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Justification of Landscape and Biotechnical Solutions for Designing Water Protection Zones.

Ekaterina A Pozachenyuk[1], Fedor N Lisetskii [2]*, Anna N Vlasova[1], and Irina V Kalinchuk[1].

[1]Crimean Federal V.I. Vernadsky University, Tavrida Academy (structural subdivision), Vernadsky ave., 4, Simferopol, Republic of Crimea, 295007, Russia
[2]Belgorod State Research University, Pobedy St., 85, Belgorod, 308015, Russia

ABSTRACT

By comparing the three main approaches to the establishment of water protection zones of small rivers (normative, theoretical and landscape), the method of delineation water protection zones with the application of GIS-technologies (GIS), as well as the basin model of the river system and the position-dynamic structure of landscapes was proposed. The landscape approach to justifying the boundaries of water protection zones for the forest-steppe and steppe, which differ in the conditions of moistening and the potential for river sediments formation, has been tested. The role of a multilevel system of biotechnical measures with the help of tree and shrub vegetation during the formation of water protection zones is shown.
Keywords: Water protection zone, position-dynamic structure, river basin, GIS-technologies.

Corresponding author

INTRODUCTION

The length of the river network in the territory the European part of Russia has decreased by 30-40 % for the last 200 years [1]. The river itself should form the optimal shape of the bed to transport sediments. But as a result of silting, the depth of the river decreases and the water level rises. River loses the self-regulation ability, as it goes beyond the bed and quickly loses energy. In this state, even the flood is not able to flush the river bed, because the stream meets a very large resistance to its current in the floodplain. Previously [2], it was shown that the contribution of high water and floods in the transfer of suspended sediments amounts from 52% of the annual runoff in major rivers to 99% in small ones. The prevailing influence of erosion-hydrological processes in the formation of surface water quality in areas of intensive agricultural development is due to long-term changes in anthropogenic, including agricultural, loads in water catchment areas [3].

The quality and quantity of water resources are largely determined by the presence of environmental constraints zones – water protection zones (WPZ) around water bodies. The WPZ is understood as the territories adjacent to the shoreline of the seas, rivers, streams, canals, lakes, and reservoirs, for which a special regime for economic activities is established to prevent pollution, clogging, and silting of these water bodies and exhaustion of their waters, as well as preserving the habitat of aquatic biological resources and other resources of flora and fauna [4]. The main component of the water protection zone is the coastal protection strip.

The procedure for determining the size and boundaries of the above-mentioned protection zones, the regime for economic activities in them in the Russian Federation is described in regulatory documents [4]. The urgency of the problem of scientific justification of the boundaries of water protection zones is due to the fact that known techniques have a number of shortcomings.

The spatial zoning method [5] is a well-tested tool for distribution of anthropogenic loads in the presence of inconsistencies between human activity and environmental safety of the environment. Provision of security functions of water protection zone is of great importance for planning and designing of various water resource projects [6]. This can be considered as the first step in the extensive distribution of technologies for managing the biogeochemical cycle of substances within the scientific field of biogeosystems engineering [7].

Currently, there are three main approaches to the establishment of water protection zones: normative, theoretical, and landscape. The size of the coastal protective strip (CPS) within the water protection zone depends on the steepness of the slope. The outer boundaries of the above zones are determined by means of special land design, which often reduces to simple calculations and limitation of zones. This procedure is not always justified from landscape point of view.

A design approach to the delineation of the water protection zones is developed for large rivers. But it is not applicable for the establishment of water protection zones of small rivers. In our opinion, a more effective approach to establish WPZ for small rivers is ecological landscape one.

At present, the landscape approach to the establishment of water protection zones is just beginning to be developed. The position-dynamic structure of the river basin landscape shows the dependence of natural conditions and processes on the terrain elevation, the position of landscape lines relative to landscape-significant boundaries, along which the intensity and direction of horizontal flows of matter and energy change [8]. Earlier, the authors developed a technique for isolating the position-dynamic structure of the river basin, including the creation of maps of morphometric characteristics, maps of the basin structure, drawing landform lines, characterizing the soil and vegetation cover and identification of homogeneous position dynamic units (landscape lines, layers, regions) [8]. Thus, when developing schemes for water protection zones using the landscape approach, not only the river length but also the geomorphological features, soil and vegetation cover and the landscape complex as a whole are to taken into account. The geodata for each river basin with its inherent morphological, functional and process characteristics are important to be harmonized, for example, using European experience in monitoring the river network within the WFD [9] and creating a single spatial data infrastructure [10].

