IRSTI 50.37.23; 50.41.25
UDC 51.74; 627.85

Water level monitoring system in hydraulic structures

T. Mazakov[1], P. Kisala[2], N. Issimov[3] and G. Ziyatbekova[4]
[1,3] RSE Institute of Information and Computational Technologies MES RK CS, Almaty, Kazakhstan
[2]Lublin Technical University, Poland
[1,4]Al-Farabi Kazakh National University, Almaty, Kazakhstan
[1]tmazakov@mail.ru, 3p.kisala@pollub.pl, [3]int_nurdaulet@mail.ru, [4]ziyatbekova@mail.ru
[1]ORCID ID: https://orcid.org/0000-0001-9345-5167
[4]ORCID ID: https://orcid.org/0000-0002-9290-6074

Abstract. The article is devoted to the creation of a system for monitoring the water level in hydraulic structures (HS) to prevent a dam break. The article discusses a system for monitoring the water level in hydraulic structures, which allows real-time information on the relative humidity and air temperature, on the distance from the crest of the dam to the water surface in the reservoir. The general characteristics of the problem and the formulation of research tasks are given. On the basis of microprocessor technology and sensor sensors, an autonomous microcomputer system for transmitting climate data has been developed. A program for monitoring breakout factors in real time has been developed. Based on the information received, the system makes it possible to estimate the predicted time for the increase in the volume of the water level from the current to the critical level and inform the population about the state of the reservoir. The task is analyzed and the main problems that may arise in the course of its solution are identified. The advantages and disadvantages of the described methods are highlighted.

Keywords: monitoring system, dam, water level sensor, breakthrough waves, water resources, hardware-software complex, hydraulic structure.

Introduction. The purpose of water resources monitoring is to obtain data from repeated observations of the elements of water resources, carried out for their assessment, according to a certain plan, using modern methodologies for measuring parameters and collecting data. It allows you to obtain information regarding the current state of water resources and assess trends in changes in their characteristics, as well as predict the limits of possible changes. Monitoring of water resources includes monitoring of water bodies (surface, underground), water management systems and structures, monitoring of water use, etc. Water resources monitoring method is intended for water specialists to assess and manage water resources. The water resources monitoring system creates information support for the management of the country's water fund. The main provisions of the formation of the monitoring system: a complex approach; continuity of monitoring in space and time; using common methodological approaches; organization of a monitoring system based on geographic information systems (GIS); the system should be open for practical linkage with other systems; focus on computer technology for collecting storage and processing data [1].

Monitoring of water resources in Kazakhstan is characterized by a number of problems, the main of which: insufficient funding, low coverage of the country by the observation network, collection of information is carried out separately and in small quantities, outdated equipment and methods for collecting and analyzing the information received, poorly equipped observation posts, disunity of the monitoring network of various departments, weak research support for the development of a water monitoring system. To solve the above problems of the development of water resources monitoring in Kazakhstan, it is necessary to introduce the following measures: determination of the required information for various water users and natural ecosystems; creation of a unified system for monitoring water resources based on GIS technologies and with the participation of all stakeholders; improving the quality of scientific research of the features of the monitoring system of the Republic of Kazakhstan.

Implementation. For practical applications, systems are being developed for monitoring the state of water bodies in real time, based on the automation of the process of collecting and processing information. Basically, the automated monitoring systems use the following sensors: inclometric; streams; deformation; temperature; pressure per pound; water level [2-4].

During the operation of hydrotechnical facilities, in particular in the mountains, the destruction of the pressure head of the hydraulic units is one of the most dangerous cases of accidents, which lead to the cystic, ecological and socio-logical, a also significantly affecting the ecology of the downstream of hydropower plants. For information monitoring systems, it is necessary to ensure the collection of data in real time.

The water level measuring equipment can be different. To ensure the functioning of the system, the measuring equipment will be interfaced with the data transmission subsystem and the power supply subsystem. The conjugation of these systems will allow monitoring the water level in moraine lakes, the location of which is extremely difficult to access. The technical means that measure the water level must be able to receive data from sensors with different periodicity [5-7]. As was said above, the data arriving from the measuring equipment will be transmitted to the data collection and processing center by means of low-orbit space communication systems.

The accumulated data will be transferred to situational centers and used by special services for forecasting possible floods and floods, calculating water consumption and for other purposes. The monitoring system can be linked to other automated systems, for example, systems for the intake and discharge of water on the webs of hydroelectric power plants, alarm systems, and other functional interconnected systems. The introduction of a water level monitoring system will allow for the prevention of emergencies.

