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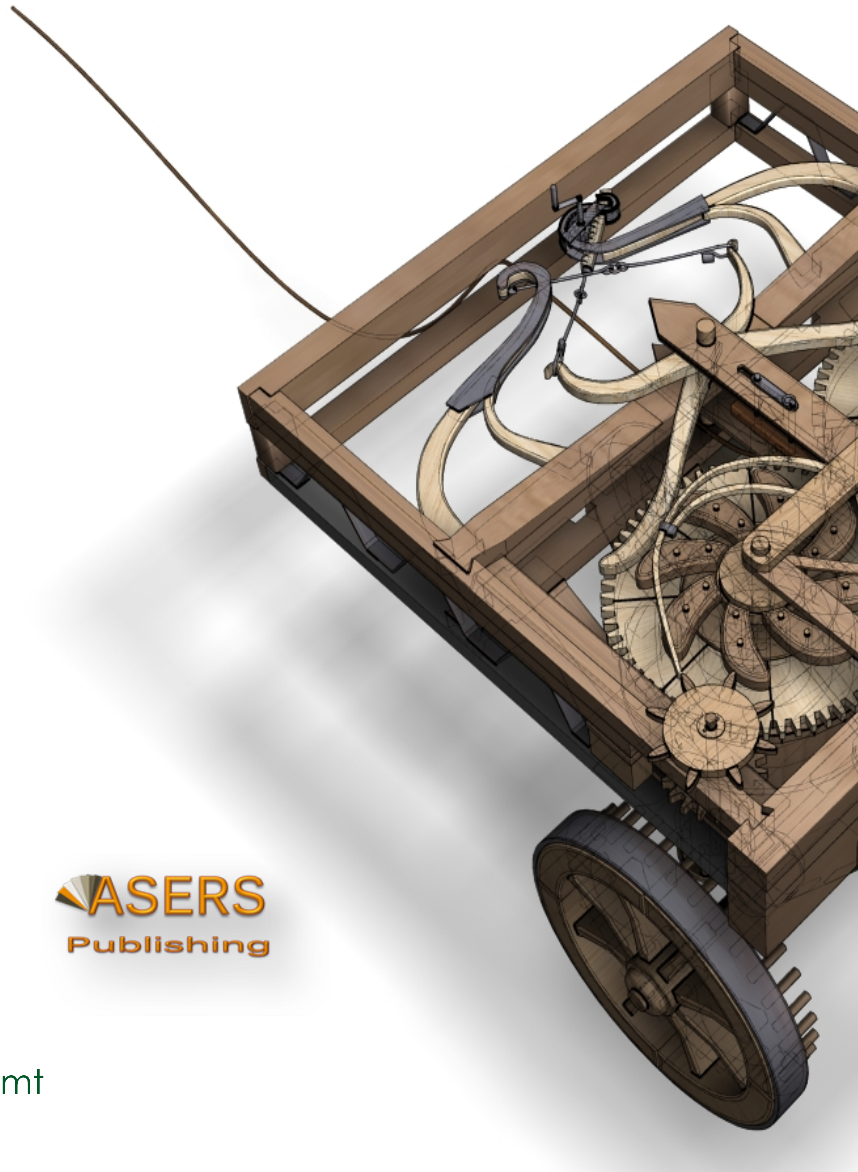

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Estimation of Spring Runoff Characteristics of Lowland Rivers in Kazakhstan

Dinara ARYSTAMBEKOVA
Al-Farabi Kazakh National University, Kazakhstan
darystambekova@mail.ru

Saken DAVLETGALIEV
Al-Farabi Kazakh National University, Kazakhstan
sdavletgaliev@mail.ru

Aleksandr CHIGRINETS
Al-Farabi Kazakh National University, Kazakhstan
ch.al.georg@mail.ru

Ainur MUSSINA
Al-Farabi Kazakh National University, Kazakhstan
mussina.aynur@gmail.com

Daulet JUSSUPBEKOV
Al-Farabi Kazakh National University, Kazakhstan
Daulet.Dzhusupbekov@kaznu.kz

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Abstract:

This paper considers the methods and results of determining statistical parameters for spring flood runoff by the main lowland river basins of Kazakhstan for the long-term period. It presents a series of observations made for the long-term period, determines statistical parameters for the depth of spring flood runoff as well as constructs the probability curves of the depth of spring flood runoff by study areas. The paper also gives an estimation of the probability values of the depth of spring flood runoff for the calculation period and for the last period of runoff formation in the context of ongoing climate change. These characteristics are determined by four river basins belonging to the lowland territory of Kazakhstan.

Keywords: calculation period; flood runoff; statistical parameters; normal runoff depth; coefficient of variation

JEL Classification: Q56; Q57

Introduction

The determination of the characteristics of spring river runoff is a very important hydro-economic task. The normal volume of spring runoff and the amount of maximum flood costs are widely used in the design and maintenance of hydraulic facilities. They serve as a kind of hydrological "standard", which is the basis for defining other runoff characteristics. Hydrological calculations and forecasts as well as the design of hydraulic facilities cannot but take into account data on long-term variations in water content of the river.

Naturally, the larger the number of observations on the regime of a river, the more valid and reliable the calculated hydrological characteristics (Shvets 1972). In terms of individual seasons, of particular importance, both in view of the ratio in annual runoff and for calculating the filling rate of ponds and reservoirs in the forest-steppe and steppe zones, is spring runoff. In addition, the spring runoff of large rivers after groundwater runoff cutting makes it possible to determine the spring runoff of small rivers and temporary streams of the forest-steppe and steppe zones, which at the same time constitutes their annual runoff in most cases. Since the main factor affecting the average of spring runoff is the amount of snow cover, having a zonal distribution, the middle depth of spring runoff has an expressed zonal distribution. But because part of spring runoff is accumulated in lakes, permeable soils, forests and swamps, the depth of spring runoff is subjected to local azonal factors to a greater extent than annual runoff.

Therefore, the latitudinal zoning of spring runoff suffers from the effect of local factors more than annual runoff (Sokolovsky 1968). The characteristics of spring runoff for the considered river basins were obtained in the 1960s-70s. These data need to be clarified with regard to recent observations and the impact of climatic and anthropogenic factors.

1. Methods

The object of this research is the main river basins of the lowland territory of Kazakhstan: Zhaiyk-Caspian, Tobol-Turgai, Yesil and Nura-Sarysu.

