Current issues of energy efficiency in water consumption and discharge, and environmental safety in St Petersburg

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Abstract. The author attempts to determine current issues energy efficiency in water consumption and discharge, and environmental safety in the field of construction activities. A methodological rationale for measures to increase in water consumption efficiency is given. Mass discharges of polluted wastewater by industrial enterprises and utilities infrastructure, diffuse runoff from urban areas, industrial sites and agricultural fields result in total pollution of surface and many underground water sources in St Petersburg. The scenario for 2030 based on a predictable number population of approximately 6.5 mn people and a specific rate of drinking water consumption of 160 l/day is considered optimal. There is one paradox: efficiency enhancement measures would have to stabilize tariffs for water use and disposal, but they are actually rising. The author analyzes a number of priority measures are required to provide for the stable operation of the water use and disposal system in public utilities and urban enterprises. Author’s concept of the utilities infrastructure functioning involves the introduction of public private partnerships. To stabilize tariffs for water use and disposal, it is necessary to implement public private partnerships. However, it shall be carefully reasoned on the basis of full information and statistics on the housing and utilities infrastructure operation.

1. Introduction

The maximum level of contamination is observed in the areas of greatest industrial and agricultural development, where 2/3 of the country’s population lives. Up to the very Urals the purification systems are heavily worn, while in Siberia they are a rarity altogether. As it frequently happens, the rigorousness of sanitary regulations is offset by the loose attitude to complying with them. According to the Russian Federation Ministry of Natural Resource report ‘On condition and protection of the Russian Federation environment in 2007’, 51.4 bn m³ of main contaminants effluents were discharged with effluents in Russia. In 2008 it was 52.1 and in 2010 – 49.2 [1]. In recent years, the water quality of the Neva River, which is part of the general water system of the basin district of the North-West ‘The White Sea – Lake Onega – Lake Ilmen – Lake Ladoga – the Neva River – the Gulf of Finland’, which has a mutual influence and common sources of man-caused load, continues to deteriorate. Up to date, direct discharge of untreated or insufficiently treated wastewater continues in the area of the Okhta River, the embankment of the Karpovka River, the Admiralteyskaya embankment, the Petrogradskaya embankment, including from the objects of the coastal line of the Kurortny district of St Petersburg. In the central part of the metropolitan there are 22 thousand refuse sewer wells. Modern technologies for biological treatment of biogenic elements, advanced treatment and decontamination are implemented only in 23% of wastewater treatment plants, which does not allow to stably ensuring the required treatment quality. 75% of the sewers cannot be inspected for their technical condition due
to the lack of connections and duplicate sections. Also there is no sewage system control. It is impossible to correct a flow in the sewers and to control effluents to the treatment plant, especially during the rainy season. A system for measuring and monitoring of effluents and pollutants has not been created, which is why it is impossible to form a chemical balance of the wastewater system (pollutants balance in quantitative terms for chemical compounds, taking into account the pollutants entering the sewage system, the efficiency of contaminants removal at aeration stations and optimization of pollutants burden for water bodies during the discharge of treated effluents). And as known, a decrease in the efficiency of wastewater treatment plants results in a high proportion of polluted wastewater. St Petersburg is characterized by emergency discharges of polluted water, as well as illegal discharges bypassing treatment facilities at night (in Russia, generally, about 20% of untreated sewage water is discharged into water bodies without treatment, therefore, only 1% of the water sources used for public water supply complies with the 1st class of the quality, i.e. they can be used without treatment) [2-4].

The maximum phosphorus load and the largest amount of total nitrogen are accounted for the Neva Bay. The same can be said for heavy metals (Pb, Cr, Cu, Zn, Fe, Al, Mn). Chlororganic compounds are regularly recorded in Lake Ladoga in amounts exceeding the sensitivity of the analysis method used, in particular pesticides of the HCH and DDT groups, polychlorobiphenyls, heptachlor and hexachlorobenzens. The presence of strong widespread fecal contamination suggests a high level of anthropogenic impact in the Lake Ladoga basin. Thus, the water entering the Neva River from Lake Ladoga is already quite polluted by effluents from Karelia, a significant part of the North-West of Russia. The pollution is close to the maximum permissible concentration (MPC) level according to many indicators [5-6].

The author supposes that a sustainable development encompasses the equilibrium economical, technological and social state of certain territories with preservation of viable habitat in the country. The goal is the same indeed: creation of a favorable environment for the life of people and business, which could become a basis for maintaining the health and working ability of the population, balanced economic development of the state as a whole [7].

