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The development of water supply and sewerage systems in St. Petersburg

Today's society, technological systems and environment are the historical results of some initial ideas, suggestions and projects, regardless whether they were fulfilled or not. Time changes our perspective: What is now regarded as an obsolete technology was once a major technical innovation. On the other hand the solutions for the future often recycle those ideas used in our past. Large technical systems change slowly - thus historical knowledge helps to understand the future, too. This article presents a brief historical review of water management in St. Petersburg, Russia. The most important changes in the development of the water supply and sewerage system in the city over the past three hundred years are discussed from a comparative point of view in order to detect relationships between them.

INTRODUCTION

St. Petersburg is the biggest city in the Baltic Sea region with a population of about five million. The city is situated on the estuary of the Neva River, on the isles and lowlands of its delta. The Neva River runs from Lake Ladoga (the largest lake in Europe, 17,600 km^2) into Neva Bay (the eastern part of the Gulf of Finland) and constitutes an important navigable thoroughfare along its entire course (Figure 1).

From its very beginning until now, the life of this growing city has been significantly influenced by the natural and climatic conditions of the area, especially by frequent floods (289 in number) sometimes turning into real natural calamities. The most significant and disastrous of them took place in 1777, 1824 and 1924, causing huge material and human losses [1, 2]. Nowadays the city is partly protected by the flood prevention facilities built from the northern coast of Neva Bay to the Island of Kotlin (Figure 2). The most recent flood occurred on 18-19 October 1998 (the water level rose to 2.20 m).

Another characteristic feature of St. Petersburg is the abundance of water resources: About 10% of its administrative area is covered with water. There are six large lakes within the city limits, and 69 watercourses with a total length of as much as 217 km, 32 km of which is the Neva River. During the period of St. Petersburg's existence, its hydrographic structure has undergone considerable changes. Projects for the construction of canals, ponds, and land reclamation have been carried out. Due to small gradients, many water reservoirs have become fouled, which has resulted in stagnant and contaminated water. Therefore, as

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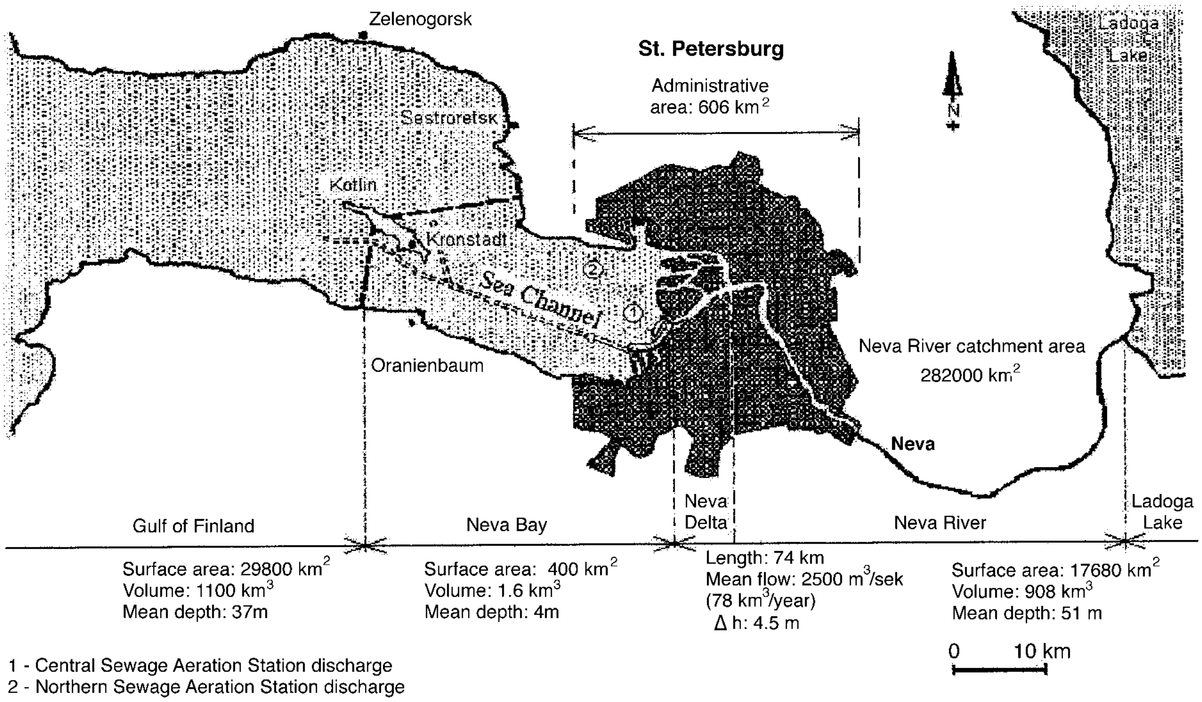

Figure 1. Water system: the Lagoda Lake – the Neva River – Neva Bay – Gulf of Finland

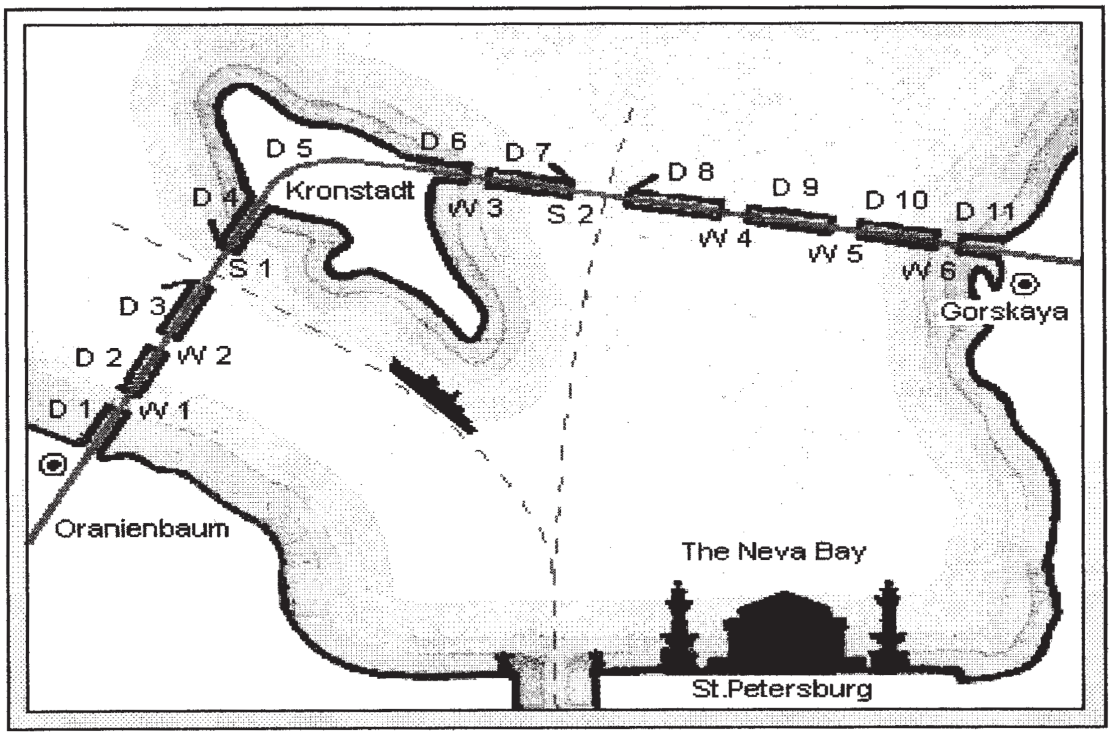

Figure 2. Plan of the Flood Prevention Facilities Complex (a design):
D1–D11: dams; S1–S2: ship outlets; W1–W6: water outlets

early as in the 18th century some polluted and useless canals and streams were filled in. In addition, the bank line of the Neva River and its branches were straightened in the process of the construction of embankments and the drainage of marshes. Thus, since 1870 up to now the number of islands in the Neva delta has steadily decreased from 101 to 42 [3, 4].