The river regime formation in the study area is largely determined by the following azonal factors: mostly by the flat nature of the terrain, which contributes to the wide flooding of rivers, numerous small closed depressions of the relief, which detain runoff and reduce flood rise, as well as sandy tracts – sites of the significant loss of surface runoff. In the main lowland spaces, melt water flows into the closed basins.

The conditions of runoff formation in the lowland territory of Kazakhstan differ from those in other areas in many respects. This is an area of deficient moisture with a pronounced continental climate, where the annual flow is low and determined by 80-90% by snowmelt runoff for flood period. Rain runoff is small, but the autumn soil moisture fluctuates from year to year in a very wide range (from 5-10 to 70-80 mm). The latter value is close to field capacity. The depth of soil freezing is large, so the degree of soil permeability during snowmelt is almost entirely determined by the degree of its hydration. The predominant soil is low-humic chernozems and chestnut soil. At sufficiently high moisture levels, these types of soil become almost impermeable and have a “blocking” impervious layer. At low soil moisture levels, they are able to absorb melt water to a considerable depth (Guide to hydrological forecasts 1989).

The climate of the lowland territory is defined by Kazakhstan’s intercontinental position as well as the nature of its surface. There is an increase in continentally from the west to the east. The degree of continentally is variable over time, and in summer it is weakened under the amplification of zonal circulation (Baidal 1964). A relatively simple surface topography provides a relatively correct latitudinal pattern in the distribution of meteorological characteristics.

Lowland Kazakhstan is open to almost unhindered penetration of air masses. Here come the Arctic, polar and tropical masses. Repeatability of various masses varies over time and in different parts of the country. The annual amount of precipitation changes on average in the territory, mainly from 140 mm to 380 mm, and the latitudinal direction of isohyets in the east are violated in connection with the relief. Apparently, a specific role is also played by both the Caspian Sea and the Aral Sea. The cold period is accounted for 20-40% of this amount, and spatial distribution is mottled.

In some years, precipitation can greatly deviate from average long-term values. For example, in Petropavlovsk its annual amount varies from 164 mm to 615 mm, which is almost 4 times more (The climate of Kazakhstan 1959; Research applied handbook on the climate of the USSR 1989). The seasonal snow cover is set in the north of the territory at the beginning of November, and collapses only in mid-April. Pre-spring snow cover ranges from at least 35 mm in the south-west to 80-90 mm in the region of Kokshetau Mountains, the most elevated part of the low hills. Their variations over time are large: in different years they may vary 4-5 times (Semenov 1986, Surface water resources of the USSR 1966, Galperin *et al*. 2011).

The paper used the following methods: geographical and hydrological; landscape differentiated analysis; the method of map definitions; system analysis, the analysis of actual observations on river water runoff; hydrological analogy. The methods of mathematical statistics were commonly used to estimate the hydrological series for homogeneity, in-row correlation and representativeness as well as to receive the studied characteristics of various probabilities.

The calculation technique with the availability of observed data is as follows. Depending on the availability of information on the river runoff regime, the normal runoff rate was calculated:

- through the data of direct observation on river runoff for a sufficiently long period, which makes it possible to determine the normal runoff rate with a given accuracy;
- by comparing the average annual runoff, obtained in a short period of observation (n ≥ 6 years), and the multi-year rate through a long series of the river-analog;
- in the entire absence of observations – by hydrological analogy, *i.e.* based on characteristics of the average runoff obtained as a result of the generalization of observations on other rivers of the area.

With the availability of observed data, the normal runoff rate, as any arithmetic mean of statistical series, was determined by the formula:

$$\overline{Q_N} = \frac{Q_1 + Q_2 + \dots + Q_N}{N} = \frac{\sum_{i=1}^{N} Q_i}{N}, \qquad (1)$$

where: $\overline{Q_N}$ – normal runoff, м³/с, Q_1, Q_2…..Q_N – annual runoff values for the period N.

The calculated coefficients of variation C_v and asymmetry C_s for three-parameter gamma distribution and binomial distribution with regard to parameter bias was given by:

$$C_v = \left(a_1 + \frac{a_2}{n}\right) + \left(a_3 + \frac{a_4}{n}\right)\overline{C_v} + \left(a_5 + \frac{a_6}{n}\right)\overline{C_v}^2, \qquad (2)$$

$$C_s = \left(b_1 + \frac{b_2}{n}\right) + \left(b_3 + \frac{b_4}{n}\right)\overline{C_s} + \left(b_5 + \frac{b_6}{n}\right)\overline{C_s}^2, \qquad (3)$$

where: a_1, …, a_6; b_1, …, b_6 – coefficients determined from Table 3 and Table 4 given in Manual on the definition of calculated hydrological characteristics (1984); $\overline{C_v}$ and $\overline{Cs}$ – biased estimates of the coefficients of variation and asymmetry respectively, determined by the known formulas of the method of moments.

If the relative error of the multi-year value $\overline{Q_N}$ does not exceed 5-10%, the observation period is considered sufficient for establishing the calculated value of the normal annual runoff.

In the system of calculating the annual normal runoff rate and the values of its estimated probability, we often have to deal with a short series of observations, the duration of which does not ensure the achievement of the result with the required accuracy (5-10%). In these cases, the average annual runoff rate obtained by the available short series is discounted to the calculation long-term period by rivers-analogues which have a long series of observations. The short series was discounted to the long-term period by the analytical method – the regression equation, if the number of years of joint observation was n ≥ 6 years. At n < 6 years, the determination of runoff values for each year or the normal runoff rates was implemented by the method of relations based on the approximate equality of modular coefficients in brief observations and analogs (Rozhdestvensky, Ezhov and Sakharyuk 1990).

To quantify the effectiveness of bringing the normal runoff rate to the long-term period, the performance indicator was used (K_y):

$$K_y = \left[\sqrt{1 - R^2 + \frac{R^2}{N}}\right]^{-1}, \qquad (4)$$

where: R is the coefficient of pair correlation, *n* – the number of years of joint observation.

