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Studying the Spatiotemporal Variability of the Components of the North Caspian Sea Water Balance Using the Water Balance Model

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Abstract—Considered is the water balance model of the estuarine seaside of the Volga and Ural rivers and the North Caspian Sea as well as of its separate parts. The following computational spatial elements, three parts of the North Caspian Sea, are singled out: the shallow zone of the Volga River estuarine seaside, the deep zone in the western part of the North Caspian Sea, and the eastern part of the North Caspian Sea. The input parameters in this model are evaporation from the water surface computed using the ISPAR technique and precipitation depth corrected using the technique of the correction of the measured amount of precipitation worked out by the Main Geophysical Observatory and Kazakh Research Hydrometeorological Institute. The computations are based on the data of observations at four weather stations: Zelenga (Russia), Peshnoi Island, Kulaly Island, and Fort Shevchenko (Kazakhstan). The water inflow to the Volga River delta top corrected by the value of natural evaporation loss in the delta is used as the water inflow to the North Caspian Sea. The water inflow from the Ural River delta to the North Caspian Sea is estimated from the data of Makhambet hydrological station. Using the water balance model, the water balance components can be computed for the separate parts of the North Caspian Sea and the water balance equation can be solved regarding the water balance outflow from these parts. The volume of the water outflow from the North Caspian Sea to the Middle Caspian Sea is determined as a result of water exchange between them. The variations of basic components of the North Caspian Sea following different typical scenarios (typical years determined from the Volga River runoff) are computed using its water balance model. Analyzed are the spatiotemporal regularities of water redistribution in the North Caspian Sea with account of the river runoff volume, evaporation loss, and amount of precipitation at different background levels of the Caspian Sea.

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Keywords: Water balance model, the North Caspian Sea, water balance components, the Volga River, runoff

INTRODUCTION

In the water balance studies of water bodies, the methods and techniques of water balance (WB) computation enable estimating quantitatively water resources and optimizing their use: working out the strategy of water policy, carrying out prognostic computations for substantiating measures on the prevention of undesirable consequences of climatic and anthropogenic changes in hydrological conditions, and developing the projects of efficient water use and environmental protection.

The water balance of the North Caspian Sea (hereinafter, the North Caspian) is the set of parameters characterizing its hydrometeorological conditions and is defined by the data of the standard observational network both on the territory of the estuaries of the Volga and Ural rivers and around the water body. The most optimal period for computing WB is a month for which seasonal and climatic changes in water resources and their hydrological conditions can be successfully analyzed. It is known that the independent estimate of all WB components, namely, the inflow and outflow of water and the change in its reserve in the water body for the computational time period is chosen as the main condition for such computation. Using the equation of the WB of the water body, only one of its components can be determined; as a rule, it can be neither measured nor estimated in another way. In this case, the value of such component contains all errors of the computation of other WB components.

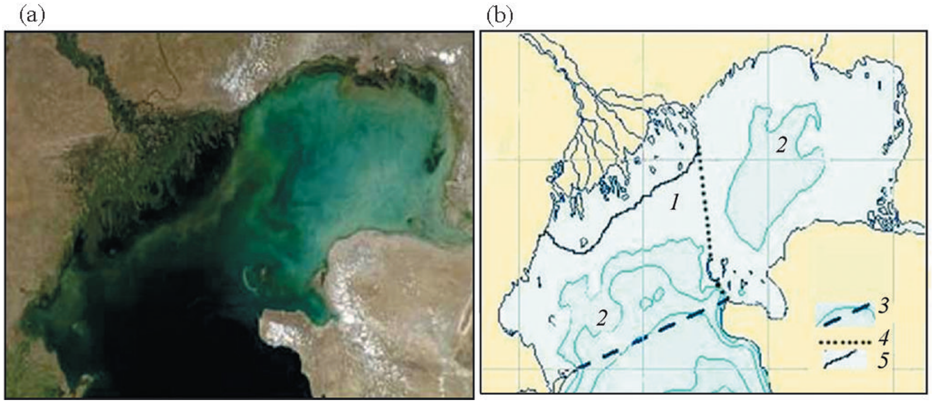

Fig. 1. (a) The satellite image of the North Caspian and (b) its scheme with the separated areas with different depths and with the borders of its parts. (*1*) The mean depth is 2–4 m; (*2*) the mean depth is 5 m and more; (*3*) the border of the North Caspian; (*4*) the border of its eastern part; (*5*) the border of the shallow zone of the Volga River estuarine seaside.

WATER BALANCE MODEL OF THE NORTH CASPIAN

Let us consider the following water balance model: the Northern Caspian–the estuarine seaside of the Volga and Ural rivers [6]. The scheme of the North Caspian with the separated parts, their borders, and depth is presented in Fig. 1. The area of the North Caspian at the sea level of –27, –28, and –29 m BS is 104.6 10^3, 90.1 10^3, and 71.9 10^3 km^2, respectively. The area of this part of the Caspian Sea was computed from the data presented in [2] depending on the water level.

