Specificity of hydrogeological monitoring of industrial waste storage facilities

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Abstract. Currently, a large number of waste storage facilities (primarily ash dumps), designed and built more than 20-30 years ago, are located within residential areas of major cities. Considering the large area of the facilities, their remoteness from the industrial sites of power plants and the low hazard class of the stored waste, only the installation of barriers at the main entrances is used as protective measures, which is not a significant obstacle for the population or domestic animals. Thus, the active inclusion of ash dumps in the sphere of industrial and recreational interests of residents of nearby areas becomes an objective reality. At the same time, since dumps are potentially dangerous objects, a system for monitoring the safety of their operation is of particular importance. This paper is devoted to the problem of the quality of monitoring the technical condition and environmental safety of industrial waste storage facilities, taking into account their active anthropogenic use. Based on the analysis of the data of field observations at the operating ash dumps, the main problems characteristic for the hydrogeological maintenance of dumps in contemporary conditions, and their influence on the quality of the work performed, are highlighted. The results of the study can be used in assessing the technical condition of test equipment networks and the reliability of the measured indicators, as well as in the development of measures to improve the quality of hydrogeological monitoring of the geological environment on the territory of industrial sites, operating and inactive storage tanks.

1. Introduction
At present, waste storage facilities (ash dumps, tailing pounds and slurry pits, etc.) are quite widespread. Many of these structures were built more than 20-30 years ago; the growth of cities was not taken into account during their design and construction, therefore a number of operating and inactive objects now are located within the residential zone (for the city of Novosibirsk, these are ash dumps of TPS-2 and TPS-3, sludge tanks of Kuzmin factory, Sibtekstilmash, etc.) [1, 2].

A storage facility for liquid industrial waste is a hydrotechnical structure intended for settling, accumulation and/or storage of waste from metallurgical, energy and other enterprises entering the form of a slurry, separation and discharge of clarified water. Industrial waste accumulators are, as a rule, earth structures (enclosing dams). At the same time, both during operation and after conservation, any industrial waste storage facility is not a strictly isolated system, but interacts with humans and environmental elements (Figure 1). That is, it is a natural-technical system (NTS). NTS is an integral,
spatially-temporally ordered set of interacting components, including tools, products and means of labor, natural and artificially modified natural bodies, as well as natural and artificial fields [3].

Figure 1. Interaction between humans, engineering structures and the environment [3]

During the operation of constructions, the geological environment (both the foundation soils and the bodies of constructions can be regarded as such) experiences technogenic loads: mechanical impact (static and dynamic pressure of constructions and systems on the soil); physical (excessive soil moisture associated with a rise in groundwater levels; an increase in groundwater temperatures) and chemical (change in the chemical composition of groundwater and soil mass) impact. Each of these loads, depending on the conditions of its manifestation, can play a significant role in maintaining the dependability of constructions, while in combination they inevitably lead to the development of unfavorable geological processes.

Industrial waste storage facilities are characterized by the transportation of stored materials by means of hydrottransport, which leads to the development of filtration processes in the body of constructions and foundation soils. Thermal pollution of groundwater is characterized by an increase in their temperatures due to the influence of technogenic factors. The increase in temperature, in turn, causes a change in the gas and chemical composition of groundwater (due to a violation of the hydrogeochemical equilibrium), the development of microflora and microfauna. With an increase in temperature, the dissolving capacity of water increases, which can lead to the development of karst-suffosion processes.

Thus, an increase in the moisture content in soils, an increase in the temperatures of groundwater and soil masses, an increase in the content of a number of chemical components (active acid and alkaline residues; aggressive carbon dioxide, etc.) leads to a decrease in the bearing capacity of soils, their strength and resistance to negative, often irreversible, changes in the geological environment. Due to the heterogeneity of the earth cover, uneven settlements can develop in the foundations of constructions (and in the body of the constructions themselves), creating a threat of unacceptable deformations of constructions and their destruction, as a result. To develop effective measures to preserve the dependability of constructions and ensure their environmental safety, an objective assessment of the state of the geological environment, the nature of unfavorable geological processes spread in space and development in time is necessary. Such an assessment can be given on the basis of materials obtained
Monitoring of the geological environment is a system of continuous observation, assessment, forecasting and management of the geological environment or any of its parts, carried out according to a pre-planned program in order to ensure optimal environmental conditions for humans within the considered natural and technical system. During engineering and geological monitoring, rocks, groundwater, subsoil, relief elements and geological processes can be the objects of observation. Groundwater is the most dynamic system of the geological environment, rapidly changing its characteristics when both external influences (natural and anthropogenic) and internal structure change. The informative value of groundwater parameters, as well as the simplicity and reliability of methods for their control, make hydrogeological stationary regime observations an important component of monitoring the geological environment on the territory of industrial waste storage facilities. The main tasks of hydrogeological monitoring are:

