

DOI: <https://doi.org/10.31073/mivg202601-444>

Available at (PDF): <https://mivg.iwpim.com.ua/index.php/mivg/article/view/444>

UDC 627.8:556.53:504.45

HYDRAULIC STRUCTURES AND INNOVATIVE TECHNOLOGIES FOR MANAGING THE HYDROLOGICAL REGIME OF SMALL RIVERS IN THE STEPPE ZONE OF UKRAINE

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Received: 24.03.2026. Revised: 27.04.2026. Accepted: 04.05.2026. Published: 30.06.2026

Abstract. *Small rivers in the steppe zone of Ukraine are the most vulnerable link in the hydrographic network, reacting acutely to climate change and anthropogenic pressure. The current trend toward their shallowing and loss of flow during the low-water period is caused by excessive regulation of river channels by ponds and reservoirs, which transforms rivers into stagnant bodies of water. Using the Dnipropetrovsk region as an example, it has been established that over the past 40 years, the number of ponds has increased 2,7-fold, and their total capacity has exceeded the volume of local runoff, posing a threat to the ecological safety of aquatic ecosystems. Traditional dams block the flow after a flood, so it is essential to develop solutions for water storage that do not disrupt the hydrological regime. The research methodology is based on the analysis of hydrological data and engineering modeling of gravity-fed flow regulation systems using algorithms from the QGIS geographic information system. The first proposed option involves modernizing channel ponds by separating the river channel from the pond basin using a retaining dam and creating a bypass channel. An open regulator is installed at the headwaters, allowing the pond to fill during periods of high water without interrupting the transit flow at all. To improve water quality, the hydraulic structure incorporates a rock-filled connecting structure that ensures intensive aeration and self-purification of the flow. The second option involves creating autonomous floodplain complexes with artificial basins. This technology allows not only for the accumulation of floodwater but also for its active discharge back into the river channel during dry periods to maintain ecological flow. A comparative analysis confirms that the river channel option is optimal for restoring flow in already regulated rivers, while floodplain reservoirs are effective for sustainable water supply without interfering with the river channel. The practical implementation of the proposed solutions was tested at a site in the Lower Tersa River basin (catchment area of 85,1 km²). Simulation results confirmed the system's operational effectiveness: at a normal water table (NWT) of 108,0–108,5 m BS and during a 1 % return period design flood (water level of 109,50 m in Baltic Normal Height System (BS), 560 thous.m³ of water while fully preserving the ecological flow in the bypass channel. The implementation of such complexes enables the principles of the EU Water Framework Directive regarding river revitalization to be realized, ensuring a “living flow” even in low-water years and creating conditions for the restoration of biodiversity in steppe ecosystems amid post-war recovery and rapid climate change.*

Keywords: *hydraulic structure; water body; river; water engineering; water technologies; hydrological regime; environmental safety*

Introduction. Small rivers in the steppe zone of Ukraine are the most vulnerable link in the hydrographic network, being the first to respond to anthropogenic pressure and climate change [1, 2]. Currently, there is a persistent trend toward their shallowing, intensive siltation, and complete loss of flow during the low-water period. One of the key factors contributing to the degradation of these waterways is the excessive and often irrational regulation of their channels by ponds

and reservoirs [3, 4]. This leads to the cessation of natural self-purification processes, a deterioration in water quality, and the transformation of rivers into a cascade of ecologically unstable, stagnant bodies of water [5, 6]. For the most part, such water bodies lack hydraulic connectivity with one another for a significant portion of the year.

An analysis of trends in hydraulic engineering construction reveals the critical scale of this problem, particularly in the arid southeastern

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regions of the country. Using the Dnipropetrovsk Oblast as an example, it has been established that over the past 30–40 years, the number of ponds has increased 2,7-fold—from 1,239 to 3,292 [4]. Currently, the total capacity of the region's artificial reservoirs exceeds 1 billion m³, while local runoff does not exceed 0,825 billion m³. This ratio poses a direct threat to environmental safety and significantly worsens water use conditions.

Analysis of recent studies and publications. Traditional engineering approaches based on the construction of transverse dams have a significant drawback: they halt the flow after the end of the hydrological period of high water levels, which stimulates wetland formation and negatively affects the ecological condition of water bodies [7]. Due to this situation, a movement to dismantle barriers (hydraulic structures) on rivers is gaining momentum

worldwide, and particularly in Europe. As of 2025 (<https://damremoval.eu/>), more than 9,000 barriers (weirs, dams, locks, and obsolete rapids) have been dismantled in Europe. Most of the removed structures (over 65%) are small hydraulic engineering structures several meters high (Fig. 1). These are precisely the types of structures most commonly found on the small rivers of the Ukrainian Steppe, which lead to siltation and the cessation of their flow. According to the EU Biodiversity Recovery Strategy, the restoration of at least 25,000 km of free-flowing rivers is planned by 2030 [8]. It is worth noting that as part of the implementation of the Association Agreement with the EU and the provisions of the Water Framework Directive 2000/60/EC, Ukraine has committed to achieving “good ecological status” for its water bodies, which underscores the urgency of addressing the aforementioned problem.

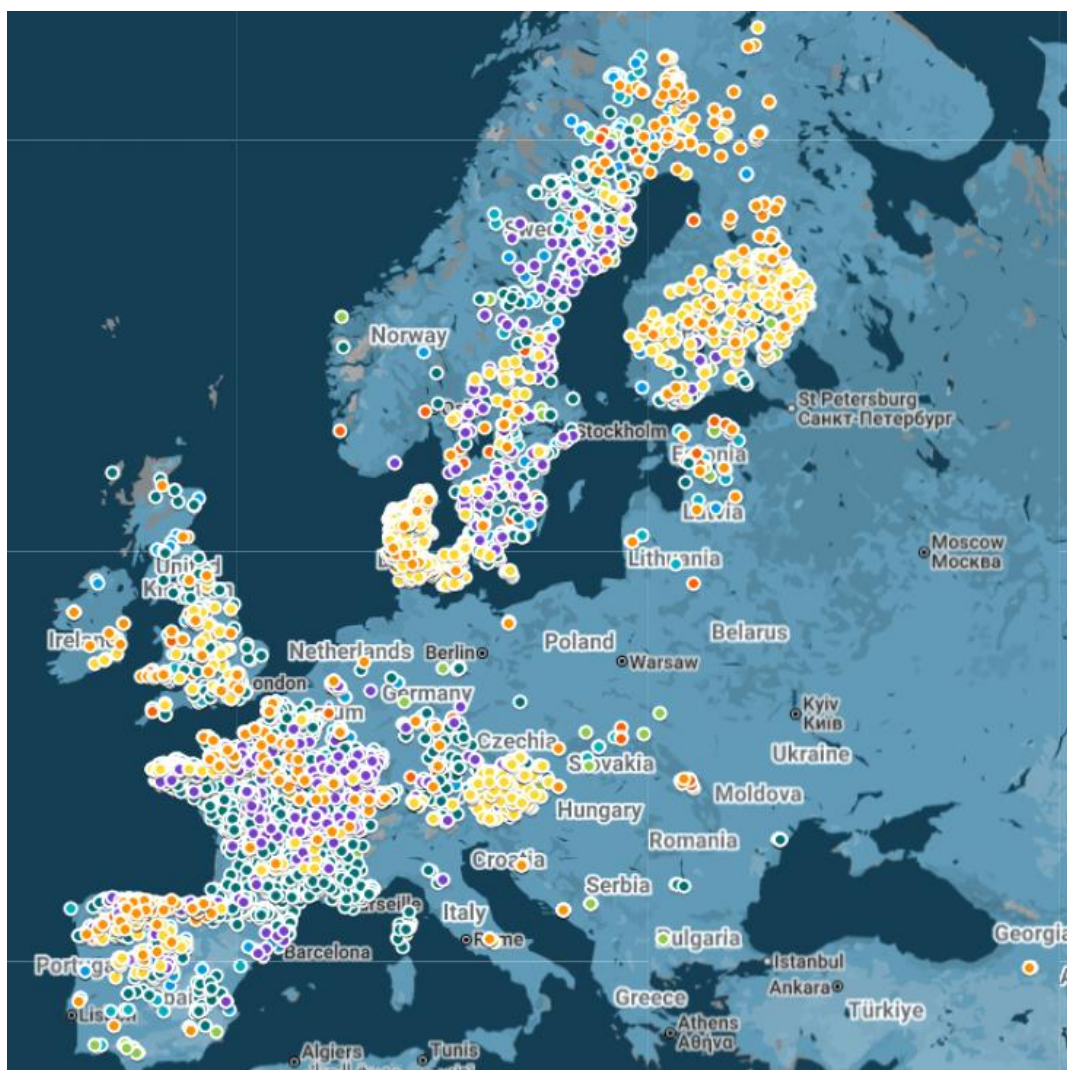


Fig. 1. Interactive map of dam (barrier) removal on European rivers (source: <https://damremoval.eu/>)