The following basic computational spatial elements were singled out:

—the shallow zone of the Volga River estuarine seaside (the area is 0.10 (hereinafter, the area is given in the fractions of the total North Caspian area) and the current mean depth is 1.5–2 m);

—the deep zone in the western part of the North Caspian (the area is 0.38 and the mean depth is 6–8 m);

—the eastern part of the North Caspian (the area is 0.52 and the mean depth is 4–5 m).

Using the water balance model [6], water balance components can be computed for the separate parts of the North Caspian and the water balance equation can be solved regarding the water balance outflow from its each concrete part:

$$W_{\mathrm{out}} \quad W_{\mathrm{in}} \quad W_{\mathrm{p}} \quad W_{\mathrm{ev}} \quad W \tag{1}$$

where W_{out} is the volume of the water outflow; W_{in} is the volume of the water inflow; W_{p} is the volume of precipitation fallen to the water surface; W_{ev} is the water surface evaporation loss; W is the change in water volume. All water balance components are converted into cubic kilometers. The equation does not include the inflow (outflow) of underground water due to the poor hydrogeological exploration of the region and due to the low significance of this variable as compared with other water balance components of the North Caspian. The volume of the water outflow to the Middle Caspian is determined as a result of water exchange between its parts.

The water balance of the North Caspian was computed for monthly time periods in typical years selected following the Volga River runoff. These are the low-water years 1977 and 2006 and high-water years 1979 and 2005. The Caspian Sea level was equal to about –29 m BS in 1977 and 1979 and –27 m BS in 2005 and 2006.

The volume of the annual water runoff at the Volga River delta top amounted to 198 and 205 km^3 in the low-water years 1977 and 2006, respectively, and 319 and 289 km^3 in the high-water years 1979 and 2005. The thorough analysis of the data of Russian and Kazakh marine hydrological stations in the North Caspian demonstrated that its mean level can be computed most reliably as the arithmetic mean of the data from Kulaly Island and Fort Shevchenko stations. Water accumulation in each part of the North Caspian per month is computed as the product of the monthly mean value of the area of the corresponding part by the difference in background water levels computed for the end and beginning of month. The sea level at Iskusstvennyi Island marine hydrological station is taken as the background level for the shallow zone of the Volga River estuarine seaside, and the mean level from the data of Fort Shevchenko and Kulaly Island stations, for the deep western and eastern parts of the North Caspian.

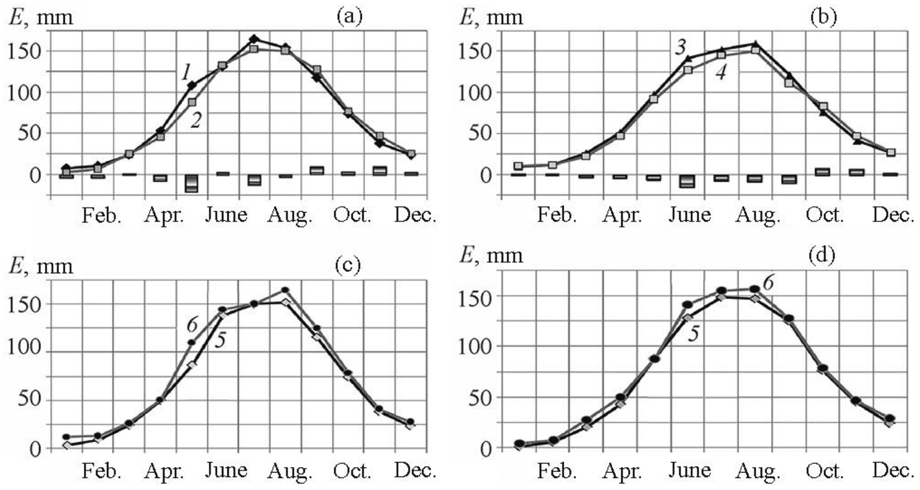

Fig. 2. The climate change impact on evaporation loss *E* from the North Caspian surface in (a) the low-water years (*1*) 1977 and (*2*) 2006 and (b) in the high-water years (*3*) 1979 and (*4*) 2005; the intraannual variability of evaporation loss in its (*5*) eastern and (*6*) deep western parts in (c) 1979 and (d) 2006.

THE INPUT PARAMETERS OF THE NORTH CASPIAN WATER BALANCE MODEL AND THEIR CLIMATIC AND SPATIOTEMPORAL VARIABILITY

The input parameters of the North Caspian water balance model are as following: evaporation depth from the water surface computed by the methods [4] implemented in the ISPAR technique (original software worked out by L.P. Ostroumova and registered in the Goskomgidromet Branch Foundation of Algorithms and Programs, inventory number Zh 051411072); the precipitation depth corrected using the technique of the correction of the measured amount of precipitation worked out by the Main Geophysical Observatory and Kazakh Research Hydrometeorological Institute (MGO–KRHI) [3, 5]; the water inflow to the North Caspian from the Volga and Ural rivers.

