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AUTOMATED SYSTEM FOR MONITORING THE THREAT OF WATERWORKS BREAKOUT

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ABSTRACT

The article is devoted to the creation of an automated system for monitoring the water level in reservoirs to prevent the breakthrough of weirs and dams. The paper offers hardware and software for monitoring the reservoir occupancy with prompt notification of interested organizations (local administrations) and local emergency departments.

The article developed an automated system for monitoring the water level in a reservoir, which allows to get real-time information about the relative humidity and air temperature, the distance from the dam crest to the water surface in the reservoir. Based on the information received, the system allows to estimate the forecast time of increasing the volume of water level from the current to the critical level and inform the population about the state of the reservoir.

Keywords: *Flood, Dam, Closure Channel, Waves, Water Resources, Water Level Monitoring, Microprocessor System, Temperature And Humidity Sensor, Raspberry Microcomputer, Arduino UNO Platform*

1. INTRODUCTION

It is necessary to analyze large volumes of heterogeneous information, inconsistency of goals of various state bodies to assess the environmental safety of the region. The solution of such tasks is impossible without the use of modern information systems for decision support.

Currently, there are 1665 hydraulic structures on the territory of the Republic, including reservoirs with volume greater than1,0 m^3 – 319 units (including in the Republican ownership – 83, in municipal ownership – 200 in private ownership – 34 and ownerless – 60); dams – 443 units (including in the Republican ownership – 32,

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in municipal ownership – 346, private ownership – 45 and ownerless – 20); dams – 125 units and other hydraulic structures – 778 units.

As of May 1, 2017, a total of 1212 hydraulic structures were examined, 865 hydraulic structures of them are in satisfactory condition, and 347 hydraulic structures are in unsatisfactory condition and require repair.

The necessity of legal regulation of the safety issues of hydraulic structures is determined by the large-scaled social and economic consequences of their damage and destruction. At the same time, human losses and material damage are comparable to the consequences of devastating natural disasters.

In Kazakhstan, the construction of many hydraulic structures was carried out in the 60-80s of the last century [1]. Their survey today shows that the actual depreciation is more than 60%, the reliability and safety of strategically important hydraulic structures are sharply reduced.

In accordance with the Water code, Presidential decree of the Republic of Kazakhstan dated November 1, 2004 No.1466, a list of water facilities (hereinafter referred to as the List) of particular strategic importance was defined, which includes 57 reservoirs and 29 retaining hydraulic structures. In accordance with Article 25 of the Water Code, these water facilities cannot be leased, trust and cannot be privatized.

The long service life and reduction in the last 20 years of funding for operating expenses, current and capital repairs, as well as the influence of climatic and seismic factors gradually lead to moral and physical deterioration of the entire complex of hydraulic structures. There are also objects located close to hazardous industries.

Today, such large reservoirs are operated as the Astana reservoir built in 1970 with a capacity of 410.9 million cubic meters, the Seletinsky reservoir – 1965 (230 million cubic meters), the Kargalinsky reservoir – 1975 (280 million cubic meters), the Bartogaysky reservoir – 1982 (320 million cubic meters), the Kapshagai reservoir – 1970 (18560 million cubic meters), the Ters–Ashibulak reservoir – 1963 (158,6 million cubic meters), the Tasotkelsky reservoir – 1974 (620 million cubic meters), the Samarkandsky – 1939 (253,7 million cubic meters), the Upper Tobol – 1972 (816,6 million cubic meters), the Karatomarskoy – 1965 (586 Bugunskoybuilt in 1967 (370 million cubic meters) and others.

The tragic occurrences of spring 2010 in the Almaty region and 2014 in the Karaganda region with human casualties and destruction, as well as floods in other regions of Kazakhstan, served as a serious lesson to prevent similar situations in the future. It is necessary to develop recommendations for equipping hydraulic structures with modern control and measuring devices, equipment and means to improve operational safety.

Monitoring systems should ensure constant monitoring of phenomena and processes occurring in nature and the technosp here, in order to anticipate increasing threats to humans and their environment. The main purpose of monitoring is to provide data for an accurate and reliable forecast of emergencies based on the combination of intellectual, informational and technological capabilities of various departments and

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organizations involved in monitoring certain types of hazards. Monitoring information serves as the basis for forecasting.

Microprocessor technology has now actively entered our lives. Versatility, flexibility, simplicity of hardware design, almost unlimited possibilities for complicating information processing algorithms - all this promises a great future for microprocessor technology. Microprocessors are used both in household appliances for the simplest signal processing and command generation, as well as in the most complex measuring systems for digital signal processing.

