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DESIGN OF COASTAL PROTECTION STRIPS OF WATER PROTECTION ZONES USING GIS TOOLS

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The regulatory and legal principles of designing water protection zones and their role in protecting the natural environment, determined the boundaries of coastal protection strips and the influence of relief on the size of restriction zones is analyzed. The territory of the Kamianopotokivska territorial community in the Kremenchuk district of the Poltava region is studied. The water bodies of the study area were classified, and the normative values of coastal protection strips were determined according to their sizes in accordance with the requirements of current legislation. Based on open data on the relief of the territory, slopes were calculated and doubling of coastal protection strips within slopes exceeding 3 degrees was provided.

A geospatial dynamic model for designing coastal protection strips of water protection zones, taking into account legislative norms and relief, and their impact on types of activities, has been developed. The model was created and tested using the Model Builder software module in ArcGIS Pro.

As a result of the study, the model was applied to the collected input data and coastal protection strips of water protection zones were designed within the studied

area. The territories were identified and analyzed, the ownership rights of which are encumbered in accordance with the designed water protection zones. This model is dynamic and suitable for use for production purposes at the local level (within territorial communities).

Keywords: *water protection zone; coastal protection strip; territorial community; water bodies; design of water protection zones; GIS technologies; geographic information systems.*

Relevance. Conservation and rational use of water resources is the key to the sustainable development of any territory. In the context of the growing impact of climate change, active land use and urban expansion (urbanization), the design of water protection zones based on the provision of coastal protection strips (CPS) is becoming critically important. These strips (CPS) act as natural filters, effectively counteract soil erosion, and, accordingly, significantly improve water quality.

To ensure spatial planning and make the right management decisions regarding the design of water protection areas, geographic information systems (GIS) are an indispensable tool. They allow taking into account multi-criteria features.

In particular, the Kamianopotokivska territorial community in the Poltava region has significant natural wealth and an extensive network of water bodies. This requires the implementation of special, well-thought-out measures to protect its coastal zones. Only taking into account local features – such as topography, hydrological conditions, and the current land use structure – will allow building a realistic and ecologically balanced model for designing water protection zones using GIS tools.

Analysis of recent research and publications. The main ecological purpose of CPS is to protect water bodies from pollution and minimize the negative impact of economic activity. Scientific studies, in particular the work of American scientists (M.G. Dosskey et al.), confirm that the vegetation cover along water bodies significantly reduces the concentration of chemical pollutants coming from the sloping areas. This

process occurs due to natural filtration: plants retain harmful substances, decompose organic compounds, and, importantly, slow down surface runoff, ensuring better water penetration into the soil. In addition, buffer vegetation effectively acts as a barrier for heavy metals and pathogenic microorganisms, delaying them on their way to the river bed [1].

CPS are of particular importance for reducing the nitrogen content in water, which is critically important for preventing eutrophication of water bodies (excessive enrichment with nutrients). A meta-analysis (P.M. Mayer et al.) showed that buffer strips can retain up to 85% of nitrates originating from agricultural lands. Given the widespread excessive application of nitrogen-containing fertilizers in Ukraine, the function of CPS to stabilize the ecological state of rivers becomes vital [2].

Along with the water protection function, CPS performs an important anti-erosion role. Dense vegetation reliably strengthens the shoreline, which leads to a decrease in landslides, soil erosion, and siltation of riverbeds. Studies (Osborne та Kovacic) emphasize that coastal vegetation slows down water flows, thereby reducing hydrodynamic pressure on the banks. This prevents the destruction of the shoreline even during floods, which makes this function a priority in flood-prone regions [3].

In addition, CPS is a key element in the preservation of biodiversity. They serve as habitats for many species of birds, amphibians, fish and insects, as confirmed by the conclusions of the European Environment Agency. Coastal protection strips also serve the role of ecological corridors, ensuring the migration of animals and maintaining the genetic diversity of populations. In the context of the fragmentation of natural environments caused by intensive land use, these strips remain the only connecting link between isolated natural areas [4].

Coastal protection strips also have significant social significance: they are recreation areas (rest), improve the microclimate in settlements, reduce noise levels, absorb dust, and improve the quality of life in general. As the EPA report notes, coastal

protection strips provide important ecosystem services for communities and contribute to the popularization of environmental education [5].

For the full realization of the ecological potential of coastal protection strips, their spatial continuity and proper legal regulation are necessary. Although Ukrainian legislation establishes requirements (for example, a ban on plowing land, using chemicals, and erecting buildings), violations often occur in practice. This not only reduces the effectiveness of water body protection, but also creates environmental threats. The existing control system requires modernization, expansion of the powers of local environmental inspections, and the introduction of public monitoring.

