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Level regime of Balkhash Lake as the indicator of the state of the environmental ecosystems of the region

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ABSTRACT:The article presents the results of studies of the level regime of Lake Balkhash, which has a characteristic, consisting in the change in the average lake horizon, the changes in the magnitudes of the seasonal and interannual amplitudes of the levels, as well as their annual and long-term ones. All this involves the change in the lake table area and its outline on the map. The results of full-scale data of modern morphometric characteristics are presented, on the basis of which the actual map of the lake depths is presented. The impact of economic activity on the fluctuations of the long-term annual average water level in the lake is observed, and the analysis of the changes in the hydro chemical composition of the water depending on the level of the lake is given.

KEYWORDS: River runoff, Lake, Water level, Bathymetric curve, Morphometric regime, Hydro chemical regime.

I.INTRODUCTION

Lake Balkhash is a large inland reservoir of Kazakhstan located in the arid zone of Central Asia and its drainage basin is trans boundary, and is located on the territories of the Republic of Kazakhstan and the People's Republic of China (Figure 1).

The peninsula Uzynaral divides Lake Balkhash into approximately equal parts: the western part is shallow, almost fresh, running off and wide (depth 3-11 m) and the eastern part is also shallow, not running off, salty and narrow, where is the most ancient and deep stretch Burlutubinskiy (up to 26 m deep) situated. Because of the geological, geochemical and other characteristics of the lake, as well as constant winds that blow in this area, the water in the lake is constantly mixed.

The main tributary and the main source of Lake Balkhash is the Ile River, originating in the territory of a neighboring state. When flowing into the lake it forms an extensive delta with an area of more than 8,000 km^2, which is a natural regulator of ecological balance in the Ile-Balkhash lake system. It provides the lake with water in droughty years and accumulates water in high water years [1,2]. In addition, from the territory of Kazakhstan, the rivers Karatal, Aksu, Lepsy and Ayaguz flow into the eastern part of the lake [3].

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Fig 1. Region of location of Lake Balkhash

The basin of Lake Balkhash is a unique natural complex, where in a relatively small area there are 5 climatic zones, ranging from glaciers of the Tien Shan to the hot deserts of the Balkhash Lake side. There are intensive processes of the circulation of substances in this area: there is condensation of moisture in the mountain region of the basin, its accumulation in glaciers and the formation of underground and surface runoff of numerous rivers; in the basin of Lake Balkhash, there is evaporation of water, accumulation of contaminants, salts and sediments washed away from the entire area of the basin [4].

The first reliable information about Lake Balkhash was obtained in the 13th century by Europeans Rubruck and Plano Carpini. In 1697, Lake Balkhash first appeared on Russian maps. In 1834, the astronomer V.F. Fedorov determined the exact location of Lake Balkhash and partially outlined its coasts.

The lands around the lake are highly saline, but with such a salt reserve, vegetation has not disappeared. The type of salt has therapeutic properties and favorably affects the health of a man. The main mystery of Lake Balkhash is connected with salts. The lake is divided into two almost equal parts (salty and fresh) by the narrow strait of Saryesik and the peninsula of Uzynaral. Water flows from west to east. The water of the western part of the lake is running and fresh, the eastern part is not running and salty. The total amount of salts and mud entering the lake with the river tributary is great. Taking into account that information, Lake Balkhash should have disappeared within 20-30 years, but Lake Balkhash has been around for millennia and the water remains slightly saline (1.0-1.5 gram per 1 liter), even in the eastern part, where the current brings all the salts. It turns out that the lake itself gets rid of salt. All the "inhabitants" of Lake Balkhash take part in this process: bacteria, algae, fish, birds, as well as reed thickets - biological filters that metabolize and store salts. At least 25 million tons of salts are buried in the delta of the Ile River! This phenomenal and harmoniously balanced system of salt exchange and salt removal has been formed for millennia, and any violation of ecological balance can result in catastrophic consequences [5].

Another mystery of Lake Balkhash is its fantastic ability to cope with the deposits. The waters of the rivers of Semirechye region contain a large amount of clay and sand. Under such conditions, the whole basin of Lake Balkhash should have been filled with sediments for 250-300 years. And again, Lake Balkhash manages to deal with the deposits, fencing off by rivers deltas, which stop the onset of silt sediments. Descending from the mountains, the rivers in the deltas are divided into tens and hundreds of branches and channels; lakes are formed between them and accumulate sediments. The water is purified up to a crystal transparency; the delta gradually rises and changes its location.