More than one hundred written studies covering various aspects of the city water system were published already in the 18th and the 19th centuries, the first one dating back to 1724. Most of them were about floods. The water supply was given much less attention and the first studies concerning directly the removal of municipal waste were not published until 1874 [10]. No analysis of the water supply in relation to waste water disposal has been undertaken in an integrated retrospective form (although some fragmentary data and general historical overviews on the topic may be found in few sources [5-9]). Hence this paper is the first to trace in a comprehensive way the development of water supply and water disposal systems from the historical point of view, as well as to detect the relationships between this development and the changes in the sanitary and ecological situation in St. Petersburg.

BRIEF HISTORY OF THE DEVELOPMENT OF ST. PETERSBURG

Founded by Peter the Great in May 1703 as a military fortress and a trade port, St. Petersburg already became the capital of Russia by 1712. The population of the city grew rapidly and reached almost 100,000 in 1750. At the end of the 18th century, over 200,000 people lived in the city and four large factories were already in operation. In the second half of

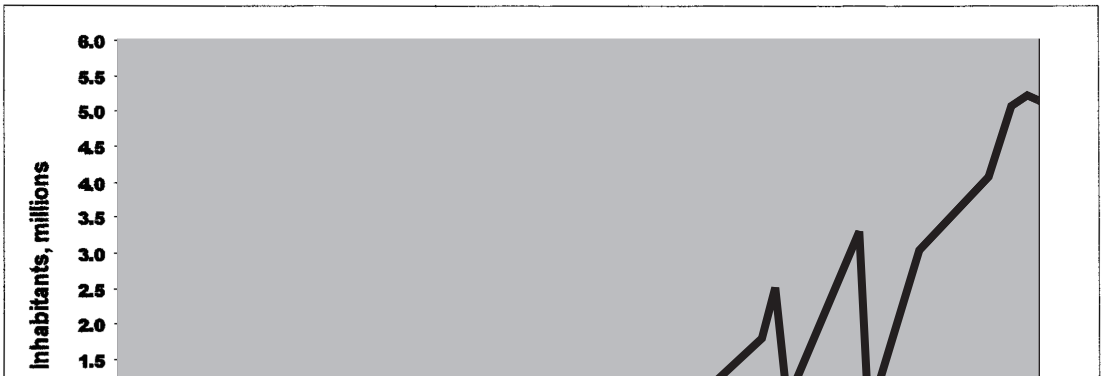

Figure 3. Population growth in St. Petersburg [12].

the 19th century the capital was a major seaport (40% of the country's freight turnover) and a focus of trade, lending and banking operations. By the early 20th century the city had taken its final shape as a masterpiece of both national and foreign urban development and architecture [1, 11].

During the history of St. Petersburg its population steadily increased, except during the Civil War and World War II. Along with this growth and industrial development the city expanded and, correspondingly, the average density of the population decreased (Figure 3).

WATER SUPPLY AND WASTE WATER DISPOSAL IN THE 18TH CENTURY

Water supply

The Ligovsky water supply canal is considered to be the first artificial water supply facility in St. Petersburg. It was constructed in 1725 to supply spring water to the Summer Palace of Peter I and the fountains of the Summer Garden. The total length of the canal was 27 km [7].

Waste water disposal

In 1717 Peter I issued special regulations to prevent streets from being littered with municipal waste. In 1719, considering the paramount significance of water bodies for the city, Peter I signed a similar decree ordering that no dung or litter was to be thrown into the Neva or other rivers [9, 11].

As the city was founded at the mouth of the river in a marshy area, it was necessary to pay special attention to the removal of rainwater during street construction. Water-diversion ditches were built along the streets and strengthened with wooden boards. Already at the time of Peter the Great underground pipes for water collection were laid in some areas [10, 13].

In the second half of the 18th century European novelties were introduced in the construction of new houses, and wooden pipes made of drilled logs were laid (15.24 cm in diameter) through which sewage and rainwater was discharged into watercourses. Pursuant to an edict issued by Catherine II in 1770, the construction of underground canals for rainwater drainage was started in the central streets of St. Petersburg. Pipes were made of bricks or wooden shields assembled of plates. Pits were dug at certain points and covered with metal screens. Surface water flowed through them into the pipes and then into rivers and canals. Underground pipelines were laid in a haphazard way with inadequate gradients or sometimes without any gradient at all [13, 14].

WATER SUPPLY AND WASTE WATER DISPOSAL IN THE 19TH CENTURY

Water supply

Until 1825 the whole population of the city took water by pails straight from the Neva River and nearby watercourses. The first waterworks equipped with manual pumps were built in 1826. The water was obtained from the Neva River and then delivered to the citizens by water carts. It was expensive but rather pure and appreciated as well.

In 1846 the first private water enterprise was established to construct a centralised water supply system in two parts of the city, but it turned out to be unprofitable and was soon closed down. The same fate was shared by another company, which was established in 1853 but closed after a couple of years.

The next attempt was more successful. The government approved the design in 1859 and on 30 November 1863 piped water was delivered for the first time. The Main Water Supply Station, completed not until 1866, was equipped with rough bar screens (Figure 4) [6,7,15]. From 1873 to 1877 water supply pipelines and three new pumping stations were constructed on the right bank of the Neva River, also without treatment facilities except for sieves.

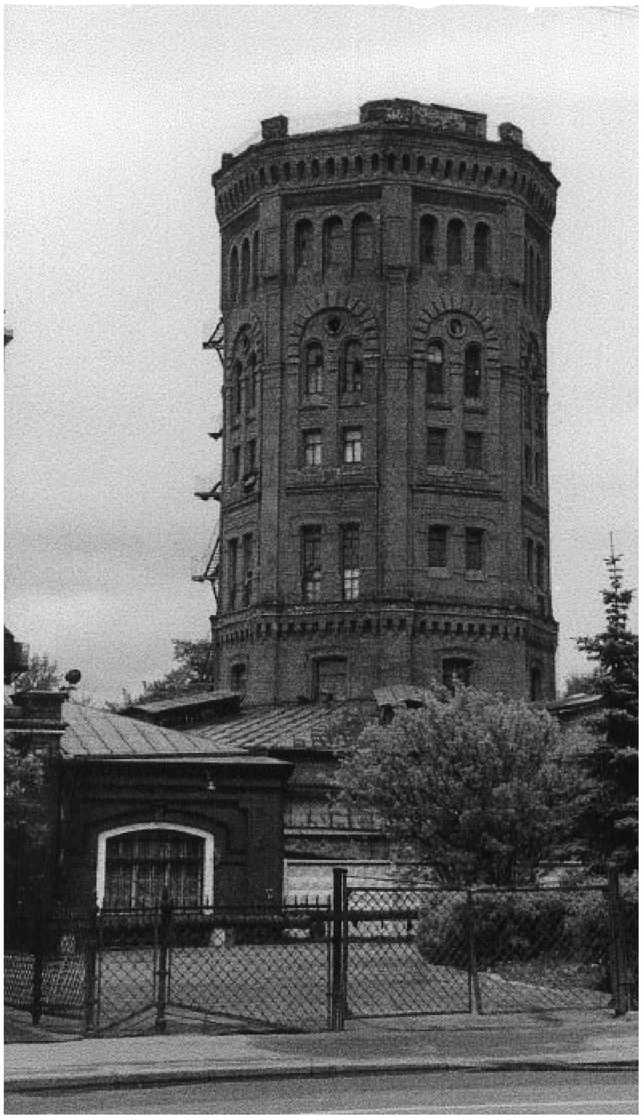

Figure 4. Water tower and the workshops are still in operation at the Main Water Supply Station. Water tower regulates inner pressure in the network.

