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Study of Internal Water Exchange in Lake Balkhash

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The terminal lake Balkhash is located in arid zone in south-east of the Republic of Kazakhstan. Lake Balkhash is fed mainly by the Ili River, which provides 80 % of the drain. The distance of the lake from west to east (the length of about 600 km, the width of about 30 km), uneven distribution of inflow of water and salt (more than 80 % of drain is supplied to the west part) along the length, intensive evaporation stipulate quasi-stationary water-balance flow and transfer of salt from east to west. Lake Balkhash consists nominally of two parts subdivided by the Strait Uzunaral: the west and the east parts. Salinity distribution along the length of the lake depends on its subdivision into reaches. With distance from the west extreme end the water mineralization increases step-wise in each of the reaches, thus creating peculiar hydrochemical districts. Despite numerous previous studies of the lake the aspects of water and salt exchange in the lake interior are not clarified up till now. This study is aimed at development of a new method of estimation of internal water exchange between the west and the east parts of the lake with consideration for hydrometeorological factors. The research procedure is based on two-dimensional numerical solution of differential equations of unsteady slowly varying water flow in free channel (Saint Venant equation). Parameterization of the equations is based on the generalized results of hydrochemical survey of the lake and measurements in the Strait Uzunaral, performed in 1983-1987. The number of water exchange cycles at the boundaries of hydrochemical districts varies from 89 to 259. The most frequent variations of the flow are in West Balkhash. This can be attributed, probably, to higher surface area and lower depth in comparison with East Balkhash. The higher is the surface area and the lower is the depth, the more intensive is the response of water body to variation of wind direction. Cumulative volume of influent water eastwards within overall ice-free period via the boundaries of hydrochemical districts varies from 24.8 km^3 to 76.7 km^3, and from 22.7 km^3 to 71.0 km^3 westwards. It should mentioned that the difference between them in each boundary in terms of direction and quantity equals to water-balance flow. For instance, the eastward flow via the Strait Uzunaral (boundary IV-V) within ice-free period amounted to 27.9 km^3, and 24.7 km^3 westwards, the difference of 3.2 km^3, is the water-balance overflow within the same period via the strait, eastwards. In East Balkhash, including the Strait Uzunaral, in the boundaries between IV-V, V-VI, and VI-VII hydrochemical districts the average time of continuous flows is twice as much as in the other boundaries. The maximum duration of flow in one direction for the east phase varies from 27.7 to 105.2 h with the volume of water overflow up to 2.33 km^3, for the west phase these properties are 35.5 h, 116.3 h, and 2.30 km^3, respectively. The highest time of water flow in one direction is in the Strait Uzunaral both for the east and for the west phase.

Key words: Terminal lake, Balkhash, Strait Uzunaral, water exchange, Saint Venant equation, two-dimensional Saint Venant equation.

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The terminal lake Balkhash is located in arid zone in south-east of the Republic of Kazakhstan. Lake Balkhash is fed by the rivers Ili, Karatal, Aksu, Lepsy, and Ayagoz as well as other minor water streams. The River Ili provides 80 % of the drain[1, 2].

The distance of the lake from west to east (the length of about 600 km, the width of about 30 km), uneven distribution of inflow of water and salt (more than 80 % of drain is supplied to the west part) along the length, intensive evaporation stipulate quasi-stationary water-balance flow and transfer of salt from east to west. The water-balance flow in the lake is influenced also by its morphometric characteristics. Lake Balkhash consists nominally of two parts subdivided by the Strait Uzunaral: the west and the east parts (Fig. 1). The difference in dimensions and shapes of the lake basins of the west and east parts is significant. West Balkhash is a wider and more shallow water body. Due to the aforementioned reasons the water-balance transfer of water and salt is always directed from west to east. It causes uneven distribution of water mineralization along the lake length. Salinity distribution along the length of the lake depends on its subdivision into reaches. With distance from the west extreme end the water mineralization increases step-wise in each of the reaches, thus creating peculiar hydrochemical districts[3, 4, 5].

