LAND AND WATER RESOURCES MANAGEMENT BASED ON THE BASIN ORGANIZATION OF NATURE USE

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ABSTRACT
Effective state and transboundary management in the field of use, protection and reproduction of land and water resources will be facilitated by the transition from the administrative-territorial to the administrative-basin system of land and water resources management, according this system, the main unit of management and development of environmental protection measures will be the basin of the water body. Studying the flows of matter, energy and information inside the basin allows modeling the anthropogenic impact on natural complexes in general and on its individual components as a result of nature use, predicting the results and adjusting agricultural activity. It is presented the method of determining the internal geomorphological structure of the catchment area and creating an ecological frame of the river basin using GIS technologies. Existing approaches and their advantages in studying the state and modeling processes of basin territorial structures are described. It is proposed a conceptual model of ecologically rational exploitation of the catchment area, which includes: creating an ecological frame of the river basin based on the identification of the internal geomorphological structure of the catchment area; the development and stuffing of the geoinformation and analytical system of the river basin, including the assessment and forecast of the ecological situation and the determination of the most agrogenically transformed sub-basins of different orders; the development of the project of the basin organization of nature use, including the ecological and resource characteristics of the current state of the territory of sub-basins of different orders and the evaluation of the effectiveness of the implementation of the project. It was developed the algorithm for assessing the state of the catchment area, also was made the project of the basin organization of nature use applying GIS and remote sensing technologies. It is proposed the creation of mechanism and justified the prospects for the introduction of a geoinformation and analytical system for the support of basin nature use principles, which foresees the systematization of multi-level and sectorial information of monitoring observations with a purpose to create of soil and water protection measures.
Keywords*: land and water resources, river basin, scientific approaches, geoinformation and analytical system, ecologically rational exploitation, management, nature use.*

INTRODUCTION

In recent years, the river basin become the most promising object of geographical research regarding the establishment of spatio-temporal patterns of organization and interrelations of stabilizing (environment) and destabilizing (anthropogenic environment) components of ecosystems, [1] it is evaluated as "a specific spatial unit of the biosphere, the most perspective for the multi-faceted study of nature, economy and environmental management".

The basins have fairly clear natural boundaries - watersheds and internal functionally holistic closure of migration flows of surface and subsoil water flow, as well as migration of dissolved substances and soil solids, the take-out of which is carried out through the closing gate of the catchment area [2]. The basin is represented as limited by a watershed part of the earth's surface, taking into account the thickness of the soil, from where the runoff of water flows into a separate river occurs. This is a water balance system in which precipitation is transformed into other elements of the water balance. Therefore, the precipitation regime, temperature characteristics of the climate and everything that determines the ratio of elements of the surface water flow balance has a significant importance for the formation of basins. From the point of view of climatic features, river basins forms where the amount of precipitation exceeds their evaporation and filtration of water in the soil [3].

Traditionally, in hydrology, the river basin is considered as a catchment surface that determines the volume of runoff, the nature of the water regime, and other hydrological characteristics of runoff, solid runoff, and flow of substances. A special place is given to the erosion research in the study of river basins [4]. Any erosion form has its own surface water runoff basin, or catchment area. Catchment areas of different rivers (watercourses) are separated from each other by watersheds.

In river basins, it is easy to distinguish such paragenetic relations, in which the upper link determines the behavior of the lower link, and the lower link integrates the phenomena that occur in the upper links of the basin [5]. In particular, the most important function of the relations between ecosystems components (biotic and abiotic) [6] occur at the basin level. Between them there are genetic, historical or functional connections, they are expressed by the continuous exchange of substances, energy and information. The river basin acts as a holistic system with established ecological, social and economic connections [7, 8]. Also, the basin is a naturally organized territorial unit that provides the possibility of establishing true spatio-temporal patterns of consequences and the degree of human activity influence on the degradation of natural ecosystems [9, 10].

The basin of any river during the commercial use is subjected to certain anthropogenic loads. Moreover, the need for water resources of rivers is constantly increasing, which, accordingly, affects the quantitative and qualitative indicators of their condition [11]. The river is both a source of water and a receiver of wastewater [12].

The most vulnerable to anthropogenic influence are small rivers, in particular, it concludes in plowing of catchment areas, their excessive saturation with row crops, melioration, insufficient forest cover [13]. All this intensifies the erosion processes that lead to siltation and pollution [14], changes in the water-physical properties of soils [15, 16], thermal and water balances [17], disruption of the hydraulic connections of surface and ground waters, as well as the conditions of flow formation [18-20].

The situation is further complicated by the fact that during the recent years there has been a tendency of active diversion of the coasts and floodplains for cottage construction, horticulture and gardening [21]. Therefore, modern approaches to the study of anthropogenic impact on catchment areas and river valleys should be based on ecosystem [22, 23] and basin approaches [1], which are focused on a comprehensive assessment of water and land resources use, on the structure of landscapes and their destruction. The advantages of basin approach using are [24]: clarity and simplicity of border highlighting; a hierarchical structure that allows to move to different territorial levels of management; organization of unidirectional flows of matter, energy and information; geo-system connection, which allows to carry out all types of ecological monitoring; affiliation of soil and vegetation cover, settlement and nature use systems to separate basin structures; localization of technogenic sources of environmental pollution along catchment basins – watercourses.

The basin approach has wide use in ecological and geographical studies [25-28]. Studying the flows of matter, energy and information inside the basin allows modeling the anthropogenic impact on environmental complexes and its individual components (including water and soil) as a result of nature use, predicting the results and adjusting commercial activities [29]. The advantages, objective necessity and expediency of the integrated water resources management, based on the basin principle, are recognized all over the world. Countries with different state systems are forced to find the ways of cooperation between the participants of the water commercial complex and to solve jointly the tasks of its development within the framework of the basins of water bodies. The result of long-term discussions by the members of the European Union of a complex policy on water resources management became the fixing of the basin principle of water resources management in the EU Framework Directive 2000/60/EC [30].

It defines that integrated water resources management based on basin principles will provide a process that will facilitate the coordinated development and management of water, land and related resources to increase the effectiveness of economic and social welfare on the principles of equity for the sustainable development of important ecosystems.

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS.

During recent years, the basin principle has been increasingly used to identify and forecast the aggravation of environmental protection problems, when territorial generalizations are made by hydrographic basins in different natural zones. Korytny L. M. [1, 24] emphasized that the basin approach is the basis of modern geoecological assessment of territories.

Dolzhenko V.A. [31] emphasized the need for a wide and consistent implementation of the principles of administration and law regulation in the field of water bodies' use and protection based on the basin approach. Shvebs G. I. [32] proposed the separation and study of natural-commercial units based on the basin approach aimed on optimizing nature use. Resulting the search of a solution to the problem of combining administrative borders with natural boundaries, the basin concept of nature use is becoming increasingly attractive [1, 22, 24, 29]. Traditionally, the mechanism of natural resource management is administrative-territorial, which in most cases does not correspond to the boundaries of natural territorial systems. This approach has priority due to the well-established system of receiving information about territories for making management decisions and assessing the economic efficiency of commercial activity. But the generalized average ecological indicators absolutely do not reflect the spatial differentiation of the evaluated indicators within the administrative boundaries [33]. Therefore, there is an awareness that multifaceted phenomena of society's interaction with nature can be studied and regulated only with the help of basin and geosystem approaches in combination with complex territorial and landscape analysis [34, 35].

