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# ASSESSMENT OF THE CALCULATED MAXIMUM SPRING FLOOD OF THE MAIN RIVERS OF CENTRAL KAZAKHSTAN

In this work, the maximum spring flood flow was calculated, statistical parameters of flow were estimated and independent runoff rates were determined. The statistical parameters of the spring flow depth and maximum water flow were determined for different characteristic periods. The methods of integrated and different integrated curves have been used to identify the features of the multi-year runoff in different basins. For the water basins under study the norms and coefficient of variation of the spring flow depth and maximum water discharge were calculated in 2 variants: based on actual observation data; for the last forty-five-year period (1970-2015); and for the conditionally-natural period (from the beginning of the representative period up to 1970), respectively on gauging stations: Selety river - Isobilnoye village, Yesil river - Turgenevka village, Moyildy river - Nikolaevka village, Zhabai river - Atbasar village, Zhabai river - Balkashino village, Selety river - Prirechnoye village, Yesil river - Astana city, Yesil river - Petropavlovsk city. The analysis of the agreement of empirical and analytical distribution functions has shown that the distribution of spring flow characteristics of most rivers corresponds to the Kritsky - Menkel frequency curve. The analysis of the mutual arrangement of the empirical frequency curve and the theoretical as well as the integral curves showed that the curve deviates least from the empirical points of the curve corresponding to the ratio $C_s/C_v = 2$. This curve was taken as a rated value.

**Key words:** water flow, integral curve, empirical curve, maximum flow, theoretical frequency curve.

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## Орталық Қазақстанның негізгі өзендерінің көктемгі су тасудың есептелген ең жоғарғы ағындысын бағалау

Бұл жұмыста көктемгі су тасудың ең жоғарғы ағынды өтімінің есебі анықталып, ағындының статистикалық параметрлері есептелді және ағындының қамтамасыздық шамалары айқындалды. Көктемгі ағынды қабатының және ең жоғарғы су өтімінің статистикалық параметрлері әр түрлі кезеңдерге сәйкес анықталды. Әр түрлі алаптардағы ағындының көпжылдық жүрісінің ерекшелігін анықтау мақсатында, жиынтық интеграл және айырымдылық интеграл қисықтары әдістері қолданылды (Методические рекомендации, 1986). Зерттеліп отырған су шаруашылық алаптар үшін көпжылдық орташа, көктемгі ағынды қабатының ауытқу коэффициенті мен ең жоғарғы су өтімінің мәндері 2 түрлі нұсқада есептелді: бақылау деректерінің фактілі мәндері, яғни соңғы қырық бес жылдық кезең бойынша (1970-2015 жж.); және шартты-табиғи кезең (репрезентативті кезеңнің басталуынан 1970 жылға дейін), сәйкесінше Селеті өзені – Изобильное ауылы, Есіл өзені – Түрген ауылы, Мойылды өзені – Николаевка ауылы, Жабай өзені – Атбасар ауылы, Жабай өзені – Балкашино ауылы, Селеті өзені – Приречное ауылы, Есіл өзені – Астана қаласы және Есіл өзені – Петропавловск қаласы бекеттері бойынша. Үлестірімнің эмпирикалық және аналитикалық функциялары келісімін талқылау көптеген өзендердің көктемгі ағындысы сипаттамаларының үлестірімі Крицкий-Менкельдің қамтамасыздық қисығына сәйкес екендігін көрсетті. Эмпирикалық және теориялық ($Cs/Cv = 1$ және $Cs/Cv = 2$) қамтамасыздық қисықтары өзара орналасуының талқылануы, эмпирикалық қамтамасыздық қисығынан ең аз алшақтаған $Cs/Cv = 2$ қатынасына сәйкес келетін теориялық қамтамасыздық қисығы екенін айқындады. Аталған қамтамасыздық қисығы есептік қамтамасыздық қисығы ретінде қолданылды.