- obtaining qualitative and quantitative characteristics of the groundwater flow;
- determination of the natural (background) regime of groundwater (level, temperature, chemical composition) and the patterns of its formation. Revealing the mutual influence and interconnection of aquiferous horizons with each other and with surface waters;
- identification of the influence of natural climatic (seasonal and perennial) and anthropogenic factors on the natural regime of groundwater. Assessment of the nature and dynamics of mutual influence of constructions and systems of industrial waste storage facilities and groundwater, including: the scale and causes of watering of soils and flooding of the territory; aggressiveness of groundwater to concrete, metal and other constructions; contamination of groundwater during the operation of constructions;
- identification of unfavorable and dangerous geological processes;
- making forecasts for the development of dangerous geological processes;
- substantiation of the necessary measures to protect the geological environment and ensure the stability of constructions.

Monitoring is characterized by:

- purposefulness - the presence of a targeted program and reaching the ultimate goal - safe and reliable management of the NTS;
- the complexity of observations, objects, goals and methods used;
- consistency - the study of interactions occurring in the geological environment for forward and backward linkages;

observation results obtained during monitoring are stored in automated information systems and are constantly updated and supplemented.

A properly organized monitoring system with high-quality performance of work allows timely recording of negative processes in foundation soils and the body of the dams, identifying their causes and developing measures to eliminate them.

The purpose of this work is to identify the shortcomings of the modern system for monitoring the geological environment, carried out at existing industrial waste storage facilities, due to the peculiarities of their design and operation.

2. Materials and methods
The objects of the study are the operating ash dumps of Novosibirsk TPSs. Currently, there are four thermal power stations in operation in Novosibirsk (TPS-2, 3, 4, 5). There are five operating ash dumps on their balance sheet. All ash dumps are equipped with a network of stationary observation wells (in accordance with the developed projects). Data on the duration of the observation period and the number of observation wells in the stationary network are shown in Table 1.
Table 1. Characteristics of the stationary network of observation wells at the objects of study

| Object                  | Year of establishment of stationary network | Number of piezometers |
|-------------------------|---------------------------------------------|-----------------------|
| Ash dump, TPS-2         | 1990                                        | 21                    |
| Ash dump, TPS-3         | 2001                                        | 33                    |
| Ash dump #3, TPS-4      | 1993                                        | 84                    |
| Ash dump #1, TPS-5      | 1991                                        | 21                    |
| Ash dump #2, TPS-5      | 2002                                        | 34                    |

The observation base is characterized by the following:

- all objects of observation are equipped with a network of control and measuring equipment, in accordance with the projects developed by specialized organizations;
- for all objects of observation, the necessary documentation has been developed in full (safety criteria for hydraulic structures, safety declarations for hydraulic structures, monitoring projects, etc.);
- objects of observation are storage facilities of the two most common: gullyling (ash dumps of TPS-4 and TPS-5) and floodplain (ash dumps of TPS-2 and TPS-3) types.
- objects of observation are located in different parts of urban area: within the city, in the immediate vicinity of low-rise and multi-storey buildings (ash dumps of TPS-2 and TPS-3); in the outskirts of the city (ash dumps of TPS-5); in the suburbs (ash dump of TPS-4);
- waste storage facilities are potentially dangerous objects and access to them by unauthorized persons must be prohibited. But, given the area of the facilities and their remoteness from the industrial sites of the power stations themselves, only the installation of barriers at the main entrances is used as protective measures, which is not a significant obstacle for local residents. All objects are characterized by their active use (with varying intensity) for travel and passage, grazing, walking and even fishing and hunting;
- most of the work on the operation, maintenance and repair of storage devices is carried out by the services of the power plants themselves, and monitoring is carried out by a specialized organization (SibIATs JSC);
- the period of continuous observations at various objects ranges from eighteen to thirty years. At the same time, during the entire observation period, not only readings of the control and measuring equipment were taken, but also all significant changes in operating conditions, deformation of structural elements and damage to instruments and equipment were recorded.

