VELYKYI LUH OR THE KAKHOVKA RESERVOIR: A MODERN VISION

VELYKYI LUH OR THE KAKHOVKA RESERVOIR: A MODERN VISION

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This is the English-language version of the 2025 publication « Velykyi Luh or the Kakhovka Reservoir: A Modern Vision» (ISBN 978-617-8501-03-7) that is primarily devoted to assessing future scenarios for the territory of the former Kakhovka Reservoir and the southern region of Ukraine that historically depended on it. The authors explore possible pathways for the region's revival, including the restoration of natural ecosystems and meeting contemporary economic and societal needs, the construction of a new reservoir, and a number of other innovative scenarios. The scenario assessment presented in this publication is based on a thorough analysis of the environmental and social consequences of the reservoir's creation in the mid-twentieth century and its impact on natural landscapes, local communities, and the regional economy. Particular attention is given to the challenges that emerged following the destruction of the dam in 2023, as well as to the prospects for the sustainable development of this unique territory.

This book will be valuable to anyone seeking to understand possible pathways for restoring the environment, historical heritage, and economic potential of southern Ukraine.

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INTRODUCTION

Construction of the Kakhovka Hydropower Plant (HPP) and the filling of the Kakhovka Reservoir in the mid-twentieth century became one of the largest infrastructural transformations in Ukraine, one which left a mixed legacy in history. This project fundamentally transformed the southern region of the country, destroyed local ecosystems, and created an entirely new economic structure and way of life for hundreds of thousands of people throughout the region.

Before the area was flooded by the reservoir, the territory of the Dnipro floodplain was known as Velykyi Luh. It was a mosaic of reedbeds, floodplain forests, meadows, and wetlands. In addition, this territory was significant as a historical and cultural landscape closely associated with the Cossack history of Ukraine. The Zaporizhzhian Siches were located here, and Velykyi Luh itself was considered the environment in which Cossack culture was formed.

The decision to create the reservoir and the hydropower plant became part of the ambitious "Stalin's Great Plan for the Transformation of Nature" of the Soviet era. Its purpose was to ensure the production of gunpowder (based on cotton-derived raw materials) for the Soviet army whose stockpiles had been exhausted by the World War II. By the time the hydropower complex had been completed and the reservoir filled, Joseph Stalin had died, and priorities in the USSR had changed. From then on, the role of the hydropower complex was presented as providing new opportunities for the irrigation of arid lands, electricity generation, industrial development, and water transport. However, this large-scale transformation of the region came at tremendous cost: the flooding of hundreds of thousands of hectares of land, the destruction of natural and cultural landscapes, the displacement of thousands of people, and the disruption of the traditional economic system of the entire region.

The flooding of Velykyi Luh led to biodiversity loss, the destruction of natural habitats, and the widespread conversion of the steppes of southern Ukraine into arable land. Following the construction of the hydropower plant, these areas began to be used for crop production rather than traditional livestock grazing. Regulation of the Dnipro River flow altered the hydrological regime of the region, initiating shoreline erosion, sediment accumulation, and eutrophication, while irrigation led to soil salinization. Intensive evaporation from the vast shallow water body increased water scarcity in the Lower Dnipro Basin and raised the level of water mineralization.

The social aspects of the reservoir's creation were equally traumatic. Dozens of villages and hamlets that preserved the memory of the Zaporizhzhian Sich era disappeared beneath the water, and their inhabitants were forcibly relocated to new places. This resettlement was accompanied by the loss of traditional ways of life, cultural identity, and economic stability. At the same time, settlers from other regions were moved into the newly established irrigation zones of Kherson, Zaporizhzhia, and Dnipropetrovsk regions. These newcomers had no connection to the

Cossack heritage of the region. Consequently, within just a few years, the traditionally pastoral region of southern Ukraine became the most extensively ploughed part of Europe. This remains the case today, largely not because new economic opportunities were created, as originally claimed, but because previous livelihoods were eliminated. The construction of the reservoir also significantly weakened transport connections between the right and left banks of the Dnipro River and created additional challenges for navigation.

Following the launch of the North Crimean Canal in the 1960s, the USSR also gained the means to resettle people from agricultural regions to northern Crimea, into areas vacated following the deportation of the Crimean Tatar population by the Soviet authorities[16]. The ploughing of the steppes of Crimea and Kherson region resulted in the effective loss of unique ecosystems and endemic species. In Kherson region, several plant species, including *Tulipa scythica*, *Phlomis scythica*, and *Allium regelianum*, became threatened with extinction. Species such as *Fritillaria meleagroides* and *Paeonia tenuifolia* disappeared entirely from the region.

Over time, the reservoir became an integral part of the regional economy, providing water supply, fisheries, recreation, and energy production. Nevertheless, its existence has always been accompanied by debates regarding the justification of such large-scale transformations, as the negative consequences significantly outweighed the expected benefits.

Today, following the destruction of the Kakhovka HPP dam, an opportunity has emerged for an expert discussion about the future of the region. The question of whether a new reservoir should be built after the destruction of the previous one has a much greater chance of being fully discussed than earlier proposals advocating the drainage of reservoirs. In the contemporary world, the restoration of natural ecosystems and historical memory, together with the search for new pathways of economic development, provide compelling arguments against reconstruction that are no less important than economic indicators.

This publication is an attempt to assess the full range of issues and perspectives associated with the former Kakhovka Reservoir – from the history of its construction and its environmental impacts to contemporary visions on possible future scenarios.

METHODOLOGY

This review was prepared to synthesize data on the environmental and social consequences of the construction and operation of the Kakhovka Hydropower Complex, with a focus on assessing possible scenarios for its future. The authors advocate the restoration of natural ecosystems within the area of the former reservoir; therefore, particular attention is paid to the environmental aspects of the scenarios discussed as of 2024, although the review is not limited to these aspects alone.

The review includes references to 404 scientific publications, articles, legislative acts, official reports, and online sources selected by the authors and compilers. Actions undertaken by public authorities, as well as legislative changes related to the adaptation of southern Ukraine to the new conditions resulting from the destruction of the Kakhovka HPP, were also analyzed.

In addition to the expert analysis of available information, the authors also collected original data during field studies of vegetation recovery and fish communities conducted in 2023 and 2024.

Botanists participated in six field expeditions. On 30 June and 19 October 2023, and on 11 and 29 April and 30 October 2024, surveys were conducted within the territory of Kamianska Sich National Nature Park in the Kherson region, in two former bays of the Kakhovka Reservoir – Mylivska Bay and Kamianska Bay, now known as the Mylivska and Kamianka ravines. On 21-22 May 2024, fieldwork was carried out on Khortytsia Island and in the vicinity of the villages of Malokaterynivka (left bank of the Dnipro) and Kanivske (right bank of the Dnipro) in the Zaporizhzhia region.

