental disputes and contradictions.

The strictest of the above standards are standards for the discharge of treated sewage into a water object for fish culture [2], regulating the quality of water for the largest number of indicators and requiring the deepest elimination of the vast majority of listed pollution. It should be noted that these standards are formally imposed on the majority of treatment plants operating in the territory of the Russian Federation, are mandatory, but according to statistics they correspond to approximately 10% of operating treatment facilities [3].
Assessing the standards for discharge into a water object for fish culture, two groups of pollution should be identified separately, the removal of which is most costly. This is primarily salt content - up to 1000 mg/l, with a separate regulation of the content of chlorides and sulfates; as well as the content of the nitrogen group - ammonium nitrogen, nitrites and nitrates.

The second strictest norm is the drinking water quality standard [4], for which the principal difference from the norm for discharging into a water object for fish culture is an easing in salt content - up to 1500 mg/l and less strictest requirements for most other indicators. Thus, it becomes obvious that water of drinking quality cannot be discharged into the environment without paying penalties for abnormal discharge, though from a formal point of view. At the same time water of water sources is rationed less rigidly [5], while the most "expensive" pollution - salt content, first of all, in water of water sources is not regulated, the norm only indicates the need. "For each particular source, the water purification scheme and required reagents are established on the basis of technological research or experience in the operation of structures under similar conditions ... ".

The third group of standards normalizes the water quality applied to water used for Irrigated agriculture [6]. These standards are in their form most closely approximated to the needs of consumers - farmers and are based on the calculation method of setting standards in each specific case, depending on the composition of the soil and the method of irrigation. At the same time, it is allowed to use pre-treated wastewater for irrigation, with the exception of certain types of industrial wastewater and observance of water-salt balance, which prevents salification of soils.

The fourth group of standards, which does not currently have a definitive formalized form, refers to the requirements for industrial water used in industry. Here, in general, departmental and even corporate requirements predominate, historically formed on the basis of the so-called SEV's standards developed in the USSR for most industries. In general, these standards are limited to requirements for salt content (up to 1500-3000 mg/l), suspended solids content (15-50 mg/l), organic contaminants content (COD 50-100 mg/l) and some others.

Thus, it should be noted that the current Russian water legislation is characterized by a very serious imbalance in the standards for water for various purposes. At the same time, the most strictest requirements are imposed on water directed to discharge into natural water objects for fish culture, which is not a commodity product for the producer (water user).

Next, we should consider some basic schemes for cleaning domestic and related sewage waters, ensuring the achievement of the above standards. The current versions of number of normative documents [7] describe quite accurately and in detail the main stages of mechanical, complete biological and deep post-treatment of sewage. At the same time, for most types of effluents, various manufacturers offer a wide range of technical solutions and ready-made equipment ensuring water treatment of the required quality. In addition, a wealth of experience in the operation of such systems has been accumulated, which makes it possible to conduct, including a cost evaluation of the various stages of wastewater treatment.

The first stage of purification is a stage of mechanical cleaning that ensures the removal of the largest contaminants (waste), as well as sand and a part of the settling substances. The basic composition of the treatment facilities of the mechanical cleaning stage includes: a coarse grating with clearances of 6-8 mm; sand trap; in some cases - a filter with clearances up to 1 mm; primary settler.

The implementation of this stage of purification allows to ensure the quality of cleaning of average domestic sewage to the level of suspended solids - up to 100 mg/l, BOD - about 150 mg/l, COD - up to 200-220 mg/l. The use of the mechanical cleaning stage does not allow for an effective reduction of the total concentration of the nitrogen group, and also to ensure the removal of dissolved contaminants, especially salts. However, the addition of a stage of mechanical cleaning with a block of disinfection (elimination of parasitic contamination of water and sediments) makes it possible to obtain purified
water, suitable for use in irrigation. At the same time, the cost of mechanical treatment of domestic wastewater averages 3-5 rubles / cubic meter.

The next stage of treatment of domestic and close to them in the composition of sewage is the stage of biological treatment. Today, the most common methods of biological purification are the so-called nitride- denitrification schemes that ensure the parallel removal of organic contaminants, as well as nitrogen and phosphorus compounds. The use of aerotanks of nitride-denitrifiers allows obtaining the quality of purification by BOD and suspended solids in the range of 10-15 mg/l, which is close to the water composition of water sources of 2 and 3 classes - i.e. sources of water supply of small and medium-sized settlements, and also used in technical water supply systems of industrial enterprises. At the same time, the cost of implementing the scheme using mechanical and biological treatment steps averages 25-30 rubles per cubic meter. The development of biological treatment technology using membrane bioreactors can significantly improve the quality of cleaning and the reliability of biological treatment facilities. The use of the membranes for separation of silt mixture and purified water, both submersible and remote - allows to obtain quality of cleaning suspended solids and BOD in the range of 1.0-3.0 mg/l, which potentially allows using purified water to replenish sources of water supply up to class 1, especially this refers to the possible recharge of groundwater through various drainage and filtration systems. The cost of using MBR technology is 30-35 rubles/cubic meter.