The performance indicator characterizes the percentage of decrease in the mean when the series is discounted to the period N. The performance indicator of bringing the coefficient of variation to the long-term period (K_{cv}) was determined by the same formula:

$$K_{C_v} = \left[1 - \sqrt{\frac{1}{n}\left(1 - \frac{N-n}{N}R^2\right)}\right] \cdot 100 \tag{5}$$

The performance indicator K characterizes the percentage of decrease in the mean error and the coefficient of variation when the series is discounted to the long-term period. The main parameters of the probability curve determining the calculated hydrological characteristics are the norm and the coefficient of runoff variation. When making various water management arrangements in the basin, one needs to know the accuracy of these parameters.

The estimation of accuracy of the norm and the coefficients of annual runoff variation is particularly important for rivers of the lowland territory of Kazakhstan, the runoff of which is characterized by high variability and often over-regulation. It is also necessary to take into account the poor exploration of the area itself, the poor quality of materials for measuring the flow rates as well as the short duration of the series of observations on many rivers and settlements.

The accuracy of determining the parameters of the probability curve was estimated according to actual observations, with a series discounted to the long-term period and a series of the last thirty-nine-year period (1974-2012).

In the first case, the random mean square errors of sample means were defined by the relationship:

$$\sigma_{\bar{Q}} = \frac{\sigma}{\sqrt{n}}\sqrt{\frac{1+r}{1-r}}, \tag{6}$$

which is applied at a coefficient of autocorrelation between the adjacent members of the series r < 0,5. As a rule, for the series of annual runoff r = 0.2-0.3.

For example, for the study area according to the data of the main rivers, which have an observation period n > 30 years, it was established that the average regional value of the coefficient of spring runoff depth autocorrelation is equal to r = 0.20 and r = 0.30.

The analysis of empirical and analytic distribution functions showed that the distribution of the characteristics of spring runoff of the most rivers corresponds to the Kritsky-Menkel probability curve at Cs = 2 Cv, therefore, the average square errors of the coefficients of variation are determined by the relationship:

$$\sigma_{C_v} = \frac{C_v}{\sqrt{2n}}\sqrt{\left(1+3C_v^2\right)\frac{1+r^2}{1-r^2}} \tag{7}$$

Of particular interest is the accuracy of estimation of the norm and the coefficient of runoff variation, discounted to the long-term period. To estimate the standard error of the mean, discounted to the long-term period, the formula by Kritsky and Menkel (1981) is applied.

$$\sigma_{\bar{Q}_N} = \sqrt{\frac{1+r'_{QN}}{1-r'_{QN}}}\,\frac{\sigma}{\sqrt{n}}\sqrt{\frac{N-(N-n)R^2}{N}} \tag{8}$$

where: r'_{QN} is the coefficient of autocorrelation of the series Q, discounted to the long-term period N; R – the coefficient of inter-series correlation between the given series of observations and the analogue over the joint observation period (n).

The estimation of standard error of the coefficient of variation was made using the formula:

$$\varepsilon_{C_V} = [illegible] \qquad (9)$$

The expressions (4) and (5) are applicable for the estimation of accuracy of the mean and the coefficient of variation, discounted to the long-term series period using one regression equation. The formulas (8) and (9) were obtained with regard to the number of equivalent periods $N_Э$, *i.e*. the amount of information, which is equivalent to the observed data. With the gradual recovery of the values of a series of hydrological characteristics, *i.e.* with the use of several regression equations for different periods, the amount of equivalently independent information is determined for each recovery period, and the total amount of information is calculated as the sum of these pieces of information.

The amount of information, which is equivalent to the observed data, was determined according to the norm $N_{Э\bar{Q}}$ and the standard square deviation $N_{Э\sigma}$ by the formulas (4, 5, 6):

$$N_{Э\bar{Q}} = \frac{N}{\left[1 + \frac{N-n}{n-2}\left(1-R^2\right)\right]} \qquad (10)$$

$$N_{Э\sigma} = \frac{Nn}{n + (N-n)\left(1-R^4\right)} \qquad (11)$$

where: n is the number of years of joint observation by a discounted series and a series of analogues; (N - n) – the number of recovered series members by the regression equation; R – the coefficient of pair or multiple correlation.

The equivalent periods defined by the formulas (10) and (11) make it possible to calculate the average square deviations of these parameters directly through the formulas (6) and (7), if n is substituted with relevant Ne. The accuracy of the normal spring runoff depth rate was estimated through the formulas (6) and (7) based on the amount of equivalent information.

3. Results and discussion

The results of the research are presented for each water basin.

3.1. The normal rate and variability of depth of the rivers of Zhaiyk-Caspian Basin

The normal rate and variability of spring runoff depth of the main rivers of Zhaiyk-Caspian Basin is estimated by nine points of observation. The data are presented in four versions: by the actual data of observations on the water flow rate, by the data discounted to the long-term period (1940-2012), over the last thirty-eight-year period (1975-2012) and over the conditional natural period (1940-1974).

The second important parameter required for estimating the characteristics of runoff of various probabilities is the coefficient of variation of annual runoff. In accordance with the requirements of regulatory documents (Manual on the definition of calculated hydrological characteristics 1984; Rozhdestvensky, Ezhov and Sakharyuk 1990; Rulebook SP 33-101-2003, 2004; SNIP 2.01.14-83, 1983), the calculation error of the normal runoff rate should not exceed 15%.

The comparison of the normal spring runoff rate of two periods 1940 - 2012 and 1975 - 2012 shows an overall reduction in runoff of the last thirty-eight-year period in contrast to the data of the first period. In general, a decrease in runoff in the basin is 1.16% - 48.1%, on average 13.3%. For example, on the river Yelek (Aktobe city) it is respectively equal to 5.2%. The largest decrease in the normal rate is found on the rivers Ulken Kobda, Shyngyrlau (Utva), Oiyl, Or, Temir (12.3% - 22.9%).

The calculation results also show a decrease in the values of the coefficients of variation of spring runoff in almost all cases. Only in a few cases, some increase is observed. On average, its decrease in the basin is 14.0%.

Studies have shown that in all the rivers considered over both compared periods, there was a decrease in the values of spring runoff depth. The coefficients of variation of the compared periods were not significantly different, but there was a slight decrease in their values.

After the series of observations was discounted to the long-term period, the accuracy of estimation of the normal spring runoff rate was slightly increased by 1-2% on average*, i.e.* the error of calculation was 14%. The extension of the series of observations led to an increase in the accuracy of calculation of the normal runoff rate not in all cases. For example, on the river Or' (Bugetsay village) and Shyngyrlau (Kentubek village) the accuracy of calculation of the normal runoff rate slightly dropped, by 0.5-1.0% on average, due to a slight increase in the coefficient of variation. After the series of observations was discounted to the long-term period, the error of calculating the coefficient of variation decreased on average by 3.2% in the basin.