Thus, it can be stated, that the basin approach to various geographical and ecological and economic problems has proven its vitality, necessity and perspective during almost half-century history. Starting with its application in land hydrology, in other sciences of the physical-geographical cycle and landscape science, it is now increasingly used in geoecological studies to solve the problems of balanced nature use, which is justified from methodical and organizational positions and has been confirmed with concrete results. The basin principle of water resources management determines the prerequisites and directions for the creation of a modern mechanism for the use, protection and reproduction of water in Ukraine [5], which will correspond to the most effective international practices and will enable the implementation of the state strategy aimed at preventing the exhaustion of water resources and achieving the high water quality [36].

Implement the theoretical and methodological justification of water and land use safety, according to the basin principles, with a help of geoinformation systems (GIS) and remote sensing technologies.

MATERIALS AND METHODS.

For the spatio-temporal study of the water and land resources state within the rivers basins, the development of environmental protection measures based on the basin concept of nature use, an important task is to create correctly the ecological framework of the river basin, with the determination of the internal geomorphological structure of the catchment area using GIS technologies.

To divide river basins into groups, depending on the order of the main *riverbed*, the Strahler-Filosofov approach [37, 38] was used. According to this approach a watercourse (or the riverbed of a temporary watercourse) that does not receive an inflow belongs to the riverbed of the 1st order. Two riverbeds of the 1st order, merging, give the beginning to riverbed of the 2nd order. According to this rule, a riverbed of a higher order begins below the junction of any same-order watercourses (the order increases by one).

When merge of different-order watercourses take place the watercourse formed below of their junction keeps the order that has the watercourse before the same-order watercourses merged (Fig. 1). The study of the features of the geomorphological work load on the river basin and all landscape components, together with determination of characteristics and water flow parameters, is possible only under the condition of basin organization of the territory at the level of catchments of erosive forms of the IV order, which foresees the possibility of detecting the landscape heterogeneity of the territory [24].

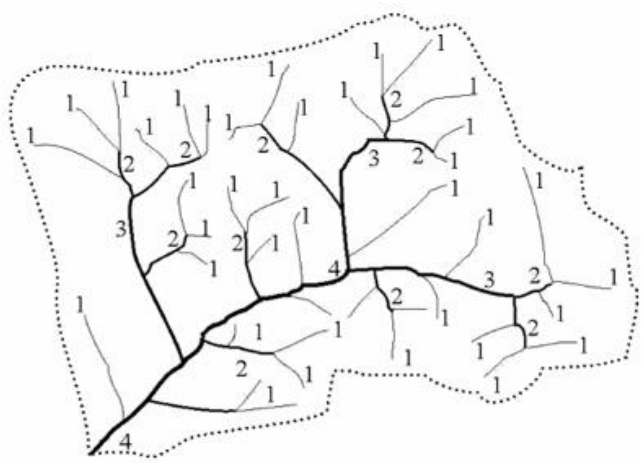

Fig. 1. The structure of the river basin of the IV order (according to the Strahler–Filosofov coding of the river basins): …. – watershed line, 1st-4th – orders of watercourses or erosion network

Division (zoning) of the territory into river basins is one of the most typical and necessary operations in hydrological and ecological research. River basins can act as the main operational and territorial unit during zoning, assessment of the intensity of erosion processes, etc. The application of the basin approach is geographically and ecologically justified (the basin is a natural and sometimes a natural-commercial system). Geomorphological studies of the positional and dynamic structure of the river basin must be carried out on the basis of data from the Shuttle radar topographic mission (SRTM) - radar topographic survey of most of the territory of the globe, with the exception of the northernmost latitudes (> 60), southernmost latitudes (> 54), as well as oceans, which was created in 11 days in February 2000 using a special radar system. The two radar sensors, SIR-C and X-SAR, have collected more than 12 terabytes of data (which is roughly the size of the Library of Congress).

The allocation of watercourses, determination of their orders and catchment areas is performed using the ArcGIS program on the basis of a digital relief model using algorithm of the hydrological geomodeling from working module the Hydrologytools of Spatial Analyst Tools, improved by our teem [39-41], which includes eight sequential modeling steps.

Step 1. Visualization of the digital relief model (DRM) based on SRTM-90 with a pixel resolution of 90x60 m.

Step 2. Filling the incorrect lowering of the relief using the "Fill" function. With the help of this function, the correction of the DRM is performed in order to create the correct grid of cumulative (total) flow.

Step 3. Modeling of the flow directions grid using the "Flow Direction" function, this allows to find out the flow direction according to the structure of the connections of 8 neighboring rhombuses. They determined by the morphometric characteristics of the relief (slopes and exposures). That is, the direction of the maximum slope from the center of the cell to the centers of 8 neighboring cells is determined.

Step 4. Modeling of the cumulative flow grid using the "Flow Accumulation" function, it is based on the flow directions grid.

Step 5. Identification of watercourse cells with values of cumulative flow above the specified value. At this stage, the procedure of selecting the limit value of the cumulative flow is performed using the "Con" tool, which is part of the "Conditional" tool set. "Con" function, an important part of the "ArcGrid" command, which is necessary to determine the correctness of the values in input data cells and comprehensive control of the output data.

Step 6. Determination of watercourse links by the "Stream Link" function. Links of watercourses are separate spatial linear segments of continuous flows, which are interconnected by a sequence of nodes (points) of exit (outflow of a 1st-order riverbed or the beginning of a higher-order outflow) with end nodes (points) of a watershed (the estuary of different-order watercourses).

Step 7. Assigning an order to each link of watercourses using the “Stream Order” function. Each watercourse, which is a link of the network, is classified according to the order given to them, which depends on the interconnection and sequence of the nodes.

Step 8. Determination of the drainage (catchment) area of each link using the “Watershed” function. The drainage (catchment) area of the watercourse basin is determined based on the grids of the flow and watercourses direction for which it is calculated.

The presented algorithm assumes that the researcher sets some limit value, expressed through the minimum number of raster cells or the minimum water catchment area (km^2), which gives surface runoff. During the building of the river network model based on the flow accumulation raster, the limit value of the selection of cells that are the components of the channel network is taken equal to 600. This limit is due to the fact that in the use of a digital relief model based on SRTM-90 data for the automatic selection of a river network by means of GIS technologies there are some limitations related to the presence on the digital relief model of vegetation and artificial structures, which complicate the reliability of the selection of the upper links of the river network and allocation of watersheds of the river basin. After obtaining the geomorphological model of the basin organization of the catchment area, additional manual correction is carried out to improve the quality of modeling.

The analysis of the internal geomorphological structure of the catchment area of the basin makes it possible to study in detail its positional-dynamic spatially-organized system, the components of which are sharply different from each other in terms of type, composition, level of organization, nature and duration of exploitation, which determines the individuality of the existing ecological situation in their catchments, which collectively form a certain ecological state of the catchment region which is studied.

RESULTS

Effective state and transboundary management in the field of use, protection and reproduction of land and water resources will be facilitated by the transition from the administrative-territorial to the administrative-basin system of land and water resources management, according which the main unit of management and development of environmental protection measures should be the basin of a water object. The introduction of integrated management of water resources according to the basin principle will contribute to sustainable territorial development, coordination of the development of the water sector, sustainable use of related resources, creation of an efficient economy and improvement of the quality of life of the local population of the state [42, 43].

