Runoff of Ural River in natural and anthropogenically modified conditions

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Abstract. The water resources of the Southern Urals are considered. The influence of the level of provision with water resources on the formation of bioresources, society and economy has been revealed. The necessity of increasing the construction of reservoirs in its basin is substantiated. The results of the study are aimed at improving the efficiency of the use of water resources by nature, in society and the economy in the Ural River basin.

1 Introduction

The Ural River and its catchment area are located in forest-steppe, steppe and semi-desert zones with a wide variety of geology and relief, intense specific anthropogenic impact. The peculiarities of river basins necessitate targeted solutions for their optimization in the interests of nature and man.

The water flow of the Ural River and economic activity in its catchment area differ significantly from other rivers in Russia [1-3]. The most important and main problem of its water runoff is a large unevenness in years and seasons. Anthropogenic changes in the formation of water runoff in the catchment area are great. Without their consideration, measures to solve environmental problems will not give the desired result. Changes in the flow regime of the Ural River cause corresponding changes in its bed and floodplain with positive and negative consequences.

The Ural River and its catchment area is a complex system of living and non-living matter, which is in evolutionary development together with the continuously changing climate, weather and the entire Nature of the Earth with and without the participation of human activity, as its evolutionarily formed part [4].

2 Materials and methods of research

The materials of the authors' field experiments, stock materials of the Orenburg Hydro meteorological Centre and the Orenburg State Statistical Office were used. The features of the flow of the Ural River and their influence on the nature of the basin have been studied by statistical processing methods with the construction of graphs.

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3 Results

The Ural River basin is characterized by uneven runoff both in the long-term regime and throughout the year. Using the data of the Orenburg hydrometeorological centre, two periods can be distinguished in the annual flow regime of the river: its increased unevenness in 1927-1957 before the construction of the Iriklinsky reservoir of long-term regulation in its upper reaches with a volume of 3.2 km^3 in 1967-2021 and after its filling in 1967-2021. In the first period before significant regulation, the river in the Orenburg region had mainly natural flow (Figure 1) with a flow rate for the year from 23 m^3/s (1936) to 303 m^3/s (1946).

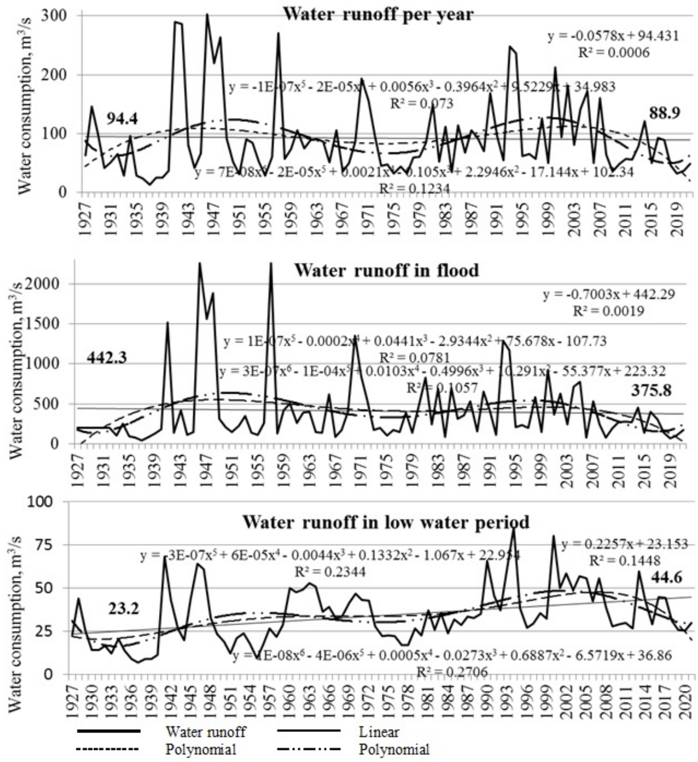

Figure 1. Water flow rate (m^3/s) in the Ural River 1927-1921 in the Orenburg region.

There are two main periods in the annual runoff of the Ural River - spring flood and low water period. The most important is the spring flood. During the flood, up to 90% of the annual runoff passed (1942). Before the construction of the Iriklinskoye reservoir in 1927-1957 in the area of the city of Orenburg, 74% of the annual river flow passed through the flood. After the reservoir was put into operation in 1967-2021, its share decreased to 58%.