The computations based on the ISPAR [4] and MGO–KRHI [3] methods were carried out using the data of observations at four weather stations: Zelenga (Russia), Peshnoi Island, Kulaly Island, and Fort Shevchenko (Kazakhstan). This enables obtaining the more accurate (as compared with the results of [6]) values of evaporation loss and of precipitation fallen to the sea surface (area) of the North Caspian and its separate parts. The water inflow from the Volga River to the North Caspian is the volume of water inflow to the delta top after deduction of the volume of total visible evaporation loss computed using the Volga River delta water balance model [7]. The water inflow from the Ural River was determined from the data of observations of water runoff at Makhambet hydrological station. These parameters are presented in cubic kilometers in water balance computations.

The ISPAR technique is intended for estimating the evaporation from the water surface. It uses the method of empirical formulae and the formula by A.P. Braslavskii that was published in 1986 in the proceedings of the 5th hydrological congress. In this technology the evaporation process is simulated as the interaction between two phenomena, namely, between the mass exchange in the water surface plane and the water vapor transport from it in the atmospheric surface layer. The parameters of the model are meteorological parameters measured at ground-based weather stations which are afterwards recalculated for the water surface. The temperature of the thin surface water layer in the water body is computed from the equation of its heat balance [4]. The variability of the values of evaporation in the water balance of the North Caspian and its separate parts in typical years is demonstrated in Fig. 2.

The analysis was carried out of the climate change impact on the value of the North Caspian Sea surface evaporation loss (Figs. 2a and 2b). The warming occurred in this area of the North Caspian from 1977 to 2006 (30 years) and the value of evaporation loss per year decreased by 30 mm on average. This took place due to every year decrease in evaporation depth that occurs from January to August. Although the difference between the water temperature and air temperature in these months increased by 0.5 C on average, the wind speed decreased by 0.4 m/s that caused evaporation decrease. The evaporation from the North Caspian Sea surface in autumn-winter period both in high- and low-water years increased. As a result, winters became warmer and more humid and the difference between the values of water temperature and air temperature decreased insignificantly, but the wind speed over the sea surface increased by 0.1 m/s on average.

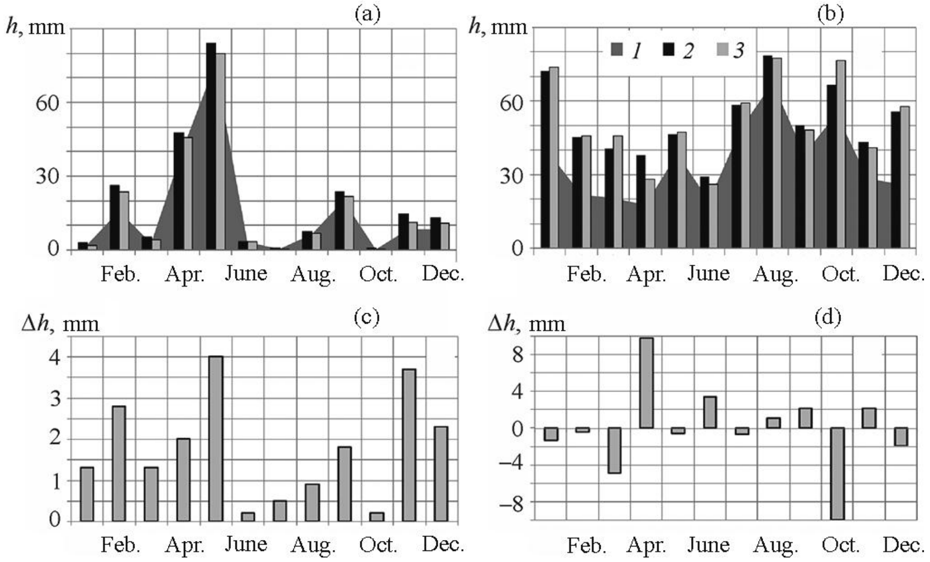

Fig. 3. Monthly values of (*1*) the measured amount of precipitation *h* and that corrected by (*2*) MGO–KRHI and (*3*) SHI–MGO methods and the difference between these methods *h* in the estimates of corrections to the total monthly precipitation. (a, c) Zelenga station, 2011; (b, d) Mud’yug station, 2009.

