Problem of environmental remediation of the river runoff of basin geosystem of the small river Alma (Republic of Crimea)

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Abstract. An assessment of the ecological state of the small river basin Alma of the Republic of Crimea has been carried out. Due to intensive nature management in the 20th century, the primary natural environment was transformed into a natural-engineering system (NES). The critical components of the NES are the lowland sector and surface waters basin. The flat sector turned into an agricultural landscape with a low coefficient of natural protection, it needs transformation based on landscape planning. Runoff the Alma River is almost completely regulated by reservoirs and ponds, as a result of which the channel is deprived of water for most of the year. It is proposed to restore the natural flow of the river by redistributing the reserves of the Partizansky reservoir and establishing Western European water consumption standards for Simferopol.

1 Introduction

There are 2.5 million small rivers in Russia, they form almost half of the total river flow, about 45% of the urban dwellers live in their basins. Small rivers are not only an important source of water supply but also one of the most environmentally sensitive elements of the landscape sphere. Unlike larger watercourses, a small river is very closely related to the natural environment, and every change in the landscape of the catchment immediately affects its regime [1]. The natural features of small rivers include relatively small volumes of runoff, low limits of self-purification processes, and significant dependence of their regime on the state of the catchment area. The intensification of UN activities in the 1980s on nature protection contributed to the development of the theoretical foundations of ecological nature management and the adoption in the Russian Federation of a series of legislative acts on environmental protection (1970-1993). The object of this research is the typological river basin of the Republic of Crimea - the basin of the small river Alma. The subject of research is the ecological state of the natural-engineering systems of the basin [2]. The methodical approach is ecological diagnostics of the natural environment and the behaviour theory of the canals process. In Crimea, the basin of the small river Alma is among the most anthropogenically altered. In this territory, during the 20th century, when intensifying the use of agricultural and water resources, environmental

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restrictions were not taken into account. The article proposes an ecologically balanced environmental management option for the Alma basin.

1. Formation of a natural basin geosystem. The basin of the small river Alma, like other rivers of the Crimea, was formed during the Quaternary period (about 1.2 million years), simultaneously with the modern topography and climate of the peninsula. Bodak river left tributary of the Alma River in the recent geological past (at the beginning of the Quaternary period) was not a tributary of the Alma River and flowed into the sea. The Alma River then flowed through the valley of the present Western Bulganak. With the general rise of the Crimean Peninsula, the river. Pra-Bodrak crashed into the basin of the neighbouring river. Alma and took her water. The formation of a common drainage basin of the Alma and Bodrak rivers took place. As it uplifted, the Crimean mountain structure differentiated into three ridges - Main, Internal, and External, separated by depressions. River basin Due to its geographical position and geological structure, the Alma was relatively well supplied with water resources in comparison with other rivers of the Crimea. The Alma basin includes three geomorphologically different sectors: plain (steppe), foothill (shrub) and mountain-forest. The main part of the river's water flow is formed in the mountain-forest zone.

2. The current state of the natural and technical system of the basin. Archaeological and historical data indicate that the ethnic, social and economic development of the territory of Crimea in the last two thousand years has been carried out with the limiting role of water resources. The situation changed after the annexation of Crimea to Russia in 1783. From the beginning of the 19th century, the development of the agricultural sector acquired a dominant and intensive character, which was very soon reflected in the fall in the water content of the rivers. At the end of the 19th century, in 1895, the geologist N.A. Golovkinsky noted with concern the decrease in the flow of Crimean rivers due to the deforestation of coastal forests. In the twentieth century, the economic development of Crimea continued. Scarce water resources were used especially intensively. In the river basin Alma in 1934, the construction of the Alma reservoir was completed, 1.8 million hectares of land were irrigated. In 1966, another reservoir was put into operation - Partizanskoye, practically all of its waters were directed outside the river basin - to supply water to Simferopol. As a result, it turned out that the Alma River was withdrawn about 80% of the annual flow. Analysis of archaeological, historical, and modern materials allows us to identify in the NES of the river basin two critical components of the geosystem - flat areas with steppe community and surface waters. Critical components in the terminology of B.V. Sochavy are considered to be the most rapidly transforming parts of the natural environment. Their current unstable depressive state is a consequence of the implementation in the twentieth century of nature management with the dominance of the criterion of economic efficiency. Let us consider the state of the critical components of the NES from the modern concept of sustainable development and harmonization of environmental management [3,4,5].