Modern opportunities for the development of various sensors [2, 3] and the cheapening of microprocessors have also opened up a wide opportunityto implement hardware-software tools for monitoring climate parameters.

In particular, the relatively cheap Arduino controller, which has a large database of developed sensors and their means of communication with a computer, has found wide application in applied problems [4, 5].

In this regard, the research in this work on the development and research of a mathematical model of a dam breakthrough and information security tools is relevant.

2. IMPLEMENTATION

The following system is proposed for monitoring the threat of a breakthrough of hydroelectric facilities, consisting of two blocks:

1) block for receiving and transmitting current information about water level, humidity and temperature on the dam crest;

2) block for processing constant and operational information about the threat of a dam break (server).

There are two options for connecting blocks.

In the first case, the Arduino microprocessor is directly connected to the server. This option requires a permanent power supply system and the presence of processing personnel at the waterworks.

In the second case, the Arduino microprocessor is connected to the Raspberry Pi microcomputer, which transmits current information to the server via satellite communication. This option does not require the constant presence of processing personnel at the waterworks. And due to its small size and low power consumption, it can be provided with small-sized solar energy.

2.1. Block For Receiving And Transmitting Current Information

The block for receiving and transmitting current information is implemented in the form of sensors about the water level, humidity and temperature and is located on the crest of the dam. The sensors are connected to an Arduino microprocessor, which provides pre-processing of data received from the sensors and transmits them for further processing.

To create an autonomous microprocessor system of transmitting climate data, we used a single-board Raspberry Pi 3 B+ microcomputer [6, 7]. Power is provided by a solar panel.

The system includes a set of necessary sensors and software. The measurement modules are connected to the computer via a USB adapter.The

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software presents the results of measurements in tabular and graphical form, and also allows to view and print the archive of measurements accumulated in the database for any period of time. It is possible to view data from sensors both on other computers of the local network and via the Internet.

The Arduino is a device based on the ATmega microcontroller 328 [8-11]. It includes everything necessary for convenient work with the microcontroller. To start working with the device, simply supply power from an AC/DC adapter or battery, or connect it to a computer using a USB cable.

2.2. The Processing Block Of Constant And Operational Information

The 2nd block contains constant information about the characteristics of the reservoir and dam, and also quickly receives current information. Based on the processing by which it calculates the level of safety, anxiety or disaster of the hydraulic unit. In the latter case, it automatically informs state authorities (emergencies, akimats, etc.) about the possible threat of a dam break.

Due to the specifics of the studied hydrological processes [12-14], fuzzy and interval mathematics are used in the work [15-17].

To assess the threat of a breakthrough, the mathematical model is proposed with the following interval linguistic variables:

1) low level;

2) safe level,

3) alarming level, and 4) catastrophic level of reservoir occupancy [18-19].

The values of the entered linguistic variables are predefined in the following percentages of the dam height:

1) low level-40%;

2) safe level– 30%,

3) alarming level – 20%;

4) catastrophic level – 10%.

For underground dams, the catastrophic level decreases by 3%. In the presence of precipitation for underground hydraulic structures, the catastrophic rate from the reference book "Name of dams or weirs" is reduced by another 2%, to take into account the possibility of dam weakening due to external precipitation.

2.3. Mathematical Model

The mathematical model considers three types of reservoirs: rectangular, trapezoidal, and pyramidal.

To calculate the volume of water that can be taken by the reservoir, until it is completely filled (along the crest of the dam), and the time sufficient for the following designations and assumptions are accepted.

The countdown is conducted every half hour:

$$\Delta T = 0.5\ hours = 30\ minutes.$$

Current time

$$T_k = T_{k-1} + \Delta T.$$

Table 1 presents all the parameters used in the mathematical model.