The example of the spatiotemporal variability of evaporation loss for monthly time periods is presented in Figs. 2c and 2d. The computation of evaporation depth from the shallow zone of the Volga River estuarine seaside was carried out using the meteorological parameters measured at Zelenga station, the evaporation from the eastern part of the North Caspian, using the measurement data from Zelenga and Peshnoi Island stations, and the evaporation from the deep western part, using the measurements from Zelenga and Fort Shevchenko stations. The resultant evaporation in the eastern and deep western parts of the North Caspian was obtained as the arithmetic mean of the data from two stations of each of these regions. Evaporation loss is affected by the position of the separate parts of the North Caspian (their northern latitude). Annual evaporation from its eastern part was smaller than from the deep western part mainly due to evaporation in summer months: in May, June, August, and September in 1979 and in June–August in 2006. The annual value of evaporation from the eastern part of the North Caspian as compared with its deep western part was smaller by 55 mm in 1979 and by 80 mm in 2006.

To assess the inflow component of the North Caspian water balance (precipitation), the data were used of precipitation observations using the Tret’yakov precipitation gage at coastal weather stations located on the territory of Russia and Kazakhstan. To obtain the real (corrected) values of precipitation, the systematic errors of measurements by this instrument are corrected by means of introducing some adjustments. The methods worked out in the 1960s–1970s and the techniques developed by MGO–KRHI (1991) [3] and State Hydrological Institute and the Main Geophysical Observatory (SHI–MGO) (2000) [1] were analyzed. This enabled introducing the following corrections to the precipitation measured by the Tret’yakov precipitation gage: the correction for the precipitation bucket wetting, the correction for evaporation from its surface, the correction for false precipitation coming to the precipitation gage during the blizzard, and the correction for the wind-induced underestimation of precipitation. The computation was carried out using the techniques [1, 3] of the introduction of corrections to the measured precipitation. The results were compared and analyzed of the numerical experiment [5] for Mud’yug station located in the Northern Dvina estuary (the north of Russia) and Zelenga station located in the Volga River estuary (the south of Russia). In the northern regions of Russia (Mud’yug station), the methods and techniques of applying the corrections to the measured precipitation worked out by SHI–MGO and MGO–KRHI gave similar results. The annual values of the amount of precipitation corrected by these methods almost coincide and amount to 626 mm. The underestimation is equal to 204 mm (49% of measured precipitation). The maximum difference between the values of the amount of precipitation corrected by these methods to 10 mm was obtained in October (Figs. 3b and 3d). It is permissible to use both these techniques for applying the corrections to precipitation in the north and northwest of Russia. In the south of Russia (Zelenga station) the difference between these two techniques in the values of precipitation correction for all months in the year had the

Table 1. Amount of precipitation fallen to the North Caspian surface measured by the Tret'yakov precipitation gage *h* and corrected by the MGO–KRHI method [3, 5] *h* and the difference between them *h* (underestimation)

Parameter	January	February	March	April	May	June	July	August	September	October	November	December	Total annual
						1977							
h, mm	5.9	6.3	1.0	0.5	4.5	14.8	5.9	14.2	7.3	15.6	6.9	7.5	90
h , mm	12.9	10.7	3.4	4.2	6.8	21.7	8.3	17.5	8.8	20.3	11.4	19.2	145
h, %	119	70	235	735	52	46	40	24	20	30	65	156	61
						1979							
h, mm	4.0	5.2	19.6	39.8	8.1	2.9	5.9	2.0	7.4	34.6	4.9	27.1	161
h , mm	12.5	12.8	25.4	47.9	9.7	4.5	11.7	3.0	10.6	46.0	11.3	37.6	233
h, %	213	148	29	20	20	52	99	54	43	33	132	39	44
						2006							
h, mm	11.9	6.5	8.6	14.1	8.3	7.1	3.1	0.8	7.2	25.0	23.9	19.2	136
h , mm	30.9	16.5	10.6	17.8	10.7	9.7	6.0	1.1	8.9	29.0	32.1	27.6	201
h, %	161	155	24	26	29	36	94	47	24	16	34	43	48
						2005							
h, mm	7.5	10.7	3.5	6.0	6.1	12.2	3.5	0.2	7.4	16.4	3.5	19.6	96
h , mm	10.4	15.1	6.6	7.3	7.9	17.1	6.8	1.0	9.9	20.6	4.9	24.1	132
h, %	39	42	89	22	31	41	94	383	34	25	42	23	37

Note: The underestimation of precipitation is given in the percents of measured precipitation.

same sign and was equal up to 4 mm (the correction by the SHI–MGO method was smaller) that indicates the systematic error in one of the methods (Figs. 3a and 3c). In our opinion, the systematic error in the correction of the measured precipitation is given by the SHI–MGO method. The higher significance of water evaporation in the south of Russia as compared with the north and the significant number of cases when small amount of precipitation was measured require the direct physically-based computation of the correction for evaporation from the precipitation bucket that, in turn, enables estimating accurately the correction in the case of the measurement of zero precipitation (precipitation trails). Such approach to applying precipitation corrections was implemented only in the MGO–KRHI technique. Therefore, it is more preferable to use this technique for the water balance studies of water bodies in the south of Russia (for southern stations) [5].