During the expeditions, 12 permanent monitoring plots were established to study the processes of vegetation recovery on the bed of the former reservoir. The plots were established in accordance with the biodiversity plot methodology of the Eurasian Dry Grassland Group (EDGG), which, in addition to classical geobotanical data, includes analyses of species – area relationships, soil sample analysis, and a number of other parameters.[6] In addition, information on habitat recovery collected by amateur naturalists was analyzed.[1]

Historical information on the habitat composition of the area flooded by the reservoir was derived from various historical photographs, cartographic materials dating from 1853-1943, and aerial photographs taken in 1943. These materials were analyzed using QGIS software. Taken together, these studies helped to provide a more objective assessment of both natural processes and the restoration scenarios currently under consideration.

Analysis of reports from environmental authorities enabled the assessment of the main trends in changes in the ichthyofauna of water bodies. Field ichthyological surveys covered the section of the Dnipro River downstream of the Dnipro Hydropower Plant dam (the former upper part of the Kakhovka Reservoir), within the following boundaries: along the right bank, from the Dnipro HPP dam to the mouth of the Kokan River in the village of Bilenke, Zaporizhzhia District; and along the left bank, to the Osetrivka railway platform in the town of Kushuhum, Zaporizhzhia District. Survey sites were selected based on the availability of historical data on recreational fishing.

This approach to ichthyological research was necessitated by restrictions resulting from the security situation along the Dnipro shoreline, which made comprehensive studies and the use of standard research methods, including scientific fish sampling, impossible.

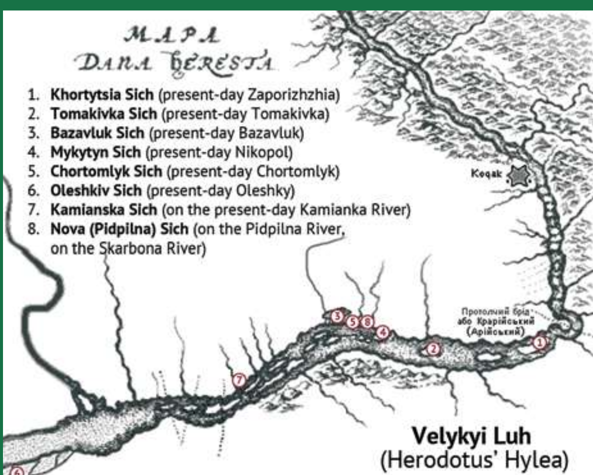
1 Users of citizen science platforms, such as iNaturalist, as well as wildlife videobloggers.

VELYKYI LUH: NATURAL AND HISTORICAL-CULTURAL SIGNIFICANCE

THE ZAPORIZHZHIAN SICH AS A POLITICAL ENTITY

Velykyi Luh is a floodplain complex south of Khortytsia Island on the Dnipro River and historically served as a center of Ukrainian state-building and national identity.

Prior to the emergence of the Zaporizhzhian Sich in the 16th century, this region served as a natural frontier between the settled and nomadic peoples of Central Europe. At different times, it was inhabited by Scythians, Sarmatians, Alans, and Goths, followed by Slavic tribes and nomadic peoples, including the Cumans and various Turkic-speaking tribes. The Mongol invasion of the thirteenth century led to the decline of the principalities of Kyivan Rus, which in turn resulted in the absence of effective political control in the steppe zone[106, 181]. This situation created the preconditions for the emergence of the free Ukrainian Cossacks of the Zaporizhzhian Sich.



Map of siches in Velykyi Luh

Prior to the development of the Zaporizhzhian Sich, Velykyi Luh remained sparsely populated because of the constant threat of raids. The local population consisted mainly of semi-settled Slavic groups engaged in hunting, fishing, and pastoralism. The establishment of the Sich became a catalyst for the active colonization of the region. Refugees from various parts of the Polish-Lithuanian Commonwealth, Muscovy, and the Ottoman Empire settled here, forming a new social group –

VELYKYI LUH

The Logic Behind the Location of the Zaporizhzhian Siches

The word *sich* derives from the Ukrainian verb sikty ("to cut" or "to chop"). In its original meaning, it referred to a fortification built by the Cossacks from timber – essentially a fortified stronghold. However, a sich was not merely a defensive fortification; it also served as a military and administrative center, as well as a focal point of the political, economic, and cultural life of the Cossacks.

The first organized Cossack centers began to emerge in the fifteenth century. During the sixteenth to eighteenth centuries, nine different siches existed, including the Khortytsia Sich (1556-1557), Tomakivka Sich (1560-1593), Bazavluk Sich (1593-1638), Kamianska Sich (1709-1711, 1730-1734), and the New Sich (1734-1775)[106]. All of them were established in locations protected by natural barriers, such as islands in the Dnipro River or the marshy areas of Velykyi Luh, and were generally located closer to the right bank of the Dnipro. This location offered important advantages: the river provided protection from nomadic tribes to the east, while the Dnipro rapids formed an impassible barrier against enemies approaching from the north. The word Zaporizhzhian itself is also derived from the rapids (porohy), literally meaning "beyond the rapids."

Thanks to its strategic location, the sich served as a barrier against the Ottoman Empire and Crimean Tatars while at the same time preserving the autonomy of Ukrainian lands.

Nenasytets Rapid – the largest and most powerful of the Dnipro rapids[88].

the Zaporizhzhian Cossacks. Opportunities for numerous nature-based livelihoods and livestock grazing almost year-round provided settlers with far more favorable conditions than those available in the surrounding steppe territories, where only a nomadic way of life was possible. By 1774, the population of Velykyi Luh exceeded 100,000 Cossacks[32].

However, in 1775, by order of Catherine II, the Zaporizhzhian Sich was destroyed, and Velykyi Luh was gradually incorporated into the Russian Empire[402].

The Zaporizhzhian Sich played a key role in the formation of Ukrainian identity, functioning according to democratic principles: all important matters were decided at the Cossack *rada* (assembly, council), and *hetmans* (top commanders) were elected by vote[181]. Over time, the Sich became a symbol of the struggle for democracy and freedom for Ukrainians, and its legacy influenced the development of Ukrainian culture, literature, and politics. To this day, the concept of the Zaporizhzhian Sich maintains its significance for Ukrainians.

WHAT IS VELYKYI LUH?

Velykyi Luh, where the Soviet government constructed the Kakhovka Reservoir, was the largest natural forest in Ukraine's steppe zone[133] and an area of great importance for biodiversity conservation and global seasonal bird migrations. Beginning in the mid-1920s, Ukrainian scholars advocated the establishment of a nature reserve in this area[308]. However, following World War II, a decision was made at the highest political level to construct a reservoir and a hydropower plant in this very location.

Origin of "Velykyi Luh"

During the period when Ukraine was part of the russian empire and later the USSR, the original Ukrainian meaning of the word *luh* gradually fell out of use. The russian language has a similar word, whose Ukrainian equivalents are *luka* or *obolon*, referring to riverside areas dominated by grassland ecosystems. Historically, however, the Ukrainian word *luh* had a different meaning: a forest regularly sustained by seasonal river floods. The toponym "Velykyi Luh" therefore refers to the ancient floodplain forest that surrounded the Cossack capital. This interpretation is confirmed by etymological dictionaries[2], and the expression appears in folk songs , in a poem[3] by Taras Shevchenko, and in other sources.