A feasible step is the introduction of a single state standard for environmental assessment of the WPA, which would integrate European experience. Protective strips should be integrated into river basin management plans, in accordance with the European Green Infrastructure policy. Success requires coordination at the level of interagency cooperation and increased control by state environmental structures. Equally important is the participation of public organizations in initiating environmental measures, conducting information campaigns, and monitoring compliance with requirements.

The effectiveness of water protection zones depends on the quality of spatial planning, legal control, and community involvement in the protection of water resources. Butenko, E., Vovna, M., & Prykhodko, M. Define spatial planning as an effective tool for managing land resources in territorial communities [8]. Modern environmental policy should be based on the integration of scientific data, legal mechanisms, and international experience.

The purpose of this study: the geospatially modelling of coastal protection strips of water protection zones of the territory based on GIS technologies.

Materials and methods of research: This work was developed in accordance with regulatory legal acts, norms and rules on land valuation: the Land Code of Ukraine, the Water Code of Ukraine, Resolution of the Cabinet of Ministers of Ukraine dated

May 8, 1996 No. 486, the Law of Ukraine “On Environmental Protection” dated June 25, 1991 No. 1264-XII, the Law of Ukraine “On Regulation of Urban Development Activities” dated February 17, 2011 No. 3038-VI. Open-access data, information from the State Land Cadastre, Google Hybrid, OpenStreet Map, and SRTM were also used in the development. Among the methods used were analytical methods, cartographic geoinformation, graphic, and statistical.

Research results and their discussion. The object of the research is the territory of the Kamianopotokiv territorial community of the Poltava region. According to Article 58 of the Land Code of Ukraine, "to create a favorable regime along the seas, around lakes, reservoirs and other water bodies, water protection zones are established, the boundaries of which are indicated in land management documentation, urban planning documentation at the local and regional levels. Information about the boundaries of water protection zones is entered into the State Land Cadastre. The procedure for determining the size and boundaries of water protection zones and the regime for conducting economic activities in such zones are established by the Cabinet of Ministers of Ukraine."

Water protection zones include CPS as well as additional territories on which restrictions also apply, but are less stringent. Within the boundaries of water protection zones, lands of coastal protection strips and diversion strips with a special regime for their use are allocated. The procedure for determining the size and boundaries of water protection zones and the regime of economic activity in them was approved by the Resolution of the Cabinet of Ministers of Ukraine of May 8, 1996, No. 486.

According to the above Resolution, "the internal boundary of the water protection zone coincides with the minimum water level in the water body", and "the external boundary of the water protection zone, as a rule, is tied to the existing contours of agricultural lands, roads, forest belts, floodplain boundaries, floodplain terraces, slope edges, beams and ravines and is determined by the line furthest from the water body: flooding at the maximum flood (flood) water level, which is repeated once in ten years;

bank erosion, meandering; temporary and permanent flooding of lands; erosion activity; coastal slopes and severely eroded lands". That is, to accurately determine the outer boundaries of water protection zones, periodic studies of changes in the shorelines of water bodies are required.

In most cases, water protection zones coincide with coastal protection strips; that is, they are minimized. Within the coastal protection strips (CPS), a number of strict rules have been established that restrict economic activity. Information about the boundaries of coastal protection strips and beach zones is entered into the State Land Cadastre as information on restrictions on land use. The legislation prohibits:

- plowing land (with the exception of areas used for haymaking or grazing livestock);
- storage and application of agrochemicals, including mineral fertilizers and pesticides;
- construction of capital structures (residential, industrial, or other) that may potentially threaten the aquatic environment;
- arrangement of landfills and placement of warehouses with toxic substances;
- mining;
- organization of parking lots and car washes.

The legal mechanism for regulating the CPS is strengthened by the provisions of the Law of Ukraine "On Environmental Protection". This Law emphasizes that the preservation of water resources is a priority task of the state's environmental policy.

It establishes that any activity related to the use of natural resources must comply with the principles of sustainable development and strictly comply with environmental requirements. The Law obliges all business entities (regardless of the form of ownership) to comply with environmental standards, emphasizing the priority of environmental protection interests over purely economic expediency. Thus, the environmental component is decisive in the formation and provision of the legal regime for the use of coastal territories.