II. BENCHMARK DATA FOR LAKE BALKHASH LEVEL ANALYSIS

Observations of the level of Lake Balkhash are available from 1931 to the present time at the post of Balkhash town, which operated under different names in the past years (Bertys Bay, PBS dock). In the years of 1954-1960, there were 4 stations relatively evenly placed along the lake, which made it possible to calculate the average water levels during this period. In the years of 1960-1967, 10 to 12 posts operated on Lake Balkhash, which made it possible to improve the accuracy of determining the average lake level [6].

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In the period of 1931-1936, the post Bertys Bay operated, since 1937, the post PBS dock (later it was called as Balkhash town) has been operated. The zero of the graph at the opening of the new post left unchanged (344.24 m nominal), therefore there has been a unified series of observations of the water level since 1932 at the post of Balkhash town. The observations on the post of Balkhash town have been published in the hydrological yearbooks since 1937 [7].

Table 1 shows the level posts, and Figure 2 shows the location of the hydrological observation points on Lake Balkhash. Currently, observations of the level of the lake are being made at four posts: the station Mynaral, Lake Algazy, the station Saryshagan, Balkhash town, according to these data, the average lake level is calculated. Absolute marks of the zeros of the graphs of the lake stations were verified on the basis of the water leveling of the Balkhash city in 1937.

Table 1. Hydrological (lake) stations on Lake Balkhash

No.	Station	Station affiliation	Period of operation		The zero point of the graph
			open	closed	
1	settl. Burylbaital	UGMS of the KazSSR	19.10.1939	30.11.1953	337 m. nominal
2	Station Shyganak	UGMS of the KazSSR	04.11.1953	01.07.1988	339 m. nominal
3	railway station Mynaral	RGP "Kazhydromet"	19.08.1961	operates	340 m.BS
4	Station Saryshagan	RGP "Kazhydromet"	01.09.1959 – 1997 Open in 2008	operates	340 m.BS
5	Balkash city	RGP "Kazhydromet"	03/01/1937	operates	339.13 m BS
6	Bertis dock	UGMS KazSSR	27.11.1931	21.02.1937	344.24 m. nom
7	Settl. Maykamys	UGMS KazSSR	24.02.1960	27.04.1966	340 m BS
8	Station Akbalyk	UGMS KazSSR	04.06.1960	28.08.1964	340 m BS
9	Burlitobe dock	UGMS KazSSR	17.04.1933	29.12.1955	338 m. abs
10	Settl.Karashygan	UGMS KazSSR	05.22.1913	31.07.1942	337 m. nom
11	Uzynaral dock	Lengidep	19.06.1954	31.10.1955	340 m. abs.
12	Island Algazy	RGP "Kazhydromet"	11.08.1950	operates	340 m. BS

