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LANDSCAPE-ECOLOGICAL FUNDAMENTALS TO THE REVITALIZATION OF THE POND IN THE B. F. OSTAPENKO DENDROLOGICAL PARK OF THE STATE BIOTECHNOLOGICAL UNIVERSITY

Purpose. To justify the comprehensive revitalization of the pond within the B.F. Ostapenko Arboretum of the State Biotechnology University as a nature-based solution for adapting the arboretum's ecosystem to climate change and implementing the landscape design proposed by A.D. Zhirnov.

Methods. Retrospective analysis of archival project decisions, landscape and environmental planning, digital terrain modeling, field, laboratory analytical.

Results. A retrospective analysis of archival design decisions from 1970–1971 revealed the main cause of the water body's dysfunction: the high infiltration capacity of the sandy bottom of the reservoir, which prevented natural water accumulation. A comprehensive landscape-ecological assessment of the territory was conducted, justifying the feasibility of restoring the pond through the implementation of modern engineering solutions, specifically the installation of an impervious liner based on bentonite barriers. A three-dimensional model of the pond bed was developed, incorporating a dedicated bio-plateau zone. A phytoremediation system involving oxygenating plants was proposed. The high quality of snowmelt water as a resource for filling the water body was demonstrated.

Conclusion. The landscape and ecological conditions of the area, combined with the application of modern technologies, will facilitate the restoration of the pond's aquatic-anthropogenic ecosystem. This will transform the dysfunctional territory into an active ecological hub, providing climatic moderation through the creation of a "moist oasis" and an autonomous irrigation reservoir. The implementation of the project directly contributes to the achievement of UN SDG 15.1 by ensuring the sustainable functioning of introduced species collections in the context of climate change.

KEYWORDS: *landscape and environmental planning, revitalization, arboretum, nature-oriented solutions, GIS modeling, bentonite barriers, bio-filtration area, oxygenating plants, Sustainable Development Goals*

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Introduction

A distinct group of objects involved in landscape planning comprises aquatic anthropogenic systems, specifically man-made ponds, the favorable ecological status of which must be maintained by their creator — a human being. Studies by L. V. Ilyin are dedicated to the investigation of the hydrochemical and hydrobiological regimes of water bodies in Ukraine [1, 2]. In a theoretical and methodological context, the contemporary research by V. K. Khilchevskiy, M. R. Zabokrytska, et al. [3, 4] is of leading importance. The works of M. H. Shcherban, V. V. Myasoiedov, V. A. Kapustnyk, S. R. Novytska, V. K. Khilchevskiy, et al. [4, 5, 6, 7] are specifically dedicated to the evaluation of recreational water bodies.

Despite this, the ecological role of such objects and their ecosystem services are often overlooked by researchers and significantly undervalued, particularly in comparison with other types of anthropogenic activities. Although artificial reservoirs usually have a simplified environmental structure compared to their natural counterparts, they are highly valuable for supporting local biodiversity [8].

The relevance of restoring small water bodies is consistent with the strategy of the EU Water Framework Directive, which since 1996 has extended protection to all types of surface and groundwater. Today, the degradation of small water bodies and their gradual loss are recognized as a significant environmental conservation problem throughout the European Union [9, 10].

The experience of successful international nature conservation strategies is of particular importance in the context of pond restoration. A notable example is the Million Ponds Project by the Freshwater Habitats Trust, whose main goal is to overcome the effects of a century of small water body loss by restoring a network of ponds in the landscapes of Great Britain. The results of the project showed that the creation of more than 1,000 new and restored ponds between 2008 and 2012 provided habitats for about 50 rare species that are threatened with extinction [11, 12].

In the context of ecologically consistent pond restoration, the application of landscape and ecological planning is instrumental for assessing the environmental status of both the water body and its adjacent territory [13, 14, 15, 16]. It is landscape and ecological planning that enables the identification of existing land-use conflicts within the pond's zone of influence and

upon the pond itself, the prediction of their consequences, and the development of optimization measures. In contrast to other systems, additional research in these cases necessitates the modeling of dynamic rather than merely static parameters, as the water management system undergoes significant transformations throughout the year (water levels, pollutant concentrations, the intensity of conflict sources, etc.).

Water bodies, as objects of study, have a long history of research from various perspectives: hydrophysics, hydrochemistry, hydrobiology, biological productivity, etc. Undoubtedly, the scientific contributions of specialists in various fields can serve as a methodological and analytical foundation for landscape and ecological planning. At the same time, landscape and ecological planning does not aim to replace specialized research, but rather to systematize, integrate, and direct it towards solving a common task — the restoration of the water management landscape (the pond).

The dendrological park of the B. F. Ostapenko State Biotechnological University is a nature reserve, the genesis of which was based on the integration of scientific research and aesthetic planning functions. In the architectural and planning concept developed in 1970–1971 by scientists from the L'viv Forestry Institute under the leadership of A. D. Zhirnov, water components — a fountain and a decorative pond — were considered as the compositional dominant and the hub of the hydrological network [17, 18].