An important role in the legal system is played by the Law of Ukraine "On regulation of urban planning activities". It obliges to take into account the CPS when developing master plans for settlements and other urban planning documentation. This requirement ensures the integration of environmental restrictions directly into the processes of spatial planning and development of territories. Establishing requirements for coastal protection at this level allows for effective avoidance of violations at the stage of construction project implementation.

One of the key regulatory documents that determines the parameters of coastal protection zones (CPS) is the Resolution of the Cabinet of Ministers of Ukraine No. 486 of May 8, 1996. This document establishes the Procedure for determining the size and boundaries of water protection zones and the management regime in them.

The width of the CPS depends on the category of water body:

- for large rivers, it must be at least 100 meters;
- for medium-sized rivers - 50 meters;
- for small rivers, streams, and ponds - 25 meters.

Within settlements, these minimum indicators can be reduced, but not lower than the limit established by law. When developing project documentation, hydrological characteristics, terrain relief, the current type of land use, and environmental load are necessarily taken into account. However, in practice, the lack of a clear procedure for drawing the boundaries of CPS in nature (on the terrain) creates significant difficulties in their implementation.

The process of establishing water protection zones and water protection zones is implemented through the preparation of land management documentation. Currently, Ukrainian legislation does not provide for the creation of a separate, specialized document solely for fixing these boundaries. In fact, the boundaries of CPS and WPZ are determined as an integral part of:

- documentation on the development of the territory;
- technical materials on the establishment of restrictions on land use;

- land management projects that directly relate to the formation of water protection zones.

According to Article 26 of the Law of Ukraine “On Land Management”, any restrictions on land use must be introduced on the basis of technical documentation, which includes scientific justification, spatial schemes, plans, and a detailed description of the territory use regime.

The State Standard OSU SCLR 00032632-005:2009 “Land Management. Land Management Projects for the Creation of Water Protection Zones. Development Rules” serves as an important methodological source for land managers. It provides a structured approach to collecting initial information, analyzing the ecological state, the nature of the riverbed, coastal vegetation, and existing infrastructure. The standard also defines the stages of coordination of documentation with executive authorities, local communities, and state cadastral authorities.

The implementation of these requirements is clearly illustrated by the practice of developing community master plans. Here, CPS are necessarily considered as zones with a special land use regime. Their spatial representation is critically important for the formation of functional zoning plans for the territory, which meets the requirements of the State Building Standards of Ukraine State Building Codes B.2.2-12:2019 "Planning and Development of Territories".

A modern and effective solution is the use of geographic information systems (GIS) for modeling and designing the boundaries of water protection zones and coastal protection strips. GIS allows you to automate the consideration of natural conditions (relief, catchment, surface runoff) and quickly analyze the compliance of design solutions with the real situation. Thanks to remote sensing data and geospatial databases, it has become possible to create high-precision interactive CPS maps.

At the first stage of geospatial modeling, water bodies are classified by type: polygonal and linear, and standards for designing coastal protection strips are determined. After the construction of buffer coastal protection zones, their unification is

envisaged. At the second stage, the relief was used, slopes were constructed, and slopes were classified by steepness. For those territories that exceeded 3 degrees, they were separated, and those territories that are included in the coastal protection zones and have slopes that exceed the permissible values were determined. Such territories are doubled and combined with those territories that are defined by the limit norms of the current legislation at the first stage to avoid duplication of the areas of restrictions. Thus, the final completed model takes the form, Fig. 1.

In Fig. 1, blue circles indicate the input files, namely the vector format of data on the boundaries of water bodies and a raster image of the relief. Yellow rectangles are the applied tools, in particular, data selection, buffer creation, intersection, extraction, reclassification, data extract, raster model to vector conversion, and union. Green circles that come out of the yellow rectangles are intermediate files, the result of each result. For example, the resulting image of this model is a vector format file called Output Feature Class.

The result of executing the GIS geospatial model using ArcGIS Pro made it possible to design the territories of the coastal protection strips of the Kamianopotokivska community, Fig. 2.

The total area of the territory included in the coastal protection zone is a significant 3706.01 hectares. The analysis revealed that a significant part of this territory is not typical for zones that should be directly adjacent to water bodies. In particular, 204 agricultural land plots were identified within the coastal protection zone, the total area of which exceeds 47 hectares.

This fact is of concern, since for such plots located in the coastal protection zone, the legislation establishes strict restrictions. According to Article 61 of the Land Code of Ukraine, in the coastal protection zone of rivers and water bodies, it is strictly prohibited:

- plowing of land;
- application of mineral fertilizers and pesticides;

- creation of dumps;
- carrying out any other activity that may cause water pollution.