The basin approach can be complemented [44, 45] and implemented in parallel by the eco-regional approach to monitoring and managing the quality of soil-land and water resources. The eco-region is a holistic natural-commercial formation, which is evaluated by the degree of anthropogenic influence and the transformation of natural landscapes. The general ecological state of eco-regions is determined by the rank of ecological tension – the degree of landscapes transformation, as a result of a certain combination and ratio of areas of ecological situations of varying severity. For example, in a certain eco-region, a specific "background" quality of local water flow is formed under the influence of geographical features, including regional geochemical conditions and the historical development of commercial activity. They determine the features of spatially distributed sources of additional substances entering water bodies. The concentration of these substances is determined by the priority sources of pollution in the eco-region, the spectrum of which is determined by the industry that dominates in this catchment area. During the agricultural development of land, these substances are nitrogen, phosphorus, potassium; during the melioration – sulfates and iron; during industrial development – chloride and sulfate ions. Each eco-region differs by range of water quality indicators typical for it and, thus, by target indicators of the state of water bodies, which are established taking into account the ecological-commercial state of the catchment area. This principle of regulating the state of water bodies is the basis of the framework Water Directive of the European Union [30] and is aimed at preventing the deterioration of the state, protecting and restoring of water ecosystems and groundwater. In

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particular, the combination of eco-regional and basin approaches allows singling out territories that are homogeneous in terms of natural-anthropogenic conditions, which become the object of further complex ecological monitoring, that combines elements of agroecological and hydrological monitoring (Fig. 2) [46].

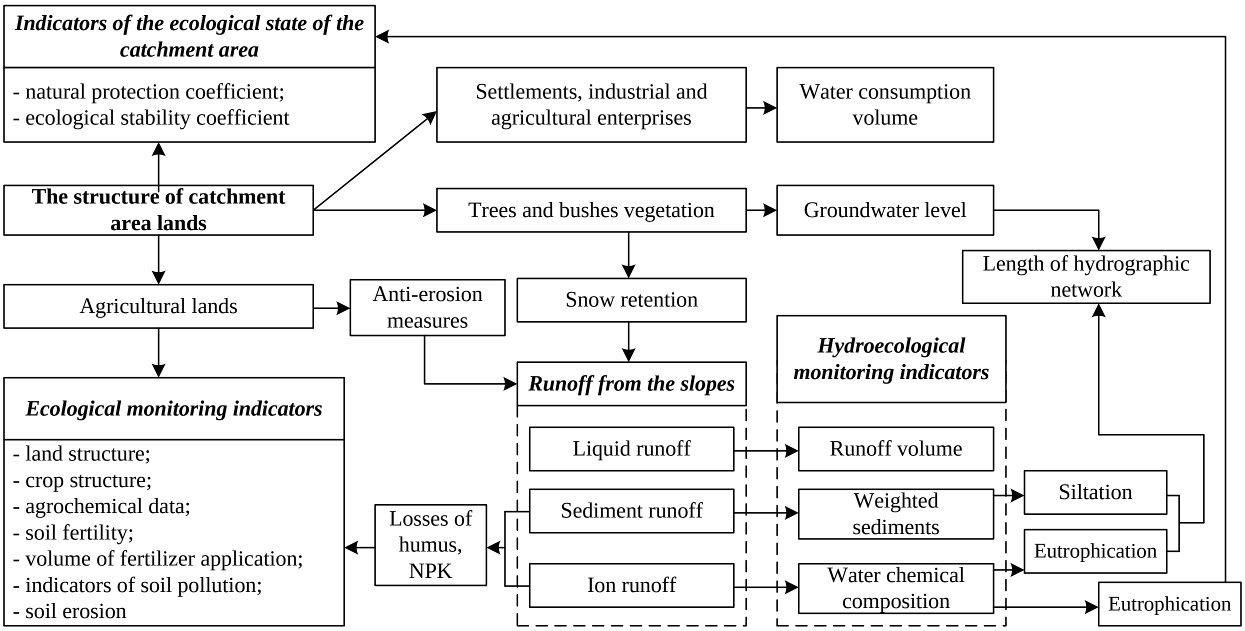

Figure *2*. Links between indicators of agro- and hydroecological monitoring.

From a basin perspective, an eco-region is a natural-commercial formation, the external and internal boundaries of which are defined by subsystems of a certain level of hierarchy, holistic by common spatial relations, which are determined by hydrofunctioning. With this understanding, the ecoregion and its basin structures become the objects of the water management complex and basin organization of nature use.

Basins are the holistic ecosystems of a high level of organization with developed feedback links. If the regime of the riverbed is disturbed in the middle stream, it will no doubt cause a certain reaction in all ecosystems of the basin - both upstream and downstream, and in lateral directions – that is, in the ecosystems located on the upper watershed levels of the basin, that are remote from the riverbed. Also, in the works of scientists [47, 48], the basin system is considered as a geoecological system with inputs and outputs for flows of matter, energy, and information. They are functions within defined space-time limits, which are allocated by the upper and lower boundaries of the watershed, and coincide with the surface of convective atmospheric processes and the upper horizon of waterproof rocks. In this regard, the ecosystem approach to the analysis of the state of river basins has acquired special importance. It is based on previously developed ecological models of small rivers and reservoirs [49], which are important local structural natural units of transboundary rivers and reflect changes in the state of rivers in the course of increasing anthropogenic influence [2, 5, 10, 11]. In particular, the basin of a small river [50, 51] is a complex self-regulating system that has the ability to function separately from changes in external conditions and is an important indicator of the state of the environment of transboundary catchment areas. This indicator is determined by the level of anthropogenic load on the components of its landscape ecosystems, which are a complex of biogeocenoses on a homogeneous area of the Earth's surface. They are combined with each other by genetic (by origin), historical (history of the development), geochemical (geochemical combination, water flow, transfer of organic and mineral substances) and biotic links (migration of animals, transfer of spores and plant material) and covered by a certain type of agricultural use [1, 2, 5].

It is proposed to use large basins zoned according to bioclimatic zones as a basis for natural-resource zoning. This principle of zoning to the greatest extent links together water, climatic, mineral and land resources. Determining the anthropogenic impact on the river basins of small and medium-sized rivers in the existing socio-economic conditions has an important sense, because the possible loss of these ecosystems will lead to a number of global environmental problems (reduction of the water level of 1st order rivers, loss of valuable biological species, etc.) [52]. The ecological revival of large transboundary rivers should be based on the development of corresponding strategies, the scientific basis of which should be real information about the ecological condition of subbasins of small and medium rivers in their composition and the constant interaction of the relevant services of the countries of the transboundary basins. In the mid-90s of the XX century the ecosystem approach was further developed for the needs of assessment the parameters of the ecosystems and their components state, taking into account functioning for the purpose of ecological regulation [53]. In the use of this approach, it is noted that the anthropogenic impact on the river ecosystems is fundamentally related to the additional supply of matter and energy. The ecosystem is able to process and absorb part of the substances, and the rest is released and taken beyond its borders. The more excess substances accumulate in the ecosystem, the more energy it needs for their disposal or transfer to another ecosystem.

