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# ASSESSMENT OF THE RESERVOIRS' IMPACT ON THE RIVER FLOW

In this article, the influence of reservoirs and ponds on the hydrological regime in the Yesil River basin is studied. To assess the impact of existing reservoirs on the annual runoff of rivers in the study basin, a simplified methodology of the State Hydrological Institute was used. The change in the annual (seasonal) runoff under the influence of ponds and reservoirs was determined using two methods: by the volume of filling the reservoirs; due to additional evaporation from the water surface of reservoirs compared to evaporation from land before their creation. When assessing the impact of ponds in terms of filling volumes or taking into account in the direct form of water intakes for economic needs, the influence of not only ponds, as artificial elements of the landscape, but also other factors of economic activity, was revealed. When assessing the impact of economic activities on the elements of the hydrological regime of rivers, including the creation of reservoirs for long-term regulation, changes in the climatic background are taken into account. According to the analysis of the results of assessing the impact on the runoff of the volumes of filling reservoirs, economic activities from 1974 to 2018 led to a decrease in runoff in the alignment of the river. Yesil – Astana in the middle years of water availability (50% supply) by 30%, and in the mouth section. Yesil – Petropavlovsk city decrease in runoff up to 7%.

**Key words**: reservoir, evaporation, precipitation, anthropogenic impact on river runoff, reduction of river runoff, decrease in natural runoff.

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## Су қоймаларының өзен ағындысына әсерін бағалау

Мақалада Есіл өзені алабындағы су қоймалары мен тоғандарының гидрологиялық режимге әсері зерттеледі. Зерттелетін бассейндегі өзендердің жылдық ағынына қолданыстағы су қоймаларының әсерін бағалау үшін Мемлекеттік гидрологиялық институттың жеңілдетілген әдістемесі қолданылды. Тоғандар мен су қоймаларының әсерінен жылдық (маусымдық) ағынның өзгеруі екі әдіспен анықталды: су қоймаларын толтыру көлемі бойынша; құрлықтағы буланумен салыстырғанда су объектілерінің, су бетінен қосымша булану есебінен, олар жасалғанға дейін. Тоғандардың су толтыру көлемі бойынша әсерін бағалау немесе шаруашылық қажеттіліктер үшін су алудың тікелей нысанын есепке алу кезінде ландшафттың жасанды элементтері ретінде тек тоғандардың ғана емес, сонымен қатар шаруашылық қызметтің басқа факторларының да әсері анықталды. Өзендердің гидрологиялық режимінің элементтеріне шаруашылық қызметінің әсерін бағалауда ұзақ мерзімді реттеу үшін су қоймаларын құру кезінде климаттық фонның өзгеруі ескеріледі. Су қоймаларын толтыру көлемдерінің ағынға әсерін бағалау нәтижелерінің талдауы бойынша 1974 жылдан 2018 жылға дейінгі шаруашылық қызмет өзеннің теңестіруіндегі ағынның төмендеуіне әкелді. Есіл – Астана сумен қамтамасыз етілудің орта жылдарында (50% қамтамасыз ету) – 30%, ал сағалық бөлігінде. Есіл – Петропавл қаласында ағын су 7%-ға дейін төмендеді.

**Түйін сөздер:** су қоймасы, булану, жауын-шашын, өзен ағынына антропогендік әсер, өзен ағынының азаюы, табиғи ағынның азаюы.

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## Оценка воздействия водохранилищ на речной сток

В данной статье изучено влияние водохранилищ и прудов на гидрологический режим в бассейне реки Есиль. Для оценки влияния существующих водохранилищ на годовой сток рек изучаемого бассейна использовалась упрощенная методика Государственного гидрологического института. Изменение годового (сезонного) стока под влиянием прудов и водохранилищ определяли двумя методами: по объему заполнения водохранилищ; за счет дополнительного испарения с водной поверхности водоемов по сравнению с испарением с суши до их создания. При оценке влияния прудов по объемам наполнения или учете в непосредственной форме водозаборов на хозяйственные нужды выявлено влияние не только прудов, как искусственных элементов ландшафта, но и других факторов хозяйственной деятельности. При оценке воздействия хозяйственной деятельности на элементы гидрологического режима рек, в том числе создание водохранилищ для многолетнего регулирования, учитываются изменения климатического фона. Согласно анализу результатов оценки влияния на сток объемов наполнения водохранилищ, хозяйственная деятельность с 1974 по 2018 год привела к уменьшению стока в створе реки Есиль – Астана в средние годы водообеспеченности (50% обеспеченности) на 30%, а в устьевом участке Есиль – Петропавловск уменьшение стока до 7%.

**Ключевые слова:** водохранилище, испарение, осадки, антропогенное воздействие на речной сток, сокращение речного стока, уменьшение естественного стока.

## Introduction

For many hundreds of years, the impact of human activity on river flow was very insignificant and had a local character. The remarkable properties of natural waters – their renewal in the process of circulation and the ability to purify – made it possible to maintain the relative purity, quantity and quality of fresh water for a long time. The situation has changed radically in recent decades: in many regions and countries of the world, the fruits of many years of irrational activity in the use of water resources and the transformation of the surface of river catchments where they are formed have begun to be discovered. First of all, this affected small and medium-sized rivers; in many densely populated regions, their water regime has undergone drastic changes (Shiklomanov, 2008: 282).

Anthropogenic activities inevitably have an impact on water resources. Due to population and economic growth, the role of water resources is constantly increasing. Unlike other natural resources, water is renewed in the process of its circulation in nature. But water resources, which are based on river runoff, are distributed extremely unevenly over the territory and in time. In many parts of the world, the available water resources cannot meet the demand for water, especially since it is often polluted by industrial waste. This fully applies to the water management basins of Kazakhstan.