On the other hand, the situation has significantly worsened as a result of full-scale military aggression, due to which Ukraine has lost about one-third of its available (engineered) water reserves [9, 10]. Widespread destruction of hydraulic infrastructure—in particular, the catastrophic destruction of the Kakhovka Reservoir—has led to the destabilization of water supply and irrigation systems across a significant portion of the country's southeastern regions [11]. Under these conditions, further economic development and the full-scale recovery of the agricultural sector are impossible without a fundamental overhaul of the water resources management strategy [12, 13]. Addressing the issue of water scarcity requires the implementation of effective methods for accumulating and conserving runoff in volumes sufficient to sustain regional livelihoods, but without repeating past mistakes associated with the excessive regulation of river channels.

In this regard, there is an urgent need for non-standard solutions—the development of simple and effective methods for managing the hydrological regime [14]—that would simultaneously allow for water storage and ensure the ecological protection of small rivers by maintaining their natural flow [15, 16]. In our opinion, the solution to this challenging problem lies in the implementation of innovative complexes of hydraulic structures in river floodplains, which allow for the rational use of floodwater resources without causing destructive impacts on the river ecosystem.

It is worth noting that the works of leading Ukrainian scientists (S.O. Afanasyev, V.I. Vyshnevsky, I.V. Voitovich, I.V. Gopchak, E.D. Gopchenko, V.V. Hrebin, N.S. Loboda, V.B. Mokin, V.I. Osadchiy, V.I. Pichura, V.M. Popov, A.M. Rokochnytskyi, M.I. Romashchenko, S.I. Snizhko, V.M. Starodubtsev, V.A. Stashuk, A.M. Shevchenko, V.K. Khilchevskyi, A.V. Yatsyk, M.V. Yatsyuk and many others).

Research Methods. The research methodology is based on a comprehensive approach that combines an analysis of modern foreign and domestic innovative solutions for managing the hydrological regime of watercourses [17, 18], statistical data, known hydrological design characteristics of river ecosystems in the steppe zone of Ukraine, and methods of engineering modeling of hydraulic structures.

The hydrographic network of small rivers in the steppe zone of Ukraine was chosen as the object of study and the basis for theoretical generalization and typification [3, 19, 20]. The analysis was based on data on the dynamics of

pond and reservoir construction over the past 50 years, as well as a comparison of the volumes of accumulated water with local runoff volumes.

To substantiate the general parameters of hydraulic structures and their operational technologies, evaluation and comparison methods were applied, in particular, well-known data on water inflow during flood periods and the spring flood season. Prospects for incorporating new technologies and methods of managing hydraulic structures took into account current and projected climate changes, as well as the actual state of river channel regulation and the level of technical operation of existing water management structures.

The methodology for developing technical solutions included the development and justification of two options [21, 22]:

1) for channel ponds—simulation of the physical separation of the channel using embankments to ensure a free-flowing (unobstructed) current.

2) for floodplain complexes—justification of the standardization of artificial excavation parameters (depth and volume) in accordance with water consumption needs and local hydrological and hydrogeological conditions.

A comparative analysis of the overall effectiveness of the proposed solutions was evaluated by comparing the technical and technological parameters of the various options.

The methodology for managing the hydrological regime is based on the principles of gravity-fed flow regulation. It involves establishing algorithms (protocols) for the operation of control structures (opening/closing of gates) depending on the phase of the river's hydrological regime; the use of artificial aeration via rock-fill connecting structures to enhance the water's self-purification capacity; modeling the processes of reverse discharge of water from reservoirs into the river channel during the low-flow period to maintain ecological flow. To implement the proposed approach at a real-world study site, we used standard methods for calculating maximum discharge (peak discharge rate) for rain-induced floods and snowmelt.

In the absence of direct hydrometric observations of maximum storm runoff in the Steppe Zone of Ukraine, the most reasonable approach is to apply the calculation models proposed by P. F. Vyshnevsky [23]. Specifically, for a storm flood:

$$Q_p = 1.67 \cdot h_m \cdot F \cdot \varphi \cdot n \cdot r \cdot r_1 \cdot \lambda, \quad (1)$$

where Q_p is the maximum instantaneous discharge (m^3/s) with a probability of exceedance of $P\%$;

1,67 is the measurement factor; h_m – maximum storm runoff yield with a 1% probability of exceedance, determined from a map and equal to 5,5 mm/10 min for the center of the watershed; φ – the reduction factor for maximum storm runoff, which depends on the slope run-off time and is determined as $\varphi = (2.26)/(1+6,3n_1)$ when $n < 1$; $-\varphi = 0,626/(1+1,02n_1)$ when $n > 1$; F – the catchment area of the river basin upstream of the design cross-section, km²; n – a coefficient accounting for the influence of forests and wetlands on runoff from the basin, which is slightly less than 1; r – a coefficient accounting for the retention of runoff by pond and reservoir systems; in the calculation, the areas of all ponds and the depth of the regulating reservoir were determined; r_1 – a coefficient for natural regulation of discharge by wetland floodplains, depending on the floodplain's shape, type of wetland coverage (proportion), and wetland areas; λ – a transition coefficient from a 1% probability of exceeding maximum water discharge to the design discharge.

The following formula was used to estimate the parameters of the maximum snowmelt runoff:

$$Q_p = 0,28 \cdot \alpha_m \cdot \varphi \cdot F \cdot \rho \cdot r \cdot \lambda, \quad (2)$$

where Q_p is the maximum instantaneous discharge (m³/s) with a probability of exceedance of $P\%$; α_m is the maximum intensity of meltwater runoff (mm/hour). In this study, a 1% confidence level (probability of exceedance) is adopted based on reference data, and for the design watershed, it equals 4,3 mm/hour; φ is the reduction factor for the maximum discharge modulus, which is determined separately for each designated cross-section; F – the area of the watershed upstream of the design section, km²; ρ – a coefficient that modifies runoff discharge from the basin due to the influence of forest cover and wetland areas; r – a coefficient accounting for the influence of the reservoir system; λ – a transition coefficient from a 1% probability of exceeding maximum discharge to another probability; 0,28 – a measurement coefficient.

The determination of minimum runoff characteristics [q , L/(sec·km²)] was based on the methodological approach proposed by V.K. Khilchevsky [24]. Data on regional average monthly runoff modules were used for the calculations. The lowest value of the runoff module with a 75% probability of occurrence was adopted as a representative indicator of the minimum 30-day water discharge.

The QGIS toolkit was used for the morphometric analysis and spatial modeling of the Nizhnya Tersa River watershed.

A 3D terrain model was created based on USGS digital elevation models (DEMs) through geospatial processing (constructing continuous surfaces by interpolation). Using terrain analysis algorithms, a hydrological correction of the DTM was performed, which made it possible to accurately determine the boundaries of the catchment area of the studied pond, calculate the water surface areas at various water levels, and derive the topographic characteristics of the pond basin $W = f(H)$.

Research Results. During the study, two promising technical solutions were developed and analyzed, aimed at restoring the hydrological regime of small rivers in the steppe zone of Ukraine. Both options are based on the principle of rational use of runoff during the flood season; however, they differ in their engineering design and functional purpose, which allows the water infrastructure to be adapted to modern operating conditions.

