Experience in application of modern technologies of measuring the structure of currents in the upstream waters of large hydroelectric complexes (on the example of the Kama HPP)

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Abstract. The creation of reservoirs on watercourses leads to significant changes in the hydrological regime of water bodies: it allows to smooth out the peaks of maximum water discharge during the flood period and to regulate low runoff. The reservoirs with a significant storage capacity enable to solve a wide range of water management problems, among which are: using the falling water energy for hydropower purposes, ensuring uninterrupted water supply and navigation. In view of the fact that dams are generally managed by hydropower companies, the regime for regulating downstream water mass discharges is often determined by the schedule of daily electricity consumption. Intraday changes in the volume of water discharge through the hydroelectric units of hydroelectric power plants form multidirectional flows in the upstream, which can affect the work of other water users. This paper examines the impact of intraday changes in flow rates of downstream water discharges on the dynamic and physical properties of the water mass in the area of the drinking water intake heads of the city of Perm.

1. Introduction
A characteristic feature of the operation of hydroelectric power plants is a technological ability to quickly and efficiently change the power generation. With this, they fundamentally differ from thermal and nuclear power plants, which require a stable operating mode. Since the population of large cities consumes electricity very unevenly during the day: minimum consumption is at night, and maximum - in the morning and in the afternoon, it is very convenient to use hydroelectric power plants to remove this energy unevenness. The uneven generation of electricity is determined, respectively, by the irregular water discharge from the upstream pool of the HPP to the downstream one. Consequently, rather sharp changes in the flow rate of water discharges through the dam of hydroelectric power plants cannot but affect the hydrodynamic regime of not only the downstream, but also the upstream pools.

For the city of Perm the hydrodynamics of the upstream water of the Kama HPP is of particular importance since the main drinking water intake of the city – the Chusovskiye treatment facilities (CHTF) – is located there. For the first time, the study of the structure of the currents formed in the
upstream of the Kama hydroelectric complex was presented as a part of the computational experiments [1]. The influence of the non-stationary water discharge on the hydrodynamic regime of reservoirs was also studied in [2, 3, 4].

Significant sensitivity of the quality of water withdrawn at the CHTF to the hydrodynamic regime in the upstream water of the Kama HPP is due to the fact that, as it was shown [5, 6], in the winter period the hardness of the withdrawn water is largely determined by the peculiarities of the confluence of the rivers Chusovaya and Sylva. In order to ensure a stable selective withdrawal of less mineralized and hard water of the river Chusovaya, the creation of bottom barriers at the water intake heads was suggested and implemented.

The influence of selective withdrawal on the stability of stratified structures in reservoirs was investigated in [7]. In general, a fairly large number of studies are devoted to the investigation of vertical density effects [8, 9] and in recent years the conditions of formation and criteria for their sustainability have been investigated [10, 11].

Based on the peculiarities of the operation of the Kama reservoir the upper level of these barriers is 98 m abs. In this regard, the hydrodynamic regime in the CHTF region is one of the main factors that determine the stability of the functioning of this water intake. With the start in 2020 of line 3 at the CHTF, including bottom barriers, it has become very urgent to study the structure of the currents generated by the significant intraday variability of the water discharge regimes on Kama HPP.

The water hardness in the area of the water intake heads undergoes significant changes during the observation period. This is mainly due to the regime of discharge flows of the Kama HPP. The close relationship between water hardness and discharge flow rates of the Kama HPP indicates that this factor is decisive for the change in water quality at the water intake during the winter low-water period.

From dynamic standpoints, the upstream water of large hydroelectric complexes is a rather complicated nonlinear oscillatory system, excited by a significant intraday irregularity of water discharges. At the same time, if in the section of the reservoir immediately adjacent to the hydroelectric complex, the velocity and direction of the current are determined exclusively by the regime of water discharges into the downstream pool, then at a certain distance the secondary currents, which can have a reverse direction, begin to play a decisive role. Modern hydrodynamic models in 2D- and 3D- settings make it possible to effectively reproduce these currents, however, these models themselves require some calibration based on actually measured data. Thus, the issue of in-situ measurements of hydrodynamic parameters in the upstream water is of particular relevance.

Nevertheless, traditional measurement methods based on hydrometric propellers are not very effective, because, on the one hand, it is required to carry out at least daily measurements with significant intra-diurnal irregularity, and on the other hand, the measured flows are characterized not only by low velocities ~ 0.05-0.001 m/s but also by the ability to change the direction to the opposite one within quite a small period of time.

2. Materials and methods

The modern instruments widely used for measuring flow dynamics are those based on the Doppler principle. The Doppler-based instruments typically use 3-5 beams to calculate velocity throughout the entire water column. The depth capabilities of the device vary with frequencies. Lower frequencies can penetrate up to 100 meters but at the same time have larger cells limiting their space-time resolution. High frequencies (up to 2.4 MHz) have small cell sizes but allow working only at shallow depths.