Since the 70's in the twentieth century, the relevance of a reliable assessment of water resources and their predicted changes under the influence of economic activity has increased even more in connection with the real problem of changes in global and regional climatic characteristics. These changes are already taking place in the Yesil Basin and may lead to large-scale transformations of the hydrological cycle, changes in water resources and their use, distribution in time and space, extreme characteristics of river flow and their variability.

In recent years, interest in assessing and forecasting quantitative changes in water resources and taking these changes into account in long-term planning has increased even more due to the real problem of possible very significant changes in global climatic characteristics (air temperature, precipitation) in the near future, with an increase in carbon dioxide concentration. Anthropogenic changes in climatic characteristics can be so significant that they will lead to significant violations of the hydrological cycle, the amount of water resources, their distribution over time and territory, extreme characteristics of river flow and their variability, which cannot be ignored when developing long-term plans for integrated use when designing long-term water management activities.

Reservoirs are the fundamental natural and man-made elements of hydraulic engineering and water management systems of any level. They make it possible to regulate the water resources of rivers and lakes to the extent necessary for the sustainable development of the economy and the population. In this regard, the creation of reservoirs has become widespread, both in Kazakhstan and around the world.

The first reservoirs on Earth appeared in the 3-rd millennium BC. (Avakyan, 1987: 4), (Avakyan, 2000: 517). At present, there are 45 reservoirs in the Yesil River basin: 3 complex – purpose reservoirs with a volume of more than 100 million m$^3$; 6 – with a volume of more than 10 million m$^3$; 36 special – purpose reservoirs with a capacity of 1 to 10 million m$^3$. The total capacity of reservoirs for complex purposes and reservoirs for special purposes is 1584 million m$^3$, the total useful capacity is 1446 million m$^3$, which is 80 % of the bas flow annual volume of the Yesil river basin. The water surface area of reservoirs is 312 km$^2$ (Moldakhmetov, 2007: 176).

In the upper reaches of the Yesil River, the Ishim reservoir for seasonal flow regulation was built with a total volume of 9.2 million m$^3$, a useful volume of 8.2 million m$^3$. The small useful capacity of the Ishim reservoir very slightly transforms the runoff in the lower reaches of the river. The main regulator of the flow for the Upper Yesil is the Astana (Vyacheslav) reservoir of long-term regulation, with a total volume of 411 million m$^3$ and a useful 378 million m$^3$. The main regulators of the Lower Yesil are the Sergeevsk reservoir, which has a total volume of 693 million m$^3$ and a useful volume of 635 million m$^3$. The closing reservoir of the Yesilsky cascade, on the territory of the Republic of Kazakhstan, is the Petropavlovsk reservoir, which has a total volume of 19.2 million m$^3$ and a useful volume of 16.1 million m$^3$, which carries out seasonal regulation of the flow.

According to the type of flow regulation, reservoirs are distinguished for long-term, seasonal (annual), monthly, weekly and daily regulation. Long-term regulation is carried out for the accumulation of runoff in high-water years, and its further use in dry years. Seasonal regulation – to delay the flow of high-water periods and its use in dry seasons. Monthly, weekly and daily flow regulation is typical for almost all reservoirs of hydroelectric power plants. On the territory of the Yesil water management basin, reservoirs with long-term regulation are prevailed, which is 60 % of the total number of reservoirs in the region under consideration.

The development of hydrotechnical construction in Kazakhstan, which was accompanied by the construction of the largest reservoirs and cascades of hydroelectric power plants, led to fundamental changes in the natural hydrological regime of most river systems that were formed under the influence of natural conditions. The problems of managing the surface runoff are solved by creating and operating reservoirs for long-term, seasonal, weekly and daily regulation, which ensure the redistribution of water resources in time. On the major rivers of the republic, reservoirs for long-term and seasonal flow regulation are mainly created and operated.

The problem of changes in the annual flow of rivers under the influence of reservoirs has been studied quite well (Galperin, 2012: 363), (Galperin, 2003: 44), (Skotselas, 1995: 42), (Kolmogorov, 1987: 72), (Leonov, 1981: 407), (Galperin, 1979: 134). However, the decisive influence in the regulation of river runoff by reservoirs is manifested, first of all, in the intra-annual distribution of runoff in the outlet section. Here, the role of reservoirs is to eliminate the natural unevenness of the runoff: an increase in the volume of runoff during low periods due to a decrease in flood runoff (Makhmudova, 2021: 153), (Galperin, 2001: 104), (Leonov, 1986:77).

The study of the influence of reservoirs on the intra-annual and seasonal distribution of river runoff is of fundamental importance for solving most water management problems. First of all, it should be noted the fact of the relative stability of the intra-annual and seasonal distribution of the runoff of the river catchment under natural conditions, which is explained by the stability of the intra-annual distribution of meteorological characteristics (precipitation, air temperature, etc.) over large areas over a long period, as well as the impact of the accumulating capacity of the catchment (Andreyanov, 1960: 79).

The construction of large reservoirs in the region under consideration led to a gradual change (leveling) of the intra-annual distribution of runoff. In order to study these changes, an analysis of long-term series of monthly runoff for the river was carried out, of the River Yesil along the length in various hydrological posts. An analysis of the average monthly precipitation and average monthly air temperatures for 30-40 years showed the relative stability of their intra-annual distribution in the basin of the River Yesil, they cannot lead to significant shifts in the intra-annual distribution of runoff (Moldakhmetov, 2007: 177).