The foundation for spatial planning was laid by large-scale geodetic surveys (1969–1970) and soil studies conducted under the supervision of D. G. Tykhonenko, which resulted in the creation of a detailed soil map on a scale of 1:2000 [17]. However, retrospective analysis shows that the implementation of hydraulic structures became the most vulnerable link in the 1972 project due to the lack of a comprehensive water supply system and the presence of a thick sand layer, which causes high soil infiltration capacity and prevents natural water accumulation. At the present stage, the grass-covered bed of the pond with an area of 0.6 hectares is in a state of long-term exposure conservation. The pond, which according to A. D. Zhirnov's plan was supposed to be a landscape accent, has turned into a grassy hollow that disrupts the integrity of the exhibition area (Figs. 1–2).

The implementation of a landscape and environmental planning in combination with the concept of green-blue infrastructure allows

the existing ravine to be transformed into a functional ecosystem node for intercepting surface runoff. In order to optimize the water balance of the territory, instead of the process of uncontrolled infiltration of atmospheric precipitation into the lower horizons, it is proposed to install an artificial waterproofing screen. This design solution will transform the pond bed from a drainage area into a functional reservoir for storing meltwater and rainwater. This will



Fig. 1 – Satellite imagery showing the spatial localization of the de-functionalized pond bed within the dendrological park's vegetation structure

Transforming the bed into a functional depot for collecting and accumulating surface runoff will solve the problem of irrigation water shortages. Creating an autonomous irrigation reservoir will ensure the technological independence of the introduction nursery and perennial flower collection, which is a necessary condition for the viability of the facility in the context of climate change.

The creation of a reservoir will initiate the development of ecotopes suitable for the formation of hydrophilic communities and coastal-aquatic ecosystems. The implementation of the proposed solutions will contribute to the natural enrichment of the arboretum's biodiversity. Thanks to the creation of a spacious littoral zone, the pond will serve as the main center of biological diversity for aquatic and coastal flora and fauna. This significantly increases the scientific and educational potential of the arboretum, presenting it as an object with fully functioning aquatic biotopes. A list of previously unavailable ecosystem services is presented in Table 1.

The failure to complete the hydraulic engineering works during the establishment of the arboretum is now seen not only as an engineer

create a “wet oasis” that will naturally ensure natural thermoregulation and optimization of the microclimate of the surrounding areas of the arboretum. The water mirror will create the conditions for effective thermoregulation and microclimate stabilization, neutralizing temperature stress for introduced species during periods of extreme summer drought. Thus, the created reservoir will act as a natural moderator of the surface air layer.



Fig. 2 –The existing relief of the ravine

ing shortcoming of the past, but also as a fundamental scientific challenge. Historical retrospectives show that the architectural concept of the founders, which envisaged the creation of a water feature, was ahead of the technical capabilities of the time. The high infiltration capacity of the soil in the 1970s became an insurmountable obstacle to natural water accumulation [17].

At the present stage, modern nature-oriented solutions are overcoming this technological gap. What was unattainable half a century ago due to the lack of perfect waterproofing means is now being implemented through innovative approaches to water resource management.

The use of modern materials to form an artificial waterproofing screen for the implementation of surface runoff interception systems is a logical conclusion to A. D. Zhirnov's historical idea, adapted to the requirements of today's climate stability. The restoration of the water mirror corrects the long-standing “landscape pause”, transforming the pond into a functional moderator of the microclimate and a center of biotopic attraction, combining the historical concept with modern environmental requirements.

Table 1

List of previously unavailable ecosystem services

Ecosystem Service Category	Current State (De-functionalized Bed)	Projected State After Revitalization	Ecosystem Effect
Regulating (Climate)	Increased air aridity; thermal stress for mesophilic introduced species.	Hydromorphic microclimate moderation; natural humidification of the surface air layer.	Reduction of summer temperature peaks; enhanced plant viability and resilience.
Provisioning (Resource)	Irreversible infiltration of runoff into sandy horizons; total dependence on external water sources.	Accumulation of surface runoff in the created reservoir for irrigation purposes.	Technological autonomy of the nursery (1.0 ha) and flower beds (0.3 ha); resource conservation.
Supporting (Biological)	Absence of hydrophilic biotopes.	Creation of ecotopes for macrophytes and coastal fauna; formation of a bio-filtration system.	Increased biodiversity; strengthening of the park ecosystem's self-regulation processes.
Cultural (Educational & Aesthetic)	Compositional fragmentation; perception of the basin as an unfinished/neglected object.	Restoration of the A.D. Zhirnov compositional dominant; enhancement of visual attractiveness.	Integrity of the landscape image; growth of recreational potential. Cognitive value: increased appeal for scientific research and education.

Research methodology, objects, and methods

A fundamental feature of this study, which we have repeatedly emphasized [14, 15, 16], is the implementation of landscape and ecological planning (LEP) not only within the potential bed of the water body but within the catchment area as a whole. Therefore, at all stages of LEP, a significant area encompassing both the water body and the adjacent land is subject to investigation.

To justify the project decision to revitalize the water body and accurately determine the morphometric characteristics of the ravine, digital terrain modeling methods were applied in the QGIS geographic information system environment. The work uses remote sensing data obtained from the OpenTopography global repository, where raster data from AW3D30 digital elevation models of the global digital product integrated into the European Space Agency Earth monitoring system was selected to ensure maximum micro-relief detail – Copernicus DEM (Digital Elevation Model) [19].