The third stage - deep sewage treatment to the requirements for discharge into the water objects for fish culture is the desalination stage. The implementation of such technologies on an industrial scale, with reference to sewage waters of settlements in the Russian Federation is not. The reason for this situation is the need to isolate and utilize salts in the form of solid waste, which makes the implementation of technology almost impossible. Nevertheless, by analogy with the desalination of saline and brackish waters, the cost of demineralizing domestic sewage, without taking into account the utilization of brines, will be 40-55 rubles/m³. It should be noted that even the achievement of standards for discharges into a basin does not release the water user from environmental payments for the use of the basin as a receiver of treated sewage. The cost of such a payment today is about 0.2-0.5 rubles/cubic meter, depending on the region. Thus, the following table can be presented.

**Table 1.** The specific cost of water, depending on the various stages of purification.

| Treatment stage | Enlarged indicators of water quality | The enlarged cost of treatment, rubles/m³ | Possible customers |
|-----------------|-------------------------------------|------------------------------------------|--------------------|
| Mechanical treatment | suspended solids - up to 100 mg/l, BOD - up to 150 mg/l, COD - up to 200-220 mg/l | 3,0-5,0 | Irrigated agriculture |
| Complete biological treatment with nitride-denitrification | suspended solids - up to 10-15 mg/l, BOD - up to 10-15 mg/l, COD - up to 35-50 mg/l | 25,0-30,0 | Irrigated agriculture, replenishment of water supply sources of 2-3 classes, technical water supply |
| Deep biological treatment with MBR reactors | suspended solids - up to 1.0-1.5 mg/l, BOD - 2-3 mg/l, COD - up to 30-40 mg/l | 30,0-35,0 | Irrigated agriculture, replenishment of water supply sources of 1-2-3 classes, technical water supply |
Desalting suspended solids - up to 1.0-1.5 mg/l, BOD 2-3 mg/l, COD - up to 15 mg/l, salt content - up to 1000 mg/l

Irrigated agriculture, replenishment of water supply sources of 1-2-3 classes, technical water supply

Analyzing the presented table, it can be concluded that, according to the current legislation, the cost of standard cleaning of domestic and related wastewater will amount to 40-55 rubles/m³ on average. At the same time, treated effluents can potentially be used in technical water supply systems, for replenishment sources of water supply, primarily underground sources, as well as for irrigated agriculture. Such decisions will reduce the need for water resources at least. Potentially, such solutions will make it possible to make deep treated water as a commodity that will be demanded by a lot of consumers. The transformation of the process of achieving formal standards in the process of commodity production - production of industrial water, will potentially change the attitude of operating organizations - vodokanals to the result of their labor. However, the potential economic efficiency will remain only as long as the cost of wastewater treatment is not transferred to the cost of re-use of treated water, which is impossible because the requirements for treatment quality are normative - established by law and not by the requirements of specific consumers. Thus, today's compliance with legal requirements is a potential opportunity to receive a free secondary water resource.

The potential need for water, the quality of which differs from the standards for discharging into water object for fish culture, creates the possibility of creating reuse schemes for run-off with a certain economic efficiency, both in comparison with the need for deep treatment of run-off and their discharge into the water object, and the use of desalination systems as the main stage of water treatment.

Table 2. Specific efficiency of water reuse after different treatment steps

| Treatment step                          | The enlarged cost of treatment, rubles/m³ | Basic technology of seawater desalination | Possible consumers, specific efficiency, rubles/m³ |
|----------------------------------------|------------------------------------------|------------------------------------------|--------------------------------------------------|
| Mechanical treatment                   | 3,0-5,0                                   | 40,0                                     | Irrigated agriculture – 35,0                      |
| Complete biological treatment with nitride-denitrification | 25,0-30,0                                | 40,0                                     | Irrigated agriculture, replenishment of water supply sources of 2-3 classes, technical water supply – 10,0 |
| Deep biological treatment with MBR reactors | 30,0-35,0                                 | 40,0                                     | Irrigated agriculture, replenishment of water supply sources of 1-2-3 classes, technical water supply – 5,0 |

In General, the basic principles of waste water recycling systems can be as follows:

1. Use for the needs of drinking and domestic water supply exclusively natural water, fresh or salt/brackish.
2. Primarily for small and medium-sized rural settlements, the use of biological treatment facilities will allow the use of treated wastewater for the needs of irrigated agriculture, as well as replenishment of water supply sources-groundwater, taking into account the seasonal nature of these consumers. Such a solution will potentially receive up to 2.0 billion secondary water resources, and the economic effect of implementing this solution on the territory of the Russian Federation may amount to 20.0 billion rubles/year.

3. Primarily for medium and large settlements, the use of biological treatment facilities based on MBR reactors will allow the use of treated wastewater for the needs of technical industrial water supply, as well as replenishment of water supply sources. The potential market for the implementation of such a solution on the territory of the Russian Federation will amount to 20.0 billion secondary water resources, and the economic effect from the implementation of this decision may amount to 200.0 billion rubles/year.