The main feature of these instruments is that they make it possible to measure the change in the dynamic characteristics of the flow along its entire thickness without regard to the near-surface and bottom layers. These devices allow to obtain the values of the velocities and directions of currents, averaged for the cell that can vary from 10 sm to 50 sm. With regard to the problem solved in this paper, such devices have a number of other disadvantages, firstly, it is the inability of autonomous operation, and secondly, the impossibility of determining physical properties of water.
All that led to the choice of the current velocity meter MIDAS ECM manufactured by Valeport as the main working tool. [12] This instrument is a point universal current meter designed for long-term operation and simple deployment. The Valeport electronics architecture allows to use multiple additional sensors as well as different communication options what makes it one of the few multi-parameter current velocity meters, allowing to make the measurement both in real time with a long cable (up to several thousand meters) and in autonomous deployments. The range of measured current velocities for a given instrument is from 0.001 m/s to 5 m/s. The instrument is a current rate meter of the electromagnetic type based on the Faraday principle. The instrument also enables to determine the physical properties of the water mass: electrical conductivity, temperature, pressure, turbidity. The main characteristics of the instrument are shown in Table 1. The instrument allows measurements to be made at depths up to 500 m. The length of the device without a protective cage is 700 mm, the diameter is 150 mm and the weight is about 15 kg.

| Sensor   | Type                  | Range          | Accuracy       | Resolution     |
|----------|-----------------------|----------------|----------------|----------------|
| Current  | Valeport EM           | 0-5 m/s        | +/-1% reading  | 0.001 m/s      |
| Direction| Fluxgate              | 0-360°         | +/-<10         | 0.001°         |
| Pressure | Piezo- Resistive      | Up to 500Bar   | +/-0.01%       | 0.001%         |
| Temperature| PRT                | -5 - +35°C      | +/-0.005°C     | 0.002°C        |
| Conductivity| Inductive        | 0-80 mS/cm     | +/-0.01 mS/cm  | 0.002 mS/cm    |
| Turbidity| Seapoint STM          | 0 – 2000FTU    | +/-2%          | 0.002%         |

3. Results and discussion
In order to achieve the goal of determining changes in the dynamic (velocity and direction of currents) and physical (electrical conductivity of water) characteristics of the current in the area of the head of the Chusovskiy treatment facilities in Perm, the field observations were organized (figure 1).

![Figure 1. In-situ measurements in the area of the heads of the CHTF in Perm.](image)

The first stage of the work consisted in determining the change in electrical conductivity along the depth of the reservoir in the area of the water intake heads. The measurement results are shown in figure 2. From the materials in figure 2 it follows that in this section of the Kama reservoir water area there is a significant vertical heterogeneity of water masses caused by the confluence of the Sylva and Chusovaya rivers 7 km upstream from the dam of the Kama HPP.
Further, the device was set up for autonomous operation and submerged to a depth of 7 m – the depth of water intake by the heads of the CHTF. The autonomous operation of the device lasted 23 hours. As a result, there were revealed the dependences of change in the values of velocities and directions of the currents and specific electrical conductivity by time (figures 3-5).

Figure 3 clearly shows the change in the velocity module during the day. Fluctuations in the range of 0.01-0.08 m/s are connected with certain phases of the passage of forward and backward waves, caused by the daily irregularity of releases through the Kama HPP. The fact of the presence of the above waves is confirmed by the results of measuring the direction of the currents. As you can see from figure 4, the main fluctuations are in the range of 120-340 degrees. That is, during the day, the direction of the current at the point of measurement changes to the opposite.
Figure 4. Change in the current direction, (degrees).

Shown in figure 5 with an hourly averaging of the value of the discharge rate of water through the dam of the Kama HPP and the models of the current velocities in the area of the heads of the CHTF clearly demonstrate the role of the releases of the hydroelectric power station, which determines the dynamics in the area of the heads of the water intake.

Figure 5. Combined chronological chart of changes in the rates and module of the current velocities in the area of the CHTF heads.

4. Conclusion
The significant intraday irregularity in the operation of the Kama HPP causes considerable fluctuations in the velocities of currents in the upstream even at a distance of ~ 15 km from the hydroelectric complex. These fluctuations can have a strong influence on the efficiency of selective
water withdrawal at the main drinking water intake in the Perm city. Therefore, the performed studies are of significant practical interest.

The complex of studies carried out with the use of the modern multi-parameter current rate meter MIDAS ECM showed that the daily irregularity of water discharges through the dam of HPP forms a very complex character of forward and reverse currents. The study of their structure is of great importance for ensuring the sustainability of the drinking water supply of the Perm city.

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