The main source of such energy is hydrophysical processes that cause certain flow processes, stream speed and wateriness of the river. They are characterized [54] as the main integrating ecological factors that participate in the formation of the geosystem and directly determine its boundaries and the direction of the circulation of substances. Currently, as a result of deforestation [55], significant plowing of landscapes [9], intensification or chemization of agricultural production [56], there is a systematic income and constant growth of biogenic elements [10] in the ecosystems of most rivers. In parallel, the costs of irreversible water consumption increased, the flow of rivers was transformed, as a result the natural energy of river ecosystems decreased, this caused a significant deterioration of the ability of rivers to transfer mineral and organic substances to other water systems. This led to their accumulation and, as a result, regulation, siltation, degradation and complete disappearance of small rivers [57]. Ecological forecasting [58] of the probability of changes in the state of river ecosystems is important for solving the problem of rivers in conditions of uncertainty and instability of their pollution sources.

Insufficient validity of the theoretical prerequisites for similar studies of transboundary rivers, violation of the principle of unity of ecological and economic aspects of the capacity of ecosystems during the exploitation of natural resources by countries in their basins, led to the various negative environmental consequences. The lack of reliable forecasts of the development of the situation on rivers and their catchment areas has led to waterlogging and salinization of large areas of land, a decrease in their productivity, and water pollution. The result of ecological forecasting of the situation and rational nature use in river basins should be the determination of the optimal structure of ecosystems of individual types in the composition of sub-basins of various orders, the determination of the links between its elements and the determination of their role in the functioning of the ecosystem as a whole.

There is a need, first, to determine the degree of transformation of the ecological balance of the river ecosystem by individual types of different sub-basins; second, to select reference sub-basins of rivers for their assignment to the conservation fund; third, to implement the integration of environmental protection strategies for the implementation of enhanced environmental protection measures on the territories of ecologically disturbed sub-basins of rivers into the Strategy for the socio-economic development of the countries of transboundary basins; fourth, make a more detailed study of the regularities of river ecosystems formation, their hydrobiological regime, to determine the productivity of the mechanism of income and behavior of pollutants, the organization of monitoring on protected and degraded river sub-basins of different orders. The results of such studies should become the basis for forecasting changes in the ecosystems of river basins and the development of reasonable concepts for rational nature use within them [59-61].

Korytny L.M. [1, 24] in his works used a geosystem-hydrological approach to study the river basin. He noted that the basin represents a real geosystem that is easily distinguished on the map and terrain, has a clear hierarchical order of river systems classification, in which water bodies most often serve as a means of spreading and accumulating pollutants. Therefore, from our point of view, the river basin can be considered as a functionally integrated shell of the geosystem with its own input and output. Inside this shell, individual naturally- and anthropogenically determined processes of conjunction and circulation of substances take place.

The main task of studying the basin organization as a geographical system is to identify the spatio-temporal hierarchy of elements and phenomena located on the earth's surface by dividing the whole into parts; determination of spatial forms of structures of different rank and identification of regularities that determine the quantitative relations between the internal elements of these structures; identification of the type of the system organization and determination the degree of its organization. Allocation of river basins is one of the most typical operations in hydrological and ecological research, which today is significantly simplified with the use of a geoinformational approach based on updated geoinformation systems. In addition, the active development of computers and geoinformation technologies recently allows obtaining the necessary characteristics of water resources reserves and the ecological state of water bodies [62] for timely management decisions regarding the rational use of water resources of a specific basin more fully and faster compared to traditional methods. Currently, various methods of analyzing surface and ground water resources, including the use of GIS technologies, have become widely used. Geoinformation systems are increasingly used both for operative calculations and assessment of water resources, their catchment areas, and for studying the hydrological regime of water bodies. The processes of collecting, processing and interpreting data, modeling hydrological networks and preparing proposals for decision-making using GIS technology and computers are solved more easily and efficiently than before in hydrological practice. GIS technology can quickly represent water bodies and their catchment areas together with hydrographic characteristics, hydrological stations and measurement data on digital or paper maps. This allows carrying out automated comprehensive analysis and interpretation of observation materials and space images to obtain a detailed picture of the processes taking place [58].

The use of geoinformation systems for a comprehensive assessment of the state of river basins involves the following types of work [63]:

- research of the structure of river basins, which allows to identify the mechanisms of the basin functioning as a geosystem;
- collection of information about natural conditions, pollution of surface and ground waters using stock materials of environmental monitoring organizations, as well as field research data;
- identification of the main factors that determine the conditions for the development of negative natural processes and changes of indicators of the surface waters state;
- modeling of generalizing maps of the natural conditions of the studied region, as well as zoning maps of the basin in relation to the level of anthropogenic transformation, the state of surface water quality;
- analysis of zoning results.

The final result of studies of the ecological state of river basins should be the establishment of ways of optimization and development of geoplanning projects of basin nature use [64, 65]. Geoplanning involves a comprehensive approach to the problems of territorial planning of the basin, which considers the integrated components of the landscape shell – nature, population and commercial activities.

Geoplanning performs geoecological aspects of the ecosystems functioning through a complex of project solutions. At the same time, the priority is the justification of their rational spatial combinations on each plot, in each basin, region and the country as a whole. The most optimal combination and interaction of the components of the landscape shell are achieved through the implementation of three components of geoplanning: the formation of the ecological framework of the region, ekistic (method of settlements creation) territorial systems and the framework of anthropogenic and technogenic loads on the environment.

In regions with agrarian specialization, the object of geoplanning is agricultural lands – a particularly valuable natural resource, here land acts as the main means of production and the basis of sustainable development. In particular, geoplanning [2] is a deep complex approach to the study of sustainable natural-anthropogenic relations in the geographical shell. It includes the principles of both ecological-landscape planning, with its emphasis on geoecological optimization of territories, and territorial planning aimed at *satisfaction* the socio-economic needs of the region. Geoplanning eliminates contradictions between ecological-geographical and socio-economic approaches to the organization of nature use, as it takes into account the ekistic factor that determines the main types of commercial activities of the population and the general level of anthropogenic-technogenic loads on the environment within the settlement system, the main indicator of which is river systems and their basins. The output object of geoplanning is an integrated territorial socio-natural-commercial complex.

GENERALIZATION OF THE STUDY

Due to the need of changing the existing situation in the management of water and land resources, to develop effective measures of basin nature use in order to solve soil protection and hydroecological problems and improve the ecological state of the environment, special measures are required.

The most promising are the development and implementation of a conceptual model of ecologically rational exploitation of the catchment area on the basis of a geoinformational and analytical system of monitoring and management of basin nature use. As well as methods for determining the structure of the catchment area land fund and developing a project for the basin organization of nature use on the catchment area of the river using GIS and RS technologies [66, 67].

The conceptual model of ecologically rational exploitation of the catchment area includes: creation of an ecological frame of the river basin based on the identification of the internal geomorphological structure of the catchment area; the development and filling of the geo-informational and analytical system of the river basin, including the assessment and forecast of the ecological situation and the determination of the most agrogenically transformed sub-basins of different orders; development of the project of the basin organization of nature use, including the ecological and resource characteristics of the current state of the territory of sub-basins of different orders and the evaluation of the effectiveness of the project implementation.