Implementation of such schemes is possible within the framework of the current legislation, which provides for a significant increase in fees for the use of fresh natural water as one of the measures to reduce water consumption [8].

Acknowledgements
The work was financially supported by the Ministry of Education and Science, agreement № 14.575.21.0159. Unique project identifier RFMEFI57517X0159

References
[1] Report "On the state of the environment in the city of Moscow in 2016" / Ed. Kulbachevsky A O. - M.: DPIOOS; NIIPGI GSP, 2017. - 363 p.
[2] SanPiN 2.1.5.980-00 "Hygienic requirements for the protection of surface waters". Research Institute of Human Ecology and Environmental Health. Sysina A N, RAMS (Corresponding Member of the Russian Academy of Medical Sciences, Professor Krassovsky G, Professor, MD Zholtakova Z I), Moscow Medical Academy Sechenov I M (professor, MD Bogdanov M V), Russian Medical Academy of Postgraduate Education (MD Plitman S I, Ph.D. Bespalko L E), The Federal Center for State Sanitary and Epidemiological Supervision of the Russian Ministry of Health (Chiburayev V I, Kudravtseva B M, Nogogibchenko M K), the Department of State Sanitary and Epidemiological Supervision of the Ministry of Health of Russia (Rogovets A I).
[3] State report "On the state and use of water resources of the Russian Federation in 2015", Rybalsky N G, Omelyanenko V A, Dumnov A D, Demin A P and others. Moscow: NIA-Nature, 2016.
[4] SanPiN 2.1.7.573-96 "Hygienic requirements for the use of wastewater and their precipitation for irrigation and fertilization". Institute of Human Ecology and Environmental Health. Sysina A N RAMS (Corresponding Member of the Russian Academy of Medical Sciences, MD Georgiy Kravskovii, MD Rusakov N V, Candidate of Medical Sciences Kryatov I A, Ph.D. Tonkopyi N I, Ph.D. Pavlov V N, Bashara L A); Russian Medical Academy of Postgraduate Education of the Ministry of Health of Russia (Bespalko L E); Institute of Medical Parasitology and Tropical Medicine. E I Marcinovsky GCSEEN of the Russian Federation (Corresponding Member of the Russian Academy of Medical Sciences, MD Romanenko N A, MD Khizhnyak N I, Candidate of Medical Science Khromenko V E P, Cand. Skripova L V, MD Gafurova Z. M, Piven V I, Evdokimov V V, Evdokimov V I); Scientific Research Institute for Agricultural Use of Wastewater NIISSV "Progress" (Ph.D. L A Muzhenko, Ph.D. Kovaleva N A, Ph.D. Kutepov L E, Mishin S I, Sytin V Z, Peregokin S N, Ph.D. Zhirkov E I, Candidate of Biological Sciences Tereshina A N, Taranin Y I, Kaminskaya N I); All-Russian Institute of Fertilizers and Agricultural Science. Pryanishnikova D N (doctor of medical sciences Merzlaya G E, doctor of physical and mathematical sciences Afanasyev R A);
Engineering-geological and geocological research center of the IGTs of the Russian Academy of Sciences (Prof. Goldberg V M, VSKhIZO (Ph.D. Sayapin V P)

[5] GOST 2761-84. "Sources of centralized household and drinking water supply. Hygienic, technical requirements and selection rules". Interstate standard. Item 2.3.

[6] SanPiN 2.1.4.1074-01 "Drinking water. Hygienic requirements for water quality of centralized drinking water supply systems. Quality control. Hygienic requirements for ensuring the safety of hot water systems".

[7] SNiP 2.04.03-85 "Sewerage. External network construction". Soyuzvodokanalproekt (Mironchik G M - the head of the topic, Berdichevsky D A, Vysota A E, Yaroslavsky L V) with the participation of VNII VODGEO, Donetsk PromstroyNIIPROekt and NIIOSP named after Gersevanov N M Gosstroy USSR, Scientific Research Institute of Communal Water Supply and Water Purification Academy of Public Utilities named after Panfilov K D and Giprokommunvodokanal of the Ministry of Housing and Communal Services of the RSFSR, TsNIIEP of engineering equipment of the State Civil Engineering Agency, MosvodokanalNIIproekt and Mosinzhproekt of the Moscow City Executive Committee, the Research and Design and Technological Institute of Municipal Economy and the UkrkommunNIIproekt of the Ministry of Housing and Utilities of the Ukrainian SSR, Institute of Mechanics and Earthquake Resistance named after Urazbaev M T Academy of Sciences of the Uzbek SSR, Moscow Engineering and Construction Institute named after Kubyshev V V USSR Ministry of Higher Education, Leningrad Engineering and Construction Institute of the Ministry of Higher Education of the RSFSR.

[8] Decree of the Government of the Russian Federation № 1509 of December 26, 2014 "On Rates of Fees for the Use of Water Objects in Federal Ownership and Amendments to Section I Rates of Fees for the Use of Water Objects in Federal Ownership".