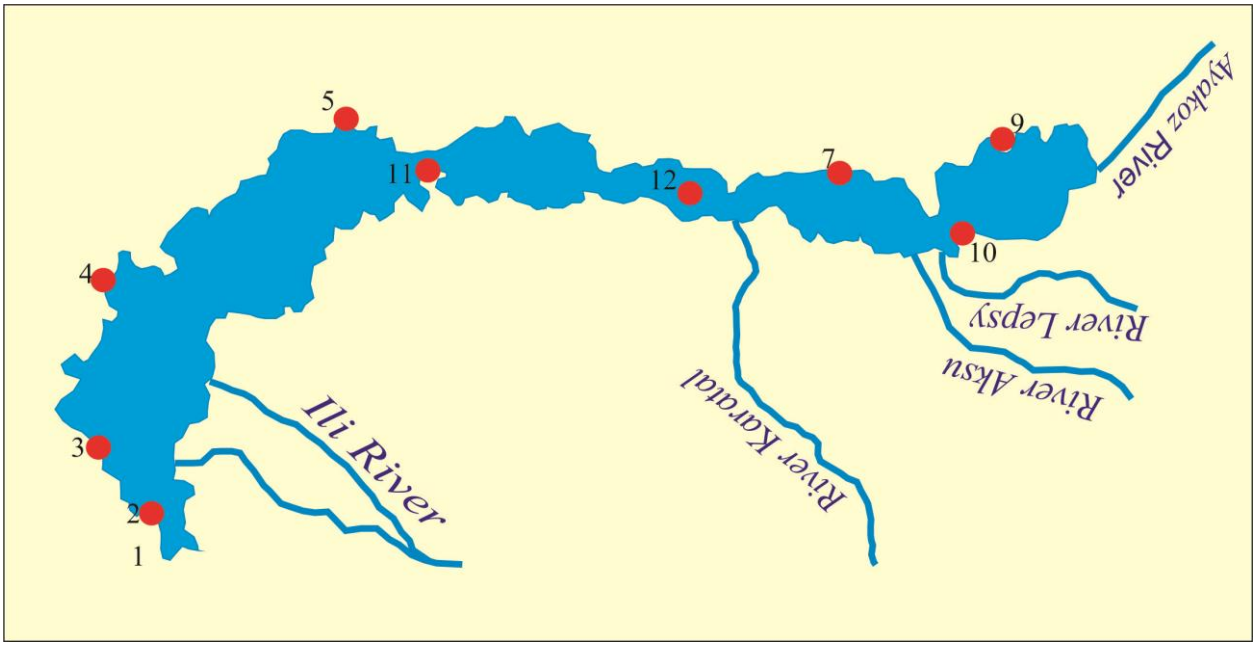

Fig 2. Scheme of the location of hydrological observation points on Lake Balkhash

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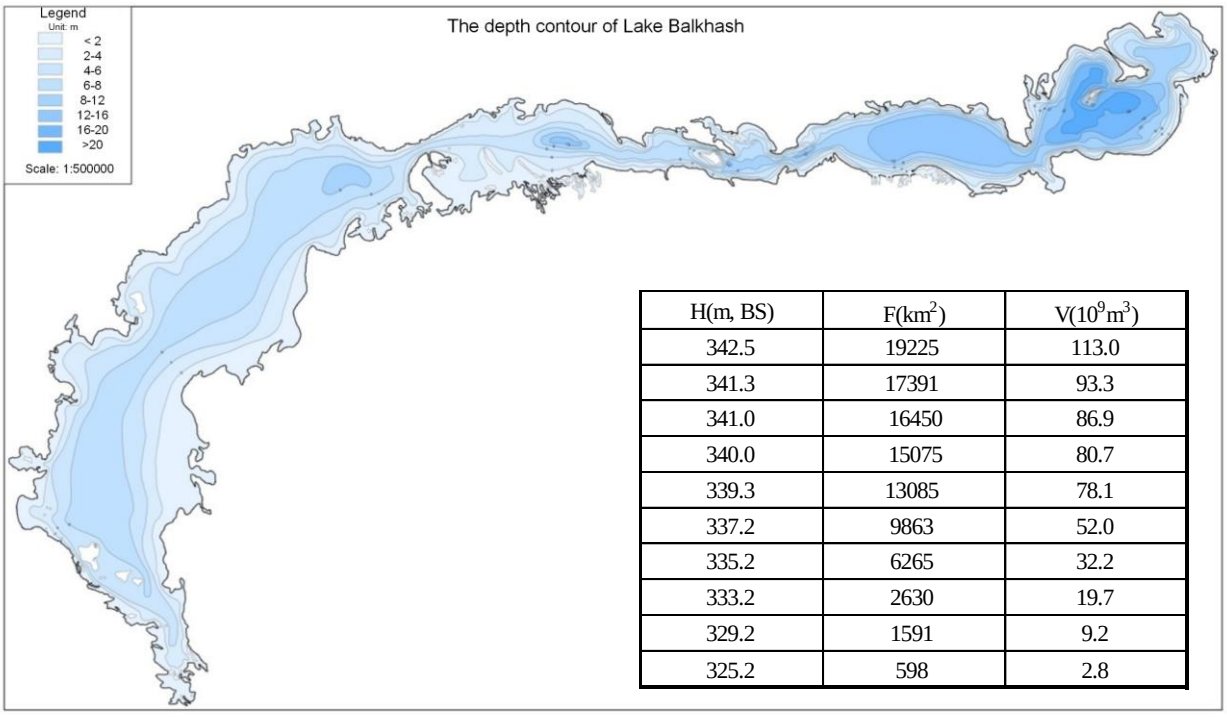
Benchmark materials for the analysis of the average annual indicators of the water level of Lake Balkhash were "Annual data on the regime and resources of surface waters of the land" [6,8,9]

III. RESULTS OF FULL-SCALE FIELD RESEARCH ON LAKE BALKHASH

In 2011-2015, the Institute of Geography of Kazakhstan carried out bathymetric work on the verification of the morphometric characteristics on Lake Balkhash with the use of the small-sized scientific research vessel "Quicksilver 640", which resulted in the bathymetric mapping of Lake Balkhash with scale of 1: 500000 using the ArsGIS program (Figure 3).

