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of the Moskva River in relation to pollution and
processes of self-purification

By S. M. Drachev

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S.M. DRACHEV

CHANGE IN THE COMPOSITION AND PROPERTIES OF THE WATER OF
THE MOSKVA RIVER IN RELATION TO POLLUTION AND
PROCESSES OF SELF-PURIFICATION

Regulation of effluent flow substantially changes the hydrological regime of rivers, primarily on account of the more or less marked equalization of flow over the seasons. When the flow has been controlled for many years, spring high water, which in river valleys accounts for 60-80% of the total annual discharge of water, is eliminated. In the case of total regulation, water discharge below a dam will be determined principally on the basis of the requirements of the national economy.

Retardation of flow alters the distribution of liquid effluent within the rivers and moves the location of precipitation of suspended matter closer to the point of discharge of the effluents. In calculations of the oxygen balance in the warm season, the development of photosynthetic processes can become the deciding factor under certain conditions. In processes

of self-purification, the role of plant organisms and zoobenthos, which until the present time has been little studied, is substantially increased. Moreover, the conditions for the development of self-purification processes in artificial reservoirs with retarded run-off differ from lake conditions. Thus, in the majority of reservoirs along the Volga and Dnieper cascades, spring flushing of the river bed and the related removal or displacement of bottom sediment are maintained all year round.

The development of self-purification processes depends on the character of a river, the means of water regulation and the kind of pollution present. In order to be able to explain the general laws of this development, it is essential that results of prolonged observation be accumulated.

Among those river basins which are regulated and utilized in the national economy to a maximum degree is the Moskva River. Scientific investigation of the Moskva River has been going on for more than one hundred years. The first analyses set out to determine the composition of compounds dissolved in the waters of the river. Subsequently, researchers elucidated problems of sanitation to do with pollution and self-purification of the river. Analysis of samples taken at various points along the river was soon supplemented by bacteriological research. At the beginning of the twentieth century hydrobiological observations became wide-spread; helminthological and radiometric observations came considerably later. Usually a passage along the river or short-term (2-3 day) stationary observations have been performed in order to study

the properties of the river and the composition of the impurities therein. In the majority of cases, observations have not been linked to the river's hydrological regime. In 1964, the Institute of the Biology of Interior Waters of the USSR Academy of Sciences began research on the Moskva River concerning problems that have not been touched upon or have received little elucidation regarding changes in water quality. Little light has been cast, either in this country or in foreign literature, on the question of changes in the basic ionic composition and cation ratio due to the effects of domestic and industrial drainage. There are almost no data published on 153 changes in the composition of elements contained in the waters of the Moskva River in trace quantities of the order of hundredths of a milligram per litre or less. However, various industrial sources of effluent enrich the water with lead, copper, nickel, chromium and other metals, including such metals as silver and molybdenum, which are rare in natural waters. An extremely important problem is the question of the stability of substances brought into the water in microquantities. The distribution of microcomponents among the water mass, the bottom sediments and the aquatic biota determines the length of time the microcomponents remain in the water and the extent of their dispersal. Data on the content and stability of fourteen elements have been presented in an article by G. V. Kol'tsov (1968).

Problems of the distribution of radioactive beta emitters that are in a state of extreme scattering have been presented in

an article by A. A. Bylinkina (1967). The effect of urban drainage on the form and content of phosphorus and nitrogen, which to a significant extent determine phytoplankton development, was elucidated by observations carried out in polluted sections of the Moskva and Oka Rivers.

The effect of water pollution on bottom sediments has been studied mainly from the point of view of changes in the oxygen regime (Nesmeyanov, 1951), inasmuch as this problem is of direct practical importance. In view of the fact that the degree of eutrophication river basin and the abundance and composition of the aquatic biota change under the influence of effluents, changes in the chemical composition of bottom sediments with respect to organic and mineral content are to be expected.

A distinguishing feature of the river's outward appearance at the dams which impede the flow of the river below the city is abundant formation of froth in the after bays. Most favourable conditions for froth formation are created when water passes over a dam. Immediately the river is covered by a layer of froth which soon breaks up into separate pieces which float downstream. Depending on wind direction, the froth usually adheres to the shore, where accumulations of it are observable, at times reaching a height of one metre or more. Part of the froth is carried by the wind onto the shore, and part is deposited at the edge and on the shoreline plants. The greater part of the organic and mineral matter which makes up the froth returns to the river. Data concerning froth formation on rivers were presented in a paper we published previously (Drachev and Bylinkina, 1965).

In the years 1944 to 1948, systematic investigations were carried out under the direction of the author at fixed observation points. The purpose of the observations was to clarify the processes of transformation of organic substances and the related oxygen regime. Regularities in the change of saprophytic microflora during the process of self-purification have been studied by Ye. V. Dianova and A. A. Vorshilova (1952), and S. M. Drachev et al. (1966). The data on the transformation of organic substance and the oxygen regime will be used in the following discussion.

The large amount of analytical material relating to observations covering a twenty-year period makes it possible to draw conclusions regarding the change in the river's condition over the elapsed period, and to compare the course of self-purification processes under various conditions.

Utilization and Scientific Investigation of the River in the Past

The birth, development and the very name of the capital of the Soviet Union--Moscow--are intimately connected with the comparatively small waterway of the same name, the Moskva River. More than eight hundred years ago, protected by the river, and its small tributaries, the Neglinka and the Yauza, "a small town, made of wood", which was destined to become a city of millions, was formed and evolved.

The river was very important in the economic life of the capital. Owing to the city's position on the river, it became

"a good bridge, a crossroads for communication in all directions, and with all the old paths of national communication," (Geinike, 1917). The significance of the river for transportation increased with the opening of the Moskva Canal in 1936.

For many years, the Moskva River was the main source of drinking and domestic-use water supply for the settlements near the river. The master stonemasons, Anton Konstantinov and Trofim Sharutin, in 1636, constructed the first of the famous Moscow water pipelines, which raised water to the Kremlin tower which still bears the name vodovzvodnaya (the 'water-raising' tower). The pumping stations of the Bab'egorodsk and Krasnokholma water systems pumped water from the river (1852--1835 [sic]). The intake of drinking water for the city (from 1903) in the upper course of the Moskva River at Rublevo retains its significance up to the present time (Trudy. . . , 1927; Tol'tsman, 1931).

The river is of great importance as the receptacle of wastes from the household, economic and industrial life of the city. In the past, springtime waters removed not only a great quantity of debris which had accumulated along the banks of the river on the ice by the famous market at the Moskvoretskii Bridge, but also garbage specially transported onto the ice at the end of the winter. The importance of the river as receptacle of city wastes increased especially from the time of the construction of the city's sewer system in 1898.

Changes in the river's sanitary condition owing to the household and economic life of the city have been observed for a long time. As early as during the reign of Tsar Aleksei Mikhailovich (1629-1676), reservoirs were developed on the Presnya River to supply water to the court of the tsar. Evidently the quality of the water from the Moskva River even at that time did not satisfy the demand for a water supply, at least for more exacting consumers. The construction of the Mytishchinsk water system (by the ukaz or decree of 1779) was motivated by the necessity to guarantee the city a qualitatively reliable source of drinking water in place of the more accessible water from the river.

The year 1835, when the Moscow chemist R.F. German carried out the first analyses of the waters of the Moskva River and of wells along its banks, marks the beginning of laboratory testing of the river (Iskol'dskii, 1948). The analyses performed by the original scientist and outstanding hydrochemist, which differed from modern studies in their form of expression (in ounces per pail) and in their methodology, encompassed almost all of the ingredients of salt composition determined in modern tests.

During the century that followed, the river repeatedly attracted the attention of researchers, who for the most part attempted to characterize its sanitary condition.

In 1877 A.P. Sobaneev, a chemistry professor at Moscow University commissioned by the city administration, carried out a thorough investigation of the Moskva River at three points:

1) above the city near the village of Troitsk ; 2) within the city limits; and 3) below the city in the Danilov suburb (Kotsin, 1889). The publication of hydrometrical data occurred about the same time (Astrakov, 1978).

An important milestone in the investigation of the Moskva River and water courses in general was the work of M.B. Kotsin (1889). A substantial part of the river was encompassed by his observations. His work includes a description of the river and chemical and bacteriological analyses. A number of observations and investigations were conducted on the river in the next thirty years (Bubnov, 1902, 1907); Nikitinskii, 1909, 1912; Sokolov, 1911, 1922; Orlov, 1912; Naumov, 1913; Stroganov, 1913; and Kotsin, 1915). Whereas chemical methods had first been applied to the study of the Neva River (1773), bacteriological, hydrobiological, helminthological (Vasil'kova, 1944) and radiometric methods (Drachev, 15 Bylinkina, 1960) have first been used widely and systematically in the study of the Moskva River.

The outstanding scientist Ya. Ya. Nikitinskii, under whose influence Russian sanitary hydrobiology took shape, carried out investigations of plankton, overgrowth and bottom biocoenoses in the Moskva River. These studies were published in the Reports of the Provisional Committee on the Protection of the Waters of Moscow Gubernia (district) (1912-1916). More exacting tests were undertaken in the years 1913-1916 in connection with the search for new sources of water for the city of Moscow. The results of these studies, published in

1927 (Ozerov, Stroganov) made an important contribution to modern conceptions as to the basic factors in the formation of the ionic composition, the rhythm of seasonal changes and the vegetable and animal biocoenoses of rivers.

Many studies were carried out in the period from 1920 to 1940 with a view to assessing the sanitary condition of particular sections above and below the city (Bruevich, 1927, 1929; Skopintsev, 1933; Znamenskii, 1935, 1936; Kononov, 1936; Kononov and Sitnov, 1939; Skopintsev and Mikhailov, 1939). As a rule investigations were conducted in conjunction with research into sanitary conditions; chemical, bacteriological and hydrobiological methods were applied. A distinguishing feature of most of these studies was the recording of observations taken at a single moment in time; the researchers attempted to obtain a "snapshot" of the river's condition. On the basis of the data obtained, B.A. Skopintsev (1933) and A.V. Znamenskii (1935, 1936) made calculations of the rate of the self-purification process and of the amount of oxygen being received from the atmosphere.

Characteristics of the condition of the river were used in papers by S.N. Stroganov (1923) and S.A. Ozerov (1929) in calculations of the amount of water necessary for improvement of the sanitary conditions through diluting the water by means of diversion of water from the Moskva Canal. The dilution method was first tested in this country. Several investigations carried out just after the Moskva Canal was opened evaluate the changes in the river's cycle during this

period (Kononov and Sitnov, 1939; Deksbakh and Musatova, 1940). The condition of the Moskva River in the region of effluent discharge from the city's large purification plants is being studied systematically by the laboratories of Mosochistvoda (Moscow Water Purification Administration) and has been published in part (Popova, 1959, 1964; Popova and Pervakova, 1959).

Systematic observations of water quality have been made along the upper course of the river from the time of the opening of the Rublevo water system. Materials from chemical and bacteriological investigations have been worked on by S.A. Ozerov (1929). The modern view of the protection of drinking water from contamination and the principles and means for the practical realization of sanitary protection zones for the Moskva River was ~~worked out~~ in articles by V.I. Muskat (1926, 1930, 1937).

Data on the River's Hydrometric Characteristics

The Moskva River, the left tributary of the Oka River, originates near Mikhal'skii Lake on the eastern slope of the Central Russian uplands. The length of the river is 502 km., the area of its watershed 17,530 km² (Bykov, 1951). The river's length along a straight line from source to mouth at the city of Kolomna is 232 km.; thus the winding factor is 2.16. There is a highly developed river network in the basin: along its whole course 89 tributaries flow into the river, of which many in turn have tributaries of their own. According to

I.L. Zdanovskii (1926), the total number of tributaries is 912. The main ones on the left are: the Istra, Ruza, Pekhorka, Gzhelka and Nerskaia, and on the right: the Pakhra, Severka and Kolomenka.

The elevation of the river's source is 249 m and of the mouth, 104 m. Thus, the mean declination of the river is 0.00029, and for the portion of the river from Moscow to the mouth, 0.000034 (Kravchenko, 1930). The duration of the ice cover 156 on the river is, on the average, 123 days. The normal ice regime within the city and below the inflow of urban run-off is disrupted due to the influx into the river of a large amount of waste heat from industrial and domestic sources.

At the present time the natural regime of the Moskva River is preserved only in the upper reaches; below the city of Mozhaisk the flow of the river is regulated a) by large reservoirs on the Istra, Ruza, Ozern, and the Moskva River at Mozhaisk (Ryabyshev, 1964); b) by the inflow of water from the Moskva Canal via the Skhodnia and Yauza Rivers and locks; and c) by the presence of nine small dams, of which five are located below the city.

The flow of the Moskva River is regulated by large reservoirs in the upper reaches of the river, by permanent dams which raise the level of the river within the city, and by removable dams which maintain navigable levels below the city during the navigation season. Regulation of the river's flow in the upper course of the Moskva began in 1934 with the construction of a dam on the Istra River and was

completed by the filling of a reservoir on the Ozern River in 1967. The total volume contained in reservoirs is 800 million m^3 . By means of dams, the run-off from 52% of the total drainage basin of the Moskva River above the city is regulated in the upper reaches of the river. Owing to the construction of reservoirs, it is now possible to maintain a minimum discharge of $29 m^3/sec$ (with 97% probability) instead of the minimum of $8-9 m^3/sec$ before regulation. The greater part of the discharge of water is taken to supply the city.

Since 1937, water has been fed into the river from the Moskva Canal so as to improve the condition of the river in the city. For a number of reasons the quantity of water supplied from the canal has fluctuated: during the war years the diversion was interrupted; after the war it was renewed to the amount of $25-30 m^3/sec$ during the summer and $5 m^3/sec$ during the winter; since July, 1964 water has been diverted the whole year round, with the exception of the period of spring flooding, at a rate of $30 m^3/sec$ into the Moskva River and $6 m^3/sec$ via the Yauza River. Beginning at the village of Petrovo-Dal'nee, 249 km. from the mouth, the river is stopped by nine small dams. Three of them--the Rublevo, Karamyshev and Pererva dams--are of the permanent type. The rest of the dams maintain river levels only during the period of navigation. The Karamyshev dam and all dams downstream from it have navigation locks. During the period of navigation the dams maintain a constant level

with fluctuations of 10-15 cm.

The presence of the dams retards the rate of displacement of the water, particularly in the sections close to the dams. In winter, when the dams are open, the velocity of the current is 0.3-0.4 m/sec. After the dams have been closed, water velocity is reduced to 0.1 m/sec in the central part of the headwater, and to 2-3 cm/sec in the sections below the dams. Under retarded run-off conditions, precipitation of suspended matter occurs, and deposits on the bottom are formed. In the case of dismountable dams, accumulation of precipitation is seasonal in nature; after the gates which maintain the increased level have been opened, conditions are right for the channel to be washed out; this occurs during the time of spring flooding.

The removal of water from the river to satisfy the appetite of the city's water supply and the discharge of industrial and household effluent from the city of Moscow have a large effect on the regime of the river. The major sources of effluent are the Lyublino, Kur'yanov, and Lyubertsy purification plants. The amount of effluent from the city is steadily increasing. In 1966, the total discharge of urban run-off was, on the average, 33 m³/sec.

The substantial changes introduced by the regulation of surface run-off have not altered the basic features of this river, which is typical of the rivers of the Central Russian Upland: high discharge rate during the spring flood period

and low flow rates in the summer and winter low water periods. The four reservoirs on the upper river cut flow rates during the spring high-water period, reducing the level of the river within the boundaries of the city by approximately 1.5 m. Nevertheless, water flow rates during the spring are many times greater than during the low-water period: in 1966 the rate of flow at the Pererva Dam was 700-800 m³/sec.