Another more powerful source of internal transfer of water and salt (agitation, to be more exact) as a consequence of extreme variation of direction is wind-induced flow. Continental location, low depths (5--6 m in average) in comparison with horizontal dimensions of the lake, significant distance in latitudinal direction are the main factors which generate the wind-induced flow in the lake. From the point of view of wind impact on water surface, the lake, except for certain districts of East Balkhash, is considered as shallow water body. The wind disturbance in this case involves the overall water body from the surface to the bottom. This explains the absence of any vertical stratifications in the lake. The shallowness also stipulates the response of flow generation in the water body to variations of wind velocity and direction. It is quick, and the time of generation of complete flows amounts to hours [6, 7, 8]. The aforementioned peculiarities of the wind-induced flow, intensively agitating water body, tend to equalize the salinity along the water body length.

Another type is the flow occurring due to the difference in water mineralization along the lake length. Its action can be insignificant and short-term. It terminates after achievement of equilibrium between the bodies of more saline and dense water and its displaced bulk, it is directed from east to west.

Construction of Kapchagay Reservoir in the main tributary of the River Ili, extensive development of irrigation and increase in other types of water consumption caused sharp drop of water level and increase in its mineralization. The internal water exchange between separate reaches also altered: an important factor determining self-purification capacity of the lake waters. Previously applied balance method of estimation did not consider for internal hydrodynamic processes stipulated by wind-induced agitation of water body. The importance of consideration for this circumstance followed from the results of more sophisticate field and experimental studies using large-scale physical model of the lake [9, 10, 11].

A significant portion of the works was performed by the Laboratory of hydrology, Institute of Geography, Academy of Sciences of the Republic of Kazakhstan. In 1987 four automatic buoy-based stations were placed on the lakescape, two of which were placed in the most narrow site of the Strait Uzunaral and two fro, the east and west side of the strait with discrete step of data recording of velocity, water flow direction, salinity, temperature amounting to two hours. The operation time of the station was about one month.

The following conclusions were arrived at after the performed studies:

a) Variations of water and salt transfer in the strait is of cyclic pattern. The average duration of water exchange cycle in the strait according to the data of instrumental studies was 60 h with minimum of 24 h and maximum of 196 h;

b) Rather close consistence between the characteristics of flow and wind in the Strait Uzunaral has been revealed. The response rate of the flow to wind amounts from several hours (8-10 h) to half of a day;

c) The growth curve of water mineralization is nearly similar to the velocity curve but is more smooth and is shifted in phase;

d) Actually within the overall phase time of water exchange cycle there exists one-way water overflow across total cross section of the strait. Periods of unsteady alternating over the strait width flow with duration of several hours were observed only at the joining point of the phases of water exchange cycles;

e) Dominance in time of the flows directed along the strait axis.

The average flow rate in the Strait Uzunaral according to the data of automatic buoy-based stations within the overall observation period was 0.18 m/s. Instant recorded velocities achieved 0.7—0.8 m/s[12, 13, 14].

This study is aimed at development of a new method of estimation of internal water exchange between the west and the east parts of the lake with consideration for hydrometeorological factors.

Previously developed mathematical models of Lake Balkhash are semi-empirical models based on long-term series of average yearly values of water level and salinity in the layer 8 of hydrochemical districts[11, 12]. Insufficient spatial and time knowledge of components of the lake water balance forced the authors of the models to apply these or that plausible hypotheses in order to describe the mentioned components, in particular, assumption with regard to generation of internal water exchange of the lake. They completely do not consider for physical essence of the processes occurring in the lake. And even if it is considered, then only indirectly via coefficients (for instance, coefficient of water exchange[15]), based on rough concepts without practical confirmation. All the more they were obtained for natural state of the water body and due to this reason they cannot be always applied in design conditions.

Another drawback of these procedures is high time steps (one year) and spatial ranges (hydrochemical district). As demonstrated by up-to-date researches, the wind-induced drift and compensating currents develop and attenuate within maximum of several days.

The current state of the lake as a consequence of significant overregulation, higher and higher increase in permanent water withdrawal and other reasons required for solution of the problem of more exact forecasting of any anthropogenic invasions into water basin of Lake Balkhash. Such estimation procedure can be implemented by the mathematical model based on a set of two-dimensional Saint Venant equations of water flow, considering for the lake configuration, water and salt balance, wind direction and velocity, and water density. The two-dimensional pattern of the model is stipulated by morphometric peculiarities of the lake (average values of its depth, width, and length are in the ratio of 1:6000:120000). This is also evidenced by the data of field observations of water and salt exchange in the lakescape: at the boundaries of hydrochemical districts cyclic alternating water and salt transfers of one direction dominate. It is solved by application of numerical difference scheme with the space increments of 1--2 km and time increments of 1—3 hours[16, 17].