MATERIALS AND METHODS

The boundary of the transition from the forest-steppe to the steppe is characterized by the maximum development of water erosion and a high degree of the river network degradation as a result of the silting [11]. Therefore, the study was carried out for two landscape zones – the forest-steppe and the steppe. Average annual precipitation in these two zones varies from 600-550 mm [1] to 450-400 mm [12].

In this paper, the basin and position-dynamic landscape structures were used to establish WPZ. The hierarchy of watercourses and their role in flow formation were taken into account not only along the river length but also by the order of the watercourses (according to Horton [13]). The background materials for justifying the boundaries of water protection zones according to the landscape approach are topographic, soil, geological maps, as well as vegetation maps, remote sensing materials, field studies. The software complex *ArcGIS* and appendix *ArcHydro* were applied, which allow us to consider the morphometric features of the territory, identify the basin and position-dynamic landscape structures, and perform a number of analytical procedures.

The landscape approach to the establishment of water protection zones for small rivers in the forest-steppe zone was tested in the study of the Khalan river basin, which is located in the Belgorod region. In *ArcGIS*, the boundaries of water protection zones and coastal protective strips of rivers were determined according to the normative approach. According to the Water Code of the Russian Federation [4], the width of WPZ of rivers up to 10 km length is 50 m, with the length of the river 10-50 km, the width of the WPZ increases to 100 m if the river is longer than 50 km – 200 m. To identify the boundaries of the water protection zone of the Khalan River according to the normative approach using *ArcGIS*, the operation of creating buffer zones with a width of 1 m was applied, since the length of the Khalan River is 35 km.

For the conditions of the steppe zone, a landscape approach to establishment of the water protection zones of small rivers using the model of position-dynamic structure was tested in studying small rivers typical for the steppe (the Salgir basin: The Maly Salgir, the Angara, as well as the lower part of the Salgir basin and Biyuk-Karasu). At the beginning of the work in *ArcGIS*, the boundaries of water protection zones and coastal protective strips of rivers were delineated according to the normative approach. To identify the boundaries of the water protection zones for the Salgir system according to the normative approach, the operation of creation of buffer zones in *ArcGIS*, as well as information on the features of the terrain and land use in the basin were used.

RESULTS AND DISCUSSION

To justify the boundaries of water protection zones of rivers, a semi-automated system for identification the position-dynamic structure for a river basin [8] was used. As a result of the analysis of slope and exposure maps, the identification of the basin structure and the determination of river orders, drawing landform lines, and the study of soil and vegetation cover, the position-dynamic landscape lines (strips) were identified in *ArcGIS* for the considered regions of the basin. Landscape strips that have a common position with respect to hypsometric boundaries and similar landscape characteristics were combined into 3 layer groups and the position-dynamic structure schemes were compiled.

The local features of the territory, geomorphological conditions, soil and vegetation cover, features of surface channel flow, vegetation, and other characteristics (geographic, geochemical, physical, and biological) were taken into account to determine the boundaries of the water protection zone using the landscape approach, which is well reflected in the position-dynamic structures. Thus, the characteristics of the territory that are necessary for the design of water protection zones have been highlighted, and natural boundaries have been taken into account that can intercept surface runoff from the entire basin to the river bed.

According to the landscape approach, the boundaries of the floodplain-terrace landscape layer (from valley bottom to ravine slopes) were used as outer boundaries of the water protection zones of small rivers. This is a zone of intensive development of dynamic processes, from which material energy flows are directed to water bodies. The boundary of the CPS, which is a part of the water protection zone, is located along the floodplain where direct contact of the water body and the land takes place, and excessive anthropogenic load can lead to deterioration of the state of water resources. Further, the boundaries of water protection zones, established according to natural characteristics, were adjusted taking into account the actual use of land.

