Landscape hydrological principles for planning the water protection zone of Lake Baikal: aims and results

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Abstract. The article presents the aims and objectives of the water protection zoning of the Lake Baikal coast as well as the main points of the landscape hydrological substantiation of the dimensions for the water protection zone of this water body, which is a World Natural Heritage site. Analysis of the legislative framework as well as current natural and ecological state of the coastal area indicate serious anthropogenic impacts on the lake and the lack of the water protection experience, especially, in residential and recreational areas. The study considers the main landscape hydrological parameters and criteria for determining the boundary of the water protection zone as well as physiological conditions and the ecological necessity to include certain types of landscapes in the protection zone. The individual hydrological characteristics of landscapes, depending on the structural components, determine water potential and water protection parameters of the area, which allows for the substantiation of the water protection zone dimensions that ensure the protection of the water resources of Lake Baikal. The problems of water resources protection in the areas of economic use are of special attention. The study suggests the approaches to functional water protection zoning of urbanized and recreational areas, including landscape hydrological principles for assessing the area and methodological elements of landscape planning as well as regulation of the natural resources use for the purposes of the ecological development of coastal areas. A scientifically grounded water protection zone of Baikal involves coordination and control of all activities related to the use and protection of the lake.

1. Introduction
Scientifically grounded planning of the water protection zone for a water body based on the landscape hydrological approach together with the analysis of socioeconomic characteristics of the coast is an element of water resources management, i.e. a tool for their protection and rational use.

The aims of landscape hydrological concept for the water protection zoning of Lake Baikal are to ensure the optimum state of its ecosystem through the implementation of the natural water protection and environmental protection potentials of coastal landscapes, to reduce anthropogenic loads and to prevent possible negative impacts on the lake. The dimensions of the water protection zone should ensure the good quality of water resources inflowing to Lake Baikal, primarily, due to the self-cleaning features of landscape components [1].

2. Objects and methods
According to the landscape hydrological approach, the processes of mass and energy exchange occurring in the landscape complex transform precipitation to the surface and subsurface runoffs that
subsequently enter a drainage water body [2]. Each landscape has the individual structure of moisture circulation and characteristics of aquatic environment that determine the width of the water protection zone. The main landscape components, such as vegetation, soil layer and geological and morphological structure of the territory, determine the processes of slope runoff, filtration into subsurface horizons, water accumulations in macro- and micro-reliefs, changes in evaporation, as well as the overall structure of water balance and water potential of the territory [3]. The study of the runoff formation conditions and nature of hydrological processes occurring in nature complexes provide the necessary basis for analysing mechanisms of precipitation transformation into the runoff as well as determining the feasibility of the environmental and water protection characteristics of certain landscapes. Evaluations of the landscape characteristics of the runoff formation and regulation, various changes in these characteristics under the influence of natural and/or anthropogenic transformations allowed for classification of the Baikal coastal landscapes according to their water protection characteristics, in particular, accumulation, filtration and self-cleaning abilities, etc. [4].

3. Results and discussion

Therefore, in the landscape hydrological planning, the dimensions (width) of the water protection zone depend on the landscape structure of the coastal territory. Following the aim to preserve the quality of water resources, protect the coastal ecosystem and prevent from the pollution of the lake, the water protection zone should be based on the landscapes characterized by high environmental protection functions. Meadow-boggy and dark coniferous landscapes on gentle slopes and flat grounds have maximum environmental and, particularly, water protection characteristics. They are characterized by uniform slow water yield, contributing to the self-purification of water on the way to the lake. Estuarine floodplain and low coastal boggy landscapes, which are the interaction zone of the surface, underground and lake waters, play an important role of the filter of the natural waters inflowing to the water body. These landscapes have good water protection characteristics and should be preserved in the natural state without any transformations [1].

Steep mountain slopes with sparse vegetation and exogenously active areas represent significant territories of the natural environment of the lake. The dangerous hydrological and geomorphological processes, which contribute to the influx of detritus and pollutants to the water body, typically occur there. Area of high exogenous activity should be included in the water protection zone for preventive purposes to reduce the anthropogenic load on these territories and avoid negative impact on the water body. Regulatory environmental standards are particularly important in the areas of existing or planned economic development, where gravitational, hydrological and geomorphological processes hazardous for the lake ecosystem and population evolve [5].

Functionally, it is reasonable to include in the water protection zone the basins of small elementary watercourses (streams and small rivers of the first order) as well as reduced inundated and flooded coastal areas, including those resulting from the raising of the Baikal water level. Such territories have a direct hydraulic relationship with the water body. They are also the shortest way for pollutants entering the lake and, at the same time, natural barrier complexes that require minimizing their anthropogenic transformation.