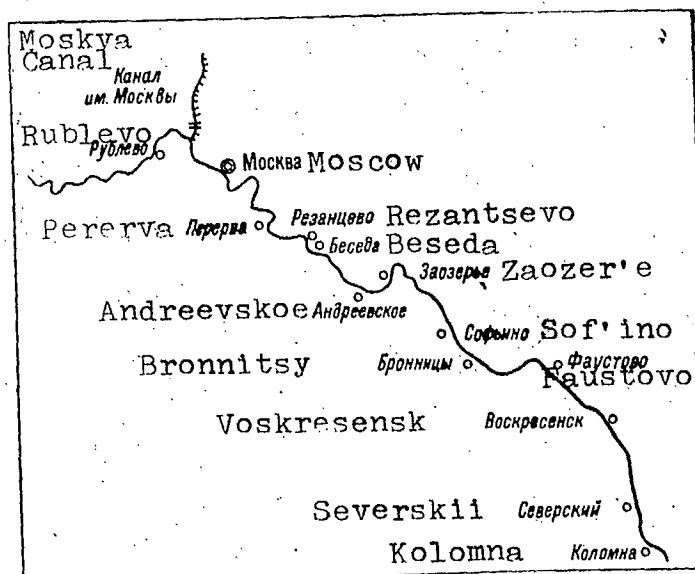


Fig. 1. Diagram of the lower part of the Moskva River

Data on the rate of flow of the river at Pererva and the quantity of effluent released in a controlled way have made it possible to carry out an analysis of available materials that takes into account not only changes in the

concentration of compounds, but also in the amount of matter passing in unit time through a section of the river (Bruevich and Anichkova, 1941). The most reliable data on the flow rate of the river have been obtained at the point in the Pererva Dam where the bulk of the water passes through the turbine of the power station. Because of the absence of hydro-metric stations along the lower part of the river, the flow rate at the other observation points was determined either by measurement or by calculations based on the area of the watershed and the modulus of flow.

Below, the characteristics of the river's condition and the patterns of change will be given 1) for the portion of the river above the city, where the Moskva River is typical of the central zone of the USSR with altered hydrological regime; 2) for the river within the boundaries of the city, where the natural composition and properties of its water have changed markedly; and 3) for the segment extending from the place where the major inflow from the city of Moscow occurs to the mouth, below Kolomna (Fig. 1).

Water Quality of the Moskva River Above the City

The part of the Moskva River above the city accounts for approximately half of the area of the river's watershed. In the territory of the drainage area of this part of the river, the landscape has remained relatively unchanged; the territory is used mainly for agriculture, and forest tracts occupy an appreciable area.

In the forming of the water's ionic composition and physical properties, the major part is played by natural factors having a large degree of constancy. In the opinion of L.S. Berg, the hydrological features of the Moskva River have not changed since the emergence of the city of Moscow. Correspondingly the composition and properties of its water have remained, within the limits of a certain amplitude of fluctuations, constant.

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The most substantial changes in the river's hydrological regime have been introduced by the construction of dams on the Moskva River at the city of Mozhaisk and ^{on} the larger left tributaries, the Istra and the Ruza. As a result, owing to accumulated springtime run-off in the reservoirs, dry season flow has increased all the way to the place where water is pumped from the river for the city of Moscow's water supply.

In spite of quite substantial changes in the river's hydrological regime, the rhythm of seasonal changes in the life of the river and the fundamental ionic composition and physical properties of the water has been maintained. The conservation of the natural composition and properties of the waters of the Moskva River's upper course has been facilitated by the fact that the whole basin from its sources to the city of Moscow is included within a sanitary water supply protection zone. The part of the river from Zvenigorod to Krasnogorsk and the Istra River with its reservoir is a part of the second region of the protection zone, which has a stricter regime; the area of this region is 2500 km². The remainder of the basin

of the upper reaches of the river, having a total area of 5000 km², which includes the Mozhaisk and Ruza reservoirs, is included within the third region of the protection zone.

Limitation of the use of the water by the populace and, most important, the regulation of the siting of industrial enterprises have checked the growth of pollution. The main sources of pollution are the cities of Mozhaisk and Zvenigorod, rest homes, sanitoriums and kindergartens. The total inflow of effluents entering the river is at this time 1.2 m/sec [sic], i.e. 4% of the present dry season discharge at Rublevo. Pollution of the river by effluent waters is diffuse in nature, i.e. individual sources of effluent are small in volume and their locations are usually separated by a considerable distance. Effluents do not flow directly into any of the reservoirs. In recent years, because of the increase in the use of the river and the growth in the discharge of effluent, there has been a clear deterioration in water quality according to bacterial indicators. It is much more difficult to detect a change in the content of dissolved compounds. In this connection a good starting point is a comparison of present-day amounts of dissolved substances with data from analyses of previous years, when the river was less polluted. In making comparisons of the present content of dissolved compounds in the water, it is necessary to take into account the changes brought about by the enhanced role of surface run-off in the low-water season. Of the sources of

inflow into the river, on the average 27% were underground sources, 61% came from melted snow and 12% from rain (Bykov, 1951). At the present time the amount of compounds dissolved in the water is determined mainly by the water from melted snow which has accumulated in the reservoirs and there has been transformed to a greater or lesser degree. The composition and properties of the water of the Moskva River are typical of many rivers of the Central Russian Upland for which lake and swamp waters are not an important source of water. Because of the absence of large areas of swamps and peat bogs, the content of organic substances is low. The chromaticity of the water in winter is minimal (of the order of 10-15°); at the end of the spring high-water period it increases, reaching 40°. The average annual chromaticity has increased in years of high water. The permanganate oxidizability has equalled 5-6 mg/l, and the biochemical oxygen demand (BOD)--usually 1.5-2.5 mg O₂ for 5 days.

The total amount of salts in the unpolluted section of the river in the spring high-water period is 50-70 mg/l. The general character of the ionic composition in the flood period corresponds approximately to that of the annual run-off with several peculiarities indicated below. Quantitatively, calcium and magnesium cations and carbonic acid anions predominate. The content of HCO₃' increases in spring relative to the low-water period.

The appearance of bicarbonates in the spring high water

to a considerable extent should be attributed to the interaction of the water from melted snow and the remains of dead plant life and topsoil. A certain amount of bicarbonate (25-30 mg/l) is contained in meteoric waters (Burkser and Fedorova, 1955). It is possible that the increased content of suspended soil particles in the river during the high-water period causes a certain amount of salts to be transferred into the water. There are rather few data available from analyses with which to calculate the univalent cation content; the high nitrogen content of ammonium salts should be noted. The insignificant amounts of chlorides and sulphates are close to the content of these compounds in meteoric waters.

After the spring high water, the importance of ground waters in feeding the river increases. In proportion to the increase in water temperature, the influence of biological processes increases, both in the river itself and in the underflow. In this period the chemical composition and the quality of the river water are determined by the properties of the ground water building up over the watershed. The water most closely corresponds to average ionic composition during the winter low-water period, when it has been changed little by biological processes. After the construction of reservoirs, the importance of ground waters in the low-water period decreased considerably.

The influence of pollution by domestic sources of runoff is felt first and foremost on the gaseous regime; questions of the influence on the oxygen regime have received the most

attention, while there are comparatively few data on changes in carbon dioxide content. There are substantial differences in the river's gaseous regime in different seasons, and ice cover is of extreme importance. The upper reaches of the Moskva River are ice-covered for four months, on the average. The ice cover, as it gradually thickens, reaching 90 cm, isolates the river from the atmosphere. This situation is reflected first of all in the gas composition. Carbon dioxide is not consumed by organisms during photosynthesis, and because of the ice cover it cannot escape into the atmosphere. The increased concentration of carbon dioxide enables the magnesium and calcium salts to remain in solution; carbonate hardness reaches 6 mg-equiv. during the winter. The winter months are characterized by a decrease in the oxygen concentration after the autumn maximum. As is evident from the long-term average annual quantities cited in Table 1 (Ozerov, 1929), the winter minimum approximates summer values in absolute terms.

Table 1

Amount of dissolved oxygen in the waters of the Moskva River (mg/l)

Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Oxygen	8.6	9.2	9.7	12.1	10.4	9.5	8.6	8.7	9.7	11.6	13.0	11.7

In the winter months the water is undersaturated with oxygen, but not to the extent that might be expected in view of

the predominant role of underground flow in feeding the river. The ground water's oxygen has been greatly depleted or is absent altogether. This is attested to by soil air in the sections occupied by plant life and also by certain data from direct analytic determinations of oxygen in ground waters.

As observations have shown, enrichment of the oxygen supply of the Moskva River in winter takes place owing to the river's tributaries, which flow rapidly and are not covered by a solid covering of ice (Drachev, 1964). Although in their upper reaches, the tributaries may be completely depleted of oxygen, in the sections with an open surface, saturation of the water proceeds most energetically owing to the increased oxygen solubility at low temperatures. Oxygen loss due to the respiration of aquatic biota is insignificant at low temperatures. An important factor in the oxygen regime in certain sections of the Moskva River is the inflow into the river of near-bottom water from reservoirs that is depleted or almost completely deprived of oxygen during the winter and the last half of the summer. Data on oxygen content in the section of the Istra River below the dam can be cited as an example. According to observations recorded in winter, oxygen content varied in the following manner (Table 2).

Table 2

Amount of oxygen dissolved in the waters of
the Istra River downstream from
the dam

Test site	Distance from weir, km.	3 III		5 III	
		mg/l	% satura- tion	mg/l	% satura- tion
At point of discharge...	0.0	2.9	21.8	3.0	21.5
Buzharovo..	1.7	7.6	54.9	7.1	42.7
Nikulino...	6.0	-	-	10.3	72.0

The aeration coefficient reached 26.7 g O₂/day for a 1 m² surface area on the river; the aeration constant reached 3-6. Thus the restoration of a normal oxygen regime in the river below the dam takes place most intensively, and the lack of dissolved oxygen is replenished within a distance of 10-15 km. A similar phenomenon takes place on the Moskva River below the Mozhaisk reservoir and the Ruza River below the dam. On the approaches to the city, at Rublevo, the river has preserved a normal oxygen regime right up to the present day. Determinations of the oxygen content at Rublevo during the most critical period have yielded the following values (mg/l):

28 II 1964 10.1
29 II 1964 11.1

Determinations made at other seasons of the year give results close to those cited in Table 1.

The amount and form of nitrogen in chemical combination

in a body of water are of interest in evaluating the condition of the body of water and its capacity for self-purification.

Average data for the Moskva River (Fig. 2) are typical for clean rivers in the central region of the European part of the USSR (Ozerov, 1929). With respect to the forms of mineral nitrogen in the unpolluted portion of the Moskva River, a significant accumulation of nitrate nitrogen has been recorded in winter.

The reason for the low nitrate content in a body of water during the summer is their consumption by aquatic plant life. The increase in the quantity of nitrates in winter has usually been explained (e.g. Ozerov, 1929) by the inflow of ground water. However, the accumulation of nitrates occurs also in lakes that are not fed by ground water. Significant amounts of nitrates are formed during the winter in the reservoirs of the Moskva Canal, the Istra and others. Determinations of nitrates and ammonia carried out in 1964 (Table 2) have shown that fluctuations in nitrogen content fall within limits determined earlier (Fig. 2). Thus, no significant change in the content of mineral nitrogen and its forms in the waters of the river above the city has been noted.

There is a vast amount of analytical material available for a characterization of the ionic composition of the water above the city at Rublevo (Ozerov, 1929). In many analyses based on data gathered at the Rublevo station over the period 1914-1927 there is a consistent error--in converting into mg-equiv., the sum of Ca^{++} and Mg^{++} exceeded the sum of the anions. 161

One analysis that was carried out correctly, judging by the correlation of cations and anions, was that of February 28, 1917. For a dry residue of 304 mg and a chromaticity of 4° on the platinum-cobalt scale, the water contained 2.9 mg/l of chlorine ions, 5.4 mg/l SO_4^{--} and 1.09 mg/l of nitrates.

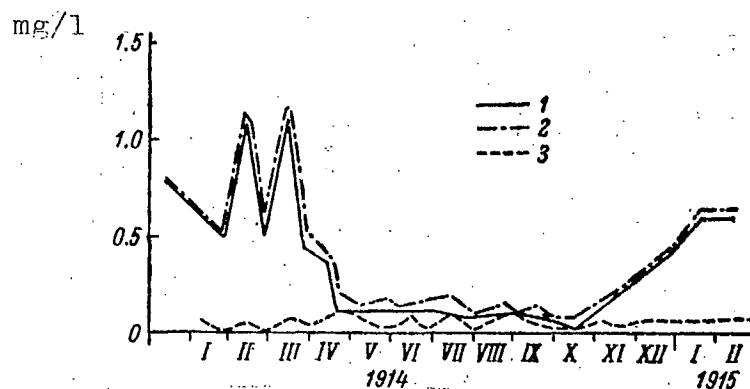


Fig. 2. Forms of nitrogen in the unpolluted part of the Moskva River

1 - nitrates; 2 - totally mineral nitrogen
3 - albumenoidal nitrogen

Calculation of the water composition from the sum of anion equivalents yields the following results (%):

	Cations		Anions
Ca ⁺⁺	71.4	HCO ₃ ⁻	94.9
Mg ⁺⁺	24.7	SO ₄ ⁻⁻	2.6
Na ⁺ + K ⁺	3.9	Cl ⁻	1.3
		NO ₃ ⁻	1.2

For the high-water period, the analysis of April 10, 1916, with a solid residue of 67.6 mg and chromaticity of 50° at a content of chlorides of 0.9, sulphates 0.9 (SO_4^{--}), and nitrates 0.16 mg, satisfies the condition that we have set.

The percentage composition of the water was as follows (equiv.):

	Cations		Anions
Ca ⁺⁺	62.0	HCO ₃ ⁻	95.3
Mg ⁺⁺	19.6	SO ₄ ⁻²	3.3
Na ⁺ + K ⁺	18.4	Cl ⁻	2.2
		NO ₃ ⁻	1.0

The relative importance of the univalent cations sharply increases in the flood water, while the anion composition is virtually unchanged. The change in cation composition in the flood water coincides with an increase in the relative importance of the univalent cations when a sample of soil is acted upon by increasing volumes of water (Drachev and Sobolev, 1926).

The results of analyses of the ionic composition of the water of the Moskva River above the city at a point in Rublevo, carried out in 1964-1965, are presented in Table 3. Certain changes are evident when these data are compared with those of analyses made about 50 years ago. Increased amounts of chlorides and sulphates are characteristic of the low-water period, and with respect to cations, magnesium content has increased somewhat.

For comparison, we shall cite data on the composition of dissolved salts taken at the low-water period on February 28, 1917 and February 28, 1964. The cation composition was (in % equiv.):

	NH ₄ ⁺	K ⁺ + Na ⁺	Mg ⁺⁺	Ca ⁺⁺
February 28, 1917	-	3.9	24.7	71.4
February 28, 1964	0.26	1.30 4.20	30.5	63.7

Table 3

Amount of salts dissolved in the waters of the Moskva River above the city
and the Moskva Canal between the 7th and 8th sluiceways (mg/l).