Analysis of the intra-annual distribution of annual runoff in a long-term context can be carried out using the method of moving averages, integral curves of monthly runoff, as well as by comparing the distribution of monthly runoff in different years with different levels of runoff regulation in the catchment area, but with approximately the same meteorological conditions. Calculation methods are also used (Veretennikova, 1982: 28), when the regulated observed runoff is compared with the restored values. However, the retransformation of the monthly and ten-day runoff by existing methods of calculation (Andreyanov, 1960: 83), as rightly noted in the work (Sokolov, 1979: 14), is difficult, due to the fact that errors in the restoration of runoff are often commensurate with monthly stock.

The final result of assessing the change in the intra-annual distribution of runoff in a year depends not only on the methods of analyzing and comparing the monthly runoff and its distribution over a long period of time with the dynamics of economic activity in the watershed, but also, to a certain extent, on comparing the natural and disturbed distribution of the runoff. It should be noted that, when describing the intra-annual distribution of runoff, there obviously are not, and cannot be, universal methods suitable for use on any rivers.

The fact of the relative stability of the intra-annual and seasonal distribution of runoff on the River Yesil in natural conditions is confirmed by data on the relative distribution of runoff by season under conditions of poor economic development of the region (conditionally natural) and after the construction of large reservoirs. For all rivers under conditions of a practically natural regime, the relative values of seasonal runoff are very stable even when averaged over short five-year periods. Their averaged values deviate from the long-term averages in the range from 2 to 5 %. Sharp changes in the distribution of runoff by seasons take place after the construction of reservoirs with the intensive development of the economy (Moldakhmetov, 2008: 291).

Thus, the main task of reservoirs is to regulate river flow in order to eliminate the shortage of water resources in dry seasons or years. At the same time, the construction of large reservoirs not only regulates runoff, but can also significantly increase the amount of irretrievable losses as a result of evaporation from their water surface. By increasing evaporation as a result of flooding large areas in areas of insufficient moisture, reservoirs reduce the total water resources, acting as one of the consumers of fresh water. In this regard, it seems necessary to take into account this role of reservoirs when assessing the total and non-returnable water consumption, especially in areas with a dry climate. The volume of additional losses due to the construction of reservoirs is estimated from the difference in evaporation from the water surface of the reservoir and the same territory before flooding, including the land surface and rivers in natural conditions.

As a rule, reservoirs built in zones of variable and insufficient moisture, and even more so in arid regions, reduce the total water resources of the catchment due to greater evaporation from the water surface compared to the flooded land. For channel-type reservoirs, the magnitude of this decrease is usually insignificant due to the fact that the additional water surface area is small, and evaporation from floodplain land areas is close to evaporation from the water table.

## Initial data and research methods

*Initial data.* Observational data on the annual river runoff of the Yesil water management basin, provided by hydrometeorological network of RGP Kazhydromet, was used in this project. Data about the total volume of filling ponds and reservoirs in the study basin are borrowed from the materials of the Committee for Water Resources of the Republic of Kazakhstan.

*Methods for estimating additional water losses due to evaporation.* The construction of reservoirs entails some reduction in renewable water resources, due to additional evaporation in the basin. In some regions, this decrease can be a significant proportion of the total irretrievable water consumption for economic needs, so this aspect is quite important in the general complex of problems for the impact of human activities on water resources.

As a result of the construction of reservoirs, there is a change in the runoff volume in the outlet section of the river ($\Delta R$) due to a change in the total evaporation in the basin ($U$), as well as a result of filling the reservoir bowl and increasing groundwater reserves ($W$):

$$\Delta R = U + W \qquad (1)$$

The first component of equation (1) $U$ is a permanent factor for the entire time of the reservoirs existence. The value of $W$ represents temporary losses for the closing section of the river, acting in the period from the beginning of the reservoir filling until the onset of a steady state groundwater regime, while the duration of the period for large flat reservoirs is very long and amounts to 7-15 years (Shiklomanov, 2008: 319). The values of $U$ and $W$, as a rule, have the highest values during the construction of reservoirs in areas of insufficient moisture: the first is due to the greater difference in evaporation from the water surface compared to land, and the second is due to the deeper standing in natural conditions of groundwater levels in the area of reservoir construction.

The volume of water losses due to changes in evaporation in the basin $U$ consists of three components:

$$U = U_F + U_{AF} = U_{LR} \tag{2}$$

where, $U_F$ – is the volume of losses from the territory flooded by the reservoir; $U_{AF}$ – the same from the adjacent flooding area; $U_{LR}$ – is the volume of losses due to changes in flooding processes in the lower reaches of the reservoir.

The main role in equation (2) is played by the first component $U_F$, the value of which is determined by the area flooded by the reservoir $A_F$ and an additional evaporation layer $E_F$ from this territory:

$$U_F = E_F \times A_F \times 10^{-6} \tag{3}$$

where $U_F$ – km$^3$, $E_F$ – mm, $A_F$ – km$^2$.

The $E_F$ value can be calculated for a month, season or year using the equation:

$$E_F = E_{WS} - R + R \tag{4}$$

the value can be obtained from the difference between the water balance equations of the area of catchment before and after the construction of the reservoir.

In equation (4): $E_{WS}$ – evaporation from the water surface of the reservoir; $P$ – precipitation on the water surface; $R$ – runoff, which is formed from the section of the valley occupied by the reservoir.

Flooded area $A_F$ in formula (3) will be equal to:

$$A_F = A_{WS} - A_R \tag{5}$$

where $A_{WS}$ – is the water surface area of the reservoir; $A_R$ – the area of the riverbed in natural conditions on the territory occupied by the reservoir.

Evaporation losses from the flood zone of lands adjacent to the reservoir $U_{AF}$ are determined by the expression:

$$U_{AF} = (E_F - E_L) \times A_F \times 10^{-6} \tag{6}$$

where $U_{AF}$ in km$^3$; $E_F$ – evaporation from the flooding zone, in mm; $E_L$ – evaporation from land before flooding, in mm; $A_F$ – is the area of the flooded territory, in km$^2$, that is, it is a land area adjacent to the contour of the reservoir with a depth of the groundwater level, usually no more than 2.0-2.5 m.

