The role of inspection of hydraulic structures in the assessment of their technical condition

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Abstract. The development of the territory of Moscow has led to the need for a survey of water bodies and inventory of existing hydraulic structures, a thorough assessment of their technical condition, typifying the main types of structures, and determining their functional features. To solve these tasks, we used methods of field expedition survey, and analytical calculations of hydraulic structures, statistical methods of information processing, and analysis of available cartographic and technical documentation. A quantitative and qualitative analysis of the state of hydraulic structures located on the territory of New Moscow and their operating conditions was performed; the current level of their safety was assessed. It is proved that it is necessary to create a unified information database for all water bodies and hydraulic structures that have passed the survey, as well as to develop a simplified form of the act of pre-Declaration inspection of structures for which there is no functional and design information. It is shown that it is necessary to develop a plan of measures to ensure the safety of hydraulic structures without registered property rights.

1. Introduction

Design, construction, and operational conditions are the key factors affecting the reliable operation of hydraulic structures (HS). Cases of structural defects and accidents of hydraulic structures, taken into account when analyzing the performance of HS in the most developed countries of the world (including Russia), show that the most important for the reliable operation of structures is the quality of work during the construction of HS.

Table 1. Information about cases of significant accidents of the HS

| Reasons for low reliability of the HS | Number of accidents and defects in structures, % |
|-------------------------------------|-----------------------------------------------|
| Design                              | 13                                            |
| Construction                        | 69                                            |
| Operation                           | 18                                            |

To ensure the normal and safe functioning of the HS, regular constant monitoring of their condition, periodic examinations, targeted and extraordinary examinations are performed [14].

Due to the growth and infrastructural development of the territory of Moscow, there is a need to inventory existing hydraulic structures, carefully assess their technical condition, type the main types of structures and determine their functional features. The object of this research is a complex of
hydraulic structures on reservoirs and watercourses in Moscow, and the subject is the assessment of the level of technical operation of these hydraulic structures.

The relevance of this work is determined by the importance, complexity and necessity of normal and safe technical operation of GTS and depends on the features of operation of hydraulic structures [1, 2, 3]. The operation of the HS is carried out for a very long time (compared to the design and construction) with a different frequency of current (from 3 to 6 years) and major repairs (up to 30 years), the random nature of the place, volume and time of these works. The operation of HS affects the interests of a significant part of the territory's population (i.e., the population of the territory), it is social in nature and is associated with constant physical wear and tear, and therefore with a large expenditure of funds, increasing over time, and attracting more and more forces and funds to carry out timely maintenance and repair.

In accordance with the Federal law "About safety of hydraulic structures" (№ 117) [4], the security of the HS in Russia is based on the following General requirements, namely [1, 5, 6]: the need to ensure an acceptable level of risk of HS; the presentation of the Declaration of HS safety; continuity of operation of facilities; the continuous implementation of measures to ensure the safety of buildings and the establishment of safety criteria, equipment buildings technical equipment for continuous monitoring of their condition. Also, the HS operation service must be staffed with employees of the necessary qualifications and be responsible for actions (omissions) that have resulted in a reduction in safety below the acceptable level. There should be sufficient funding for measures to ensure the safety of structures and modern organization of the system of maintenance and repair of the HS.

The main causes of HS accidents are an unsatisfactory technical condition of structures and low level of operation, defects in construction, incorrect estimation of flood sizes, design errors. Often the cause of accidents is neglect by the owner of structures of the principles of priority financing of measures aimed at ensuring the safety of the HS during their operation. Many HS have increased the risk of accidents due to the loss of the owner or his bankruptcy (insolvency).

The reliability of the structure and its operational efficiency are the keys to the safe operation of the HS, the entire complex of structures included in the water management system of any scale from a small territory and locality to large urban megacities and regions.

Today, the issues of HS security are on the agenda both at the Federal, regional and municipal levels. According to the Protocol of the operational meeting of the Security Council of the Russian Federation dated 31.01.2019, the Federal service for environmental, technological and nuclear supervision, together with the Federal Agency for water resources and other interested Federal Executive authorities and Executive authorities of the Russian Federation, was instructed to ensure control over the safe condition and operation of HS of all forms of ownership and departmental affiliation, and pay special attention to the state of ownerless HS. In April 2019, instructions were given at the regional Moscow level to clarify the list of ownerless, as well as HS with a low level of safety; to appoint officials responsible for their accident-free operation, as well as to make decisions on each of them to ensure safe operation.

The modern hydrotechnical system of the Metropolitan metropolis is a whole network of water objects and hydraulic structures.