Point of observation	Date	Cations					Anions				
		NH ₄ ⁺	K ⁺	Na ⁺	Mg ⁺⁺	Ca ⁺⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ⁻²	NO ₂ ⁻	NO ₃ ⁻
Rublevo	28 II 1964	0.20	2.8	5.3	20.29	69.74	262.3	11.4	12.75	—	0.95
	29 II 1964	0.20	2.4	5.8	15.67	65.53	280.6	11.4	11.72	—	0.88
	2 III 1964	0.20	2.5	6.5	15.31	67.74	280.6	11.4	11.73	—	1.80
	4 IX 1964	0.05	2.6	5.8	13.61	43.69	195.4	6.1	—	0.002	—
	5 IX 1964	0.04	2.1	5.4	13.24	43.28	195.2	6.1	—	0.002	0.05
	7 IX 1964	0.06	2.7	5.4	13.85	43.69	194.0	6.2	—	0.002	—
Above Shchukin	15 VI 1965	—	—	—	—	28.13	101.2	11.5	—	—	—
Moskva Canal	28 II 1964	0.25	2.8	9.9	10.08	60.92	225.7	17.0	34.56	—	1.30
	29 II 1964	0.28	2.5	10.0	10.33	58.72	231.8	14.2	48.96	—	2.50
	2 III 1964	0.23	3.0	12.5	13.00	78.56	231.8	17.0	44.85	—	—
	4 IX 1964	0.15	1.9	7.0	9.96	29.46	141.5	5.2	18.71	0.005	—
	5 IX 1964	0.14	1.8	6.3	8.14	30.26	133.0	4.9	—	0.005	0.12
	7 IX 1964	0.18	1.9	7.2	9.00	30.66	138.5	4.9	—	0.004	—
	3 VII 1965	—	2.2	6.7	—	—	65.7	10.2	—	—	—

For the more recent analysis, increased magnesium and univalent cation content are characteristic; as a result, the relative amount of calcium present has decreased. It is possible that the changes in cation composition are to a certain degree related to the lower salt concentrations of the sample taken in 1964; the dry residue from the sample measured 273 mg/l in 1964 and 304 mg/l in 1917. At the present time both the winter and summer low-water periods of the Moskva River are less mineralized owing to the inflow of water from the reservoirs in the upper reaches of the river.

The anion composition of dissolved salts can be characterized as follows (in % equiv.):

	HCO ₃	SO ₄	Cl	NO ₃
February 28, 1917	93.5	3.3	2.2	1.0
February 28, 1964	86.6	5.4	6.7	1.4

According to the data of the latter analysis, there has been an increase in anions of strong acids, particularly of the chlorine ion. Correspondingly, bicarbonate ions have decreased by 7%. The data on anion composition are in agreement with a change in the nature of natural waters under the influence of domestic effluents.

The composition and properties of the Moskva River at the city of Moscow are affected by the regular inflow of water from the Moskva Canal in an amount exceeding by a factor of four the minimum flow of the river under natural conditions. Data on the amount of salts dissolved in the water of the canal are presented in Table 3. Evidently, during the winter low-water

period, the canal's waters differ from the water in the Moskva River by their greater content of chlorine and sulphate ions. According to data from observations made in the period 1946-1950, the content of chlorine and sulphate ions was, on the average, 3.0 and 6.0 mg/l, with maximum quantities not exceeding 13.0 mg/l for Cl⁻ and 17.2 for SO₄²⁻ (Drachev, 1956). The most likely reason for the increased chlorine and sulphate ion content in the waters of the canal is the discharge of effluent from the city of Kalinin into the Volga, which is the principal source for the canal. This hypothesis is supported by the detection of small quantities of copper, which is characteristic of the industrial sources of effluent of Kalinin, in the waters of the canal. The specific features of the canal's water are evident from the following data on cation composition (in % equiv.):

	NH ₄ ⁺	K ⁺	Na ⁺	Mg ²⁺	Ca ²⁺
February 28, 1964	0.4	1.6	3.8	18.9	69.3

In anion composition, the chlorine ion and especially the sulphate ion content have increased (%):

	HCO ₃ ⁻	SO ₄ ²⁻	Cl ⁻	NO ₃ ⁻
February 28, 1964	74.1	14.4	9.6	1.9

The amount of sulphate ion exceeds that of the waters of the Moskva River by 3 times, and of chlorine ion--by 1.5 times. The main source of pollution of the canal--effluent from the city

of Kalinin--is separated by a distance of about 200 km; this effluent is slowed down by the Ivankov reservoir and by the reservoirs at the divide.

Change in composition and properties of the river water within the Moscow city limits

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For a distance of 72 km, from Rublevo (232 km from the mouth) to the Pererva Dam, the Moskva River crosses the territory of the city of Moscow. In this part of the river, which comprises 14.3% of its total length, the river acquires more than 30 tributaries, of which the most important are the Yauza and the Setun'. The river level is regulated by two permanent dams, the Karamyshev and Pererva Dams, built in 1935-1936. Prior to the construction of the dams, the average low-water discharge of the Moskva River and its tributaries at the former Bab'egorod Dam went down to $8.2 \text{ m}^3/\text{sec}$ in winter, and in summer to $7.7 \text{ m}^3/\text{sec}$.

At the present time the regime of the river within the city has been altered by the inflow of water from the Moskva Canal. Since 1964 there has been a transfer of water all year round, rather than just in the spring high-water period. During the low-water period the amount of water transferred from the canal is 4-5 times greater than the natural low-water discharge of the Moskva River. Consequently the waters of the upper Volga, to some extent transformed in their passage through the canal and the reservoirs at the divide, are of paramount importance

among the Moskva River's sources of supply.

The tributaries of the Moskva River which enter within the boundaries of the city introduce a great deal of pollution into the river. Prior to the construction of a sewer system, the Yauza, and especially the Neglinka, were widely used as outlets for impurities and were considerably more polluted than they are at the present time (Lushchikhin, 1947). One of the most polluted tributaries is the Yauza River; its upper reaches receive the domestic and industrial effluent of the city of Mytishch. The total amount of effluent flowing into the Yauza River and its tributaries has been calculated at $0.58 \text{ m}^3/\text{sec}$, which amounts to about half of the river's natural flow. Because effluents enter the river unpurified, the condition of the river remains completely unsatisfactory, in spite of the addition of $6 \text{ m}^3/\text{sec}$ of clean water from the Moskva Canal. The Moskva River acquires a significant amount of pollution from its left tributary, the Nishchenka, the waters of which receive wastes from dozens of enterprises. Industrial effluents have a great effect on the composition and properties of the river water within the city.

The total volume of industrial effluent entering the Moskva River, directly or after insufficient purification, was calculated in 1965 to be $300,000 \text{ m}^3/\text{day}$. Not taken into account, but deserving of attention and study, are deposits on the river bottom and surface run-off from the territory of the city, which occupies 870 km^2 . The most important factor

in the formation of bottom deposits is the Pererva Dam, which creates a backwater along the whole length of river right to Karamyshev. The role of bottom deposits increases in proportion to one's proximity to the dam and becomes particularly marked within the waters of that southern river port.

According to certain indices, surface runoff from urban territory resembles domestic runoff waters (Shigorin, 1956, 1963; Kvitnitskaya, 1959). No work has yet been carried out on quantitative evaluation of surface runoff from Moscow and so there are no calculated data available. It is essential that work be done in this direction before the question can be elucidated or improvements in sanitary conditions undertaken.

Within the city's territory are four small purification stations where water undergoes full biological purification. The total output of the local stations is 145,000 m³/day, which amounts to 5% of the total runoff entering the city's network of waterways. The importance of this source of pollution in relation to organic substances and the oxygen regime is not great; however, as sources of bacteria they are most significant.

Owing to the multiplicity of sources of pollution, it is a complicated task to explain their nature and relative significance. In view of the importance of preserving the river as a component feature of the city in good condition, the laboratories of the Basin Administration and Sanitary

Inspection carry out systematic analyses of water samples. Processing of analytical data should give not only a basis for practical measures to improve the river's sanitary conditions (Trakhtman and Skidal'skaya, 1956), but also serve as material for generalization in relation to self-purification processes in a river where unusual conditions are present.

The effect of all the positive and negative factors which influence the river within the boundaries of the city is summed up when the water leaves the city at the Pererva Dam. The outlets of the three major purification plants, the Kur'yanovo, Lyublino and Lyubertsy biological purification stations, are situated below the dam.

For a characterization of the river's condition when it leaves the city, we have data from seasonal analyses made in 1946-1948 and 1964-1966. The availability of hydrometric data enables us to calculate the discharge of matter in the river per unit time.

The data presented in Table 4 characterize the river's condition at the Pererva Dam in 1946 and 1964. According to the latter observations, the amount of ammoniate nitrogen and chlorine ions has increased, in spite of the increased discharge of water.

The most significant sign of deterioration in the condition of the river is the reduction in oxygen content. In the autumn of 1964 there was a drop of almost 50 percent in oxygen

content as compared with the same period in 1946. In the summer and winter the river was on the verge of anaerobiosis. Data on the oxygen regime of the river at the Pererva Dam are in accord with the high oxygen demand, which in 1965 was considerably higher than during the years immediately after the war.

Table 4

Seasonal fluctuations in water composition of the Moskva River at Pererva in 1946 and in 1964-1965.

Season, year	No. of samples	pH	Alkalinity meq/l	Nitrogen mg/l		Dissolved oxygen mg/l	% saturation by oxygen	BOD ₅ mg O ₂	water discharge m ³ /sec	
				Ammoniacal	Nitrate					
Summer 1946	7	7.59	3.25	2.2	0.30	28.2	4.5	44	4.3	33
Autumn 1946	6	7.58	3.49	2.0	0.67	28.1	8.4	62	4.1	33
Winter 1947	5	7.35	4.53	4.9	0.60	41.5	3.0	21	7.2	18
Summer 1965	4	7.03	2.85	3.9	—	42.0	1.1	14	6.2	55.5
Autumn 1964	4	7.12	2.82	2.6	1.70	35.0	4.5	38	—	55.0
Winter 1964	3	7.10	3.80	7.3	0.50	87.0	0.8	6	14.0	25.0

The smallest amount of ammoniate nitrogen was detected in samples taken in the autumn, as was the case in 1946. One of the reasons for this phenomenon may be the more limited influence of bottom deposits in the autumn period when oxygen

is present in the water in appreciable quantities. It is known that the entry of ammoniate nitrogen from bottom deposits takes place most vigorously under anaerobic conditions. As for chlorine ions, large fluctuations were recorded, possibly due to changes in the discharge of the river and of industrial effluents.

Table 5

Discharge of particular compounds
by seasons in 1946 and 1964 (T/day)

Compounds	1946	1964
-----------	------	------

Summer

Ammoniate nitrogen.....	6.3	18.7
Chlorides.....	80.4	201.4
Dissolved oxygen.....	12.8	5.3
BOD ₅ in O ₂	12.3	29.8

Autumn

Ammoniate nitrogen.....	5.7	12.3
Chlorides.....	80.1	166.3
Dissolved oxygen.....	24.1	21.4
BOD ₅ in O ₂	11.6	-

Winter

Ammoniate nitrogen.....	7.6	15.7
Chlorides.....	64.5	187.9
Dissolved oxygen.....	4.7	1.7
BOD ₅ in O ₂	11.2	30.4

On the basis of analyses and hydrometric data, calculations of the discharge of individual components were carried out for a hydrometric section at the Pererva Dam. Information on water discharge during the time of the investigation was

obtained from the Moskva Canal Administration. Data on discharges were calculated according to the amount of water passing through the turbine of the hydroelectric station and discharged through the sluices. The data of Table 5 indicate that in the two decades that have elapsed, there has been a substantial increase in the content of a number of compounds except for dissolved oxygen. The ammoniate nitrogen level--the basic index of domestic-fecal contamination--has increased more than two-fold. It is difficult to say to what extent the increase is due to the increasing quantity of effluent water caused by population growth or to the effect of other factors. The increasing influence of bottom deposits or of wash from the considerably increased area of the city are not excluded.

The quantity of chlorine, which is discharged mainly by industry, has increased 2-3 times (Table 5). A study carried out in the summer of 1966 in the river at Pererva found 34.5 mg/l of sodium and 7.5 mg/l of potassium. The sodium-potassium ratio was close to that found in the effluents from the city of Moscow (mg/l):

Purification station dis- charges	Sodium	Potassium
Kur'yanovo.....	80.6	14.5
Lyublino.....	122.5	15.0
Lyubertsy.....	74.4	15.0

These ratios differ markedly from those of data obtained

for pure river water and for a number of industrial effluents. The absolute discharges at Pererva were 36 T/day of potassium and 165 T/day of sodium. It follows from a comparison with chloride content that some of the alkali metals are combined with sulphates. Below the city, sulphate content is much higher than in unpolluted sections of the river. Industrial effluents play the major role in raising the sulphate ion content.

Industrial sources of run-off increase the amount of copper, nickel, lead, molybdenum and silver in the waters of the river. According to the findings of G.V.Kol'tsov (1968), the content of the above metals in the water at the Pererva Dam was greater than at any point of observation downstream. Even at a point situated below the inflow of all of the run-off 167 from the city, the concentration of the majority of elements was lower than right at the point where the river flows out of the city.

The organic content, according to the biochemical oxygen demand (BOD_5), increased from 1946 to 1965 by almost 2.5 times. The increase in the amount of easily oxidizable organic substance, together with the increase in approximately the same proportion of the ammoniate nitrogen content, indicates increased effluent of a domestic nature or increased pollution of a second order through bottom deposits. One of the reasons for the deterioration in the river's oxygen balance is the increase in unpurified run-off water discharged into the river. In 1945 this amounted on the average to

38,000 m³/day; in 1965 this quantity had grown to 201,000 m³/day. When the value of the biochemical oxygen demand (BOD₅) is 180 mg/l, the daily discharge of easily oxidizable organic substance amounts to 36 T. Small city purification plants discharged 145,000 m³/day into the Moskva River, the value of BOD₅ of the purified water being on the average 10 mg/l, which amounts to 1.45 T/day of organic material. The amount of organic pollution entering the river from the city's territory can be calculated very approximately. Assuming that pollution introduced by the city's surface run-off amounts to 15% of the pollution from domestic run-off (Pravoshinskii, 1965), and postulating that the latter value is 300 T/day in the city of Moscow, we obtain a value for discharge into the river from surface flow of 45 T/day. Where the river exits from the city at Pererva, the daily discharge of organic material, estimated according to the BOD₅, is 30 T/day. Thus, the self-purification capability of the river within the city is several dozen, (no fewer than 50) tons per day of organic material. The latter quantity is minimal, as the influence of bottom deposits and the production of organic substances due to photosynthesis in aquatic plant life are not taken into account.

Composition and properties of the water of the Moskva River below city effluent at points of mixing

The first purification "plants" of the city were the fields of irrigation near the settlements of Lyubertsy and Lyublino, which came into use at the end of the last century.

Run-off from the Lyublino irrigation fields and ponds entered the Moskva River at Chagin; run-off from the Lyubertsy irrigation fields discharged into the Pekhorka River, a left tributary of the Moskva River. Fields of irrigation, fields of filtration and biological ponds were very effective in purification, but at the same time gave rise to profound changes in the ionic composition and the amount of basic nutrient elements contained in the section of the river below the city (Kalashnikova, 1913; Obzor, 1928).

One of the most sensitive indices of pollution by domestic run-off is dissolved oxygen. According to studies made 80 years ago, a decrease in dissolved oxygen below the city was noted before the construction of a city-wide sewage system. M.B.Kotsin (1889) showed that in the summer and winter, oxygen content in the river water below the city was somewhat reduced. Dissolved oxygen content was (mg/l):

	In January	Average over the summer
Lokhino (above the city)...	6.23	8.96
Shelepikha (in the city)....	6.69	8.52
Chagino (below the city)...	5.33	6.97

In proportion to the increase in the quantity of run-off and in accordance with the transition to methods of artificial biological purification, the effect of city run-off on the composition and properties of the river water increased.

Whereas before construction of the sewage system the ammoniate

nitrogen content below the city increased by tenths of a mg per litre, several mg/l were detected in the river after the opening of the purification plants.

In 1937, as a method of improving the condition of the river, the flow of the river was increased by water added from the Moskva Canal. The investigations of V.N.Kononov and S.T.Sitnov (1939) revealed an improvement in water quality in the river on account of this method within the city. However, according to the data of N.K.Deksbakh and A.Ya.Musatova (1940), the effect of the added water was noticeable only in the portion of the river near the place where pure water was added.

Difficult conditions prevailed on the Moskva River below the city in wartime and in the immediate postwar years. Construction and putting into operation of purification plants and city sewers were held up, and the transfer of water from the Moskva Canal was reduced; in the winter it was interrupted entirely.