2. Materials and Methods
The analysis of criteria of environmental safety in connection with the sustainable development of the construction sphere is based on the experience of identification of the system-level eco-economic processes (it is a case of the method of ecological balance). The authors adhere in their scientific rationale to the well-proven dynamic model of Meadows group. Its subject matter consists in that the mankind has already exceeded the limits of self-renewal of the Earth’s eco-systems.

The optimization water use and discharge approach is typical of many scientific studies [8-12]. But hardly anybody of the authors considers the issues of tariffs’ stabilization for water use and disposal, necessity to implement public private partnerships and criteria of environmental safety in connection with the sustainable development of construction activities [13]. On the contrary, an issue of eco-economic equilibrium until now evokes fierce debates and remains to be one of the most complicated. D.L. Meadows, J. Randers, D., W. Behrens, D.H. Meadows, et alia have made the greatest contribution into implementation of this problem [14]. The works of V.I. Vernadsky, N.F. Rejmers, V.I. Telichenko, M.Y Slesarev, A.N. Tetior and many others can be distinguished [15-18]. In connection with the foregoing, the author has the following tasks: to consider the current issues energy efficiency in water consumption and discharge (as water consumption decreases, the energy costs of pumping stations are reduced also); to study the issue of sustainable development of water use and discharge for environmental safety enhancement; to analyze the conditions for budgeting communal infrastructure, as well as the possibility of involving public-private partnerships.

3. Results
The standards for receiving wastewaters from the community (350 L/day per person and more) were applied at the initial design stage of the trunk sewer tunnel (i.e. the main sewerage trunk collector)
diameter, resulting in a tunnel with an inner diameter of 3.2 m and outer tunnel diameter of 4.1 m. Good rainfall, the fall of which results in wastewater discharges through storm water inlets, occurs only during the year period from May to October; precipitation distribution across St Petersburg is uneven (a level of unorganized rain and melt water flow into the centralized combined and separate utilities water disposal system is approximately 12% of the total volume of treated effluents). Taking into account the pressure and gravity regimes, the expected liquid flow rate was assumed to be within a range of 0.7 m/s to 1.5 m/s, ensuring the removal of contaminants from the trunk sewer run, and the chosen diameter was considered sufficient for transportation during dry weather and in case of rain.

In St Petersburg there are two centralized water disposal systems: 1) a centralized combined and separate utilities water disposal system, in which part of the service areas has a combined sewage system receiving both utilities, industrial, and surface (rain, melt) waste water, and part – separate utilities one receiving only utilities waste water flows; 2) centralized separate rainwater dispose system, in which rainwater and meltwater are collected separately from the rest of the effluents and are partially discharged without treatment, are partially treated at surface flow treatment facilities.

In general, the water consumption of any country is determined by the general level of its development – in developed countries, agriculture accounts for up to 50% of water consumption, industry – up to 40%, and utilities needs – approx. 10%. In Russia, in 2019–2020, the bulk of the extracted water (64%) is used in industry, 17% – in agriculture and 19% – for drinking needs. Industry remains the most water-intensive sector of the economy, which accounts for more than half of the total volume of total water withdrawal from natural sources. In total, enterprises and thermal power plants consume an amount of water comparable to the total annual flow of the Yenisei and Lena Rivers.

In the period from 1975 to 1990, total water consumption in Russia was about 100 km$^3$/year; it began to decrease slightly only in the late 1980s, then there was a sharp and since 1995, a smoother fall, which continues now (Figure 1) [4].

![Figure 1. Change in water consumption in St Petersburg (in shares of the city water consumption in 1992).](image)

A brief comment should be made here on the increased regulations for receipt of effluents from the population in Russia. According to the SP rules (construction standards and instructions) in the 2012 wording, the norms of daily discharge of communal effluents in the districts of urban development must be established depending on the degree of provision of amenities in these districts and with due regard to climatic, sanitary, hygienic and other local conditions (see Table 1).

| Name of effluent source | Unit of measurement | max. daily water discharge, L | max. hourly water discharge, L |
|------------------------|---------------------|-------------------------------|-------------------------------|
| Residential buildings: | 1 resident          |                               |                               |
| with running water supply, sewage without baths | | 120 | 6.5 |
| with running water supply, sewage and baths with gas water heaters | | 225 | 10.5 |
| with centralized hot water supply | | 300 | 15.6 |
| with centralize hot water supply in buildings higher than 12 storey | | 400 | 20 |
The norm of effluent discharge is taken to be equal to that of water consumption. It is known that in the UK the norm of effluent discharge is 150-180-250 L/day. In St Petersburg, like generally in Russia, the standard norm for cold water consumption in houses without baths (7.01 m³ for a man per month) is overrated by a factor of two. Naturally, the effluent discharge is also overrated. For example, if the water consumption rate for 1 resident (in an apartment without a bath) is 120 L in a mean day, then in 30 days the water consumption will be 3.6 m³. If an apartment has no individual water meter, but instead of it a communal one is mounted, then the payment is made based on the standard norm (Table 2).