Rational nature use, based on the conceptual model of ecologically rational exploitation of the catchment area, in addition to optimizing the use of natural resources, should ensure support for mechanisms of their reproduction by searching for optimal scenarios of nature use. They will form the perspectives of effective territorial development and improvement of the hydrogeoecosystem of the river. For this purpose the most promising will be the introduction of a geoinformational analytical system (GIAS) to support basin nature use, which provides the systematization of multi-level and branch information of monitoring observations for organizing soil and water protection measures.

A river basin is an information unit of the GIAS. It is a natural-commercial system in which all types of natural resources use are interrelated.

The basin also acts as an integrated natural-commercial-demographic system, which is the most effective object for managing [68].

The creation of an integrated multi-level GIAS of basin nature use should be carried out on the basis of information resources and the interaction of specially authorized coordinating bodies. Structurally designed GIAS is a logical model that includes three subsystems - a database, special software support and an analytical unit. The analytical part is based on a multidimensional relational database that contains subject-oriented information.

The GIAS analytical unit includes methods, algorithms and programs focused on the subject area. Within the framework of the system, two subject areas are considered (Fig. 3), which have the conditional names "Hydrosystem" and "Geosystem". The subject area "Hydrosystem" includes such sections as: hydrogeology (conditions), hydrology (resources), and ecology (quality). The subject area "Geosystem" includes such sections as: conditions (natural potential), resources (characteristics), ecology (quality) in relation to the territorial objects.

For a comprehensive analysis of the ecological state of the river basin in GIAS, it is desirable to single out the following information blocks and indicators: characteristics of the basin (indicators: morphological and morphometric features, administrative-territorial and basin distribution, etc.); climatic conditions (indicators: air temperature, precipitation, climatic energy, etc.); water resources and water use (indicators: hydrological and hydrochemical features, etc.); land resources and land use (indicators: share of the main types of land use, availability of arable land, etc.); vegetation (indicators: natural lands, forests, etc.); territories that are under protection (reserve fund); economic activities (indicators: gross domestic product, demographic load index, etc.); demographic situation (indicators: population density, migration, morbidity, mortality, birth rate, etc.); indicators of the ecological state (indicators: erosion processes, factors affecting the ecological state, etc.).

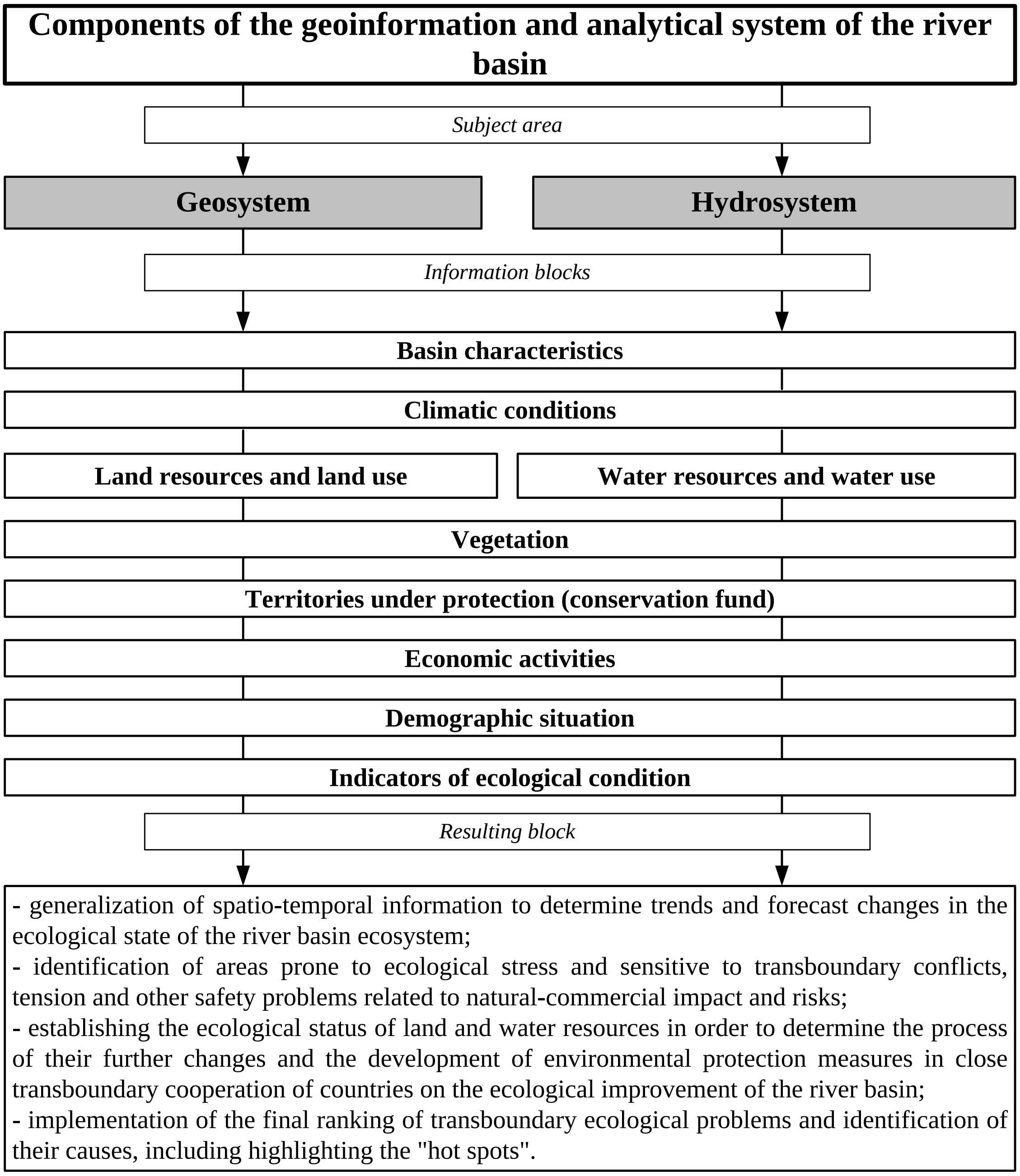

Fig. 3. Structural scheme of the GIAS of the river basin

The reorganization of the land structure is the basis for the spatial organization of catchment areas based on basin principles. It is stated in our methodology [69] for determining the structure of the catchment area land fund and developing a project for the basin organization of nature use on the catchment area of the river using GIS and RS technologies. The reorganization should include the following stages: 1 – land management of arable land based on positional-dynamic and basin principles; 2 – projecting of forest plantations; 3 – projecting of water protection zones; 4 – rationalization of fodder lands use; 5 – projecting of recreational areas; 6 – detection of new nature reserves.

The projects of the basin organization of nature use on the territory of the river catchment area, will analyze the ratio of two main groups of land: commercial use and natural undisturbed complexes or slightly disturbed by human activity, which constitute the ecological fund of lands and perform the most important ecological-biosphere functions, or "ecological services".

For the development of basin nature use projects, successive stages of actions are defined (Fig. 4).