Later the high-capacity Kur'yanovo and Lyublino purification plants were put into operation, and subsequently the Lyubertsy station with full biological purification (1965), which all had an effect on the condition of the river. A large amount of analytical data from the studies of 1945-1948 and 1964-1966 characterize the condition of the river at the point of complete mixing.

During the period 1945-1948, the discharge of purified

run-off water below the city was 8-9 m³/sec; the greater proportion of the effluent entered from the Lyublino purification plants above the Beseda Dam. In the section of the river above the dam, water composition has been noted to be inhomogeneous over a cross-section. A fall of water facilitates mixing, and in the section below the Beseda Dam the river is practically homogeneous in cross-section. The relatively small proportion of effluent coming from the Lyubertsy purification plants did not introduce significant changes in the regime of the river. In 1965, after the opening of purification plants at Lyubertsy having an output of 1 million m³/day, the situation changed considerably. The discharge of effluent below Zaozer'e gives rise to ~~anastomosis~~ over a cross-section, and the river becomes homogeneous in cross-section below the dam at Sof'ino. Thus, in order to take into account the effect of all effluent from the city, it is necessary to compare data from the first period of investigation below the Beseda Dam with later data taken below the Sof'ino Dam.

Average data on water composition at the Beseda Dam by seasons for the years 1947-1948 are shown in Table 6.

Table 6

Average data on water composition at Beseda, by seasons

Season, year	Number of samples	Air Temperature in °C	Ammonia-nitrogen	Cl ⁻ mg/l	Dissolved oxygen mg/l	BOD ₅ mg O ₂ /l
Summer 1947	33	21.4	6.2	36.0	4.8	10.7
1948	12	21.4	7.4	54.2	4.1	10.3
Autumn 1947	28	8.4	7.0	49.0	7.2	19.6
1948	12	9.4	7.5	54.0	6.8	8.9
Winter 1947	20	0.4	8.6	53.0	4.9	23.9
1948	12	0.7	10.2	64.0	5.2	24.9

The results of the analyses of the two postwar years were similar for BOD₅ and dissolved oxygen. Ammonia and chlorine ion content increased considerably in 1948. In spite on the high value of the BOD₅, the water always contained dissolved oxygen. The percentage saturation by oxygen was greatest in the autumn (57-72) and least in the winter (34-36). The comparatively satisfactory oxygen regime in autumn and summer is to be explained to a considerable extent by oxygen saturation while the water flows from Pererva and falls over the Beseda Dam. The minimum summer oxygen content has been recorded at a point situated several kilometers above the Beseda Dam at Rezantsevo, according to data from three years of observations (Fig. 3). The winter reduction in the amount of oxygen after the autumn maximum was not so sharply defined. As will be shown below, at the end point of observation, at the city of Kolomna, the seasonal variation in the oxygen regime is completely different

from that represented in Fig. 3.

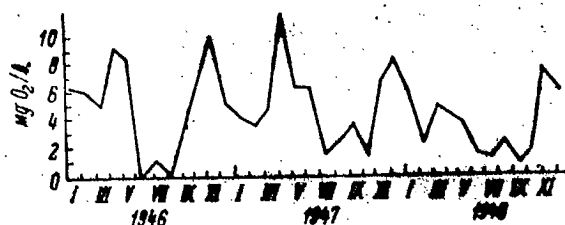


Fig. 3. Amount of oxygen dissolved in the Moskva River at Rezantsevo.

When considering the oxygen regime near the point of inflow of run-off waters that have undergone complete purification, one must take note of oxygen content in the run-off itself, which usually fluctuates between 5 and 6 mg/l. The value of the BOD₅ in the river was unusually high in the years 1946-1948, especially during the winters. The explanation of the reasons for this phenomenon was indicated above.

Within 18 years of the postwar study of the river, substantial changes in the watershed area and in the regime of the river had taken place. The population of the city had increased by 2 million, and the discharge of effluent into the river had increased by more than 3 times (from 9 to 30 m³/sec).

In order to compare with the condition of the river below the points of discharge of effluent from the city, we shall present data from the investigation carried out in 1964-1965 (Table 7).

Table 7

Average data on water composition below the Sof'ino Dam in 1964-1965, by seasons.

Date	Number of samples	Air temperature in °C	Ammonia nitrogen	Cl ⁻ mg/l	Dissolved oxygen mg/l	BOD ₅ mg of O ₂ /l
March, 1964	3	0.1	7.0	123.4	2.6	14.0
October, 1964	3	11.3	7.2	63.5	8.2	7.7
June, 1965	3	19.8	5.8	77.0	5.5	8.2

In assessing the condition of the river by seasons, it is necessary to bear in mind that in the winter of 1964, 1.8 m³/sec of water were added from the canal and the discharge of water at the Pererva Dam in the period of observations (March) reached 27.1 m³/sec. This circumstance explains the chlorine ion concentration of 123.4 mg/l, the highest value of all published data for the Moskva River. In spite of the sharp rise in the chloride concentration during the winter in comparison with the data of Table 6, the oxygen demand is just over half as high. The water contained 2.6 mg/l of oxygen, while in previous years in March at Sof'ino the supply of dissolved oxygen was almost exhausted. In summer and autumn, when a considerable amount of water was being added from the canal, the chlorine ion content fell sharply. In spite of the increase in the discharge of effluents, values of BOD₅ were considerably lower than in 1946-1947.

Thus, despite the increase in the volume of run-off,

the chemical indices of pollution indicate a more favourable picture of the condition of the river than previous investigations.

Table 8

Daily discharge of chlorine ions at Beseda
in 1946-1948 (T/day)

Season	Years			
	1946	1947	1948	1949
Summer	-	154	232	-
Autumn	155	167	184	-
Winter	-	155	213	196

Calculations made on the basis of average data on the content of particular ingredients in the river and discharges of water give a representation of the absolute quantities of substances brought into the river by effluents. Table 8 presents data on the daily discharge of chlorine ions below the inflow of the run-off water from the city in the post-war years.

Taking into account the substantial differences in hydrological conditions and possible fluctuations in discharges of industrial chlorine, one may assume that the data obtained yield quite constant values of between 150 and 230 T/day. Of this amount, about 10% should be attributed to the natural discharge of the unpolluted river. Domestic consumption in the city with 4 million population amounts to 40 T. of chlorine ion per day; industry three to four times as much.

Chlorine ion discharges at the Sof'ino Dam have been
(in T/day):

Winter, 1964 604	Autumn, 1964 527	Summer, 1964 552
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On the assumption that 5% of the chlorine ions would be present in unpolluted water and 10% are attributable to the population of the city (6 million), we obtain a flow of between 450 and 500 tons of industrial chlorine ions. In comparison to previous studies, the ratio of domestic chlorine to industrial chlorine has risen to 1:9 (cf. 1:3.5); i.e. the discharge of industrial chlorine has increased by approximately three times.

Changes in anion composition have taken place due to the influence of effluent run-off (Table 9).

Table 9

Anion content in river water at Sof'ino
during the summer of 1965
(mg/l)

Date	HCO ₃	Cl ⁻	SO ₄ ²⁻
June 16	206.5	79.0	72.0
June 18	203.8	82.9	72.0
July 2	201.4	69.4	69.6

Sulphate ion content was approximately equal to that of chlorine ions.

Domestic sources of effluent are of paramount importance in relation to ammoniate ion content, which builds up

in large amounts after the hydrolysis of urea and constitutes 12.5% of the cation composition of urine.

Calculations of the amount of ammoniate nitrogen at a point of complete mixing (below Beseda) are shown in Table 10.

Attention is drawn to the high degree of equality of the data for summer and autumn. In 1947 the flows were similar in all of the seasons of the year; in 1948-1949 the winter flow of nitrogen was considerably higher.

During the investigation of 1964-1965, the flow of nitrogen in the river below the discharge into the river of all run-off from the city of Moscow (at Sof'ino) was (in T/day):

Winter	Summer	Autumn
62.6	38.7	57.3

Attention is again drawn to the higher inflow of ammoniate nitrogen in winter than in the summer, which possibly is related to the decline in urban population during the summer.

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Table 10

Daily discharge of ammoniate nitrogen at Beseda (T)

Season	Years			
	1946	1947	1948	1949
Summer	-	21.5	21.6	-
Autumn	22.5	22.1	23.9	-
Winter	-	19.0	34.4	32.5

The daily contribution of ammoniate nitrogen to the sewage system by one person is taken to be equal to 6-10 g. In the years 1946-1949, when the population of the city was 4 million, the minimal norm corresponds to 24 T/day of nitrogen. As can be seen from Table 10, this amount was exceeded only in the winter months. In other seasons of the year the quantity calculated was quite close to those obtained in the summer and autumn of 1947 and 1948.

According to the data of 1964-1965, the nitrogen discharge actually found in the summer was close to the minimum calculated above, while in autumn and winter it approached the maximal norm for daily nitrogen discharge, which corresponds to 60 T/day for a population of 6 million.

S.N. Stroganov has shown (1923) that the nitrogen content in the sewage water is closely linked to the feeding habits of the population. It would seem to be plausible that the increase in the daily discharge of nitrogen in the river can be explained in terms of improvement in the nourishment of the population. The comparative consistency of the data obtained makes it possible to proceed to a calculation and quantitative expression of the change in the natural regime of bodies of water affected by discharges of domestic effluent. Observations and calculations over a number of years show that the content of one of the most important nutrient elements--nitrogen--increases in a volume of water in direct proportion to the number of inhabitants

served by the sewage system.

From the level of the biochemical oxygen demand for a five year period, the quantity of organic easily oxidizable matter may be calculated. Data on the flow of organic matter by season below the Beseda Dam are shown in Table 11.

Table 11

Discharge of organic material below main sources of effluents, based on the BOD₅ (T/day)

Season	Year			
	1946	1947	1948	1949
Summer	-	45.8	37.1	-
Autumn	61.0	65.0	30.0	-
Winter	-	95.0	95.2	76.5

The amplitude of fluctuations from year to year and from season to season in the amount of organic substance lies within the limits 30 T - 95 T, considerably exceeding the divergence in amounts of ammonium and chlorine ions. The main causes of this have been changes in the operation of the purification plants and in the river's self-purification processes. According to data from 1947 and 1948, the value of the BOD₅ in winter was twice as high as in summer. The quantity of organic matter in the winter of 1947 was 95 T/day, while in the summer it was 45.8 T/day; corresponding figures for the next year were 95.2 and 37.1 T/day.

One should point out the increase in the concentration of liquid effluent from the city of Moscow in winter which was first noted in a survey of the operations of the Lyublino

filtration fields.

From the results of four years of observations, it has been established that in the summer, the average value of oxidizability was 53.6 mg/l and of BOD₅ was 310, while in winter the oxidizability was 70.8 mg/l and the BOD₅ 430, i.e. 34% higher than in the summer. In summer, the content of suspended matter was 410.6; in winter, 498.0 mg/l -- a difference of almost 20%. Subsequent observations taken at the Kozhukhovo aeration station have confirmed these results. Consequently, both the purification plants and the rivers have a higher load in the winter than in summer.

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Deterioration in the work of the purification plants during the winter has been noted in the literature. According to the data of N.A. Bazyakina (1948), the effective oxidizing power of the biological filters is appreciably lower in winter in the case of aerofilters, and especially percolator filters.

How much the operation of purification plants deteriorates during the winter period can be seen from the data of N.M. Popova (1959). On the average over a three year period, (1946-1948), the purification plants yielded effluents containing almost twice as much organic matter (based on the BOD₅) in winter than in summer.

In 1964-1965, the flow of organic matter below all sources of run-off of the city constituted (in T/day):

Winter	Summer	Autumn
74.8	70.6	63.9

According to data obtained in the studies of 1964-1965, the amount of organic matter in the water at Sof'ino was somewhat less than in the winters of 1947-1949, and was close to that recorded in the autumn of 1946 and 1947.

Assuming a daily norm of inflow into the sewage system from a single inhabitant of 50 g/day, based on the BOD₅, we obtain a total of 200 T of organic matter for 1947 and 300 T for 1964. Thus, while in the first period of investigation, up to 48% of calculated values of organic matter were detected in the river, in the period 1964-1965 the maximum load entering the river did not reach 25% of the calculated values.

In the 1964-1965 investigation of the river, a determination of the content of mineral and total phosphorus in the polluted section of the river below the city was made. Data on phosphorus content below the inflows of all run-off in the summer period are presented in Table 12.

Table 12

Phosphorus content in river water below the inflow of city effluents in the summer of 1965 (mg/l)

Date	Total phosphorus	Mineral phosphorus	Organic phosphorus
June 16	0.65	0.40	0.25
June 18	0.60	0.30	0.30
July 2	0.63	0.25	0.38

In comparison with the unpolluted section of the river, the content of total phosphorus increased by one order of magnitude. Approximately the same results were obtained for both summer and autumn. Calculations of daily flows of phosphorus give the following values (T):

Winter	Summer	Autumn
4.4	5.4	5.8

Taking the magnitude of the daily inflow of phosphorus into the sewage system to be 0.73 g for each inhabitant, we obtain a total phosphorus discharge of the order of 4.4 g per day. This value coincides with that detected in the river in winter and is appreciably lower than that given by data obtained in summer and autumn. Because some of the phosphorus is eliminated along with sediment when the run-off waters are purified, it is to be supposed that there are other sources of phosphorus.

Determination of the alkali metal content in a hydro-metric section at the Sof'ino Dam (Kobyakova, 1968) has made it possible to compare seasonal fluctuations in the concentration of these elements and to calculate daily flows (Table 13).

Fifteen tons of potassium and 30 T of sodium enter the river with domestic fecal effluents. Four times this amount of potassium and ten times this amount of sodium were detected in the river; the difference is to be attributed to industrial effluents.

Table 13

Content and flow of alkali metals at the
Sof'ino Dam

Date	Potassium		Sodium	
	mg/l	T/day	mg/l	T/day
Mar. 6-8, 1964	13.0	67.3	62.0	321.1
Oct. 9,17, 1964	9.3	67.2	47.5	343.4
June 16 and July 2, 1965	9.31	66.6	47.3	339.1

The data presented on the total flows of certain ingredients of the ionic composition and of nutrient elements are generally quite steady and can serve as a basis for forecasting changes in the composition of the water when city effluents are discharged into the river. In the case of nitrogen, one may assume that 8 g/day is the norm for each inhabitant. Approximately 0.8 g/day of phosphorus per unit of population have been found in the river below the inflow of city effluent. It would be interesting to compare our data with those of studies made on rivers that flow through other major cities.

The changes in the ionic composition due to the influence of city and industrial waters amount to an increase in potassium and especially sodium ions, chiefly owing to a drop in calcium. With respect to anions, there is an increase in the relative chlorine and sulphate ion content due to a drop in the amount of bicarbonate ion. This rule holds generally

for carbonaceous-calcareous waters.

Conversion of organic matter in the river in summer

Under summer conditions a powerful factor in the conversion of matter and energy in a body of water is the action of the aquatic biota. Quantitative ways of investigating the role of water organisms in self-purification processes have been discussed in a paper by G.G. Vinberg (1964). The phenomenon of eutrophication of a body of water affected by domestic and industrial effluents and changes in the abundance of aquatic biota have been studied in lakes in Switzerland (Hasler, 1947), the Federal Republic of Germany (Thienemann, 1955; Ohle, 1965), the U.S.A. (Edmondson, 1961; Davis, 1964; Carr and Hiltunen, 1965). Slow currents in parts of the Moskva River near the dams create conditions to a certain extent approximating those of ponds.