The research procedure is based on two-dimensional numerical solution of differential equations of unsteady slowly varying water flow in free channel (Saint Venant equation). Parameterization of the equations is based on the generalized results of hydrochemical survey of the lake and measurements in the Strait Uzunaral, performed in 1983-1987 by complex research expedition of Kazakh National University and Institute of Geography, Academy of Sciences, Republic of Kazakhstan (general guidance by Prof. A. A. Tursunov).

EXPERIMENTAL

In the world there are numerous mathematical models of planar flows described by two-dimensional Saint Venant equations. The planar model is widely applied in the calculations of flows in rivers, shallow lakes and seas, as well as in sea shelf zones, and Lake Balkhash is shallow, with significantly homogeneous in-depth distribution of velocity, temperature and salinity. Thus, the planar model can be applied in this case[18, 19].

The planar model equations (Saint Venant equations) for large-scale wind-induced circulations are as follows:

$$\frac{\partial Q_1}{\partial t} - lQ_2 = -gH\frac{\partial z}{\partial x} + \tau_{wx} - \tau_{bx}$$

$$\frac{\partial Q_2}{\partial t} - lQ_1 = -gH\frac{\partial z}{\partial y} + \tau_{wy} - \tau_{by} \quad ...(1)$$

$$\frac{\partial z}{\partial t} + \frac{\partial Q_1}{\partial x} + \frac{\partial Q_2}{\partial y} = 0$$

where t is the time; x and C are the horizontal coordinates; Q_1 and Q_2 are specific flow rates along the directions E and C, respectively, (Q_1=H.u, Q_2=H . ν, H is the depth, u and v are the depth average flow rates); z is the level of water surface; g is the acceleration of gravity; is the Coriolis parameter ($l=2w \sin \varphi$, where w is the angular velocity of Earth rotation, φ- is the geographical latitude of the locality); τ_w and τ_g are the wind stress and the frictional stress., respectively. The stress is described by the following equations:

$$\tau_{wx} = C_w|W|W_x, \tau_{wy} = C_w|W|W_y$$

$$\tau_{bx} = \frac{\tau|Q|Q_1}{H^2}, \tau_{by} = \frac{\tau|Q|Q_2}{H^2} \quad ...(2)$$

$$|W| = \left(W_x^2 + W_y^2\right)^{1/2}, |Q| = \left(Q_1^2 + Q_2^2\right)^{1/2}$$

where C_w and τ are the coefficients depending only on roughness of water surface and bottom, respectively.

The lake margin Σ is subdivided into hard Σ_0 and "liquid" Σ_1 portions. The liquid portion is comprised of the mouths of rivers inflowing into the lake. The lake margin includes the following boundary conditions for the set of equations (1):

$$Q_n = 0 \text{ for } (x,y) \in \Sigma_0$$

$$Q_n = q\,(t,x,y) \text{ for } (x,y) \in \Sigma_1$$

where Q_n is the normalized component of specific flow rate with regard to the lake margin, q is the preset function. In addition to the boundary conditions (3) for the set of equations (1) it is necessary to define initial conditions in the form of distribution of specific flow rates Q_1 and Q_2 of water surface level z over space, for instance, $Q_1 = Q_2 = 0$, $z=z_n$, where z_n is the water level position in steady state.

Approximation over space is implemented in the Arakawa C-grid [20], according to which the water surface level is calculated in the center of difference grid and the specific rates in lateral faces: Q_1 – in the face perpendicular to the E_1 axis, Q_2 - in the face perpendicular to the E_2 axis.

The adequacy of the developed mathematical model of water transfer to actual conditions was estimated. With this aim the water transfer in the Strait Uzunaral was calculate within ice-free period. The input data were comprised of the data by Hydrometeorological service of the Republic of Kazakhstan and the results of field observations by Institute of Geography, Academy of Sciences of the Republic of Kazakhstan in 1987. The obtained results were compared with the measurement results of water mineralization in the Strait Uzunaral for September, 1987.