**Түйін сөздер:** су өтімі, интегралдық қисық, эмпирикалық қисық, ең жоғарғы ағынды, теориялық қамтамасыздық қисығы.

 

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**Оценка расчетного максимального стока весеннего половодья основных рек Центрального Казахстана**

В данной работе был произведен расчет максимальных расходов воды весеннего половодья, вычислены статистические параметры стока и определены обеспеченные величины стока. Статистические параметры слоя весеннего стока и максимальных расходов воды определены за различные характерные периоды. Для выявления особенностей многолетнего хода стока в различных бассейнах использованы методы интегральных и разностных интегральных кривых. Для исследуемых водохозяйственных бассейнов нормы и коэффициент вариации слоя весеннего стока и максимальных расходов воды были рассчитаны в 2-х вариантах: по фактическим данным наблюдений; за последний сорокапятилетний период (1970-2015 гг.); и за условно-естественный период (от начала репрезентативного периода до 1970 г.), соответственно по гидропостам: р.Селеты – п.Изобильное, р.Есиль – п.Тургеневка, р.Мойылды – п.Николаевка, р.Жабай – п.Атбасар, р.Жабай – п.Балкашино, р.Силеты – п.Приречное, р.Есиль – г.Астана, р.Есиль – г.Петропавловск. Анализ согласия эмпирических и аналитических функций распределения показал, что распределение характеристик весеннего стока большинства рек соответствует кривой обеспеченности Крицкого – Менкеля. Анализ взаимного расположения эмпирической кривой обеспеченности и теоретической, а также интегральных кривых показал, что меньше всего отклоняется от эмпирических точек кривая, соответствующая отношению Cs/Cv = 2. Эта кривая была принята за расчётную.

**Ключевые слова:** расход воды, интегральная кривая, эмпирическая кривая, максимальный сток, теоретическая кривая обеспеченности.

## Introduction

The study and calculation of river maximum flow characteristics is a very important national economic task. If we consider the hydrological regime of rivers throughout зthe year (calendar, hydrological or hydroeconomic), the maximum flow will be understood as the highest water flow rate, volume or flow depth during the multi-hydrological phase - a high flood or flush flood.

The maximum flow is usually expressed by the highest (maximum) flow rate, volume or flow depth per main flood wave or the most high flood in a given year. The maximum water flow can be the highest average daily, urgent or instantaneous. On small rivers there may be significant differences between these characteristics, but the larger the river, the smaller the difference (Methodical Guidelines 2014: 28).

The problem of calculating maximum flow is not only one of the most important, but also the most difficult task in hydrological calculations. Assessment of the parameters of high floods and flush floods has great scientific and practical meaning.

From a scientific point of view, high floods and flush flood determine the general features of the runoff regime of the rivers in a given region. The volume of their flow represents the main part of the rivers' flow, and for small rivers in the arid zone it can represent the entire flow, so information on maximum flow is necessary when studying many aspects of the hydrological regime of rivers.

In practical terms, the maximum flow refers to the category of catastrophic phenomena of nature. Overflow water account for 40% of the all world's natural disasters. Catastrophic overflow water not only cause great material damage, but are sometimes accompanied by numerous human casualties (Arystambekova 2017: 14).

Under modern conditions, the water regime of Kazakhstan's rivers is undergoing significant changes. Human economic activity and climate changes make significant adjustments to the flow characteristics and river hydrological regime as a whole. In particular years, when catastrophic peaks are formed, there are river floods and flooding of immense territories, overflow water causing huge damage to the economy of the country (Schar 2004: 14). Therefore, the study and calculation of maximum flow rates of river are urgent hydrological problems of Kazakhstan (Cherednichenko 2016: 18).

The information basis for the study of the theme are materials from the observations of "Kazhydromet" RSE for 1932-2015: Hydrology annuals (HA), Annual data on land surface water regime and resources (ADS), Main hydrological characteristics (MHC), Multiyear data on land surface water regime and resources (MDS). Surface water resources of the USSR. The names of hydrological stations and rivers are given as they are given in the cadastre materials of "Kazhydromet" RSE (Surface Water Resources 1958: 790).