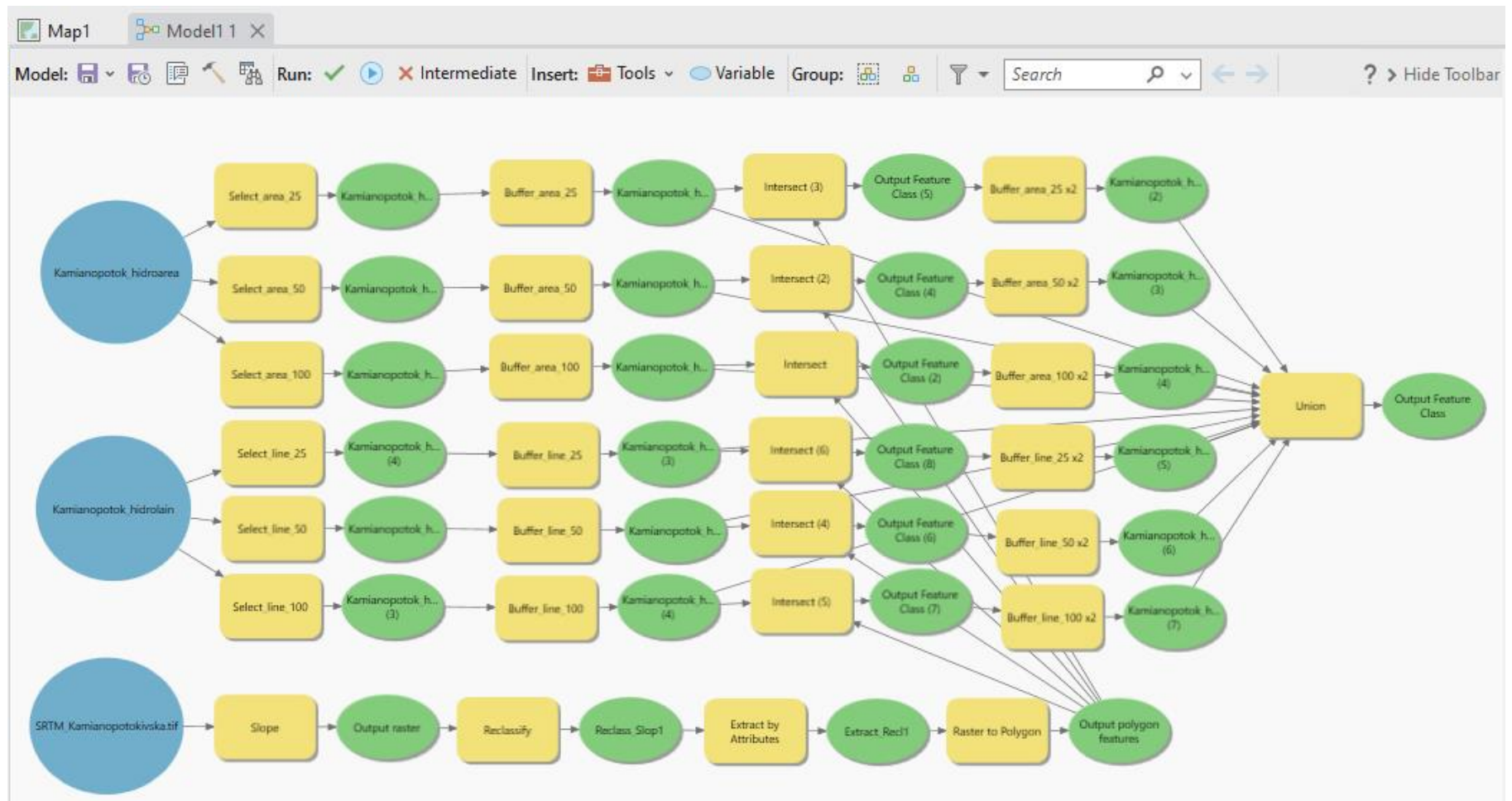


Fig. 1 Final automated model for designing coastal protection strips of water protection zones