Figure 2 illustrates the curves of calculated (1) and measured (2 and 3) [2] velocities of water flows in time (from September 11 to 25) in two locations of the most narrow site of the Strait Uzunaral. The first location is situated closer to the south coast (2, Fig. 2a), and the second one to the north coast (3, Fig. 2a). As can be seen in Fig. 2a, there is the agreement between the curves of calculated and measured velocities of water flow, especially in the extreme points. Certain slightly higher deviations of the calculated velocities of water flow from the field observations can be seen in the south location (Fig. 2a). It can be attributed to the complex configuration of the lake south coast in the vicinity of the strait. The coefficient of correlation between the calculated and actual velocities of water flow is τ = 0.84, which evidences sufficiently close relationship[21, 22]. Figure 2b illustrates the curve of projections of wind velocities in time onto the lake longitudinal axis for two meteorological stations in the vicinity of the Strait Uzunaral. Therefore, the results of the performed numerical experiment confirm cyclical pattern of variation of water mineralization in the lake in the course of time as a function of wind direction and velocity. Comparison of the obtained simulated values with the field observations demonstrates that the developed mathematical model describes adequately the process of water exchange between West and East Balkhash via the Strait Uzunaral. Certain irrelevance can be attributed to the complex configuration of the coasts, high distances between the interpolation points of meteorological elements.

RESULTS

We developed two-dimensional mathematical model, by means of which it is possible to estimate water and salt exchange within lake Balkhash.

The performed calculations were aimed at clarification of the mechanism of water exchange between adjacent hydrochemical districts defined by M. N. Tarasov (Fig. 1), that is, calculations of

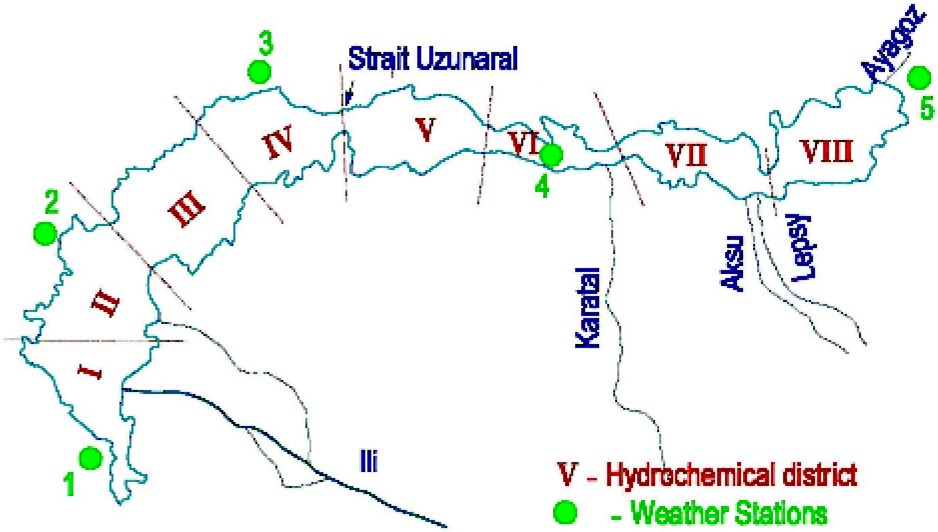

Fig. 1. Schematic view of Lake Balkhash and its subdivision into hydrochemical districts

