

Operational Paper

Ensuring the reliability of the water piping of the Moscow water supply system

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ABSTRACT

The article describes the results of the investigation work carried out by Mosvodokanal Public Enterprise on improving the reliability of the water distribution pipelines in the city of Moscow. In recent years in Moscow there has been serious concern with regard to the reliability of its water supply network. This was caused by insufficient attention paid during the time of the former USSR to reliability and the operating conditions while designing and constructing the system as well as a period of increased rate of wear to the water pipes and insufficient financial resources for repairing the systems.

The decrease in average daily supply, increasing capacities of the water pipelines, pumping stations and the cleanwells caused a whole series of technical problems. These included a reduction in water velocity, the formation of stagnant sections, slowdown of water renewal, and deterioration of water quality in the distribution system. This caused considerable difficulties and led to higher costs for the operation of the city water supply system.

This article describes practical methods for preventing the unsatisfactory situation brought on by the decreased water consumption in Moscow. It describes the software used to evaluate water pipeline reliability and to plan the rehabilitation and renewal of the water supply system.

Key words | distribution, estimation, operation, pipeline, reliability, water

INTRODUCTION

In the 21st Century, Russia as well as the other industrialized countries is faced with the serious problem of rapid ecological degradation.

Transformation to a market economy, the reforming of public utilities in Russia, whose equipment is wearing out and aged, and the lack of material and financial resources for their rehabilitation and renewal have greatly increased the critical environmental situation in the country in recent years (Khramenkov & Primin 1999).

The water pipe system is a vital component of a modern city infrastructure. At present the water distribution systems in the Russian Federation supply 25.5 billion m³ of water per year, including 17.2 billion m³ of domestic water supply. The total length of the water pipelines is 434,000 km

including 105,200 km of water and sewage pipelines. More than 60% of the water and sewage pipes have exceeded their operational life. More than 150,000 km of them require rehabilitation.

The unsatisfactory state of the water transportation mains in most of the cities of the Russian Federation has produced an adverse impact on the urban ecosystems where people actually live. Obviously, operational reliability and environmental safety are the basic requirements for systems of vital importance such as water distribution and sewerage.

In recent years, in Moscow, the capital of the Russian Federation, there has been a serious situation with regard to the reliability of its water supply system. This was caused by insufficient planning in previous years in the former USSR.

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There was little consideration of reliability and operational conditions during the design and construction of the water distribution network. Neither was sufficient consideration made for the increasingly rapid wearing out of the water piping and related equipment and there was inadequate financing for the future rehabilitation of the system (Primin 2000).

Mosvodokanal Public Enterprise has been operating the largest municipal water distribution system in Europe, which is also one of the oldest. Moscow has been supplied with drinking water from four water treatment plants, Rublevsky, Western, Eastern and Northern.

In order to supply water to the central part of the city, areas located at higher elevations, and those located further from the stations, 13 booster pumping stations have been provided together with regulating facilities, in order to increase the pumping capacity. The average daily amount of water supplied to the city is around 5 million m³. In recent years the need for repair has considerably increased. Every year more than 10,000 failures in the water distribution system are reported.

The elimination of about 50% of such failures involves excavation work. The most frequent failures (90%) occur in steel water pipes with a diameter of 100–400 mm. In most cases the leaks are caused by holes resulting from internal and external corrosion. In cast iron pipes the leaks are caused by defective socket and spigot joints and pipe fractures.

The poor reliability of water pipes in Moscow which appeared during the 1980s was caused by disregard for the design rules for water pipes which required the protection of steel pipes from inside and outside by corrosion resistant coatings. This is the reason why, at present, the service life of water pipes in Russia and in other countries of the former USSR, is one of the shortest in the world.

The great majority of water distribution pipelines in Moscow (more than 60%) at present are physically worn out. They were laid and put into operation decades ago, without due consideration for either the material strength or the operational rules that could have been used by the operating companies. The average age of steel water pipes is now 33 years, while that of cast iron pipes is 41 years. At present more than 4,200 km (60% of the total length of the distribution system) have exceeded their operational lifetime (Primin 2000).

The average value of the frequency of water pipe failures in the Moscow water distribution system is $W = 0.5$ per one km in one year which is higher than that for water pipelines in the majority of European cities, but lower than the average value in other Russian Federation cities. The frequency of water pipe failures is directly related to the diameter of the pipes. Furthermore, statistical investigation showed that piping made from ductile iron, which in recent years has been widely used by Mosvodokanal, has significantly fewer failures compared with piping made from steel or grey cast iron (Figure 1).

In recent years, the decreasing demand for water in Moscow has considerably complicated the task of ensuring reliable and efficient operation of the municipal water supply system.