The highest value is usually the maximum flow, which determines the height of the water level rise, i.e. the flooded area, the stream velocity, i.e. the erosion capacity of the flow, and in general the water pressure on structures, especially in the case of overflow waters (Methodical Note 1986: 168).

**Objects and research methods**

Central Kazakhstan has both small and medium, as well as large rivers. Small rivers have flow only in spring period and dry up in summer. The Nura, Sarysu and Yesil rivers (the Yesil River is represented on the territory of Central Kazakhstan only by its upstream) are large rivers, while the Sherubainura, Sokyr, Zhaman-Sarysu and Kara-Kengir rivers are medium in terms of catchment areas (Surface Water Resources 1960: 420). The catchment area of the Yesil River is 177,000 km$^2$, of which about 20% of the area falls on the territory of Russia, within which about 30% of the flow is formed. Central Kazakhstan accounts for about 10% of the water catchment basin. Main tributary streams on the territory of Kazakhstan: right – Kalugoi, Zhabai, Akkanburluk, Imanburlyk; left – Terisakkan. On the territory of Central Kazakhstan, the right tributary stream of the Kargaly River flows into the Yesil River (Figure 1).


**Figure 1** – Scheme of location of hydrological posts and meteorological stations in the basin of the Yesil River

Rivers on the country's flatlands are mainly fed by snow with spring high water and belong to the special Kazakhstan type by water regime. Therefore, the main factors determining the annual flow of flatland rivers are the pattern of distribution of snow cover on the surface of catchments, water reserves in the snow, the degree of moisture and the depth of ground freezing by the beginning of snow melting, the intensity of snow melting. Water reserves in the snow by the end of winter, according to the latitudinal zonality, decrease from 100-80 mm in the north to 40-20 mm in the south. Summer rains have almost no effect on river nourishment, since at this time there is a deficit of air humidity and ground dryness so high that there is "enough" weather elements only for evaporation and wetting of the top soil layer (Guidebook 2004: 337). Snow melting in the basin in spring usually begins at negative air temperatures due to the inflow of heat from solar radiation. Since the onset of positive air temperatures, snowmelt has been intense. In an open area, snow cover melts within a few days, often 5-7 days. Fluctuations of water equivalent in snow are significant - up to 4-5 times, which determines the large fluctuations of flow during the high water period. The flatland relief of the territory favours the development of wind activity and uneven distribution of snow cover (Wang 2011: 12).

When calculating maximum flow, two problems usually have to be solved: – ensuring the accident-free operation of facilities and the safety of adjacent territories and the population; — not to overestimate the cost of facilities as a result of taking unnecessarily high water consumption (Methodical Guidelines 2014: 28).

Thus, it is necessary to scientifically combine and justify safety requirements and economic questions, and, ultimately, economic efficiency of hydro-technical utilities. For this purpose, the observed maximum water discharge is established on the basis of an analysis of the hydrological regime of the river and the probability of their overflow is calculated, and the maximum water flow of the required capacity (estimated annual probability of overflow) is ultimately determined. Estimated frequency is determined depending on the category of importance of the hydro-technical utility. In the presence of hydrological observation data, the task of calculation of the maximum flow is reduced to selection of a statistical scheme describing the law of distribution of the available range of values, determination of parameters of this distribution and calculation of flush flood (high water) characteristics of a given (calculated) probability of annual overflow (frequency).

The total surface water resources in the area under observation are about 2.76 km$^3$, of which the Yesil River basin is 2.40 km$^3$. Water management design of the Yesil River is based on a multiyear series of monthly runoff rates for the period most covered by observations (from 1930 to 2015).

Concerning the representativeness of series of data for the basin under observation, the following can be said. According to the presence of periods of low water level, the calculated range satisfies the condition of representativeness, as it includes adverse periods of low water level: 1930 - 1940, 1950 - 1953, 1967 - 1969, 1975 - 1978. Of all these periods, the low water level of 1930-1940 is distinguished, which in terms of flow deficit (relatively average) is much higher than the other periods. The range also includes periods of high water level: 1941-1942, 1946-1949, 1971-1972, but the high water level years are represented insufficiently and do not fully compensate the periods of low water level.