Thus, the results of calculating the parameters of spring runoff depth of the rivers of Zhaiyk-Caspian Basin show that, except for certain points, the accuracy of estimation of the norm and the coefficient of runoff variation does not fully meet the requirements set forth in (Manual on the definition of calculated hydrological characteristics 1984, Rozhdestvensky, Ezhov and Sakharyuk 1990, Rulebook SP 33-101-2003, 2004, SNIP 2.01.14-83, 1983). The low accuracy of estimation can be explained by the high variability of runoff, the difficulty in accounting the impact of economic activity and the insufficient duration of the series of observations.

The effectiveness of bringing the norm and the coefficients of spring runoff depth variation to the long-term period was estimated. Calculations were made by the formulas (4) and (5). If the performance indicators K_y (normal runoff depth) and K_{Cv} (the coefficient of variation) ≥ 60%, bringing them to a multi-year period is considered to be effective. The performance indicator of normal spring runoff depth was 98-44% and the coefficient of variation – 92-41%.

3.2. The normal rate and variability of spring runoff depth of the rivers of Tobol-Torgai Basin

The normal runoff rate of the rivers of Tobol Basin was estimated by four stream gauges. The data were obtained in the following ways: by the actual data of observations on the water flow rate, by the data discounted to the long-term period (1938 - 2012), over the last recovered thirty-eight-year period (1975 - 2012) and over the conditional natural period (1938 - 1974).

The analysis of comparing the normal spring runoff rate of two periods 1932 - 2012 and 1975 - 2012 shows a decrease in runoff over the last thirty-eight-year period in contrast to the total calculation period, except for one cross section (the river Tobol – Kostanay city). A decrease in runoff around the entire basin of the river Tobol is 12% on average. For the river Tobol (Kostanay) the values of spring runoff depth showed an increase of 7.44%. In all cases, the results of calculations for the considered periods show a decrease in the values of the coefficients of spring runoff variation. A decrease in the values of the coefficients of variation ranged from 12.2% to 65.7%. The average value of this indicator for the entire basin of the river Tobol was 33.5%.

In the observation points of the Tobol river basin on the river Togyzak (Togyzak village), Tobol (Grishenkov village), Ayat – (Varvarinka), the estimates of the values of spring runoff depth are slightly more than the calculation accuracy (23.2%-17.3%). On average, the estimate of accuracy of the coefficients of variation was 21.3%.

The extension of the series led to an increase in the accuracy of calculation of the normal runoff rate. After the series of observations was discounted to the long-term period, the accuracy of estimation of the normal spring runoff rate generally rose from 11.6% to 24.7%, averaging 15.8%, *i.e*. amounting to the figure just above the permissible value. The error calculation of the normal spring runoff rate of the river Tobol (Kostanay), according to the observed data, is 25.1%, and according to the recovered data over the conditional natural period (1938 - 2012) - 11.6%; on the river Tobol (Grishenkov) – 20.7% and 14.0% respectively.

After the series of observations was discounted to the long-term period, the calculation error of the coefficient of variation decreased on average by 7.4% in the basin.

Thus, the results of calculating the parameters of spring runoff depth of the main rivers of Tobol Basin show that, except for the river Ayat (Varvarinka village), the accuracy of estimation of the norm and the coefficient of runoff variation meets the requirements set forth in (Manual on the definition of calculated hydrological characteristics 1984, Rozhdestvensky, Ezhov and Sakharyuk 1990, Rulebook SP 33-101-2003 2004; SNIP 2.01.14-83, 1983).

The effectiveness of bringing the norm and the coefficients of spring runoff depth variation of Tobol Basin to the long-term period was estimated. The performance indicator of the norm of spring runoff depth is from 100% to 59.7% and the coefficient of variation – from 10% to 38.4%.

The normal runoff rate of the main rivers of Torgai Basin is estimated by four hydrological gauges. The data were also obtained in four versions: by the actual data of observations on the water flow rate, by the data discounted to the long-term period (1932 - 2012 for the river Torgai (Tosym), Kara Torgai (Akotkel) and 1940 - 2012 for the river Yrgyz (Dongeleksor) and Yrgyz (Shenbertal), over the last recovered thirty-nine year period (1974 - 2012) and over the conditional natural period (1932 - 1973).

The comparison of the normal spring runoff rate for the periods of 1932 - 2012, 1940 - 2012 and 1974 - 2012 shows an overall reduction in runoff by individual gauges of the last thirty-nine year period in contrast to the data of the first period. A general decrease of runoff in the basin ranges from 1.3% to 27.4%. The largest fall in the normal runoff rate was observed on the river Yrgyz (Dongeleksor) – 22.3% and on the river Yrgyz (Shenbertal) – 27.4%.

In individual stream gauges, there is an increase in the value of spring runoff depth. For example, on the river Kara Torgai (Akotkel) it rose by 0.5%, The calculation results show a decrease in the values of the coefficients of spring runoff variation in almost all cases, except for one, where there is some increase in its value. A decrease in the coefficient of variation in the considered basin amounts from 6.0% to 39.1%, on average – 22.8%. The greatest decrease is observed on the river Yrgyz in the cross sections of Dongeleksor village and Shenbertal village (30.5% and 39.1%).

After the series of observations was discounted to the long-term period, the accuracy of estimation of the normal spring runoff rate as a whole increased from 0.8% to 12.7%. *For example*, the calculation error of normal spring runoff of the river Torgai (Tosym), according to the observed data, was 17.6%, and according to the recovered data over the conditional natural period of 1932 - 2012 – 16.1%.

After the series of observations was discounted to the long-term period, the calculation error of the coefficient of variation in the entire basin decreased by 3.3% - 9.1%. The calculation error of the coefficient of spring runoff variation of the river Torgai (Tosym), according to the observed data, was 16.1%, and according to the recovered data over the conditional natural period of 1932 - 2012 – 12.8%. The calculation error of the coefficient of variation for the entire Torgai Basin was 12.4% on average.