In many river basins, the effect of large reservoirs on evaporation is manifested not only within the flood zones, but also below the location of the reservoirs due to changes in the regime and flood areas of the river floodplain and delta. Usually, there is a decrease in evaporation below the reservoir $U_{LR}$ due to a reduction in the areas of floodplain and delta flooding as a result of a decrease in maximum water discharges during flow regulation. As studies have shown (Shiklomanov, 1974), under constant meteorological conditions within the considered areas below the reservoir, the value of $U_{LR}$ is proportional to the change in the flooding parameter, which reflects the change in the maximum area and duration of flooding as a result of a decrease in maximum flows and spring flood volumes due to the creation of reservoirs.

During the construction of reservoirs, the flow of the river in the outlet section changes not only due to additional evaporation, but also as a result of accumulation in the reservoir bowl $W_A$ and replenishment of groundwater reserves $W_{GW}$:

$$W = W_A + W_{GW} = W_A + W_{RB} + W_{BR} \tag{7}$$

where $W_{RB}$ – is the water consumption for saturation of the aeration zone of the reservoir bed; $W_{BR}$ – are the volumes of water entering the banks of the reservoirs, while the total water resources in the basin due to $W$ do not decrease, there is only their redistribution and the transition of one type of water resources to another.

Determination of $W_A$ is not difficult in the presence of water balances of reservoirs. $W_{RB}$ value is determined for each reservoir depending on the thickness of the aeration zone of the reservoir bed prior to its construction and the lack of soil saturation, which depends on the soil characteristics of the aeration zone. Saturation of the aeration zone occurs, as a rule, in the first 10-20 days after the filling of the reservoir bed.

It is much more difficult to determine the volumes of water that form artificial groundwater reserves in areas adjacent to reservoirs $W_{BR}$. Replenishment of groundwater reserves for various reservoirs can occur for many years after their filling and represents very significant values that should be taken into account in a comprehensive assessment of the impact of a reservoir on river flow.

*Simplified scheme for estimating additional evaporation*. Obviously, due to the lack of a significant part of the necessary initial data, a detailed methodology for a comprehensive assessment of the impact of reservoirs on renewable water resources cannot be applied to all watersheds, and even more so to regions. Therefore, based on the analysis of the obtained calculation results for a large number of different types of reservoirs located in different physical and geographical conditions, the State Hydrological Institute (Russian Federation) developed a simplified calculation scheme. It is based on the use of design data available for each large reservoir, generalized information on water management, hydrometeorological and hydrogeological characteristics, and cartographic materials.

Calculations according to the simplified scheme are performed not for each specific year, but on average for at least 5-10 year periods, which makes it possible to significantly reduce the amount of required initial information and simplify calculations.

The volume of losses from the flooded area $U_F$ is determined by formula (3), however, to calculate the additional evaporation layer $E_F$, instead of formula (4), the equation is used:

$$E_F = E_F - E_L \tag{8}$$

this equation can be easily obtained from equation (6) by averaging the elements over long-term periods. In formula (8) $E_F$ and $E_L$ are the norms of evaporation from the water surface and land, respectively, for the area where the reservoirs are located; they are determined by available formulas or maps.

The average flood area $A_F$ is calculated approximately depending on the type of reservoir and the design area of the water surface $A_{NRL}$ with the introduction of the necessary coefficients:

$$A_F = K_R \times K_F \times A_{NRL} \qquad K_R = A_{WS}/A_{NRL} \qquad K_F = A_F/A_{WS} \tag{9}$$

The values of the coefficients $K_P$ are determined by the ratio of the actual average water surface area $A_{WS}$ for the period to the area at NRL when the reservoir is completely filled and obviously depends on the nature of flow regulation (daily, weekly, monthly, seasonal, long-term) and the type of curve of dependence of the reservoir area on level. For most of the mountain and semi-mountain reservoirs of seasonal regulation and flat daily and weekly regulation $K_R \approx 1$. For lowland reservoirs of seasonal regulation $K_R$=0.80-0.90.

The $K_F$ coefficient is determined by the ratio of the areas of flooding and the water surface of the reservoir and depends mainly on the type of reservoir (river, valley, lake) and on the amplitude of fluctuations in water levels in the river under natural conditions. For lake reservoirs on lowland rivers – $K_F$=0.90-1.0; for lake-valley – $K_F$=0.80-0.90; for valley-channel – $K_F$=0.70-0.80; for channel – $K_F$=0.65-0.70.

Losses for additional evaporation from the areas of reservoir flooding $U_{AF}$ usually make up an insignificant part of the value $U_F$, ranging from 4 to 10 % for lowland reservoirs, depending on the depth of groundwater and climatic characteristics. For mountain and semi-mountain reservoirs, this value can practically be neglected.

The values of $U_{LR}$ can play an important role in assessing the complex effect of reservoirs on the runoff and water balance of such rivers, in the lower reaches of which, under natural conditions, there were significant losses of runoff due to unproductive evaporation. These are, as a rule, rivers that have a flood regime in the warm season. For an approximate estimate within large regions, the values of $U_{AF}$ and $U_{LR}$ can be neglected, especially since they largely compensate each other in magnitude.

Reducing the river runoff in the outlet due to the accumulation of water in the reservoir bowl $W_A$ is determined approximately by the value of the design total volume of the reservoir at the NRL and the period of its filling. In the periods after the filling of the reservoirs, the value of $W_A$ on average over a long period is taken equal to zero.