High accuracy of morphometric analysis of the territory was ensured by using the ALOS World 3D (AW3D30) global digital surface model [20]. This dataset, provided by the Japan Aerospace Exploration Agency (JAXA), is based on the results of precision stereomapping

performed using the PRISM panchromatic sensor of the DAICHI satellite. The methodological advantage of the selected dataset lies in its genesis: the model with a horizontal resolution of about 30 meters (1 arc second) is derived from a high-precision commercial network with a 5-meter step.

The use of AW3D30 in the study is due to its recognized stability and high vertical accuracy, which currently meets the leading global standards among open sources of geospatial information. The use of archival data in combination with modern GIS correction tools made it possible to form a reliable topographic basis for designing the reservoir bed, minimizing errors associated with micro-relief features.

By spatially restricting the object's geographic coordinates, it was possible to localize the pond bed and adjacent slopes, which created a reliable basis for further design. As a result, the digital model obtained became the basis for calculating the volumes of the future pond bed, determining the boundaries of the water mirror, and designing a waterproofing screen, taking into account all the features of the natural slope of the surface (Fig. 3).

The final stage of digital data processing was the development of a spatial relief model in

the SketchUp architectural design environment [21], namely, the transformation of vectorized relief data into a three-dimensional analytical model. The use of SketchUp tools in combination with surface interpolation methods made it possible to create a digital copy of the pond bed, which is a necessary condition for the transition from two-dimensional planning to three-dimensional engineering design. The process began with the integration of raster and vector materials obtained in GIS into a three-dimensional environment. This ensured the topographic

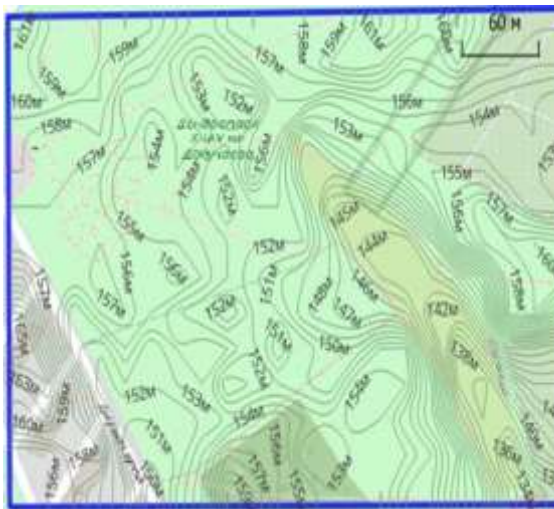


Fig. 3 – Digital Elevation Modeling (DEM) for pond restoration in QGIS environment.

The introduction of volumetric modeling solves a number of tasks, namely, it provides the opportunity to study in detail the steepness of slopes and morphological features of the bed from any angle, allows

Research findings and discussion

The justification for the algorithm of water body restoration within the arboretum's structure is based on the concept of landscape and ecological planning [22, 23, 24, 25]. Since landscape and ecological planning focuses on small-scale areas at the local level of environmental organization, the application of this approach allows for the creation of a water body to be considered an organic element of the arboretum's landscape organization.

The inventory stage traditionally encompasses the study of natural landscape components and the socio-economic environment, alongside the creation of corresponding cartographic works. The work commenced with the delineation of the catchment area boundaries,

accuracy of the future model and its correspondence to the actual geographical coordinates of the object (Fig. 4).

The generation of a polygonal grid based on 0.5 m contour lines enabled a high-precision reconstruction of the object's morphological structure. Specifically, it allowed for the clear localization of the ravine thalweg, which determines the natural runoff vector, as well as the geometric parameters of the ravine brows that form the spatial boundaries of the catchment area and the designated bio-filtration zone

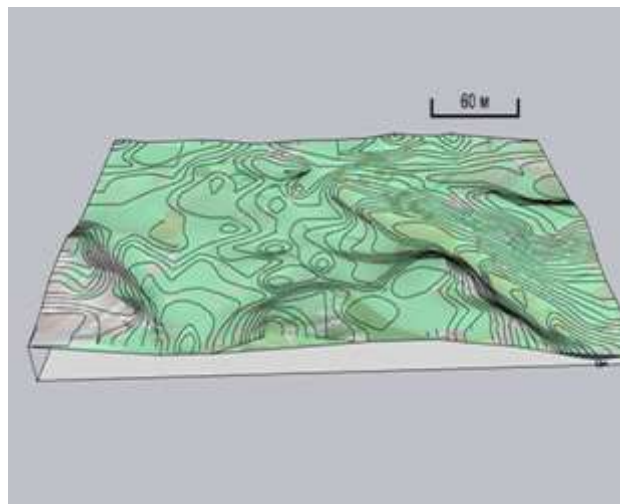


Fig. 4 – 3D digital terrain model of the projected pond bed, visualized in SketchUp.

identifying the lowest relief marks for the rational placement of hydraulic structures, and creates a basis for calculating the filling levels of the reservoir and modeling the water mirror.

which directly participate in forming the ecological status of the water body. For this purpose, GIS modeling of the catchment territory was employed (Fig. 1). The use of geographic information systems for generating terrain contours creates a basis for predicting hydromorphometric indicators, while the application of the "from model to object" principle allows for the transformation of digital data into a precision design of the pond bed. The construction of a polygonal model in the SketchUp environment served as a tool for transitioning from theoretical analysis to the practical reproduction of the water body's geometric parameters.