Table 2. Tariffs for water disposal in St Petersburg in 2018 (rubles/m³).

| Indicator                        | 2016 first half | 2016 second half | 2020 first half | 2020 second half |
|----------------------------------|-----------------|------------------|-----------------|------------------|
| Public service contractors       | 19.60           | 21.56            | 28.70           | 31.57            |
| Population (including VAT)       | 23.13           | 25.44            | 33.87           | 37.25            |
| Other consumers                  | 28.67           | 32.11            | 45.11           | 50.52            |
| Storm water sewer                | 19.65           | 19.65            | 27.61           | 30.92            |

As is clear from the table, the prices compared to 2016 increased by 62% despite the measures for increase in water consumption efficiency. The same regards to water disposal, which has got up by 64%, although the entire 2016 the storm-water sewers tariff remained constant. What is the reason? It should be noted that in St Petersburg the decrease in water consumption began in 1991 and it has decreased by 44% to the date (2020).

To the greatest extent, the consumption of cold water for drinking needs has been decreased. In St Petersburg, the forecast of drinking water consumption for the megacity for 2025 and 2030 was carried out according to seven scenarios, which, in addition to the projected population, also differ in the specific norms of drinking water consumption of the population in the range from 120 to 200 L/day per person and total water consumption considered in the range of 164 to 274 L/day per person. All scenarios take into account the transition to a closed hot water supply principle. The scenario for 2030 based on a predictable number population of approximately 6.5 mln people and a specific rate of drinking water consumption of 160 L/day is considered optimal and promising (Table 3).

Table 3. Forecast of drinking water supply in St Petersburg for 2025 and 2030 (L/day).

| Item No. | Indicator                               | Value 2020 | Value 2025 | Value 2030 |
|----------|-----------------------------------------|------------|------------|------------|
| 1        | Total specific water consumption, L/day per person | 251        | 229        | 219        |
| 2        | Specific drinking water consumption, L/day per person, including: | 182        | 167        | 160        |
|          | Cold water                              | 117        | 105        | 100        |
| 2.2      | Hot water                               | 65         | 62         | 60         |

As is clear from the table, the measures for saving drinking water supply taking into account the prospects up to 2030 will save significant volumes of water (more than one annual rate of cold water will be only saved for 10 years). Efficiency enhancement measures would have to stabilize tariffs for water use and disposal, but they are actually rising.

According to officials, the growth of standard norms is one of the measures urging the population to install meters and counters. The resident pays for water based on the meter readings with standard amount of effluents in our case being 7.01 m³. However, Gorvodokanal (City’s Water Supply and Discharge Department), does not make any amendments for the consumer though the actual water consumption has dropped. On the other hand, the suppliers say that the payment covers only 70% of their services, which is why the rates must be continuously increased. Resulting from the change of the socio-economic system in the state and due to coming up market relations in 1993 normative standards of water use were reconsidered both for the community and for the industry (Table 4).
Table 4. Water discharge pattern for the Russian population.

| Facilities provided with sewage | Specific mean daily (yearly) water discharge per one resident in built-up area (L/day) |
|-------------------------------|-------------------------------------------------------------------------------------|
|                               | Before 1990 | Before 2000 | 2019 |
| Towns                         | 500         | 550         | 350  |
| Villages                      | 125         | 150         | 160  |

This is due to the fact that under the sanctions regime, the amount of budget financing in St Petersburg just as throughout Russia has significantly decreased, and continues to decline. The social budgeting component is increasingly deformed. The new concept of the utilities infrastructure functioning involves the introduction of public private partnerships. But private investors with high investment attractiveness and the ability to upgrade production assets take its time to invest in this sector of the economy, since they do not consider it profitable, but too costly. There are reasons for this mistrust.