Using the collected data on hydrologic exploration degree of the area under study, a database on spring high water flow in the rivers of the Yesil water basin was created (Surface water resources 1960: 420). It contains information on spring high water flow from 33 gauging stations of the area under study. In addition, in order to reconstruct the series and bring them to a representative period, data on average annual flows at selected gauging stations were collected. There are 45 water reservoirs in the territory under observation.

In order to assess the water resources of an area, it is necessary to have a sufficiently long and representative series of observations which allow to reliably assess the calculated characteristics of annual flow. Due to the lack of such data for most rivers, the task of restoring the flow values that have been missed arises using the materials of similar rivers, i.e. using the hydrological analogy method.

The long-term process of river flow in a significant part of Kazakhstan, including its central regions, has such very typical features: exceptional low water levels in the 30s and very high water levels (however, due to individual years) in the 40s. Therefore, when calculating the multiyear flow rate, it is necessary that the calculation period includes both of these abnormal groupings. The 1933 calculation period of the Central Kazakhstan river basins was took as a start. Thus, the calculation period includes the years 1933-2015 (Arystambecova 2016: 10). For revealing of features of a multiyear course of flow in various basins, methods of integrated and difference integrated curves are used. Figure 2 shows the difference integrated curves of the Yesil river basin.

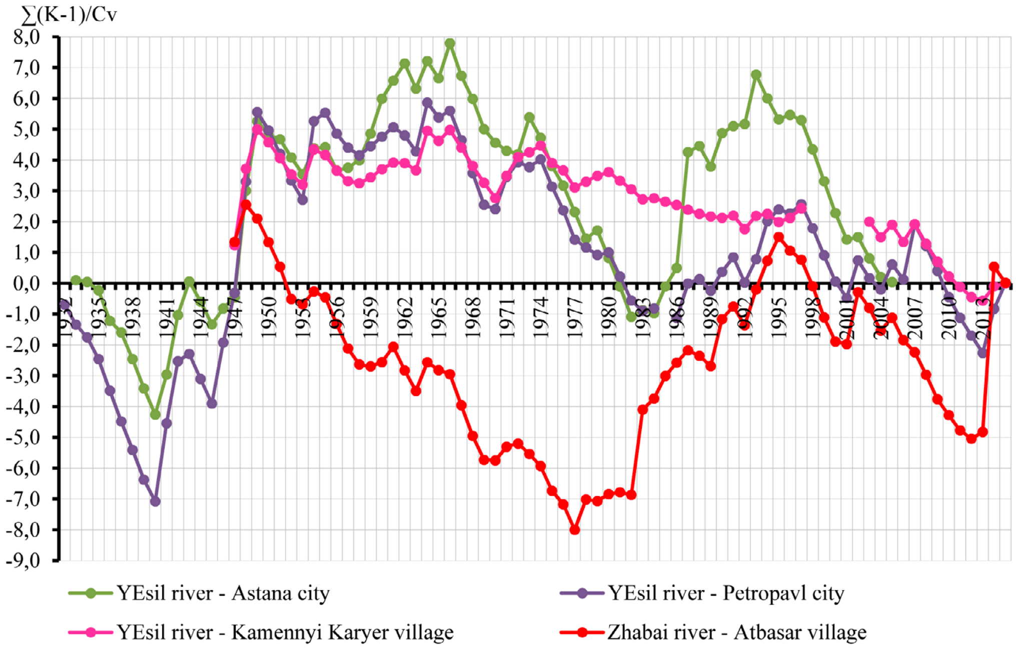


**Figure 2 –** Differential integrated curves of average annual water discharge of the main rivers in the Yesil river basin, for the period 1932 - 2015

Taking into account the water management and hydrological features of each catchment basin, the assessment of changes in the annual flow distribution that have been affected by water reservoirs has been made for each catchment basin. The periods of river flow at different levels of economic activity were determined according to the integrated curve constructed using data: i.e. the conditionally natural period (1933 - 1969) and the period of destruction of the natural hydrological regime (1970 - 2015).