In 1957, all villages inhabited by descendants of the Zaporizhzhian Cossacks, who preserved the memory of the formation of Ukrainian statehood, disappeared beneath the waters of the reservoir, and their residents were forcibly relocated.

The Soviet government created the reservoir in great haste and without adequate archaeological investigations. It is therefore possible that the construction of the

Forestry buildings within Velykyi Luh shown on an 1853 map[52].

2 "Oi, ne shumy, luzhe...", "Oi, u lisi, u luzhechku teren protsvitaie...", and others.

3 Taras Shevchenko's epistle poem to Hryhorii Kvitka-Osnovianenko (1839).

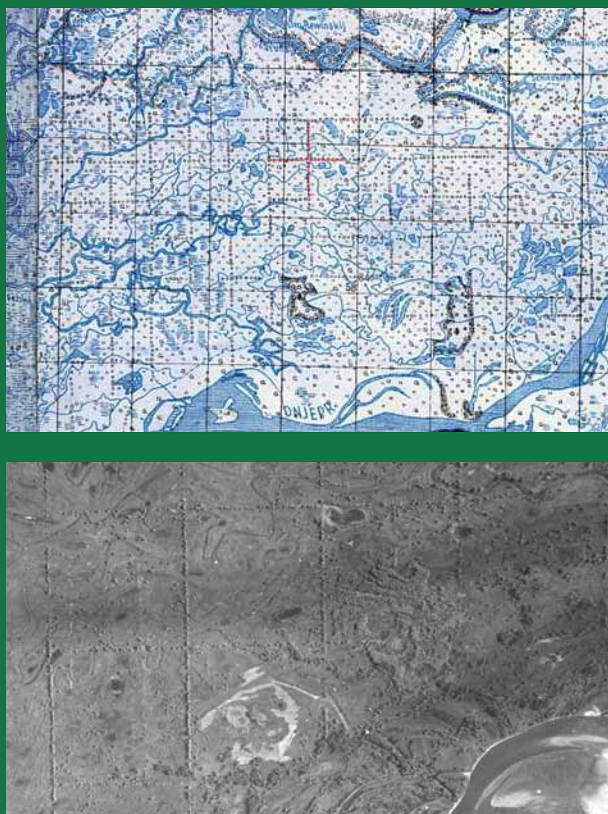
Kakhovka Hydropower Plant and Reservoir served, at least indirectly, another of Joseph Stalin's objectives: the destruction of a historical landscape that symbolizes resistance to the subjugation of Ukrainians by the russian empire and the assimilation of the descendants of the Zaporizhzhian Cossacks[263].

ECONOMIC HISTORY OF VELYKYI LUH

From an economic perspective, the territory of Velykyi Luh was used for timber harvesting, hunting, fishing, and beekeeping[402], as well as for grazing and haymaking. The principal economic activity in the region was livestock husbandry, primarily the breeding of fine-wool and coarse-wool sheep, as well as cattle for dairy and meat production.

During the Soviet period, the economic role of the area changed: former timber-harvesting areas were converted into pastures and hayfields for collective farms. As a result, forest cover declined substantially, and meadow ecosystems developed in its place. Consequently, by the time the reservoir was created, only 20% of Velykyi Luh was covered by forest vegetation (see the section **"Environmental Consequences of the Construction of the Kakhovka Reservoir: Loss of Biodiversity and Natural Habitats"**). This explains why modern Ukrainians tend to perceive Velykyi Luh as a meadow landscape rather than a forested one.

The flooding of Velykyi Luh resulted in the loss of the land that had served as the only suitable grazing areas during drought years.[4] [325, fols. 71–95; 325, fol. 84; cited in 302].



Division of the hay meadows of Velykyi Luh into plots allocated to collective farms through the establishment of shelterbelts (shown on the map[53] and in a 1943 aerial photograph[51]).

4 Available records indicate that this shortage of grazing lands resulted, within a short period of time, in livestock mortality and the forced slaughter of animals.

CONSTRUCTION OF THE KAKHOVKA RESERVOIR

Between 1927 and 1976, the Soviet government constructed six reservoirs on the Dnipro River, the fourth-longest river in Europe[221]. The cascade of Dnipro reservoirs regulated the river channel along a stretch corresponding to 90% of its length within Ukraine[90], with the Kakhovka Reservoir becoming the last reservoir in the cascade. In essence, the creation of the reservoir began with the construction of the Dnipro Hydropower Plant (Dnipro HPP), located at the upper reaches of the Kakhovka Reservoir.

Construction of the First Hydropower Plant on the Dnipro: Dnipro HPP

In 1927, construction began in Ukraine (then the Ukrainian SSR) on the first hydropower plant on the Dnipro River – the Dnipro Hydropower Plant (Dnipro HPP), with a capacity of 560 MW. The plant was built downstream of the section of the Dnipro characterized by rapids, near Khortytsia Island[154]. At the time, the hydropower plant was intended to be the largest and most powerful in the world. However, it reached its full generating capacity only 23 years after construction had begun (in 1950), due to its destruction by Soviet troops in 1941[68].

It was one of the largest construction projects of its time. Nearly 15,000 builders from 300 cities across different republics of the USSR worked on the project simultaneously[5]. Construction proceeded under intense time pressure and in the spirit of "socialist competition" among the workers. A total of 1,100 vehicles, 30 excavators, 75 cargo cranes, 100 bulldozers, 14 steam locomotives, and 7 dredgers were deployed[24]. Alongside the hydropower plant, the city of Nova Kakhovka – which had not previously existed – was also built. Within two years, 396 buildings were constructed, and the city was prepared to accommodate up to 10,000 new residents.[6] A new 154-km railway branch line was also built to connect the city.[7] The first generating unit of the Kakhovka Hydropower Plant was commissioned on a trial basis on 4 October 1955.[8]