The development of the Moscow water supply system was accomplished by the continuous exploration for new water sources, increasing the production capacity of water treatment plants, and the construction of oversized distribution systems to obtain extra financing from the government budget. The Moscow Master Plan of the year 1975 was oriented on an extensive development of the water supply system. No measures for water conservation or water saving technologies were envisaged. Furthermore, until now the economic pattern of water consumption in Moscow has not been encouraging water awareness (Khramenkov & Primin 1999).

The existing water distribution system was based on the estimated water demand by 2000, which was 8,070,000 m³ day⁻¹. However, the changes in the reform period affected not only the outward appearance of the city but also its

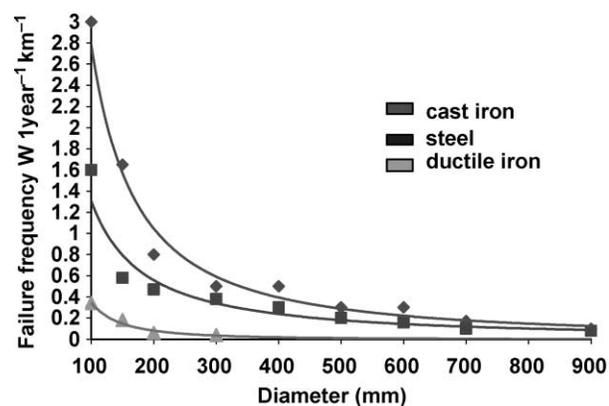


Figure 1 | Dynamics of pipe failures in relation to pipe diameter in the Moscow water distribution system.

infrastructure. This concerned the city water supply in particular, especially the level of water consumption.

It was known that before 1985 Moscow's population growth was accompanied by an increase in the city water supply. From 1990, Moscow's population growth did not actually increase but the water supply continued to increase. Water consumption reached a peak in 1995; from that time to the present day the demand for water has been gradually decreasing. In 2000 the difference between the actual consumption and that predicted in the Master Plan of 1974 was $2,839,700 \text{ m}^3 \text{ day}^{-1}$. The decrease in water demand aroused a number of serious problems that had to be eliminated during operation. The problems were: the decrease in water flow rate, the decrease in the frequency of water renewal, water quality deterioration in the pipes, change in the hydraulic elements, the lowering of the efficiency of the pumping stations (decreasing energy saving), and as a result a negative disturbance of the optimum operation of the water distribution network and pumping stations.

All of this causes an increase in operating costs, brought about by the necessity for additional flushing of the system, for water quality control, and so on. Figure 2 illustrates the dynamics of water demand for the period 1975–2000 in comparison with the predicted demand estimated in the Master Plans of 1974 and 1998.

The background to the current situation has been a considerable decrease in water consumption by industry, the closure of a number of large, unprofitable plants and factories, the introduction of closed-loop water systems at industrial enterprises, the promotion of water conservation, the improvement of the city development concept, the decrease in domestic and commercial water consumption (the installation of water saving equipment and water meters in dwellings and the elimination of leaks in the system).

Logically, the decrease in water consumption should mean a loss of income for Mosvodokanal. However, the supply of water to the population is unprofitable for the following reasons: the selling price of water is lower than the cost of distribution and payment is charged on the basis of a flat rate regardless of actual consumption. These two factors compel the company to exert effort to lower specific water consumption.

At the same time the negative impact of the decreased water consumption in Moscow on the sanitary reliability and efficiency of the water supply is evident. The length of the distribution network has continually increased over the years and reached 85% of the entire length of piping in the city. In order to provide a reliable water supply, the total capacity of the clear water reservoir in the city was also increased in accordance with the Master Plan of 1974. In 2001 the total capacity of the water pipelines and the clear

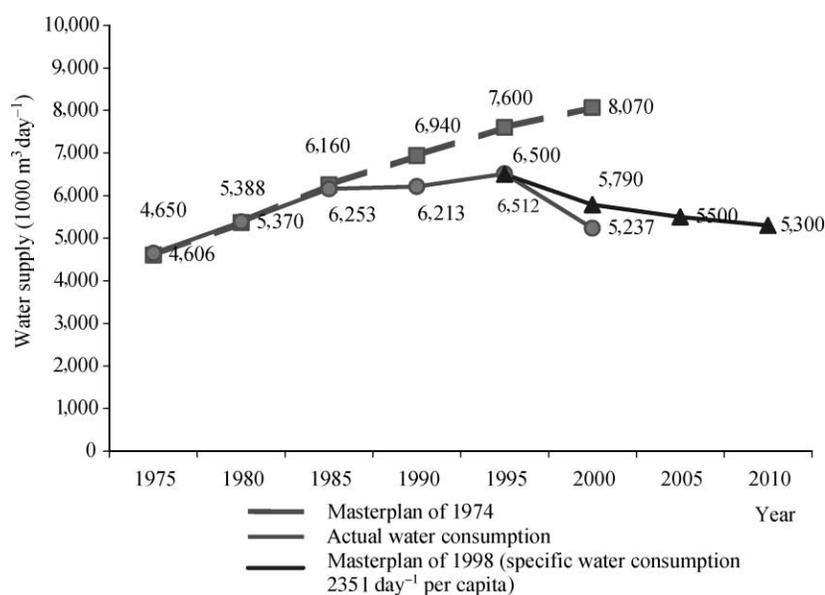


Figure 2 | Average daily water consumption both actual and predicted in the Master Plans of 1974 and 1998.

water reservoir was 3,270,100 m³, or 63.1% of the daily water consumption of 5,178,200 m³.