4. Discussion

The water use and disposal system will require huge investments with a payback of several decades. The housing and utilities infrastructure sector is one of the most energy-consuming and technologically difficult. In addition, it is extremely difficult to implement the measures to increase energy and environmental efficiency [19-20]. The water-and-sewage complex cannot survive due to private investment, especially in conditions of economic stagnation and population poverty increase. For example, a share of electricity in the tariffs of water supply and disposal enterprises in St Petersburg is more than 35% (the main energy consumption is associated with of pumping stations operation: 29% is accounted for water rising and 63% – for pumping), and it is necessary to purchase water at market. In Russia, about 8% of pipelines are in pre-emergency condition, 38% of water pipelines do not have the necessary system of treatment facilities for water decontamination, 21% of water is lost in housing stock networks due to pipes corrosion and wear. In St Petersburg, 65% of the city existing water supply network has been in operation for over 40 years and is in pre-emergency condition, but repairs are not being carried out due to a lack of funds. A significant decrease in water consumption in the city resulted in changes in the hydraulic mode of the supply and distribution of tap water, the speed of water flowing in pipelines (especially in urban areas remote from water plants) sharply decreased, water quality deteriorated due to stagnation. At most sewage effluents treatment plants there is deterioration of process equipment, mechanical and biological treatment facilities. Thereby, the used technologies do not provide wastewater treatment to the level of standard fishery and sanitary-epidemiological requirements for discharge. For example, only 19% of the total volume of treated wastewater is subjected to ultraviolet disinfection before discharged into water bodies. Sewer networks deterioration is 78%.

Previously, a unified technique and regulatory documentation should be developed based on the analysis of occurred accidents, continuous monitoring of networks, statistics on methods for repair and restore of pipelines and sewers. Only then private investors should be gradually attracted. Otherwise, the transfer of the entire housing and utilities infrastructure sector to private companies could result in the destruction of energy-efficient and rational parts of the water supply and disposal system. On the one hand, in terms of the international sanctions regime against Russia, it is not possible to ensure the transparency of private companies by transferring to international accounting standards for each type of activity with enormous costs to upgrade the water supply and disposal systems. On the other hand, corruption among officials, a high percentage of investment risk in Russia (traditionally, any investment risks in Russia are higher than in developed countries), consistent reduction in the key rate by the Bank of Russia, etc. can interfere with an independent audit within the country to determine real investment needs, with subsequent identification of costs and investment needs and its coordination with the tariff control of other natural monopolies (in particular, with the profitability of other industries).
Thus, to provide for the stable operation of the water use and disposal system in public utilities and urban enterprises, a number of priority measures are required: improvement of forms and methods of management, financing and pricing in the housing and utilities infrastructure sector (while it is possible to restore the pre-emergency condition of the system primarily based on the state budgeting); timely and quality repair and replacement of worn-out components of water supply networks; optimization of the hydraulic mode of water supply network operation; equipment of pumping stations with energy-saving devices; the use of water-saving fittings; installation of apartment water meters and head controllers in the internal water supply systems of buildings; maintenance of sewer networks in good condition; minimization of operational costs; widespread implementation of pollution sources monitoring system (to obtain statistics on the shares of economy sectors in the total pollution of water bodies), increase in the pipelines service life due to modern automation, control and analysis equipment; timely and reasonable reconstruction of networks, etc.

In addition, it should be noted that very serious problems can arise in view of global climate change. For Russia, changes in the precipitation regime caused by global warming are likely to be unfavorable. Important changes in both the average annual surface air temperature and the total annual precipitation will occur in the first half of the 21st century. In the European part of Russia, deterioration in available water supply is predicted. However, the forecasting changes in precipitation regime look more disturbing. The expected significant increase in the unevenness of precipitation means a simultaneous increase in the threat of both floods and droughts within this territory. All this indicates the imminent extremely adverse impact of climate change on hydrological characteristics, which are fundamental both for available water supply, and to reduce flood damage to water disposal systems. In addition, it should be remembered that the direct impact can be increased by indirect effects from the watersheds ecological situation deterioration [21].

5. Conclusions
Finally, it is necessary that source control techniques be designed to counter increased discharge of water. Buildings should be provided with power saving technologies, hot water recirculation systems. In addition, it is necessary to modernize the existing hot water supply facilities, and to install low-cost highly efficient small heat exchangers – instead of obsolete locally based boilers – rather than just increasing the norms, coefficients and tariffs.

In order to stabilize tariffs for water use and disposal, it is necessary to implement public private partnerships. However, it shall be carefully reasoned on the basis of full information and statistics on the housing and utilities infrastructure operation. The high degree of main electromechanical equipment deterioration, pipelines emergency condition due to microbiological corrosion, secondary pollution by corrosion products and other engineering deficiency in the water use and disposal system can only be corrected with the help of significant budget investments. Following the example of St Petersburg the big industrial cities will build plants for burning sediments. The burial ground disposal and disposal at the landfills will remain in the middle and small communities. However, the problem of rational and efficient waste management is still not resolved in Russia.

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