The main information for monitoring the risk of dam failure is the data from the water level sensor. Additional information is provided by data received from temperature and precipitation sensors.

The unit for receiving and transmitting current information is implemented in the form of sensors about water level, humidity and temperature and is located on the crest of the dam. The sensors are connected to the Arduino microprocessor [8-10], which provides preliminary processing of the data coming from the sensors and transfers them for further processing.

To measure the water level in the reservoir, we used an ultrasonic sensor US-015, which works by sending sound waves at a certain frequency.

Specifications US-015:

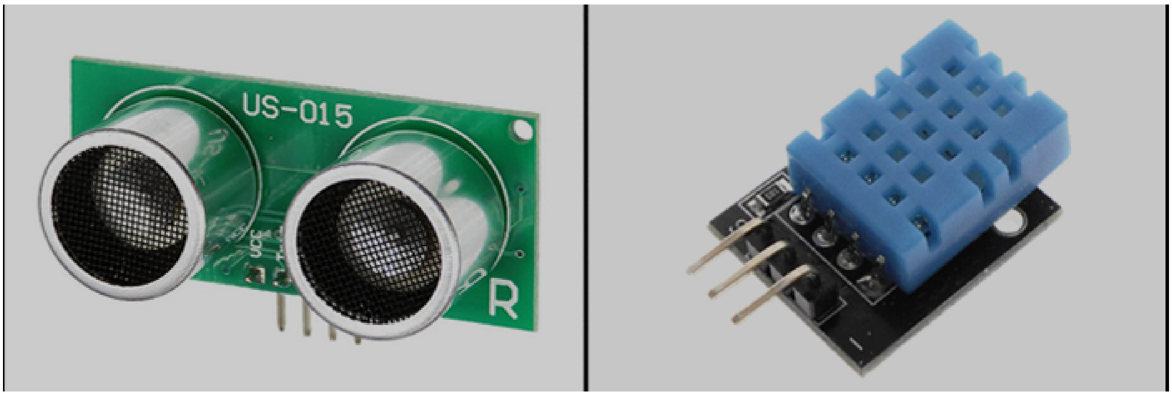
- Supply voltage: 5 V;
- Power consumption: 20 mA;
- Standby current consumption: 2.2 mA;
- Measurement angle: 15°;
- Measuring distance range: 2 - 700 cm;
- Accuracy: 0.3 cm + 1%.

To measure the temperature and the presence of precipitation, a DHT11 sensor was used, which has one digital output, therefore, readings can be taken no more often than once every 1-2 seconds.

DHT11 characteristics:

- Power and I/O 3-5V;
- Determination of humidity 20-80% with 5% accuracy;
- Determination of temperature 0-50 degrees with 2% accuracy;
- The sampling rate is no more than 1 Hz (no more than once every 1 sec.).

Figures 1 and 2 show the type of sensors used, their design and layout.



a) Sensor US-015 б) DHT11 sensor

Figure 1 - Type of sensors: a) water level sensor US-015 and b) temperature and humidity sensor DHT11