To ensure that the crossing structures are designed correctly and operate normally throughout their lifetime, it is necessary to calculate the size of the structures based on a sufficiently accurate forecast of possible $Q_{max}$ values. Until the 1930s, the maximum flow rate corresponding to the highest observed water level, called the High Historical Horizon (HHH), was taken as the calculated one.

At present, the forecast of maximum discharge values for rivers is based on statistical data on the water flow regime of the river (published in hydrological yearbooks) for the period preceding the construction of a bridge crossing, using the theory of probability. The application of methods of the theory of probability and mathematical statistics in solving hydrological problems has gained wide spread use (Methodical Guidelines 2014: 28).

The maximum design flow for bridge crossing structures is characterized by the probability of its exceeding even higher flows. The higher the maximum flow, the less probability of its exceeding by even higher flows. To build constructions which are not threatened by loss of stability by any high waters, it is necessary to accept as the calculated maximum flow physically possible limited flow $Q_{max}$ 0,01 %, the so-called peak-peak, frequency of excess of which is nearly equal to zero. However, the structures will be very expensive, so it is more economical to limit the maximum design flows to values that actually exceed, allowing the need to restore or repair individual structures on the roads after passing the flow exceeding the design flow.

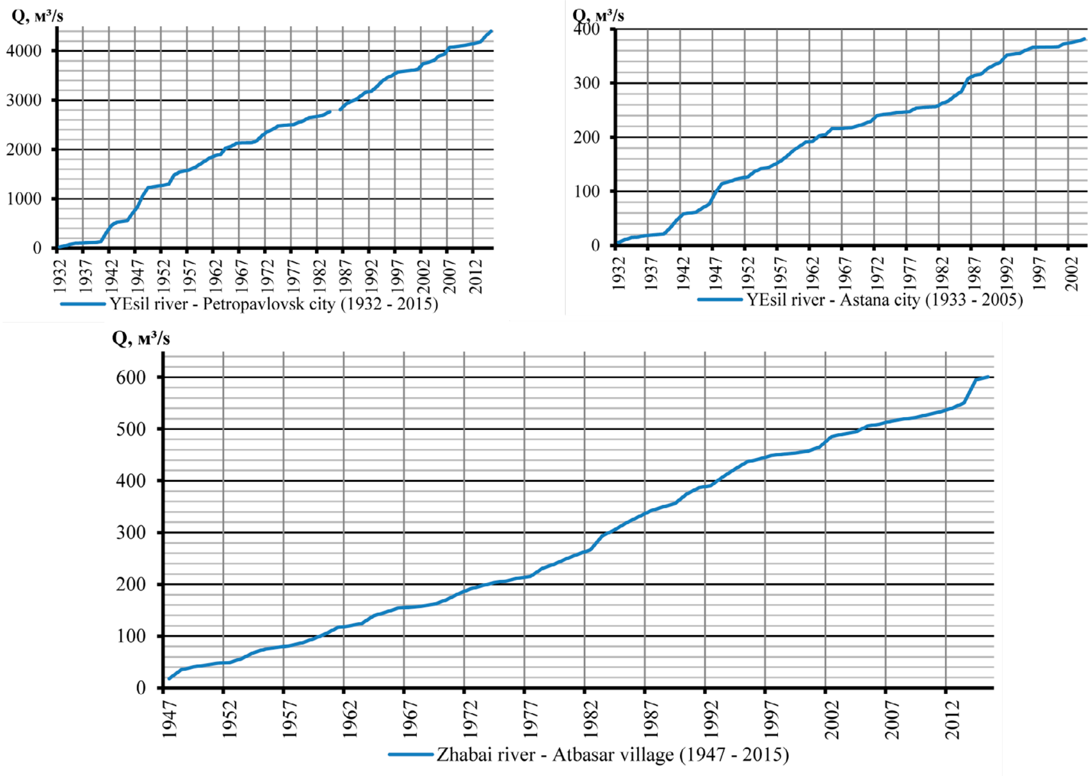


**Figure 3** – Integrated curve of average annual water flows

In contrast to the Gauss normal distribution, its mod M (the line of the most frequent repetitive flows) is shifted relative to the center of distribution C (the line corresponding to the arithmetic mean of the series of flows $Q_0 = \frac{\sum Q_i}{n}$ . The amount of this displacement, i.e. the asymmetry of the distribution curve is characterized by the asymmetry coefficient $C_s$. The number and amount of deviation of all flows relative to their arithmetic mean (center of distribution C) is estimated by the coefficient of variation (variability) $C_v$, which when n below 30 is expressed through dimensionless modulus coefficients (relative flows) $K_i = \frac{Q_i}{Q_0}$.