At Zelenga station the underestimation of precipitation by the SHI–MGO method as compared with the MGO–KRHI technique amounted to 21 mm per year (12% of the amount of measured precipitation): it varies from 0.2 to 3.7 mm depending on the month (Fig. 3c). The precipitation component in the water balance of the North Caspian was obtained by means of averaging the precipitation measured and corrected by the MGO–KRHI method for four stations (Zelenga, Peshnoi Island, Kulaly Island, and Fort Shevchenko). The monthly and annual variability of this water balance component in typical years is presented in Table 1. The annual maximum amount of such corrected precipitation fallen to the North Caspian Sea surface (that equals 233 mm) was obtained for 1979, the minimum one (132 mm), for 2005. The maximum amount of precipitation falls in October and the minimum falls in August, as a rule.

The application of corrections to the measured precipitation is needed for water balance computations because the value of precipitation per year increases by the value from 20 to 60% and that of monthly precipitation, by tens and hundreds of percents, especially in the case of the small amount of precipitation and if we account precipitation registered as precipitation trails.

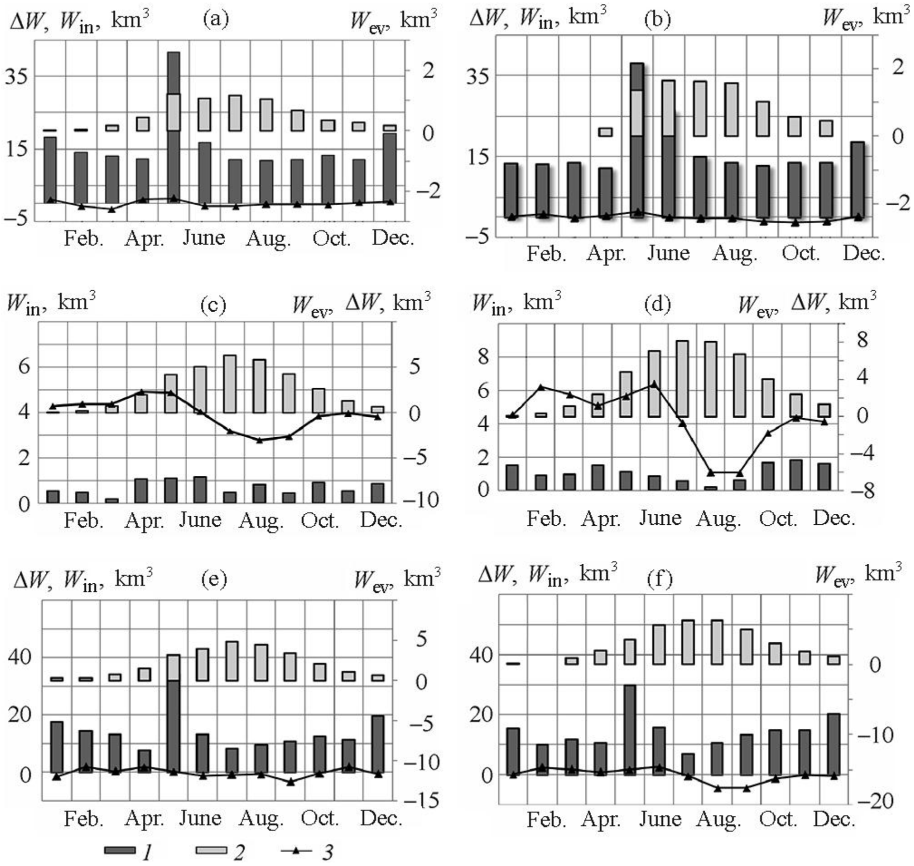

Fig. 4. Monthly variations of the volume of water balance components: (*1*) the inflow component W_{in} equal to the water inflow plus precipitation, (*2*) the outflow part W_{ev} equal to evaporation loss, and (*3*) the variations of the volume W in the different parts of the North Caspian in the low-water years (a, c, e) 1977 and (b, d, f) 2006 at the sea level close to –29 and –27 m BS, respectively. Here and in Fig. 5: (a, b) The shallow zone; (c, d) the eastern part; (e, f) the deep western part of the North Caspian.

THE WATER BALANCE OF THE NORTH CASPIAN AND ITS SEPARATE PARTS

The basic components of the water balance of the North Caspian and its separate parts obtained using the water balance model following various typical scenarios for 1977 and 2006 (low-water years) and 1979 and 2005 (high-water years) enable assessing their spatiotemporal variability. The comparison of separate water balance components and their monthly variations computed for each separated part of the Caspian Sea was carried out for the low-water years when their features are most strongly pronounced (Fig. 4). For example, the shallow zone of the estuarine seaside of the Volga River is transit for its monthly runoff (Figs. 4a and 4b). The maximum value of the outflow component in this zone was equal to 1.0–1.2 km^3 from May to July, 1977 and 1.1–1.6 km^3 from May to August, 2006. The inflow of the Ural River water to the eastern part of the North Caspian is much smaller than the evaporation loss in all months of the year except winter ones (Figs. 4c and 4d). In some months the water inflow to the deep western part is comparable to the value of evaporation loss but is in general larger than it (Figs. 4e and 4f).