Poor water quality caused frequent epidemics in the city. To improve the situation in 1887-1889 slow sand filters were built, similar to the design of Berlin. The Main Water Supply Station produced nearly 120,000 m^3 of purified water per day, but despite all efforts the filters operated imperfectly [16].

The first water supply network was only 113 km long. It was extended to 140 km by 1877 and became 80 km longer by spring 1878. In 1883 the network length reached 260 km. In the early 1890s water pipelines covered almost all parts of the city, supplying them with potable water. By 1893 the length of the network on the left bank was 256 km and that on the right bank was 81 km [6, 7]. By that time all private water companies had become municipal. As special emphasis was laid on the water quality, new filtering facilities were installed, and alternative sources of raw water were sought. Lake Ladoga and some countryside water bodies were considered, but no decision was made to construct a new system.

Waste water disposal

The first attempt to construct a closed sewage canal was made in 1818 along the Fontanka River. However, it was not completed because of the lack of money [17]. Nevertheless, by 1834 the length of municipal underground drainage pipelines in the streets of St. Petersburg had reached 95 km. In Paris the length of total drainpipes was just 45 km in 1830 [18]!

Indoor hygienic equipment of that time could be used on the condition that the sewage was carried away. House lavatories were arranged in the yards (earth closets), in lean-tos or under stairways and in warm premises only in houses with modern amenities. To collect sewage from lavatories, cesspits were dug in backyards with walls laid in wood or stone. House owners were responsible for cleaning the cesspits. Sewage was transported to vegetable gardens and landfills, often located within the city limits, by means of primitively equipped sanitation carts. In the summer period waste could be dumped also into Neva Bay from barges [19, 20].

With the growth of the population and increases in the cost of sewage removal, owners of apartment houses started to make unauthorised connections from cesspits to street drains, thus discharging sewage into rivers and canals. In 1845 intensive pollution of water bodies forced the government to issue an ordinance making it illegal to connect cesspits to municipal pipes. However, this ordinance was not enforced firmly and unauthorised connections to street drainage went on [8,13,17,21].

By 1848 the water in canals as well as in small rivers had become so filled with waste that it became necessary to carry out an extensive dredging operation financed from the city budget in order to make them navigable again. However, that turned out to be not enough from the sanitary point of view, as the average death rate in St. Petersburg was usually more than forty-seven people per thousand and in some parts of the city up to seventy during epidemics. In addition, the extreme density of the population eased because of the diseases [22]. Such data caused much concern, but only after several cholera epidemics did St. Petersburg's authorities take more drastic measures to improve the situation [6]. After the construction of water pipelines had been started in St. Petersburg, it became evident that water supply could not develop without a sewerage system. Therefore, in 1864 the Municipal Government appointed a special commission responsible for the construction of pavements and sewage removal pipelines. In 1865 the first competition was announced for the submission of proposals for waste water disposal projects [8,13,15,23].

In the late 1860s, after the centralised water supply system had been constructed, the first baths and water closets appeared in the houses. Besides these appliances, cesspits were still set up in backyards. By this time sewerage in St. Petersburg was simply a fragmented system of hundreds of sewers. Many of those pipes were out of operation or clogged, which caused flooding of the basements, which were usually inhabited by the poorest people. This was additionally aggravated by rapid industrial growth: There were about four hundred industrial and handicraft enterprises in St. Petersburg by the end of the century [3, 4].

WATER SUPPLY AND WASTE WATER DISPOSAL IN THE 20TH CENTURY

Water supply

By the early 20th century, water pipelines on the left and right banks of the Neva River had become 313 and 120 km long, respectively [6, 7]. Potable water was not disinfected till the last severe cholera epidemic, which started in 1908 and could not be suppressed within a few years [22]. In the early 1910s disinfection technologies at water supply pumping stations were gradually introduced. Thus, to provide the northern part of the city with clean water a new treatment station was built in 1911. Raw water there was subsequently treated with coagulant (aluminium sulphate), supplied to sedimentation tanks, then to rapid sand filters and finally ozonised [5]. In 1913 the disinfection of drinking water by chlorination was implemented at the Main Water Supply Station. Figure 5 depicts this sequence as it was in operation in 1913.

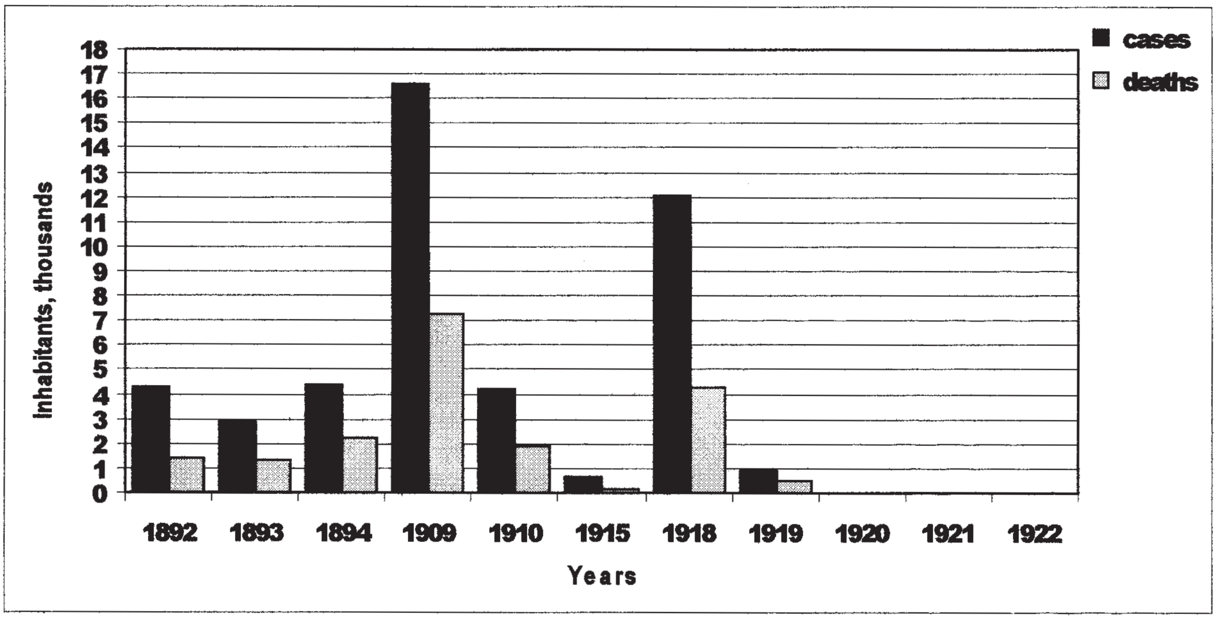

Figure 5. Cholera cases and deaths in St. Petersburg in 1892–1922 [24]

However, the main problem was that the Neva River was exposed to contamination. In 1914 the Municipal Government approved a plan to take raw water from the Ladoga Lake [25]. In spite of high estimated costs, the construction was about to be started, when in July 1914 World War I broke out, followed by the Revolutions of 1917 and the Civil War of 1918-1922; thus the solution was not implemented. By that time, the development of water treatment facilities had not been meeting the city demand and there was a period when the Main Waterworks were partially supplying unfiltered and infected water, due to the absence of chlorinated lime water (1918-1919), which caused the last epidemic outbreak (Figure 5). Cholera cases have not been recorded since then.

The development of the water supply system during the post-revolutionary period resulted mostly in the constant growth of the network length and the capacity of raw water treatment complexes. The only notable technological change was the implementation of the treatment methods based on contact coagulation.