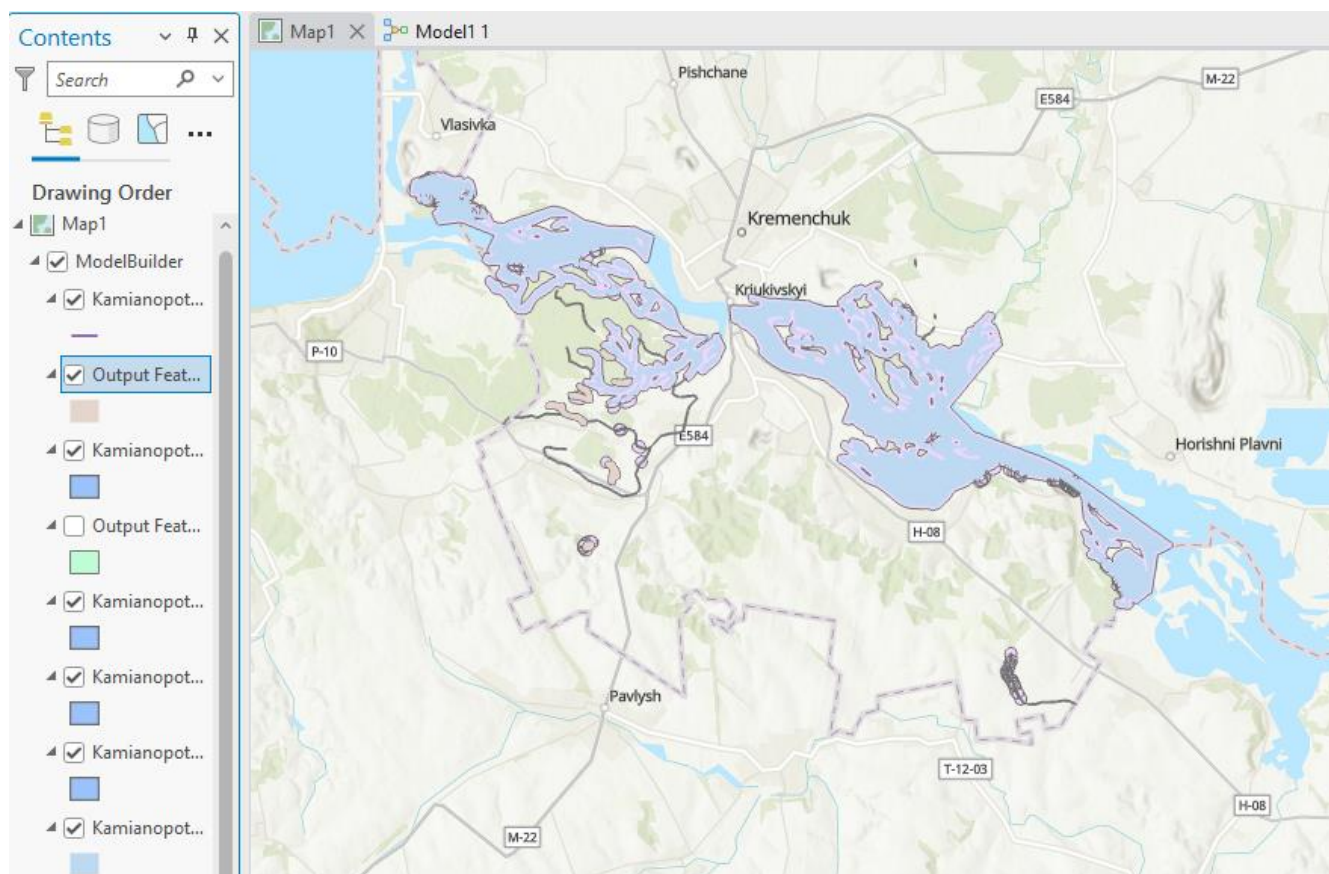


Fig. 2 The border of the Kamianopotokivska community with the designed coastal protection strips of water protection zones

Table 1

Distribution of land within the coastal protection zones of water protection zones
by category

№	Category	Number of land parcels	Area, hectares
1	Water fund lands	2	0,51
2	Residential and public development land	10	0,49
3	Lands of forestry purpose	74	3564,86
4	Lands of agricultural purpose	204	47,02
5	Land of industry, transport, communications, energy, defense, and other purposes	10	91,10
6	Lands of recreational purpose	3	2,03
Всього			3706,01