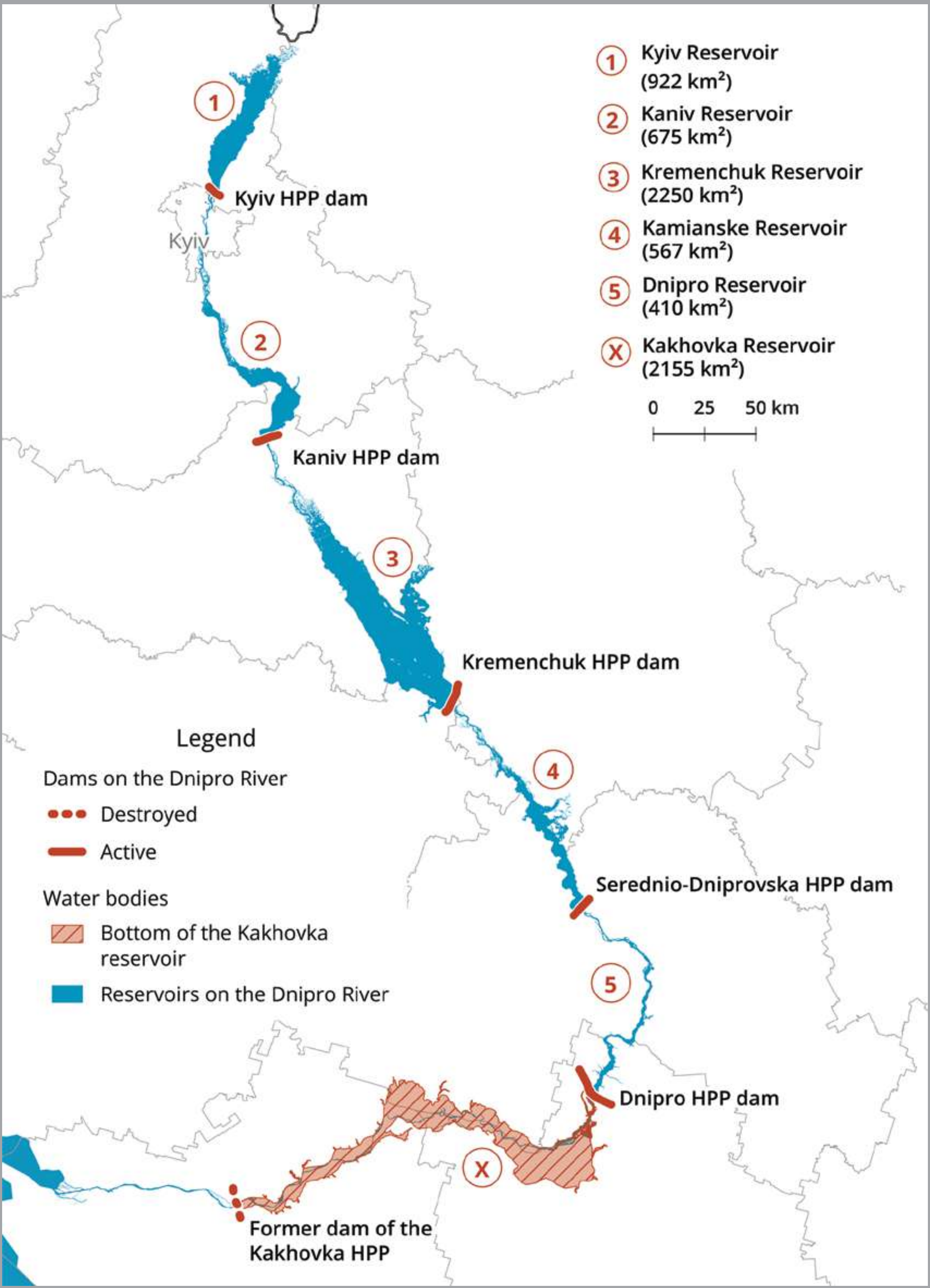
5 Resolution of the Council of Ministers of the USSR on the construction of the Kakhovka Hydropower Plant, 20 September 1950. Pravda Ukrainy, 21 September 1950.

6 Report of the Academy of Sciences of the USSR on the work of a team of scientists established to assist the construction project, 15 February 1952 [192, fol. 111].

7 From a report by the Kherson Regional Trade Union Council presented at the regional trade union conference on the achievements of the builders of the Kakhovka Hydropower Plant (published no earlier than 30 June 1952) [373, fols. 89–92].

8 From a radio address by S. M. Andrianov, Head of Dniprobud and Deputy of the Supreme Soviet of the Ukrainian SSR, on the successful testing of the first generating unit of the Kakhovka Hydropower Plant [374, fols. 20–23].

Cascade of Dnipro Reservoirs



Technical Characteristics of the Former Kakhovka Reservoir

The Kakhovka Hydropower Complex consisted of a hydropower plant building 193 m in length, a concrete spillway dam with a total length of 435 m, an earth-fill dam 3.2 km long, and a single-chamber navigation lock measuring 320 × 18 m. The hydropower plant was designed for a discharge of 4,962 m^3/s with a 0.1% exceedance probability. The turbines, with a diameter of 8 m, had a flow capacity of 485 m^3/s and an output of 58.5 MW each. The spillway dam had 28 openings, each 12 m wide and was designed to allow passage of 15,438 m^3/s of water. The right-bank earth-fill dam was 1,206 m long, while the breakwater embankment extended 1,100 m.

Average annual electricity generation was 1,489 million kWh. The mean long-term annual runoff[9] was 52.2 km^3. The total and active storage capacities of the reservoir were 18.2 km^3 and 6.8 km^3, respectively. At a normal water level[10] of 16 m, the reservoir covered an area of 2,155 km^2 and had a length of 230 km. Its maximum and average widths were 25 km and 9.3 km, respectively, while its maximum and average depths were 24 m and 8.4 m.

The Kakhovka Reservoir supplied water to the intakes of several major canal systems used for irrigation, industrial water supply, and municipal water supply, including the Dnipro-Kryvyi Rih Canal, Upper Rohachyk Canal, Kakhovka Canal, and North Crimean Canal[298].

CONSTRUCTION

Land Flooding

Given the considerable length of the reservoir and the corresponding variation in elevation, not only the floodplain but also parts of the higher river terraces in its middle and lower sections were flooded. This later resulted in significant shoreline erosion and the formation of high abrasion cliffs.

The area designated for flooding included 56,800 hectares of agricultural land, 63,000 hectares of forests, and 17,480 households. The value of the lost land, property, and natural resources was not included in the estimated cost of constructing the Kakhovka Hydropower Plant and Reservoir[399]. A total of 34,000 people from 75 settlements (primarily small hamlets and villages with 10–100 households) and 26 industrial enterprises were subject to relocation. In addition, the flooding zone included 50 km of railway lines, 65 km of roads, and 193 km of communication lines[164, fol. 151; 166, fols. 71–72; cited in 302].

To replace the flooded settlements, new ones were established at some distance from the reservoir. Residents were required to dismantle and transport parts of their homes and reconstruct them at the new locations. Extraordinary measures were taken against those who failed to relocate in time, including forced resettlement and even the destruction of dwellings [399].

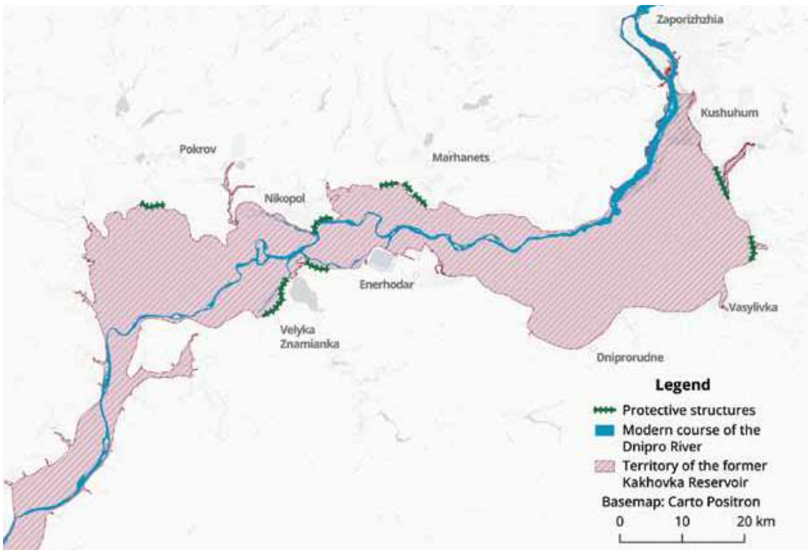
9 Mean long-term annual runoff is the difference between average annual precipitation and evaporation.