Table 1. The Parameters Of The Reservoir

No.	Symbol	Name	Unit	Type
1	h_0	damheight	m	constant
2	h_1	distance from dam crest to water surface at the moment of time T_k	m	observed
3	h_2	height by which water rose in time interval $[T_{k-1}, T_k]$	m	calculated
4	h_3	distance from the dam crest along water surface at the moment of time T_{k-1}	m	observed
5	l_0	length of reservoir at the base	m	constant
6	l_1	length of reservoir at the level of the dam crest	m	constant
7	l_2	length of reservoir along water surface at the moment of time T_k	m	calculated
8	l_3	length of reservoir along water surface at the moment of time T_{k-1};	m	calculated
9	ω_0	width of the reservoir at the base	m	constant
10	ω_1	width of reservoir by the level of the dam crest	m	constant
11	ω_2	width of reservoir along water surface at the moment of time T_k;	m	calculated
12	ω_3	width of reservoir along water surface at the moment of time T_{k-1};	m	calculated
13	S_0	area of reservoir at the base	m^2	calculated
14	S_1	area of reservoir by dam crest level	m^2	calculated
15	S_2	area of reservoir along water surface at the moment of time T_k	m^2	calculated
16	S_3	area of reservoir along water surface at the moment of time T_{k-1}	m^2	calculated
17	V_0	total volume of the reservoir	m^3	calculated
18	V_1	unfilled reservoir volume at the current moment of time T_k	m^3	calculated
19	V_2	volume of water entering the reservoir in the time interval $[T_{k-1}, T_k]$	m^3	calculated
20	V_3	volume of waterat the moment of time T_{k-1}	m^3	calculated
21	T_p	forecast time when the reservoir will be completely filled	h	calculated

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Surface areas can be calculated by the formula

$S_i = l_i * \omega_i, i = \overline{1,4};$ (1)

Since the parameter h_0 is constant, h_1 is measured at the moment of time T_k, h_3 is already known by the time T_k, the formula is valid.

$h_2 = h_0 - h_1 - h_3$ (2)

Volumes V_i, $i = \overline{1,4}$ –are calculated by the formulas depending on the type of reservoir (rectangular, trapezoidal and pyramidal).

2.4. Rectangular Reservoir

The view of a rectangular reservoir is shown in Figure 1.

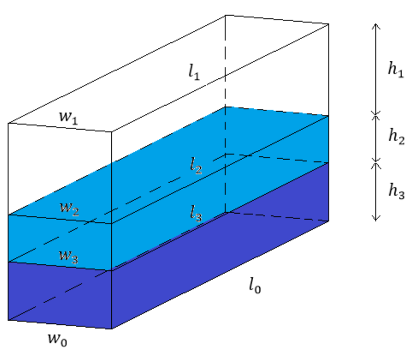

Fig. 1. View of a rectangular reservoir

Due to the fact that the length and width of the reservoir are unchanged, we will adopt the following designations: $\omega = \omega_0 = \omega_1 = \omega_2 = \omega_3$, $l = l_0 = l_1 = l_2 = l_3$. Then

$S = l * \omega, \ V_i = S * h_i, \ i = \overline{0,3}$.
(3)

2.5. Trapezoidal Reservoir

The view of a trapezoidal reservoir is shown in Figure 2.

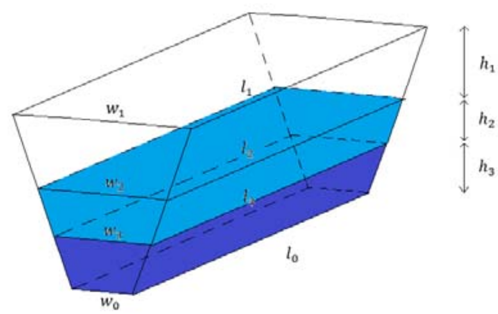

Fig. 2. View of a trapezoidal reservoir

Due to the fact that the length of the reservoir is unchanged, we will adopt the following designations: $l = l_0 = l_1 = l_2 = l_3$. The widths of the reservoir along the base ω_0 of the dam and the crest of the dam are known as ω_1. The heights h_i, $i = \overline{0,3}$ are also known, then the width of the reservoir at the moment of time T_k can be calculated using the formula

$\omega_2 = (\omega_1 * h_0 + \omega_0 * h_1 - \omega_1 * h_1)/h_0$
(4)

Then

$S_i = l * \omega_i, \ i = \overline{0,3},$

$S_i = l * \omega_i, \ V_i = 0.5 * (S_i + S_{i-1}) * h_i,$
$i = \overline{1,3}$,

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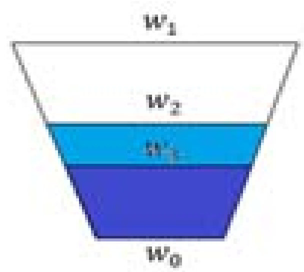
(5)

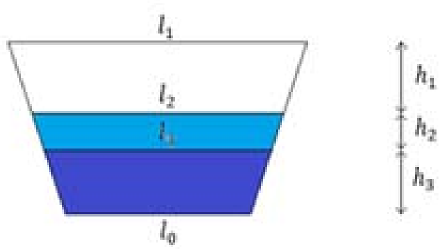
$V_0 = \sum_{i-1}^{3} V_i$,

2.6. Pyramidal Reservoir

The view of a pyramidal reservoir is shown in Figure 3.



a) front view



b) left view

Fig. 3. View of a pyramidal reservoir (a; b)

Due to the fact that the length of the reservoir at the base l_0 and the crest of the dam l_1 are known. In addition, we are given the width of the reservoir at the base ω_0 and the crest of the dam ω_1.