Option 1) A method for constructing a complex of hydraulic structures based on existing channel ponds. This option involves transforming the existing hydraulic complex by introducing a set of structures that separate the functions of water storage and ensuring a continuous river flow. The main idea is to physically separate the river channel from the reservoir's regulating capacity. The technical details of the construction are as follows (Fig. 2). Along one of the reservoir's banks, a coffer dam is built using local soil materials, forming a bypass channel (the river channel). This structure bounds the channel on one side, while the natural shoreline serves as the other barrier. The embankment is designed such that its crest elevation prevents any interaction (overflow) between the regulating reservoir and the river channel during all phases of the river's flow regime. An open control gate is installed at the head of the reservoir (upstream). The reservoir's filling regime is controlled either manually or automatically—by installing a simple automated system to monitor water levels upstream and downstream of the regulating structure. This ensures unimpeded flow of domestic water through the river channel. The construction of additional structures (regulatory, control, connecting, and spillway structures) as part of the hydraulic complex and the achievement of the specified hydrological regime of the river are carried out under conditions of gravity-fed flow regulation, taking into account the river's current water availability. To increase the efficiency of water intake during reservoir filling, a backwater structure—a stone weir combined with a flow-directing intake spur—is constructed next to the

regulator. This allows water to be directed into the reservoir even at low water levels. Once the reservoir is filled to the normal backwater level (NBL) or to the lowest hydrologically feasible level, the regulator gate is closed, and all domestic wastewater is diverted through a bypass channel. An additional water discharge structure is installed in the existing dam to allow water to flow into the lower reach. It is constructed as a rock-fill connecting water-passage structure (a rapid with artificial roughness or a drop). This solution ensures intensive aeration of the flow, which is a key factor in enhancing the river's self-purification capacity. The spillway, which is typically part of the hydropower complex, will perform its function during years of high water levels. This technology allows the reservoir to be used as a regulating capacity without interrupting the river's transit flow, thereby minimizing environmental risks.

Option 2) Technology for creating autonomous floodplain complexes with artificial basins. The second technological option involves creating new storage basins in the river floodplain at a certain distance from its natural channel (Fig. 3). This solution is most effective for flat terrain, where it is necessary to ensure a guaranteed water supply for agriculture without blocking the river channel. The key components of this complex of hydraulic structures are constructed in the following sequence. First, during the low-water period, an excavation pit for an artificial reservoir is formed in the floodplain of a small river. Its

depth and volume are calculated based on water consumption needs, local hydrogeological conditions, and the river's guaranteed water flow or the characteristics of its hydrological regime.

To prevent water loss, the bottom and walls of the excavation on the river side are lined with protective screens made of clayey rock. The connection to the river is established via a special channel equipped with a control structure at its mouth. The technology provides not only for water intake during floods (passive accumulation) but also for the active discharge of water from the excavation back into the river channel during dry periods via a water outlet. This allows for the artificial regulation of the river's flow, prevents it from drying up, and maintains an ecologically safe natural state (discharge) of its floodplain during the dry season. Under these technical and technological conditions for the construction of the water management system complex, the method of managing the hydrological regime of small rivers is carried out in such a way that during a flood, water from the river flows through a control structure located at the mouth of the intake channel into the excavation pit and into the artificial reservoir. In this case, the regulator's shut-off device remains open until the pit is filled or until a hydrologically justified level is reached under the conditions of a specific high-water phase. When the water level in the river channel drops, the regulator's shut-off device is closed to prevent reverse outflow of water from the pit. During the dry season, when the river

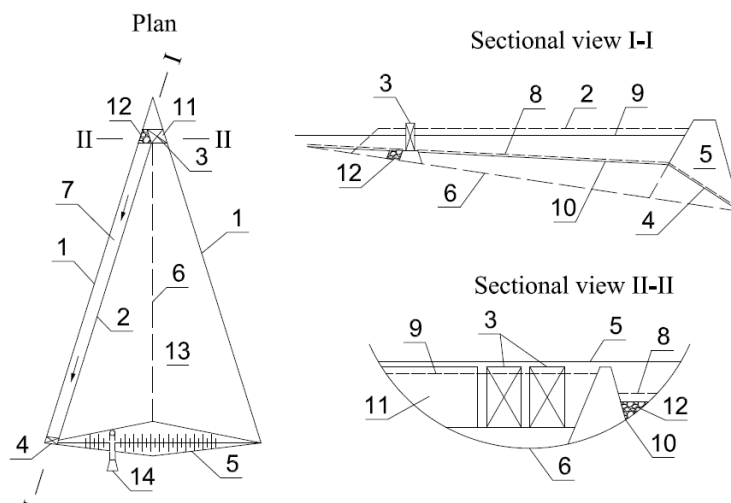


Fig. 2. Schematic diagram of the construction of hydraulic structures on existing channel ponds [21]:

- 1 – pond shoreline; 2 – embankment; 3 – open regulator; 4 – water passage structure; 5 – existing weir; 6 – pool thalweg; 7 – bypass channel; 8 – low-water level of the watercourse; 9 – normal backwater level of the pool; 10 – bottom of the bypass channel; 11 – flow-directing (water-intake) spur; 12 – retaining structure-rap; 13 – pond; 14 – spillway

water level drops below its minimum value, water is discharged from the artificial reservoir back into the river channel by opening the control structure's shut-off device and/or the spillway to prevent the river from drying up. Thus, managing the volumes and timing of river water intake and discharge using a complex of hydraulic structures

ensures flow regulation and the achievement of a predetermined, ecologically safe hydrological regime for small rivers.

Based on the presented results of the technological methods for constructing hydraulic structures, a comparative analysis of these methods has been compiled (Table 1).

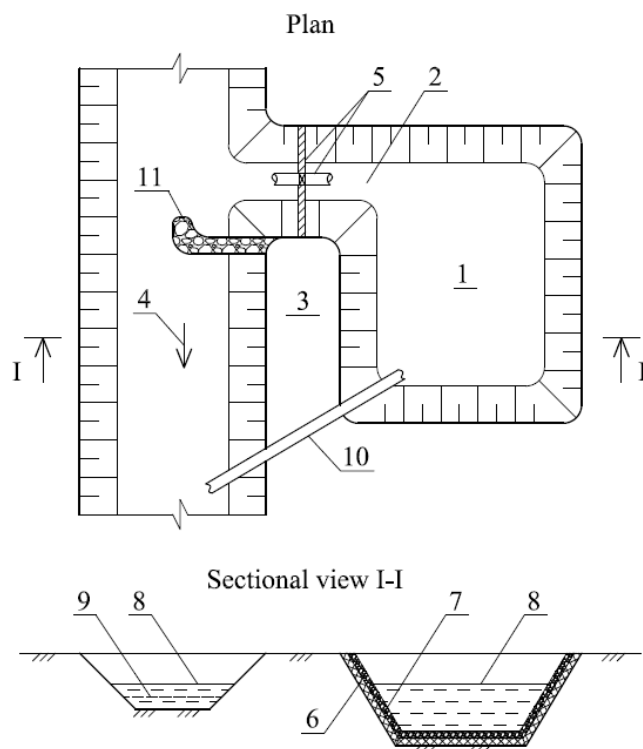


Fig. 3. Schematic diagram of the creation of autonomous floodplain complexes with artificial basins [22]:

1 – basin for an artificial reservoir; 2 – intake channel; 3 – embankment; 4 – river channel; 5 – control structure; 6 – anti-filtration screen; 7 – protective layer of bedrock; 8 – maximum and 9 – minimum water levels in the river; 10 – water outlet; 11 – water intake spur to increase the water intake coefficient

1. Comparative characteristics of the proposed technical solutions

Comparison parameter	Option 1: channel pond	Option 2: floodplain reservoir
Main objective	✓ Restoration of a natural river flow within the pond basin with the ability to store runoff	✓ Accumulation of runoff and replenishment during the low-flow period
Key technological element	✓ Bypass channel and distribution regulator	✓ Excavation with an anti-filtration screen
Environmental impact	✓ Aeration and self-purification of the flow, restoration of free flow	✓ Prevention of riverbed drying
Advantages	<ul style="list-style-type: none"> ✓ Ensures continuous transit of water and sediment through the riverbed; ✓ Improves oxygen levels (aeration); ✓ Does not require the acquisition of new land parcels 	<ul style="list-style-type: none"> ✓ Minimal impact on the natural river channel; ✓ Eliminates the risk of silting in the main channel during floods; ✓ Allows for precise control of water discharge during low-water periods.
Disadvantages/Risks	<ul style="list-style-type: none"> ✓ Technical complexity of constructing a spillway dam within an existing reservoir; ✓ The need for constant monitoring of the technical condition of the bypass channel; 	<ul style="list-style-type: none"> ✓ Significant earthwork is required to excavate the foundation pit; ✓ Risk of localized flooding if the integrity of the screen is compromised.