Thus, extensive factual material has been accumulated on the objects of observation, allowing not only to assess the technical condition and trace the dynamics of its change during the operation of ash dumps, but also to assess the effectiveness of monitoring itself and identify its most problematic aspects, taking into account the specifics of operating conditions.

The research methodology consisted in analyzing the data of hydrogeological monitoring of the geological environment by objects during the entire observation period.

3. Survey of literature

The procedure for carrying out hydrogeological monitoring on the territory of ash dumps of thermal power stations is simultaneously regulated by three current regulatory documents: guidelines for monitoring the regime of groundwater at thermal power plants under construction and in operation: RD 153-34.1-21.325-98 [4]; recommendations for monitoring the state of groundwater in the area of ash dumps of TPS: P-78-2000 [5]; recommendations for diagnostic control of the filtration and hydrochemical state of ash dumps: P89-2001 [6].

A large number of studies, materials and articles have been published in the Internet and in printed publications on the geochemical safety of the operation of specific industrial waste storage facilities and their impact on the natural and social environment. The search for materials on the topic of the study provided no results.
4. Results and discussion

Analysis of the data makes it possible to single out a number of problems typical for hydrogeological monitoring of industrial waste storage facilities in the contemporary conditions, which are conventionally divided into three large groups. These are problems associated with the shortcomings of (1) monitoring programs (organizational and planning ones), (2) test equipment (technical ones) and (3) data processing.

4.1. Problems caused by the shortcomings of monitoring programs

1. Inconsistency of regulatory documents for monitoring the geological environment. The composition and frequency of different types of observations are regulated by several regulatory documents [4–6]. At the same time, the composition of the monitored parameters has been worked out in sufficient detail (and is the same in different regulatory documents), and the frequency of parameter measurements varies within a fairly wide range. For example, the frequency of measurements of groundwater parameters ranges from once a season (2 times a year) to once every 7-10 days, and in special cases - up to daily measurements. The design features, operating conditions and technical condition of the monitoring object are actually not taken into account when determining the observation frequency. The accumulated data is sufficient for identification of the most dangerous periods of operation of storage facilities (on an annual basis) and justified adjustment of the frequency and composition of observations - this would allow not only to qualitatively improve the monitoring system, but also in most cases to reduce the cost of work. The situation is the same with the measurements of a number of other parameters - all parameters are measured independently (without linking the timing of observations and joint processing of the results).

2. Disunity of certain types of monitoring. Hydrogeological monitoring is divided into two parts: monitoring the technical state of storage facilities (a system of regular visual and instrumental observations of the performance indicators and technical condition of constructions, of the manifestation and development of man-made and natural processes and phenomena hazardous to the constructions, carried out according to a specific program) and environmental monitoring ( an integrated system for monitoring the state of the environment). These types of monitoring differ in the objectives of the observations. The goals of the first are an objective assessment of the operational reliability and safety of structures, forecasting changes in the technical condition of constructions and the timely development of repair measures. The objective of the second is to identify the background regime of groundwater, assess the influence of anthropogenic factors on groundwater regimes and predict changes in the state of the environment under the influence of anthropogenic factors, while the test equipment used (observation wells) and the controlled parameters (levels, temperatures, chemical composition) coincide. The observation results could mutually complement each other and give a more complete picture of the processes occurring in the studied soil mass. But at present these types of monitoring are carried out by different organizations without coordinating the observation periods, which leads to a loss of connection between the results and the impossibility of their joint analysis.