Thus, the results of calculating the parameters of spring runoff depth of the rivers of Torgai Basin show that, except for certain points, the accuracy of estimation of the norm and the coefficient of runoff variation does not fully meet the requirements set forth in (Manual on the definition of calculated hydrological characteristics 1984, Rozhdestvensky, Ezhov and Sakharyuk 1990, Rulebook SP 33-101-2003, 2004, SNIP 2.01.14-83 1983). The low accuracy of parameter estimation can also be explained the high variability of runoff, the difficulty in accounting the impact of economic activity and the insufficient duration of the series of observations.

The effectiveness of bringing the norm and the coefficients of spring runoff depth variation to the long-term period was estimated. Calculations were made by the formulas (4) and (5). The performance indicator of normal spring runoff depth is 100-85% and the coefficient of variation is 100-74%.

3.3. The normal rate and variability of spring runoff depth of the rivers of Yesil Basin

The normal rate and variability of spring runoff depth of the main rivers of Yesil Basin was estimated by eight rivers and points of observation. The data were obtained in four versions: by the actual data of observations on the water flow rate, by the data discounted to the long-term period (1933 - 2012), over the last thirty-eight year period (1975-2012) and over the conditional natural period (1933 - 1974).

The comparison of the normal spring runoff rate of two periods – 1933 - 2012 and 1975 - 2012 – shows both a decrease and an increase in normal runoff of the last recovered thirty-eight year period in contrast to the total calculation period. A decrease in runoff ranges from 0.65% (the river Yesil – Petropavlovsk city) to 6.9% (the river

Yesil – Astana city) with 3.0% on average. The largest increase in the normal spring runoff rate is found on the rivers Kalkutan (23.5%) and Zhabai (Atbasar city – 13.0%).

The calculation results also show a decrease in the values of the coefficients of variation of spring runoff. On average, a decrease in the values of the coefficients of variation of spring runoff in the basin was 12.1%. On the river Yesil (Petropavlovsk) there was the largest decrease (16.5%). The smallest decrease was observed on the river Zhabai (Atbasar) – 2.8%.

After the series of observations was discounted to the long-term period, the accuracy of estimation of the normal spring runoff rate was mainly increased. The calculation error of normal spring runoff of the river Yesil (Astana), according to the observed data, was 25.5%, and according to the recovered data over the conditional natural period of 1933 - 2012 – 11.4%. For the point of Petropavlovsk city, these figures were 34.7% and 12.7%, respectively.

After the series of observations was discounted to the long-term period, the error of calculating the coefficient of variation in the basin decreased on average by 6.7%.

Thus, the results of calculating the parameters of spring runoff depth of the rivers of Yesil Basin show that the accuracy of estimation of the norm and the coefficient of runoff variation fully meets the requirements set forth in Manual on the definition of calculated hydrological characteristics, 1984; Rozhdestvensky, Ezhov and Sakharyuk, 1990; Rulebook SP 33-101-2003, 2004; SNIP 2.01.14-83, 1983. As a result of calculating the effectiveness of bringing the average values of spring flood runoff depth and the coefficient of variation to the long-term period, it has been revealed that the effectiveness of bringing the normal runoff rate in the basin ranges from 99.8% to 62.9% on average, and the coefficient of variation – 99.6%-61.8 %.

3.4. The normal rate and variability of spring runoff depth of the rivers of Nura-Sarysu Basin

The normal rate and variability of spring runoff depth of the river Nura was estimated by four points of observation. The data are presented in four versions: by the actual data of observations on the water flow rate, by the data discounted to the long-term period (1932 - 2012), over the last thirty-nine year period (1974 - 2012) and over the conditional natural period (1932 - 1973).

The comparison of the normal spring runoff rate of two periods: 1932 - 2012 and 1974 - 2012 shows a general increase in runoff of the last thirty-nine year period in contrast to the data of the first period. An increase in runoff in the basin is 1.65%-54.6% with 18.7% on average. The long-term annual average depth of spring runoff on the river Nura (Besoba village) over the two considered periods (1932 - 2012 and 1974 - 2012) remains unchanged at 13.6 mm.

The calculation results show both a decrease and an increase in the values of the coefficients of variation of spring runoff. On average, its decrease is 24.6%. An increase in the values of the coefficients of variation of spring runoff amounts to 7.2% on average.

After the series of observations was discounted to the long-term period, the accuracy of estimation of the normal spring runoff rate was largely increased – by 3.8% - 24.3%. The calculation error of normal spring runoff depth was 13.6% on average. The extension of the series of observations in all considered cases led to an increase in the accuracy of calculation of the normal runoff rate. After the series of observations was discounted to the long-term period, the error of calculating the coefficient of variation decreased on average by 5.9%. The smallest decrease was observed on the river Nura (Romanovskoe village) – by 2%. The error of calculating the coefficient of variation of spring runoff depth of the river Nura in the basin was 13% on average.

Thus, the results of calculating the parameters of spring runoff depth of the rivers of Nura Basin show that the accuracy of estimation of the norm and the coefficient of runoff variation fully meets the requirements set forth in Manual on the definition of calculated hydrological characteristics (1984), Rozhdestvensky, Ezhov and Sakharyuk (1990), Rulebook SP 33-101-2003, 2004; SNIP 2.01.14-83, 1983.

The effectiveness of bringing the norm and the coefficients of spring runoff depth variation to the long-term period was estimated. Calculations were made by the formulas (4) and (5). The performance indicator of normal spring runoff depth is 99-75% and the coefficient of variation – 99-61%.

The normal runoff rate of the main rivers of Sarysu Basin was estimated by three rivers and points of observation. The data are presented in four versions: by the actual data of observations on the water flow rate, by the data discounted to the long-term period (1932 - 2012), over the last forty-seven year period (1966 - 2012) and over the conditional natural period (1932 - 1965).

The comparison of the normal spring runoff rate of two periods – 1932 - 2012 and 1966 - 2012 – shows both a decrease and an increase in normal spring runoff depth of the last forty-seven year period in contrast to the data of the first period. A decrease in runoff in the basin was 13% on average. On the river Zhaksy Sarysu (Sarysu village) it was 16.0%. The largest decrease in the normal rate is found on the river Sarysu (a passing loop of 189 km) – 30%.