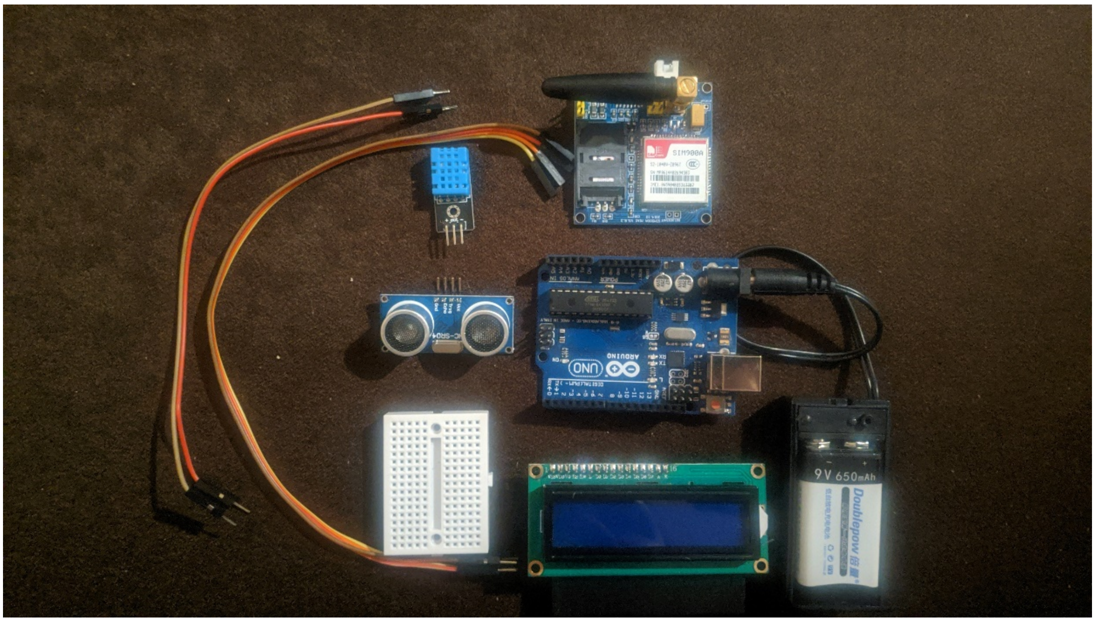


Figure 2 - Composition of sensors detecting information on climate and water level

Catastrophic flooding, which is the result of a hydrodynamic accident, consists in the rapid flooding of the area by a breakout wave. Hydraulic structures can be breached due to natural forces (earthquake, hurricane, landslide, etc.), structural defects, violations of operating rules, impact of floods, destruction of the dam base, etc. During the breakthrough of the hydraulic structures, a gap (closure channel, passage) is formed, through which the water flows from the upper downstream to the lower one and the formation of a breakthrough wave. Breakthrough wave is the main striking factor of this type of accident, characterized by wave height and speed [11, 12].

In [13], it was found that the following hydroelectric complex parameters and the conditions of propagation of a breakthrough wave in the downstream most significantly affect the h_{max} values: reservoir volume before the accident (W_{water}), reservoir depth at the dam before the accident (H_0), roughness of the upstream wall (n_0), the amount of opening of the gap (B_{gap}), water flow in the downstream of the hydroelectric facility before the accident (Q_0), the distance from the damsite to the observation site (L). The dependence of the maximum flooding depth on the main influencing factors was obtained and presented in general form by the expression:

$$h_{max} = 2{,}51 \frac{H_0^{0,98} n_0^{0,02} Q_0^{0,05}}{W_{water}^{0,05} L^{0,13}} \tag{1}$$

The limits of applicability of formula (1) are indicated: reservoir volume (W_{water}) – from 50 to 5000 thousand m^3; depth of water upstream of the dam (H_0) – from 2 to 20 m; water flow in the downstream of the hydraulic facility before the accident (Q_0) – from 1 to 100 m^3/s; reservoir length – from 0.8 to 2 km, if there is no backup from the downstream hydraulic structures; distance from the dam site to the considered section (L) from 0.5 to 50 km; roughness (n_0) from 0.02 to 0.2.

In addition, the formula (1) has the following disadvantages:

1) missing parameter – the amount of opening of the gap (B_{gap}),

2) the volume of the reservoir before the accident (W_{water}) is placed in the denominator, which leads to a contradiction to the basics of hydrology – "a larger volume of reservoir filling leads to a decrease in the breakthrough wave".

In [14], due to the limitations of the applicability of the formula (1), it was proposed to use the dependence (2) proposed by V.I. Volkov to determine the maximum depth of flooding:

$$h_{max} = 0{,}34 H_0 \left(\frac{L}{H_0}\right)^{-0,13} \tag{2}$$

As a disadvantage of the formula (2), it should be noted that it does not use such important parameters of the hydraulic structures as the reservoir volume before the accident (W_{water}), the amount of opening of the gap (B_{gap}). This fact greatly narrows the applicability of this formula.

To correct these shortcomings, the article proposes the following approach.

The maximum depth h_{max} is sought in the form

$$h_{max} = \alpha_0 B_{gap}^{\alpha_1} H_0^{\alpha_2} W_{water}^{\alpha_3} L^{-\alpha_4} \cos\theta, \tag{3}$$

where θ – is the angle of inclination of the earth (relief) at a distance L.

In the formula (3) all the coefficients $\alpha_i > 0, i = \overline{0,4}$.

Let n = 4 be the number of information parameters of hydraulic structures that affect the size of the breakthrough wave; $x = (x_0, \dots, x_n)$ – the vector whose components characterize the hydraulic structures.

For the convenience of further calculations, we will accept

$y = h_{max};\ x_0 = 1,\ x_1 = B_{gap};\ x_2 = H_0;\ x_3 = W_{water};\ x_4 = L.$

We introduce the following designations:

m– the number of versions (situations);

X_{ij} – the value of the i-th parameter in the j-th version,

where $i = \overline{0,n}$, $j = \overline{1,m}$.

Y_j – maximum breakthrough wave depth in the j –th situation, where $j = \overline{1,m}$.