The next component of the natural characterization of the study object, as with other

territories, is the geological one; however, since the focus is on the restoration of the pond, the authors utilized results from previous research in the project.

The specificity in addressing the next component – soils – lies in the fact that they are clearly distinguished within the catchment basin but 'disappear' within the boundaries of the water body itself. However, the very existence of the pond necessitates the formation of natural-technogenic ecosystems, which consist of the aquatic ecosystems proper and transitional ecosystems between them and the adjacent land, which territorially correspond to water protection zones. These encompass zones of flooding, partial inundation, and zones of erosional activity, which are appropriately delineated within the project.

In the inventory phase documentation, particular emphasis is placed on climatic characteristics, as the water body is sensitive to climatic changes. In addition to studying data on temperature dynamics, precipitation patterns, periods of ice cover, and flood events, the assessment stage of the landscape and ecological planning involved an investigation of the snow cover to determine potential pond contamination from surface runoff during the spring thaw.

The final natural component required to form a comprehensive understanding of the landscape is vegetation. Consequently, significant attention was paid to the accurate representation of the structure of both the current phytocenosis and the one that preceded it. At the same time, the revitalization project envisages the replacement of the natural vegetative cover.

The pond is surrounded by developed green spaces and pine massifs that function as a natural buffer. The preserved natural herbaceous cover of the arboretum significantly minimizes the risks of agrochemical runoff, while the absence of impermeable asphalt surfaces within the adjacent territory contributes to the maintenance of a healthy hydrological regime.

Consequently, the results of the inventory stage provided the basis for the subsequent assessment stage of landscape and ecological planning, in which ecological-geochemical studies of the defined territory constitute a mandatory component. Within this approach, assessing the quality of water resources intended for filling the reservoir enables the prediction of the aquatic system's state upon completion of the works.

Given the specific features of its creation and location, the filling of the water body is

significantly facilitated by atmospheric precipitation and surface snowmelt runoff. This paper presents the results of a chemical analysis of the snow cover sampled within the territory of the arboretum during the winter period.

The aforementioned analysis is regarded as an integral component of the comprehensive monitoring of the aquatic environment's quality. These data constitute a necessary link for understanding the baseline ecological status and assessing the potential nutrient loading on the ecosystem during the spring flood period. Such an approach enables the detection of early signs of anthropogenic impact and serves as a foundation for further long-term observations to ensure the sustainable functioning of the water body within the arboretum.

The study was conducted by sampling the snow cover within the territory of the arboretum. Snow water was obtained by controlled melting of samples at room temperature. This approach made it possible to analyze the chemical composition of precipitation in its "primary" state, reflecting the level of atmospheric load on the ecosystem. The obtained water was analyzed for the content of priority pollutants. Given the absence of direct standards for the content of chemicals in snow cover, the quality of the melted snow water was assessed by comparison with the Hygienic Water Quality Standards, approved by Order No. 721 of the Ministry of Health of Ukraine, dated May 2, 2022 [26]. This approach allows us to predict changes in the chemical composition of pond water during spring snowmelt and to determine the compliance of snow water with the water quality requirements for water bodies used for domestic and industrial purposes.

The assessment methodology under the above-mentioned order provides for the use of maximum permissible concentrations (MPC) or indicative permissible levels (IPL) of substances. The assessment is based on the limiting hazard indicator, which determines the most sensitive area of impact of a substance: sanitary-toxicological, general sanitary, or organoleptic. An important element of the analysis is also the classification of pollutants by hazard classes, which allows the identified substances to be ranked according to their potential risk to the aquatic environment and public health [26]. The comprehensive combination of these parameters ensures a high degree of reliability of the environmental forecast within the framework of developing

measures for the revitalization of the reservoir. The assessment was carried out according to physical, chemical, and chemical indicators characterizing its hydrogen index, salt

composition, the presence of biogenic elements, and potentially toxic substances.

The results of determining the content of chemicals in snow water are presented in Table 3.

Table 3

Integrated ecological assessment of snow water chemical content, 2026

Parameter	Value	MPC [26]	IPL [26]	Limiting Hazard Indicator	Hazard Class
pH	6.62	6.5–8.5	–	–	–
Nitrates, mg/dm ³	0.18	45	–	Sanitary-toxicological	3
Phosphates, mg/dm ³	0.02	3.5	–	Organoleptic	3
Chlorides, mg/dm ³	3.00	350	–	Organoleptic (affects water taste)	4
Calcium, mg/dm ³	1.00	–	200	Organoleptic (affects odor and taste)	3
Magnesium, mg/dm ³	0.60	–	50	Organoleptic (affects odor and taste)	3
Sodium, mg/dm ³	0.30	200	–	Sanitary-toxicological	2
Sulfates, mg/dm ³	2.49	500	–	Organoleptic (affects water taste)	4
Iron, mg/dm ³	0.0002	0.3	–	Organoleptic (affects color)	3
Zinc, mg/dm ³	0.011	1.0	–	Effect on the overall sanitary regime of the water body	3
Copper, mg/dm ³	0.001	1.0	–	Organoleptic	3
Manganese, mg/dm ³	0.000	0.1	–	Organoleptic (affects color)	3
Cadmium, mg/dm ³	0.001	≤ 0.001	–	–	2
Chromium [Cr ⁶⁺], mg/dm ³	0.002	0.05	–	Sanitary-toxicological	3
Cobalt, mg/dm ³	0.005	0.1	–	Sanitary-toxicological	2
Nickel, mg/dm ³	0.004	0.10	–	Sanitary-toxicological	3
Lead, mg/dm ³	0.008	0.03	–	Sanitary-toxicological	2