Basic cartographic characteristics of Lake Balkhash are represented by the following parameters: at water level of 342.5 m BS, the area of water table was 19225 km², and the water volume in the lake was 113 km³. The maximum measured depth of the lake on the Burlutobin stretch was 23.5 m.



H(m, BS)	F(km^2)	V(10^9m^3)
342.5	19225	113.0
341.3	17391	93.3
341.0	16450	86.9
340.0	15075	80.7
339.3	13085	78.1
337.2	9863	52.0
335.2	6265	32.2
333.2	2630	19.7
329.2	1591	9.2
325.2	598	2.8

Fig 3. Lake Balkhash in the isobaths based on the results of the bathymetric survey of 2011-2014.

Comparing the results of bathymetric survey of 2011-2015 with previous studies, it can be noted that there were insignificant changes in the shape of the shores because of the overgrown reed and the following formation of sand bars in the shallow parts of the lake. Morphometric characteristics of the Uzynaral channel changed quite considerably. If in 1984, there were insignificant thickets of reeds on the banks, the water cut was clearly traced and the free surface of the channel was about 8 km wide, at maximum depths of up to 2 m, then, according to the results of the 2012 survey made by the Institute of Geography, the channel width free from the thickets of reeds was 1.25 km, while the maximum depths of the channel was 7 m. In 2012, measurements were made on 4 sections in total in the Uzynaral channel. On a section in the easternmost part of the channel, at the beginning of its expansion, three courses are traced in the underwater relief indicating that delta processes are taking place. If in 1984 the studies carried out in the channel to measure the speed and direction of the water currents were determined mainly by wind speeds and direction, then, according to the results of observations in 2012, it can be concluded that the primary factors of water flow from the western part into the eastern part was determined by water pressure.

Figure 4 shows the bathymetric and volumetric curves of Lake Balkhash, made according to the results of the bathymetric survey of the Institute of Geography in 2011-2014, as well as the dependence of the table area of Lake Balkhash on the volume of water in the lake. The analysis of these curves shows that up to the level of 344 m BS, the

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increase in the volume of water in the lake and its table area is only the result of the filling of the deep-water Burlutobinstretches in the eastern part of the lake. With the further increase in the water level, the shallower stretches of the Eastern Balkhash are filled.

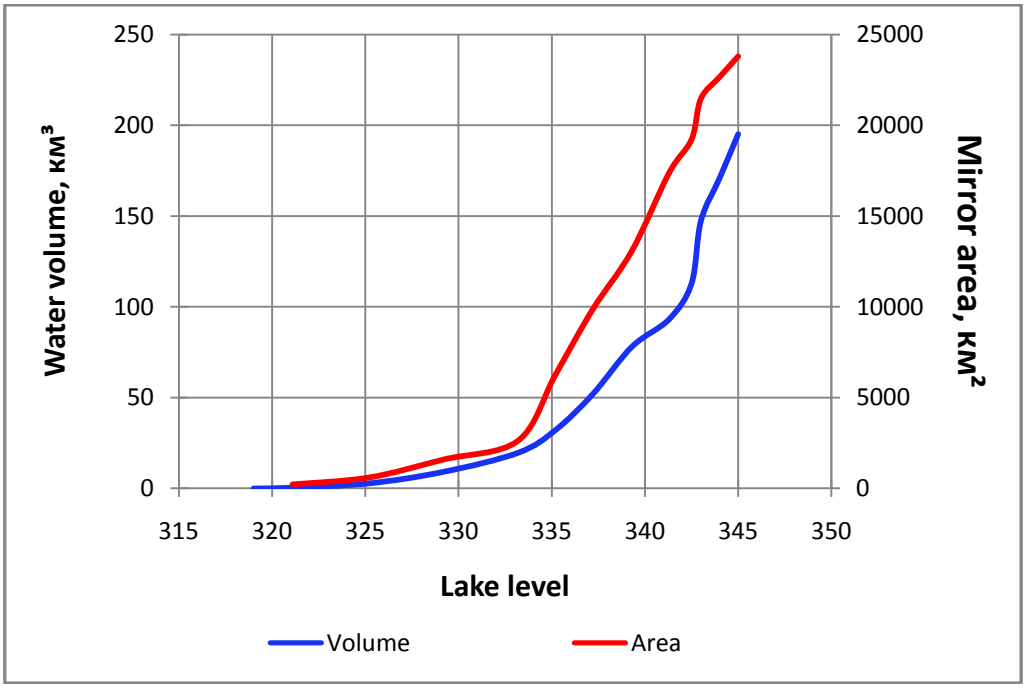

Fig 4. Batigraphic and volume curves of Lake Balkhash

The level of Lake Balkhash is one of the main indicators of the state of the entire ecosystem of the basin. Prior to the regulation of run off, the lake level varied cyclically, mainly between elevations of 341 and 342 m BS. After the construction of the Kapshagai HPP, the lake level was less than 341 m BS from 1984 to 1989 (minimum level of 340.65 m BS was in 1987).