Then formula (3) can be rewritten in the form:

$$Y_0 = \alpha_0 * \left(\prod_{k=1}^{3} x_k^{\alpha_k}\right) * x_4^{-\alpha_4} \tag{4}$$

$$Y = Y_0 * cos(\theta)$$

Formula (4) corresponds to the optimization problem, where the coefficients α_k, are unknown, which determine the influence of the k–th information parameter on the overall result.

We will take the logarithm of the expression (4):

$$ln(Y_0) = \alpha_0 + \sum_{k=1}^{3} \alpha_k ln(x_k) - \alpha_4 ln(x_4) \quad (5)$$

The coefficients α_k in formula (5) can be found from the minimum condition for the functional

$$S = \sum_{j=1}^{m} \left(ln(Y_{0j}) - \alpha_0 - \sum_{k=1}^{3} \alpha_k ln(X_{kj}) + \alpha_4 ln(X_{4j}) \right)^2 \quad (6)$$

We introduce the set

$$A = \{0 \le \alpha_i \le 10\} \quad (7)$$

It is easy to show that A is a convex closed set in R^m space.

The algorithm for finding the coefficients of functional (6).

Step 1. The minimum of functional (6) is found by the least square method, by reducing to a system of linear algebraic equations of the form

$$C\beta = d$$

Where C – (n+1)*(n+1) – the matrix, $d - (n+1) -$ the vector made up of values

$$ln(Y_{0j}), ln(X_{kj}), k = \overline{0,n}, \; j = \overline{1,m}.$$

If all elements of the vector $\beta_i > 0, = \overline{0,n}$, then we take $\alpha_i = \beta_i, i = \overline{0,n}$ and go to step 5.

Step 2. Denote by α_i^n the n-th approximation for calculating the coefficient α_i.

As a zero approximation, we select

$$\alpha_i^0 = \begin{cases} \beta_i, & if \beta_i > 0 \\ \varepsilon, & if \beta_i \le 0 \end{cases}.$$

Here $\varepsilon > 0$ – is a sufficiently small number.

Step 3. The minimum of the functional (6) is defined on the set (7).

Let's build an iterative process

$$\alpha_i^{n+1} = \Pi_A(\alpha_i^n - \gamma_n S'(\alpha_i^n)) \quad (8)$$

Here Π_A – projection operator onto the set A. The coefficients $\gamma_n \ge 0$, the determine the step length at the n-th stage, can be found from the condition

$$S(\alpha_i^n - \gamma_n S'(\alpha_i^n)) = \min_{\gamma \in R} S\left(\alpha_i^n - \gamma S'(\alpha_i^{k,n})\right)$$

or in the process of splitting the step.

Step 4. Discrepancy is sought $r = min_i \left(abs(\alpha_i^{n+1} - \alpha_i^n)\right)$.

If $r < \varepsilon$, then go to step 5. Otherwise, increase the iteration number and go to step 2.

Step 5. Algorithm completion.

The convergence of the proposed algorithm is provided by the following theorem.

Theorem 1. Let the set A be convex and closed. Then the sequence $\{\alpha_i^n\}$, defined by the formula (8) converges to the solution of the problem of minimizing the functional (6) on the set (7).

Proof. Since the set A is convex and closed, the functional (6) is convex and differentiable, then any limit point of the sequence $\{\alpha_i^n\}$ is the minimum point [15].

Based on the available information about the breakthroughs, 30 versions of parametric data were prepared. Based on this information, the following formula is obtained:

$$h_{max} = 1{,}34 * H_0^{0{,}55} B_{gap}^{0{,}32} W_0^{0{,}04} L^{-1{,}4} \cos(\theta) \quad (9)$$

In the formula (9), the volume of the reservoir (W_{water}) is measured in millions of m^3; the water depth in the upstream wall of the dam (H_0) is in m;the amount of opening of the gap (B_{gap}) – in m; the distance from the dam site to the observation site (L) - in km; θ is measured in degrees.

Conclusion. The analysis of existing methods of solutions and the formulation of problems for monitoring hydrological processes. The general characteristics of the problem and the formulation of research tasks are given. On the basis of microprocessor technology and sensor sensors, an autonomous microcomputer system for transmitting climate data has been developed. A program for monitoring breakout factors in real time has been developed [16].

The model problem (events that took place in Kyzylagash village of the Almaty region of the Republic of Kazakhstan) shows the effectiveness of the developed mathematical model of predicting the consequences of a dam break.