The results of chemical analysis of snow water collected in the winter of 2026 indicate an extremely low level of anthropogenic load. The values obtained for all indicators comply with the requirements of Order No. 721 of the Ministry of Health. Particular attention is drawn to the state of substances of the 2nd hazard class. The concentration of highly hazardous cobalt and lead in the samples is minimal, in particular, the lead content is 0.008 mg/dm³ with an MPC of 0.03 mg/dm³, and cobalt is 0.005 mg/dm³ with a MPC of 0.1 mg/dm³. However, the concentration of cadmium is 0.001 mg/dm³, which is equal to the MPC. This

“borderline” situation requires special attention, as cadmium has the property of bioaccumulation in the food chains of aquatic ecosystems [27].

Mineralization indicators: chlorides – 3.0 mg/dm³, sulfates – 2.49 mg/dm³, sodium – 0.30 mg/dm³, calcium – 1.0 mg/dm³, magnesium – 0.60 mg/dm³ demonstrate an extremely low content of dissolved salts. Total mineralization is 0.013 g/dm³. The pH of 6.62 is close to neutral. Such snow water acts as a natural “solvent” that can reduce the total concentration of salts in the surface waters of the pond after summer evaporation. The annual filling of the pond with water

of such high quality is a factor in its sustainable functioning.

The content of biogenic compounds, namely nitrates, is 0.18 mg/dm^3 , phosphates – 0.02 mg/dm^3 , which is extremely low compared to their MPC: 45 mg/dm^3 and 3.5 mg/dm^3 , respectively. The minimal presence of biogenic elements in meltwater inhibits the primary productivity of algae at the beginning of the growing season and creates conditions for the competitive advantage of higher aquatic vegetation. The latter, thanks to their longer vegetation cycle, effectively assimilate nutrients, inhibiting the development of blue-green algae throughout the season.

Low concentrations of Fe, Mn, Zn, Cu, Co, and Ni in snowmelt do not pose a toxicological threat, as they are significantly lower than the established MPCs. In the context of an artificial ecosystem of a pond with container-grown macrophytes, these concentrations can be considered not as pollutants, but as a potential source of essential micronutrients, in particular, iron, manganese, copper, and zinc, which are essential cofactors of photosynthetic enzymes and components of chlorophyll [28].

Summarizing the results of hydrochemical analysis, it can be stated that snow cover in the arboretum is a source of high-quality water with minimal anthropogenic impact. The absence of excess biogenic substances, low mineralization, and favorable pH create the conditions for the formation of a stable hydrochemical regime in the pond and prevent the intensification of eutrophication processes. At the same time, a balanced content of essential microelements, whose concentrations are significantly lower than the maximum permissible levels but physiologically significant, can contribute to maintaining the functional activity of macrophyte metalloenzyme systems during their vegetation. However, the concentration of cadmium, which is approaching the maximum permissible limit, indicates the need for systematic environmental monitoring to control the dynamics of this priority toxicant.

The next stage of landscape and ecological planning is generalization and forecasting. This stage is specifically dedicated to the development of the pond restoration project. An individual approach to the design object takes into account the specific nature of the arboretum as an object of the nature reserve fund and the particularities of land use within its

boundaries. The revitalization strategy focuses on the formation of stable ecotopes capable of self-regulation.

The application of a systematic algorithm of landscape and ecological planning transforms the pond revitalization into a scientifically managed process, where every stage – from digital modeling to hydrobiological observations of water quality and bottom sediments – is aimed at forming a stable, functional, and self-regulating aquatic component of the arboretum.

The creation of a water body should serve as a factor for increasing landscape diversity. According to the principles of landscape and ecological planning, the revitalization of a pond should be based on the creation of a heterogeneous bed structure. Instead of a uniform deep-water bed, a division into two main functional zones is proposed: a deep-water accumulative part and a shallow-water biological treatment zone (bioplato).

Digital modeling confirms that the morphology of the beam already contains a formed depression, which serves as the basis for the future reservoir. Although the bed requires technological refinement to achieve the design marks, the scope of this work is significantly smaller compared to the construction of an artificial basin “from scratch.” The presence of such a prepared relief allows the focus to shift from massive earthworks to precision bottom planning. This minimizes soil excavation and provides favorable conditions for laying a waterproofing screen. Thus, the use of the natural contours of the ravine significantly optimizes the cost structure of the project, transforming landscape features into a significant economic asset. Thus, the integration of natural forms into the project model ensures the rational use of funds, transforming the geomorphological features of the territory into an economic asset for revitalization measures.