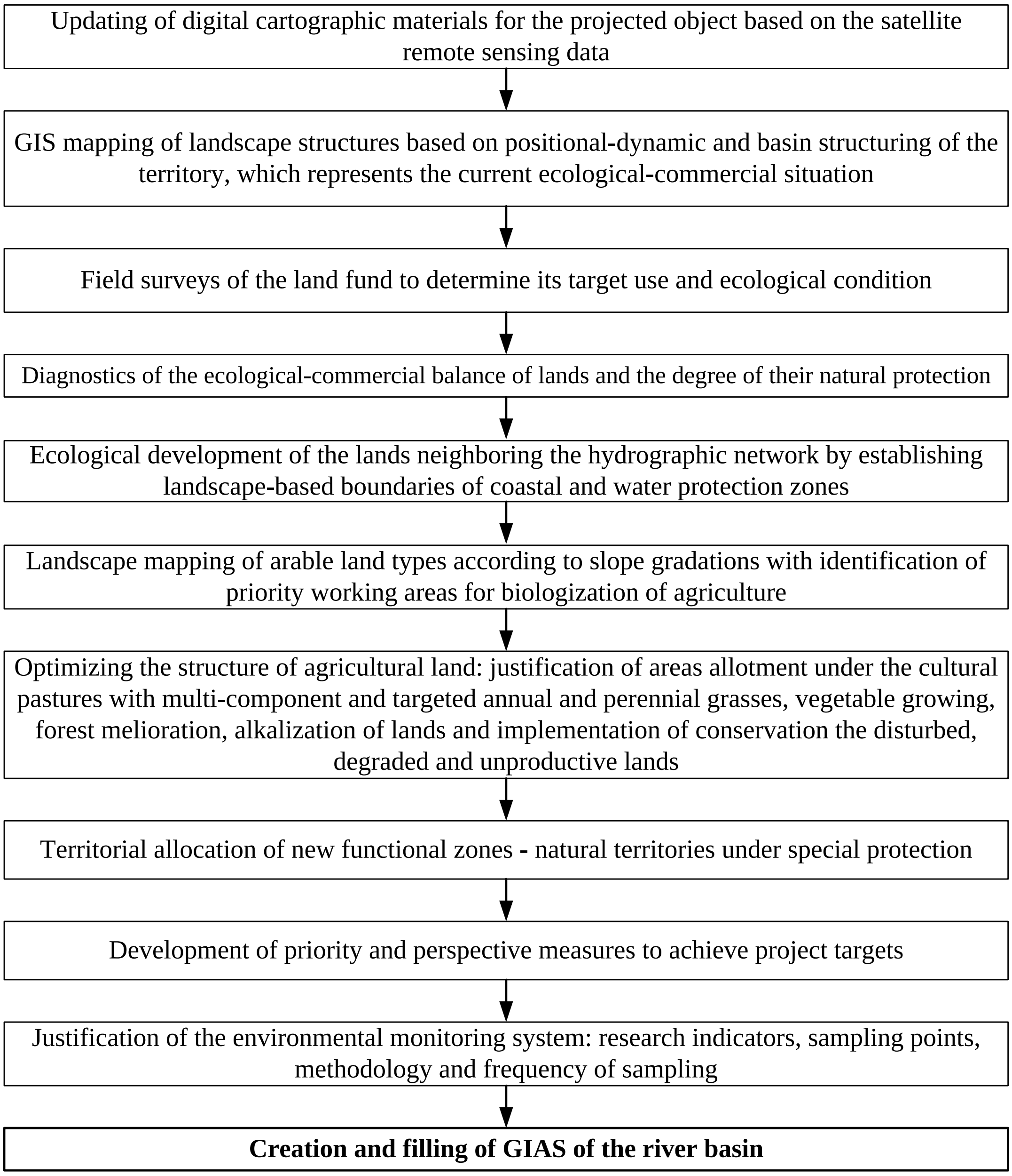

Fig. 4. Stages of GIAS creation for the development of basin nature use projects

To transfer the development and implementation of corresponding soil and water protection measures related to arranging the catchment area of the river into scientific-legal plane of nature use organization, appropriate land management actions should be done. They are presented in Figure 5.

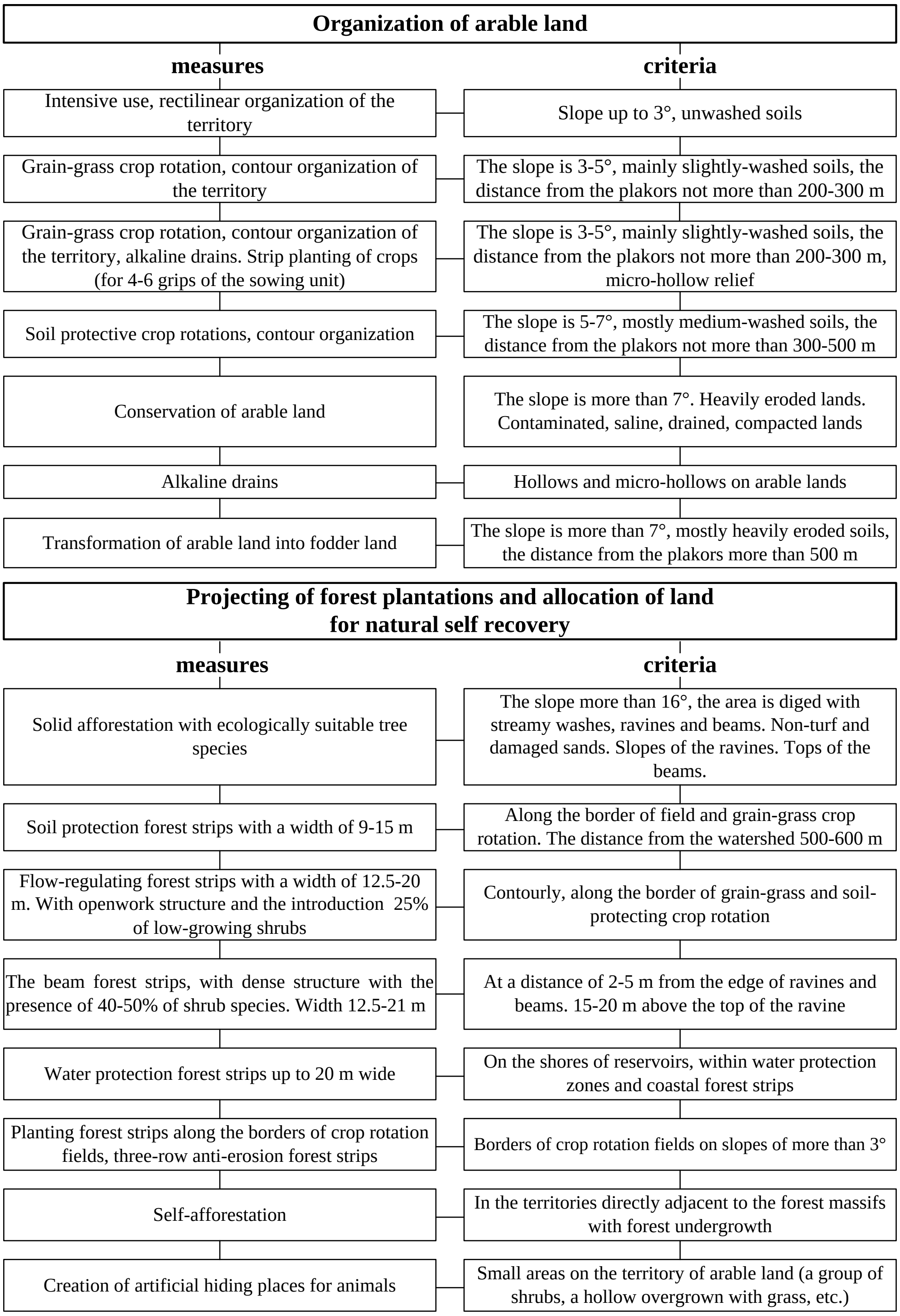

Fig. *5*. Criteria and measures of land management works during basin organization of nature use

During the territorial planning of catchment basins, it is necessary to find a compromise between achieving ecological sustainability of agricultural landscapes and economically profitable intensity of agricultural production with stable harvests. For this purpose, it is necessary to determine the most priority methods of greening of arable land, among which its reduction is an extreme measure.