2.1. Ecodiagnosics of the plain-steppe sector of the basin territory was carried out by one of the authors of this article. According to B.I. Kochurov, calculation of the coefficients of absolute, relative tension, and natural protection (Ke_z) was carried out. It was found that the mountain-forest sector of the basin has a high $Ke_z = 0.8$, while the larger foothill-lowland part of the basin has $Ke_z < 0.5$. This parameter indicates a critical ecological situation resulting from unbalanced nature management. To transfer the critical component to a stable state, it is proposed to perform landscape planning. In this work, the object of the study is the second critical component of the natural environment of the Alma river basin are surface waters [6].

2.2. Assessment of the degree of anthropogenic impact on water resources. The main indicator of the state of water resources is the main watercourse of the river basin - its channel, flow volume and water quality [7]. All river engineering structures are divided into

two classes according to the degree of influence on the factors of the channel process: active and passive. The active class includes structures that lead to a change in the determining factors of the channel process: water runoff, sediment runoff and restriction of the free development of the channel (water management natural-technical systems (NES) intended for the implementation of intra-basin flow regulation - ponds, reservoirs, canals, as well as bridges). The class of passive engineering structures includes NES of water supply and wastewater disposal (municipal, agricultural, industrial), improvement of river landscapes, an arrangement of recreational areas, etc. In the twentieth century, as the social and economic development of the Crimean Peninsula on the territory of the river basin. Alma turned out to be, in addition to intra-basin, two objects of inter-basin significance. These include: 1) Alma artesian basin and 2) Partisan reservoir. The Alma artesian basin includes groundwater, the area of distribution of aquifers of which for the most part coincides with the area of the drainage basin of the Alma River. The water intake of artesian waters is located near the village Vilino-2. From a 140 m deep well, water flows into a 44 km long water pipeline supplying Bakhchisaray.

Partisanskoe reservoir came to be used in 1966, has a design capacity of 80 thousand m³ / day, including in Simferopol - 0.67 m³ / sec, in the Alma river bed - 0.08 m³ / sec. In fact, this meant the cessation of water discharge into the river bed. Accordingly, numerous measures to regulate and redistribute the flow were stopped or frozen. Partisanskoe reservoir collects water from the upper reaches of the Alma River and supplies the micro districts of Simferopol: Novoromanovka, Zalesye, Central Market. The hydrosystem includes an earthen dam, a tower-type water intake structure and a coastal spillway. An embankment dam of Aptian clays and alluvial loams blocked the river bed near Kizilovka village. The height of the dam is 42 m, its length along the ridge is 356 m, the width at the top is 10 m, the width at the base is 290 m. The length of the reservoir is 4.5 km; maximum width - 1.5 km; maximum depth - 40 m, average depth - 15 m; water surface area - 225 hectares. The water intake structure consists of a shaft water intake tower 40 m high and 6 m in diameter, a tunnel, and an open chamber with a throughput of 1.6 m³ / s. The spillway for discharging flood waters includes a 36 m wide inlet channel, a spillway, a reinforced concrete rapid flow and a stilling well. The spillway is five-span, closed by metal segmental gates 6 meters wide with a head of 2.5 m. The length of the rapid flow is 584 m; width - 20 m; it is designed for a water flow rate of 286 m³ / s. On May 16, 2019, the actual filling of the Partizanskoe reservoir had been 28.8 million m³ of water, as of 07/09/2020 - 8.4 million m³ of water (with an ULV of 2.2), the total volume is 34.4 million m³, the design capacity - 80 thousand m³ / day (Fig. 1,2).

Fig. 1,2. The water level of Partizanskoe reservoir on July 9, 2020

Expert examination of the condition of the Alma river basin and bridges was carried out by us in the summer low-water period (July 2020). Condition of bridges.

21 bridges were built on the river Alme (Table 1, Fig. 4), including 18 automobile, two pedestrian and one railway. Based on the results of the survey, a base of bridge crossings

was compiled according to criteria values. Most of the bridges were built in the 1970s, simultaneously with large-scale work to straighten the river with the aim to increase usage of the floodplain for agricultural purposes. Since the technical numbering of the bridges is made from the mouth upstream, the channel description is given in the same direction. All road bridges are of the same type. They are assembled from reinforced concrete slabs, walls and supports. The roadway of the largest bridge has 18 m length with a 4 m support height (Fig. 3,4). The technical condition of all the bridges is satisfactory.