In Moscow, within the Moscow ring road, there are about 150 small rivers and streams and more than 300 open reservoirs (ponds and lakes). More than 90 watercourses of the capital are taken into reservoirs, and a number of ponds and small rivers are completely or partially filled in. Within the historical part of the city, there are still some reservoirs-remnants of the once rich Moscow hydraulic system. More than 40 ponds have been preserved in public parks and gardens organized by the city for festivities in the XIX century (Sokolniki and Izmailovo), as well as on the territory of a large garden and Park ensembles of Palace complexes (Kolomenskoye, Tsaritsyno) and former city and suburban noble and merchant estates [5].

In connection with the expansion of borders of Moscow and the development of the Troitsky and Novomoskovsky administrative areas, development of industrial zones and depressed areas along the ring roads and Railways in the number of water bodies in the zone of interest and responsibility of the
Moscow Government every year only increases. In recent years, ponds in the former estates of Chereimevo, Butovo, Zakharino, Vinogradovo; in the districts of Kurkino, Shcherbinka, Mitino; in the industrial zone of the Ochakovo microdistrict, etc. have fallen within the city limits. The water system of the Troitsky and Novomoskovsky administrative districts of New Moscow consists of more than 400 water bodies, including 47 rivers, of which 20 are more than 10 km long.

The last major comprehensive survey of more than 400 reservoirs of Old Moscow, i.e. before the expansion of its borders with the Troitsky and Novomoskovsky administrative districts organization, to assess the technical condition of the HS was carried out at the turn of the century in 1998...2010. Most of the water bodies (about 280 ponds in Moscow) were surveyed by employees of the Moscow State University of environmental engineering [7...10]. The results of this work showed that at that time 176 reservoirs were formed by soil dams and dams with a height of less than 3 to 12 m. There were 164 spillways on the ponds, including 23 of the open type. Most HS had been in operation for more than 40-45 years at the time of the survey. About 30% of the ponds are non-flowing bodies of water. About 40 reservoirs are ponds with a volume of 0.5-0.1 million m$^3$, and most of the ponds have a volume of fewer than 0.1 million m$^3$. The purpose of Moscow ponds is very different: 37 % perform recreational, bathing, and fire-fighting functions, 6% have a special, including scientific purpose. Most often, such water bodies are used to solve drainage, regulatory and other water management problems. The capital's reservoirs at that time belonged to various departments and organizations: the State unitary enterprise for the operation of Moscow drainage systems («Mosvodostok») (more than 200), the Exhibition of achievements of the national economy, the Main Botanical garden and other economic entities.

Given the situation with the expansion of borders of Moscow and almost a doubling of the number of water bodies in the city, and pursuant to the instructions of the Security Council of the Russian Federation from 31.01.2019. The Moscow City Government in cooperation with «Mosvodostok», as the main owner of HS capital region, continuing the practice of the last twenty years has arranged for current inventory of hydrotechnical and engineering structures, with signs of hydraulic structures, in the composition of the water objects located on the territory of the city of Moscow, including on water objects, which are under the economic management of the state unitary enterprise «Mosvodostok». In 2019, a list of engineering structures (250 objects) with signs of hydraulic structures was formed. This list is not final and will be adjusted as the result of the identification of new HS installed on them without ownership rights or establish the facts that the relationship identified for HS are not regulated by the Federal law of 21.07.1997 №117 "About safety of hydraulic structures", while they themselves are HS facilities centralized wastewater system with change of their functional purpose.

Since funding for the implementation of a complex of works on the safety of the HS will be funded from the city budget, it is necessary to reliably determine the list of such objects to provide target use of the allocated funds and after completion of works on inventory and surveys of HS approve the final list of hydraulic structures and their subsequent transfer to the operating organizations and make information about them in the Russian register of hydraulic structures.

The purpose of the research was to develop scientifically-based solutions to improve the operational reliability of hydraulic structures on water bodies in Moscow, including recommendations for further operation and the Declaration of the safety of these structures. Research objectives: based on the inventory survey of structures on water bodies in Moscow determine the list of hydraulic structures that meet the requirements of the Federal law [4], find out the situation with the owner of these structures, perform a quantitative and qualitative analysis of the technical condition and operating conditions of structures, as well as the current level of their safety.

2. Materials and Methods
Statistical methods of information processing were used in the study. As a result of the expedition work carried out in 2019 by sue «Mosvodostok» and an expert organization (Moscow state University of civil engineering) to inventory and survey hydraulic and engineering structures that have the
characteristics of hydraulic structures, as part of water bodies located on the territory of the city of Moscow:
- the functional state of objects as "hydraulic structures" (HS) subject to Federal law №117 has been determined, and the possibility of an emergency (accident) has been assessed at such objects;
- hazard classes for hydraulic structures were assigned (class I - extremely high-hazard HS; class II - high-hazard HS; class III - medium-hazard HS; class IV - low-hazard HS);
- recommendations on the need to enter or not enter information about GTS in the Register of hydraulic structures of the Russian Federation [12, 13].