IV. INTERANNUAL LEVEL FLUCTUATION OF LAKE BALKHASH

The water level of Lake Balkhash, like other inland lakes in the semi-arid zone, is experiencing large-scale and long term cyclical fluctuations because of climate variability [10,11]. Cyclical development of the delta of the Ile River played a certain role in the long-term fluctuations of Lake Balkhash level. Intra-annual fluctuations in the level were determined by the intra-annual water balance, related to the annual climatic cycle, as well as to baric-wind impacts.
Instrumental observations of the water level of Lake Balkhash are made from 1931 to the present time. The number of hydrological posts on the lake varied significantly in different years. It is quite reasonable that the average lake level in the area has been calculated since 1960, the number of posts during this period was 7-13. The longest series of observations is available for the post of Balkhash town; it fairly well reflects the development of the average annual level indicator.

The development of fluctuations in the water level of Lake Balkhash was traced in outline, from 1931 to 2015. (Figure 5).

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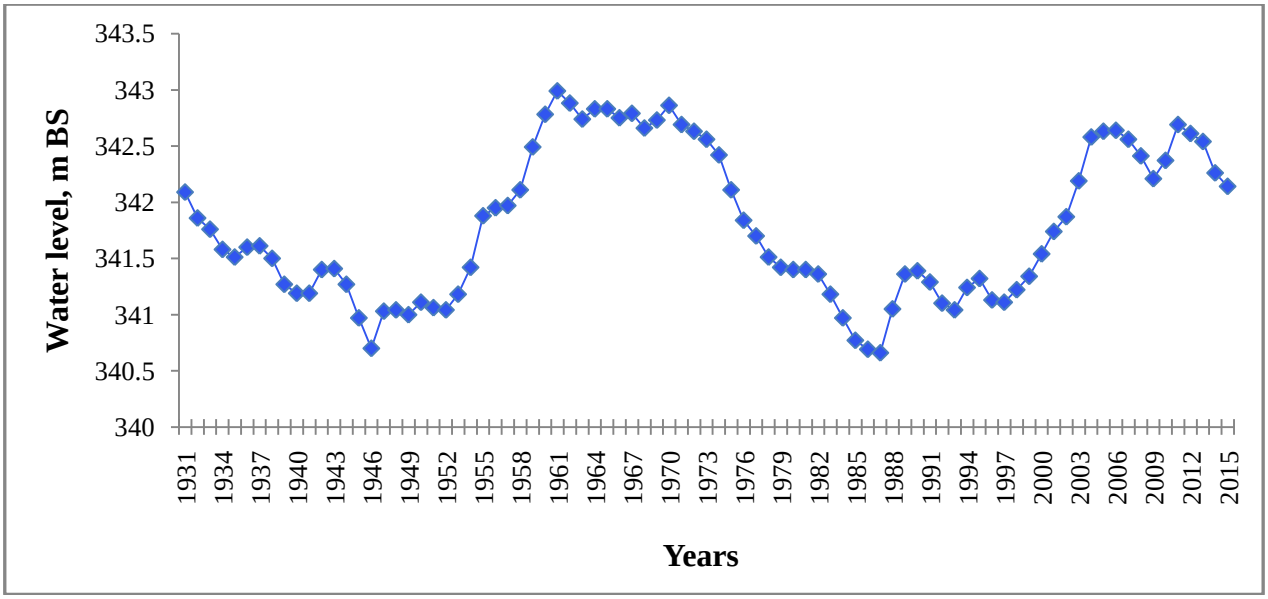

Fig 5. Average annual level fluctuations in Lake Balkhash for the period of 1931-2015

The graph shows that the level of the lake intensively decreased during the first 15 years of this period. For the period of 1931 – 1946 the average annual level of the lake decreased by about 2 m. During the next 6 years, the lake level was almost stable. The maximum level of 342.99 m BS for the period of 1931-2015 was recorded in 1961. From 1962 to 1969, there were no sharp changes in the level. In 1970, the level of the lake began to decrease sharply because of putting the Kapshagay reservoir into operation, and also as a result of climate change (Figure 6).