The heights h_i, $i = \overline{0,3}$ are also known, then the width and length of the reservoir at the moment of time T_k can be calculated using the formula:

$$\omega_2 = (\omega_1 * h_0 + \omega_0 * h_1 - \omega_1 * h_1)/h_0$$

(6)

$$l_2 = (l_1 * h_0 + l_0 * h_1 - l_1 * h_1)/h_0$$

Then

$S_i = l_i * \omega_i$, $i = \overline{0,3}$,

(7)

$$V_i = (1/3) * h_i * (S_i + \sqrt{S_i * S_{i+1}} + S_{i+1}),$$
$$i = \overline{0,2}$$
$$V_3 = V_0 - V_1 - V_2$$

Regardless of the type of reservoir, knowing the unfilled volume of the reservoir and the distance from the dam crest to the surface of the water at the current time T_k, then, provided that the water inflow rate for the previous interval $[T_{k-1}, T_k]$ is maintained, we can expect the risk of overflow through forecast time calculated by the formula

$T_p = (V_1/V_2) *$
ΔT (8)

2.7. Software Implementation

An automated system for monitoring the threat of a breakthrough of hydroelectric facilities includes a number of reference books, input data and implements two modes: monitoring and forecasting.

The reference book "Types of dams and weirs"

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consists of 2 fields:

Codv – code - numeric type;

Nazv – name - symbolic type.

The reference book “Name of dams and weirs” consists of 17 fields:

Codp – code-numeric type (concrete -1; ground -2);

Nazp – name - symbolic type;

Codv – dam type code – numeric type (rectangular - 1; trapezoidal - 2; pyramidal -3);

Xpl – dam height (in meters) - numeric type;

Dpl – dam length (in meters) - numeric type;

Hpo –thickness of the dam base (in meters) – numeric type;

Hpg – thickness of the dam crest (in meters) – numeric type;

Hvmin – the width of the reservoir at the base (in meters) – numeric type;

Hvmax – width of the reservoir at the base at the level of the dam crest – numeric type;

Dvmin – length of the reservoir at the base of the dam crest level (in meters) – numeric type;

Dvmax – reservoir length (in meters) – numeric type;

Yni – low water level of the reservoir – interval type

Ybz – safe reservoir level – interval type;

Ytr – alarming reservoir level – interval;

Ykt – catastrophic reservoir level – interval type.

The input data table consists of 6 fields:

Codp – code-numeric type;

Data – date of information receipt – date type;

Vrem – time of information receipt – numeric type;

Yrov – level of fullness of the reservoir – numeric type;

Temp – temperature in the area of the reservoir – numeric type;

Osad – presence of precipitation – logical type.

2.8. Model Problem

All further calculations simulate the events that took place in the village of Kyzylagash of Almaty region on March 11 and 12, 2010.

Figure 4 shows the view of the reservoir and the location of the village before the specified event. The 45-meter-high dam was designed to store 42 million cubic meters of water.

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Fig. 4. Location Of The Reservoir And Village Of Kyzylagash Before The Dam Break

Rainfed and irrigated agriculture is developed in the village of Kyzylagash. Cereals, potatoes, and sugar beets are cultivated. Sheep breeding and meat and dairy farming are developed. Agriculture of the region develops in two agroclimatic zones: mountain-steppe and foothill desert-steppe. Arable land in the mountain-steppe zone is used in rainfed, to a lesser extent, irrigated agriculture. Cereals are mainly cultivated here. Before the tragedy of 2010, the Kyzylagash reservoir irrigated more than 5 thousand hectares of cultivated land with irrigation water. Figure 5 shows a graph of water consumption for irrigation of agricultural land for decades from March to September 2009.The ordinate axis presents data on water flow (in millions of cubic meters).