The Moskva River is a suitable object of research into conversion processes inasmuch as the effluents from the city of Moscow represent a concentrated, massive source of pollution. Below the nearest dam this effluent is mixed homogeneously with river water. Further changes in the composition and properties of the water are to be attributed mainly to processes taking place in the river, as over the whole remaining extent of the river there are no other sources of pollution comparable in scale to the drainage from the city. Before the opening of the Lyubertsy aeration station, the

section of river suitable for the study of self-purification processes from Beseda to the mouth of the river was 140 km long; in 1964 this was reduced to 90 km (from Sofino to the mouth).

Certain complications are introduced to the regime of the river by polluted tributaries--the Pakhra River, having a watershed area of 2614 km², and the Pekhorka River, which has acquired effluent from the Lyubertsy irrigation fields; however, the relative influence of these tributaries is small. Data on the change in certain fundamental indices of water quality in the section from Beseda to Kolomna during the summer of 1948 are shown in Table 15.

Average data for the season record an improvement in the oxygen regime from the point of complete mixing at Beseda to the river's mouth; the percentage saturation rises from 46 to 98% at Kolomna. Downstream along the river, a decrease in the content of chlorine ion and ammoniate nitrogen takes place. A small reduction in permanganate oxidizability has been recorded along this section of the river. The other important indices of the condition of the river--the biochemical oxygen demand, the content of matter in suspension, and the transparency--do not show a picture of gradual decrease from the point of greatest pollution to the final point of observation.

The BOD₅ level, rather high for the river, proved to

be practically steady for the whole 30 km distance from Beseda to Zaozer'ya. By Sof'ino, situated 50 km from the initial point of observation, the value of the BOD_5 has increased by a factor of 1.4. Further on, at Bronnitsy, the BOD_5 dropped, but only toward the final point of observation 140 km from Beseda did this quantity fall to 25% of its initial value. According to the calculations of M.G.Ryabyshev (1964), displacement of the water mass in this section of the river took 9 days. At the usual rate of decay of organic matter (constant 0.1) the value of the BOD_5 towards Kolomna should be only 13% of the BOD_5 value found at the initial observation point. An increase in the amount of suspended matter has been established at Sof'ino and particularly at Bronnitsy; this is possibly related in some way to the increased BOD_5 .

One of the basic indices of the condition of a body of water is the magnitude of the biochemical oxygen demand; therefore, data on the change in BOD_5 over each of the summer months of 1948 are shown in Table 15.

According to average monthly data, the magnitude of the BOD_5 was higher at Sof'ino, 50 km from the point of discharge of the main bulk of city effluents, than at the point of complete mixing of effluents into the water. This phenomenon was especially well defined in June at Sof'ino and Bronnitsy and in July, when the BOD_5 at Sof'ino was twice as high as at the starting point. Less distinctly, an increase in the BOD_5 was recorded for the same section of the river in the summer of 1947.

As early as 1913, S.N.Stroganov, when considering data on the Moskva River, made note of a period which was characterized by a retardation of oxidation processes and even an increase in the BOD (1913, p.141).

The distinctive course of change in BOD_5 in the polluted section of the river was noted by B.A.Skopintsev (1933). A deterioration in the condition of a body of water at a certain distance from a source of pollution, occurring after the decay of the bulk of the polluting organic material, has long been recorded as a phenomenon of second-order pollution. In rivers this phenomenon is far from the rule. The conditions of appearance of this phenomenon and the quantitative parameters for expressing its scale and consequences have received little study. Causes of the deterioration of a body of water at a considerable distance from the source of initial pollution may be bottom deposits that have settled as a result of a slowing down of the current at a certain distance from the initial source of pollution. A second and more frequent case of second-order pollution is an increase in the formation of organic matter by higher water plants and phytoplankton. The conditions for luxuriant development of water plant life in the section of the river below the discharge of effluents are most favorable. The amount of nitrogen in the polluted water has been increased by more than two orders of magnitude (Tables 6, 7, 14); phosphorus content is one order of magnitude

higher and the concentration of calcium is 5-7 times greater. In the polluted section of the river the abundance of trace elements is considerably augmented and quantitatively enriched.

The development of water plant life in bodies of water that have received substantial amounts of effluents that have undergone purification (Kokin, 1963) is reflected in the quality of the water and gives rise to a number of difficulties in its utilization for industrial and domestic purposes. Because of this, methods have been studied for eliminating nitrogen and phosphorus from run-off waters. Bogan et al, (1960), have shown that with the aid of algae, a substantial amount of phosphorus can be eliminated. Bush et al (1961) 175 have established in field experiments that 50-70% of the nitrogen and from 19-68% of the phosphorus can be eliminated using algae. Gates and Borchardt (1964) have made a detailed study of the conditions of extraction of the principal nutritive elements by algae. The question of potassium in this regard has not been considered. Inasmuch as the increase in potassium content accompanying eutrophication of bodies of water proceeds at a slow rate, the development of certain species of water plants may be limited by a lack of potassium. Gothas et al (1954) have established that a factor limiting the development of algae in lagoons^{is} inorganic carbon. Bush et al (1961) have found that the addition of carbonic acid

facilitates successful development of algae which extract matter from domestic effluent. Abundant development of

Table 14

Variation in composition and properties of river water in the summer season of 1948 (average data)

Indices	BESEDA	ANDREEVSKOE	MOSKVA	BRONITSY	KOLOMNA
Water temperature, °C	21.4	20.6	21.5	20.8	20.2
Dissolved oxygen, mg/l	4.1	6.4	7.5	8.5	9.3
% saturation (oxygen)	46	70	80	92	98
BOD ₅ mg O ₂ /l	10.3	9.8	14.7	10.9	7.9
Oxidizability, mg O ₂ /l	13.0	12.4	12.0	11.9	10.6
Nitrogen in ammonia mg/l	7.4	6.5	6.6	5.9	5.9
Chlorides, mg/l	54.2	49.9	48.1	44.5	50.0
Clarity, cm	16.0	18.1	23.0	19.4	23.3
Suspended matter, mg/l	13.4	10.2	13.9	23.6	13.1
Number of determinations	12	13	14	10	17

phyto- and zooplankton in the Moskva River has been noted repeatedly. In experiments on determination of photosynthesis, it has been shown that in the upper pool between Beseda and Andreevskoe, a large quantity of organic matter is being produced at the same time as destructive processes occur, although in this section no increase in BOD₅ has been noted. As the experiments of G.G. Vinberg et al (1966) have shown, the presence of even a maximum amount of living algae does not cause an increase in the BOD₅; however, the decay of dead cells is related to the consumption of large amounts

of oxygen. It follows from Table 14 that the increase in organic matter in July approached the magnitude of BOD₅ at the initial point of observation. Available data (Drachev and Sosunova, 1953) make it possible to calculate approximately, on the basis of the difference between oxygen content in dark and light flasks, the amount of "clear production" of oxygen. For water flows of 92.4, 46.0 and 28.4 m³/sec in the river, oxygen production was 33.1, 46.6 and 27.6 T/day respectively. The average value of 36.3 T/day is of the same order as the amount of organic matter at the initial point of observations at Beseda (Table 11). The data shown give an idea of the scale on which organic matter is produced in the polluted river. A substantial increase in the biomass of plankton could have affected the increase in the amount of suspended matter in the river at Sof'ino and Bronnitsy (Table 14).

Table 15

Biochemical oxygen demand (BOD₅) in summer (mg/l)

Point of observation	Distance from mouth (km)	Months			Number of observations
		VI	VII	VIII	
Beseda	140	11.7	8.8	10.1	12
Zaozer'e	120	9.3	10.5	9.5	13
Sof'ino	90	16.2	17.5	11.1	14
Bronnitsy	80	18.6	8.7	9.4	10
Kolomna	6	7.9	7.8	8.7	17

Determinations carried out in 1965 by A.G. Bakulina showed an increase in organic carbon content in the water of the Moskva River above Voskresensk of up to 17.0 mg/l, compared with 13.2 mg/l upstream at Bronnitsy. For a water flow of 80 m³/sec, an increase in carbon content by 3.8 mg/l above Voskresensk constitutes about 30 T/day.

Thus, during the summer the content of organic matter, and consequently the river's oxygen regime as well, are mainly determined, in spite of the low transparency of the water (Table 14), by the action of photosynthesis in plants. On the basis of the biochemical oxygen demand, the greatest accumulation of organic matter was observed in the section of river at a distance of 50-80 km from the point of inflow of effluents, which corresponds in time to 3-5 days of water displacement. The total daily production of organic matter approximately corresponds in magnitude to the quantity of organic matter discharged into the river with the effluents from the city.

The oxygen regime of the river and self-purification processes during the autumn

The distinctive features of the balance of organic material in the Moskva River in the summer are to a considerable extent explicable in terms of the retardation of the rate of the current by dams. The predominance of processes of synthesis over decay of organic matter is related to the abundant development of phytoplankton in sections of retarded flow.

As autumn approaches, the activity of phytoplankton, especially the blue-green algae, begins to be limited by temperature conditions.

In carrying out autumn observations, changes in readily decaying organic matter and the features of the river's oxygen regime were investigated. In particular, a study was made of the significance of aeration through the surface of the water and when the water passed over dams (Medvedev, 1940). Questions concerning the balance of dissolved oxygen were investigated in 1947 in the section of the river bounded by the dams at Beseda and Andreevskoe. The general picture of organic matter decay processes and the oxygen regime were studied in 1948 for the complete length of the river; repeated observations under varied conditions were made in 1964.

Studies, relating to the autumn period somewhat conditionally, encompass the months September to November. The most characteristic feature of this period is the drop in water temperature from summer maximum to stable winter levels.

The increased solubility of oxygen at low temperatures, coupled with the reduction in the oxygen consumption in the river, is responsible for the maximal oxygen content in the autumn in the unpolluted part of the river (Table 1).

Owing to the steady decrease in temperature, each of the autumn months has its own characteristics. Data for September, particularly when autumn is fine, belong

with those of the summer, although the initial drop in temperature does introduce some changes. Data from later in the autumn are more interesting, as they describe the period preceding the transition to the winter period of ice cover. It is possible to determine the effect of the ice cover by comparing the data for late autumn, when the temperature of the water is nearly that of winter, with data taken during the winter.

The results of a study of the oxygen regime in the autumn of 1947 in the most polluted section of the river, the Beseda-Andreevskoe section, and along the whole river in the autumn of 1948 are presented below.

Meteorologically and hydrologically, the autumn of 1947 was distinguished by a dry, warm September and a warmer than usual October and November. In November there was a considerable amount of precipitation, which fell evenly during the month. As a result of the dry weather in September and October and the absence of prolonged rains in November, the autumn as a whole was characterized by low, evenly distributed water content.

Simultaneous investigations were begun on October 14 at the Beseda and Andreevskoe points. Samples were taken twice a day (morning and evening) at each point, making it possible to obtain comparable data. During the observation period, air temperature gradually fell from $+11^{\circ}$ to -2 , -3° . Water temperature fell from $+9^{\circ}$ at the beginning of the

observation period to $+2.8^{\circ}$. For the most part the weather remained calm, which facilitated the manifestation of oil pollution in the river. The presence of a film and surface pollution ranging from 2 to 5 on a five-point scale were recorded continuously. Water discharges in the river were steady and over the observation period constituted, on the average, $36.7 \text{ m}^3/\text{sec}$, of which effluents accounted for $9 \text{ m}^3/\text{sec}$. Thus, with respect to hydrological and meteorological conditions, the period of observations was typical for late autumn. The 14 km.-long Beseda-Andreevskoe section has no tributaries, and therefore water discharges were taken to be equal at the initial and final points. In this section of the river, processes of self-purification took place intensively. After receiving the effluent of the largest source of pollution at that time, the Lyublino complex of purification plants, the river water became homogeneous in composition and physical properties after passing over the Beseda Dam. In spite of the evenness of river flow and the comparative stability of the weather in the autumn of 1947, substantial day to day fluctuations in the abundance of dissolved oxygen, suspended matter and in BOD_5 have been recorded, as can be seen from Table 16, which shows amplitudes of fluctuations over the observation period and average data on the basic indices of water quality.

On the basis of water discharge over the period of observation and data on chemical composition, a calculation

of the discharge of certain substances at the points of observation was carried out (Table 17).

Stability of ammonium salt abundances was manifested with adequate definition. Variations in the content of suspended matter in the given section of the river were insignificant. Against this background, the change in the values of BOD₅ and dissolved oxygen are clearly evident.

On the basis of the data obtained, it is possible to calculate the oxidation rates of organic substances. The hourly decrease in the abundance of organic substances, according to S.N. Stroganov (1939), was 0.38 mg. Calculating the value of the decay constant for the organic matter by means of the accepted formula (Bazyakina, 1933), we obtain the value $k_1 = 0.26$.

Thus, in spite of the low temperature, the oxidation rate of organic matter, based on the BOD₅, is higher than in summer.

The considerations expressed above as to the role of photosynthesis in the balance of organic matter in the river is in accord with the data obtained during the autumn. At low temperature, processes of formation of organic matter proceeded on a substantially reduced scale if at all. The dissolved oxygen content was reduced by almost 1/3 and the reduction in the abundance of organic matter (based on the BOD₅) was even more substantial.

Table 16

Basic indices of water quality, October 1947

Indices	Number of determinations	Content		
		Minimum	Maximum	Average
BESEDA				
Water temperature, °C. . .	20	3.0	9.5	5.7
Dissolved oxygen, mg/l..	20	3.4	10.0	7.2
% oxygen saturation.....	20	27	74	45
BOD ₅ , mg O ₂ /l.....	20	14.1	24.4	19.6
Oxidizability, mg O ₂ /l..	20	12.7	21.4	15.4
Ammoniate nitrogen, mg/l	20	5.0	9.5	7.0
Chlorides, mg/l.....	20	44.4	57.6	49.0
Clarity, cm.....	19	8.0	14.6	10.4
Suspended matter, mg/l..	20	8.0	20.4	14.2
ANDREEVSKOE				
Water temperature, °C. . .	18	3.0	10.0	5.7
Dissolved oxygen, mg/l..	18	0.8	8.6	4.7
% oxygen saturation.....	18	6.0	64	36
BOD ₅ , mg O ₂ /l.....	18	8.3	14.4	11.6
Oxidizability, mg O ₂ /l..	18	12.8	17.7	15.2
Ammoniate nitrogen, mg/l	18	3.4	10.2	7.3
Chlorides, mg/l.....	18	42.2	54.9	49.2
Clarity, cm.....	18	7.0	18.0	11.6
Suspended matter, mg/l..	18	8.0	20.0	13.2

Table 17

Daily discharge of matter in autumn

Indices	Beseda		Andreevskoe	
	mg/l	T/day	mg/l	T/day
Ammoniate nitrogen..	7.0	22.0	7.3	23.1
Chlorides.....	49.0	155.4	49.7	157.6
Dissolved oxygen.....	7.2	22.8	4.8	15.2
BOD ₅ (O ₂).....	19.6	62.1	11.6	36.8
Suspended matter.....	14.8	46.9	13.2	41.8

The decrease in the abundance of organic matter in the water of the river between Beseda and Andreevskoe was 25.3 T/day; the dissolved oxygen content dropped by 7.8 T/day. Subtracting the latter value from the former, we obtain that the oxidation of 17.5 T/day of organic matter should be attributed to oxygen entering the water from the air: For a water surface area of 2 km², the coefficient of aeration through the surface can provisionally be taken to equal 8.8 g O₂/day.

The intensive development of oxidizing processes in the Beseda-Andreevskoe section diminishes considerably farther down the river. Thus, in November the BOD₅ was, on the average, 27.4 at Beseda, 8.5 at Andreevskoe, and 7.3 mg O₂/l at Kolomna--a drop of 18.9 mg O₂/l in the 14 km stretch, followed by a drop of 1.2 mg O₂/l in the 152 km section. A rather high BOD₅ level was very stably maintained for a long distance down the river.

Observations carried out in 1948, comparable as to weather conditions with the preceding year, but wetter, yielded results as shown in Table 18.