Fig. 3,4. Railway bridge

The state of the river bed was assessed by the expert method on a 4-point scale proposed by the Ministry of Ecology of the Russian Federation in the early 1990s. 25 surveyed sites received the following status assessments: norm - 1 (a fragment of the Bodrak River channel, left tributary of the Alma River), risk - 5, crisis - 19. The morphology of the river channel is disparate in different parts of the valley, in most cases it bears traces of noticeable technical impact and indicates the degradation of natural channel processes due to the lack of water or insufficient amount of it.

Fig. 5-7. Embouchment of the Alma River. Photo on July 6, 2020

The survey took place on the 7-10 June, 2020, water was completely absent on the sections of bridges No. 5, 6, 7, 8, 21 (Table 1). There is an elite boarding house ‘Chernomorets’ on the seashore near the embouchment of the Alma river (N 44 ° 50’45.8’’ E 033 ° 35’36.6’’) (Fig. 5-7). The river does not reach the sea, water in the channel is dirty, blooms, has a green color and swampy smell. The channel is silted up to the bridge No. 5.

Fig. 8. Bridges over the small Alma River

Table 1. Runoff conditions along the river bed

N bridge	Coordinates	Water availability and quality
1	Bridge on the private territory 'Chernomorets' boarding house	
2	N 44°50'28.0''E 033°36'23.2''	The water is turbid, has green colour and swampy smell. The current speed is 0.1 m / s
3	N 44°50'31.0''E 033°36'48.6''	Turbid water, swampy smell. There is no flow stream.
4	Bridge near Rassadnoe village. Private territory, passage is closed	
5	N44°50'17.3''E033°39'30.0''	There is water only under the bridge in a technical depression, the riverbed is dry.
6	N 44°50'42.0''E 033°42'01.5''	Water only under the bridge (technical deepening), the bed is dry. Near the bridge, outlet channel K-1-4 (L = 11.5 km)
7	N 44°51'20.1''E 033°43'36.4''	The bed is dry (Fig. 8-10)
8	N 44°51'39.3''E 033°45'48.7''	The bed is dry
9	N 44°51'55.5''E 033°47'34.2''	The flow speed is 0.3 m / s. There is a hydraulic engineering structure No. 6 for irrigation below the bridge. Local population is pumping out water for irrigation purposes.
10	N 44°52'04.6''E 033°47'54.4''	There is water, the flow velocity is 0.3 m/s. The local population is pumping out water for irrigation purposes.
11	N 44°52'07.9''E 033°48'33.9''	The flow speed is 0.3 m/s.
12	N 44°52'04.9''E 033°51'05.9''	The flow speed is 0.3 m/s.
13	N 44°51'44.7''E 033°53'14.9''	The flow speed is 0.2 m/s.
14	N 44°50'23.0''E 033°54'46.1''	Hunting ground. There is water, the flow speed is 0.2 m/s, grazing is below the bridge.
15	N 44°50'10.1''E 033°55'32.3''	The flow speed is 0.3 m/s.
16	N 44°49'48.9''E 033°55'59.3'' Railway bridge	The flow speed is 0.3 m/s. There is grazing below the bridge.
17	N 44°49'46.6''E 033°56'40.6''	The flow speed is 0.2 m/s. The channel is overgrown with bushes.
18	N 44°49'46.7''E 033°56'40.5''	Near the right bank under the bridge the riverbed is dry, it is used as a road. There is water near the left bank, the flow speed is 0.2 m/s.
19	N 44°49'46.7''E 033°56'40.5'' The construction of the bridge takes place (highway "Tavrida")	
20	N 44°50'01.0''E 034°00'51.1'' Pedestrian bridge	The flow speed is 0.2 m/s.
21	N 44°49'25.3''E 034°02'37.9''	There is no water in the channel near the bridge and above, there is a swamp below the bridge.

Fig. 9. Section of the Alma river under the bridge № 2

Fig. 10,11. Bridge № 7

Fig. 12. Section of the Alma river under the bridge № 7 (no water)

There is an untitled watercourse passing near the eco-farm, rabbit farm and treatment facilities below the bridge near Kizilovoe village (Fig. 13). It is possible that various effluents are discharged into this stream. This watercourse flows into the Alma river below the bridge No. 21. Above the bridge, the riverbed is overgrown with bushes, there is no water (Fig. 14,15), which indicates the absence of discharges from the Partizanskoe

reservoir. Winter 2019 was practically snowless, autumn 2019 and spring 2020 were also very poor in precipitation, which exacerbated the situation of ‘water hunger’.