10 Normal Water Level (NWL) is established during the design of reservoirs, dams, and other water-management structures as the upper limit of water level under normal operation conditions to ensure their stable operation and to prevent flooding or inadequate water supply.

The loss of access to pastures (productive for up to ten months of the year), the river's natural resources, and sheltered locations well suited for settlement led to a substantial decline in the quality of life and economic well-being of the resettled rural population. This, in turn, accelerated migration – particularly among younger residents – to urban areas and their subsequent assimilation there. The possibility of returning to formerly inhabited places continues to be discussed to this day[392].

Protected Land Tracts Along the Reservoir

Within the area affected by the Kakhovka Reservoir, some territories were intentionally left outside the flooding zone in order to avoid relocating large numbers of local residents and to prevent substantial losses to the industrial enterprises of Nikopol. To protect these territories, large embankments (saddle dams) were constructed, creating four protected land tracts (polders): "Kamianskyi Pid", "Nikopol Protection Area", "Eastern Manganese Deposit Area" and "Western Manganese Deposit Area" (totalling 16,000 hectares). These protected tracts included 18 settlements, among them the cities of Nikopol, Marhanets, and Kamianka-Dniprovska.



The largest of the protected tracts (Kamianskyi Pid) is enclosed by three saddle dams with a combined length of 17.4 km and a height of 20.0 m. The surface of the dams was constructed from a mixture of stone and synthetic rubber. Drainage water was pumped into a special reservoir known as the "Bilozerskyi Lyman" by means of a pumping station with a capacity of 360 m^3/min[153].

The construction of the dams and the Kakhovka HPP dam required substantial quantities of construction material, the extraction of which was accompanied by the destruction of natural ecosystems[11].

11 For example, it is known that the construction of the dam of another hydropower plant – the Kremenchuk HPP alone – required 65 million m^3 of excavated material [108, p. 332 ff.].

IDEOLOGY

The decision to construct the Kakhovka Reservoir was made during the period of Stalinist gigantomania, the era of the so-called "Great Construction Projects of Communism".[12] The purpose of constructing the Kakhovka Hydropower Complex was to increase the cotton production needed to supply the Soviet military.

Before the Second World War, cotton was an important raw material for the production of gunpowder (nitrocellulose). As late as 1950, 100,000 hectares in southern Ukraine were planted with cotton. However, without irrigation, yields remained low – 2-2.5 centners per hectare, whereas the global norm was 20-30 centimeters per hectare[223].

Alongside efforts to expand domestic cotton production (not only in the Ukrainian SSR), the Soviet leadership sought opportunities to purchase cotton from other countries. Ultimately, this approach proved effective: after 1956, supplies of cotton from Egypt were established[223]. Ten tons of Ukrainian wheat were exchanged for one ton of Egyptian cotton. Later, cotton was also exchanged for weapons in a similar manner. As a result, collective farms gradually abandoned the cultivation of cotton, a crop not typically found in temperate latitudes[380]. Thus, during the course of its construction, the reservoir effectively lost its original purpose.

Some historians argue that the cascade of Dnipro reservoirs also served another military function: it acted as a water barrier in the event of a future war[100]. This hypothesis is supported by the demolition of the Dnipro HPP dam by Soviet troops in 1941 (as well as by similar actions undertaken by russian forces in 2023), and by the secrecy surrounding both the documentation and even the decisions concerning the construction of the reservoirs.

The construction of the Kakhovka HPP was accompanied by an extensive political propaganda campaign. Party organizations enlisted agricultural and forestry specialists, secondary-school teachers, and other professionals in propaganda activities[135]; altogether, their numbers reached the tens of thousands[172]. The press vividly described the positive changes that were expected to occur in Ukraine's steppe regions following completion of the Kakhovka Reservoir[211]. Newspapers published promises that *"Kherson would become a major center of the cotton industry in Ukraine... New oil-extraction plants for processing cottonseed would be built, including facilities in Kherson and Melitopol."*[13] Scientific institutions welcomed publications and dissertations devoted to the history of the "Party's struggle" for the construction of the hydropower plant or to "socialist competition among hydropower builders"[301]. The first scholarly monograph describing exclusively positive consequences of the hydropower project was published even before construction of the dam had been

12 The Great Construction Projects of Communism were large-scale infrastructure projects undertaken in the USSR during the 1930s–1950s. They were intended to promote industrialization, strengthen the economy, and demonstrate the superiority of socialism. These projects relied heavily on forced labor and were often accompanied by substantial human losses and low economic efficiency. The most notable examples include the Dnipro Hydropower Plant, the White Sea–Baltic Canal, the Magnitogorsk Iron and Steel Works, and the Baikal-Amur Mainline (railroad line). In some years, such projects consumed as much as 15–20% of the USSR state budget [46].

13 A plant of this kind was indeed built in Kherson; however, it subsequently operated for many years using imported raw materials.

completed[398]. The reservoir was intended to complete the vision of the "Great Stalin Plan for the Transformation of Nature" and the promised "victory over drought" proclaimed during the interwar period[168, fols. 24, 60–66; cited in 302].

Military Motives Behind the Construction of the Kakhovka Hydropower Complex

Resolution No. 3887 of the Council of Ministers of the USSR, "On the Construction of the Kakhovka Hydropower Station on the Dnipro River and the South Ukrainian and North Crimean Canals," dated 20 September 1950, stipulated:

"1. To undertake the construction of an irrigation system for the irrigation of 1.5 million hectares and the watering of an additional 1.7 million hectares of land in the southern regions of Ukraine and the northern regions of Crimea, and to create a new hydropower base on the Dnipro River to supply electricity to agriculture and industry.

The following shall be constructed in the above-mentioned regions:

a) a hydroelectric power station on the Dnipro River in the vicinity of the city of Kakhovka, with an installed capacity of 250,000 kW and an annual electricity generation of approximately 1.2 billion kilowatt-hours in an average-water year; a dam, a navigation lock, a large reservoir with a storage capacity of 14 billion cubic meters, and pumping stations [...]

3. To provide, in irrigated agricultural areas, for the expansion of cotton cultivation [...]

12. To instruct the Ministry of Agriculture of the USSR to transfer to the Ministry of Cotton Growing of the USSR:

a) water-management organizations, irrigation systems, and irrigation-construction projects in the Kherson, Zaporizhzhia, Mykolaiv, and Izmail regions of the Ukrainian SSR;

b) machinery-repair workshops in the Kherson, Mykolaiv, Odesa, and Izmail regions, as well as the earthworks unit in Zaporizhzhia region;

c) the Ukrainian Trust for the Design of Irrigation Systems and Hydraulic Engineering Structures, 'Ukrvodproekt', while retaining its responsibility for water-management planning and survey work throughout the Ukrainian SSR"[104].