As a consequence of an improvement in the quality of effluent purification and a somewhat higher water content, the initial value of BOD₅ in the river at Beseda was half as high as for October of the preceding year.

Table 18

Average water quality indices for the section of river from Beseda to Kolomna, autumn 1948

Indices	Beseda	Zaozer'e	Sof'ino	Kolomna
Water temperature, °C.	9.4	9.0	7.7	7.4
Dissolved oxygen, mg/l.	6.8	8.1	8.9	10.2
% oxygen saturation	57	62	68	83
BOD ₃ , mg O ₂ /l.	6.2	5.1	3.2	3.2
BOD ₅ , mg O ₂ /l.	8.9	7.6	6.7	6.4
Oxidizability, mg O ₂ /l.	12.8	12.2	10.6	10.7
Ammoniate nitrogen, mg/l.	7.5	7.3	6.2	7.1
Chlorides, mg/l.	54.8	53.6	46.8	42.6
Clarity, cm.	16.5	17.9	25.5	22.5
Suspended matter, mg/l.	11.1	16.8	18.3	11.1
No. of determinations	12	11	12	16

Further downstream, BOD₅ changed little, a decrease of 2.5 mg O₂/l being reached only at Kolomna. The BOD₅ at the final observation point, Kolomna, 6.4 mg O₂/l, exceeds by a factor of 3 the value usually found in the unpolluted section of the river above the city.

The relative stability of the BOD₅ over the whole length of the river in autumn was confirmed in the autumn of 1964 (Table 19).

Table 19

Biochemical oxygen demand and dissolved oxygen content in October 1964

Observation point	No. of determinations	BOD ₅ , mg O ₂ /l.	Dissolved oxygen, mg/l
Bronnitsy	9	4.48	8.32
	17	4.48	8.14
Voskresensk	15	3.52	8.14
	16	4.32	8.14
Severskii	10	4.80	7.80

In autumn the BOD₅ did not fall below 3.5 mg/l over the whole length of the river; its average value was 4.5, the abundance of dissolved oxygen remaining high and stable. Thus there is no foundation for considering lack of oxygen to be a factor limiting the possibility of oxidation of organic matter.

The constant presence in the river water of a rather high, practically stable amount of organic matter can perhaps be explained by the stability of compounds contained in effluents that have undergone complete biological purification. This pertains especially to the data of 1964, when the quantity of effluents that had undergone complete purification had increased.

Probably the increase in BOD₅ occurs due to oxygen consumption in the oxidation of ammoniate and nitrite nitrogen. In flasks, nitrification processes usually begin to develop on the 5th to 10th day after the start of the experiment. In waters that have been subjected to complete purification, earlier influence from this process is possible. The data of Table 18, where determinations of 3 and 5-day BOD are shown, indirectly confirm this supposition, as in the case of longer periods of observation, a sharp drop in BOD has been recorded downstream along the river. However, in the case of 3-day observation periods, when effects of the nitrification process are unlikely, the BOD remains high even at distant points of observation.

Not excluded is a BOD increase caused by slowly acting photosynthetic processes. As is known, abundant phytoplankton development is sometimes observed in winter in ice-covered conditions. Finally, a certain increase in BOD is possibly due to the influence of bottom deposits that have accumulated because of retarded flow.

In the transition period from navigational to winter regime with free river flow, suspended substances are distributed in a distinctive longitudinal profile. At the Beseda observation point, above which there are no dismountable dams, there are, on the average for the season, 11.1 mg/l of suspended matter. At Zaozer'e and Sof'ino, situated below the Beseda and Andreevskoe dams, where bottom deposits have principally accumulated, the abundance of suspended matter increases to 16.8 and 18.3 mg/l. At the Kolomna observation point, located below the Severskii Dam, where bottom deposits have not accumulated as much, the content of suspended matter returns to its initial value.

A sharp change in the river's oxygen balance occurs late in the autumn after ice formation on the surface. It was found during a passage in November, 1946, that the abundance of dissolved oxygen increased from 10.4 at Beseda to 12.6 mg/l at Zaozer'e and was 10 mg/l at Bronnitsy. Towards the city of Kolomna, above which as a result of heavy frost ice 20 cm thick had formed on the river, the oxygen content dropped to 7.6 mg/l. The discharge of

dissolved oxygen in the river fell from 66.3 T/day to 47.9 T/day.

As a whole, the autumn period is more favourable than summer and winter in relation to the oxygen balance, as can be illustrated by a correlation of dissolved oxygen and BOD₅ (Table 20).

Table 20

Relation of dissolved oxygen content to BOD₅ (%)

Season, date	Beseda	Bronnitsy	Kolomna
Summer (VI, VII 1946)	17	37	53
Autumn (IX 1946)	65	265	260
Winter (III 1947)	20	6	4

This circumstance is confirmed by data on the absolute supply of oxygen in the river, which sharply increases in autumn in comparison with summer and winter. In the absence of ice cover, the favourable condition of the oxygen regime would be subsequently maintained, as in the case of rivers which do not freeze in winter.

One factor in the oxygen regime is aeration of the water as it passes over a dam. The bulk of the water in the river passes over the dam with a drop of 2.5-3.0 m. Because of loosely-fitted sluice gates, part of the water sprays out in jets through the gaps. The comparatively small proportion of the water which passes through navigation locks is not subjected to this aeration. Observations

made at the Andreevskoe Dam in summer and autumn have shown that enrichment of the water's oxygen supply when it passes over the dam depends on the oxygen deficit of the water. During the summer period, when the saturation level was about 60%, no perceptible enrichment of the water with oxygen was recorded at the Andreevskoe Dam. In the autumn, when the saturation level above the dam was fluctuating from 6 to 55%, the fall of water had a marked effect. On the basis of the discharge of water and increase in oxygen content below the dam, it was established that the daily addition of oxygen when the water passed over the Andreevskoe Dam was 13 T, and at the Beseda Dam, 9 T, which added together amount to 35% of the demand for oxygen (BOD_5) at the Beseda Dam. Thus, on the Moskva River there is a factor for improvement of the oxygen regime which goes into effect automatically during the period of low oxygen abundance; the favourable effect of this action increases in proportion to the drop in oxygen content. As indicated above, the inflow of oxygen through the surface of the river in October in the Beseda-Andreevskoe section was 18.7 T/day--an amount comparable in magnitude to the quantity of oxygen entering the river as it passes over the dams. Oxygen enrichment when the water passes over the dams is a cheaper way to supply oxygen to the river than aeration through turbines (Scott, 1958) or by means of special equipment (Kaplinsky, 1964).

A sharp increase in dissolved oxygen, ensuring a favourable oxygen regime, is a characteristic sign of autumn on the

Moskva River. This is generally true of many rivers in the Soviet Union; as a result, autumn conditions are more favourable for self-purification of the rivers than those of summer and winter.

Oxygen regime and water quality under winter conditions

Features peculiar to the winter period are: low water temperature, decreased flow, and ice cover which isolates the water from the atmosphere. Each of these factors exerts an influence on the oxygen regime of the river and the course of processes of self-purification. In the late autumn, maximal saturation of the water with oxygen has been noted (Table 1), related to the increase in solubility of oxygen in cold water and reduction of the biochemical oxygen demand to minimum levels. Retardation of biochemical oxidation processes is especially well-defined at temperatures nearing zero (Drachev, 1964).

For many rivers, winter discharges are at a minimum compared to other seasons of the year. According to the classification of M.N. L'vovich (1938), rivers of the Volga type, in which sources fed by melted snow predominate, have two subtypes. Northern rivers of the Russian Plain have minimal flows in winter, while in the case of southern rivers, minimal flows occur during the summer. According to the data of V.D. Bykov (1951), in 27 years of observations on the Moskva River, minimal flows were recorded 13 times in summer, 9 times in winter; on 5 occasions summer and winter discharges

were equal. Since water began to be transferred from the canal, the behaviour of the river in the city and downstream has been determined principally by the amount of water added. The significance of the canal water was clearly shown in the winter of 1964, when no canal water was added, and maximal pollution and salt concentrations were detected.

Ice cover is the controlling factor as regards the oxygen regime, especially for polluted rivers. As indicated in Table 1, in the winter months the least level of saturation of the water with oxygen (59-66%) was recorded in the unpolluted section of the river. Ground waters, which predominate 182 in feeding the river in winter, contain an insignificant amount of oxygen. The maintenance of the comparatively favourable oxygen regime of the Moskva River can be explained by oxygen saturation via polynias and waterfalls (Drachev, 1964).

On the average, the duration of ice cover on the Moskva River in the city has been 123 days (with fluctuations from 94 days in 1933, to 168 days in 1810). The discharge of a large volume of effluents has sharply altered the conditions of ice-formation in the section of river within the city and below.

Data on the oxygen regime in the Moskva River under winter conditions have been presented in several previous papers. M. B. Kotsin (1889) was the first to carry out determinations of oxygen above and below the city; it was also he

who first determined the biochemical oxygen demand, the "coefficient of oxygen variability", calculated according to the decrease of oxygen in two days in a thermostat at a temperature of 33° . Determinations below the city showed a small decrease in oxygen content in winter; such a decrease was more clearly evident in summer.

A different picture resulted from an investigation carried out in 1915 in the section from Shelepikha to the Severskii locks. These materials were presented in tabular form in the 1915 Report of the Provisional Committee on Finding Ways to Conserve Water Reserves, without textual commentary. From the tables, it is clear that in January, oxygen content in the river below the city fell to 1.0-2.6 mg/l.

Observations made by S. V. Bruevich (1927, 1929) showed that in winter self-purification processes take place very slowly. At Kolomna, the point most distant from the source of effluents, the Moskva River was extremely polluted. In the section below the Andreevskoe locks, the water contained 1.0-2.0 mg of dissolved oxygen per litre.

In the winter studies of 1946-1949, greatest attention was paid to the oxygen regime and biochemical oxygen demand. Weekly extraction of samples was carried out for the whole winter period at Beseda, Zaozer'e, Sof'ino, Bronnitsy and Kolomna. At the end of the winter, samples were taken at certain points every day. The data obtained give a representation of the condition of the river and the course of self-purification over the whole winter season.

Hydrological measurements and calculations of water flows and current velocities and observations of the condition of the ice cover were carried out under the guidance of M. G. Ryabyshev.

A factor constantly affecting the regime of the river was the removal of water above the city by stations of the Moscow water system at the rate of 8.8-8.9 m³/sec. The amount of run-off water from the city somewhat exceeded the volume of water collected by the water system from the Moskva River, which can be explained by the inflow of water into the city from other sources.

Observations on the river were begun in 1946-1947. A comparatively early freeze-up followed a dry, cold November. December was distinguished by low precipitation (40% of the long term average for Moscow and 90% for Kolomna). The temperature in December was close to the longterm average. January was cold, especially in the first and third ten-day periods. Deviations of 1.1-3.7° from minimal temperatures were recorded. February and the first twenty days of March had freezing weather, especially in the first twenty days of February. Deviations from average temperatures for ten-day periods were 6.5-5.2°. A feature peculiar to February and March was the large amount of snowfall (282% of the norm in Moscow, 410% in Kolomna), forming a thick covering on the river. A stable transition to positive daily average temperatures was recorded from March 21, towards the time of completion of winter observations. The

River froze over during the second ten days of November. Below Andreevskoe, ice stayed all winter. Towards the end of the winter, its thickness in the lower course of the river reached 60-70 cm. All dams on the river below the inflow 183 of the city effluent were dismantled after the freeze-up in the second half of December, with the exception of Sof'ino, which was dismantled at the end of January, 1947. Because of stable weather conditions and the absence of winter high-water periods, fluctuations in water levels were insignificant over the whole winter.

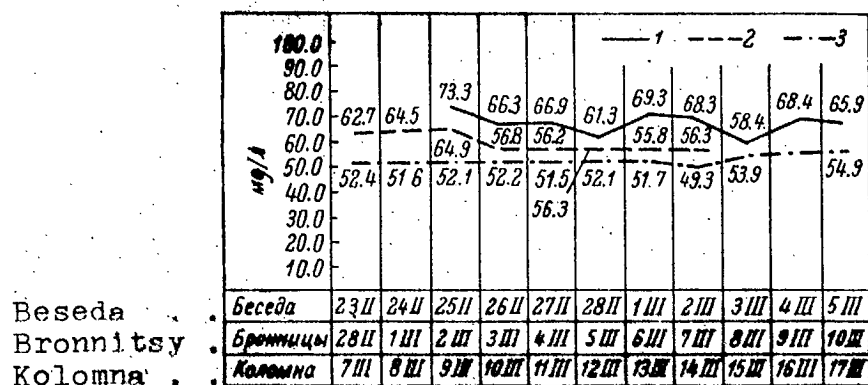


Fig. 4. Chlorides in the Moskva River (corresponding samples).

1. Beseda 2. Bronnitsy 3. Kolomna

The work began with manifestation of vertical and horizontal homogeneity of river flow. Investigations during the summer established equalization of ionic composition and physical properties of the water in the section below the Beseda Dam. This work was repeated under winter conditions after the dams were dismantled. The data showed complete

equalization of ionic composition over a cross section of the river at the Bronnitsy and Kolomna observation points. The ionic composition and water properties were relatively homogeneous over a cross section of the river below Beseda. Nevertheless, at the point below Beseda, three samples were taken over a cross section of river so as to arrive at an average sample for chemical analysis.

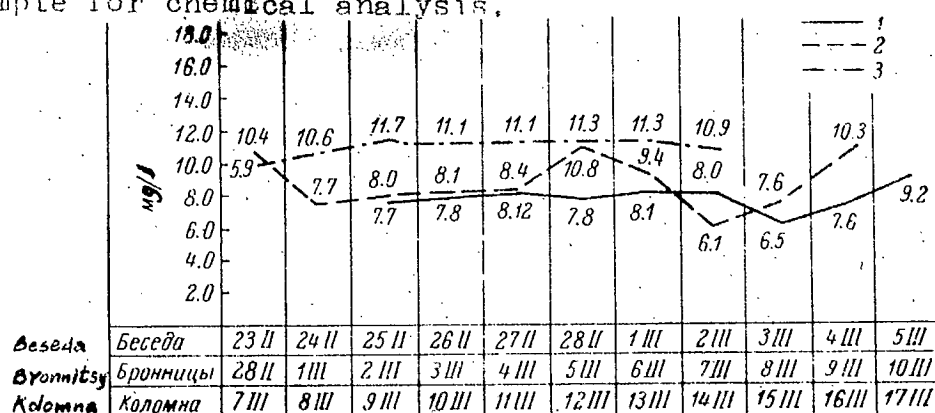


Fig. 5. Ammoniate nitrogen (N) in the Moskva River (corresponding samples)

Notation the same as in Fig. 4.

The transposition of a mass of water from the uppermost observation point to Kolomna took 11 days. In accordance with this figure, observations were begun at various intervals so as to obtain synchronized samples. Water flow for the whole winter was extremely stable. The average flow at the Beseda observation point in the last ten days of February constituted $27 \text{ m}^3/\text{sec}$, and in the first and second ten-day periods of March, 26 and $28 \text{ m}^3/\text{sec}$, almost exactly coinciding with average monthly values for January and February.

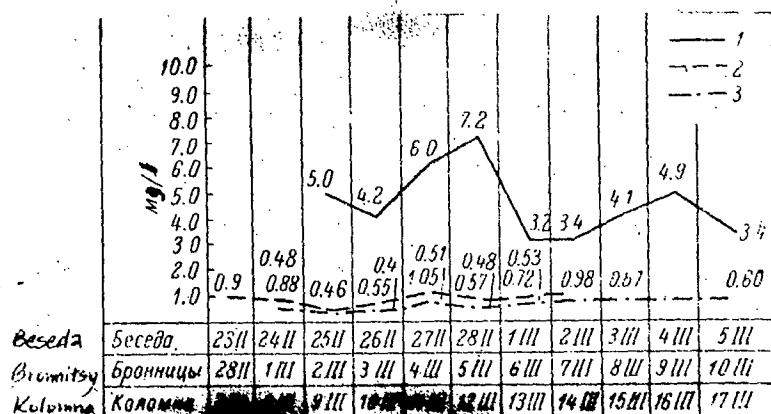


Fig. 6. Dissolved oxygen in the Moskva River (corresponding samples)

Notation the same as in Fig. 4.