Fig. 13. Disposal works of the eco-farm above Kizilovoe village.

Fig. 14,15. Bridge № 21

The Bodrak River, a tributary of the Alma River, currently the catchment area of the Bodrak river is 76.5 km², its length is about 15.5 km, width of the channel in summer is no more than 2-3 meters, depth is about 30 cm (Fig. 16-18). Often in dry years, in summer and autumn, the river (along its entire length) completely dries up.

Fig. 16,17. the Bodrak River

Fig. 18. Section of the Alma river – the Bodrak river (influx)

The quality of surface and ground waters depends on the ecological state of natural environment. Surface waters filling the Partizanskoe reservoir are formed in the forest reserve zone and comply with sanitary standards. In the steppe region of the Alma river receives less than a fifth of the river's runoff while the water, due to the high anthropogenic load, is heavily polluted with domestic wastewater and chemicals. It belongs to the classes "dirty" and "very dirty" and is suitable only for technical purposes. Therefore, the supply of most of the settlements of the Alma river basin drinking water is currently provided by groundwater - artesian and partly groundwater. Only a few villages located in low mountains use surface waters.

3. The main directions and measures for the ecological optimization of the NES of the Alma river basin.

3.1. It is recommended to carry out landscape planning to reduce the anthropogenic load on the plain-steppe part of the basin.

3.2. Restoration of the natural flow of the Alma river. Calculation of ecological (sanitary) runoff for small rivers located in zones of insufficient moisture (steppe, semi-desert) and drying up during the low-water period, usage of the term “ecological runoff” is incorrect. This term also does not make sense for the modern NES of the Alma river basin. But in the natural basin system of the river, which existed until the 19th century, the river runoff also existed during low water periods. In the order of the Ministry of Natural Resources of the Russian Federation of 12.12.2007, No. 328, the standards of permissible impact on natural water bodies are given. These recommendations are always individual in landscape and ecological terms, the calculations of the ecological pass are carried out for each object separately. On rivers with a flow of less than 1 m³ / sec to which the Alma river belongs. Therefore, it is recommended to take the minimum allowable withdrawal equal to the minimum monthly consumption of 95% security. The ecological flow of the Alma river is determined on the basis of a long-term database:

Table 2. Ecological water discharge of Crimean rivers and their changes along the length.

№	Settlement (gauging station)	Distance from the embouchment, km	Drainage area, km ²	Water discharge, Q ^{min} _{95%} , m ³ /s
1	Above Partizanskoe Reservoir	55	19,6	0.012
2	Reservoir in Karagach village		249	0.004
3	Pochtovoe village	38	300	0.000
4	Krasnoarmeyskoe village		607	0.000
5	Peschanoe village	0	635	-

Analysis of the internal reserves of the water supply system of Simferopol.