4.2. Problems caused by shortcomings of test equipment.

1. When planning new wells of a stationary test equipment network, the spatial variability of the groundwater regime in dense urban areas is often not taken into account. The indicated drawback applies only to test equipment for environmental monitoring (test equipment for monitoring the technical condition of storage facilities is installed in strict accordance with the developed project for the installation of test equipment, the current safety declaration and safety criteria). As a rule, a network of wells is installed without a specially developed project along the perimeter of a storage facility and its main disadvantages are the following: equipment of wells for only one aquiferous horizon (groundwater); lack of observation diameters both along and across the main aquiferous horizon; lack of wells in the storage bowl; lack of gauging stations on surface watercourses; placement of wells only
in the immediate vicinity of the storage facility; insufficient number (or absence) of wells outside the zone of influence of the facility.

2. When installing new test equipment, the real geological structure of the soil mass is not taken into account. When developing the design of test equipment installation, the design structure of the body of the enclosing dams is taken into account. In most cases, the design of the enclosing dams is homogeneous. The real structure of the body of the enclosing dams often does not coincide with the designed one and is a complex combination of layers and lenses of different soils (clay and sand, construction waste and industrial waste) of various capacities (Figures 2 and 3).

Figure 2. An example of the designed engineering and geological structure of the enclosing dams of the storage facility (dam of the 1st tier with topped dams of 2-3 tiers)

Figure 3. An example of the actual engineering-geological structure of the enclosing dam of a storage facility according to the data of engineering-geological studies (dam of the 1st tier)

Filtration takes place through lenses and layers of more permeable soils and, as a result, two or more aquifers can be observed in the body of the dams. When installing observation wells and processing data without taking into account the real engineering and geological structure, the results provided will give a distorted picture. The technical characteristics of piezometers can also affect the reliability of the data obtained. Practice has shown that when installing a well filter simultaneously in two aquifers (shaft-type wells), the piezometer readings will differ from the real values of the parameters in each of them.

3. Lack of quality control of the installed test equipment. Strong competition in the market among organizations providing drilling and well equipment services leads to a decrease in the purchase price for these types of work (with a tender procurement system). In the absence of control on the part of the customer, unscrupulous operators often try in every possible way to minimize their costs during work, both by saving materials (no filter, reduction or absence of sanding, absence of collar sleeves, etc.), and by saving time, spent on the performance of work (reducing the open ration of the filter, installing wells by the thrust boring method, etc.). This leads to the fact that some of the wells installed on storage facilities, already at the stage of commissioning, may be inoperative.

4. Low quality of technical documentation provided for test equipment (or its complete absence). According to the current regulations, a passport of the established form must be drawn up for each observation well during its installation, indicating all the necessary technical information and providing an engineering-geological profile. Correctly issued passports allow not only to assess the performance of a well during its operation, but also to analyze more fully the results obtained. At present, the passports of most observation wells do not correspond to the established form. Geotechnical columns are often
not reliable (the given geological structure is not confirmed by repeated geotechnical surveys) or are completely absent. For all wells, there is no data on their pumping and recovery of water levels at the time of putting into service, which leads to difficulties in determining the operability of well filters and assessing the reliability of the data obtained.

5. Low preservation of test equipment. When a storage facility was located within the city limits (in an unguarded territory), frequent damage to observation wells by unauthorized persons was noted (see Figure 4). The most typical is damage or dismantling of external equipment (well heads and flag indicators), while the filter columns, as a rule, are preserved. However, wells located on the crest and in the upper part of the downstream slope are periodically damaged by operational services when clearing snow in winter and spring (see Figure 5). In this case, in the best case, the filter column jams (the well is repairable), and in the worst case, a part of the filter column is turned out of the ground (the well cannot be repaired).

![Figure 4. Examples of damage to observation wells by "outsiders"

![Figure 5. Examples of damage to observation wells by operational services

The number of mechanical damage to observation wells (with the exception of their complete destruction by operational services) detected at ash dumps of Novosibirsk TPSs over the past five years is shown in Table 2. The number of wells destroyed by operational services during repair work, landscaping and clearing the crests of dams from snow over the past five years is shown in Table 3.