Waste water disposal

By 1917 altogether sixty-five sewerage system designs had been drawn, submitted and considered by various commissions (those of Burov, Alexeevsky, Popov, Lindley, Wulf, Rikkert, Griboyedov, Shishko, Ruzsky and many others) [26-36]. Among these, the projects designed by the specially hired British engineer William Lindley in 1876-1900 [26-28] and in 1912-1913, as well as the design by Professor D. P. Ruzsky, approved in 1914 but dropped due to the outbreak of World War I [34-36], should be mentioned particularly (Figure 6). More than fifty years of sewerage system designing have resulted in a great variety of approaches towards the improvement of the sanitary situation in St. Petersburg. Different systems have been proposed: combined, separate and combined-separate. Collectors were oriented to all directions. Depending on the plan, waste water discharge was arranged at one point or several points, near the city or far from it, into Neva Bay or to the nearby fields [37]. Pumping stations were equipped with steam or electric machines. Different types of mechanical, biological and chemical treatment and also combined methods were proposed [38]. Several ways of sludge disposal were under consideration: drying, briquetting, incineration, use as a fertiliser, dumping into the sea, burying in the ground, composting and use for land reclamation.

In 1917 the total length of streets in the city was nearly 800 km and that of sewage pipelines was only 486 km, including 356 km of wooden pipes (or 44% of the streets) and 130 km of concrete pipes (or 16% of the streets). Hence 314 km of streets (or 40%) had no sewerage at all [8, 23].

The actual implementation of a sewerage system including a pipeline network and pumping stations was not

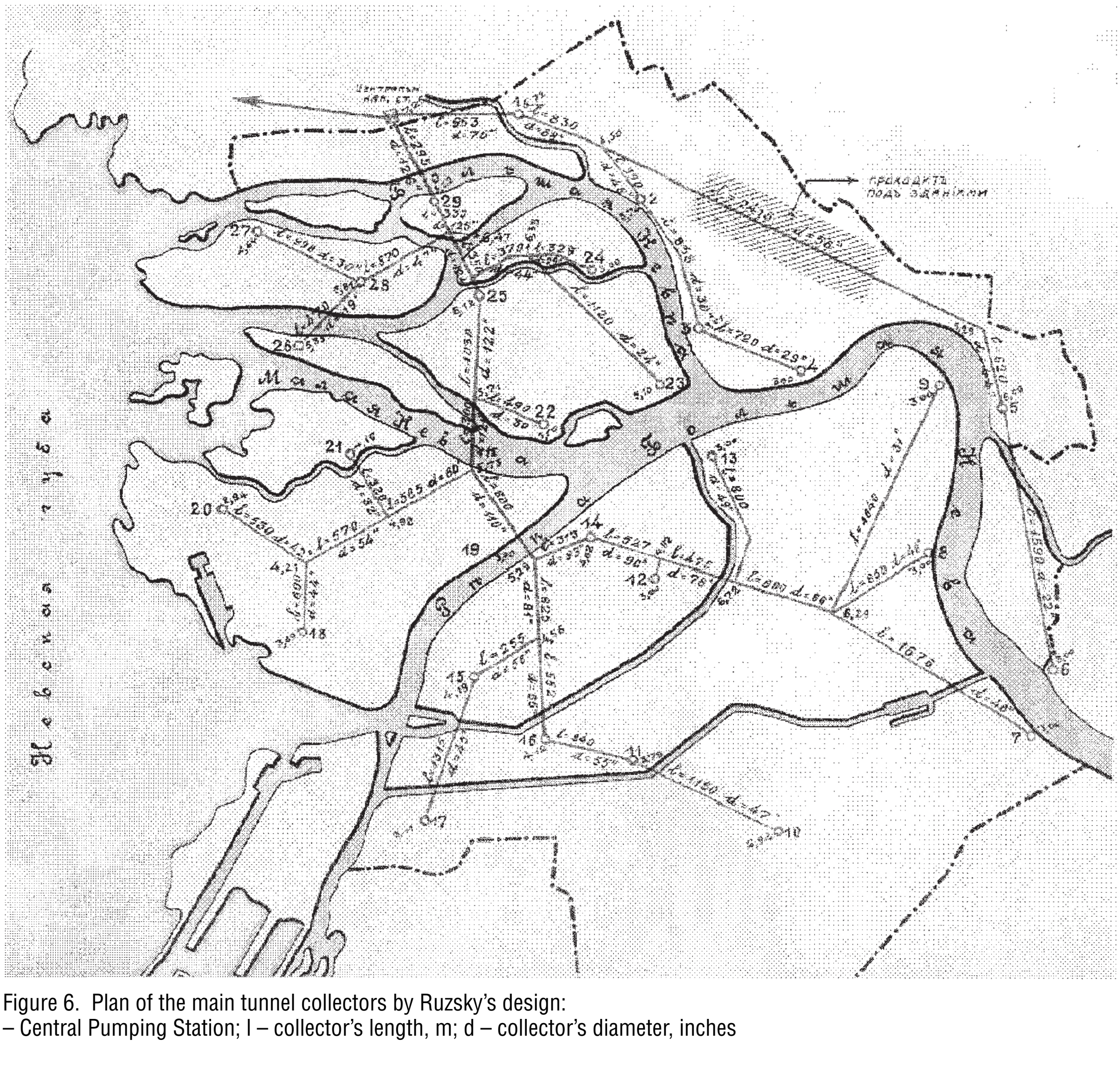

Figure 6. Plan of the main tunnel collectors by Ruzsky's design:
– Central Pumping Station; l – collector's length, m; d – collector's diameter, inches

begun in Leningrad until 1925, based on the design of Professor N. K. Tchizhov, which was officially approved by the City Council in the same year [23]. The construction of the first sewage pumping station was not completed until 1930 (Vasilievsky Island Sewage Pumping Station). The main difficulty was that the flat topography and large network length resulted in the need to deepen the sewers and to insulate both pipes and wells hydraulically. In 1890 Professor Tchizhov had established a Waste Water Disposal Chair at the St. Petersburg State University of Architecture and Civil Engineering [39].

These events were preceded by the outstanding studies of the sanitary conditions of Neva Bay, which were carried out in 1911-1913 under the leadership of Professor G. V. Khlopin. Due to these studies the most suitable locations were found for waste water discharges that would have maximised self-purification processes and would have brought minor hazards to the water basin [40]. For a long time no sewerage project could be considered if it was not based on the results obtained by Professor Khlopin. Thus, for example, the Galerny and Korabelny Fairways, which had been dredged for shipping, were mainly recommended for sewage disposal purposes. And later the sewer outlets from Vasilievsky Island Sewage Pumping Station were directed exactly to this location, providing a better water exchange.

Meanwhile, there was almost no water treatment except for a rough mechanical process. This can be partly explained by the fact that the Neva River and Neva Bay possess a rather high self-purification ability [40, 41]. According to Professor Khlopin's research these water basins were able to cope with the pollution before contaminated water reached the town of Kronstadt, situated on the Island of Kotlin. The construction of sewage treatment facilities was also delayed by the implementation of potable water disinfection since 1911, which diminished the danger of infectious diseases [5, 22].

Nevertheless, the expansion of the city and the growth of its population as well as industrialisation continued to affect both the inner water bodies and Neva Bay. That was confirmed by numerous investigations made in the 1930s and 1940s [42, 43]. The necessity of waste water treatment facilities became evident when extensive studies of the Neva Bay's sanitary state were carried out by scientists of the St. Petersburg State University of Architecture and Civil Engineering under the leadership of Professor N. F. Fedorov in 1960-1963. These studies, made at the same inspection stations as those in 1911-1913, showed that the pollution level of Neva Bay had increased drastically between 1913 and 1963 (Figure 7). Complete mechanical sewage treatment facilities were recommended for construction first, with an area reserved for biological treatment [44].