The following categories of land fell within the boundaries of the coastal protection strips of water protection zones: forestry lands (3564.86 ha), water fund lands (0.51 ha), and recreational lands (2.03 ha). In accordance with Articles 60 and 63 of the Land Code of Ukraine, these lands are either already part of the natural protection belt or perform the function of supporting the hydrological and ecological balance. Their inclusion in the CPS not only does not contradict the protection regime, but also enhances the environmental efficiency of the territory. For example, forest plantations stabilize soils, prevent erosion, and absorb part of the surface runoff. The water fund is naturally an element of the CPS, and recreational lands, as a rule, have minimal technogenic impact and contribute to the formation of an ecological culture. At the same time, more than 91 hectares of land classified as industrial, transport, communications, energy, defense, and other purposes were identified in the CPS. According to Articles 60 and 61 of the Land Code of Ukraine, it is strictly prohibited to place facilities in these territories that may negatively affect the state of the water environment, including warehouses, gas stations, and storage facilities for harmful substances. All existing engineering structures must be operated only under strict compliance with environmental standards, with all protective measures and constant monitoring. Failure to comply with these requirements creates a risk of pollution of surface and groundwater, which is especially dangerous in densely populated regions.

Ten residential and public development sites with a total area of 0.49 hectares have also been recorded within the protective strip. Article 61 of the Land Code of Ukraine prohibits the construction of capital structures in the CPS, except for hydraulic engineering and facilities specially provided for by law. It is also forbidden to arrange cesspools, septic tanks, and sewage systems without proper treatment. These restrictions are aimed at protecting water bodies from pollution and preserving the natural drainage balance. The presence of even small areas of development within the boundaries of the CPS creates potential environmental threats [6].

Article 88 of the Water Code of Ukraine and Article 60 of the Land Code of Ukraine clearly regulate that the boundaries of coastal protection strips for all water bodies without exception must be established on the basis of individual land management projects [7]. Within settlements, these projects must take into account the requirements of urban planning documentation. According to the explanations, existing facilities already located in the CPS may continue to be operated if they do not violate the established regime. However, such facilities are subject to all restrictions, including the prohibition of any new construction on the relevant land plots. These restrictions are effective from the moment the relevant regulatory legal acts enter into force (Article 111 of the Land Code of Ukraine).

Based on the results of the study, a student research paper was written, which took 3rd place in the 1st round of the All-Ukrainian competition of student research papers in the specialty "Geodesy and Land Management".

Conclusions and prospects. The results of spatial analysis revealed both areas registered in the State Land Cadastre (SLC) that comply with the environmental protection regime, and a significant amount of land that falls under the restrictions established by the Land Code of Ukraine. Namely, over 91 hectares of land classified as industrial, transport, communications, energy, defense, and other purposes, and ten areas of residential and public development, the total area of which was 0.49 hectares. This confirms the critical need to use GIS technologies in planning the development of territories to ensure compliance with environmental requirements when forming land use boundaries. The designed CPS model of water protection zones not only identified conflict areas, but also outlined opportunities for further spatial planning in accordance with environmental standards. This geospatial model can be supplemented with multiple studies of changes in the shorelines of water bodies to accurately determine the outer boundaries of water protection zones or dynamically update them according to an established algorithm.

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**ПРОЕКТУВАННЯ ПРИБЕРЕЖНО-ЗАХИСНИХ СМУГ
ВОДООХОРОННИХ ЗОН ЗАСОБАМИ ГІС**

Проаналізовано нормативно-правові засади проектування водоохоронних зон та їх роль для охорони природного середовища, визначення меж прибережно-захисних смуг та вплив рельєфу на розміри зон обмежень. Досліджено територію Кам'янопотоківської територіальної громади Кременчуцькому районі Полтавської області. Проведено класифікацію водних об'єктів території дослідження, визначено нормативні значення прибережно-захисних смуг відповідно до їх розмірів згідно вимог чинного законодавства. На основі відкритих даних про рельєф території здійснено розрахунок схилів та передбачено подвоєння прибережно-захисних смуг в межах схилів понад 3 градуси.

Розроблено геопросторову динамічну модель проектування прибережно-захисних смуг водоохоронних зон з урахуванням законодавчих норм та рельєфу та їх вплив на види діяльності. Модель створено та апробовано за допомогою програмного модуля Model Builder в ArcGIS Pro.

Як результат дослідження, застосовано модель до зібраних вхідних даних та запроектовано прибережно-захисні смуги водоохоронних зон в межах досліджуваної території. Визначено території та проведено їх аналіз, право власності на які обтяжуються відповідно до запроектованих водоохоронних зон. Дана модель є динамічною та придатною до застосування у виробничих цілях на локальному рівні (в межах територіальних громад).

Ключові слова: водоохоронна зона; прибережно-захисна смуга; територіальна громада; водні об'єкти; проектування водоохоронних зон; ГІС технології; геоінформаційні системи.