The presented and substantiated technological methods for managing the hydrological regime of small rivers allow us to move from theoretical analysis to practical modeling of the operation of hydraulic structures. To verify the proposed technical solutions and assess their effectiveness under real-world conditions in the Steppe Zone, a typical site was selected—a channel pond (Fig. 4)—located in the basin of the Nyzhnia Tersa River (Dnipropetrovskiy region). This site was chosen for its representativeness: the morphometric characteristics of the watershed and the degree of anthropogenic transformation of the river channel correspond to general regional trends. Based on a digital elevation model (DEM) created using the QGIS GIS toolkit, a detailed alignment of the calculated water levels with the actual topographic base was performed, which made it possible to substantiate the design parameters of the innovative hydraulic structure.

To determine the hydrological parameters of maximum discharge at the actual study site, calculations were performed for storm floods and spring floods (Equations 1 and 2; Table 2).

Based on the results of these calculations, it was determined that for the studied watershed, the zoned value of the minimum runoff coefficient is $0,07 \text{ L}/(\text{sec}\cdot\text{km}^2)$. Accordingly, the calculated minimum (30-day) water discharge with a 75% probability of occurrence is $660 \text{ L}/\text{sec}$. The obtained results correlate with regional patterns of runoff formation within the selected physiographic zone.

To perform further water management calculations and justify the design parameters of hydraulic structures at this site, a spatial analysis and modeling algorithm was used in the QGIS environment. A 3D model (Fig. 5) was created, and the topographic characteristics (Fig. 6) of the pond's floodplain were determined.

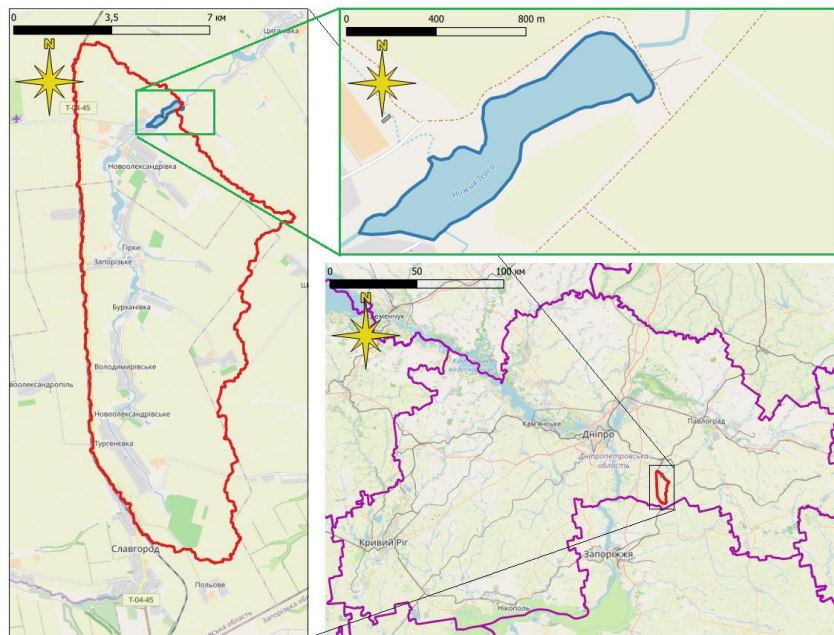


Fig. 4. Study site for substantiating the proposed engineering solutions (ponds near the village of Novooleksandrivka on the Nyzhnia Tersa River, Dnipropetrovsk Oblast)

2. Calculations of maximum discharge during spring floods and rain-induced floods on the Nyzhnia Tersa River at the pond site near the village of Novooleksandrivka

Site characteristics: Nyzhnia Tersa River; cross-section of the studied reservoir, $F_{\text{bas}} = 85,1 \text{ km}^2$		Confidence level P, %					
		0.5	1	2	5	10	25
Spring Flood							
Maximum instantaneous flow rate	m^3/s	35	31	26	21	17	11
Maximum average daily flow rate	m^3/s	19	17	15	12	9	6
Flood discharge volume	million m^3	7,8	6,9	6,1	5,0	4,1	3,0
Rain-induced flooding							
Maximum flow rate	m^3/s	40	33	27	17	12	4
Flood discharge volume	million m^3	3,4	2,9	2,4	1,7	1,1	0,6

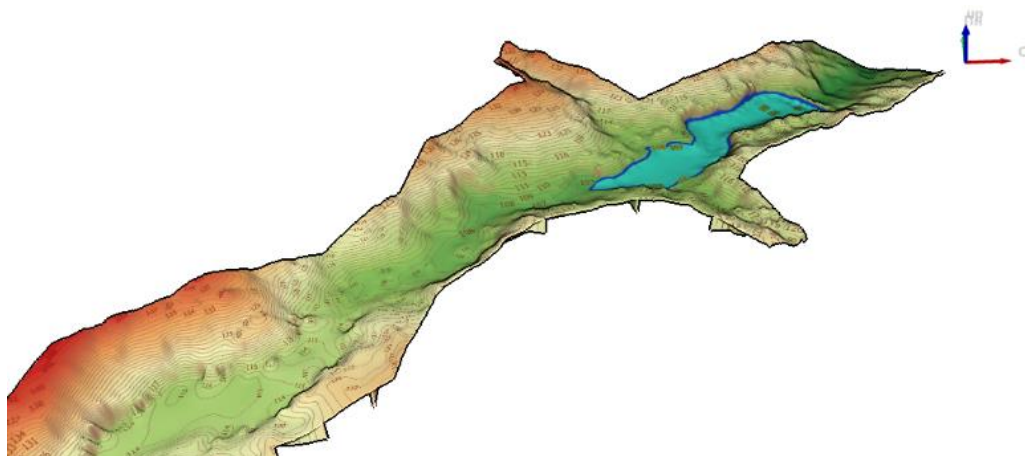


Fig. 5. 3D model of a section of the pond's floodplain in the upper reach

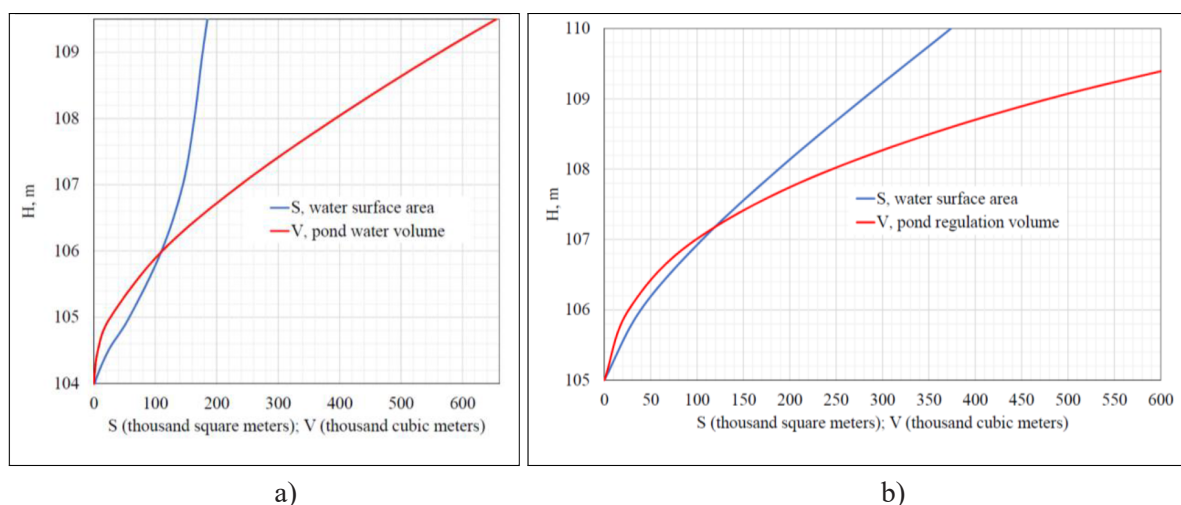


Fig. 6. Topographic characteristics: a) the pond, b) the regulating capacity of the upper reach

As can be seen in Figure 6, the curve representing the pond area shows a marked upward trend. This is explained by the erosion of the banks by water at levels close to the normal (NPG) and forced (FPG) water tables, as confirmed by the topography. At the same time, in the upper reach—which is almost always a marshy area with dense vegetation and shallow depths—such erosion was simply impossible, so the curve showing changes in area exhibits a classic pattern.