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These methods are presented below in the order of priority of their use:

1. Change a share of stabilizing crop rotations on arable land by increasing the area of perennial herbs. This is the most optimal way to increase the ecological stability of arable land without reducing its area [72].

In the structure of field crop rotation on slopes with a steepness of 0–3°, it is necessary to introduce up to 20% of perennial herbs. On slopes of 3–5°, grain-herb crop rotations are implemented with a share of perennial leguminous-cereal herbs up to 50%, and row crops are not allowed to be grown. The most erosion susceptible areas of arable land on slopes with a steepness of more than 5° must be completely under herbs and soil protection crop rotations.

The use of perennial herbs in crop rotations is aimed at solving several tasks at the same time: accumulating organic substances and increasing soil fertility; decreasing the intensity of water-erosion processes; reduction of the total anthropogenic load on the environment. In addition, the long-term use of perennial herbs will reduce the cost of mineral fertilizers, will lead to a reduction of weeds and the number of harmful insects, as well as will reduce crop diseases.

2. Implementation of agroforest-melioration measures on arable land, such as increasing the share of contour anti-erosion forest strips on slopes. Numerous studies have convincingly proven that under the protection of forest strips, the productivity of arable land increases by 15-30%. The average yield of grain crops under the protection of forest plantations is higher by 18-23%, technical crops – by 20-26%, fodder – by 29-41%. The most stable landscape conditions are formed when the share of agroforest-melioration plantations on arable land is 3.0-3.5% in the Forest-Steppe zone and 3.5-4.5% in the Steppe zone [5, 73].

3. Temporary (revolving) conservation of heavily eroded arable land. Such lands should be transferred to a long-term preservation. The successions that appear on the preserved lands are typical for zonal ecosystems, have a significant resource and biosphere potential and especially important for restoring soil fertility. To form the ecologically stable preservations of lands, it is necessary for them to reach at least 10 years of age, and their premature return to agricultural use will increase their erosional destruction. Spatial identification of such lands is very difficult, but an increasingly promising solution of this task is the use of Earth remote sensing data [74].

4. Transformation of heavily degraded arable land into other types of land. At the same time, the physical and geographical conditions of the territory should be taken into account: for the Forest-Steppe zone - mainly selective afforestation, for the Steppe - transfer to natural fodder areas. On the arable land remaining after reduction, energy and material resources should be concentrated as much as possible for ecologically safe intensification of agricultural production in order to obtain the volumes of products necessary for the sustainable development of the economy of the region and the country.

The other way to increase the ecological sustainability of basin landscape territorial structures is the arrangement of natural fodder lands, in particular, the allocation of areas for their natural self-regeneration and the creation of conditions for enhanced reproduction of soil fertility. Natural self-regeneration is planned to be carried out by solid afforestation, planting of forest strips, selection of areas for self-recovery with forest, creation of artificial hiding places for animals. Measures for the afforestation of the territory are carried out by creating different types of plantations and taking into account the high natural ability of deciduous plantations to excrescence from the small forest areas. When projecting afforestation sites, the following techniques are used: solid afforestation of steep eroded slopes; afforestation in the shape of beam forest strips on the border of arable land and fodder land; solid afforestation of the upper part of the beams in the headwaters of rivers and places of accumulation of springs; afforestation of water protection zones of rivers.

Special attention should be paid to water protection forests - forest plantations within the water protection zone prevent pollution, siltation of water bodies and depletion of their waters. The water protection forest is of particular importance in the Forest-Steppe and Steppe zones, where the amount of precipitation is 1.5–1.7 times less than the amount of evaporation. For the purpose of protective afforestation, preference

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should be given to fast-growing species so that they begin to perform their water-regulating functions as early as possible such as birch, maple, bird-cherry, green and downy ash, etc.

On arable lands, where there are islands of natural vegetation on unsuitable areas, it is proposed to organize areas with partially artificially thickened vegetation, with a forbidden on livestock grazing and haying, these areas serve as a shelter for wild animals. Areas remote from settlements are assigned for self-growth. These are the headwaters of ravines and beams adjacent to large fore ravines forest strips or forest massifs, and in which there are signs of renewable successions. In some cases, such beams are "framed" by projected additional forest strips to enhance the growth of tree-shrub vegetation.

The development and implementation of appropriate soil and water protection measures for the arrangement of the catchment area optimally should be carried out at the basins of the 5^{th}-4^{th} orders or lower on the basin positional-dynamic, adaptive-landscape and geosystem principles and carried out in accordance with the algorithm for assessing the state of the catchment area and developing the project of the basin organization of nature use with the help of GIS and RS technologies (Fig. 6).

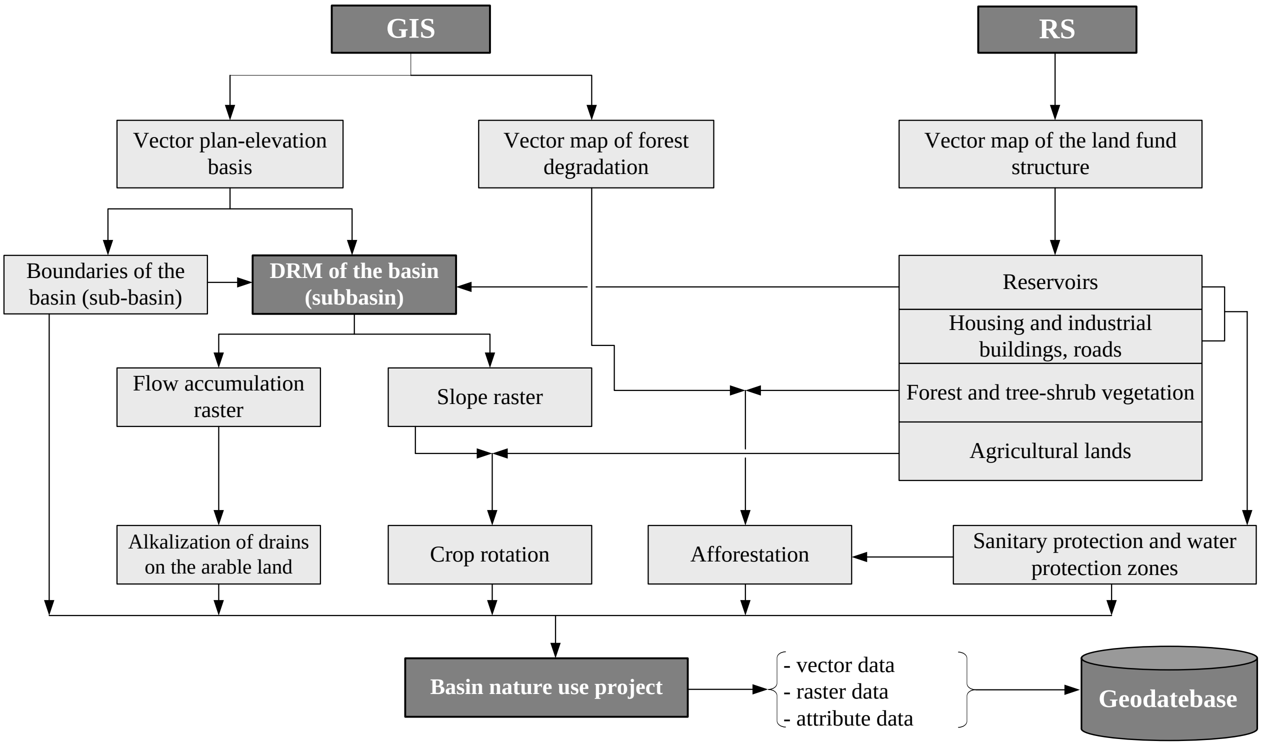

Fig. 6. Algorithm for assessing the state of the catchment area and development of the project of the basin organization of nature use with the use of GIS and RS technologies