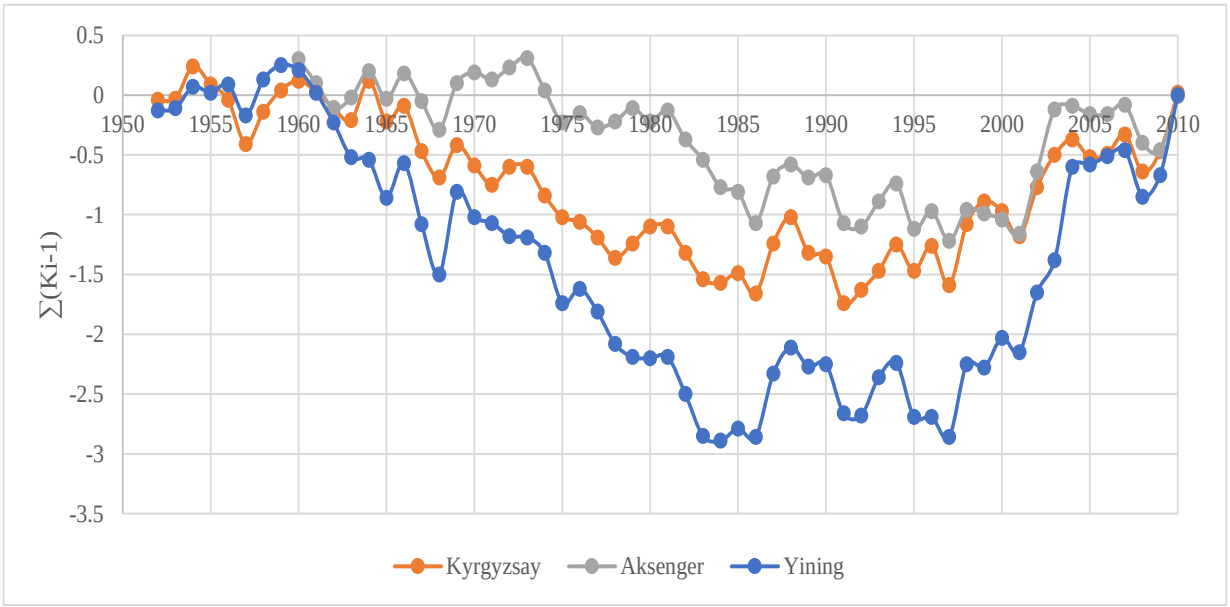

Fig 6. Difference integral precipitation curve of some MS

The difference integral precipitation curve at some meteorological stations (Kyrgyzsai, Aksenger, Yining, etc.) shows that the period of 1969 – 1986 was characterized by low-water years. The period of 1987 – 2015 was characterized as the years rich in precipitation. Thus, the decrease in the level coincided with the low-water phase of the hydrological regime of the Ile River. Taking into account the fact that the climate change impacts the water level indicators of Lake Balkhash, we could distinguish the following three periods:

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1) Conditionally natural period (before 1970,) prior to the beginning of the filling of the Kapshagay reservoir with a slight influence of the anthropogenic;
2) The period of filling the reservoir with reduced water content (1970-1987) with the broken regime, related with water management in the Kazakhstani part of the basin of the Ile River;
3) The period of the regulated runoff of the Ile River with increased water content (1988 - 2015) with broken regime, related with water management in the territory of the Republic of Kazakhstan and intensive reduction of the inflow of the Ile River from the territory of China.

The period prior to 1970, that is, before the beginning of the filling of the Kapshagai reservoir, can be considered as a conditionally-natural period during which the impact of economic activity in the Lake Balkhash basin on the fluctuation of the lake level was insignificant.

With the beginning of the filling of Kapshagay reservoir, there was a dangerous ecological situation and an unpredictable course of events in the Balkhash side, which had more dangerous tendencies and caused great public anxiety and resulted in a great consolidation of the scientists of the former KazSSR.

Thanks to the republic's efforts, an intermediate stage of comprehensive research was successfully completed in 1986 (Tursunov 1989), and it was approved at a number of republican conferences, then was ratified at a special session of the Council of Ministers of the USSR by Order No. 282 of 04.08.1987 of the Ministry of Water Resources of the USSR and the corresponding orders of the Ministry of Water Resources of the Kazakh SSR. This document stated to localize the area of irrigated land in the Ile-Balkhash basin through the use of surface waters; to limit the filling of Kapshagai reservoir up to the volume of 14 km^3, not to the project volume of 28 km^3; to implement the reconstruction of irrigation systems.