In Fig. 5, the variations are presented of the inflow and outflow components of water balance in the separate parts of the North Caspian in low-water years at the different levels of the Caspian Sea.

The water balance outflow from the eastern part of the North Caspian computed from the water balance equation is a negative value (Figs. 5c and 5d). It is obvious that the inflow of the Volga River runoff to the eastern part is needed for maintaining the single water level in the North Caspian. The water outflow from the deep western part to the Middle Caspian decreases dramatically in April and July (Figs. 5e and 5f) being the months with the high values of evaporation loss and the low runoff of the Volga and Ural rivers (Figs. 4e and 4f).

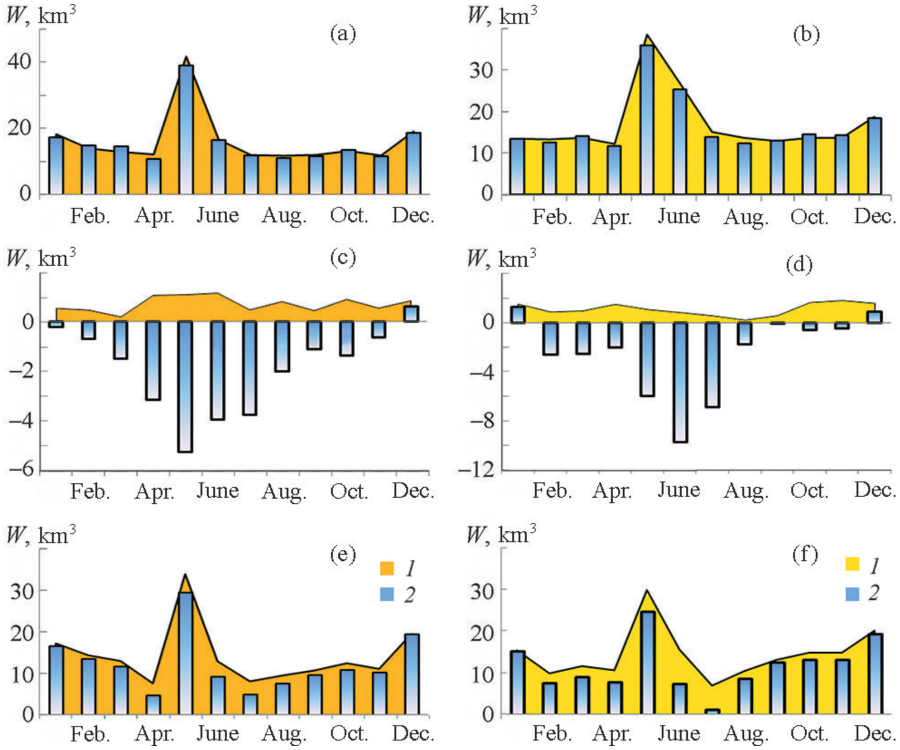

Fig. 5. The intraannual variability of (*1*) the inflow component $W_{\text{in}} + W_{\text{p}}$ and (*2*) the water balance outflow W_{out} in the different parts of the North Caspian in the low-water years (a, c, e) 1977 and (b, d, f) 2006. The explanations are the same as in Fig. 4.

In Fig. 6, the annual values are compared of the water balance of the North Caspian and its separate parts in the typical year selected according to the water runoff at the top of the Volga River delta in the periods when the Caspian Sea level was about –29 and –27 m BS.

The shallow zone is the zone of the Volga River runoff transit not only for the month but also for the year. Natural evaporation loss, precipitation, and water accumulation are insignificant as compared with the runoff volume (Fig. 6a). In the eastern part the most important role is played by natural evaporation loss that defines the hydrological conditions in this part of the North Caspian. The water balance outflow has a negative value. This means that a part of the Volga River runoff having this volume comes to the eastern part (Fig. 6b). The inflow to the deep western part is the Volga River outflow from the shallow zone after deduction of the water outflow needed for maintaining the water level in the eastern part (a part of the outflow from the shallow zone). The water balance outflow to the Middle Caspian Sea is obtained by means of solving the water balance equation for the deep western part of the North Caspian (Fig. 6c).

The variability of the annual values of water balance components is presented in Fig. 6d, and the annual water balance of the North Caspian in typical years is given in Table 2. The difference in the North Caspian surface evaporation loss at the Caspian Sea level of –27 and –29 m BS is 12 km^3 in high-water years 2005 and 1979 and 25 km^3 in low-water years 2006 and 1977. At the higher levels of the Caspian Sea, the volume of evaporation from the Caspian Sea surface is larger in spite of the fact that evaporation is smaller. The water outflow to the Middle Caspian Sea depends to the highest degree on the value of the Volga River runoff.