The text of the Resolution clearly indicates that, immediately after its construction, the irrigation system was to be transferred to the USSR Ministry of Cotton Growing.

However, experiments with cotton cultivation were discontinued within the first years following the filling of the reservoir[104]. This decision is associated with the rise to power of Nikita Khrushchev (1956), who reduced the size of the armed forces and signed a trade agreement with Egypt for cotton supplies. Following the abandonment of cotton cultivation, the Kakhovka Hydropower Complex was repurposed to support the cultivation of other irrigated agricultural crops.

The sheer scale of resources devoted to propaganda efforts suggests that the local population did not share the Soviet state's optimism regarding the promised positive changes. People still recovering from the devastation of war were confronted with the fact that they would soon have to leave their homes forever.

COST

The irrational nature of the Kakhovka Reservoir project was evident from the outset. Even according to the calculations of the reservoir's designers, the construction of river transport infrastructure within the reservoir area would only pay for itself after 46 years of operations[165, fol. 2; cited in 302]. The project documentation was repeatedly revised in an effort to reduce costs. Cost reductions were achieved by increasing the area of the reservoir and reducing the number of protective structures[14] [166, fol. 56; cited in 302]. One of the project reviewers, I. I. Sarafanov, wrote: *"In their objections, the authors of the project are entirely biased and reject the experts' comments not because they believe their technical position to be correct, but because they are determined not to allow any criticism of the project, regardless of state or economic considerations"*[166, fols. 148–149; cited in 302].

Soviet Efforts to Reduce the Construction Cost of the Kakhovka HPP

At the initial planning stage, the project envisaged a reservoir with a volume of 14 km³, which would inundate 65% of the floodplain wetlands[325, fol. 96; cited in 302]. Subsequently, a decision was made to increase the storage volume to 19 km³. To achieve this, the design's normal water level was raised from 14 to 16 m[165, fol. 56; cited in 302].

Designers at the Hydroenergoproject Institute considered the allocation of additional resources for the construction of protective dams along the reservoir to be an unjustified expense. Therefore, dams and pumping stations[325, fols. 56, 74–75; 167; cited in 302] were planned only to protect the city of Nikopol, the manganese deposits of Dnipropetrovsk region, and the Kamianskyi Pid lowland in Zaporizhzhia region[325, fols. 147–148; cited in 302] (see the section **"Construction of the Kakhovka Reservoir"**). The site in Zaporizhzhia region had no industrial significance, but it was protected by embankments in order to reduce the costs of relocating local residents. Had the area been flooded, more than 20,000 people would have had to be resettled, and this would have been considerably more expensive than protecting the territory with a dam[325, fols. 56, 74–75; 167; cited in 302]. Moreover, it could have triggered public resistance.

Thus, rather than seeking to reduce the scale of the damage caused by the project, the Soviet authorities focused on a different objective – reducing construction costs.

14 During the preparation of the draft Resolution of the Council of Ministers of the Ukrainian SSR No. 3135-1233s of 12 July 1952, "On Approval of the Design Proposal for the Construction of the Kakhovka HP Station on the Dnipro River," the reservoir volume was increased from 14 to 19 km³ at the expense of floodplain wetlands.

OPPOSITION

Opposition to the Kakhovka Reservoir project emerged during the planning stage[302] and continued after the reservoir was constructed. During the Soviet period, such opposition was both dangerous and largely ineffective. As early as the 1950s, censors prohibited editors from publishing articles mentioning the negative consequences of reservoir construction[252]. Editors and journalists who failed to comply with censorship requirements were sent to Soviet labor camps as political prisoners[312; 314].

Expert Assessment of the Project

Despite these constraints, some experts attempted in 1952 to draw attention to the problem of flooding Velykyi Luh. Records have been preserved of reports prepared by M. Vaskov, an engineer in the Department of Hydraulic Structures, emphasizing the importance of the floodplain wetlands for local agriculture, which was largely based on pasture livestock farming[325, fols. 116–121; cited in 302], as well as the unique role of the Dnipro floodplains in the cultivation of bast fiber crops (e.g. flax), which were important for the post-war recovery of agriculture[325, fol. 117; cited in 302]. Moreover, he stressed the ecological importance of the floodplain wetlands, arguing that their preservation could create an oasis near industrial centers that would be attractive for recreational purposes[325, fol. 118; cited in 302].

Even after the Kakhovka Reservoir had been filled, scientists did not abandon hopes of restoring the floodplain wetlands. They argued that even the costs of draining the reservoir would generate greater economic benefits than the irrigation system created through its construction in southern Ukraine[118]. As an alternative, they proposed constructing a protective dam and pumping station and restoring the floodplain wetlands by pumping out the water[172], or at least lowering the water level by 1-2 m[369, fols. 234–241], which would once again convert the shallow-water zone of the reservoir into dry land. Methods for increasing agricultural productivity in southern Ukraine without irrigation from the Kakhovka Reservoir were also proposed by the Ukrainian academician B. Y. Paton[15]. However, all of these ideas were rejected by the Soviet authorities[375, fol. 19].

Public Debate

The negative consequences of the Kakhovka HPP became apparent within the first years after its completion. At that time, no environmental movement yet existed in the USSR, and public discussion of the consequences of the Dnipro reservoirs unfolded primarily in the pages of the newspaper Literaturna Ukraina, beginning in 1967[194; 195]. Readers eagerly submitted letters calling for the protection of the Dnipro, and the newspaper soon became a genuine platform for discussing the environmental consequences of hydropower development on the river. The debate itself became the first environmental campaign in post-war Ukraine.

15 Borys Yevhenovych Paton (1918–2020) was a distinguished Ukrainian scientist specializing in welding, metallurgy, and materials science. He became the first researcher in the world to pioneer welding in space.

In 1969, the satirical newsreel Fitil featured an episode entitled "Measure Seven Times" about the losses Ukraine was suffering as a result of poorly planned hydropower projects. The editor-in-chief of the newsreel appealed to the Council of Ministers of the Ukrainian SSR for an official response[370, fol. 79]. The replies received from government officials were restrained[[370, fol. 104; 313].

In the 1980s, soil salinization in southern Ukraine sparked a broader public discussion about whether the Dnipro reservoirs were needed at all. The debate began with an article by the writer S. Plachynda, which included testimony from scientists and hydraulic engineers confirming that saline groundwater was rising from deep geological layers[313; 314] as a result of irrigation with the highly mineralized waters of the Kakhovka Reservoir. This article marked the first time that criticism of the Dnipro reservoirs appeared publicly in the pages of a nationwide Ukrainian newspaper.

It is possible that public awareness of the negative consequences of the Kakhovka HPP helped prevent the construction of another reservoir planned during the 1980s. This proposed reservoir would have flooded the remaining floodplains of the Dnipro Delta as well as the waters of the Dnipro-Buh Estuary[233]. Public criticism delayed the project for many years, until the dissolution of the USSR in 1990.