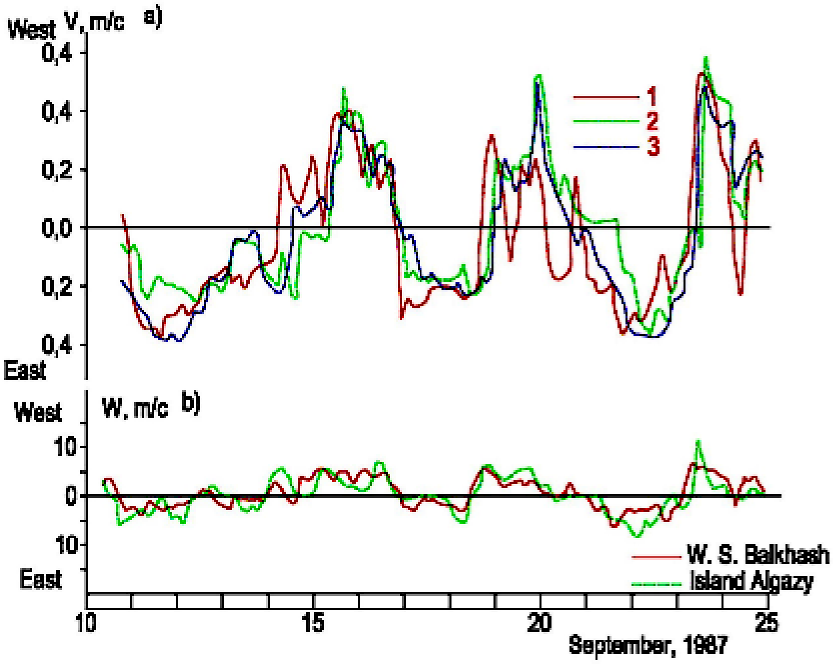

Fig. 2. Water velocity curves (a) in time in the Strait Uzunaral, as well as the projections of wind velocities (b) onto longitudinal axis of Lake Balkhash: 1 - calculations; 2 - measurements at the Station ABC-2; 3 - measurements at the Station ABC-3

Table 1. Calculated characteristics of water exchange cycles within the boundaries of hydrometeorological districts of Lake Balkhash

Boundaries between hydrochemical districts	Average time of one direction, hours	Total number of the cycles	East phase: Maximum time, hours	East phase: Maximum amount of transfer, km^3	East phase: Average amount of transfer, km^3	East phase: Total amount, km^3	West phase: Maximum time, hours	West phase: Maximum amount of transfer, km^3	West phase: Average amount of transfer, km^3	West phase: Total amount, km^3
I-II	10.4	259	29.7	1.38	0.20	51.2	35.5	1.49	0.21	51.6
II-III	11.2	254	27.8	2.30	0.31	76.7	44.6	2.30	0.29	71.0
III-IV	11.2	230	39.9	1.58	0.24	53.6	44.6	1.47	0.23	50.0
IV-V	21.7	89	105.2	2.33	0.32	27.9	116.3	1.78	0.28	24.7
V-VI	21.7	119	84.1	1.91	0.27	30.0	110.7	1.76	0.24	28.2
VI-VII	20.3	128	76.0	1.14	0.24	30.4	105.7	1.52	0.22	27.2
VII-VIII	12.3	227	41.6	0.87	0.12	24.8	57.8	0.72	0.11	22.7

dynamics of water flow in the lake during the ice-fee period (April to November) with consideration for hydrometeorological factors. In addition to current data for wind, observed in 1987 from April to November by five meteorological stations, the main elements of water balance were applied, such as: inflow of surface waters, visible evaporation. The river influxes are illustrated in Fig. 1. Space increment of 5000 m and time increment of 3 h were applied in the model.

In general, the lake can be characterized by cyclical pattern of the flow, consisting of the west and east phase. The main statistical data are summarized in Table 1.

As can be seen in Table 1, the number of water exchange cycles at the boundaries of hydrochemical districts varies from 89 to 259. The most frequent changes of the flow are observed in West Balkhash. Probably, this can be attributed to higher surface area and lower depth in this part of the lake in comparison with East Balkhash. The higher is the surface area and the lower is the depth, the more intensive is the response of water body to variation of wind direction.

DISCUSSION

On the basis of the obtained data the averaged calculated values of characteristics of water overflow via the site of the strait during ice-free period were determined. Cumulative water overflow eastward in this period amounted to 29.8 km^3, and overflow westward to 26 km^3, the resultant overflow within the ice-free period at the level height of about 341.5 m was directed to east and amounted to 3.8 km^3.

Table 1 summarizes some characteristics of west and east phases of the cycles during the ice-free period. Average amounts of water overflowing via the boundaries of hydrochemical districts within east phase vary from 0.12 km^3 to 0.32 km^3, and within west phase from 0.11 km^3 to 0.29 km^3. If the west and the east phases of water exchange cycles are considered in the whole, then the average water amounts overflowing within one phase are of the same order of magnitude. However, their value in extreme boundaries are slightly lower than those in internal boundaries. Cumulative amount of the water overflow eastward within total ice-free period via the boundaries of hydrochemical