An example of implementing this approach to river water regime management and the construction of hydraulic structures based on the first design option is shown in Figures 7 and 8. It is worth noting that the dimensions of the regulator and the weir can be varied to achieve an optimal hydrological regime for the watercourse, based on hydrological calculations and specific management objectives.

The next step in justifying the operating parameters of the hydraulic structures is to

perform hydraulic calculations for the water-passage structures. Such a flow balance calculation was performed for floods with 1%, 10%, and 25% return periods (Figures 9, 10, and 11, respectively) and to determine the conditions for filling the reservoir's useful capacity.

The initial conditions for the calculation are as follows: the minimum water level in the upper reach is close to the domestic water level during the inter-flood period and is 106 m BS. This level is taken as the bottom of the weir channel. The water level in the lower reach of the reservoir is close to the dead storage level (DSL) and is 105,0 m BS.

It should be noted that the presence of a spillway ensures the simultaneous discharge of excess water; therefore, the FPG will be slightly lower than the value calculated in the balance calculation and will subsequently drop to the NPG level. The symbols used in Figures 9–11 share the following characteristics: Q% – hydrograph

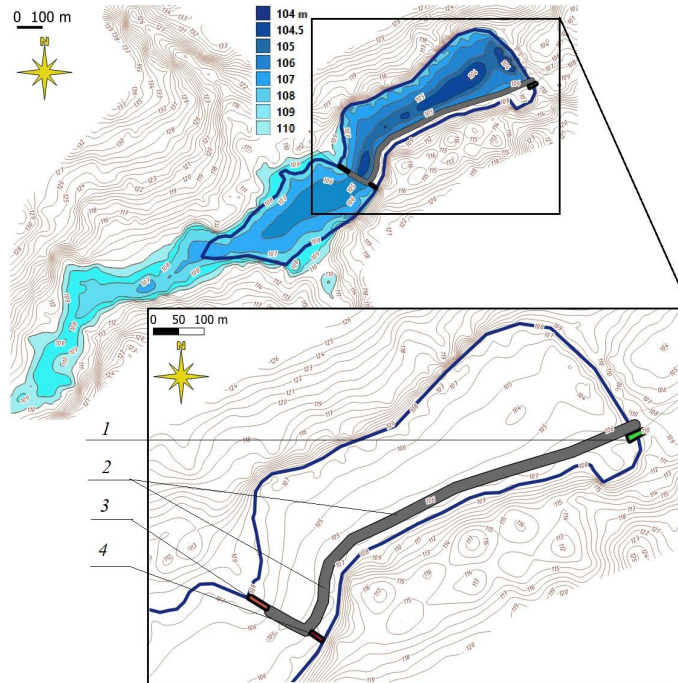


Fig. 7. Determination of topographic characteristics (water surface area) in QGIS using a 3D digital elevation model and an example of the practical implementation of a technical approach to the construction of hydraulic structures for river water regime management:

- 1 – connecting (water-passing) structure; 2 – embankment dam; 3 – regulator (open regulator);
4 – channel weir

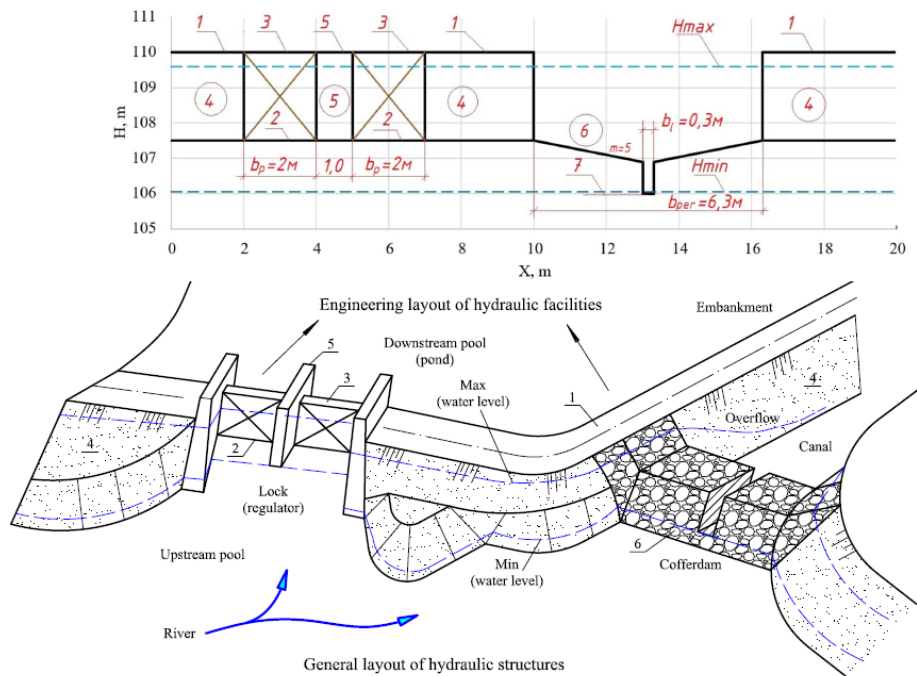


Fig. 8. General view of the hydraulic structures at a channel-type reservoir for managing the river's hydrological regime:

- 1 – crest of the spillway dam; 2 – weir of the regulating intake; 3 – upper edge of the flat gate;
4 – embankment; 5 – regulator weir; 6 – channel cross-connection; $H_{\max(\min)}$ – water level limits in the upper reach (H_{\min} corresponds to the passage of the minimum flow through the cross-connection channel; H_{\max} corresponds to the discharge of the 1% flood flow, thereby determining the structural dimensions of the complex of structures)

of the % probability of occurrence, accounting for flow transformation by the upper reservoirs; Q_{per} – water flow through the spillway; Q_{st} – flow rate for filling the reservoir through the control gate; T_{close} – gate closure time (optimal condition: equalization of levels in the reservoir and the upper reach; in practice, for any probability of occurrence, this corresponds to the period when the hydrograph

begins to decline); T_{open} – start of reservoir filling; dH – difference in levels between the flood control basin and the reservoir; H_{flood} – the level regime in the flood basin during a flood of a given probability – determined under conditions of hydraulic equilibrium, i.e., the continuity equation ($Q_{inlet(flood)} = Q_{outlet(overflow\ through\ the\ control\ structure\ and\ spillway)}$); $H_{reservoir}$ – the reservoir filling regime.

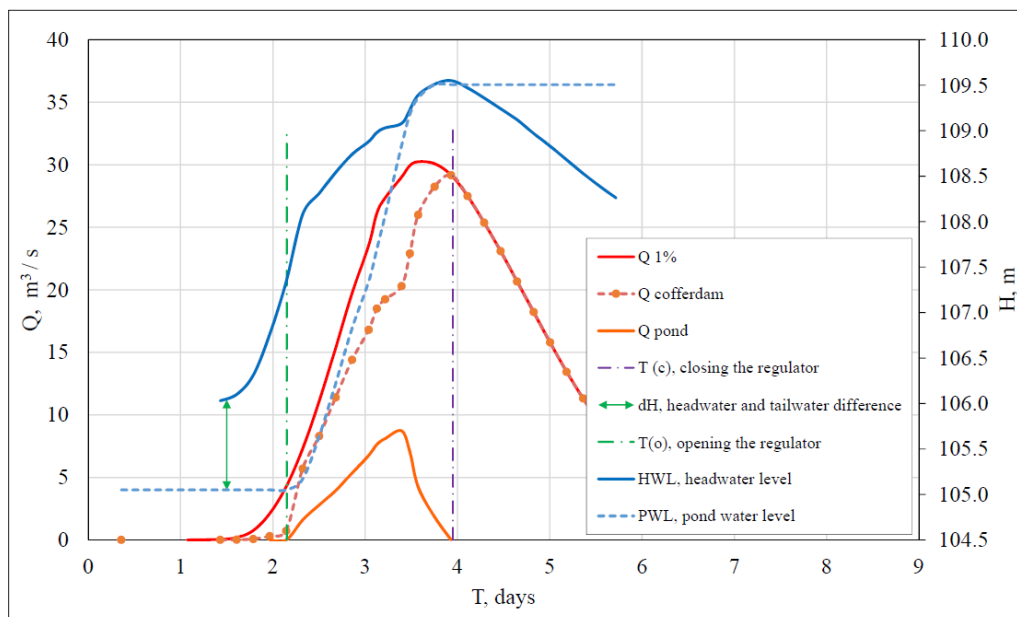


Fig. 9. Balance calculation for the discharge of a 1% probability flood and the filling of the reservoir's usable capacity