One-time seepage losses in the bed and banks of reservoirs for replenishment of groundwater reserves $W_{GW}$ are usually estimated approximately depending on the areas of flooding and the level of groundwater occurrence in the reservoir area. These losses take place in the period from the beginning of the filling of reservoirs to the established regime of groundwater in the adjacent territories. In subsequent years, these values are taken equal to zero.

## Results and discussion

*The influence of reservoirs and ponds on the hydrological regime in the basin of the River Yesil.* Reservoirs and ponds are built to regulate the flow, both seasonally and long-term, to provide water to the population, industry and agricultural production. In Kazakhstan, water in ponds and reservoirs is mainly used for water supply, irrigation, fish farming, and partly for irrigation of agricultural fields, orchards and orchards, and cattle watering.

The flow regime of small rivers in flat Kazakhstan is characterized by extremely uneven long-term and intra-annual distribution. The main part of the runoff occurs during the spring flood (90-100 % per annum). In this regard, pond farming has found wide development here. In order to save water for economic use, dams and dams are built on the rivers, accumulating part of the spring runoff. The water accumulated in spring is annually used for household needs in the rest of the year.

The influence of ponds and reservoirs on the flow of rivers manifests itself in different ways. The annual and spring runoff tends to decrease, which is associated with the filling of containers, additional evaporation and the economic use of water accumulated in reservoirs. Ponds and reservoirs built on rivers that dry up or with very low flow increase the flow in the summer.

The change in annual (seasonal) runoff under the influence of ponds and reservoirs can be determined by two methods:

1) by the volume of filling of reservoirs;

2) by additional evaporation from the water surface of reservoirs compared to evaporation from land before their creation.

Therefore, it is natural that the use of these methods for calculating the effect of ponds on river runoff gives different results, in some cases easily comparable with each other. When evaluating this influence of ponds in terms of filling volumes or taking into account in the direct form of water intakes for economic needs, the influence of not only ponds, as artificial elements of the landscape, but also other factors of economic activity is revealed.

The decrease in runoff occurs mainly due to dry years, while in high-water years these disturbances are not significant. With an increase in the areas of flooding, not only the average long-term runoff values change in a certain way, but also the coefficients of variation and asymmetry. Therefore, when designing water management facilities in areas of insufficient moisture, the use of statistical parameters of natural runoff series, even if the averages remain homogeneous, is not legitimate. Failure to take this circumstance into account can lead to an overestimation of runoff indicators, especially in the area of high availability.

When assessing the impact of economic measures on the elements of the hydrological regime of rivers, including the creation of reservoirs for long-term regulation, it is absolutely necessary to assess changes in the climatic background.

Methodological techniques based on the use, mainly, of network observations, give only an integral assessment of the influence of a complex of anthropogenic factors in the basin, but do not allow us to identify the role of each factor separately and thus do not always provide the possibility of scientifically based forecasts of the river regime for the future, taking into account economic development plans. Therefore, for watersheds with intensive use of water resources, the ongoing changes in runoff should be assessed in parallel by two mutually independent methods, namely: by a differentiated water balance calculation of irretrievable water losses in the basin and by analyzing long-term fluctuations in water discharges in hydrometric sections (taking into account fluctuations in meteorological factors). When calculating for the future, it is important to assess the changes in runoff under the influence of economic activity not only for average water content, but also for exceptionally dry and high-water years.

To assess the impact of the existing reservoirs on the annual runoff of the rivers of Central Kazakhstan, a simplified method of the State Hydrological Institute was used. This technique makes it possible to quantify runoff changes in the outflow gate due to a complex of factors that act during channel regulation (additional evaporation losses from flooding and underflooding zones, water accumulation in the bowl of reservoirs, compensation for runoff losses as a result of reduced flooding of floodplains in the lower pond).

The influence of ponds and reservoirs on river flow manifests itself in different ways. The annual runoff under the influence of reservoirs and ponds tends to decrease, which is associated with the filling of their reservoirs, additional evaporation and economic use.

The change in runoff under the influence of reservoirs was determined by two methods: by additional evaporation from the water surface of reservoirs compared to evaporation from land before their creation, and by the volume of filling of ponds and reservoirs. These methods are not equivalent: according to the first one, irretrievable losses include only losses for additional evaporation from the water surface, according to the second, irretrievable losses include, in addition to evaporation losses, spending on various economic needs.

The influence of ponds and reservoirs on river runoff can be taken into account in absolute terms or with the help of runoff change coefficients (in fractions of a unit). Data on the total volume of filling of ponds and reservoirs (on the share of the annual drawdown volume) in the study basin are borrowed from the materials of the Committee for Water Resources of the Republic of Kazakhstan. The layer of losses for additional evaporation for an average water content year for Central Kazakhstan is given in “Resources ...” and is 800 mm. Precipitation and evaporation of different probability are given in Table 1. Modular coefficients were used to transfer from the average long-term values of evaporation from the water surface to the provided values.

**Table 1** – Precipitation and evaporation (calculated provision)

| Water content of the year (calculated provision), P % | The amount of precipitation for the warm period (IV-X), *P* mm | Evaporation from the water surface during the warm period (IV-X), $E_{WS}$ mm | Evaporation from land, $E_L$ mm | $E^{/}=E_{WS}-E_L$, mm |
|---|---|---|---|---|
| 10 | 334 | 696 | 300 | 396 |
| 25 | 280 | 744 | 300 | 444 |
| 50 | 227 | 800 | 250 | 550 |
| 75 | 180 | 848 | 175 | 673 |
| 80 | 170 | 920 | 158 | 762 |
| 95 | 125 | 936 | 125 | 811 |

Table 2 shows the results of calculations by the first method, which takes into account additional evaporation from the water surface, performed for three sections along the Yesil River. When calculating river runoff losses due to evaporation from the water surface, the following data were used:

– Water content of the year, P, %;

– Total water surface area of ponds and reservoirs, $\sum F_{WS,}$ km$^2$;

– Precipitation on the surface of ponds and reservoirs, *X*, mm;

– Loss of runoff for evaporation from the water surface, $W_{WS}$, million m$^3$;

– Annual runoff, *W*, million m$^3$;

– Decrease in natural runoff, $R_1$.