In accordance with the stability of river flows and of amount of run-off entering the river, the ionic composition was distinctly uniform; a rather high degree of alkalinity was found in the river: at Beseda, within the limits 4.72-5.71 mg-equiv., on the average 5.16, and, at Bronnitsy, 5.08-5.45 mg-equiv. The relatively stable content of chlorides at Beseda, which subsides steadily towards the mouth of the river, is shown in Fig. 4. The average chloride content at the Beseda observation point was 66.8 mg/l, at Bronnitsy, 56.6 mg/l, and at Kolomna, 51.0 mg/l. In the case of many rivers of the Soviet Union, an increase in the concentration of chlorides towards the mouth has been recorded. The drop in chloride content in the Moskva River testifies to the addition of water to the river from tributaries and underground sources.

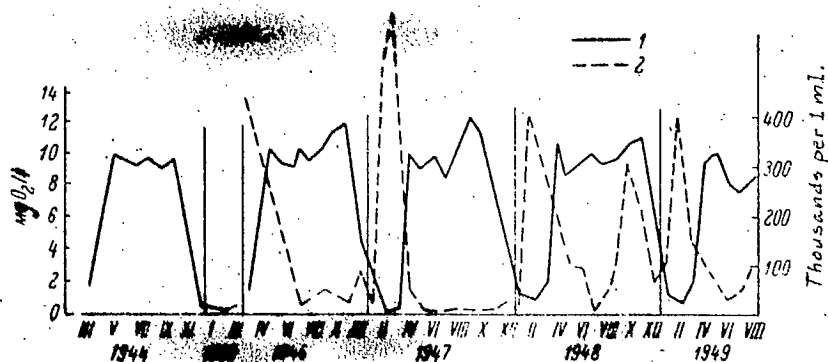


Fig. 7. Dissolved oxygen and saprophytic bacteria
 1. Oxygen, mg/l. 2. Number of bacteria/ml.

Ammonium content was quite stable both at the 185
 initial observation point and at downstream points (Fig. 5).
 The forms of chemically-combined mineral nitrogen for the
 period of observation were characterized as follows (mg/l):

	Beseda	Bronnitsy	Kolomna
Ammoniate nitrogen	8.3	11.0	8.7
Nitrite nitrogen	0.10	0.003	0.000
Nitrate nitrogen	0.16	0.11	0.00

The presence of oxidized nitrogen, which is characteristic of natural reservoirs in winter (Fig. 2), was recorded at the point of greatest pollution; at Bronnitsy its content decreases and by Kolomna has dropped to zero. These changes are completely in accord with the general direction of processes in a polluted river. The oxygen deficit was sufficiently significant that in the waters of the river at Kolomna, even chemically-combined oxygen in the form of nitrites and nitrates was completely exhausted.

The reasons for this phenomenon can be clarified from Fig. 6, where data on dissolved oxygen content are shown. The

highest oxygen content is found at the point of greatest pollution at Beseda. At Bronnitsy, the oxygen content is vanishingly small, and, at Kolomna, is calculated in amounts of the order of tenths of a mg per liter.

The high oxygen content in winter at the point close to the point where the effluents are discharged is not a coincidence. It is clear from Fig. 3 that in the winter, at the place where effluents have been discharged for a number of years, a rather high oxygen content has been recorded in the winter. A directly opposite picture is given by determinations of oxygen at the final observation point in Kolomna (Fig. 7), where summer maxima are replaced by winter minima.

The content of quickly-oxidizing organic matter remains high, and approximately uniform, both at the Bronnitsy observation point and at Kolomna. Average values of the BOD_5 and oxidizability are shown in Table 21.

Table 21

Content of organic matter (based on BOD_5)
in winter, average data

Point of observation	BOD_5 , mg of O_2/l	Oxidizability, mg of O_2/l	$BOD_5 \cdot 100$; oxidizability, %
Beseda	25.1	23.2	108
Bronnitsy	11.5	16.2	71
Kolomna	12.1	13.0	90

In Table 21, the magnitude of BOD_5 at the Beseda observation point is given with a correction for the consumption of oxygen due to nitrification. At the points situated down-

stream, according to the data of L. A. Mikhailovskaya, no consumption of oxygen due to oxidation of nitrogen occurred in the waters investigated over the incubation period.

For 11 days--the time for the water to travel from the upper observation point to Kolomna--organic matter was only partially oxidized. At Kolomna, there remained, on the average, 45% of the initial amount of organic matter, calculated on the basis of the BOD_5 , and 56% calculated on the basis of oxidizability.

The relation of the magnitude of the BOD_5 to oxidizability remained high (70-90% up to the mouth), while for pure bodies of water, it is 20-25% (Drachev, 1941). A drop in BOD_5 occurred in the section of river from Beseda to Bronnitsy, and further downstream towards Kolomna, a certain tendency for the BOD_5 to increase was noted. The latter is especially marked when calculations of absolute quantities of matter in the river are made (Table 22).

A very substantial decrease in BOD_5 (by 21.2 T) occurred in the Beseda-Bronnitsy section; the decrease in dissolved oxygen here was 9.5 T. Ignoring the relatively small amount of chemically-combined oxygen used up (NO_2' , NO_3'), one may conditionally assume that about 12 T of organic matter had been oxidized due to oxygen entering from the atmosphere. For a 10 km^2 area of river surface, we obtain an aeration value of 1.2 g/m^2 for the section of river from Beseda to Bronnitsy. The duration of the displacement of a mass of

water from Beseda to Bronnitsy is about 5-6 days.

Table 22

Content and daily flow of dissolved oxygen
and the BOD₅

	Beseda		Bronnitsy		Kolomna	
	mg/l	T/day	mg/l	T/day	mg/l	T/day
Dissolved oxygen	5.0	11.7	0.75	2.2	0.49	1.7
BOD ₅	25.1	58.6	11.5	37.4	12.1	44.9

A large quantity of suspended matter, gradually precipitating downstream with the current, was introduced with the effluent from the city into the river. A well-defined drop in the content of suspended matter occurs in the Beseda-Bronnitsy section. Near Kolomna, a certain increase in the content of suspended matter has been recorded, especially marked when daily flows are calculated (Table 23).

Table 23

Content and flow of suspended matter

Point of observation	Number of determinations	Water flow m ³ /sec	mg/l	T/day
Beseda	10	27.0	49.9	116.4
Bronnitsy	7	33.5	19.3	55.8
Kolomna	6	43.0	23.0	85.4

The precipitation of suspended matter proceeds quite intensively in the Beseda-Bronnitsy section; the drop in the daily flow of suspended matter is 61 T. Counterposed to the process of precipitation of suspended matter is a reverse transfer from bottom deposits of deoxidized gaseous, dissolved and suspended compounds.

A deterioration in water quality occurred in the Bronnitsy-Kolomna section; this was expressed as a reduction in the content of dissolved oxygen, and deoxidation of mineral nitrogen. At the same time, the BOD₅ and the biochemical index of pollution increased. The content of suspended matter rose. Detailed bacteriological observations carried out by Ye. V. Dianova and A.A. Voroshilova (1952) showed a significant increase in the number of prophytic bacteria at Kolomna (Fig. 7).

Thus, observations at the end of a winter which approximated long-term averages with respect to meteorological conditions, indicated the absence of aeration in the section with constant ice-cover.

The observations described encompass the end of the winter period, when all of the features of this season are most well-defined. Observations on particular months of the winter will be considered below.

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The ice cover formed in the lower section of the river in mid-November; immediately, it had the effect of reducing oxygen content at Kolomna. According to observations carried out in December at Beseda (3 analyses) and Kolomna (4 analyses),

the condition of the river was characterized by the following data (Table 24).

Table 24

Data on water composition, December, 1946.								
Point of observation	Water temp, °C	mg O ₂ /l	BOD ₅ mg O ₂ /l	Oxidizability mg O ₂ /l	Nitrogen			Chlorides mg/l
					Ammon-iates	Nit-rate	Nit-rite	
					mg/l			
Beseda	+1.9	5.5	28.9	22.9	7.0	0.18	0.68	61.8
Kolomna	+0.1	5.0	4.9	15.4	7.7	0.16	0.40	53.7

The river contained dissolved oxygen up to the mouth, on the average 33% of complete saturation; toward the mouth, the BOD₅ fell sharply. One may judge as to the changes in the nature of the organic matter towards the mouth by the reduction in the biochemical index of pollution from 127 at Beseda to 32 at Kolomna. The changes in the form of the nitrogen testify to the growth of reduction conditions; nitrite and nitrate nitrogen diminished in content towards the mouth.

Table 25

Basic indices of water quality at Beseda,
Winter, 1947.

Indices	Months		
	I	II	III
Water temperature, °C	0.63	0.20	0.76
Dissolved oxygen, mg/l	3.2	5.9	4.6
% saturation with oxygen	23.	41.	31.
BOD ₅ , mg O ₂ /l	25.	19.7	22.7
Chlorides, mg/l	69.8	67.7	66.4
Ammoniate nitrogen, mg/l	8.9	7.	8.6
Clarity, cm	4.6	6.2	7.5

The results of observations on the change in dissolved oxygen content and BOD₅ in subsequent months are shown in

Tables 25-27. In proportion to the distance of the point of observation from the place where pollution is greatest, a sharp and steady decrease in oxygen content is clearly traced out. A second circumstance, also clearly recorded in the tables, is the substantial drop in BOD₅ in the Beseda-Bronnitsy section and the extremely small decrease in the Bronnitsy-Kolomna section. Curves of BOD₅ in some periods of observation intersect for these two points.

Table 26

Basic indices of water quality at Bronnitsy, Winter, 1947

Indices	Months		
	I	II	III
Water temperature, °C	0.8	0.0	0.0
Dissolved oxygen, mg/l	3.2	1.8	0.7
% saturation with O ₂	22.	12.	5.
BOD ₅ , mg O ₂ /l	12.4	13.9	10.7
Ammoniate nitrogen, mg/l	10.7	10.4	11.2
Chlorides, mg/l	63.2	57.8	59.3
Clarity, cm	7.4	8.3	13.8

The decrease in dissolved oxygen (mg/l) at Bronnitsy and Kolomna, on the average, is stable from month to month, as is clear from the following figures:

	XII	I	II	III
At Bronnitsy	-	3.2	1.8	0.7
At Kolomna	5.0	2.2	0.7	0.6

Winter observations on the Moskva River were continued in 1947-1948. The winter of 1946/47 had been close to the long-term average with respect to hydrological and meteorological

conditions; the next year was different. November was marked by warm weather and heavy precipitation; all of December there was unstable warm weather, with frequent thaws 188 and precipitation in the form of rain and snow--213% of the norm in Moscow and 275% in Kolomna. Positive deviation from long-term average temperatures was $+4.1^{\circ}$ in contrast to December of the preceding year (-1.5°). Warm weather continued in January (deviation from long-term average, $+6.9^{\circ}$) and the first six days of February, after which steady freezing weather held until the end of February. Negative deviations from normal temperatures were recorded in the second and third ten-day periods of March, as a result of which a winter regime held sway on the river until the end of the month. Dams on the river were dismantled in the second half of November; dismantling of the Beseda Dam was delayed until December 16. Warm weather and heavy precipitation in November and December gave rise to increased water flows over almost the whole winter (Table 28).

Table 27

Basic indices of water quality at Kolomna,
Winter, 1947.

Indices	Months		
	I	II	III
Water temperature, $^{\circ}\text{C}$	0.2	0.1	0.1
Dissolved O_2 , mg/l	2.2	0.7	0.5
% saturation with O_2	18.	14.	3.5
BOD mg O_2 /l	9.7	11.3	10.3
Ammoniate nitrogen, mg/l	9.7	8.7	8.7
Chlorides, mg/l	51.0	53.7	51.8
Clarity, cm.	20.7	19.5	16.0

Table 28

Average monthly flows at the Pererva Dam			
Months	1946/47	1947/48	% of long term average
	m ³ /sec	m ³ /sec	
XII	18	41	200
I	18	33	249
II	18	34	220
III (first and second ten-day periods)	18	46	91

In the winter of 1947/48, river flows exceeded the long-term average almost twofold. The quantity of effluent entering the river remained practically at the level of the preceding year (9.0-9.1 m³/sec).

The increased flows caused an increase in the velocity of the current. The time for the displacement of a mass of water from one point of observation to another was (hr.):

Years	Beseda- Andreevskoe	Andreevskoe- Sof'ino	Sof'ino- Bronnitsy	Bronnitsy- Kolomna	Beseda- Kolomna
1947	21	59	57	126	263
1948	10.5	27.5	28	71	128

The observations of the winter of 1947/48 were carried out according to the program of the preceding year, but with the addition of points at Andreevskoe and Sof'ino.

Daily observations began February 20, and finished March 20. During the period of observations, the river remained under winter conditions. The increase in the flow of water in the first and second ten-day periods of March from 32.7 to 47.4, and 49.7 m³/sec in February was caused by the addition of water from the Istra Reservoir (19 m³/sec). During the whole winter, the river at Beseda was free of ice; at Andreevskoe, ice

on the river was 10-15 cm thick until March 5. When the weather grew warmer and flow increased, the river was freed from ice which happens very rarely here in winter. In the section between Kolomna and Bronnitsy, the ice was constant and solid, 40-60 cm in thickness, and only in rapids were there ice-free spots.

Comparing the results of the 1948 analyses (Table 29) 189 with the preceding dry year (Table 25), we see that, in 1948, there was a decrease in chloride content at the initial point of observation, although not in proportion to the dilution. Such a decrease in chlorides had been also noted by V.V. Fovanov (1925) in his investigations of the Volga.

In 1948, the content of dissolved oxygen was greater; ammoniate nitrogen and the BOD did not decrease. The latter circumstance is particularly marked when calculations of absolute daily flows of matter in the river are made (Table 29).

The more rapid oxidation of organic matter in the winter of 1947/48 is clearly shown by the data of Table 27. An acceleration of the oxidation of organic matter, compared to the previous winter is plainly visible when calculations of daily flows of organic matter are made on the basis of BOD₅ (Fig. 8).

Table 29

Pollution indices according to average seasonal data, Winter, 1948.

Indices	Content	
	mg/l	T/day
Beseda, flow 51.7 m ³ /sec		
Ammoniate nitrogen . . .	8.56	38.2
Chlorides	53.0	237.0
Dissolved oxygen	4.95	22.1
BOD ₅	23.9	106.8
Suspended matter	39.4	176.0
Andreevskoe, flow 52 m ³ /sec		
Ammoniate nitrogen . . .	7.57	34.0
Chlorides	53.3	240.0
Dissolved oxygen	3.56	15.9
BOD ₅	19.0	84.9
Suspended matter	47.4	212.9
Bronnitsy, flow 58 m ³ / sec		
Ammoniate nitrogen . . .	8.34	41.7
Chlorides	41.1	206.0
Dissolved oxygen	2.26	11.3
BOD ₅	7.75	38.8
Suspended matter	13.0	65.1
Kolomna, flow 68.1 m ³ / sec		
Ammoniate nitrogen . . .	9.7	57.0
Chlorides	38.0	223.6
Dissolved oxygen	1.89	11.2
BOD ₅	7.42	43.6

The data on flows enable us conditionally to calculate the amount of oxygen (in g.) received from the atmosphere for this section of the river and for each square meter of the surface of the water (A, the aeration coefficient).