The figure shows the variability of the runoff of the Ural River during the spring flood in April, the month of the highest water flow in spring, in the alignment of the city of Orenburg in 1927-2021. In the flood runoff, similarly to the annual runoff, a period is distinguished before the construction of the reservoir and after its filling. In 1927-1957, the flow of water in the river was 460 m^3/s and varied from 24 m^3/s (1939) to 2260 m^3/s in 1946 and 1957. The reservoir reduced the average flood flow to 391 m^3/s, but increased the minimum flow to 66 m^3/s (2019) and reduced the maximum to 1350 m^3/s (1970), eliminating the extremely small and extremely large flows.

In the low-water runoff of the Ural River, periods are also observed before and after the construction of the Iriklinskoye reservoir. Its main minimum is in July-February. In 1927-1957, the natural low flow of the river averaged 24 m^3/s and varied from 7 m^3/s (1937) to 68 (1941). After the construction of the reservoir, the average low flow increased to 38 m^3/s, which is 1.6 times the low flow before its construction, and ranged from 17 m^3/s (1977 and 1978) to 85 m^3/s (1994).

The unregulated water flow of the Ural River with large fluctuations over the years and seasons with rapid spring floods and prolonged shallow waters in low water does not contribute to the efficient use of its water resources. Most of them are discharged into the Caspian by spring floods without prior use in society and economic activity, intensifying erosion processes in its channel.

4 Discussion

A distinctive feature of floods in the Ural River basin, lasting about a month, is a rapid change in temperature and turbidity of water, volumes, level and speed of its flow. The rapid change in the living conditions of living organisms makes it difficult for them to adapt to new and new conditions, they slow down development in a stressful situation and die in many, the species composition changes. The spring flood of the Urals begins in mid-April and lasts until May 10. The temperature of the water in the river during the flood, according to the Orenburg hydrometeorological centre, is in the range of 5-10 °C with large fluctuations over time, which is below the optimal temperature regime for the spawning of many fish species. The quantity and species composition of benthos in the river begin to recover after winter anabiosis with an increase in temperature after the flood and stabilization of water runoff during low water periods [6-8].

The bottom, channel, banks are the most dynamically changing elements of the river system by natural processes, including the movement of water, its waves, ice floes and other objects floating in the watercourse. The watercourse meanders under the influence of denudation, tectonic processes, the Coriolis force, obstacles in the way of the watercourse, turbulence of the flow, transverse circulation of the flow, displacement of the axis of water movement, and other reasons. The meandering flow is characterized by the asymmetry of the channel and the changing speed of the current. According to geological studies, the ancient channels of the Ural River are found several kilometres from its present position.

The natural processes of changing the channel, bottom and banks of the river cannot be attributed only to negative factors for the river ecosystem. Their destruction and redeposition increase the amount of silt and the availability of nutrients for the living organisms of the river.

The flood of steppe rivers is a short-term, but significant period in the life of settlements located near it. When choosing a place for them, the first settlers solved a difficult question - which is better: proximity to the river during the year, more fertile lands of its valley in household plots, proximity to forest vegetation, shallow and accessible occurrence of groundwater, more favorable microclimate of floodplain relief depressions territories with periodic flooding in high floods, or uplands blown by hot steppe dry winds, deprived of the advantages of the location of the settlement near the river. Mostly in the steppe zone, historically, sometimes with a change in the originally chosen location, the settlements are located near the river, often with high floods flooding some of their parts. Flooding by floods causes damage to buildings, creates inconvenience for residents and production, and the death of people, animals, crops and other vegetation is possible.

In seasonal low water areas, the areas of aquatic vegetation and bottom silt containing benthos are reduced, the food base of the ichthyofauna and other aquatic animals is destroyed. The number of ichthyofauna and its species composition is determined by the low water volume, and not by average and short-term floods. According to the research of D.K. Kozhaeva, S.Ch. Kazanchev and D.V. Zhantegolov [9] for ichthyofauna, the water depth in the reservoir should be at least 2.5-3 meters. The average depth of the Urals in the region of Orenburg in the low water period is 0.6-0.7 m, which is not enough for the functioning of a productive ichthyofauna and is the reason for its small number in it and its tributaries.