The first waste water treatment plant with activated sludge was put into operation in 1978 on an artificial island, White Island. The area of its main location is 57 hectares and its rated capacity of 1.50 million m^3 per day was reached in 1985 (Figure 8). In 1986 the second biological waste water treatment plant (Northern Sewage Aeration Station) was built near Olgino, a suburb of St. Petersburg, with a capacity of 0.60 million m^3 per day. At present its main site area has reached 65 hectares and the daily capacity has been increased to 1.25 million m^3, but the station treats only about 0.65 million m^3 of domestic sewage, industrial waste and rainwater. Figure 9 shows how this has influenced the Neva Bay's sanitary condition: a certain decreasing tendency in the water basin's faecal pollution level (in terms of BOD_5), which had progressed till the late 1970s [45, 46]. Nowadays the stabilisation of the environmental situation is also being supported by a reduction of the industrial production. Meanwhile, the actual improvement of water quality started after the construction of biological sewage treatment facilities [45-48].

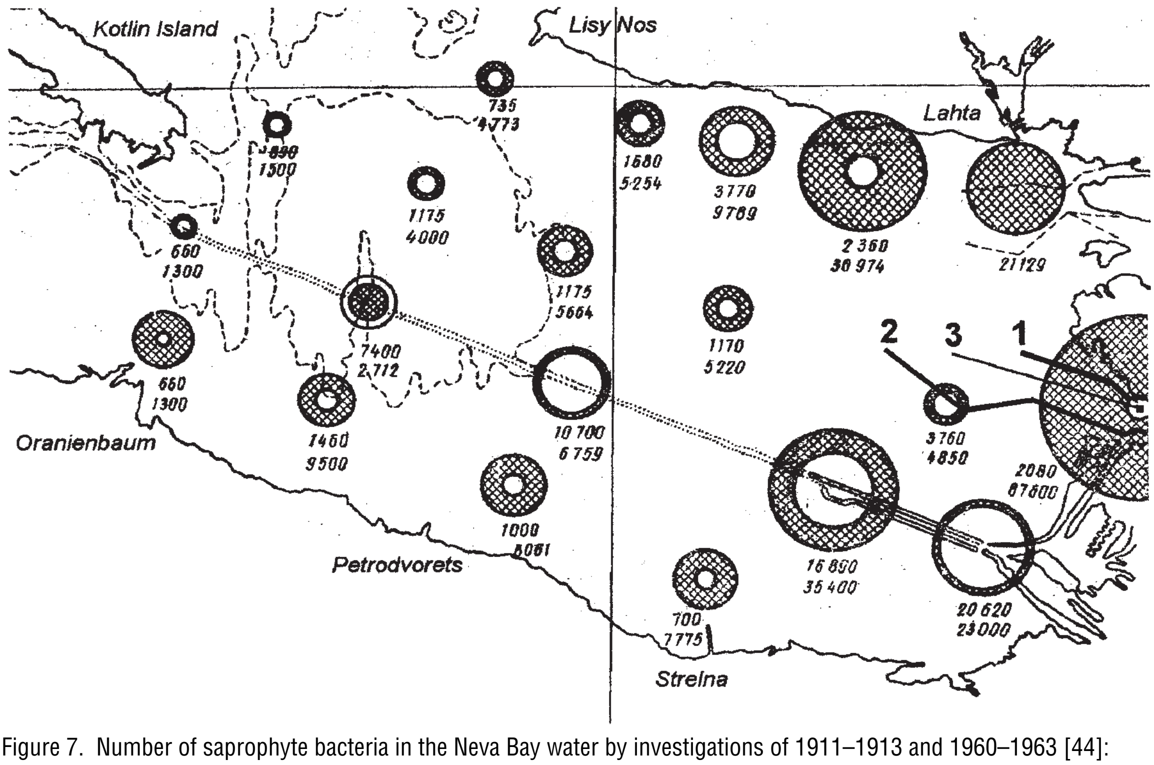

Figure 7. Number of saprophyte bacteria in the Neva Bay water by investigations of 1911–1913 and 1960–1963 [44]:

○ Saprophyte bacteria colonies per ml, 1911-1913 ● Saprophyte bacteria colonies per ml, 1960-1963

1- Galerny Fairway, 2- Korabelny Fairway, 3- Vasilievsky Island Sewage Pumping Station discharge

Figure 8. Central Sewage Aeration Station – the largest waste water treatment plant in Europe

CONTEMPORARY ST. PETERSBURG

At present St. Petersburg's water network is 4,419 km long. The combined sewer and tunnel collector length is 6,201 km. The ageing of the pipes is one of the core problems. Six hundred ninety-seven kilometres of pipeline (or 16%) is more than fifty years old, which exceeds all admissible maintenance standards. Only 805 km (or 18%) of the water supply pipelines are less than ten years old. Consequently, leakage, soil erosion and sagging are quite acute problems today. Moreover, the leakage of sewage is polluting the groundwater. Nowadays foreign knowledge (Insituform, Channeline, Trolining and other technologies) is being applied to rehabilitate the pipelines without tearing up the roads.

The mean daily consumption is currently 3.20 million m^3. To treat such a huge amount of water, the city has five water supply plants consisting of water intake and treatment facilities, primary and secondary pumping stations. There are also fifty-five clear wells with an aggregate storage capacity of 721,000 m^3, sixteen large boosting substations, approximately 60,000 shutoff valves and about 19,000 fire hydrants. Regardless of all efforts made to provide clean water to the citizens, water quality remains a major concern in St. Petersburg. Occasionally the water treated with contact clarifiers does not meet Russian and European requirements. Therefore, the introduction of more reliable, though more expensive, flotation treatment systems (ensuring subsequent filtration) is planned.

The present sewerage system of St. Petersburg consists of almost 414,000 wells and two municipal WWTPs with a total capacity of 2.75 million m^3/d. All waste water is discharged into Neva Bay and the Neva River. The Neva is a relatively short (74 km) river, with an average flow of 2,500 m^3 per second. Hence the volume of sewage from waste water treatment plants is small (no more than 2%). However, its impact on the water quality of Neva Bay is significant. The Neva River contributes about 50% of the Neva Bay's mean BOD_5 value, approximately 40% of it is waste water. In terms of phosphorous the share of sewage amounts to 60%. The pollution of the basin still remains the most vital problem.

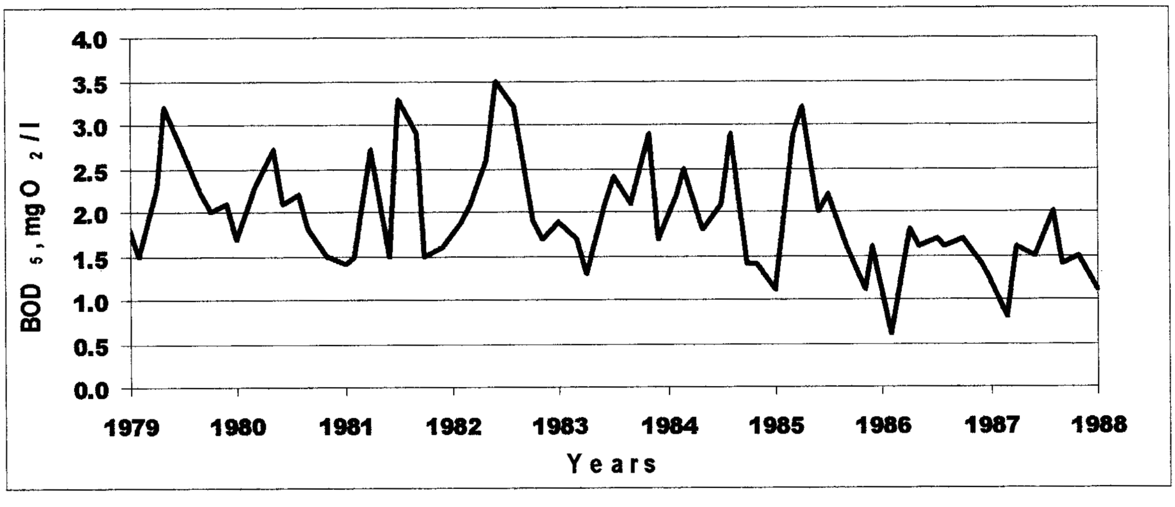

Figure 9. Changes of the mean BOD_5 values in the Neva Bay [47]