B. A. Skopintsev (1933) carried out calculations according to the formula

$$A = \frac{Q (D_1 - D_2)}{F}, \quad (1)$$

where Q is the debit of the river (m^3/day); D_1, D_2 are the total biochemical consumption of oxygen in the river at points 1 and 2 (g/m^3); F is the surface area of the river (m^2).

According to M.M. Popova and T.S. Nagibina (1934), the calculation is carried out according to the formula

$$A = \frac{Q [(a_1 - a_2) + 1.71 (n_1 - n_2) - b]}{F} \quad (2)$$

where Q is the daily flow of water (m^3); n_1, n_2 represent the content of ammoniate nitrogen at points 1 and 2 (g/m^3); a_1, a_2 are the BOD at points 1 and 2 (g/m^3); b is the difference between oxygen content at points 1 and 2; F is the surface area of the water (m^2).

This formula can be applied when introducing a correction for the nitrification process when determining BOD. The two above formulae assume equal flows of water at the points of observation. For points that are far apart, one should use the

following formula:

$$A = \frac{(Qa - Q_1a_1) - (QO - Q_1O_1)}{F} \quad (3)$$

where Q and Q_1 are the flows (m^3/day) at the upper and lower points; a and a_1 are the BOD_5 (g/m^3) at the upper and lower points; O and O_1 represent oxygen (g/m^3).

Calculations performed according to the latter formula yielded the following results (Table 30).

Table 30

Aeration coefficients, Winter, 1948

Point of observation	Daily flow, T		Surface area	Aeration, g/m^2
	BOD_5	O_2		
Beseda	106.8	22.1	2.0	7.9
Andreevskoe	84.9	15.9	8.0	5.2
Bronnitsy	38.8	11.3	11.4	0.0
Kolomna	43.6	11.2		

In the calculations cited, we take a five-day oxygen demand instead of the total BOD. No correction was made, in addition, for the value of the BOD in the river at temperatures close to zero. Such corrections have various signs; the coefficient for the transition from BOD_5 to total BOD usually is taken to be equal to 1.45 (when K_1 is equal to 0.1). To take the influence of temperature into account, the coefficient 0.6 is used, so that the total magnitude of the correction may be considered to lie within the limits of the error in the determination of atmospheric aeration.

The data obtained showed the high value of the aeration coefficient in 1948 for the Beseda-Bronnitsy section. On the section of the river, there was no constant and continuous ice cover, but it froze partially and temporarily. Winter ice cover was observed several times. In the Bronnitsy-Kolomna section, air did not enter the water in either year of observation.

The data obtained make it possible to perform a calculation of the aeration constant k_2 , according to the formula

$$k_2 = \frac{x_t + (O_2 - O_1)}{2.3 D_{avg} t} \quad (4)$$

where x_t is the consumption of oxygen in time t (mg/l); O_2, O_1 are the contents of oxygen at points 2 and 1 (mg/l); D_{avg} is the average oxygen deficit in the section of the river between points 1 and 2 (mg/l); t is the time in days.

A calculation of the magnitude of k_2 for the first three months of 1948, using average data, yield the following values

Section	k_2
Beseda-Andreevskoe	0.30
Andreevskoe-Sof'ino	0.26
Sof'ino-Bronnitsy	0.40
Bronnitsy-Kolomna	0.00

High values were obtained for all the sections situated above Bronnitsy. The average value of the constant is also high for the Sof'ino-Bronnitsy section, with its variable ice cover.

The data indicate that the process of oxidation of 191 organic matter goes on at a substantial rate in winter in the upper part of the river. The constant of the rate of oxygen consumption k_1 is calculated according to the formula

$$k_1 = \frac{1}{t} \lg \frac{L_2}{L_1} \quad (5)$$

where L_2 and L_1 represent the BOD_5 at the lower and higher points; t is the displacement time for a body from point 1 to point 2. Calculating k_1 on the basis of data from the observations, we obtain for the Beseda-Bronnitsy section the value 0.2, and for the same section in 1947, 0.06.

Determinations of BOD for 3 and 6 days make it possible to calculate the constant of the rate of oxygen consumption by means of the formula usually applied in this kind of calculation (Bazyakina, 1933).

The magnitude of k_1 , according to data from laboratory experiments at Beseda and Andreevskoe, averaged from 18 pairs of determinations, was 0.13 (with fluctuations from 0.05 to 0.24); consequently, it was rather close to the value usually used (0.1). Churchill and Buckingham (1956) have indicated substantial fluctuations in this constant, obtained in studies of the highly-polluted Potomac River.

For the transition from the experimental temperature (18-20°) to river temperatures of 1-3°, it is necessary to introduce a correction of 0.4; thus, there is a difference in oxidation rates in the river and in a flask.

For a more complete calculation of the oxygen regime and the aeration of a water basin, it is necessary to take into account the precipitation of a portion of the easily-oxidizable compounds with suspended matter to the bottom and the transfer into the water of deoxidized compounds formed by reduction processes on the bottom of the basin.

Observations made for two winters that were very different in hydrological and meteorological conditions gave a picture showing certain similar features. In the first stage of conversion of organic matter in a highly polluted river, a rapid drop in BOD_5 takes place. The 1947 and 1948 values of BOD_5 --25.1 mg/l and 26.6 mg/l--which were very high for the river, decreased towards Bronnitsy to 11.5 and 8.8 mg/l respectively. Judging by the rate of displacement of a water mass, this occurred in the first year in five days, and in the next year in two days. In the winter of 1949, when water content and meteorological conditions were nearly the same as the year before, just as rapid a drop in BOD_5 was recorded towards Bronnitsy of from 20.4 to 6.9 mg/l in a period of the order of two days.

The second feature peculiar to the winter is a rather high, almost stable amount of organic matter in the Bronnitsy-Kolomna section. Average values of BOD_5 were (mg/l):

	1947	1948	1949	1964
Bronnitsy	11.5	7.7	6.2	11.5
Kolomna	12.1	7.4	6.3	7.6

In none of the years of observation did the BOD_5 at Kolomna drop below 6.3 mg/l, i.e. 3-4 times more than the value characteristic of the river in its unpolluted part. Moreover, in the years just after the war, there was practically no drop in BOD_5 recorded over a section 80 km long. Water passed over this route in from 3-6 days, depending on the dryness of the year. A marked drop in BOD_5 was recorded in 1964, when the conditions of effluent discharge were altered and the oxygen regime improved somewhat. In the winter of 1964, oxygen content in the water between Bronnitsy and Kolomna was within the limits 1.7-3.1 mg/l, whereas earlier it had been less than 1 mg/l in the same section.

The rapid drop in BOD in the upper section of the river and the extremely retarded or even completely halted decay of organic matter in the lower course of the river is related first of all to the dissolved oxygen content. Data on the high value of the coefficient and constant of aeration in the section of river which was free of ice or had disturbed ice cover have been presented above. However, the presence of oxygen, which is a necessary condition for the oxidation of organic matter does not explain the causes of the rapid development of oxidation processes, which exceed usual rates of processes of oxidation of organic matter in rivers in winter.

One factor in the reduced BOD may be precipitation of suspended matter on the bottom, which occurs intensively in the Beseda-Bronnitsy section. In calculating the daily discharge of

suspended matter on the basis of average values, the following data have been obtained (T):

	1947	1948
Beseda	118.4	176.0
Bronnitsy	55.7	65.1
Kolomna	88.0	57.0

The most intensive precipitation of suspended matter occurs in the section above Bronnitsy; further on, the process slows down greatly. In 1947, at Kolomna, the content in the water even increased.

In 1947, 62.7 T were precipitated per day in the Beseda-Bronnitsy section; in 1948, 110.8 T and, in 1949, 85.7 T. The decrease in BOD₅ and dissolved oxygen per day were as follows (T):

	1947	1948	1949
BOD ₅	21.2	68.0	47.0
Dissolved oxygen	9.5	10.8	3.2

Assuming that the decrease in organic matter occurred due to the oxidation by oxygen which entered from the atmosphere in the Beseda-Bronnitsy section, we obtain the following values (T):

1947--11.7 1948--57.2 1949--43.8

Attributing these values to a 10 km² surface area of the river, we provisionally calculate the amount of oxygen entering from the atmosphere per unit area. The aeration coefficients were 1.2, 5.7, 4.4 g/m² in 1947, 1948 and 1949 respectively. The low aeration value in 1947 is due to the significantly more severe

winter compared with the mild winters of 1949 and especially 1948.

The drop in BOD in the Basesa-Bronnitsy section, as indicated above, may occur in part due to precipitation of suspended matter which has been observed on a large scale in that section of the river. According to the data of Balmat (1957), 15.2% of the total oxygen consumption in run-off waters is attributable to the precipitating fraction of suspended matter (greater than 100 microns in size). In the Thames estuary, oxygen consumption by suspended matter fluctuated greatly, being on the average about 3% of dry weight (Effects... , 1964). According to determinations made in the waters of the Moskva River, 19% of the total oxygen consumption was attributable to the precipitating fraction (Drachev, 1962). In order to explain the role of the precipitating fractions of suspended matter and the entry of deoxidized products from the bottom in the oxygen balance, it is necessary for special investigations to be carried out.

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Data from investigations carried out for a number of years indicate that a considerable amount of oxygen enters in mild winters through the ice-free surface below the points of discharge of effluents into the river. In severe winters, the magnitude of atmospheric aeration drops sharply. For such years it is advisable to calculate the oxygen balance of the river and the necessary degree of purification of effluents, disregarding the entry of oxygen from the air.

By using the results of observations that have been carried out, and taking into account the fact that the winter period is critical in the life of river basins, one may establish the degree of dilution and purification of the effluents from the city of Moscow necessary to restore sanitary conditions to the Moskva River (Boldyrev, 1948).

In the following calculation, we have assumed that, within the boundaries of the city, the Moskva River and its tributaries do not receive either industrial or domestic fecal effluents, and consequently that the content of dissolved oxygen above that inflow of effluents is equal to 8 mg/l. (Table 1).

On the basis of the discharge of effluents ($30 \text{ m}^3/\text{sec}$) and complete purification (up to 10 mg BOD_5), let us determine the minimum dilution for effluent fluids in a volume of water by means of the formula

$$\frac{Q}{q} = \frac{0.55 \cdot x_1 + 4}{O_2 - 0.55x_2 - 4} \quad (6)$$

where Q and q are the discharges of river and effluents (in m^3/sec); x_1 is the BOD_5 of the purified effluents (in g/m^3); x_2 is the BOD_5 of pure river water in g/m^3 ($2 \text{ g}/\text{m}^3$); O_2 is the dissolved oxygen content (in g/m^3) in the river above the city in February and March.

Substitution of the appropriate figures yields the magnitude of the necessary dilution (3.2). Thus, in order to

support the necessary minimum of oxygen under conditions of complete purification it is necessary for the discharge of water in the river to be greater than effluent run-off by $66 \text{ m}^3/\text{sec}$ in the winter low-water period.

Let us now calculate the maximum oxygen consumption by city effluents which can be released into the river at existing river discharges, by means of the formula

$$x_1 = 1.8 \frac{Q}{q} \cdot (O_2 - 0.55x_2 - 4) - 7.3, \quad (7)$$

where the notation is the same as in (6).

Substituting numerical values with Q equal to $60 \text{ m}^3/\text{sec}$. we obtain the requirement that the purification level be as great as the magnitude of BOD_5 (3.1 mg/l). This value so far lies beyond the realm of practical feasibility in purification. Therefore, given present-day flow, the Moskva River will remain deficient in oxygen even after complete purification of all effluents.

Various ways of eliminating the oxygen deficit in the river are conceivable. One of these methods was considered in detail in the years of the construction of the Moskva Canal (1932-1935) and was realized in practice. The essence of this method consists in dilution of the river by pure water saturated with oxygen.

The method of calculating the amount of water needed to eliminate the oxygen deficit has been described above. These amounts are just within the bounds of possibility for

water supplied from the Moskva Canal. Economic considerations, which forced abandonment of this method for restoring favourable sanitary conditions to the river in the war years and which have retained their force up to the present day, compel us to seek other technical solutions. Such solutions may be: further reduction in the abundance of organic matter in purified effluent waters; the supply of oxygen to the river by adding air from the atmosphere; and the use of effluents, after purification, to supply the needs of industry and agriculture.

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There is no doubt of the technical feasibility of the first method, as equipment exists which produces more purified water than the amounts used in our calculations. Consequently, it is the economic possibilities that constitute the deciding factor. Artificial enrichment of rivers with oxygen has a practical means of implementation. In the United States, air is added by means of pumps (Kaplovsky, 1964) and via turbines in hydroelectric stations (Scott, 1958).

In investigations of the Moskva River, data have been obtained on oxygen saturation of the water when it passes over a dam. It has been established that when the deficit of dissolved oxygen is 60-70%, the river's supply is augmented by 5-15 T/day as it passes over a dam.

During winter, when oxygen solubility increases in the cold water, the importance of this method increases. Leaving dams on the river in operation until the end of the winter

under present conditions can substantially reduce the oxygen deficit in the river if not eliminate it entirely.

The most radical means of improving the oxygen regime of a river and completely restoring favourable sanitary conditions in a river basin is by reducing the discharge of effluents by utilizing them in industry and agriculture. In England and the United States, effluents find application in the metallurgical and petroleum industries. At the same time, the enterprise pays for the effluents consumed (Powell, 1956). In spite of the shortage of water in Moscow and the Moscow area, this method of utilizing effluents has not been taken advantage of.

The question of using effluents from Moscow to irrigate fields southeast of the city has been discussed more than once (Lorkh, 1957 and others). The main obstacle to wide use of purified effluents is the necessity for major investment of capital (Gorin, 1957). From the point of view of preserving rivers from pollution, year-round irrigation using effluents, for which favourable technical prerequisites exist (Kanardov and Novikov, 1957) is of the utmost importance.

Conclusions

1. The Moskva River, in its upper reaches, has retained all of the characteristics of a natural river basin, on the basis of its oxygen regime, content of nutrient elements, and ionic composition.

In its lower course, substantial changes in the composition and properties of the water of the river have taken place due to the influence of industrial and domestic sewage. A relatively small increase in the total amount of dissolved salts occurs due to univalent cations--sodium, potassium and ammonia--and anions of strong acids--the sulphate and chlorine ions. The total nitrogen and phosphorus contents have increased by approximately one order of magnitude, which corresponds to the addition to the river of 6-10 g of nitrogen and 0.7 g of phosphorus for each inhabitant of the city. The inflow into the river of sodium, potassium, chlorine and sulphate ions proceeds mainly due to industrial effluents. Domestic sewage yields no more than 10-15% of the chlorine, about the same percentage of sodium and 20% of the potassium.

2. Self-purification processes differ markedly in the lower course of the river, both in summer and in winter. In summer, when there is an abundance of nutrient elements and retarded flow, reduction in the biochemical oxygen demand is small and at a certain distance from the point of maximum pollution, processes of accumulation of organic matter begin to predominate over decomposition processes. The amount of matter formed due to photosynthesis is approximately equal to that introduced with city effluents.

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In winter, a very sharp decrease in the biochemical oxygen demand is recorded in the unfrozen section of the river.

In the open part of the river, the aeration constant varied between 0.26 and 0.40; in mild winters the aeration coefficient has reached 7.9 g/m^2 , and is considerably less in more severe winters. In the lower ice-covered section of the river, under anaerobic conditions that have been created, stabilization of organic matter and even a certain increase in the abundance of easily oxidizable compounds occur.

3. For the past 20 years, the quality of river water below the sources of effluent has not deteriorated, despite a more than two-fold increase in the volume of liquid effluents entering the river. In winter, the biochemical oxygen demand at the present time is considerably lower and a certain improvement in oxygen regime has been recorded. Aside from improvements in the quality of purification, increases in the amount of water supplied from the Moskva Canal have had a positive effect.

Retention of the fall of water over dams in winter is an effective and economical way to improve the oxygen regime of the river.

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