Following the Chornobyl disaster, Ukraine experienced a surge in environmental activism. In 1989, a group of writers organized the "Slavutych-89" expedition to the headwaters of the Dnipro, aiming to draw attention to the river's problems, including those associated with the Kakhovka Reservoir[196].

After Ukraine declared independence, the Committee for the Rescue of the Dnipro was established[250], and calls by experts to drain the Kakhovka Reservoir were renewed with greater intensity[109; 316]. However, they remained insufficient to initiate a full-scale discussion at the state level.

In the early 2000s, one of the most influential opponents of the Dnipro reservoirs was A. H. Shapar (1936–2021), Corresponding Member of the National Academy of Sciences of Ukraine, Doctor of Technical Sciences, and Professor. At the academic level, he substantiated the need to decommission all reservoirs of the Dnipro cascade[382–391], and the Kakhovka Reservoir in particular[82; 381].

ENVIRONMENTAL CONSEQUENCES OF THE CONSTRUCTION OF THE KAKHOVKA RESERVOIR

The environmental consequences of the reservoir's construction became apparent within the first years after it was filled, and their study began as early as 1957.

RISING GROUNDWATER LEVELS

Changes in groundwater levels are a typical consequence of reservoir construction. The Kakhovka Reservoir was no exception: groundwater levels rose within a zone extending 30-35 km from the reservoir banks. During the filling of the reservoir, waterlogging of adjacent lands caused problems for settlements: cellars were flooded and house foundations were damaged (affecting 6,730 households)[309].

Waterlogging also damaged buildings along irrigation canals. For example, 255 houses were demolished for this reason in the area surrounding the Krasnoznamyanska Irrigation System in Kherson region[369, fol. 48]. On the low-lying left bank of the Dnipro, even a slight rise in groundwater levels proved sufficient to inundate orchards and vineyards covering 6,730 hectares[309; 399].

The rise in groundwater levels triggered extensive erosion processes on the reservoir slopes. Enormous resources were invested in bank protection works. Meanwhile, the saturation of soil horizons with water and the disruption of their natural integrity reduced the seismic stability of the affected areas[315].

Over time, people became accustomed to the new groundwater levels and came to regard them as normal. Consequently, although the decline in groundwater levels following the 2023 blasting of the Kakhovka Dam is often viewed as a negative consequence, groundwater has in fact returned to its natural pre-dam level[57; 282]. Some experts predict that if the reservoir were rebuilt, groundwater levels would require as long as 33.5 years to return to their pre-war state[119].

EROSION AND SEDIMENTATION

The Kakhovka Reservoir alone accounted for 43%[153] of all agricultural land flooded as a result of the construction of the Dnipro cascade. Some experts estimate that the losses associated with the flooding of chernozem soils – the most fertile soils of the steppe zone – were 400 times higher than the economic benefits generated by the six hydropower plants on the Dnipro[115]. In addition to the directly flooded land, areas adjacent to the reservoir were also affected by intensive erosion.

The reservoir's shallow depth and large surface area generated waves that actively eroded its banks. The reservoir banks consisted predominantly of loess-like loams, which are highly susceptible to erosion. At the time of the dam's destruction, the reservoir shoreline extended for 800 km, of which 369 km had been affected by erosion[153]. The most intensive erosion occurred during the first 5-7 years after the reservoir was filled, but continued until 2023. During this period, 2,839 hectares of land were lost to bank erosion[387], with annual retreat rates ranging from 1 to 7.5 meters[158].

The increase in moisture content within the loess deposits gave rise to another phenomenon – subsidence cracks. These cracks typically reached depths of 4-7 m[220, p. 66], lengths of 2.0-2.5 km, and occurred as far as 800 m inland from the water's edge. They were followed by landslides, which began to appear in large numbers several years after the reservoir was filled. Landslide zones reached lengths of 200-400 m and widths of 40-50 m.

Subsidence cracks on slopes adjacent to the reservoir (Photo by O. Vasyliuk)

The development of landslides required urgent erosion-control measures. As a result, protective forest plantations were established on a large scale along the reservoir slopes, primarily consisting of *Robinia pseudoacacia* and other non-native tree species. To establish these plantations, the slopes were ploughed, resulting in the destruction of native steppe vegetation. Yet it is precisely this vegetation that is most effective at retaining fertile topsoil.

Once the planted trees reached maturity, many began to be uprooted by strong winds, exposing the soil and thereby accelerating erosion. While alive, the trees provided at least some degree of slope stabilization, although less effectively than natural steppe vegetation. However, after their death – whether due to illegal logging, fire, drought, or disease – the herbaceous vegetation that developed within these artificial plantations, largely composed of ruderal species (early colonizers), proved incapable of preventing erosion. Erosion was further accelerated by slope terracing, which was repeatedly used to prepare slopes for afforestation. On natural steppe slopes, rainfall and snowmelt runoff typically flow toward rivers in a relatively uniform sheet. Terracing, however, concentrates water runoff along specific pathways and transforms diffuse surface erosion into concentrated erosional flows, thereby increasing land degradation.

As a result, many of the erosion-control measures proved ineffective, while some had the opposite effect and contributed to the intensification of soil loss and slope erosion. Erosional processes altered not only the relief of the Kakhovka Reservoir banks but also the reservoir bed itself. Waves redistributed bottom sediments and contributed to the expansion of shallow-water areas, gradually levelling the relief of the flooded floodplain[198]. As a result, former sandy ridges and dunes that once rose above Velykyi Luh were eroded, while oxbow lakes became filled with sediments. This process expanded the shallow-water zone, where soil particles and plant material washed from arable land and surrounding areas accumulated. The result was extensive sedimentation, with bottom deposits reaching thicknesses of up to 1 m in some locations[387].

The formation of bottom sediments was most intense during the first years after the reservoir was filled, when bank erosion and abrasion had peaked, original soils and peatlands were being eroded, and massive blooms of blue-green algae (cyanobacteria) occurred. Later, these processes stabilized and the rate of sediment accumulation – predominantly silts – declined [198]. Silted areas ceased to perform important ecological functions, such as serving as fish spawning grounds or providing habitat for species dependent on well-oxygenated environments. By the time the dam was destroyed, 82% of the reservoir bed had become silted[198].

EUTROPHICATION

The accumulation of nutrients, primarily as a result of agricultural intensification and increasing volumes of municipal wastewater, created conditions conducive to eutrophication (excessive growth of microalgae) and the subsequent decomposition of organic matter.

Following the die-off of microalgae and the decomposition of organic material, toxic substances such as hydrogen sulfide, methane, and ammonia are released into the water body[103; 262]. Oxygen availability is closely linked to organic loading. Dissolved oxygen concentrations in the Kakhovka Reservoir did not even meet the criteria for good ecological status, and the reservoir's oxygen regime exhibited signs of unsatisfactory conditions throughout the year[311, p. 380]. Oxygen depletion resulted in fish kills and the mortality of other aquatic organisms, including crustaceans and many species that formed the food base of fish communities. In addition, these altered hydrological conditions facilitated the spread of invasive species (including *Lepomis gibbosus*, *Pseudorasbora parva*, and *Carassius gibelio*, among others), which are better adapted to stagnant water bodies with low dissolved oxygen concentrations[368].