The longer the series of observations of hydrological characteristics, the more reliable the calculated maximum flow $Q_{max}$ P% can be determined. The considerable duration of the series of observations (when n > 50 years) allows to construct a smooth and full actual curve of the exceedance probability. By calculating the frequency percentage for all the members of the series, a graph can be constructed - the curve of exceedance probability (EP), which is also called the frequency curve (Figure 4). This curve, built on ordinary paper, has a very steep rise and fall in its upper and lower sections, which makes them difficult to use. And especially their extrapolation. Therefore, probability paper is often used, which significantly straightens the ends of the frequency curve due to uneven division of the horizontal axis (Gal'perin 1994: 173). According to the obtained frequency curve, the calculated flow $Q_p$ of the given exceedance probability P (%) is found. If necessary, the curve is extrapolated to the set value P (%).

On the Yesil river it is possible to see influences of factors of a climatic origin and water reservoirs where water reservoirs of long-term regulation have started to function since 70th years. As a result, it is possible to estimate 2 parts: 1) up to 60s - climate factor; 2) 70-80s - after filling the water reservoirs.

For the basins under observation, integrated curves were constructed on the basis of multiyear data of average annual water flows in order to determine the moment of dehomogenization. The main fractures are found at the end of the 40s and 50s, which is clearly associated with the climate factor, and since the early 70s, which, incidentally, does not always coincide with significant changes in the level of economic activity on the river or water catchment (Berkaliyev 1959: 278). Figure 3 shows the integrated curve of average annual water flows of the Yesil river - Petropavlovsk city, the Yesil river - Astana city, also shows the integrated curve of average annual water flows of the Zhabai river - Atbasar village. Water reservoirs of this region of long-term regulation were brought into operation by the beginning of the 70s. In the region under observation, the human impact on low flow rivers is more noticeable, and water flows have decreased significantly since the 1960s.

The flow of rivers in natural conditions is the most accurate description of a water catchment river and the construction of large dams leads to noticeable shifts in the annual distribution regime in the end part of the river. When assessing changes of annual flow distribution under the influence of dams, it should be taken into account that the water management system of the river basin is constantly evolving and, therefore, along with the average flow characteristics, there should be a flow distribution of each specific year (Galperin 1994: 173).