An important criterion for evaluating the operational efficiency of the water distribution network is the number of fresh water renewals, which is expressed by the ratio of the average daily water consumption to the total capacity of the water pipelines and clear wells. In 1976 the frequency of water renewal was 2.93 and in 2001 it had fallen to 1.58 (Figure 3).

The calculation of pipe diameters in the municipal water distribution network was made on the basis of the Master Plan data on the specific water consumption (industrial + commercial + domestic); that is, more than 500 litres per person per day; and fire fighting water consumption of 100 litres per second.

The actual hydraulic computerized calculations, carried out with the use of a mathematical model of the water distribution in a number of Moscow districts, revealed the low water velocity in the pipes: 0.01–0.2 m s⁻¹, rarely, 0.3 m s⁻¹. These calculations were in agreement with the data from actual physical measurements of the water flow rates. For the water mains there was also noted an increased number of pipes with a flow rate of 0.2–0.5 m s⁻¹.

At present, according to the *Norms and Rules for Designing, Planning and Building in Moscow*, the specific water consumption provided is 360 litres per capita per day. The results of the hydraulic calculations on the distribution network in one of the new districts of the city indicated that, on lowering the rated water consumption to 360 litres per day per person, the flow velocity in the pipes, even when taking account of water abstracted for fire-fighting in the peak hours of maximum flow velocity, was only 0.04 to 0.53 m s⁻¹ for 300 mm water pipes.

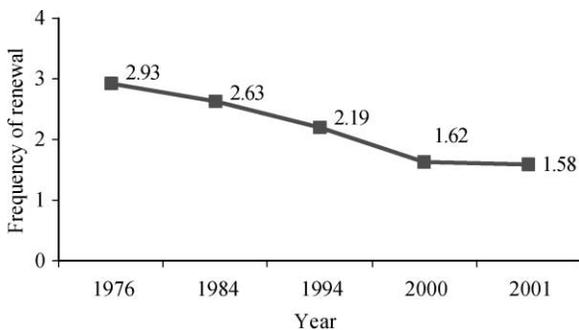


Figure 3 | Dynamics of water renewal in the Moscow water distribution pipelines.

Obviously the decrease in the amount of water supplied, and the increase in water piping and clear water reservoir capacities caused a number of technical problems. There has been a decrease in water velocity, formation of stagnant areas, disruption of the fresh water renewal rate and deterioration of water quality in the distribution network. This to a great extent caused an increase in the costs of operating the distribution network.

METHODS

To provide solutions for the current situation, Mosvodokanal considers it necessary to carry out the following measures:

1. Calculations of the fire-fighting water rate used in engineering should be made based on the actual number of inhabitants of a given district.
2. Cancel the existing minimum design diameter standard of 300 mm for the water mains. The diameter of the pipe should be selected by taking into account the most economically efficient or the maximum diameter that provides for a water velocity of 2.5 m s⁻¹ for fire-fighting at the water head of more than 10 m of water column in the control point. The city development concept should be changed when building new districts or reconstructing old ones. Artificial or natural water sources are to be used for fire-fighting or process needs; the city distribution network kept as a reserve.
3. The design of the networks in the newly developed municipal areas should include water outlets that could be used for flushing the low flow pipe sections, particularly in the summer period to maintain the required residual chlorine in the network. In addition, special devices are needed so that mechanical equipment can be placed into the pipes for local cleaning and chlorination, especially in dead ends.

In order to eliminate the negative effect of decreased water consumption in the city on the network operation, its characteristics and sanitary reliability, the company Mosvodokanal developed a mathematical model of the network. The model in combination with the corresponding software allows the company to:

- make assessments and forecasts of the hydraulic operational mode of the water supply and distribution network in order to choose an optimal combined mode for the network and waterworks operation;
- carry out comprehensive engineering of the water distribution network in newly built and old districts of the city;
- identify ‘weak’ (in terms of sanitary reliability) sections of the pipelines, optimize water quality, plan the points, periodicity and duration of flushing and disinfection;
- identify non-functional sections of water pipelines to either shut them off or keep on stand-by;
- manage the flow distribution in order to improve the hydraulic characteristics of the distribution network.