In order to search for reserves for restoring the Alma river flow, an assessment of the state of the water use system in Simferopol was carried out and a comparative analysis of water consumption rates in Crimea and Western Europe was carried out [8,9,10]. In Brussels, the capital of the Kingdom of Belgium ($F = 30.5$ thousand km²; population 11.4 million people; average density 368 people / km²). Water consumption for household needs is 85 thousand m³ / day. In Simferopol, the capital of the Republic of Crimea ($F = 27.0$ thousand km², population 1.914 million people; average density 73 people / km²), 342 thousand people live. For household needs is 175 thousand m³ / day. In the Alma river basin, in the Bakhchisarai district, according to a survey of 01.01.2018, 90.9 thousand people live. The length of water pipelines and water supply networks in the joint venture of the Bakhchisaray municipal district is 503 km, including 278 km in need of replacement. The depreciation level of wear and tear of water supply networks was 55%, which leads to an accident rate reaching 1.55 per km per year. The share of losses and leaks reached 40% in relation to the water supply. The specific consumption of electricity consumed in the technological process of preparing drinking water per unit volume of water supplied to the network was 0.67 kW / cubic meters. m. The actual water consumption by the population of Bakhchisarai in 2016 was 3.3 thousand m³ / day, the specific actual water consumption by the population covered by the centralized water supply (about 26 thousand people) was 127 l / day. person. The expected consumption of all types of water is calculated based on the design indicators of the territorial planning scheme and the prospective rate of water consumption (160 l / day. person). Actual water consumption by the population of the Bakhchisarai district in 2016 amounted to 7.2 thousand m³ / day, the specific actual water consumption by the population covered by the centralized water supply (about 44 thousand people) - 164 l / day. person. The expected consumption of all types of water is calculated based on the design indicators of the territorial planning scheme and the prospective rate of water consumption (140 l / day per person). In the unified water supply and sewerage scheme of the Republic of Crimea, it is noted that water supply to the urban district of Simferopol ($N = 362$ thousand 301 people) was $W = 55.863$ million m³ / year = 153.05 thousand m³ / day = 422 l / (person * day). Even with an overestimated water consumption $W = 160$ l / (person * day) - this is 2.64 times more than the norm, and if we assume that a more reasonable rate is no more than 85 l / (person * day), this is more than 5 times more than expected. According to, in the Republic of Crimea it is proposed to increase the water supply rate for the population of Simferopol by 1.5 times by 2030 from $W = 20.0675$ million m³ / year to $W = 30.031$ million m³ / year (with $W = 54.979$ thousand m³ / day = 152 l / (person * day) to $W = 82.277$ thousand m³ / day = 227 l / (person * day)). With the announced water shortage in Simferopol, we forecast an increase in its consumption by 50%. The situation is similar in general for the Republic of Crimea: - 2016 $W = 87$ million 435.3 thousand m³ / year = 239.6 thousand m³ / day = 125 l / (person * day); - 2030 $W = 140$ million 331.7 thousand m³ / year = 384.5 thousand m³ / day = 201 l / (person * day).

2 Conclusions

On the basis of a long-term and comprehensive survey of the natural and technical systems of the Alma river basin (Republic of Crimea), the authors have come to the following conclusions.

1. The critical components of the NES of the Alma river basin are the following: 1) a plain landscape with primary steppe communities, now represented by an agricultural landscape with an agricultural functional type of anthropogenic load; 2) water surface, the bulk of which is accumulated in the Partizanskoe reservoir and is used outside the basin.
2. According to natural conditions and the degree of anthropogenic load, the Alma River basin is divided into two sharply different parts: mountain forest with a high degree of

natural protection ($K_{ee} = 0.8$ according to the method of B.I. Kochurov), while the foothill-lowland steppe zone is characterized by a critical ecological situation with $K_{ee} < 0.5$. For the latter, landscape planning is recommended.

3. Expert examination of the Alma river basin in the low-water period (July 2020) showed: 1) The Partizanskoe reservoir was only 23% full. Due to the shortage of water, the constant discharge of 0.08 m³ / sec into the water channel provided for by the project was not carried out; the Alma river bed was deprived of water all the way down the reservoir.

4. A method of ecological optimization of the basin NES is supposed including a list of the following activities in the form of a tree of goals: a) landscape planning of the lowland sector of the river basin; b) ensuring a constant flow of the river including the low-water period by regulating the reserves of the Partizanskoe reservoir; c) transfer Sevastopol to Western European water consumption standards. The conservation in the Alma River of nature protection (ecological, not disturbed, basic, etc.) water flows imposes certain restrictions on the regulation of runoff in the hydrographic network of other rivers of Crimea. 5. Restoration of the volume of the natural runoff of the Alma river is quite real. It is recommended to implement it at the expense of two sources: 1) increasing the share of the intra-basin runoff of the Partizanskoe reservoir, 2) creating the necessary water reserve in the Partizanskoe reservoir, which will be used for intra-basin needs; this is possible by optimizing water usage within the water management system of Simferopol, primarily by reducing water consumption to the Western European level.

6. It is shown that intensive economic activity in the basin of the Alma river will lead to the complete disappearance of the watercourse by means of an example of the small Alma river. Unlike medium and large rivers, the protection of which already has some organized forms, small rivers, for the most part, are at the disposal of local land, forest and water users and outside the control of water management bodies, capable of assessing and anticipating the consequences of natural and anthropogenic processes occurring in river basins [11]. As a result, many small rivers and especially temporary watercourses ceased to exist or turned into sewage channels for industrial, household and agricultural waste.

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