**Table 2** – Calculations of river runoff losses on the evaporation with water surface

| River – point | *P*, % | $\sum F_{WS,}$ km$^2$ | $E^{/}$, mm | *X*, mm | $E_{WS}$, mm | $W_{WS}$, million m$^3$ | *W*, million m$^3$ | $R_1$ |
|---|---|---|---|---|---|---|---|---|
| Yesil – Nur -Sultan | 10 | 63.2 | 396 | 334 | 62 | 3.92 | 329 | 0.99 |
| | 25 | | 444 | 280 | 164 | 10.4 | 212 | 0.95 |
| | 50 | | 550 | 227 | 323 | 20.4 | 116 | 0.82 |
| | 75 | | 673 | 180 | 493 | 31.2 | 57.2 | 0.46 |
| | 80 | | 762 | 170 | 592 | 37.4 | 46.5 | 0.20 |
| | 95 | | 811 | 124 | 687 | 43.4 | 17.3 | 0 |
| Yesil – Kamennyi Karier | 10 | 159.2 | 396 | 334 | 62 | 9.87 | 2688 | 0.996 |
| | 25 | | 444 | 280 | 164 | 26.1 | 1730 | 0.98 |
| | 50 | | 550 | 227 | 323 | 51.4 | 946 | 0.95 |
| | 75 | | 673 | 180 | 493 | 78.5 | 467 | 0.83 |
| | 80 | | 762 | 170 | 592 | 94.2 | 380 | 0.75 |
| | 95 | | 811 | 124 | 687 | 109 | 141 | 0.22 |
| Yesil – Petropavlovsk | 10 | 285.6 | 396 | 334 | 62 | 17.7 | 4045 | 0.996 |
| | 25 | | 444 | 280 | 164 | 46.8 | 2588 | 0.98 |
| | 50 | | 550 | 227 | 323 | 92.2 | 1396 | 0.93 |
| | 75 | | 673 | 180 | 493 | 141 | 668 | 0.79 |
| | 80 | | 762 | 170 | 592 | 169 | 536 | 0.68 |
| | 95 | | 811 | 124 | 687 | 196 | 171 | 0 |

To track the change in runoff under the influence of economic activity in years of different water content, a decrease in natural runoff was calculated. An analysis of the calculations shows that in high-water years (10 and 25 % supply), the runoff decreases due to additional evaporation from the water surface of artificial reservoirs to 5 %. In average water content years (50 % availability), the annual runoff decreases to 18 % (Yesil – Astana).

In dry years (80 % availability) – the decrease in annual runoff is from 25 to 80 % (the Yesil River – Astana, the decrease is 80 %, the Yesil River – the village of Kamennyi Karier, the decrease is 25 %, the Yesil River – Petropavlovsk, the decrease is 32 %. In exceptionally dry years (95 % availability), the entire annual runoff is retained in reservoirs and is irretrievably lost due to evaporation and use for household needs.

For the period from 1982 to 2018 years the decrease in runoff was calculated according to the volume of total water consumption for regular irrigation, the flooding of estuary irrigation areas, domestic and industrial needs, as well as the pond economy of the Yesil Water Management Basin. The calculation results are summarized in Table 3.

When calculating river runoff losses for filling ponds and reservoirs, the following data were used:

– Water content of the year, $P$, %;
– Total volume of reservoirs, $W_T$, million m$^3$;
– Runoff losses, $W_{RL.}$, million m$^3$;
– Annual runoff, $W$, million m$^3$;
– Decrease in natural runoff, $R_2$.

**Table 3** – Calculation of river flow losses on the filling ponds and reservoirs

| Year | $P$, % | $W_T$, million m$^3$ | $W_{RL}$, million m$^3$ | $W$, million m$^3$ | $R_2$ |
|---|---|---|---|---|---|
| *Yesil – Astana (Vyacheslav reservoir)* | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 |
| 1982 | 82.2 | 410.9 | 37.2 | 13.9 | 0 |
| 1983 | 15.6 | 410.9 | 40.4 | 198 | 0.80 |
| 1984 | 48.9 | 410.9 | 44.9 | 150 | 0.70 |
| 1985 | 6.67 | 410.9 | 46.4 | 297 | 0.84 |
| 1986 | 17.8 | 410.9 | 51.6 | 257 | 0.80 |
| 1987 | 20.0 | 410.9 | 56.6 | 216 | 0.74 |
| 1988 | 31.1 | 410.9 | 56.4 | 195 | 0.71 |
| 1989 | 57.8 | 410.9 | 55.3 | 63.3 | 0.13 |
| 1990 | 8.89 | 410.9 | 55.6 | 328 | 0.83 |
| 1991 | 35.6 | 410.9 | 56.6 | 199 | 0.72 |
| 1992 | 86.7 | 410.9 | 44.5 | 41.3 | 0 |
| 1993 | 28.9 | 410.9 | 54.5 | 410 | 0.87 |
| 1994 | 22.2 | 410.9 | 42.5 | 46.3 | 0.08 |
| 1995 | 40.0 | 410.9 | 50.4 | 157 | 0.68 |
| 1996 | 44.4 | 410.9 | 42.4 | 188 | 0.77 |
| 1997 | 37.8 | 410.9 | 20.2 | 138 | 0.85 |
| 1998 | 75.6 | 410.9 | 22.5 | 19.8 | 0 |
| 1999 | 91.1 | 410.9 | 26.6 | 6.30 | 0 |
| 2000 | 95.5 | 410.9 | 37.6 | 6.62 | 0 |
| 2001 | 60.0 | 410.9 | 32.3 | 33.1 | 0.02 |
| 2002 | 13.3 | 410.9 | 52.3 | 177 | 0.70 |
| 2003 | 71.1 | 410.9 | 41.9 | 58.9 | 0.29 |
| 2004 | 55.6 | 410.9 | 34.2 | 71.8 | 0.52 |
| 2005 | 24.4 | 410.9 | 20.4 | 140 | 0.85 |
| 2006 | 88.9 | 410.9 | 20.7 | 14.9 | 0 |
| 2007 | 4.44 | 410.9 | 22.0 | 113 | 0.81 |
| 2008 | 66.7 | 410.9 | 20.2 | 106 | 0.81 |
| 2009 | 84.4 | 410.9 | 20.1 | 37.9 | 0.47 |
| 2010 | 77.8 | 410.9 | 20.8 | 140 | 0.85 |
| 2011 | 73.3 | 410.9 | 20.4 | 45.3 | 0.55 |
| 2012 | 64.4 | 410.9 | 20.3 | 59.9 | 0.66 |