RESULTS AND DISCUSSION

Hydraulic calculations using mathematical simulation of the water supply network confirmed the effectiveness of the mathematical simulation of the water supply network and enabled the number of low flow sections and stagnant zones to be reduced. As a result optimum diameters of water pipes were determined which were close to the most economically efficient water velocities, which in turn raises the sanitary reliability of the water distribution network.

In the conditions of decreased water consumption in the city, an ageing network and lower levels of reliability, it is necessary to devote special attention to planning the operation of the network, optimizing the reconstruction and renewal of the piping. The basis for solving these problems consists of an evaluation and analysis of the actual level of reliability of the municipal water distribution network.

In this connection the Mosvodokanal has developed a computerized system that provides for pipe damage and failure recording, a pipeline certification and operation database, reliability assessment and prediction algorithm and software. The system acquires reliability statistics for the water pipes and equipment in any district of the city: average annual number of pipe failures; pipe failure frequency assessment and prediction; ‘survival’ probability forecasts; no-failure operation probability for a set

operation period; failure risk assessment; and average failure-free time period.

It is also possible to determine the average repair time distribution function which allows assessments to be made of the possible elimination of the failure for a certain repair time period.

Within the system an electronic plane-table map is being developed for each of the city districts in order to analyse the dynamics of the water pipeline failures and their environmental impact. The density of failures is represented in graphic form. On the basis of mathematical models of pipe ageing and rehabilitation priority selection Mosvodokanal has developed a number of computerized information management systems (CIS), ‘Reliability’, ‘Rehabilitation’ and ‘Anticorrosion’. The systems have been used to evaluate and analyse the reliability of the water distribution network, to schedule the restoration of water pipes and to control the operation (Khramenkov & Primin 2001).

The scarcity of finance for the renovation and replacement of the numerous worn-out lengths of the water pipes stipulates the need to choose a number of priority sections which is done with help of the pipeline rehabilitation strategy based on the evaluation and prediction of the reliability statistics for the pipelines and computerized selection from the water pipes to be restored. The choice of these priority areas is made by evaluating and ranking numerous factors that influence the reliability of the pipelines.

In order to follow the strategy and plan the restoration of piping, a computerized information management system ‘Rehabilitation’ is used, which includes a pipeline operation database (before and after rehabilitation), an information retrieval system for the selection of potential and high-priority pipe sections to be restored (‘SAN’ and ‘RANGE’ software).

Using a stochastic approach in the scheduling strategy, the required rate of the Moscow water distribution network rehabilitation and renovation has been predicted. The predicted data help to minimize damage from pipe failures.

Calculations have shown that a decrease in failures in the Moscow water distribution network down to $W = 0.15 \text{ km}^{-1} \text{ year}^{-1}$ will limit the amount of water escaping into the environment from pipe failures and latent leaks to 4–5% of the average daily water supply. It will reduce the total

material and environmental damage more than 2.7 times. The required amount of restoration of steel piping will amount to more than 2,360 km by 2015. Investigations have confirmed that the demand for the restoration of piping in the Moscow water distribution system in the future should be much higher than at present; consequently, the volume of rehabilitation works will have to be increased (Primin 2000).

The risks of failures causing material and environmental damage will persist until the pipe failure flow factor is controlled and becomes predictable in terms of time and location of the failure. In this regard, it is necessary to improve the technical diagnostics for pipe condition and practical methods for the evaluation and prediction of pipeline reliability.

The new approach used by Mosvodokanal to account for the reduction in water consumption – the introduction of the information management systems – allows the optimisation of the operation of the water distribution network, and provides for the efficient management of the operation and reliability of the pipelines, along with reasonable scheduling of pipe rehabilitation and replacement.

CONCLUSIONS

1. The elimination of the existing weak points in the system of water supply and distribution under the conditions of decreased water consumption in the city will require significant investment and material resources. Minimization of costs will be possible only through the optimization of the construction and upgrade of the water works in Moscow, and improvement of the distribution network operation.
2. The main criteria and technologies for ensuring the required reliability and optimum functioning of the system and prevention of accidents are the following:
 - optimization of hydraulic control of the water supply and distribution network under the conditions of decreased water consumption in the city;

- selection of the optimal cooperative operation of the network and the pumping stations;
- correction of the standards for the design of municipal water distribution networks to provide for the most efficient water velocities in the pipes and required water quality in the distribution network under the conditions of actual water consumption in the city;
- use of reliable and long-life corrosion-resistant pipes and fittings;
- optimization of the strategy for the restoration and renovation of the network, increasing the amount of pipe replacement and rehabilitation using primarily no-dig methods;
- efficient electrical corrosion protection of water pipes;
- wide use of information technologies in the control and operation of the city water supply network;
- scheduling the routine maintenance of the pipelines and equipment taking account of the specific operation and reliability requirements, the existing technical condition and logistical support.

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