The growth of many settlements in the Orenburg region is limited by the low availability of water resources. They suffer during the low water period from low water, and spring floods from its excess. It is necessary to accumulate meltwater in reservoirs in areas of promising settlements. They will become centers of attraction for the population from unpromising settlements. In growing settlements, it is cost-effective to create high-tech production and a socio-cultural base for a comfortable life for the population. In rural areas, these will be agricultural towns.

Without improving the efficiency of the use of water resources in the natural system of the Ural River Basin, which are mainly discharged into floods without prior use, the harmonious development of its nature and the improvement of the life of the population are problematic.

Negative impacts of water flow instability are eliminated or reduced by the construction of reservoirs and ponds.

The water resources of the Ural River Basin are formed by precipitation interacting with a specific earth's surface, living matter, subsoil and atmosphere in a continental climate. Natural processes are affected by the anthropogenic factor, which shifts the dynamic natural balance in one direction or another and replaces one process with another. But anthropogenic impacts also depend on the availability of water to the territory.

Industry and agriculture are highly developed in the Ural River basin, creating a double anthropogenic impact on nature: industrial zones in urban agglomerations, occupying about 2% of the territory, and agricultural land use on 90% of its territory. Agriculture affects less per unit area, but in total it significantly exceeds the industrial one in terms of the entire area. The agricultural use of the land has changed the quality of the soil and their water-physical properties, and changed the balance of natural waters [10].

In arid zones, agricultural land use is focused on increasing moisture reserves in fields, pastures and hayfields by reducing water runoff. The moisture accumulated on them is spent on transpiration and evaporation from the soil surface, increasing its amount in the atmosphere. Atmospheric moisture capacity limits create conditions for additional atmospheric precipitation, increasing the small water cycles on the continent, which increases the efficiency of its use.

The ratio of expenditure items of the water balance in the catchment significantly affect the filtration properties of the earth's surface. They determine what part of the water that has entered the earth's surface will go to increase the moisture reserves in the soil, seepage into groundwater and surface runoff into the hydrographic network. Our studies of the expenditure part of atmospheric precipitation near the city of Orenburg on various lands showed that on the elevations of arable land with large reserves of snow (0.12 m) and water runoff from them (on average 0.028 m), it almost did not go beyond the arable massif (on average 0.0023 m) and did not feed groundwater, without going beyond the layer of soils and soils from which vegetation consumes moisture without feeding groundwater. Partially draining, it accumulates in closed depressions. The melt water accumulated in them saturates the active layer of the aeration zone (on average 1.5 m), from which it is consumed by plants, goes to feed groundwater, and the unabsorbed water, overflowing the depression, flows down the slope into the hydrographic network [10].

According to our studies on arable land, depressions occupy 11% of the studied slope. They accumulated an average of 0.27 m, which, based on the entire area of arable land, is

0.029 m. On broken virgin land with an average snow reserve of 0.134 m, the runoff of melt water from the elevations of the relief was 0.078 m, and their runoff from the total land area was 0.041 m. An average of 0.017 m was spent on feeding groundwater. On the virgin soil with an average snow reserve of 0.18 m, the flow of melt water from the hills was an average of 0.053 m, and the total runoff from the slope was 0.008 m. 0.361 m, which is calculated on its entire area - 0.05 m.

Studies of the water balance in the autumn plowing, virgin lands that were not cut out and knocked out during the snow melting, revealed a significant influence of the state of the earth's surface on surface and underground runoff. Prior to the intensive development of cattle breeding and the development of virgin lands in the Southern Urals, the low-water fullness of the rivers in the Ural basin was provided by a large share of infiltration of melt water on virgin lands that were not cut out. An increase in the number of livestock has deprived the virgin lands of a significant part of the turf, the soil has become compacted, which as a result has reduced water infiltration, respectively increasing floods and reducing low water runoff. The plowing of virgin lands and the transition to autumn plowing led to a general decrease in the flow of melt water into the rivers.

Studies of the water balance in the steppe zone of the Southern Urals showed the presence of both evaporative and infiltration types of water exchange on all types of land. The first is confined to elevations, and the second - to closed relief depressions. Together they form a patchy variety of soils, vegetation and many other components of nature, uneven supply of groundwater over the area.