The basis for the organization of ecologically rational exploitation of the territory is the results of a complex geomorphological analysis of the studied territory of the basin at the local level. The modern software product ArcGIS is used to carry out this task. The geoinformation system has a wide set of tools and modules for modeling, spatial analysis of processes and phenomena.

Data on the structure of the land fund of the river basin territory serves as the initial information for anti-erosion landscape design. The main source of up-to-date information for geoplanning is remote sensing data from Landsat satellites with a spatial resolution up to 15 meters. The use of satellite photography allows not only to reflect the modern structure of the land fund, but also to trace its dynamics through the time. Based on the remote sensing data, vector thematic layers are created. They can fully reflect the structure of the terrain and are combined into spatial databases or geodatabases. The presence of only the vector data fully allows many analytical procedures: calculation of geometric characteristics (area of polygonal and

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length of linear objects), analysis of spatial compatibility by overlay method (overlay analysis), various statistical and geostatistical operations.

Sets of raster data for the operational territorial unit of spatial analysis - the river basin is the basis for anti-erosion soil and water protection projection of the catchment area. This data is obtained on the basis of a digital relief model (DRM). While constructing the DRM, special attention should be paid to the correctness of its hydrological component. First, the obtained DRM must be checked for the presence of local reductions - topological errors that arise due to the peculiarities of the model construction algorithm and can be corrected using the "Fill" operation.

The obtained DRMs are systematized in the catalog of raster data at the local level of GIAS, from which they are available for further analytical operations. The project organizational structure of arable land is developed on the basis of grids of slopes of the earth's surface obtained by spatial analysis of the DRM. The slope cell values are grouped into groups with intervals: 0–3°, 3–5°, 5–7°, more than 7°. The structure and configuration of crop rotations are determined using a semi-automated way by imposing slopes grids and a vector layer of land in accordance with the Table. 1. The projecting of drains calcification is carried out by identifying the talwegs of the fluvial network.

To do this, with the help of the "Gidrology" tool set, rasters of runoff accumulation are created. The places of concentration of water flows are displayed on this rarters. After processing the raster data and converting it into a vector format, an erosion network of beams is obtained, which are recommended for alkalization.

As a result of the implementation of all spatial operations, geo-informational projects of anti-erosion optimization of the land fund structure are created on the basis of soil and water protection arrangement of territories for each basin or sub-basin. Priority arrangement is carried out in the territories of different level sub-basins with a high degree of agrogenic transformation of landscapes.

The ecological efficiency of optimizing the agro-landscapes of the basin must be evaluated by the ratio of stabilizing and destabilizing lands, expressed through a set of coefficients.

1. Natural protection coefficient (K_{NP}) [75] determines the level of resistance of natural landscapes to anthropogenic influences, which depends, first of all, on the amount and nature of the distribution of the lands of the ecological fund: natural biogeocenoses and natural territories under protection:

$$K_{NP} = \frac{\sum S_{SL}}{S}, \qquad (1)$$

where S_{SL} – area of ecological fund lands; S – the area of the research territory. To achieve a critical level of protection, at least half of the entire land fund should belong to stabilizing landscapes.

2. Sustainability of the agricultural landscape (K_{SL}) can be estimated by the ratio of the areas under medium-forming and destabilizing lands according to the formula [76]:

$$K_{SL} = \frac{\sum S_{SL}}{\sum S_{DL}}, \qquad (2)$$

where S_{SL} – area of stabilizing lands; S_{DL} – area of destabilizing lands.

To favorable ecological sustainability corresponds $K_{SL} \geq 0{,}71$, relatively favorable – 0,70-0,60, satisfying – 0,59-0,56, tense – 0,55-0,46, critical – $K_{SL} \leq 0{,}45$.

Stabilizing elements of the landscape include natural tree and shrub herbaceous vegetation, gardens, fodder lands, part of arable land occupied by perennial herbs, swamps, water bodies; destabilizing – arable land, ravines, landslides, areas under construction and roads, industrial facilities, other areas that have suffered of significant anthropogenic changes.

3. A more detailed assessment of the ecological state of landscapes is given by the coefficient of ecological stability (K_{ES}), which takes into account the differentiated contribution of each element of the landscape through a system of coefficients [77]:

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$$K_{ES} = \frac{\sum S_i \cdot k_i}{S} \cdot K_{MS} \quad (3)$$

where S_i – land area of *i-type*; k_i – coefficient of environmental stability of the land of *i-type* (Table 1); S – the total area of the assessed territory; K_{MS} – coefficient of morphological stability of the relief (1 – for stable areas, 0,7 – for unstable areas, for example, sand, landslides, steep slopes).

Table 1. Coefficients of ecological assessment of lands

Land type	Coefficient of ecological stability of the land, k_i
Built-up territories and roads	0,00
Arable lands	0,14
Vineyards	0,29
Forest strips	0,38
Orchards and shrubs	0,43
Kitchen-gardens	0,50
Hayfields	0,62
Pastures	0,68
Reservoirs and swamps of natural origin	0,79
Forests of natural origin	1,00

If the value $K_{ES} \leq 0,33$ – the territory is ecologically unstable, 0,34-0,50 – moderately stable, 0,51-0,66 – average degree of stability, $K_{ES} \geq 0,67$ – the territory is ecologically stable.

CONCLUSIONS

The justification of the safety of water and land use and the implementation of a conceptual model of ecologically rational exploitation of the river basin territory as an integral positional-dynamic and spatially organized system of interconnected natural-anthropogenic components will allow to optimize the structure of the land fund, reduce the risks of ecological destruction of land and water resources, ensure greening of agriculture and improving of the ecological situation in river basins.

It is emphasized that the conceptual model of ecologically rational exploitation of the basin catchment area includes: creating an ecological frame of the river basin based on the identification of the internal geomorphological structure of the catchment area; the development and filling of the geoinformational and analytical system of the river basin, including the assessment and forecast of the ecological situation and the determination of the most agrogenically transformed sub-basins of different orders; the development of the project of the basin organization of nature use, including the ecological-resource characteristics of the current state of the territory of sub-basins of different orders and the evaluation of the effectiveness of the implementation of the project. Geoplanning of the structure of the catchment area land fund and development of the project of the basin organization of nature use is carried out using GIS and RS technologies.

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