An essential aspect of ensuring the functional stability of artificial reservoirs is the creation of a reliable anti-seepage liner. Modern waterproofing for such facilities is represented by two main types of materials: polymer geomembranes and geosynthetic clay liners. Within the framework of our project, we consider the use of geosynthetic clay liners, specifically bentonite mats, as the optimal solution for pond restoration.

Bentonite mats are a high-tech composite consisting of natural sodium bentonite mineral and polymer fibers, which allows for the

combination of natural clay's environmental friendliness with the strength and adaptability of synthetic materials [29]. These materials ensure the long-term sustainability of ecosystems due to their ability to adapt to the physicochemical changes of the environment. The primary advantage of these materials, in contrast to traditional polymer geomembranes, is their self-healing capacity for minor damages, facilitated by the sodium bentonite that swells upon contact with water. This is particularly crucial when installing on existing microrelief with a significant number of inflections. The ultra-low filtration coefficient of these materials upon full hydration guarantees the retention of the calculated water volume and the stability of the water table, even during periods of precipitation deficit [30].

Modern approaches to improving anti-seepage liners are aimed at increasing their operational reliability by enriching materials with natural components. As evidenced by current research [31], the introduction of biopolymers, specifically agar-agar, significantly increases the strength of bentonite mats, ensuring their structural integrity under the pressure of the water mass. Another promising direction is the regulation of bentonite swelling properties: optimizing this parameter helps prevent deformations of the pond bed and preserves the designed contours of shallow-water bioplatoons [31].

When designing the pond, we rejected the idea of creating a geometrically correct reservoir in favor of a natural model of a water body. Instead of a monotonous bottom, the project envisages the formation of zones of varying depths. Research by Linares et al. identifies the physical conditions of the habitat as an indispensable tool for maintaining biodiversity in artificial reservoirs, directly affecting their ecological sustainability. The creation of various depth gradients with a smooth transition from the shore to the deep zone ensures the formation of a stable and rich ecosystem [32]. According to the conclusions of Oertli and Parris [33], the main focus in design should be on the banks of ponds, as they support a significant part of the overall biodiversity of the water body, providing fauna with places for shelter, reproduction, and migration between aquatic and terrestrial environments. An expanded shallow water zone ensures faster water warming, activates zooplankton development, and creates numerous ecological niches. Although diversity of shore characteristics at the landscape level is

desirable, it is shallow water profiles, according to researchers, that promote the development of aquatic vegetation and create high habitat heterogeneity, which should become the norm in urban and park landscape design [33, 34].

The basis was the modeling of the bed profile with a smooth concave curve, with an expanded shallow zone, which occupies about 40% of the total water surface area, to the maximum depth. Sufficient space creates conditions for the development of macrophytes and benthic communities, which are the basis for the natural self-purification processes of the reservoir. The deep-water zone of the reservoir will serve as an ecological refuge for aquatic organisms during extreme temperatures, preventing complete freezing or overheating, thereby enhancing the overall stability of the ecosystem.

For the development of the shallow-water zone, a layer of high-density geotextile is laid over the previously installed bentonite mats. Its primary function is to provide mechanical protection for the bentonite liner against punctures by plant rhizomes and to prevent substrate erosion. A mineral substrate with a thickness of 15–20 cm is placed on top of this protective layer. It is recommended to use a mixture of washed gravel and zeolite. Zeolite acts as an ion-exchange filter that absorbs ammonium and phosphates, thereby preventing eutrophication and maintaining the required water quality.

Oxygenating plants are the actors of aquatic ecosystem health. They are planted in substrate or coconut mats, and for many species, plant parts can be added directly to the water. These plants are the real secret to the health of a pond, which is usually hidden beneath its surface, so they remain largely invisible to the eye. Since the substrate is inert, oxygenators are forced to absorb nutrients directly from the water column, acting as a “biological pump” and saturating the water with oxygen, working tirelessly to keep the water clean and clear. The root system of oxygenators develops horizontally within the substrate, without reaching the waterproofing layer thanks to a separate layer of geotextile.

A list of recommended oxygenating plants, compiled on the basis of an analysis of the works of G. Speichert, S. Speichert, and D. G. Hessayon, is presented in Table 2 [35, 36].

Coastal flora forms a transitional zone of the reservoir. Its root system is immersed in the bottom substrate under water, while the main

Table 2

Recommended aquatic oxygenators and their Functional Significance in pond ecosystems