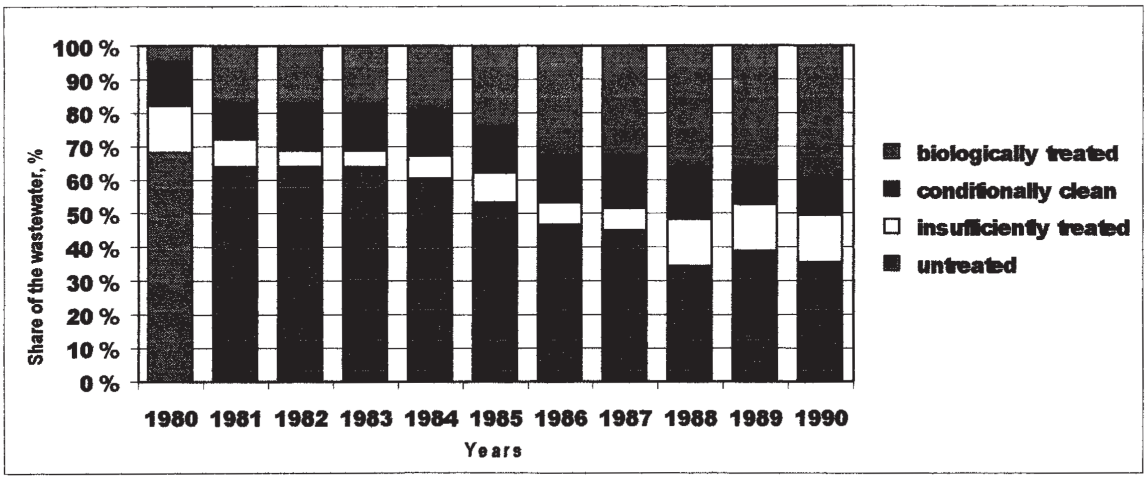

Figure 10. Waste water treatment in St. Petersburg [45,47]

Significant volumes of industrial and surface wastes are discharged into water bodies insufficiently treated or without any treatment at all (Figure 10).

A vast programme, aimed to prevent untreated sewage effluence to rivers and canals by 2005, envisages the construction of two lines of deep-laid municipal collectors with the subsequent diversion of direct discharges into them, and completion of the Southwest Waste Water Treatment Facilities project.

The share of industrial waste water (with typically significant amounts of petroleum products, heavy metals, wastes with high COD and other contaminants) in the overall volume of municipal sewage is rather high (35-40%), which essentially complicates the operations of waste water treatment plants and prevents the use of sludge as a fertiliser. Permanent efforts have been made to diminish solid deposits through centrifugal dehydration with precipitation preheating, incineration and other procedures. In 1997 the largest slurry incineration plant in Eastern Europe was constructed at the Central Sewage Aeration Station (Figure 11), although the first project of sludge incineration dates back to 1908. The amount of ash is ten times smaller than the amount of dehydrated sludge (about 750 m^3 daily). The ash can be used as an additive to concrete. Recently JSC «Baltvod» developed a method of using sludge as a raw material (Vermipolymer) in the rubber industry.

Eutrophication of the Baltic Sea has also brought new challenges to St. Petersburg. The removal of biogenic substances should be considered because the activated sludge method applied on municipal waste water treatment facilities is intended mostly to remove organic matter from the effluent with a BOD_{20} reduction down to 6-7 mg O_2 per litre (Table 1). Which nutrient should be removed: nitrogen or phosphorus? What processing method should be applied? A combined method is preferable from the point of view of environmental issues, but more expensive as well. The opinions of both ecologists and technologists vary greatly, but it is quite clear, however, that this problem should be solved on a regional level. Certain international agreements are required; at present we have none. Because St. Petersburg's waste water biological treatment facilities do not prevent eutrophication in some coastal areas of Neva Bay as well as in the eastern part of the Gulf of Finland [45, 47], the problem of nutrient removal from sewage is very important now [49].