Table 2. Probable distributions of water exchange coefficients in lake Balkhash

Probability of falling of the water exchange coefficient in the % intervals	Boundary between hydrochemical districts													
	I-II		II-III		III-IV		IV-V		V-VI		VI-VII		VII-VIII	
	West phase	East phase	West phase	East phase	West phase	East phase	West phase	East phase	West phase	East phase	West phase	East phase	West phase	East phase
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
19	0	0	0	0	0	0.9	1.1	1.1	0.9	23.5	10.4	0	0	0
19-18	0	0	0	0	0	1.3	2.3	1.1	0	1.7	3.2	0	0	0
18-17	0	0	0	0	0	0.4	0	1.1	0.9	1.7	0.8	0	0	0
17-16	0	0	0.8	0	0	0.9	1.1	0	0	1.7	4.8	0	0	0
16-15	0	0	0.4	0.4	0	0	1.1	2.3	0	0.9	0.8	0	0	0
15-14	0	0	0	0	0	0.9	0	2.3	0	0	0.8	0	0	0
14-13	0	0.4	1.2	0	0	0.9	1.1	1.1	2.6	0.9	0.8	0	0	0
13-12	0	0	1.2	0	0	1.4	1.1	1.1	0.9	2.6	5.6	0	0	0
12-11	0	0	0.8	0.8	0	1.4	3.4	2.3	0.9	2.6	2.4	0	0	0
11-10	0.4	0.4	0.8	1.2	0	3.6	6.9	3.4	0.9	1.7	2.4	>	0	0
10-9	0.8	1.2	1.2	0.8	0	0.4	3.4	4.6	3.5	2.6	3.2	0	0	0
9-8	1.6	1.2	1.6	0.8	0.4	2.7	2.3	8.0	3.5	5.2	8.8	0	0	0
8-7	2.0	1.2	0.8	1.2	0.9	4.0	3.4	0	5.2	3.4	4.8	0.8	0	0
7-6	1.2	0.8	2.8	2.8	1.4	2.3	4.6	8.0	3.5	2.6	1.6	1.6	0	0
6-5	2.4	3.2	3.2	1.6	2.3	5.9	3.4	1.1	2.6	0.9	4.8	5.6	0.5	0
5-4	3.6	5.2	10.6	4.5	5.4	10.0	5.4	8.0	11.3	7.0	8.0	4.8	0	0.5
4-3	10.4	8.4	13.4	9.8	6.8	18.1	10.3	4.6	13.9	8.7	7.2	8.8	1.5	10.0
3-2	15.7	24.5	22.4	22.4	12.2	16.7	13.8	3.4	7.8	10.4	10.4	8.8	4.9	2.9
2-1	35.3	31.3	24.8	28.4	35.3	12.7	21.8	23.0	13.9	7.0	6.4	20.0	19.0	16.8
<1	26.5	22.1	13.8	25.6	35.3	15.4	12.6	23.0	27.8	14.8	12.8	49.6	75.1	79.0

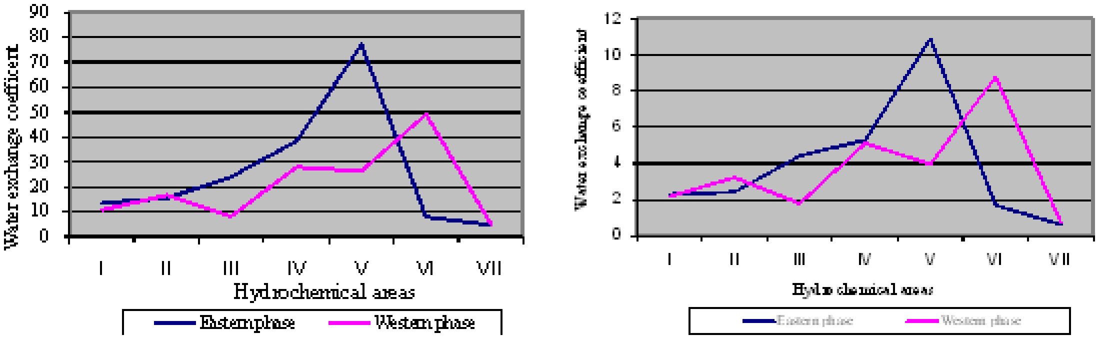

Fig. 3. Average and maximum values of the coefficients of internal water exchange at the boundaries of hydrochemical districts within east and west phases

districts varies from 24.8 km^3 to 76.7 km^3, and the same value westward varies from 22.7 km^3 to 71.0 km^3. It should be mentioned that the difference between them in each boundary with regard to direction and amount equals to water-balance flow. For instance, via the Strait Uzunaral (boundary IV-V) during ice-free period the water overflow eastward was 27.9 km^3, the overflow westward was 24.7 km^3, the difference of 3.2 km^3 gives the water-balance overflow for the same period via the strait, eastward direction. The amount of water exchange during ice-free period at the boundaries of the west part of Lake Balkhash is about twice as high as the water exchange in the east part of the lake including the Strait Uzunaral. Average duration of continuous water flow in one direction varies from 10.4 h to 21.7 h.