Plant Name (Latin)	Optimal Depth (m)	Max Depth (m)	Functional Significance
<i>Elodea canadensis</i>	0.2–0.8	up to 3.0	Powerful oxygenator. Has one of the highest oxygen release rates per unit of biomass. Acts as a high-capacity biological pump, absorbing mineral nutrients.
<i>Myriophyllum spicatum</i>	0.5–1.5	up to 3.5	Powerful oxygenator. Thanks to its finely divided structure, the leaves provide maximum gas exchange area. Works effectively in synergy with <i>Elodea canadensis</i> .
<i>Potamogeton crispus</i>	0.5–1.2	up to 2.5	Early starter. Ensures oxygen balance in early spring while other plants are still dormant.
<i>Chara vulgaris</i>	0.4–1.0	up to 5.0	Biogenic calcification. In addition to oxygenation, it effectively absorbs carbonates and clarifies water.
<i>Potamogeton lucens</i>	0.8–1.5	up to 3.0	Deep-water aeration. Large leaves effectively saturate the middle and lower layers of the water body with oxygen.
<i>Ceratophyllum demersum</i>	0.5–2.0	up to 9.0	Nitrogen control. Ideal for ammonium absorption; functions even in low-light conditions at significant depths.
<i>Eleocharis palustris</i>	0.0–0.2	up to 0.5	Bank stabilization. Creates a dense sod mat that prevents bank erosion and filters surface runoff. Stabilizes zeolite substrate. Provides bottom aeration and shelters fish fry.
<i>Eleocharis acicularis</i>	0.1–0.5	up to 1.0	Benthic filter. Forms underwater "meadows" that purify the near-bottom water layer.
<i>Hottonia palustris</i>	0.3–0.6	0.8	Bioindicator of water purity and oxygen saturation. Superior spawning substrate: soft leaves do not damage fish eggs.
<i>Fontinalis anti-pyretica</i>	0.4–1.0	4.0	Year-round aeration and heavy metal sequestration. Provides bactericidal protection for fish eggs; remains active even under ice.
<i>Tillaea aquatica</i>	0.0–0.2	0.3	Egg protection in extreme shallows.

part of the shoots actively develops in the air. Unlike oxygenators, coastal plants have almost no effect on the biological balance or purification of water, performing primarily a decorative and landscaping function of visually softening the contours of the reservoir. They skillfully blur the boundary between the water surface and the free, natural contours of the reservoir. In summer, plants such as *Iris pseudacorus*, *Acorus calamus*, *Alisma plantago-aquatica*, *Caltha palustris*, *Butomus umbellatus*, *Carex stricta*, *Pontederia cordata*, *Scirpus lacustris*, and *Veronica beccabunga* become the main accents, decorating the pond with their flowers and textured leaves (Fig. 5).

The use of the existing dam as a structural element allows for the implementation of a gravity aeration system. The installation of an overflow pipe in the dam body provides a waterfall effect. This technical solution promotes intensive gas exchange at the air-water interface, further enriching the flow with oxygen before it enters the deeper part of the pond, thereby optimizing the reservoir's water chemistry. To maintain continuous circulation, an autonomous solar power generation system is installed on the dam

Photovoltaic panels power pumps that provide vertical and horizontal water exchange, equalizing the temperature regime (Fig. 6). The combination of natural purification methods with technological solutions allows the creation of a sustainable center for biodiversity conservation, which simultaneously performs the economic tasks of the park, in particular, the accumulation of water for irrigation. The distribution of the dam allows you to simultaneously create a decorative area with a significant amount of coastal plants, stabilize the hydrological regime by creating a reservoir volume, and does not interfere with the natural purification of water by oxygenating plants. The presence of areas with calm water opens up the possibility of introducing a collection of species and cultivars of the genus *Nymphaea*. These plants require a stable water surface without strong currents, which is made possible by the correct zoning of the reservoir [35, 36].

The formation of a branched vegetation structure – from submerged macrophyte beds to dense coastal helophyte thickets – is conducive to maintaining a high level of biological diversity in the reservoir. The creation of such natu-



Fig. 5 – Visualization of part of the pond with coastal plantings



Fig. 6 – Forced aeration and water circulation in the project model of the pond

ral centers, where plants with different requirements for immersion depth and insolation intensity are harmoniously combined, is one of the most ecologically justified and effective approaches to ecosystem management. Enriching the floristic composition stabilizes the internal ecosystem of the water body and creates a stable basis for the development of all associated fauna [33].

The ecological stability and biological diversity of a pond are largely determined by the nature of land use within its catchment area. A pond of high ecological quality is characterized

primarily by high water quality, in particular, the absence of excessive inflow of biogenic substances and low concentrations of pollutants. Important features of such a reservoir are developed areas of aquatic vegetation, natural morphology of the banks with gentle slopes, and the absence of invasive alien species [33].

The mechanisms of functioning of artificial water body ecosystems require special attention from researchers, as they differ significantly from their natural counterparts. The revitalization of the water body in the arboretum gives cause for optimism regarding water quality.

Conclusions

To restore the pond in the B. F. Ostapenko Arboretum, a complex of landscape and ecological planning measures was conducted. The inventory phase resulted in a GIS terrain model of the area where the aquatic anthropogenic landscape is planned, along with a systematic collection of the territory's natural characteristics (geological-geomorphological, pedological, climatic, and vegetative).

The assessment stage focused on determining the potential impact of the catchment basin's landscape on the hydrochemical water characteristics by evaluating the chemical composition of the snow cover, which serves as the primary source of water inflow to the pond via surface runoff. It was established that the meltwater possesses low mineralization and a minimal content of nutrients, which acts as a determining factor in inhibiting eutrophication processes and maintaining the pond's clarity. Despite safe concentrations of most heavy metals, the detection of cadmium at the threshold of the maximum permissible concentration (MPC) indicates potential risks of its bioaccumulation within the trophic chains of the artificial ecosystem. At the same time, the presence of Zn, Cu, Fe, Mn, and Co in non-toxic concentrations creates a favorable background for the mineral nutrition of macrophytes in container culture.