The boundaries of the water protection zone, which are justified in the territorial aspect, may change over time. The intrinsic periodicity of natural processes [14, 15], which is reflected in the rhythm of the climate and water content of rivers, can determine the variation of the steady (in the dimension of decades) river water levels and, accordingly, the location of coastal zones in the landscape. In delineating the boundaries of water protection zones of small rivers in the forest-steppe using the landscape approach (using the example of the Khalan River), local features of the territory, geomorphological conditions, the nature of soils and grounds, features of the channel flow, vegetation, territory development, natural and artificial boundaries and obstacles capable to intercept surface runoff from overlying territories (river valley edges, road transport network, etc.) were taken into account (Fig. 1.).

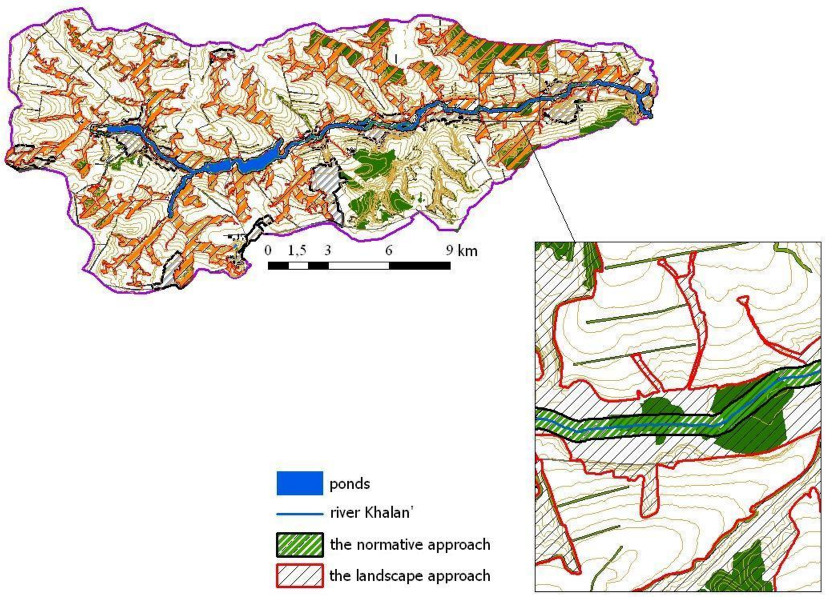

Figure 1: Water protection zones for the Halan River, which are based on the normative and landscape approaches

According to the Water Code of the Russian Federation, the normative width of the coastal protective strips of rivers depends on the steepness of the banks and is 30 for the reverse and zero slopes, 40 m for the slope of 0-3°, and 50 m for slope more 3°. The boundaries of coastal protective strips, which are drawn along the boundaries of landscape strips, take into account the features of different regions of the basin. In the upper reaches of the basin, the CPS width is 40-50 m, which is typical of mountain areas. In the lower part of the basin, the normative width of the CPS (30-40 m) should be increased to 50 m, taking into account the landscape structure and the anthropogenic load. Table 1 show a comparison between the size of water protection zones and coastal protective strips, which are based on the normative and landscape approaches in various parts of the basin of the Salgir River (steppe zone). The boundaries of the protection zones, which are established according to the landscape approach, correspond to the configuration of the position-dynamic structure.

As recommended [4], the minimum width of the water protection zones of rivers should gradually increase from the source to the mouth, which corresponds to different landscape conditions at the source and at the mouth of rivers, taking into account the anthropogenic load (potentially clean and polluted watercourses). This approach is reflected in this paper, as well; the size of water protection zones in the upper reaches in the mountainous part of the basin of the Salgir River and its tributaries are 70-100 m, in the foothill part – 100-250 m, which does not contradict the normative approach. When drawing the boundaries according to the landscape approach, the WPZ width increases uniformly from the source to the mouth in the plain part of the basin (the lower reaches of the Salgir and Biyuk-Karasu rivers) 200-350 m (Fig. 1).