CONCLUSIONS

The transit outflow of the Volga River water to the deep zone of the western part of the North Caspian dominates in the shallow zone of the Volga River estuarine seaside: 250 and 217 km^3 in high-water years 2005 and 1979, respectively, and 140 and 143 km^3 in low-water years 2006 and 1977, respectively. Its intraannual variability agrees with the form of the runoff hydrograph on the marine edge of the Volga River delta. In May–August here the maximum volume of evaporation from the water surface is 1.2–1.9 km^3 per

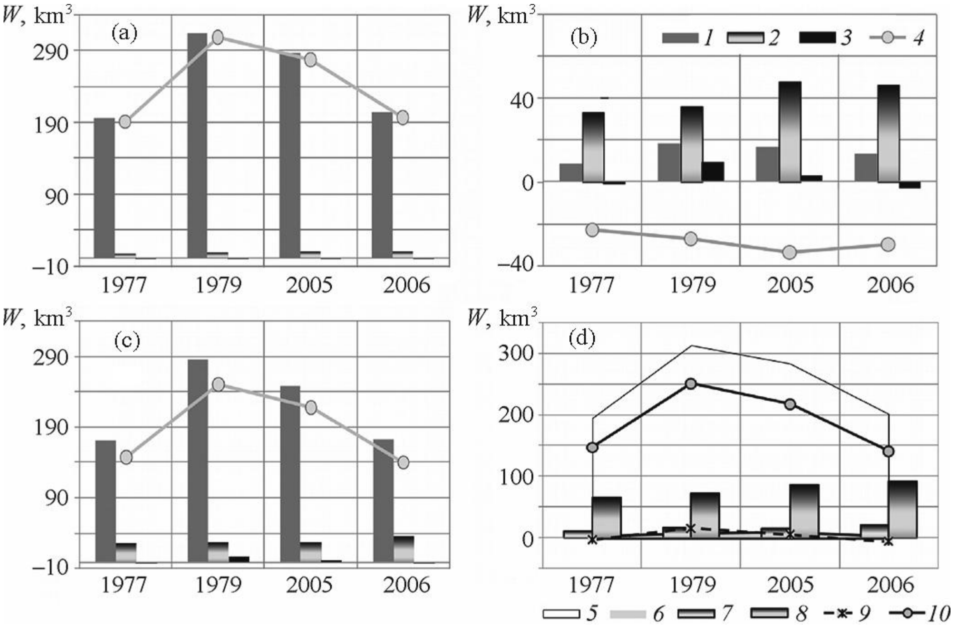

Fig. 6. Annual water balance of the North Caspian and its separate parts in the typical years: (a) the shallow zone of the estuarine seaside; (b) the eastern part; (c) the deep western part; (d) the North Caspian at the sea level of –29 m BS (1977 and 1979) and –27 m BS (2005 and 2006). (*1*) Water inflow; (*2*) visible evaporation from the water surface; (*3*) the volume change; (*4*) the water outflow; (*5*) the Volga River runoff; (*6*) the Ural River runoff; (*7*) precipitation; (*8*) evaporation; (*9*) the North Caspian volume change; (*10*) the water outflow to the Middle Caspian.

Table 2. Annual values of the water balance components (km^3) of the North Caspian

Year	Water runoff		Precipitation	Evaporation	Volume change	Outflow to the Middle Caspian
	Volga River	Ural River				
1977	195	2.9	10.8	65.3	–3.5	147
1979	313	7.8	16.5	71.9	15.2	250
2005	283	9.6	14.2	86.1	4.6	217
2006	201	2.8	19.6	90.6	–6.9	140

month. In the years with the various water content the maximum monthly volume of water accumulation in May varies within 1.3–3.3 km^3 and the water runoff on the marine edge of the delta varies within 38.0–64.7 km^3.

In the eastern part of the North Caspian, the water balance outflow to the deep zone of its western part computed from the water balance equation, turned out to be negative during the most part of the year (especially in the year that is considered low-water according to the Ural River runoff), i.e., water flows from the deep western part to the eastern part. In the case of the decreased inflow of water to the eastern part from the Ural River, especially in the months with high evaporation from the water surface, the considerable water balance transport takes water from the deep western part of the North Caspian to its eastern part (up to 9.7 km^3 in June 2006). As a whole, the volumes of inflow components of the water balance in the eastern part of the North Caspian are much smaller than for the shallow and deep western parts where the Volga River runoff prevails. The monthly volumes of evaporation from the sea surface in the eastern part of the North Caspian are comparable and even exceed the volumes of the water balance inflow from the deep western part (from 4 to 9 km^3 in summer months) both in 1979 and 2005 and in 1977 and 2006.