In the spring of 2010, a tragedy overtook the Almaty region - a flood, with human casualties and destruction. The reign of the elements occurred as a result of the break of the dam. And also in 2014 the same tragedy was repeated in the Karaganda region. These alarming situations for all the peoples of the country served as a serious lesson in preventing similar situations in the future These alarming situations for all the peoples of the country served as a serious lesson in preventing similar situations in the future. To improve the operational safety of equipping hydraulic structures, it is necessary to develop recommendations with modern instrumentation, equipment and means [17, 18].

Acknowledgements. The work was carried out at the expense of grant funding of scientific research for 2018-2020 under the project AP05131027 «Development of biometric methods and information protection tools».

References

1. Mazakov T.Zh., Jomartova Sh.A., Kisala P., Ziyatbekova G.Z. Problems and measures for the development of monitoring of water resources // Bulletin of KazNRTU, 2020. – № 2 (138). – P. 365-369.
2. Shtork S.I., Vieira N.F., Fernandes E.C. On the identification of helical instabilities in a reacting swirling flow. – Fuel, 2008. – Vol. 87. – No. 10-11. – P. 2314-2321.
3. Coleman, Stephen. Dittrich, Andreas; Koll, Katinka; Aberle, Jochen; Geisenhainer, Peter (Hg.) Fluvial sediment transport and morphology: views from upstream and midstream. River Flow. Karlsruhe: Bundesanstalt für Wasserbau, 2010. – P. 11-22.
4. Hydraulic structures. Textbook for universities. – M.: Publishing house of the Association of building universities, 2008. – Part 1. – 576 p.
5. Kotyuk A.F. Sensors in modern dimensions. - M.: «Radio and communication», 2006. - 96 p.

6. Freiden J. Modern sensors. – M.: «Technosphere», 2005. – 592 p.
7. Aleinikov A.F. Gridchin V.A. Tsapenko M.P. Sensors (promising areas of development). – Novosibirsk: NSTU, 2001. – 176 p.
8. Aliaskar M.S., Dzhomartova Sh.A., Ziyatbekova G.Z., Isimov N.T., Amirkhanov B.S., Mazakova A.T. Autonomous microprocessor system for transmitting climatic data // Bulletin of KazNRTU im. K.I. Satpayev. – Almaty, 2019. – No. 1 (131). – P. 371-377.
9. Karvinen T., Karvinen K., Valtokari V. Making sensors: projects of sensor devices based on Arduino and RaspberryPi. – M.: LLC «I.D. Williams», 2017. – 432 p.
10. Vavilov V.D., Timoshenkov S.P., Timoshenkov A.S. Macrosystem sensors of physical quantities. – M.: Technosphere, 2018. – 550 p.
11. Arefyev N.V., Mikhalev M.A., Skvortsova A.S. General erosion of the channel and lowering of the water level in the downstream // Environmental Engineering, 2008. – No. 1. – P. 83-87.
12. Klimovich V.I., Prokofiev V.A. The calculation of the parameters of the breakthrough wave and the definition of the border of the flood zone during the accident at the ash disposal site // Hydrotechnical construction, 2001. – No. 1. – P. 38-44.
13. Sekisova I.A. Development and testing of a system for assessing the state of hydraulic structures of river low-pressure hydroelectric facilities // Dis. Cand. tech. sciences for special. 05.23.07. – Moscow, 2008. – P. 230.
14. Chernykh O.N., Volkov V.I., Altunin V.I. Safety problems of the territories of the lower reaches of the capital's ponds // Environmental engineering, 2017.– No. 1. – P. 47-55.
15. Sukharev A.G., Timokhov A.V., Fedorov V.V. Course optimization methods. – M.: Nauka, 1986. – P. 328.
16. Jomartova Sh.A., Mazakov T.Zh., Isimov N.T. Mazakova A.T. Real-time forecasting program // Bulletin of the National Engineering Academy of the Republic of Kazakhstan. – 2017. – No. 4 (66). – P. 27-32.
17. T.Zh. Mazakov, P. Kisala, Sh.A. Jomartova, G.Z. Ziyatbekova, N.T. Karymsakova. Mathematical modeling forecasting of consequences of damage breakthrough // News of the National Academy of Sciences of the Republic of Kazakhstan. Series of Geology and Technical Sciences. – 2020. – Vol. 5, No 403. – P. 116-124. URL: https://doi.org/10.32014/2020.2518-170X.111 (online; accessed: 11.12.2019).
18. T. Mazakov, Sh. Jomartova, G. Ziyatbekova, M. Aliaskar. Automated system for monitoring the threat of waterworks breakout // Journal of Theoretical and Applied Information Technology, 2020. – Vol. 98, – No 15. – P. 3176-3189. ISSN: 1992-8645, E-ISSN: 1817-3195.

Funding
The authors received no direct funding for this research.