Against the general background, we can note the high damageability of wells on the territory of the ash dump of TPS-3, associated with its proximity to new residential areas and the use of enclosing dams as a walking area and recreation place.
Table 2. Damageability of observation wells in 2016-2020.

| Object                    | Composition of stationary network | Number of detected damages |
|---------------------------|-----------------------------------|-----------------------------|
| Ash dump, TPS-2           | 21                                | 3 5 2 3 1                   |
| Ash dump, TPS-3           | 33                                | 4 14 3 13 14                |
| Ash dump #3, TPS-4        | 84                                | 7 3 3 3 3                   |
| Ash dump #1, TPS-5        | 21                                | - - 1 1 4                  |
| Ash dump #2, TPS-5        | 34                                | 1 1 2 1 2                  |

Table 3. Preservation of observation wells in 2016-2020.

| Object                    | Composition of stationary network | Number of destroyed wells |
|---------------------------|-----------------------------------|---------------------------|
| Ash dump, TPS-2           | 21                                | - - - - -                 |
| Ash dump, TPS-3           | 33                                | - 1 - 1 -                 |
| Ash dump #3, TPS-4        | 84                                | 4 1 2 1 -                 |
| Ash dump #1, TPS-5        | 21                                | - - - - -                 |
| Ash dump #2, TPS-5        | 34                                | - - - 1 1                 |

4.3. Problems caused by deficiencies in data processing.

1. Lack of approved, mandatory, uniform requirements for processing hydrogeological monitoring data and the content of technical reports. The guidelines for monitoring the groundwater regime at thermal power stations under construction and in operation [4] provide an established sample of a technical report, based on the results of observations, for hydrogeological monitoring on the territories of industrial sites. It sets out in detail the structure and composition of the technical report; requirements for the content of individual sections; form for providing information, etc. In the current normative and technical documentation a similar established template for the design of technical reports is not provided for hydrogeological monitoring of industrial waste storage facilities.

2. Lack of consolidated databases on monitoring objects. The observations are cyclical (the duration of one cycle is one calendar year). Observation results are provided in the form of annual reports in printed and electronic (non-editable formats) form. There are no electronic databases. This makes it difficult to perform multivariate analysis and obtain a qualitative assessment of the technical condition and environmental safety of industrial waste storage facilities.

3. Insufficient use of modern computer technologies in data processing. The absence of consolidated electronic databases makes it impossible to use modern computer software systems for data processing.

4. Lack of forecasting changes in the state of the natural and man-made system. The essence and content of monitoring the geological environment is a system of purposeful engineering-geological and engineering activities, consisting of an ordered set of procedures organized in cycles: observations, assessing the state of the environment based on the results of observations, forecasting the development of the geological environment and management [3]. Then the observations are supplemented with new data, at a new cycle, and then the cycles are repeated at a new time interval (Figure 5).
In fact, at the present time, on most of the objects considered, the cycle ends at best at the stage of assessing the state of the environment based on the results of observations. In some cases, only the results of observations are provided. The forecast of the development of the processes is not done. The forecast of the development of the geological environment is replaced by a search for the causes of the occurrence of disturbances in the operation of the NTS that have already occurred.

Thus, it can be argued that the entire system of monitoring the geological environment is currently reduced only to regime engineering-geological (engineering-hydrogeological) observations.

5. Conclusion
In conclusion, it should be noted that all the identified problems of hydrogeological monitoring of storage facilities are caused by only one reason - the lack of interest of the owners and operating organizations in obtaining a high-quality "product". Execution of work is perfunctory. The work is carried out exactly in such amount that allows one to avoid penalties from the controlling organizations. In the absence of the operating organizations' interest in obtaining the most reliable information that is possible, the existing observation system (together with all its problems) will not qualitatively change.

To improve the quality of work performed, it is necessary, first of all:
1. to strengthen the quality control by the customer of the work performed at all stages;
2. to create consolidated databases for each object of monitoring. At the same time, information on all test equipment installed on the storage facilities should be entered into the structure of the database. The creation of consolidated databases will be the first step towards the development and implementation of an automated information system;
3. to ensure a higher preservation of observation wells of the stationary network in conditions of increased anthropogenic load. Good results were shown by the use of above-ground equipment made of plastic materials, which excludes the possibility of theft for selling it as scrap metal.

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