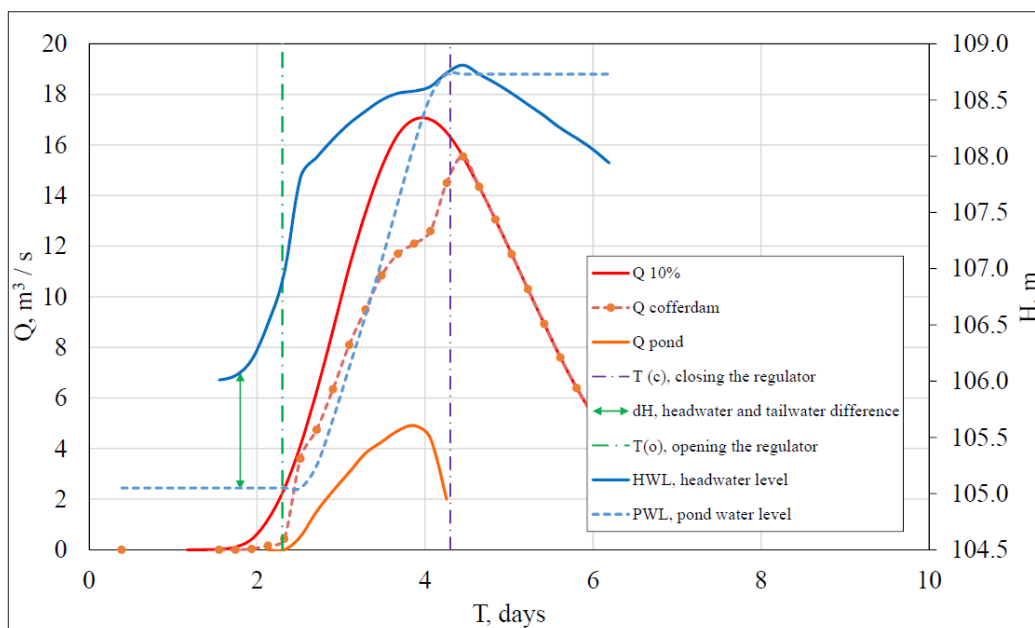


Fig. 10. Balance calculation for flood discharge with a 10% probability and filling of the reservoir's usable capacity

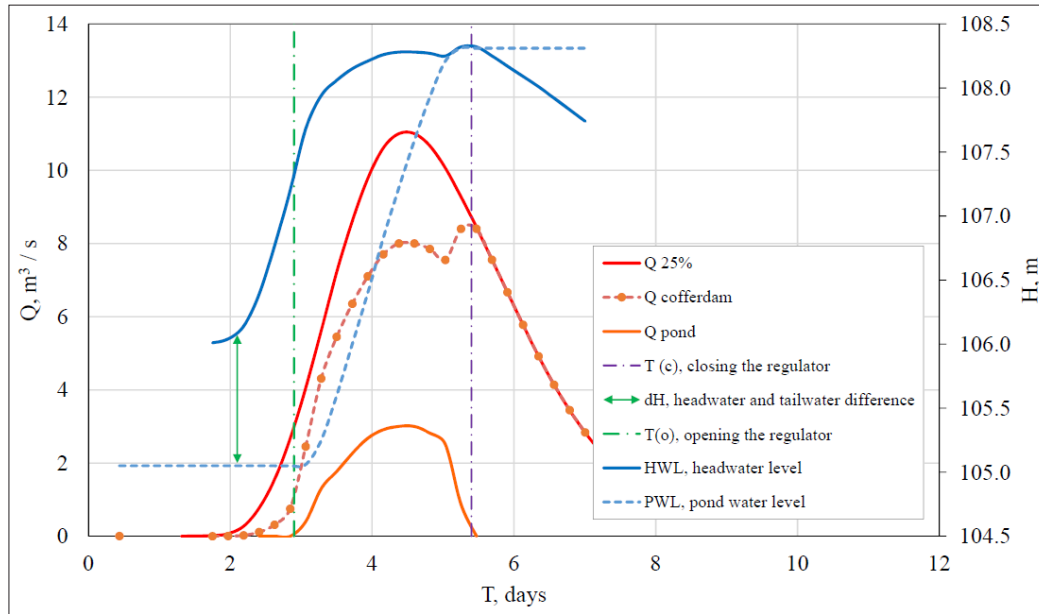


Fig. 11. Balance calculation for flood discharge with a 25% probability and filling of the reservoir's usable capacity

An analysis of the hydraulic operating regime of the hydraulic structure revealed characteristic fluctuations in water discharge at the spillway, which are caused by the regulator operating in a submerged mode. A decrease in the regulator's discharge capacity under such conditions leads to a redistribution of flow toward the spillway. This process is described by the continuity equation for water flow, according to which the total discharge of a 1% probability flood is equal to the sum of the discharges through the spillway: $Q_{1\%} = Q_{\max} + Q_{\text{spillway}}$. It has been established that when critical flooding levels are reached, the main hydraulic head is transferred to the bridge, which must be taken into account when calculating the static stability of the structure.

Based on the hydrological calculations and an analysis of high-water levels in the reservoir basin, it has been determined that the normal water level of the reservoir under study, assuming the presence of a spillway, is estimated at 108,0–108,5 m (in Baltic Normal Height System). At the same time, the minimum elevations of the dam crest are recorded at 110.0 m, which ensures the necessary safety margin. During a 1% probability design flood, the maximum possible water level in the reservoir reaches 109,50 m. According to the constructed storage capacity curve, at an elevation of 109,0 m, the reservoir's storage volume is approximately 560 thousand m^3 . Analysis of the data indicates that floods with a probability of occurrence of

40–50% or higher ensure stable filling of the reservoir basin to the design water level.

Environmental and economic assessment of the proposed solutions. The practical implementation of the proposed innovative technology for managing the hydrological regime of a water body involves a number of engineering, hydrotechnical, and financial and economic challenges. For channel ponds in the steppe zone of Ukraine with an area of 10–50 hectares, the scale of such work is significant, since the length of the distribution embankment, depending on the geometry of the reservoir basin, can range from 500 to 1,000 meters. Depending on hydrological conditions, the thickness of bottom sediments, the availability of specialized equipment, and environmental requirements for the conservation of biota, we have identified and analyzed two main technical options for constructing the distribution dam. For the conditions of the site under study, a comparative analysis of the technical, economic, and environmental indicators of both options was conducted (Table 3).

The comparative analysis presented in Table 3 illustrates the dilemma between technological simplicity and environmental responsibility. International practices are clearly focused on minimizing environmental risks. As a result, Option 1 (with dewatering) is considered economically unfeasible in developed countries due to the enormous associated costs and environmental compensation requirements.

3. Comparative analysis of technical and economic options for constructing a partition dam for a pond with an area of 10–50 hectares