The calculation results show both a decrease and an increase in the values of the coefficients of variation of spring runoff depth. On average, its decrease in the basin is 11.4%. After the series of observations was discounted to the long-term period, the accuracy of estimation of the normal spring runoff rate was slightly increased – by 1-2% on average, i.e. the calculation error of normal runoff was 10-15%. After the series of observations was discounted to the long-term period, the error of calculating the coefficient of variation decreased on average by 4.6%.

The calculation error decreased by 4.2% on the river Sarysu – a passing loop of 189 km. The error of calculating the coefficient of variation of spring runoff depth of the river Sarysu (189 km), according to the observed data, is 17.9%, and according to the recovered data over the conditional natural period of 1932 - 2012 – 16.7%. For the point of the river Zhaksy Sarysu (Sarysu village) these figures are 16.8% and 13.2%, respectively. The error of calculating the coefficient of variation in the entire district is 15.8% on average.

Thus, the results of calculating the parameters of spring runoff depth of the considered rivers of Sarysu Basin show that the accuracy of estimation of the norm and the coefficient of runoff variation does not meet the requirements set forth in Manual on the definition of calculated hydrological characteristics, 1984; Rozhdestvensky, Ezhov and Sakharyuk, 1990; Rulebook SP 33-101-2003, 2004; SNIP 2.01.14-83, 1983.

As a result of calculating the effectiveness of bringing the average values (norm) of spring flood runoff depth and the coefficient of variation to the long-term period, it has been revealed that the effectiveness of bringing the normal runoff rate in the basin ranges from 100% to 62% on average, and the coefficient of variation – 98%-53%.

3.5. Calculation of the characteristics of spring flood runoff of various probabilities

On the lowland rivers of Kazakhstan, the bulk of annual runoff is melt water, which determines a huge role of spring flood in the formation of the general regime of rivers. The main result of the research was the calculation of the characteristics of spring flood runoff of various probabilities. Calculations were carried out with regard to the recovered series of the main rivers of lowland Kazakhstan. The norms and the coefficients of variation were obtained by calculation, and the third parameter of runoff – the coefficient of asymmetry – was defined by the extent to which the data of observations complied with the theoretical probability curve. The analysis of the data of most rivers showed that the most suitable type of the probability curve of spring flood runoff of the district rivers was the Pearson Type III curve at $C_s = 2C_v$. The parameters obtained as a result of the conducted studies are shown in Table 1.

3.5.1. The probability values of spring flood runoff of the rivers of Zhaiyk-Caspian Basin

The probability values of spring flood runoff of the rivers of Zhaiyk-Caspian Basin are defined by the long-term data discounted to the period of 1940-2012 and over the last thirty-eight year period: 1975-2012. The obtained norms, coefficients of variation and depth of spring river runoff of various probability, calculated for the periods indicated, are shown in Table 1.

3.5.2. The probability values of spring runoff of the rivers of Tobol-Torgai Basin

The probability values of spring runoff depth of the rivers of Tobol Basin are calculated with regard to the long-term data discounted to the period of 1938 - 2012 and over the last thirty-eight year period: 1975 - 2012 (Figure 1).

The probability values of spring runoff depth of the rivers of Torgai Basin are defined by the long-term data discounted to the period of 1932 - 2012 and 1940 - 2012 (for the river Yrgyz (Dongeleksor village), Yrgyz (Shenbertal village) and over the last thirty-nine year period 1974 - 2012. The obtained norms, coefficients of variation and depth of spring river runoff of various probabilities, calculated for the periods indicated, are shown in Table 1.

3.5.3. The probability values of spring runoff of the rivers of Yesil Basin

The probability values of spring runoff depth of the rivers of Yesil Basin are calculated with regard to the long-term data discounted to the period of 1933-2012 and over the last thirty-eight year period 1975 - 2012. The obtained norms, coefficients of variation and depth of spring river runoff of various probabilities, calculated for the periods indicated, are shown in Table 1. The third parameter of runoff – the coefficient of asymmetry – was defined by the extent to which the data of observations complied with the theoretical probability curve.

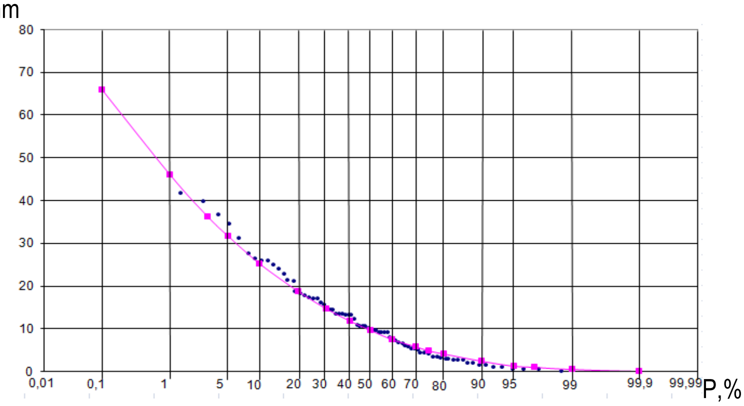
3.5.4. The probability values of spring runoff of the rivers of Nura-Sarysu Basin

The probability values of spring runoff depth of the main rivers of Nura Basin are determined through the long-term data discounted to the period of 1932 - 2012 and over the last thirty-nine-year period: 1974 - 2012.

The probability values of spring runoff depth of the main rivers of Sarysu Basin are determined through the long-term data discounted to the period of 1932 - 2012 and over the last thirty-seven-year period – 1966 - 2012. The obtained norms, coefficients of variation and depth of spring runoff of various probabilities for the rivers of Nura-Sarysu Basin, calculated for the periods indicated, are shown in Table 1.