The calculation of probable damage was preceded by the justification of scenarios for the most likely and most severe HS accident, at the initial stage of which the HS hazards were identified and the possibility of an emergency was determined.

In the absence of any initial data, i.e., for example, for the conditions of an ownerless HS, a field (expeditionary) survey of the condition of areas of the capital territory that are likely to be affected by an accident was conducted. The choice of the method for determining the probable harm (detailed assessment, flatbed, aggregated indicators) was made depending on the scale of the predicted accidents of the HS and their consequences. Since it is desirable to use expedition survey techniques for ownerless HS, the method of detailed assessment was applied to them.

3. Results and Discussion
A commission survey of 155 hydraulic structures was conducted. As a result of the conducted surveys, it was established that an emergency may occur at 26 hydrotechnical objects, respectively, they are subject to Declaration following the established procedure. In relation to 89 hydraulic structures, it is established that an emergency cannot occur, and they are not subject to the Declaration. Moreover, of these newly identified during the inventory were 6 hydraulic structures. For 20 hydrotechnical objects, the decision on the possibility of an emergency was not made, of which 3 structures were again identified during the inventory.

At one site, work is currently underway to reconstruct the hydraulic structure and bring it into compliance with operational requirements. For one of the newly identified HS, the owner and operating organization have been identified. In respect of 6 newly identified structures during the inventory, the absence of a HS was established following article 3 of the Federal law of 21.07.1997 No. 117 “About safety of hydraulic structures” [4]. Structures on 13 water bodies had limited access. Of these, in respect of one HS, it is advisable to decide to register it in Moscow.

In the course of the survey, attention was paid to such important aspects as the legal status of the object (the presence of the owner, operating organization or ownerless) and its technical condition (changes in the state of the structure – dam, culvert, etc.), the safety assessment of the structure.

The surveyed water bodies and structures on them, as a rule, were built in the 70-80th of the last century and have the following purpose: watering/cattle driving, irrigation, fire water supply, recreation, fisheries, technical and economic needs, transport, and complex. Some objects have lost their original function over time. In the main mass of the surveyed structures had class IV.

By volume, the largest number of ponds had a volume significantly less than 1 million m³, but some of them had a volume of about 3-5 million m³. Among the surveyed retaining structures, embankments up to 1.5-2.5 m high on ponds, usually for fire and recreational purposes, predominated, but among those surveyed in New Moscow, there were dams 8-10 m high. Moscow ponds located within the boundaries of the Moscow ring road, mainly have power with recharge from the city water supply, since the historical water network has undergone strong anthropogenic changes. Both the ecological condition of reservoirs and structures on ponds located on the territory of Moscow (mainly within the Moscow ring road) are in a satisfactory condition, and regular monitoring is carried out over the water area. On the territory of New Moscow, ponds fed by surface runoff, groundwater, and springs are more common.
The layout of structures with low embankment dams up to 2.0-2.5 m high, in addition to the retaining structure, usually includes tubular culverts located both in the Central part of the embankment, and on the left or right sides, and even without input and output heads. Sometimes tubular culverts, if there is more than one, are laid at different points. The majority of small reservoirs do not have structures for working out the pond (spillways). Ponds with dams more than 6 m high have tubular two-point culverts with a reinforced concrete entrance head, usually of the mine type with a grid on top, devices for extinguishing energy in the lower stream in the form of water walls or walls together with piers. Several ponds were also examined with a channel dug parallel to the reservoir and going into the lower area. Such channels do not have anchors and when passing through them a flow of rare repeatability, uncontrolled erosion, and washing of the steep slope are possible. On small ponds behind culverts, there are often no energy dampers, and the flow flows down the natural slope into the lower terrain. Also, structures with dams of more than 6 m height include spillways, but they were not always detected during a visual inspection, and where spillways were present, they were inoperative, and wells with latches were flooded.

Dams, as a rule, are homogeneous ground from sandy loam or loam. At low dams, above - water slopes are strengthened by seeding grasses. Most low dams have a passageway or passageway along the crest of the dam. Dams with a height of more than 6 m have reinforced concrete slabs on the upper slope (Figure 1), the mounting condition is generally satisfactory. A single or two-lane paved road runs along the ridge (Figure 1). On one of the objects, there was intensive processing of the top undefended slope (in the above-water part) by wave action (Figure 2). The depth of most ponds ranges from 1 to 2 m, also, it is often less due to high siltation.
Since there are no owners for most hydrotechnical objects in New Moscow, the operation of reservoirs and structures is usually not carried out. During the survey, an assessment was made of the presence of significant damage that may pose a security threat.