The above mentioned measures allowed stabilizing the level of Lake Balkhash to an age minimum and being prepared for the next high water period in order to ensure increased water releases that were made in 1988 when the inflow to the Kapshagai Reservoir was 22.64 km^3 per year at the standard rate of 14, 8 km^3 per year.

During the period of 1988 – 2013 of the regulated run off of the Ile River with increased water content, the level of Lake Balkhash gradually increased. From early 1998 to 2005, there was a sharp increase in the level because of the increase in the inflow of water it the lake. The increase in the level was because of the increase in the humidification of the area during this period, the increase in the air temperature. From 2006 to 2009, the lake level decreased by 32 cm (342.53 m BS - 342.21 m BS). In 2010, the situation changed, the lake level increased by 15 cm and was 342.36 m BS.

V. CHANGE IN TOTAL MINERALIZATION AND QUALITY OF LAKE WATER

With the beginning of intensive economic activity in the basin, the natural regime of the ecosystem was disturbed, including the hydrological regime of Lake Balkhash. By 1991, the total volume of water consumption had almost doubled and was 7.51 km^3 per year. Accordingly, the inflow of water in Lake Balkhash decreased to 12.1 km^3 per year in 1992, of which 10.5 km^3 in the Ili River (1992). As a consequence, in the 1980s, the level of Lake Balkhash and the degradation of coastal areas decreased. The surface area of the lake decreased from 21.4 thousand km^2 in 1961 to 17.07 thousand km2 in 1999. The flow of water from the western part of the lake to the eastern part decreased from 2.7 to 2.1 km^3 per year, which resulted in the increase in the salinity of water in the region of Balkhash town from 1.5 to 2.3 gram per l liter [5, 12, 13]

Lake Balkhash is also characterized by close relationship between the level of water and mineralization of water. The latter is the most important indicator for inland brackish reservoirs, it determines the suitability of water resources for all household needs and biological life in reservoirs.

Figure 7 shows the dynamics of mineralization of water in the lake and the long-term character of Lake Balkhash level. In it you can see that when the water level decreased less than 341 m abs. in 1984 - 1986, the mineralization of water in the lake was more than 3000 milligram per l liter. The area of the water surface and the volume of water in the lake decreased significantly, which resulted in the separation and drainage of numerous shallow bays. For this period, the area of the delta's fisheries fund decreased by more than 80% and was 110-120 km^2.

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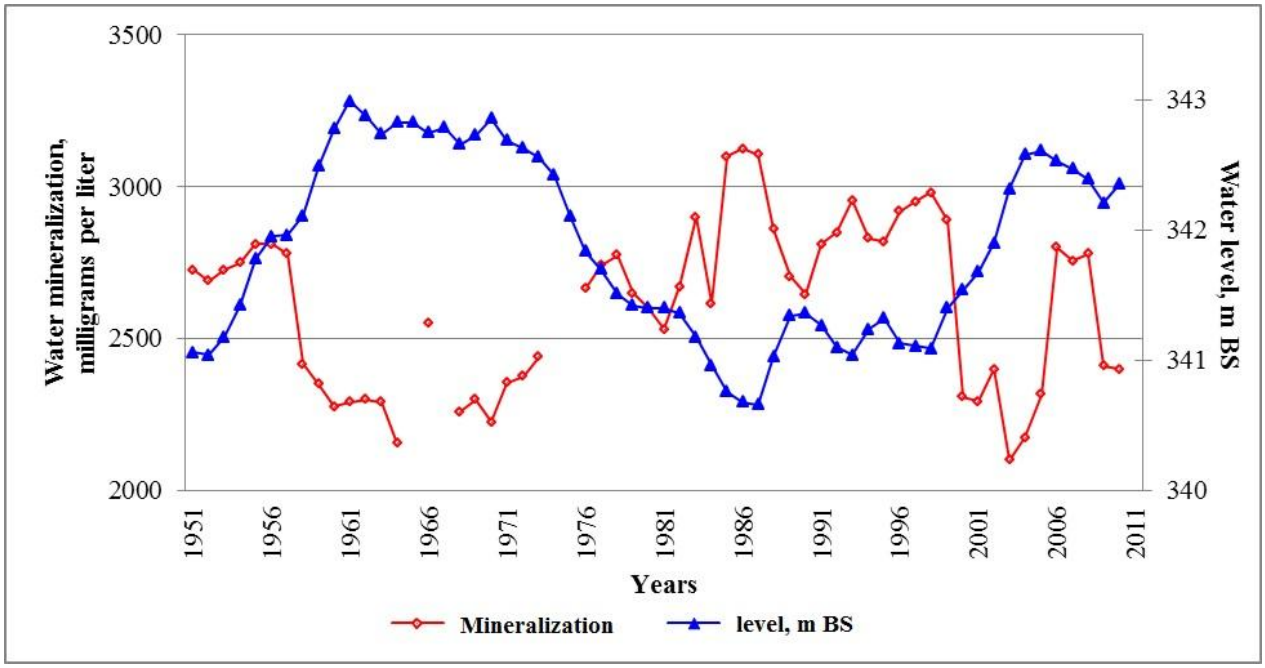