Figure 1. The probability curve of spring runoff depth (h, mm) of the river Tobol – Kostanay city for the periods a) 1933 - 2012 and b) 1975 - 2012

a) h, mm



b) h, mm

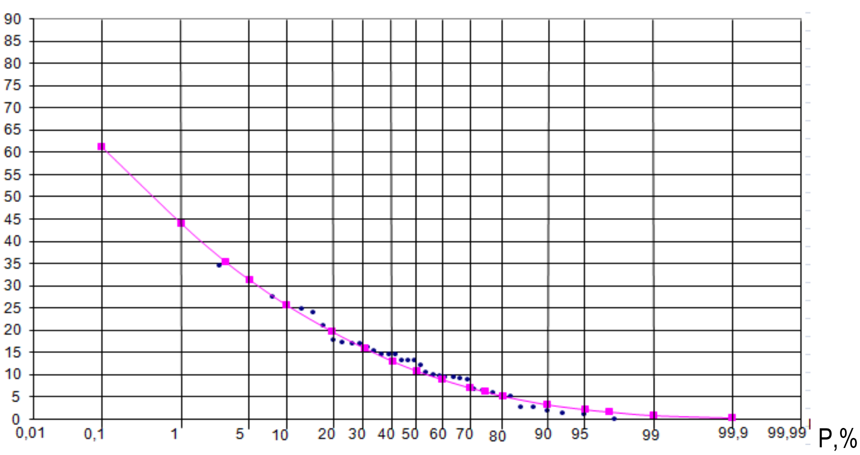


Table 1. Norms and coefficients of variation of spring flood runoff depth of various probability for the calculation period of 1932 (1933, 1938, 1940)-2012 and the last period of 1966 (1974, 1975)-2012, (h_{avg}, mm)

No	River-point	Average runoff depth / coefficients of variation (h_{avg}/C_v)		Spring runoff depth for the calculation period								Spring runoff depth for the last period							
		For the calculation period	For the last period	5%	10%	25%	50%	75%	90%	95%	97%	5%	10%	25%	50%	75%	90%	95%	97%
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	1. Zhaiyk-Caspian Basin																		
1	Zhaiyk - Atyrau city	25,2/0,59	23,9/0,50	53,4	45,1	33,2	22,4	14,1	9,07	6,55	5,29	46,4	39,9	30,6	24,9	15,1	10,3	8,13	6,93
2	Or' - Bugetsay vil.	23,0/0,92	19,9/0,91	64,9	50,8	32,2	17,0	8,05	3,45	1,84	0,92	55,7	43,8	27,9	14,7	6,97	2,99	1,59	0,80
3	Yelek - Aktobe city	42,1/0,62	44,0/0,50	97,6	80,4	56,4	35,8	21,0	12,2	8,25	6,32	85,4	73,5	56,3	40,5	27,74	18,9	15,0	12,8
4	Bolshaya Kobda – Novoalekseevka vil.	19,2/0,96	14,8/0,89	55,9	43,4	26,5	13,8	5,95	2,30	1,15	0,77	40,8	32,4	29,4	11,0	5,18	2,22	1,18	0,74
5	Shyngrlau (Utva) – Kentubek vil. (Grigorievka)	20,5/0,77	16,8/0,75	63,8	48,2	26,4	13,7	5,33	1,85	0,82	0,41	41,3	33,6	23,0	13,8	6,55	4,03	2,52	1,85
6	Shagan – Kamennyi vil.	49,9/0,66	46,4/0,56	113	93,8	66,8	42,9	26,0	15,0	10,5	7,98	95,6	81,2	60,5	41,8	27,4	18,1	13,5	11,1
7	Oiyl-aul Alty-Karasu	17,6/1,00	14,5/1,17	52,8	40,5	24,8	12,1	5,10	1,76	0,88	0,53	48,0	36,2	20,2	8,85	3,19	0,87	0,29	0,15
8	Zhem (Emba) – Zharkamys vil.	13,5/0,62	12,6/0,55	37,3	2,7	18,8	10,1	4,76	2,16	1,22	0,68	25,7	22,4	16,4	11,3	7,56	4,91	3,78	3,02
9	Temir – Leninskiy vil.	26,8/0,79	23,5/0,74	68,3	54,9	36,7	26,5	11,5	5,90	3,48	2,68	57,3	44,6	31,7	19,5	10,8	5,88	3,76	2,82
	2. Tobol-Torgai Basin																		
1	Tobol – Grishenka vil.	16,4/0,99	15,3/0,60	49,2	37,8	26,4	11,8	4,72	1,72	0,84	0,49	56,7	39,9	24,7	7,50	1,93	0,35	0,10	0,04

No	River-point	Average runoff depth / coefficients of variation (h_{avg}/C_v)		Spring runoff depth for the calculation period								Spring runoff depth for the last period							
		For the calculation period	For the last period	5%	10%	25%	50%	75%	90%	95%	97%	5%	10%	25%	50%	75%	90%	95%	97%
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
2	Tobol – Kostanay city	12,1/0,81	13,0/0,70	31,6	25,3	18,8	9,56	4,88	2,38	1,36	0,97	31,3	25,6	19,6	10,9	6,18	3,37	2,19	1,68
3	Ayat – Varvarinka vil.	17,1/1,15	13,9/0,59	56,6	41,9	27,8	10,4	3,71	1,06	0,39	0,21	29,8	25,2	19,9	12,3	7,73	4,89	3,56	2,81
4	Togyzak - st. Togyzak	8,9/0,89	7,09/0,58	24,8	19,5	14,0	6,66	3,13	1,37	0,73	0,41	14,9	12,6	10,1	6,32	4,06	2,62	1,94	1,55
5	Torgai - Tosym sands	5,14/1,17	5,02/0,92	17,5	12,8	7,12	2,98	1,03	0,26	0,08	0,04	14,2	11,1	7,00	3,71	1,71	0,70	0,38	0,22
6	Kara Torgai – Akotkel vil.	18,6/0,83	18,7/0,78	48,9	39,1	25,8	14,5	7,44	3,53	2,05	1,49	47,3	38,2	25,8	15,2	8,04	4,11	2,43	1,83
7	Yrgyz – Dongeleksor vil.	19,3/1,31	15,0/0,81	69,5	49,6	26,3	10,0	2,90	0,58	0,17	0,07	38,8	31,2	20,8	12,0	6,15	3,00	1,80	1,26
8	Yrgyz – Shenbertal vil.	15,3/1,38	11,1/0,84	58,1	40,4	20,6	7,04	1,68	0,24	0,06	0,02	29,4	23,4	15,4	8,66	4,33	2,11	1,17	0,79
	3. Yesil Basin																		
1	Silety – Prirechnoe vil.	22,1/0,98	21,7/1,03	67,3	51,3	31,0	15,0	6,22	2,22	1,13	0,73	67,4	51,0	30,5	14,5	5,73	1,95	0,87	0,50
2	Shagalaly – Pavlovka vil.	17,8/0,82	18,6/0,79	50,6	40,0	25,8	14,1	6,95	3,24	1,90	1,25	51,8	41,1	26,9	15,0	7,71	3,78	2,36	1,70
3	Yesil- Astana city	24,6/0,78	22,9/0,81	62,1	50,2	33,9	19,9	10,6	5,44	3,25	2,41	62,0	49,0	31,8	17,5	8,74	4,20	2,56	1,77
4	Yesil - Petropavlovsk city	15,3/0,85	15,2/0,71	40,9	32,5	21,3	11,8	5,88	2,77	1,55	1,03	40,0	31,0	19,8	11,0	6,30	4,24	3,66	3,47
5	Kalkutan- Kalkutan vil.	13,6/1,04	16,8/0,91	42,3	32,0	19,1	9,06	3,59	1,22	0,54	0,31	47,1	37,0	23,5	12,5	5,81	2,50	1,33	0,74
6	Zhabai – Balkashino vil.	33,1/0,71	36,6/0,63	78,7	64,6	45,0	27,8	16,0	8,80	5,79	4,44	86,8	71,5	50,4	32,0	19,3	11,6	8,48	6,97
7	Zhabai – Atbasar city	25,4/0,72	28,7/0,70	61,0	49,9	34,6	21,3	12,0	6,58	4,27	3,28	67,7	55,6	38,9	24,3	14,0	7,81	5,19	3,99