Indicator / Evaluation criterion	Option 1 (full or partial draining)	Option 2 (without draining the reservoir)
Work Procedure	This approach involves draining water through the existing spillway during the summer-fall low-water period. After the pond bed has been drained (or temporary drainage channels have been constructed to dewater the construction site), the dam is built using traditional mechanized methods with bulldozers and excavators, with layer-by-layer soil compaction.	The work is carried out directly in the aquatic environment. To prevent the displacement of weak silty soils in the foundation and the erosion of the dam body, modern geosynthetic materials are to be used; these are laid on the bottom before backfilling with rock or sandy-clay soil. In global lake restoration practice [25, 26], the most effective variation of this method involves the use of geotextile tubes, which are filled with bottom sediment using dredgers.
Capital expenditures for earthworks	Base (100%)	Increased (125–150%) due to geomaterials and soil loss in water
Need for special materials	Minimal (local soil)	High (geotextiles, geogrids, crushed stone)
Project Duration	Long (depend on the rate of bed drying)	Short (not dependent on the water level in the reservoir)
Environmental damage and penalties	High (loss of water resources, riverbed desiccation, destruction of the biocenosis)	Minimal (local impact in the backfill area)
Economic losses to the water user	Significant (loss of water management functions and fish productivity for 1–2 seasons)	None or minimal (the pond remains fully operational)
Environmental impact assessment procedure and environmental approvals	Complex and time-consuming	Simplified (equivalent to revitalization measures)
Advantages	High-quality compaction of the dam body, minimal material loss due to scouring, ability to precisely profile the transit channel “on dry land”	Preservation of the water volume and ecological balance of the reservoir during construction; no need to drain the water; simplified environmental compliance procedure.
Disadvantages	Temporary suspension of the pond’s operation leads to significant environmental damage (death of aquaculture, ecosystem degradation) and a loss of revenue for water users for at least 1–2 seasons. In domestic practice, the direct cost of earthworks using this method is considered the baseline. However, when evaluating similar projects in the EU and the U.S. (https://ascelibrary.org/), this method is regarded as the most expensive. The direct cost of excavating and compacting soil “dry” abroad is approximately \$20–45 per m ² , while associated compensation payments for the destruction of wetlands can reach \$25,000–100,000 per hectare of drained land. Furthermore, obtaining permits to completely drain large water bodies (50 hectares or more) in Western practice takes years and costs between \$20,000 and \$100,000. Thus, the total estimated cost of implementing Option 1 for a 1,000-meter-long dam, based on European prices, may exceed \$1,0–1,5 million.	The technology requires increased soil consumption (by 20–30% due to silt absorption and initial underwater erosion) and the use of specialized materials. Heavy woven geotextiles cost between \$5 and \$50 per m ² on the global market, depending on their strength. The average cost of constructing underwater barriers and dams using geotextile tubes is \$600–750 per meter. Thus, the total estimated cost of constructing a 1,000-meter dam without draining the water, based on global benchmarks, is approximately \$600,000–850,000. Despite the higher direct material costs, this option offsets, to some extent, environmental fines and losses resulting from the cessation of the reservoir’s operation.

At the same time, given current domestic realities, the most technologically feasible and engineering-wise approach remains the “dry” embankment construction—provided the reservoir is completely drained or during its summer-autumn low-water period (Option 1). This is due to the availability of traditional equipment and the lack of a need for expensive imported geosynthetic materials.

The situation is complicated by institutional factors. Under current conditions, which are burdened by a deep economic crisis, the consequences of military operations, and the inadequacy of domestic environmental legislation, the actual completion of environmental impact assessment (EIA) and strategic environmental assessment (SEA) procedures for projects of this scale is quite complex and atypical for Ukrainian practice. Due to excessive bureaucracy or, conversely, a purely formal approach to oversight, these tools often fail to fulfill their regulatory function. In light of this, in our opinion, under current development conditions, the likelihood of the first option being implemented—albeit without a proper and comprehensive environmental review—is the highest.

Thus, a comprehensive analysis shows that although, from the perspective of balanced natural resource use and European experience in water resource management, Option 2 (or a combined method involving a partial reduction in water level by 30–40%) is significantly safer, the actual economic and geopolitical context in Ukraine forces water users to choose simpler, albeit more environmentally destructive, engineering solutions.

Conclusions:

1. It has been proven that the critical degradation of small rivers in the Ukrainian Steppe is caused by a disruption of the hydrological integrity of watercourses due to the cascade regulation of their channels. It has been established that the existing model of reservoir operation, where the storage volume exceeds the volume of local runoff, leads to the cessation of “living flow” during the low-water period, which requires the implementation of new technological schemes for runoff management [27].

2. The use of GIS tools (QGIS) and the analysis of digital elevation models have improved the accuracy of morphometric calculations for watersheds. The reservoir capacity curves constructed using GIS algorithms served as the

basis for accurately predicting flood discharge transformation, which is an essential step in designing innovative hydraulic structures under complex physical and geographical conditions.

3. It has been scientifically demonstrated that separating the river channel from the reservoir’s storage capacity using a bypass channel and control structures (the authors’ Ukrainian utility model patents No. 154298 and No. 156105) is a promising and effective method for river revitalization. The proposed technology for equipping existing ponds with bypass channels and distribution regulators allows for the separation of water storage and flow transit functions. This ensures a continuous river flow throughout the year, activates self-purification processes through aeration on rocky rapids, and promotes the restoration of the watercourse’s ecosystem functions. The creation of artificial basins in floodplains with protective anti-filtration screens is an effective method for ensuring a reliable water supply without blocking the river channel. Such a system allows not only for the accumulation of water during floods but also for the replenishment of the river during dry periods of the year.

4. Calculations and modeling of the implementation of the proposed approaches at a real-world site in the Lower Terna River basin confirmed the feasibility of these solutions. It has been established that at a normal water level of 108,0–108,5 m BS and during a 1% probability flood (maximum level of 109,50 m BS), the system provides for the accumulation of 560,000 m³ of water. At the same time, a continuous transit flow through the bypass channel is maintained, which eliminates the risk of overflow over the dam (elevation 110,0 m BS) and sustains the hydrological regime of the river downstream. Filling the reservoir basin to the design water level is ensured with a 40–50% probability of flooding and a higher level of reliability.

5. The proposed technologies are consistent with the strategic objectives of the EU Water Framework Directive and can be used as model solutions for the post-war restoration of Ukraine’s hydraulic infrastructure. This will help balance the interests of the agricultural sector and ensure compliance with environmental requirements for the conservation of biodiversity in small rivers amid global climate change.

Conflicts of interest: the authors declare no conflict of interest.

Use of artificial intelligence: the authors confirm that they did not use artificial intelligence technologies during the creation of this work.

References

1. Chushkina, I., Hapich, H., Matukhno, O., Pavlychenko, A., Kovalenko, V., & Sherstiuk, Y. (2024). Loss of small rivers across the steppe: climate change or human activity? A case study of the Chaplynka River. *International Journal of Environmental Studies*, 81 (1), 260–274. <https://doi.org/10.1080/00207233.2024.2314853>
2. Andreev, V. H., Hapich, H. V., & Kovalenko, V. V. (2021). Impact of economic activity on the geoeological transformation of the Zhovtenka River basin (Ukraine). *Journal of Geology, Geography and Geoecology*, 30 (1), 3–12. <https://doi.org/10.15421/112101>
3. Hapich, H., Andrieiev, V., Kovalenko, V., & Makarova, T. (2022). Analysis of the spatial distribution of artificial reservoirs as anthropogenic elements of river fragmentation in the Dnipropetrovsk Region, Ukraine. *Journal of Water and Land Development*, 53 (IVVI), 80–85. <https://doi.org/10.24425/jwld.2022.140783>
4. Khilchevskiy, V., Grebin, V., Zabokrytska, M., Zhovnir, V., Bolbot, H., & Plichko, L., (2020). Hydrographic characteristics of pond distribution in Ukraine–basin and regional features. *Journal of Water and Land Development*, 46, 140–145. <https://doi.org/10.24425/jwld.2020.134206>
5. Khilchevskiy, V.K. (2021). Water resources of Ukraine: Assessment based on the FAO Aquastat database. In: *15th International Conference on Monitoring of Geological Processes and Ecological Condition of the Environment*, European Association of Geoscientists & Engineers (EAGE Publications BV), 1–5. <https://doi.org/10.3997/2214-4609.20215k2005>
6. Osadchy, V.I. (2017). Resources and quality of surface water in Ukraine under conditions of anthropogenic load and climate change. *Visnik National Academy of Sciences of Ukraine*, 8, 29–46. <https://doi.org/10.15407/visn2017.08.029>
7. Schmutz, S., Moog, O. (2018). Dams: Ecological Impacts and Management. In: Schmutz, S., Sendzimir, J. (eds.) *Riverine Ecosystem Management. Aquatic Ecology Series, Springer, Cham.*, 8, https://doi.org/10.1007/978-3-319-73250-3_6
8. Stoffers, T., Vuorinen, K.E.M., & Schroer, S. (2026) A collaborative research agenda for restoring free-flowing rivers. *Commun Earth Environ* 7, 303. <https://doi.org/10.1038/s43247-026-03428-9>
9. Gleick, P., Vyshnevskiy, V., & Shevchuk, S., (2023). Rivers and water systems as weapons and casualties of the Russia-Ukraine War. *Earth's Future*, 11, e2023EF003910. <https://doi.org/10.1029/2023ef003910>
10. Vyshnevskiy, V., Shevchuk, S., Komorin, V., Olynyk, Y., & Gleick, P. (2023). The destruction of the Kakhovka dam and its consequences. *Water International*, 48:5 (5), 631–647. <https://doi.org/10.1080/02508060.2023.2247679>
11. Hapich, H., Novitskiy, R., Onopriienko, D., & Dubov, T. (2024). Water on fire: losses and the post-war future of ecosystem services from Ukraine's water resources. *Regional Environmental Change*, 24 (4). <https://doi.org/10.1007/s10113-024-02320-6>
12. Romashchenko, M., Faybishenko, B., Onopriienko, D., Hapich, H., Novitskiy, R., Dent, D., Saidak, R., Usaty, S., & Roubik, H. (2025). Prospects for restoration of Ukraine's irrigation system. *Water International*, 50 (2), 104–120. <https://doi.org/10.1080/02508060.2025.2472718>
13. Romashchenko, M., Yatsiuk, M., Shatkovskiy, A., Usaty, S., Polishchuk, V., Saidak, R., Kolomiets, S., Usata, L., & Sardak, A. (2025). Current Status and Prospects for the Rehabilitation and Modernization of Land Reclamation Systems in Today's Context. *Land Reclamation and Water Management*, 1, 5–16. <https://doi.org/10.31073/mivg202501-414>
14. Everard, M., 2019, A socio-ecological framework supporting catchment-scale water resource stewardship. *Environmental Science & Policy*, 91, 50–59. <https://doi.org/10.1016/j.envsci.2018.10.017>
15. Romashchenko, M., Shevchenko, A., Shevchuk, S., Shevchenko, I., Kozytsky, O., & Bozhenko, R. (2023). Prospects and problems of using local water resources for irrigation in the basins of small rivers in the forest-steppe of Ukraine. *Land Reclamation and Water Management*, 1, 75–84. <https://doi.org/10.31073/mivg202301-351>
16. Wang, X. Integrative strategies for sustainable agriculture in the face of climate change. *npj Sustain. Agric.*, 3, 66 (2025). <https://doi.org/10.1038/s44264-025-00108-7>