In East Balkhash, including the Strait Uzunaral, in the boundaries between IV-V, V-VI, VI-VII hydrochemical districts the average duration of continuous flows is twice as high as in the other boundaries. Maximum duration of flow in one direction for the east phase varies from 27.7 to 105.2 h, with the amount of water overflow during this time up to 2.33 km^3, for the west phase these characteristics are 35.5 h, 116.3 h, and 2.30 km^3, respectively. The highest duration of water flow in one direction both for the east and for the west phase is in the Strait Uzunaral.

In order to clarify the mechanism of mineralization distribution over the lake length, as well as internal migration of slats the water exchange between hydrochemical districts is of high importance. Quantitative estimation of internal water exchange is based on the coefficient k_{iwe} (internal water exchange), expressed in percents and equaling to the ratio of amount ($\Delta\Omega$), supplied to a separate hydrochemical district per one phase of water exchange cycle, to total amount (Ω) of this hydrochemical district, that is,

$$k_{iwe} = 100 \cdot \Delta\Omega / \Omega \qquad ...(4)$$

The coefficient of internal water exchange k_{iwe} is calculated for the west and east phases for all water exchange cycles within ice-free period in all boundaries of hydrochemical districts. The calculated values of coefficient of internal water exchange k_{iwe} were analyzed, the obtained results are summarized in Table 2. Here the recurrence of falling into percent intervals to 19 % and higher is shown.

As can be seen in the table, mainly at more than 70 % of water-exchange cycles the coefficient of internal water exchange k_{iwe} does not exceed 6-7 %. Certain exclusion is the hydrochemical district VI. Probably, it can be attributed to relatively low water amount (W_{VI} = 2.58 km^3) in this hydrochemical district in comparison with the adjacent districts (W_V = 6.35 km^3, W_{VII} = 14.78 km^3).

Figure 3 illustrates average and maximum values within the east and west phases, from here it can be seen that the average value of the water exchange coefficient in the west phase varies from 0.77 to 8.77 %, and the maximum value from 5.0 to 49.2 %. For the east phase these characteristics are 0.64; 10.9; 4.62; and 77.01, respectively.

Based on the preformed studies of the internal water exchange in Lake Balkhash with consideration for the influence of hydrometeorological factors the following conclusions can be made:

A mathematical model of internal water exchange has been developed considering for hydrometeorological factors and the lake morphometry. Numerical experiments demonstrate that the developed model describes adequately the considered process.

During wind-induced flow the water velocity in the Strait Uzunaral is by an order of magnitude higher than during other types of flows. During average wind velocity of 5 m/s the velocity of wind-induced flows is 0.30 m/s.

Therefore, it is exactly wind-induced flows that determine hydrometeorological processes and water agitation between the lake reaches.

Using the mathematical model, the pattern of water exchange at the boundaries of hydrochemical districts has been studied, the following conclusions have been made:

a) the most frequent changes of the flow direction are in West Balkhash. This can be attributed to the higher surface area and lower depth of the lake in this part in comparison with East Balkhash;

b) at all boundaries the pattern of the water exchange is cyclic, it consists of the east and the west phases. Average water amounts overflowing per one phase are of the same order of magnitude. However, their value at the boundaries of extreme reaches is slightly lower than at the internal boundaries;

c) the amount of water exchange during ice-free period at all boundaries of the west part of Lake Balkhash is about twice as high as the water exchange at the boundaries of the east part including the Strait Uzunaral;

d) the average duration of continuous water flow in one direction in the boundaries varies from 10.4 h to 21.7 h.

In East Balkhash, including the Strait Uzunaral, the average duration of continuous flows is about twice as high as that in West Balkhash;

e) the maximum duration of flow in one direction for the east phase varies from 27.7 to 105.2 h with the volume of water overflow up to 2.33 km^3, for the west phase these properties are 35.5 h, 116.3 h, and 2.30 km^3, respectively. The highest time of water flow in one direction is in the Strait Uzunaral both for the east and for the west phase;

f) the water exchange pattern depends on average width of hydrochemical district.

Using the developed model it is possible to estimate alternative means of adjustment of salinity of West Balkhash within critical situations, such as decrease in overflow of West Balkhash; damming of the Strait Uzunaral by water regulating facility.

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