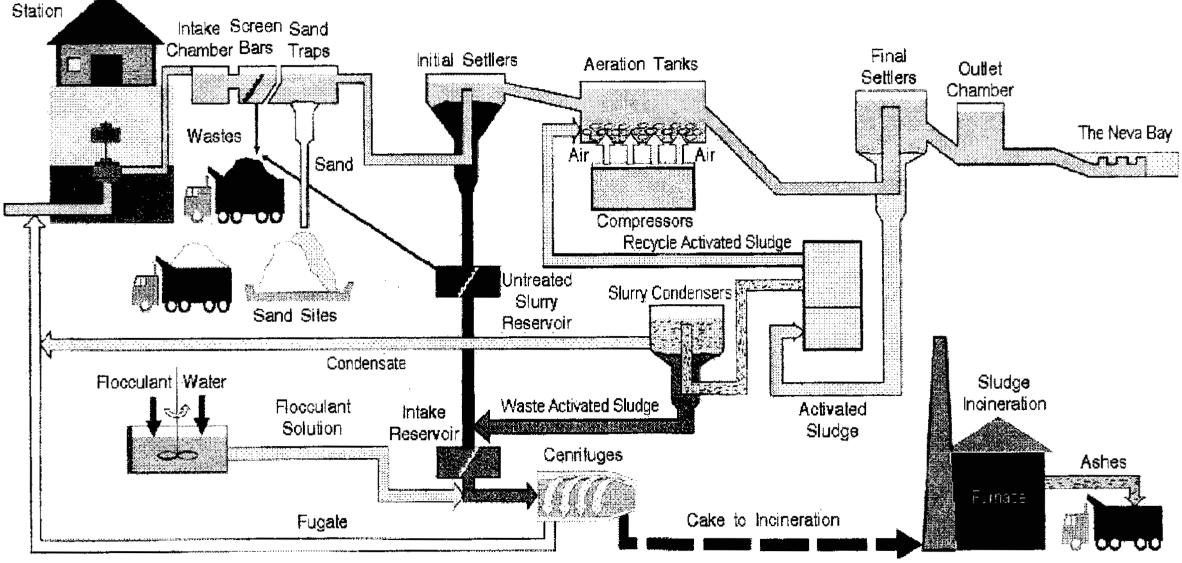

Figure 11. Waste water treatment technology at Central Sewage Aeration Station

Table 1. Waste water quality at Central and Northern Sewage Aeration Stations

Parameters	Units	WWTP, 1998 Untreated	WWTP, 1998 Mechanically treated	WWTP, 1998 Biologically treated	WWTP, 1998 Treatment efficiency %	WWTP, 1997 Untreated	WWTP, 1997 Mechanically treated	WWTP, 1997 Biologically treated	WWTP, 1997 Treatment efficiency %
Temperature	°C	21.0	22.0	23.0	–	18.7	18.8	19.2	–
pH		6.83	6.87	6.50	–	7.10	7.20	7.30	–
Transparency	cm	5.27	7.17	>30.00	–	2.20	2.80	>16.00	–
Dissolved oxygen	mg/l	6.9	5.1	8.6	–	3.5	3.6	6.5	–
Suspended solids	mg/l	190.0	62.3	5.5	97.11	370.0	290.0	8.5	97.70
BOD_{20}	mg O_2/l	230.0	130.0	9.3	95.96	200.00	160.0	4.8	97.60
BOD_5	mg O_2/l	86.7	52.7	2.6	97.00	110.0	88.0	2.7	97.55
COD	mg O_2/l	260	170	46	82.31	440	360	40	90.91
Evaporation residue	mg/l	300.0	310.0	300.0	–	310.0	300.0	280.0	9.68
N_{tot}	mg/l	22.4	16.9	8.9	60.27	35.0	32.0	13.0	62.86
N–NH_4	mg/l	12.1	11.2	1.4	88.43	17.0	17.0	8.5	50.00
N-NO_2	mg/l	0.13	0.14	0.14	–	0.03	0.027	0.26	–
N-NO_3	mg/l	0.34	0.18	6.50	–	0.12	0.12	3.40	–
P_{tot}	mg/l	3.40	2.93	1.20	64.71	7.40	7.50	0.93	87.43
P-PO_4	mg/l	1.23	1.17	0.87	29.27	2.50	3.10	0.70	72.00
Chlorides	mg/l	69.0	68.0	69.0	–	47.0	47.0	47.0	–
Sulphates	mg/l	48.0	41.0	43.0	10.42	37.0	37.0	37.0	–
Fe_{tot}	mg/l	5.13	2.50	0.21	95.91	8.00	6.40	0.31	96.13
Cr_{tot}	mg/l	0.0293	0.0153	0.0020	93.17	0.0370	0.0370	0.0023	93.78
Zn	mg/l	0.463	0.537	0.057	87.69	0.290	0.220	0.400	–
Ni	mg/l	0.0313	0.0140	0.0086	72.52	0.0290	0.0340	0.0100	65.52
Hg	mg/l	0.000227	0.000160	0.000020	91.19	0.000470	0.000430	0.000014	97.02
Cu	mg/l	0.0600	0.0237	0.0044	92.67	0.0810	0.0600	0.0028	96.54
Cd	mg/l	0.0022	0.0010	0.0002	90.91	0.0100	0.0070	0.00013	98.70
Al	mg/l	1.667	0.700	0.128	92.32	1.500	1.200	0.100	93.33
Co	mg/l	0.0047	0.0023	<0.0001	97.87	0.0016	0.0014	<0.0001	93.75
Mn	mg/l	0.330	0.210	0.019	94.24	0.570	0.470	0.240	57.89
Pb	mg/l	0.0470	0.0200	0.0022	95.32	0.0210	0.0170	0.0012	94.29
Phenols	mg/l	0.0072	–	0.0040	44.44	0.0120	–	0.0055	54.17
Petroleum products	mg/l	0.70	0.37	0.15	78.57	3.80	3.10	0.23	93.95
Synthetic surfactants	mg/l	0.837	0.650	0.045	94.62	1.000	0.810	0.590	41.00
Coliform bacteria	10^7/l	38.0	33.0	1.7	95.53	–	–	–	–

CONCLUSIONS

Natural and climatic factors as well as a difficult demographic situation have always had a significant effect on life in St. Petersburg and on the water sector [45]. The main factors influencing St. Petersburg's water system are:

- Natural:
  - abundant water resources
  - efficient self-purification ability of the Neva River and the Neva Bay
  - frequent floods
- Anthropogenic:
  - daily load of five million m^3 of waste water
  - flood barriers and other coastal structures
  - multipurpose use of the water system (industry, agriculture, navigation, timber rafting, recreation, etc.)

The following steps should be emphasised in the history of water supply and waste water disposal in St. Petersburg [50]:

- With the growth of the population and industrial development the water supply sources deteriorated and waterborne epidemics (typhus, cholera, dysentery and others) broke out.
- The fact that polluted surface water was the main source of the water supply led to the development of systems to treat and disinfect the drinking water.
- The development of water supply systems inevitably led to the construction of sewage disposal systems.
- The concentration of the discharged sewage caused intensive pollution of water basins and led to the construction of waste water treatment facilities (primarily with mechanical, later biological treatment).
- The biological treatment of waste water stimulated the increase of biogenic loads throughout the water basins, and this has made it necessary to purify the water completely by removing all biogenic substances.

Water supply and waste water disposal have a divided history in St. Petersburg. There is a wide temporal gap between the construction of municipal water and sewerage systems, which is not a typical feature of similar huge coastal cities situated on large rivers (such as London or Hamburg). The development of the waste water system took place at least half a century after the development of the water supply system:

- the beginning of the construction of the first centralised water supply system 1859
- the beginning of the construction of the first centralised sewerage system 1925
- the construction of the first water supply pumping station 1863
- the construction of the first waste water pumping station 1930

– the first water treatment facilities 1889
– the first WWTP 1978

Some possible reasons (which should be seen not as separate but complementary) for the disparity are presented in the following summary:

The social reasons are conditioned by the strained economic situation in the country and the escalation of internal and international conflicts taking place in the early 20th century: the Japanese War (1904-1905), the First Revolution (1905-1907), World War I (1914-1918), the Revolutions of 1917 and the devastating Civil War (1918-1922).

The political reasons can be related to the general crisis of a system of government that could not build a sewerage system at the time when it was built in most of European capitals: Dozens of designs were requested from leading national and foreign engineers, but the inertia of authorities prevented them from being implemented. It was not until after eighteen years of violent turmoil that Leningrad was able to start the construction of the sewerage works.

The technical reasons are conditioned by the flat topography and the extent of the network. These factors made it necessary to deepen the sewers, which in turn caused certain difficulties while laying them in permeable soil with a high ground water level (above all, the need for the hydraulic insulation of both pipes and wells).

The sanitary reasons are conditioned by the fact that the most urgent pollution problems were shifted away from the centre of the city by building separate collectors to the Neva River. The necessity of the sewerage system was also reduced by the introduction of raw water disinfection in the early 20th century.

The ecological reasons are a function of the high self-purification ability of the Neva River and Neva Bay, which allowed St. Petersburg's water system to cope with the increasing load and to support relatively high water quality level for a long time.

Further studies are needed to satisfactorily solve the problems caused by water pollution in such a large city as St. Petersburg. However, the work done already has made one problem obvious: Is it really possible to analyse and forecast the environmental and social changes if the water protection methods and the history of their development in St. Petersburg have hardly been studied at all?