Fig 7. Dynamics of total mineralization and level of water of Lake Balkhash

The data for the last decade also shows a noticeable fluctuation in the mineralization of the lake water, when there were small changes in the level in certain years.

Violations of the hydrological regime of the lake would have been more significant if the delta of the Ile River did not play the role of a natural counter-regulator. Like a "sponge", it removes runoff to the lake at the expense of its own destruction with the corresponding ecological and socio-economic consequences.

Long time research carried out by a number of scientific institutions and scientists has shown that the only source of the existence of the Balkhash basin is the Ile River. Lake Balkhash functioning as a geographical object, the quality of water resources, the bio-production potential and the entire aquatic ecosystem of the lake as a whole exists thanks to the inflow of the Ile River. The incoming part of its water balance is 80%. Lake Balkhash is characterized by its heterogeneity of the mineralization of water along its length in the combination of a very elongated form of the reservoir only because of the inflow of fresh water from the Ile River to its western part [10].

At the same time, on the basis of the analysis of long-term data, a different intensity and degree of salinity in the lake water depending on the causes resulted in the reduction of the Ile River run off and water level reduction in the lake is revealed [13,14]. Thus, during the period of the decrease in the lake level in 1970-1978 because of the reduction in the volume of fresh inflow of Ile River into the Western Balkhash, the mineralization of water was much higher than in the period before 1970 (with the same level indicators), when the cause of periodic fluctuations in lake level was mainly the change in the total moisture content in its basin. As for the Eastern Balkhash, the nature of the relationship between the level and mineralization of water over two compared periods remained practically unchanged.

It is known that when developing Stage I of the Scheme for the integrated use of water and land resources in the Balkhash Basin for the period of 1975-1985. [15] at a meeting of the Council of Ministers of the KazSSR, it was accepted that the lake level should not decrease lower than 341.0 m BS and this indicator was determined as critical one. However, by 1984 the average annual level indicator of the lake had decreased to 340.96 m BS and since that year it continued to decrease till 1987, when it was 340.65 m BS. The years with a water level of 341.0 m and lower showed that the lake entered the period of ecological regression. The volumes of Ile River is supposed to provide levels more than 341.0 m BS to achieve satisfactory hydrological and hydro chemical conditions for the conservation of the sustainable ecosystem of the delta of Ile River and Lake Balkhash.

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VI. CONCLUSION

The proper management of water resources is one of the primary goals for the life support of the population. The level regime, corresponding to the regime of salinity of water takes a special place in providing ecological and socio-economic functions of Lake Balkhash. The change in the water level causes particularly rapid and deep deformations of various biotic and abiotic components of the lake complex.

The level of Balkhash Lake is characterized by significant cyclic fluctuations and depends mainly on the inflow of rivers entering it. In modern conditions, the change in the level of the reservoir depends not only on the natural factors that determine the amount of the river run off, but also on the operating mode of the Kapshagai HPP and irretrievable water consumption in the upper part of the basin of Ile River on the territory of China, as well as in the middle part of the basin on the territory of the Republic of Kazakhstan.

The mineralization of lake water in the period of natural low water in the basin (1952-1957) increased on average to 2.95 gram per dm^3, and with the increase in the level up to 343.0 m (1960-1964); it decreased to 2.1-2.2 gram per dm^3. The decrease in the level of the lake under the influence of anthropogenic factors (1970-1987) because of the filling of the Kapshagay reservoir and the development of irrigation, the average mineralization increased to 3.2-3.3 gram per dm^3, and in the East Balkhash to 5.0 gram per dm^3. In the following period, the water salinity stabilized at 2.9-3.0 gram per dm^3 on average over the lake, to 1.4-1.5 gram per dm^3 in the Western Balkhash.

According to the results of processing the field measurements, as well as analysis of long-term fluctuations in the level, it is established that when the water level of the lake was lower than 341 m BS, a number of bays were separated, that significantly affected the water table area and, accordingly, the amount of evaporation.

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