No	River-point	Average runoff depth / coefficients of variation (h_{avg}/C_v)		Spring runoff depth for the calculation period								Spring runoff depth for the last period							
		For the calculation period	For the last period	5%	10%	25%	50%	75%	90%	95%	97%	5%	10%	25%	50%	75%	90%	95%	97%
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
8	Imanburluk – Sokolovka vil.	16,9/0,92	17,6/0,84	40,3	28,4	24,8	12,5	5,52	2,21	1,33	0,96	50,6	39,8	25,4	13,7	6,57	3,06	1,82	1,20
4. Nura-Sarysu Basin																			
1	Nura – Besoba vil.	13,6/0,86	13,6/0,92	36,7	29,1	18,9	10,5	5,17	2,45	1,32	0,86	38,4	30,1	19,0	10,1	4,62	1,90	1,03	0,58
2	Nura – Sergiopolskoe vil.	10,2/0,75	12,0/0,62	25,1	20,4	14,0	8,36	4,59	2,45	1,53	1,12	26,3	22,0	16,2	10,6	6,48	4,08	2,88	2,28
3	Nura – Romanovskoe vil.	9,49/0,85	10,2/0,79	25,4	20,2	13,2	7,31	3,61	1,71	0,95	0,66	26,0	20,9	14,1	8,21	4,28	2,14	1,33	0,95
4	Sherubainura - Kara-Murun (pass.loop)	12,6/0,92	12,7/0,91	35,6	27,9	17,4	9,29	4,27	1,81	0,96	0,54	35,6	27,9	17,5	9,42	4,39	1,89	1,00	0,56
5	Sarysu - pass.loop No. 189 (57)	2,51/1,44	1,74/1,34	9,74	6,70	3,25	1,08	0,23	0,03	0,01	0,00	6,44	4,53	2,30	0,85	0,22	0,04	0,01	0,00
6	Kara Kengir – 5.0 km (12 km) above the mouth of the river Zhilandy	11,7/0,95	12,7/0,82	33,8	26,3	16,2	8,42	3,74	1,51	0,77	0,44	33,2	26,5	17,4	10,0	5,12	2,50	1,42	1,02
7	Zhaksy-Sarysu – Sarysu vil.	25,6/1,06	21,5/1,10	79,6	60,2	35,5	17,1	6,76	2,30	1,02	0,59	69,2	51,6	29,9	13,8	5,18	1,59	0,65	0,34

Conclusion

The norm of the spring runoff depth for the rivers of Zhaiyk-Caspian Basin was defined by ten points, Yesil Basin – eight points, Tobol-Turgai - eight points, Nura-Sarysu – seven points. The coefficients of variation and asymmetry are calculated with regard to the negative parameter bias.

In Zhaiyk-Caspian Basin, the comparison of the normal spring runoff rate of two periods: 1940 - 2012 and 1975 - 2012 shows a general decrease in runoff of the last thirty-eight year period in contrast to the data of the first calculation period. In general, a decrease in runoff in the basin is 1.16%-48.1%, on average – 13.3%. The calculation results also show a reduction in the coefficient of variation of spring runoff depth in the basin by 14% on average.

The probability values of spring flood depth were defined. The probability values of runoff depth for the rivers of different districts were established primarily by the probability curve at Cs = 2Cv. The analysis of comparing the normal spring runoff rate of two periods: 1938 - 2012 and 1975 - 2012 for Tobol Basin shows a decrease in runoff over the last thirty-eight year period in contrast to the total calculation period. The calculation results for these periods also show a decrease in the values of the coefficients of spring runoff variation in almost all cases.

The comparison of the normal spring runoff rate of the rivers of Torgai Basin for the periods of 1932 - 2012, 1940 - 2012 and 1974 - 2012 shows an overall reduction in runoff by individual gauges of the last thirty-nine year period in contrast to the data of the first period. A general decrease of runoff in the basin ranges from 1.3% to 27.4%. The calculation results show a decrease in the values of the coefficients of spring runoff variation by all cross sections considered.

In Yesil Basin, the comparison of the normal spring runoff rate of two periods: 1933 - 2012 and 1975 - 2012 shows both a decrease and an increase in normal runoff of the last recovered thirty-eight year period in contrast to the total calculation period. The calculation results also show a decrease in the values of the coefficients of variation of spring runoff.

The normal runoff rate of Nura-Sarysu Basin was estimated by seven points of observation. In Nura Basin, the comparison of the normal spring runoff rate of two periods: 1932 - 2012 and 1974 - 2012 – shows a general increase in runoff of the last thirty-nine year period in contrast to the data of the first period. The calculation results show both a decrease and an increase in the values of the coefficients of variation of spring runoff.

The normal runoff rate of the rivers of Sarysu Basin was estimated by three rivers and points of observation. The comparison of the normal spring runoff rate of two periods: 1932 - 2012 and 1966 - 2012 shows both a decrease and an increase in runoff depth of the last forty-seven year period in contrast to the data of the first period. A decrease in runoff is 13% on average. The calculation results show both a decrease and an increase in the values of the coefficients of variation of spring runoff.

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