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| 2013 | 62.2 | 410.9 | 20.1 | 123 | 0.84 |
| 2014 | 11.1 | 410.9 | 20.7 | 210 | 0.90 |
| 2015 | 33.3 | 410.9 | 19.5 | 175 | 0.89 |
| 2016 | 26.6 | 410.9 | 19.2 | 85.9 | 0.78 |
| 2017 | 2.22 | 410.9 | 35.1 | 119 | 0.71 |
| 2018 | 10.8 | 410.9 | 33.4 | 216 | 0.85 |
| *Yesil – Petropavlovsk (Sergeevskoe reservoir)* | | | | | |
| 1982 | 80.0 | 1103.9 | 188 | 479 | 0.61 |
| 1983 | 17.8 | 1103.9 | 185 | 3528 | 0.95 |
| 1984 | 48.9 | 1103.9 | 171 | 1364 | 0.87 |
| 1985 | 6.67 | 1103.9 | 152 | 4064 | 0.96 |
| 1986 | 20.0 | 1103.9 | 165 | 3497 | 0.95 |
| 1987 | 22.2 | 1103.9 | 171 | 3371 | 0.95 |
| 1988 | 33.3 | 1103.9 | 156 | 2766 | 0.94 |
| 1989 | 57.8 | 1103.9 | 191 | 1096 | 0.83 |
| 1990 | 8.89 | 1103.9 | 145 | 4001 | 0.96 |
| 1991 | 35.6 | 1103.9 | 186 | 2388 | 0.92 |
| 1992 | 84.4 | 1103.9 | 172 | 422 | 0.59 |
| 1993 | 31.1 | 1103.9 | 144 | 2819 | 0.95 |
| 1994 | 15.6 | 1103.9 | 179 | 3560 | 0.95 |
| 1995 | 37.8 | 1103.9 | 195 | 2243 | 0.91 |
| 1996 | 46.7 | 1103.9 | 146 | 1474 | 0.90 |
| 1997 | 40.0 | 1103.9 | 107 | 2123 | 0.95 |
| 1998 | 77.8 | 1103.9 | 144 | 488 | 0.70 |
| 1999 | 91.1 | 1103.9 | 174 | 331 | 0.47 |
| 2000 | 95.6 | 1103.9 | 158 | 284 | 0.44 |
| 2001 | 60.0 | 1103.9 | 157 | 851 | 0.82 |
| 2002 | 13.3 | 1103.9 | 148 | 3623 | 0.96 |
| 2003 | 68.9 | 1103.9 | 134 | 743 | 0.82 |
| 2004 | 55.6 | 1103.9 | 146 | 1103 | 0.87 |
| 2005 | 28.9 | 1103.9 | 143 | 2911 | 0.95 |
| 2006 | 86.7 | 1103.9 | 145 | 400 | 0.64 |
| 2007 | 4.44 | 1103.9 | 154 | 4379 | 0.96 |
| 2008 | 73.3 | 1103.9 | 141 | 605 | 0.77 |
| 2009 | 82.2 | 1103.9 | 141 | 447 | 0.68 |
| 2010 | 88.9 | 1103.9 | 146 | 378 | 0.61 |
| 2011 | 71.1 | 1103.9 | 143 | 646 | 0.78 |
| 2012 | 64.4 | 1103.9 | 142 | 788 | 0.82 |
| 2013 | 62.2 | 1103.9 | 141 | 819 | 0.83 |
| 2014 | 11.1 | 1103.9 | 145 | 3843 | 0.96 |
| 2015 | 26.7 | 1103.9 | 137 | 2930 | 0.95 |
| 2016 | 24.4 | 1103.9 | 134 | 3182 | 0.96 |
| 2017 | 2.22 | 1103.9 | 246 | 6174 | 0.96 |
| 2018 | 51.1 | 1103.9 | 234 | 3150 | 0.93 |

An analysis of Table 3 shows that in high-water years (2018) at the hydrological post Yesil – Astana, the runoff decreases by 15 %, in the hydrological post of the Yesil – Petropavlovsk, the flow decreases by 4 % (2014). In dry years, the flow decreases by 50-100 % in the upper reaches of the river, and by 30-50 % in the lower reaches of the river, respectively. Table 4 shows the results of assessing the impact on the runoff of the filling volumes of reservoirs. According to these data, economic activity from 1974 to 2018 led to a decrease in runoff in the alignment of the Yesil – Astana in the average years of water content (50 % availability) by 30 %, and in the hydrological post of the Yesil – Petropavlovsk, the decrease in runoff is up to 7 %.