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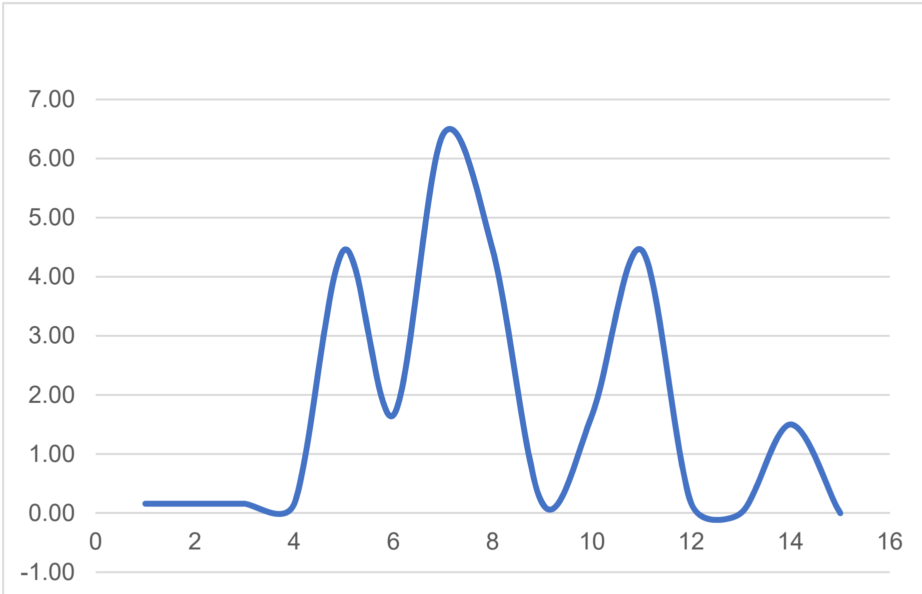

Fig. 5. Graph Of Water Consumption For Irrigation Of Agricultural Land

Figure 6 shows a graph of reservoir occupancy over decades from March to September 2009. The ordinate axis presents data on the volume of water in the reservoir (in millions of cubic meters).

Fig. 6. Graph Of Water Consumption For Irrigation Of Agricultural Land

On the night of March 10, the water level reached 30 million cubic meters. The next day, in the afternoon or in the evening, I can not say the exact time, the water level exceeded 40 million cubic meters. In other words, 15-16 million cubic meters of water was added to the Kyzylagash

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reservoir in 15-16 hours. The dam broke on March 11 at 10.30 p.m. Two hours later, the water gushed towards the village of Kyzylagash. The wave width of the mudflow was 1.6 kilometers, and the height was 3 to 4 meters. According to official figures, most of the village was severely damaged. 70% of the village of Kyzylagash was destroyed. The tragedy in Kyzylagash claimed the lives of 44 people.

Figure 7 shows a view of the destroyed reservoir.

Fig. 7. Destroyed Reservoir

Based on the developed automated system, the situation for March 11-12, 2010 in the village of Kyzylagash was simulated. Table 2 presents the chronicle of events. The first two columns provide information about the date and time. Information in columns 3 through 5 is obtained in automated mode. Based on the above proposed mathematical model, calculations were performed on the level of safety, reservoir occupancy and the expected overflow time over the dam crest (columns 6-8).

In the 6th column, the following security level encoding is adopted: 1- low; 2 - safe; 3 - alarming; 4 – catastrophic

Figure 8 shows an hourly chart of the reservoir occupancy. As can be seen from table 2 and the graph in figure 8, theakimat (local administrations) and emergency authorities would have been alerted at 21.00 on March 11. According to the forecast time was still 3.5 hours before the tragedy. But the lack of communication facilities and the mercantile interests of the owners of the reservoir led to disastrous results.