Table 1: The sizes of WPZ and CPS for different sections of the basin according to normative and landscape approaches

Part of the basin	River	Approaches	width WPZ (m)	width CPS (m)
Mountain	Maly Salgir	normative	100	30–50
		landscape	100–250	50
	Angara	normative	100	50
		landscape	100–150	30–40
Plain	The lower reaches of Rivers Salgir and Biyuk-Karasu	normative	200	30–40
		landscape	200–400	50

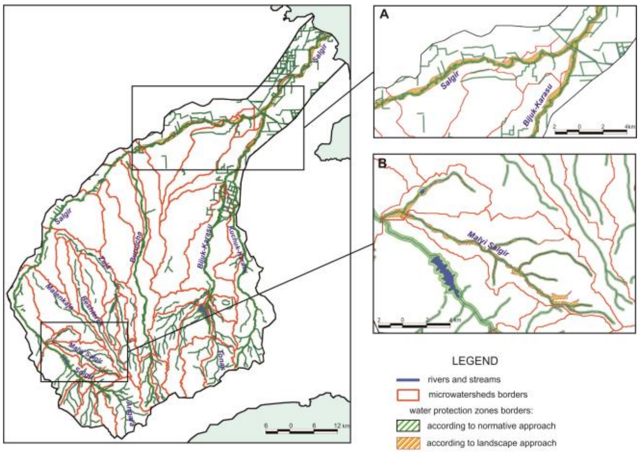

Figure 2: Water protection zones of the river basin Salgir, which are distinguished according to the normative and landscape approaches (A – the lower reaches of the Biyuk-Karasu River and the Salgir River, B – the Maly Salgir River basin)

Within the water protection zones, cemeteries, animal burial sites, waste burial sites, discharge of untreated sewage, and parking of vehicles are prohibited. Design, construction, reconstruction, and operation of economic and other facilities within water protection zones are allowed only under the condition that such facilities are equipped with structures that ensure protection of water bodies from pollution, debris, and depletion of water in accordance with water legislation and legislation in the field of environmental protection. Within the boundaries of coastal protective strips, ploughing of lands, dumping of eroded soils, grazing of agricultural animals, any construction, except for special ones are prohibited [4]. It is necessary to comply with a special regime for natural resource use within the WPZ, which is part of a set of environmental measures to improve the environmental state of water bodies.

CONCLUSIONS

The proposed method of establishment of boundaries of water protection zones of small rivers relies on the use of GIS technologies and river basin model system, as well as of position-dynamic structure of the landscape of the river basin. Transformation of the general scientific landscape map into the landscape-hydrological map using the basin and position-dynamic principles allows adapting the design soil and water protection solutions for the landscaping of riverine zones to the structure of the valley-river geosystems, which is distinguished by the variability in the spatio-temporal relation.

The recommended scope of planned projected activities includes:

- Determination of the area of arable land for which grassing is provided;
- Placement of water protection forest cover of a certain width;
- Improving forage lands grass stand to increase their protective functions;

- Proposals for carrying out summer camps and facilities that may become a source of pollution outside the water protection zones;
- Reclamation of disturbed lands.

The share of forests both in the water catchment area and especially in coastal and water protection zones is of great importance for the overall environmental sustainability of the basin landscape structures. With the general increasing negative dynamics of the forest resources, climatic changes may cause an increase in the surface drainage during spring, a decrease in the channel runoff, worsening of watering and water quality of large river basins [16].

The use of the landscape approach to justify water protection zones makes it possible to determine the location of soil protection forests and shrubs, as well as water protection forests and shrubs within their boundaries. This forms the basis for a multi-layer system of biotechnical measures.

Wave breakers at steep banks of one or two rows of shrub willows allow damping the wave shock force, which destroys the banks. Lower bank protection plantations are arranged in the flooding zone; on the areas between the highest and the lowest water horizons under periodic flooding, tree and shrubby willows are planted. Above the flooding zone (on the washed-out coastal regions and slopes), the upper bank protection stands are created by the technology of creation of water-regulating, ravine forest strips or erosion-preventive forest ranges.

Coastal plantings at the intersection of troughs are compacted with additional rows of shrubs, and in the upper part of such plantations, ridges are arranged. Gaps in the coastal stripes, which are necessary for cattle driving or the passage of transport, are necessarily assigned to elevated areas of the relief. Along water-conducting hollows, it is necessary to create well-point planting in alternation with grassy bottoms of troughs. Plantings should be placed in the form of strips with a width of 20-30 m.

Organization of a special regime in water protection zones should be considered as an integral part of a set of environmental measures to improve the hydrological, hydrochemical, hydrobiological, sanitary, and environmental state of water bodies and the improvement of their coastal areas.

The landscape approach to the establishment of water protection zones of rivers takes into account the features of various regions of the basin, is simple enough to apply and can be used as an addition to the normative approach.

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