**Table 4** – Comparison of the water content of the Yesil River during periods with conditionally-natural and disturbed flow, $m^3/s$

| River – point | $P$, % | Conditionally-natural period, $Q_1$, $m^3/s$ | Disturbed period, $Q_2$, $m^3/s$ | $R_1$ | $R_2$ | $Q_{CV}=Q_1 \times R_1$ | $Q_{CV}=Q_1 \times R_2$ |
|---|---|---|---|---|---|---|---|
| Yesil – Astana | 10 | 13.5 | 8.16 | 0.99 | 0.85 | 13.4 | 11.5 |
| | 25 | 5.41 | 5.14 | 0.95 | 0.85 | 5.14 | 4.60 |
| | 50 | 4.43 | 2.68 | 0.82 | 0.70 | 3.63 | 3.10 |
| | 75 | 2.01 | 1.22 | 0.46 | 0.55 | 0.92 | 1.11 |
| | 80 | 1.59 | 0.96 | 0.20 | 0.47 | 0.32 | 0.75 |
| | 95 | 0.44 | 0.27 | 0 | 0 | 0 | 0 |
| Yesil – Petropavlovsk | 10 | 127 | 123 | 0.996 | 0.96 | 126 | 122 |
| | 25 | 80.7 | 77.9 | 0.98 | 0.95 | 79.1 | 76.7 |
| | 50 | 42.5 | 41.1 | 0.93 | 0.93 | 39.5 | 39.5 |
| | 75 | 19.5 | 18.9 | 0.79 | 0.70 | 15.4 | 13.7 |
| | 80 | 15.5 | 15.3 | 0.68 | 0.61 | 10.5 | 9.46 |
| | 95 | 4.37 | 5.51 | 0 | 0.44 | 0 | 1.92 |
| Note: $Q_{CV}$ – corrected value | | | | | | | |

An analysis of the obtained data shows that the decrease in runoff from the conditionally natural period to the disturbed period cannot be entirely attributed to the influence due to the influence of reservoirs. Apparently, the anthropogenic impact is due to agro-technical measures and climate change. Anthropogenic and climatic components (Table 4) of runoff reduction are determined by correcting the river runoff (multiplying the runoff of a conditionally natural period by the runoff reduction coefficients $R_1$ and $R_2$). In the case when there is no climatic trend, an approximate coincidence of the runoff of different probability and the "corrected" runoff is expected. In high-water years, there is a difference in these values, apparently, when the runoff is not significantly distorted by economic activity, the main role is played by the climatic trend.

## Conclusion

At the end of the twentieth century, the fait accompli of global warming began to be recognized as proven (Klige, 2006), (Georgievsky, 1996: 93) however, discussions about the causes of modern climate change remain unfinished. Many scientists recognize the fact of anthropogenic climate change as a result of the accumulation of carbon dioxide in the atmosphere, others are firmly convinced that the energy power of the processes occurring in the natural cycle is several orders of magnitude higher than man-made energy capabilities. Space rhythms, natural rhythm and its phases have a significant impact on many processes occurring on Earth, including long-term fluctuations in river flow, which are an integral indicator of climate change. As for the anthropogenic changes in the runoff of the last modern period, they are quite justifiably disturbing for humanity. They really exist, but their values are not comparable with natural cyclic climate changes of different nature. The danger of anthropogenic changes lies in their irreversibility.

In addition, the totality of accumulating anthropogenic and cyclic natural climate changes is dangerous because there are periods of years when anthropogenic and natural changes are directed in the same direction and can manifest themselves with alarming speed, so minimizing the anthropogenic component is a safety option for humanity. As a result of the conducted scientific research, the following main conclusions were obtained:

1. To track the change in runoff under the influence of economic activity in years of different water content, a decrease in natural runoff was calculated. An analysis of the calculations shows that in high-water years (10 and 25 % supply), the runoff decreases due to additional evaporation from the water surface of artificial reservoirs to 5 %. In average water content years (50 % availability), the annual runoff decreases to 18 % (Yesil – Astana). In dry years (80 % availability) – the decrease in annual runoff is from 25 to 80 % (Yesil – Astana, the decrease is 80 %, Yesil – the village of Kamennyi Karier, the decrease is 25 %, Yesil – Petropavlovsk, the decrease is 32 %. In exceptionally dry years (95 % availability), the entire annual runoff is retained in reservoirs and is irretrievably lost due to evaporation and use for household needs.

2. For the period from 1982 to 2018 years the decrease in runoff was calculated according to the volume of total water consumption for regular irrigation, the flooding of estuary irrigation areas, domestic and industrial needs, as well as the pond economy of the Yesil Water Management Basin. Data analysis shows that in high-water years (2018) at the hydrological post of the River Yesil – Astana city, the runoff decreases by 15 %, in the hydrological post of the River Yesil – Petropavlovsk city, the flow decreases by 4 % (2014). In dry years, the flow decreases by 50-100 % in the upper reaches of the river, and by 30-50 % in the lower reaches of the river, respectively.

Analysis of the results of assessing the impact on the runoff of the volumes of filling reservoirs. According to these data, economic activity from 1974 to 2018 led to a decrease in runoff in the alignment of the River Yesil – Astana city in the average years of water content (50 % availability) by 30 %, and in the outlet section of the River Yesil – Petropavlovsk city, the decrease in runoff is up to 7 %. The decrease in runoff from the conditionally natural period to the disturbed period cannot be entirely attributed to the influence due to the influence of reservoirs. Apparently, the anthropogenic impact is due to agro-technical measures and climate change. In the case when there is no climatic trend, an approximate coincidence of the runoff of different probability and the "corrected" runoff is expected. In high-water years, there is a difference in these values, apparently, when the runoff is not significantly distorted by economic activity, the main role is played by the climatic trend.

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