REFERENCES

1. B. P. Usanov. Dialog between the city and the sea (in Russian). Leningrad, Knowledge Society Publishing House, (1989), 32 pp.
2. Leningrad without floods. Collection of articles, edited by V. T. Senin (in Russian). Leningrad, Lenizdat Publishing House, (1984), 128 pp.
3. Leningrad: historical and geographical atlas. Edited by N. V. Razumikhin (in Russian). Moscow, Chief Department of Geodesy and Mapping of the USSR Council of Ministers, (1981), 120 pp.
4. News of the Imperial Russian Geographic Society. St. Petersburg, (1883).
5. Water supply and the methods of sewage disposal in the cities of Russia (in Russian). St. Petersburg, Senior Medical Inspector's Department at the Ministry of Interior Affairs, (1912).
6. Proceedings of the 6th, 7th, 8th, 9th, 10th, 11th and 12th All-Russian Water Supply and Sanitary Appliances Congresses (in Russian). St. Petersburg, Moscow and Leningrad, Scientific Chemical and Technical Publishing House, 1907, 1908, 1909, 1910,1911, 1924, 1925.
7. Y. V. Lipkin, V. V. Moiseev and M. P. Ushakov. Development of the Leningrad municipal water supply system. Municipal economy. Collection of articles, edited by V. V. Bolotny (in Russian). Leningrad, Goslitizdat Publishing House, (1957), pp. 53-74.
8. M. M. Slenin. Leningrad sewerage system development. Municipal economy. Collection of articles, edited by V.V. Bolotny (in Russian). Leningrad, Goslitizdat Publishing House, Leningrad, (1957), pp. 75-97.
9. L. M. Gusev. Development of sanitary treatment methods on the territory of the city of Leningrad. Municipal economy. Collection of articles, edited by V.V. Bolotny (in Russian). Leningrad, Goslitizdat Publishing House, (1957), pp. 98-113
10. J. Erichsen. Zur Frage über die Canalisation und Reinigung von St. Petersburg. Ein Plan über die Voruntersuchungen dieses Unternehmens. St. Petersburg, Kaiserliche Hofbuchhandlung H.Schmitzdorff, (1874).
11. B. P. Usanov and L. I. Tsvetkova. Water factor in the reconstruction and development of Petersburg City. Proceedings of the 3rd International Symposium Reconstruction of St. Petersburg 2005 (in Russian). St. Petersburg, (1994), pp. 38-42.
12. Reports of the Statistical Department of St. Petersburg's Administration (in Russian). St. Petersburg, (1995).
13. M. A. Savitsky. Notes on the study regarding St. Petersburg's area, carried out in connection with municipal sewage disposal and arrangement of pavements therein (in Russian). St. Petersburg, (1882).
14. V. F. Ivanov. Sewerage systems of populated areas (in Russian). St. Petersburg, (1911).
15. V. E. Timonov. Water supply and sewerage. Volume 2 (in Russian). St. Petersburg, (1906)
16. B. M. Asche. Global Hygiene Exhibition in Dresden in 1911 (in Russian). Petrograd, (1915).
17. K. O. Grindberg. Of St. Petersburg's sewage system (in Russian). St. Petersburg, (1885).
18. M. Y. Belyavsky. Municipal sewerage systems (in Russian). St. Petersburg, (1909).
19. V. E. Timonov. Sewerage (in Russian). St. Petersburg, (1904).
20. Glumer. Domestic waste disposal and utilization (in Russian). St. Petersburg, (1903).
21. A. K. Jensch. Municipal sewerage systems and wastewater treatment (in Russian). St. Petersburg, Stroitel magazine typography, (1903).
22. V. P. Kashkadamov. Sanitary state of St. Petersburg City (in Russian). St. Petersburg, (1909).
23. I. A. Archangelsky and V. M. Privalov. Sewerage systems and their significance for populated areas. (in Russian). Edited by F. Y. Lavrov Moscow, Municipal Economy Ministry, (1926).
24. K. P. Kovrov. Contemporary state of Leningrad City's water supply system; its defects and measures of correcting them. Thesis of report for the 12th All-Russian Water Supply and Sanitary Appliances Congress (in Russian). Leningrad, Scientific Chemical and Technical Publishing House, (1925), pp. 86-89
25. G. V. Khlopin. The most important ways of water supply improving (in Russian). Petrograd, (1915).
26. W. Lindley. Sewerage of the capital city of St. Petersburg. Project on the arrangement of sewers in the area between the Greater Neva and Obvodny Canal, made under the appointment of St. Petersburg's Municipal Government. Part 1. Report (in Russian). St. Petersburg, (1883).
27. W. Lindley. Sewerage of the capital city of St. Petersburg. Project on the arrangement of sewers in the area between the Greater Neva and Obvodny Canal, made under the appointment of St. Petersburg's Municipal Government. Part 4. Estimates (in Russian). St. Petersburg, (1882).
28. W. Lindley. Sewerage of the capital city of St. Petersburg. Project on the arrangement of sewers in the area between the Greater Neva and Obvodny Canal, made under the appointment of St. Petersburg Municipal Government. Part 5. Explanatory note (in Russian). St. Petersburg, (1884).
29. Proceedings of municipal preparative commission for the

development of issues relating to sewerage system design for St. Petersburg City, elected on the 2nd of November 1905 (in Russian). St. Petersburg, (1908).
30. N. P. Dobroumov. Brief information on the sewerage system of the city of St. Petersburg by the Briansk Enterprise Society design. Report to the 8th Russian Water Congress (in Russian). Moscow, (1909).
31. D. K. Griboyedov. Sewerage system design for the city of St. Petersburg. Sewerage Plan (in Russian). St. Petersburg, (1910).
32. Report on the initial researches in order to make a sewerage system project for the city of St. Petersburg. Issue 1 (in Russian). St. Petersburg, (1911).
33. L. P. Shishko. Sewerage system design for St. Petersburg City. Explanatory note. Part I (in Russian). St. Petersburg, typo-lithography Revin Brothers, (1913).
34. Explanatory note to the sewerage project for St. Petersburg City. Part I. Municipal executive commission for the construction of sewerage systems and rehabilitation of waterworks of St. Petersburg (in Russian). St. Petersburg, (1914).
35. Explanatory note to the sewerage project for St. Petersburg City. Part II. Municipal executive commission for the construction of sewerage systems and rehabilitation of waterworks of St. Petersburg (in Russian). St. Petersburg, (1914).
36. Constructional and operational estimates for the disposal of domestic sewage. Annex to the first part of the explanatory note to the sewerage project for St. Petersburg City. Municipal executive commission for the construction of sewerage systems and rehabilitation of waterworks of St. Petersburg (in Russian). St. Petersburg, (1914).
37. N. A. Chesnokov. Municipal sewerage system by means of the advanced wastewater filtration (in Russian). St. Petersburg,(1909).
38. F. A. Danilov. Biological wastewater treatment (in Russian). St. Petersburg, 1912
39. N. K. Tchizhov. Sewerage (in Russian). St. Petersburg, (1895).
40. G. V. Khlopin. Materials on the researches of the Neva Bay water in terms of sanitary situation. Report for Municipal Government (in Russian). St. Petersburg, (1913), 47 pp.
41. S. M. Visloukh. Initial data on biological researches of the Neva Bay from the 1st of August till the 1st of December 1911. Report to Municipal Government (in Russian). St. Petersburg, (1913), pp. 47-52.
42. S. V. Moiseev. Water quality of the open water basins of Leningrad city and its sanitary assessment (in Russian). Moscow, All-Union Scientific and Research Institute of Water Supply and Sanitary Appliances, (1934), 87 pp.
43. N. V. Krasovskaya. Researches of the sanitary state of the Neva Bay (in Russian). Leningrad, (1934).
44. Sanitary situation of the Neva Bay. Collection of papers 46, edited by N.F. Fedorov (in Russian). Leningrad, Leningrad Institute of Civil Engineering, (1963), 144 pp.
45. M. I. Alexeev, B.P. Usanov and L.I. Tsvetkova. Impact of Petersburg's industrial activity on the sanitary and environmental situation of the Neva Bay. Proceedings of the International Symposium Reconstruction of St. Petersburg 2005 (in Russian). St. Petersburg, (1992), pp.47-53
46. Environmental situation in St. Petersburg and Leningrad Province in 1993-1994 (in Russian). St. Petersburg, Lencomecology Publishing House, (1995), 237 pp.
47. Annual Reports of Baltic Sea water quality by hydrochemical parameters (in Russian). Leningrad, State Meteorological Committee of the USSR, 1979-1988.
48. B. P. Usanov. Key principles and elements of the system of water protection measures while investigating and building up the Neva Bay coast. Doctoral dissertation (in Russian). St. Petersburg, (1992), 70 pp.
49. L. I. Tsvetkova and S. L. Basova. Development of eutrophication in the Neva Bay and the Gulf of Finland for the last 100 years. Thesis of report for White Nights Scientific Readings (in Russian). St. Petersburg, International Academy of Ecology and Life Protection Sciences, (1998), pp.90-91
50. K .I. Krasnoborodko, A. M. Alexeev and L. I. Tsvetkova. Historical aspects of water supply and sewerage systems development in St. Petersburg. Thesis of report for White Nights Scientific Readings (in Russian). St. Petersburg, International Academy of Ecology and Life Protection Sciences, (1998), pp.87-89