The outflow of the Volga River water to the Middle Caspian exists in the deep western part of the North Caspian in all months of the year. The water outflow to the Middle Caspian decreased dramatically both in high- and in low-water years in the months with the maximum evaporation of water after the snowmelt flood (July–August) and reached the zero value in the low-water year 2006. The maximum monthly evaporation falls on August (about 6 km^3 both in 2005 and 2006 and about 4 km^3 both in 1979 and 1977). In this part the decrease in the water volume takes place inside the year during the summer-autumn low-water period (up to 1.5–2.1 km^3 in September 1979 and 2005 and up to 0.3–1.7 km^3 in November 1977 and 2006).

In the high-water year 2005 the water balance outflow from the North Caspian to the Middle Caspian amounted to 250 km^3 and (for the comparison) the inflow of water to the Volga River estuary top was equal to 313 km^3. In the low-water year 2006, these values were equal to 140 and 201 km^3, respectively. In 2005 the Ural River runoff was also much larger than in 2006 (9.6 and 2.9 km^3, respectively). The maximum water balance outflow to the Middle Caspian in the high-water year 2005 was equal to 54.7 km^3 in May, and the minimum one, 3.6 km^3 in July. In the low-water year 2006, the maximum value of the water balance outflow to the Middle Caspian was equal to 24.8 km^3 also in May. The water balance outflow decreased to 1.3 km^3 in July and was equal to 7.4 and 8.7 km^3 in June and August, respectively. The similar picture was also observed in the low-water year 1977: the maximum value of the water balance outflow to the Middle Caspian was equal to 29.4 km^3 in May. The water balance outflow decreased to the minimum value of 4.9 km^3 in July.

The intraannual distribution of the volumes of inflow and outflow of water in different years is of changeable and complex nature depending on the intraannual distribution of the runoff of the Volga and Ural rivers and on evaporation and precipitation in the North Caspian Sea area.

The water balance outflow to the Middle Caspian for the time periods of the month and year can be assessed from the North Caspian water balance equation. The accuracy of computation of water outflow to the Middle Caspian based on the water balance equation (1) can be obtained taking into account the accuracy of determination of all its components: water runoff S_{r}, precipitation S_{p}, evaporation S_{ev}, and accumulation $S\ _W$. The total root-mean-square error S_{out} for estimating the water outflow to the Middle Caspian obtained from the water balance equation can be computed from the following equation:

$$S_{\text{out}} \quad \sqrt{S_{\text{r}}^2 \quad S_{\text{p}}^2 \quad S_{\text{ev}}^2 \quad S\ _W^2}\,. \tag{2}$$

Let us assume that the determination error is 5% for S_{r}, 5% for S_{p}, 4% for the year and 11% for the month for S_{ev}, and according to the data of [4], the North Caspian Sea level is 2 cm at the estimation of $S\ _W$. Then, the value of S_{out} is equal to 10 km^3 and 16 km^3 at the water outflow volume to the Middle Caspian of 149 (1977) and 250 km^3 (1979), respectively. The probable error equal to $0.674S_{\text{out}}$ amounted to 7 km^3 in 1977 and 11 km^3 in 1979. In July 2006, the value of S_{out} was equal to 0.7 km^3 at the water outflow volume of 1.3 km^3 and the probable error was 0.5 km^3. In July 1977, the value of S_{out} was equal to 0.65 km^3 at the water outflow volume of 4.9 km^3 and the probable error was 0.4 km^3.

REFERENCES

1. E. G. Bogdanova, V. S. Golubev, B. M. Il'in, and I. V. Dragomilova, "New Model for Correction of Measured Precipitation and Its Use in Russian Polar Regions," Meteorol. Gidrol., No. 10 (2002) [Russ. Meteorol. Hydrol., No. 10 (2002)].
2. M. V. Bolgov, G. F. Krasnozhen, and A. A. Lyubushin, *The Caspian Sea: Extreme Hydrological Events* (Nauka, Moscow, 2007) [in Russian].
3. A. P. Braslavskii, "Correction of Precipitation Values," Trudy KazNII, No. 65 (1980) [in Russian].
4. L. P. Ostroumova, "Determination of Real Values of Precipitation from the Observations at Weather Stations Used in the North Caspian Water Balance," Trudy GOIN, No. 215 (2014) [in Russian].
5. L. P. Ostroumova, "Calculation of Surface Evaporation from Water Bodies in Delta Areas of Russian's Southern Seas," Meteorol. Gidrol., No. 9 (2004) [Russ. Meteorol. Hydrol., No. 9 (2004)].
6. L. P. Ostroumova and V. F. Polonskii, "Water Balance Model of the North Caspian and Its Separate Parts and Estimation of River Water Inflow to the Middle Caspian Sea," Trudy GOIN, No. 213 (2011) [in Russian].
7. V. F. Polonskii and L. P. Ostroumova, "New Water-balance Model of the Volga's Delta as the Way to Optimal Supervision by Its Water Rate," Ekologicheskie Sistemy i Pribory, No. 12 (2005) [Ecological Systems and Devices, No. 12 (2005)].