At the stage of generalization and forecasting, utilizing GIS modeling and 3D visualization methods based on Copernicus DEM and AW3D30 data, the projected bed was adapted to the existing microrelief of the gully with high

precision. This minimizes the volume of earthworks and ensures optimal zoning of the water body, with the delineation of an accumulative zone and a shallow-water biological treatment zone (bioplato).

Several technological solutions are proposed to minimize the negative environmental impact of adjacent landscapes on the aquatic anthropogenic landscape:

- The implementation of bentonite barriers allows for the mitigation of the high infiltration capacity of the sandy bed;

- The use of geotextiles in the coastal zone ensures mechanical protection of the bentonite liner and stabilizes the shoreline;

- The synergy between the ion-exchange properties of the zeolite substrate and the vital activity of macrophyte oxygenators enables effective self-purification;

- The introduction of a solar power system for forced aeration and water circulation ensures the stability of the hydrochemical regime, even during periods of extreme drought.

The creation of a reservoir will transform a dysfunctional area into an ecological asset for the arboretum. The implementation of the project will generate new ecosystem services, from the climate moderation of a “wet oasis” to the formation of an autonomous irrigation reservoir, which directly contributes to the achievement of UN SDG 15.1: Ensure the conservation, restoration, and sustainable use of terrestrial and inland freshwater ecosystems.

Conflict of interest

The authors certify that although one of the authors of the article is the Editor-in-Chief of this journal, the peer-review process, the publication decision, and the editing process were conducted independently, without their participation or influence. The peer review and the final decision were carried out by other members of the editorial board who are not co-authors. Any potential conflicts of interest were fully mitigated through external oversight of the process.

In addition, the authors have fully complied with ethical standards, including plagiarism, data falsification, and duplicate publication.

Authors Contribution: all authors have contributed equally to this work.

AI Statement

In this study, generative artificial intelligence was not used.

Project compliance

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ЛАНДШАФТНО-ЕКОЛОГІЧНІ ОСНОВИ РЕВІТАЛІЗАЦІЇ СТАВКА В ДЕНДРОЛОГІЧНОМУ ПАРКУ ІМЕНІ Б. Ф. ОСТАПЕНКА ДЕРЖАВНОГО БІОТЕХНОЛОГІЧНОГО УНІВЕРСИТЕТУ

Мета. Обґрунтування комплексної ревіталізації ставка дендропарку ДБТУ ім. Б. Ф. Остапенка як природо-орієнтованого рішення для адаптації екосистеми до кліматичних змін та відновлення історичного ландшафтного задуму А. Д. Жирнова.

Методи. Ретроспективний аналіз архівних проектних рішень, ландшафтно-екологічне планування, цифрове моделювання рельєфу, польові, лабораторно-аналітичні.

Результати. Шляхом ретроспективного аналізу архівних проектних рішень 1970–1971 рр. виявлено головну причину дефункціоналізації водного об'єкту – високу інфільтраційну здатність піщаного дна водойми, що унеможливило природну акумуляцію води. Проведено комплексну ландшафтно-екологічну оцінку території та обґрунтовано можливість відновлення водойми завдяки впровадженню сучасних інженерних рішень, зокрема створення протифільтраційного екрана на основі бентонітових бар'єрів. Розроблено тривимірну модель ложа ставка з виділенням зони біоплато. Запропоновано систему фіторе mediaції за участю рослин-оксигенаторів. Доведено високу якість снігової води як ресурсу для наповнення водойми.

Висновки. Ландшафтно-екологічні умови території та використання сучасних технологій дозволять відновити водно-антропогенну екосистему ставка. Це трансформує дефункціоналізовану територію в активний екологічний вузол, що забезпечує кліматичну модерацію завдяки створенню «вологого оазису» та автономного іригаційного резервуара. Реалізація проекту безпосередньо сприяє досягненню ЦСР 15.1 ООН, гарантуючи стале функціонування колекцій інтродуцентів в умовах змінення клімату.

КЛЮЧОВІ СЛОВА. Ландшафтно-екологічне планування, ревіталізація, дендропарк, природоорієнтоване рішення, ГІС-моделювання, біоплато, біорізноманіття, рослина-оксигенатор, ціль сталого розвитку

Конфлікт інтересів

Автори засвідчують, що, незважаючи на те, що один із авторів статті є головним редактором цього журналу, процес рецензування, прийняття рішення щодо публікації та редагування проводилися незалежно, без їх участі чи впливу. Рецензування, остаточне рішення ухвалювалося іншими членами редакційної колегії, які не є співавторами. Будь-які потенційні конфлікти інтересів були повністю усунені шляхом зовнішнього контролю процесу.

Крім того, автори повністю дотримувались етичних норм, включаючи плагіат, фальсифікацію даних та подвійну публікацію.

Внесок авторів: всі автори зробили рівний внесок у цю роботу.

Декларація про використання ШІ

У цьому дослідженні не використовувався генеративний штучний інтелект.

Відповідність проєкту

Дослідження виконане в межах реалізації бюджетної НДР «Шляхи відновлення зелено-блакитної інфраструктури прифронтових міст».

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