Changes in land, the ratio of their shares in the catchment area with different filtration properties of the surface change its water balance. With a decrease or increase in the filtration supply of groundwater, taking into account the time of their travel, the river runoff changes accordingly.

The water balance in the catchment area of a small river in the Southern Cis-Urals is considered on the example of the upper reaches of the Samara River ($S = 1260\ km^2$) to the site in Novosergievka urban settlement for periods of economic activity in 1934-2020, depending on its plowing. Periods of 5-10 years or more are accepted for research. Long-term periods make it possible to average the influence of the variety of rapidly changing weather conditions of individual years on runoff indicators, bringing them closer to the more stable climatic indicators of climate and its cycles that we considered earlier [10], and to reduce their influence on the results of studying factors of long-term action on the filtration properties of the earth's surface: arable land, autumn plowing, perennial biocenoses and more stable climate indicators.

The plowing of the watershed has a great impact on the water runoff in the Southern Urals. It increases the filtration properties of the earth's surface, which reduces surface runoff, contributes to the accumulation of moisture in the soil and the nourishment of groundwater. The impact of autumn plowing on the expenditure items of melt water is especially great [10].

In the analyzed period (1934-2020) in the steppe upper reaches of the Samara River, three periods of intensive plowing of the catchment area were considered. In 1934-1965, during the period of extensive land use in crop production, arable land occupied less than a third of the watershed, and autumn plowing, on average, 11% of its area. The main part of the watershed was occupied by overgrazed pastures and hayfields with compacted soil. As a result, on average, 62% of the melt water went to the flood runoff of the river and 31% of the annual atmospheric precipitation was spent on the formation of the annual runoff. During this period, the average annual flow of the river from the studied part of the watershed in the alignment of the village of Novosergievka was 0.105 m, and the flood was 0.065 m.

The plowing of virgin lands in 1954-1960, and especially the transition to autumn plowing in the 60s of the XX century, changed the filtration properties of the earth's surface in a large part of the catchment area. During the period of intensive use of land in crop production (1955-1990), the share of arable land doubled on average to 62% of the catchment area. Autumn plowing began to occupy half of it. The moisture reserves in the soil of arable lands increased, which increased the evaporation of moisture from them. The annual flow of the river decreased to 0.09 m per catchment area, and the flood flow to 0.048 m from 0.065 m in the previous period of extensive use of land in crop production, with an increase in precipitation by an average of 9%. The coefficient of the annual flow of the river in this period according to atmospheric precipitation is 0.24, and the coefficient of the flood according to winter precipitation is 0.53.

After 1990, in the study area of the watershed, a multi-layered use of land in crop production is formed with an increase in the share of farms in the watershed. The areas under grain crops are decreasing and the sowing of tilled crops, mainly sunflower, with a system and terms of tillage that differ from grain crops with corresponding changes in filtration properties, which have not yet been studied, is increasing. In 1991-2020, annual and winter precipitation increased by 11% compared to the previous period, and the area of autumn plowing decreased by 2.5 times. Under these conditions, the annual river flow in terms of the studied part of the catchment area increased by 1.5 times to 0.137 m, and the flood flow by 1.4 times to 0.069 m. The river flow coefficient for atmospheric precipitation increased to 0.34. Consequently, since 1990, the effectiveness of the use of precipitation on arable land, which is scarce in the steppe part of the Southern Urals, has decreased.

5 Conclusion

The current state of the Ural River and its tributaries with large irregularities in flow over the years and seasons is not favourable for the development, biodiversity and productivity of biosystems in its channel and floodplain, as well as society and human economic activity.

Catastrophic floods with short-term spills create stressful conditions for the living organisms of the river and floodplain with many victims.

In the dry low water of the Urals and its tributaries, the areas of aquatic ecological systems are reduced, which leads to a decrease in the species composition of the ichthyofauna and its productivity, unfavourable conditions for society and the development of production are formed.

The system of reservoirs in the upper reaches of the Ural River improved the ecological situation for the population and increased the productivity of nature in the regulated part of the basin, and increased the low-water runoff in its lower part.

The solution of many problems of ecology, society and human economic activity in the Ural River basin is possible on the basis of a stable supply of water resources in the required volume, which are a system-forming component of water-deficient territories.

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