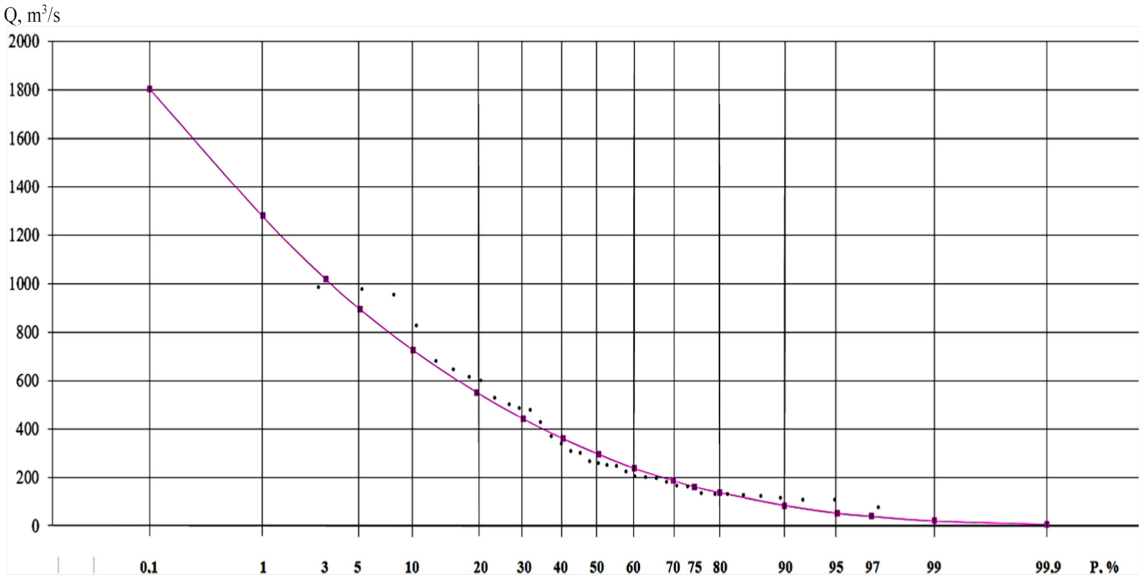


**Figure 4 –** Empirical and theoretical integrated distribution (frequency) curves for the Selety river gauging station – Izobilnoye village (1970-2012)

The defined maximum calculated flows of gauging stations in basins under observation with probability of exceedance P = 5% ($Q_{max}$5%) by mathematical statistics method using theoretical integrated distribution curves are shown in Table 1.

**Table 1 –** Ordinates of empirical and theoretical integrated K distribution curves

| $Q_0$, м³/s | | $C_v$ | | 5% | | 25% | | 50% | | 75% | | 95% | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Before 1970 | After 1970 | Before 1970 | After 1970 | Before 1970 | After 1970 | Before 1970 | After 1970 | Before 1970 | After 1970 | Before 1970 | After 1970 | Before 1970 | After 1970 |
| Selety river – Izobilnoye village (1970-2012) | | | | | | | | | | | | | |
| 361,4 | 369,4 | 0,73 | 0,70 | 2,71 | 2,51 | 1,38 | 1,34 | 0,83 | 0,84 | 0,50 | 0,51 | 0,22 | 0,20 |
| Yesil river – Turgenevka village (1970-2015) | | | | | | | | | | | | | |
| 223,8 | 219,8 | 0,83 | 0,77 | 2,68 | 2,75 | 1,56 | 1,40 | 0,80 | 0,80 | 0,40 | 0,43 | 0,11 | 0,11 |
| Moyildy river – Nikolayevka village (1973-2015) | | | | | | | | | | | | | |
| 73,0 | 59,2 | 0,92 | 0,89 | 3,08 | 3,00 | 1,51 | 1,42 | 0,82 | 0,75 | 0,41 | 0,36 | 0,16 | 0,07 |

*Continuation of the Table 1*

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Zhabai river – Atbasar village (1970-2015) | | | | | | | | | | | | | |
| 317,4 | 377,5 | 0,90 | 0,93 | 2,68 | 3,34 | 1,58 | 1,42 | 0,66 | 0,75 | 0,35 | 0,36 | 0,16 | 0,08 |
| Zhabai river – Balkashino village (1970-2012) | | | | | | | | | | | | | |
| 49,3 | 72,8 | 0,86 | 0,57 | 2,54 | 2,27 | 1,52 | 1,34 | 0,77 | 0,88 | 0,51 | 0,57 | 0,20 | 0,23 |
| Selety river – Prirechnoe village (1970-2015) | | | | | | | | | | | | | |
| 70,9 | 72,1 | 1,03 | 1,03 | 2,82 | 3,25 | 1,41 | 1,43 | 0,71 | 0,69 | 0,28 | 0,30 | 0,10 | 0,05 |
| Yesil river – Astana city (1970-2012) | | | | | | | | | | | | | |
| 330,6 | 338,9 | 0,93 | 0,83 | 2,42 | 2,57 | 1,45 | 0,89 | 0,64 | 0,82 | 0,24 | 0,43 | 0,08 | 0,13 |
| Yesil river – Petropavlovsk city (1970-2012) | | | | | | | | | | | | | |
| 960,8 | 961,6 | 1,22 | 0,79 | 3,12 | 2,57 | 1,51 | 1,35 | 0,52 | 0,82 | 0,26 | 0,43 | 0,21 | 0,13 |