Table 2. The Simulation Results Of A Dam Break

Date	Time	Waterlevel (m)	Temperature	Precipitation	Securitylevel	Water volume (cbm)	Time to overflow (hour)
1	2	3	4	5	6	7	8
11/03/2010	10.00	15	12		2	30 000,0	
	10.30	14.75	12		2	30 250,0	
	11.00	14.5	13		2	30 500,0	
	11.30	14.25	13		3	30 750,0	14.25
	12.00	14	13		3	31 000,0	14
	12.30	13.75	14		3	31 250,0	13.75
	13.00	13.5	14		3	31 500,0	13.50
	13.30	13.25	14		3	31 750,0	14.25
	14.00	13	15		3	32 000,0	13
	14.30	12.75	15		3	32 250,0	12.75
	15.00	12.5	15		3	32 500,0	12.50
	15.30	12.25	14	rain	3	32 750,0	11.75
	16.00	12	14	rain	3	33 000,0	11
	16.30	11.25	14	rain	3	33 750,0	10.25
	17.00	10.5	13	rain	3	34 500,0	9.30
	17.30	9.75	13	rain	3	35 250,0	8.75
	18.00	9	13	rain	3	36 000,0	8
	18.30	8.25	13	rain	3	36 750,0	7.25
	19.00	7.5	12	rain	3	37 500,0	6.50
	19.30	6.75	12	rain	3	38 250,0	5.75
	20.00	6	11	rain	3	39 000,0	5
	20.30	5.25	11	rain	3	39 750,0	4.25
	21.00	4.5	10	rain	4	40 500,0	3.50
	21.30	3,75	10	rain	4	41 250,0	3
	22.00	3	9		4	42 000,0	2.50
	22.30	2,5	9		4	42 500,0	2
	23.00	2	9		4	43 000,0	1.50
	23.30	1,5	8		4	43 500,0	1

12/03/2010	00.00	1	8		4	44 000,0	0.50
	00.30	0,5	7		4	44 500,0	0
	01.00	0	7		4	45 000,0	0
	01.30	0	6		4		

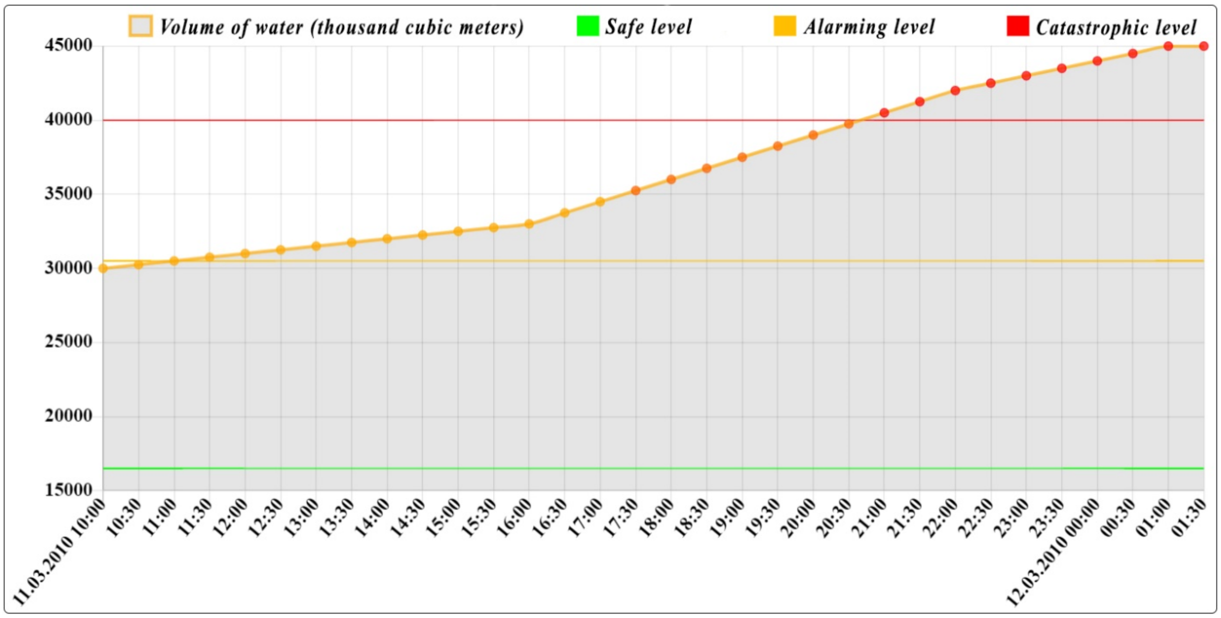

Fig. 8. Graph of the Reservoiroccupancy

3. CONCLUSION

This article analyzes the characteristics of dams, the capabilities of modern control systems based on the use of microprocessor technology. A mathematical model for monitoring the state of the reservoir has been developed, on the basis of which a hardware and software complex of rapid notification of interested organizations (local administrations) and local emergency departments has been implemented.

The tragic events in the spring of 2010 in the Almaty region and in 2014 in the Karaganda region with human casualties and destruction, as well as floods in other regions of Kazakhstan, served as a serious lesson to prevent similar situations in the future. It is necessary to develop recommendations on equipping hydraulic structures with modern control and measuring devices, equipment and means to improve the safety of operation.

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