The substantiation of the dimensions of the water protection zone for urbanized and recreational areas should directly depend on the current state of the natural environment as well as the degree and character of the impact of the planned economic activities on the natural waters. In these areas with anthropogenic transformations, landscapes are significantly modified and polluted; thus, the water body endures the greatest loads, which requires special regulation for the use of these areas. The establishment of water protection zones for water bodies in the Russian Federation is not focused on the physical and geographical conditions of the coast, and the regulations for the water protection zones and coastal protection belts in settlements are minimally fulfilled. Regarding Lake Baikal, Water Code of the Russian Federation [6] and law “On Protection of Lake Baikal” [7] define an individual procedure for establishing the water protection zone. The status of Lake Baikal as a World Natural Heritage site imposes additional obligations and implies special legislative regimes for the
overall site. This necessitates the establishment of the water protection zone throughout the entire coast of the lake, including the territories with settlements, economic facilities and recreational areas, to protect this water body from pollution and degradation. The planned water protection zone of Lake Baikal suggests a functional water protection zoning of residential and recreational areas based on an analysis of the natural and social economic conditions of a certain area.

The natural boundary of the water protection zone in the economically developed areas of the coast should be adjusted depending on the engineering and transport communications as well as present and future conditions of planning and construction. In the regulation issues of economic activity on the coast of Lake Baikal, in addition to using technological schemes, considering the natural conditions of an area and assessing the self-cleaning capabilities of the natural complexes are also advisable. According to the landscape hydrological approach, the state of the underlying terrain, i.e. the soil-plant complex, water-bearing strata of rocks and grounds as well as asphaltered and built areas, determine the polluted surface and subsurface runoffs from economic areas. The main parameters for assessing water-ecological potential of the urbanized areas are the filtration and sorption characteristics of soils, the composition of the soil in the aeration zone, direction and intensity of subsurface runoff, protection of subsurface water from pollution, and the degree of hydraulic relationships between the surface and subsurface waters of the coastal area and the lake [8, 9].

![Figure 1](image-url)  
**Figure 1.** Reduction of the water protection area to 200 m. Recreational area “Baikalskaya Gavan” (Baikal Harbour), Turka settlement, the Republic of Buryatia.

The planning of the Lake Baikal water protection zone based on the landscape hydrological approach, which was developed in V.B. Sochava Institute of Geography, limits the coast by an area of less than 2.5 thousand km² with a maximum distance from the coast of up to 5 km at certain sites. The boundaries of the water protection zone of Lake Baikal were described by maps on a scale of 1:50000, considering complex physiographic and cadastral material as well as aerial and satellite imagery data, and topographically represented on a scale of 1:100 000. In the areas of settlements and recreational sites, the boundary of the water protection zone described by physiographical conditions
lies in close proximity or partially crosses the area with no significant restrictions on economic activities. Only in some cases, does it force to move production areas 1-2 km back from the coast. At the same time, the current water protection zone of Lake Baikal, which was approved by the Government of the Russian Federation, is an integration of the nature-based version prepared in V.B. Sochava Institute of Geography and proposals of administrative-territorial bodies. As a result, the width of the water protection zone of the natural area ranges from 0.5 to 5 km, and within the boundaries of settlements it is 200 m (equal to the width of the coastal protection belt) from the water edge of Lake Baikal (see figure 1).

The dimension of 200 m for the water protection zone of Lake Baikal is not environmentally justified, since for such a reduction of the water protection zone there are no available technological systems (storm sewers, parapets of embankments, etc.) that protect the water body from pollutions coming from settlements. The most transformed and polluted coastal areas are virtually removed from the protected elements of the lake ecosystem.

4. Conclusion
The results of the landscape hydrological analysis combined with the assessment of the sources and extent of anthropogenic loads on natural waters allow for functional water protection zoning of the territory. The structural element of such zoning is the development of proposals to minimize negative loads and regulate activities in certain areas within the general water protection zone of the lake. Therefore, the assessment of natural and anthropogenic conditions in urbanized areas can be a basis for developing a system of geographically fixed restrictions on activities in areas with highly dense industries, population and recreational facilities in order to prevent the influx of polluted waters to the water body and preserve the ecosystem of Lake Baikal. A landscape hydrological basis of functional water protection zoning not only substantiates restrictions but also determines the direction for the development of economic activities through spatial localization of areas with different environmental management and protection regimes. Functional water protection zoning can be considered the optimal mechanism for the development of the territory with a special nature conservation status in terms of the aquatic environment, with no damage to Lake Baikal [10].

References
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