17. Ptak, M., Szyga-Pluta, K., Zhu, S., Osmanaj, L., & Sojka, M. (2023). Effect of Hydraulic Structures on Mitigating Extreme Hydrological Conditions of a Small River in the Temperate Zone (Główna River, Central Europe). *Sustainability*, 15 (21), 15278. <https://doi.org/10.3390/su152115278>
18. Halych, O., Nowak, P., Bilkova, E., & Riabenko, O. (2025). Mitigating Environmental Impacts of Small Hydropower Plants Through Advanced Hydraulic Modeling. *Environmental and Climate Technologies*, 29 (1), 313–322. <https://doi.org/10.2478/rtuct-2025-0022>
19. Hapich, H., Andriev, V., Kovalenko, V., Hrytsan, Yu., & Pavlychenko, A. (2022). Study of the impact of the fragmentation of small riverbeds by artificial water bodies on the quality of water resources. *Naukovyi Visnyk Natsionalnoho Hirnychoho Univer.*, 3, 185–189. <https://doi.org/10.33271/nvngu/2022-3/185>
20. Andriev, V., & Hapich, H. (2020). Impact of pond and reservoir construction on the environmental safety of small river basins in the steppe zone of Ukraine (the case of the Dnipropetrovsk region). *Land Reclamation and Water Management*, 1, 158–166. <https://doi.org/10.31073/mivg202001-228>
21. Kovalenko, V.V., & Hapich, H.V. (2024) Method for constructing a complex of hydraulic structures on channel-type ponds to ensure the flow of small rivers. Utility Model Patent of Ukraine No. 156105. Application No. U202305695, published on May 8, 2024. Bulletin No. 19. <https://sis.nipo.gov.ua/uk/search/detail/1798419/>
22. Andriev V. G., Yakubenko L. V., Hapich H. V., & Kovalenko V. V. (2023) Method for constructing a complex of hydraulic structures in the floodplains of small rivers to manage their hydrological regime. Utility Model Patent of Ukraine No. 154298. Application No. U202302110, published on November 1, 2023. Bulletin No. 44. <https://sis.nipo.gov.ua/uk/search/detail/1769182/>
23. Kaganer, M.S. (Ed.). (1971). Surface Water Resources of the USSR. Ukraine and Moldova. *The Middle and Lower Dnieper Region.*, 6 (2). Hydrometeoizdat, 495 p. <https://www.twirpx.com/file/644871/>
24. Khilchevsky, V.K., Romas, I.M., Romas, M.I., Hrebin, V.V., Shevchuk, I.O., & Churnaryov, O.V. (2007). Hydrological and Hydrochemical Characteristics of Minimum Discharge in the Rivers of the Dnieper Basin. Kyiv: Nika–Center, 184. https://geo.knu.ua/wp-content/uploads/2025/01/hilchevskij_gidrol-gidrohim.-min.stoku-dnipra-2007-1.pdf
25. Härkönen et al. (2025) Innovation in lake restoration: Literature review. Deliverable 1.1, *FutureLakes*. Retrieved from: <https://futurelakes.eu/knowledge-hub/deliverables>
26. Dunalska, J. A. (2025). Lake restoration techniques: A review of methods and future pathways. *Science of The Total Environment*, 979, 179450. <https://doi.org/10.1016/j.scitotenv.2025.179450>
27. Vlasova, O., Savchuk, D., Shevchenko, I., Shevchenko, A., & Kozytskyi, O. (2025). Spatial and temporal changes in the ecological and reclamation status of undrained areas. *Land Reclamation and Water Management*, 1, 17–27. <https://doi.org/10.31073/mivg202501-417>

УДК 627.8:556.53:504.45

ГІДРОТЕХНІЧНІ СПОРУДИ ТА ІННОВАЦІЙНІ ТЕХНОЛОГІЇ УПРАВЛІННЯ ГІДРОЛОГІЧНИМ РЕЖИМОМ МАЛИХ РІЧОК СТЕПОВОЇ ЗОНИ УКРАЇНИ

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Анотація. Малі річки степової зони України є найбільш вразливою ланкою гідрографічної мережі, що гостро реагує на кліматичні зміни та антропогенний тиск. Сучасна тенденція до їх обміління та втрати течії в меженний період зумовлена надмірним зарегулюванням русел ставками і водосховищами, що перетворює річки на застійні водойми. На прикладі Дніпропетровської області встановлено, що за період останніх 40 років кількість ставків зросла у 2,7 рази, а їхня загальна місткість перевищила об'єм місцевого стоку, що створює загрозу екологічній безпеці водних екосистем. Традиційні греблі зупиняють потік після наводки, тому актуальним є розробка рішень

для акумуляції води без порушення гідрологічного режиму. Методика дослідження базується на аналізі гідрологічних даних та інженерному моделюванні систем самопливного регулювання стоку із застосуванням алгоритмів геоінформаційної системи QGIS. Перший розроблений варіант передбачає модернізацію руслових ставків шляхом відокремлення русла річки від ємності ставка за допомогою дамби обвалування та створення обвідного каналу. У верхів'ї встановлюється відкритий регулятор, що дозволяє наповнювати ставок у періоди високих вод, взагалі не припиняючи транзитну течію. Для підвищення якості води у складі гідровузла застосовується кам'яно-накидна сполучна споруда, що забезпечує інтенсивну аерацію та самоочищення потоку. Другий варіант полягає у створенні автономних заплавних комплексів із штучними котлованами. Ця технологія дозволяє не лише накопичувати паводкову воду, а й здійснювати її активний скид назад у русло в посушливий період для підтримки екологічного стоку. Порівняльний аналіз підтверджує, що русловий варіант оптимальний для відновлення проточності вже зарегульованих річок, тоді як заплавні водойми ефективні для сталого водозабезпечення без втручання в русло. Практична реалізація запропонованих рішень апробована на об'єкті в басейні річки Нижня Терса (площа водозбору 85,1 км²). Результати моделювання підтвердили працездатність системи: при нормальному підірному горизонті (НПГ) 108,0–108,5 м БС та проходженні розрахункового паводка 1 % забезпеченості (рівень наповнення 109,50 м БС) забезпечується акумуляція 560 тис. м³ води при повному збереженні екологічного стоку в обвідному каналі. Впровадження таких комплексів дозволяє реалізувати принципи Водної рамкової директиви ЄС щодо ревіталізації річок, забезпечуючи «живу течію» навіть у маловодні роки та створюючи умови для відновлення біорізноманіття степових екосистем в умовах повоєнного відновлення та стрімких змін клімату.

Ключові слова: гідротехнічна споруда; водний об'єкт, річка, водна інженерія, водні технології, гідрологічний режим, екологічна безпека