The analysis of the mutual position of the empirical frequency curve and the theoretical and integrated curves showed that the curve deviates least from the empirical points of the curve corresponding to the relation $C_s/C_v=2$. This curve is taken as a calculated one. Therefore, the maximum design flow for periods applied at a probability of exceedance of P = 5 %: 1933 – 1969 and 1970 – 2015 are shown in summary table 2.

**Table 2 –** Maximum estimated flows with a probability of exceedance of P = 5% ($Q_{max5\%}$)

| № | Name of hydrological posts | $Q_{max5\%}$ (м$^3$/s) | | % |
|---|---|---|---|---|
| | | 1933 – 1969 | 1979 – 2015 | |
| 1. | Selety River – Izobilnoye village | 979,4 | 927,2 | -5,33 |
| 2. | Yesil River – Turgenevka village | 599,8 | 604,5 | 0,78 |
| 3 | Moyildy River – Nikolayevka village | 224,8 | 177,6 | -21,0 |
| 4. | Zhabai River – Atbasar village | 850,6 | 1260,8 | 32,5 |
| 5. | ZhabaiRriver – Balkashino village | 125,2 | 165,3 | 24,3 |
| 6. | Selety River – Prirechnoe village | 199,9 | 234,3 | 38,9 |
| 7. | Yesil Rriver – Astana city | 800,1 | 871,0 | 8,14 |
| 8. | Yesil River – Petropavlovsk city | 2997,7 | 2471,3 | -17,6 |

## Conclusion

Thus, as a result of the article formation of spring runoff of the lowland rivers of the Central Kazakhstan, a special role is played by autumn soil moisture and the nature of the onset of spring (simultaneous onset of spring flood formation factors). In recent years, an increase in winter precipitation and a sharp increase in temperature with the onset of spring are often observed in the region under consideration. Under such meteorological conditions, the soil still remains frozen until a certain time, and the snowmelt area covers a large area. As a result, conditions are created for the passage of flood waves in a short time and with a destructive force.

In the Yesil hydroeconomic basin, comparison of the spring flow rates of two periods - 1933-1969 and 1970-2015 - shows both a decrease and an increase in the flow rates of the last forty six-year period as compared to the general calculation. The calculation error of the coefficient of variation of the maximum flows is on average from 1.4 to 14.7%.

Comparison of the maximum flows for the period 1938-2012 with the data given in the surface water resources shows both the decrease in the maximum flows of the multiyear period as compared with the data published in the end of the fifties - beginning of the sixties of the last century, and its significant increase in the average flow decrease was 15.8%.

On the Selety river, a comparison of the maximum flows of the two periods shows a 5.33 % decrease in the Izobilnoye gauging station and a 38.9 % increase in the Prirechnoye gauging station. On the Yesil river under observation it is possible to see, on gauging stations of Turgenevka village and Astana city, increase of the maximum flow, accordingly by 0,78 % and 8,14 %, and on gauging station of Petropavlovsk city decrease by 17,6 %. Also significantly decreased at the gauging station of the Moyildy river - Nikolaevka village by 21%. Along the Zhabai river, we note an increase of maximum flow at the gauging stations of Atbasar village and Balkashino village by 32.5% and 24.3%, respectively.

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