During the survey, characteristic damages were noted for the corresponding types of structures. On the dam, this is usually uneven precipitation of the ridge, washouts at the ridge, and on the lower slope, washing away the upper slope, skewing the fixing plates. On some spillways with low dams, the inlet and outlet heads are not designed, which causes a washout around the pipes, in spillways with dams more than 6 m high, there are displacements of the links of the tubular structure on the lower slope and damage to the attachment (most common), as shown in Figures 3 and 4. Most often, the mating walls are filled up, energy extinguishers are skewed, and the culvert or apron plates are destroyed (Figures 3 and 4). Spillways, usually in a non-working state, can also be filled in when working in the lower stream. In this regard, it is usually not possible to raise the level in the pond and repair work.

Figure 3. Blocked wall of a water well

Figure 4. Destroyed artificial roughness on the rapid flow of the spillway
On some hydraulic structures, the need to repair individual parts, usually fixing in the downstream, ridge structures, upper and lower slopes, has been noted. Some of the surveyed objects after reconstruction are in good condition, both the retaining front and the culverts (Figures 5 and 6).

The complexity of the access to a number of objects is noted. In some cases, a partial road along the crest of the dam is blocked by barriers, and in some cases, a full road—the pond is located in a fenced area. Some cascade reservoirs are located on the territories of different owners, and access to them is blocked accordingly (dam №3 in the village of Senkino-Sekerino, dam №1-3 in the village of Mikhailovsky, etc.).

In most ponds, there is a strongly overgrown shrub-and-tree vegetation downstream (channel and banks). On the one hand, this plays a positive role, since if the pressure front breaks through, it will create additional resistance to the break wave, reducing its speed, but on the other hand, it reduces the flow capacity of the riverbed when passing through the structures of flood flows.

On some small objects, usual ponds for fire or decorative purposes, the local population constantly lays bricks, bags, boards part of the section of the entrance heads to raise the water level in the pond. In future reconstructions, to take this into account, it is preferable to arrange a Sandor node on the entrance part.

The ecological state of some ponds is also a concern. Due to the low flow rate, there is an intensive flowering and overgrowth, as well as water pollution due to discharges into the pond, both from food production and from the territory of private cottages.

The survey identified problems related to the potential threat to the HS:
- the presence of communications laid along the crest of the dam or in the downstream (gas, heat, water);
- located in the downstream of power transmission towers;
- transformers located in the downstream, just behind the dam (on supports);
- two-lane paved transit road along the ridge;
- the complete absence of project documentation for almost all surveyed facilities;
- the location of buildings (dacha buildings, farms) in the lower reaches of the river at low levels, which makes it necessary to clarify geodetic works to exclude the destruction of these buildings in the event of a potential hydrodynamic accident.

4. Conclusions

1. A quantitative and qualitative analysis of the state of hydraulic structures located on the territory of New Moscow and their operating conditions was performed; the current level of their safety was assessed. The analysis of the number of hydraulic structures that have fulfilled the established service life is made. The exact number of hydraulic structures that are operated beyond the specified service life has been obtained. It is established that a significant part of the structures on the water bodies of the Troitsky and Novomoskovsky administrative districts does not have an owner and is not operated, which is why there is an urgent need to implement the requirements for the safety of these structures and make an operational decision on the future fate of these objects.

2. The necessity of creating a unified information database for all water bodies and hydrosystems that have passed the survey is proved. Their documentation should include: drawing up passports of objects (in simplified form), measurement work, and a preliminary estimate of the cost of repair or reconstruction of the structure.

3. The need to develop a simplified form of the pre-Declaration inspection report for structures for which basic information is practically absent is determined.

4. For some water objects it is necessary to conduct work on their improvement (cleaning, making the shoreline, the preparing the reservoir bottom), for some especially heavily contaminated or lost its functional purpose (watering, farm water supply, which is not) - the decision on the drawdown of the reservoir and rehabilitate the site.

5. The procedure for registering the city of Moscow for water bodies where there are no hydraulic structures has been developed following article 3 of Federal law No. 117 of 21.07.1997 "About safety of hydraulic structures".

6. It is necessary to develop an algorithm for decision-making actions for water bodies and structures with restricted access.

7. It is shown that it is necessary to develop a plan of measures to ensure the safety of hydraulic structures without registration of ownership rights for the period until the construction is assigned to the operating organization on the right of economic management.

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