Consequences of eutrophication in the Kakhovka Reservoir (photo by M. Maksymenko)

Among all reservoirs of the Dnipro cascade, eutrophication reached its greatest extent in the Kakhovka Reservoir due to its shallow depth, large surface area, and the accumulation of wastewater and agricultural fertilizers. Phosphate concentrations alone rendered the reservoir water only of limited suitability for water supply purposes[114].

At the same time, reservoir conditions proved unfavorable for other groups of planktonic organisms. Water flowing down the Dnipro gradually passes through the turbines of all hydropower plants in the Dnipro cascade (except for dead storage volume). As a result, up to 60% of phytoplankton and 15% of zooplankton are killed, while a further 50% of zooplankton are injured[376; cited in 397].

ENVIRONMENTAL CONSEQUENCES

CHEMICAL POLLUTION

Because the Kakhovka Reservoir accumulated water from the entire Dnipro cascade, pollutants from all upstream reservoirs eventually accumulated in it. A substantial portion of the reservoir consisted of dead storage volume, meaning that pollutants entered the reservoir, settled there, and did not continue downstream.

The principal sources of pollution in surface waters are overloaded sewerage and wastewater treatment systems that are in poor operational condition. More than 90% of the polluted wastewater discharged into the Dnipro River basin originates from municipal water utilities in Dnipropetrovsk region and from mining and metallurgical enterprises located in Dnipro, Kamianske, Kryvyi Rih, the Nikopol manganese basin, and Western Donbas[333].

As early as 1952, scientists predicted excessive pollution of the Kakhovka Reservoir as a result of the accumulation of industrial and domestic wastewater from surrounding settlements. Serhii Petrovych Fedii, Head of the Dnipropetrovsk Hydrobiological Station, argued that: *"Following the regulation of the Lower Dnipro in the Kakhovka area, the discharge of industrial and domestic wastewater may lead to the accumulation of harmful substances in the reservoir, resulting in the mass mortal-*

Discharge points of industrial and domestic wastewater into the Dnipro River in Zaporizhzhia.

The Sukha Moskovka River (also known as the Kapustiana or "Red River") at the point where it flows into the Dnipro River. Photographs A and B were taken in different years before the destruction of the reservoir; photograph C shows the site as of May 2024 (photos A and C by M. Maksymenko; photo B from zp.depo.ua).

Discharge outlet of treated municipal wastewater downstream of Zaporizhzhia. Photograph A shows the site before the reservoir was drained; photographs B and C show the site after drainage, as of January 2025.

ity of aquatic organisms. Therefore, within the framework of sanitary protection of the Kakhovka Reservoir, special attention should be given to the construction of dedicated settling ponds. Only after the treatment of industrial and domestic wastewater should its discharge into a system of ponds not connected to the reservoir be permitted... If the measures outlined above are not implemented, a time may come when the waters of the Kakhovka Reservoir can no longer be used for the water supply of settlements and major administrative centers, nor for maintaining a highly productive fishery"[110].

Modern wastewater treatment facilities within the Dnipro River basin have proven incapable of treating wastewater to environmentally safe standards. The alkaline conditions that develop within bottom sediments promote the binding and deposition of toxic substances, making their complete removal from the Dnipro–Buh estuarine system more difficult. A substantial quantity of pollutants accumulated in the bottom sediments of the reservoir, including within the tissues of zebra mussels, owing to their ability to filter large volumes of water[33].

Industrial Sources of Pollution Affecting the Kakhovka Reservoir

More than 400 industrial and agricultural facilities discharging wastewater are located within the Kakhovka Reservoir basin alone, with a combined discharge volume of 6.1 million m^3 per day. Industrial enterprises in Zaporizhzhia discharge 282 million m^3 of untreated or insufficiently treated wastewater annually into the upper part of the Kakhovka Reservoir. For example, the coke chemical plant, Dniprospetsstal, an aluminium plant, and a hardware manufacturing plant together discharge 20.9 million m^3 of wastewater per year. In Dnipropetrovsk region, the principal sources of pollution affecting the Kakhovka Reservoir are Nikopol-based industrial enterprises that discharge more than 50 million m^3 of wastewater annually, including 47 million m^3 of polluted wastewater.

SOIL SALINIZATION

Large areas of agricultural land were irrigated with water from the Kakhovka Reservoir. Owing to a combination of natural and anthropogenic factors, water from this reservoir was the most saline and polluted among all reservoirs of the Dnipro cascade, with a mineralization level of 253-433 mg/L[257] (the normal range for water used for irrigation).

As a result of global climate change, the average air temperature during the growing season increased from 15.9°C to 20.5°C between 1938 and 2018. This led to increased evaporation and, consequently, to higher water mineralization. Significant volumes of water evaporated during transport through the canal network and also during sprinkler irrigation, which literally sprays water into the air, including during the hottest days. Evaporation losses were greatest during periods of maximum water abstraction into the main canals.

In the European Union, agricultural irrigation typically uses 2,500-3,000 m^3 of water per hectare annually[12], with application rates regulated according to crop requirements, whereas in Ukraine irrigation rates are often not standardized. For example, cereal crops in the EU generally receive about 500–800 m^3/ha[16], whereas in Ukraine irrigation rates may exceed 1,000 m^3/ha[8, Appendix D]. Consequently, the prolonged use of irrigation water with elevated or near-threshold salinity promoted the gradual accumulation of salts in the soil.

The Kakhovka Reservoir also received highly mineralized water from steppe rivers[378, p. 15]. Dissolved salt concentrations in the Oril, Inhulets, and Mokra Moskovka rivers exceed 1,000 mg/L, which is the maximum permissible concentration for drinking water under the Ukrainian sanitary standard DSanPiN 2.2.4-171.10[145], indicating generally elevated salinity.

In addition, the soils of southern Ukraine are naturally susceptible to secondary salinization. The aquifers along the border between the Kherson and Zaporizhzhia regions are composed of geological formations with naturally high salt content because this area was once part of the seabed. The highest concentrations of readily soluble salts occur at depths of up to 2 m[287]. Consequently, the shallow occurrence of saline groundwater – particularly in Kherson region – promotes secondary salinization during irrigation using any source of water. The resulting saline solution spreads throughout the entire wetted layer of the soil profile[282]. As a result, irrigated land is gradually rendered unsuitable for cultivation[261].

As the mineralization of water from the Kakhovka Reservoir increased, so did its alkalinity. While the reservoir operated, water pH increased from 7.6 in 1960 to 8.05 in 2018[277]. In the regulated main irrigation canals, both alkalinity and salinity were even higher, with pH values reaching 8.3-8.5. The development of alkaline conditions promoted phytoplankton growth ("water blooms") while also enhancing the binding of toxic elements and their accumulation in the bottom sediments of the reservoir and irrigation canals. The highest concentrations of Cu, Ni, Co, Fe, and Zn were detected in water samples collected from the terminal sections of the canals, where evaporation effects were greatest, whereas the lowest concentrations were recorded near canal intakes[366].

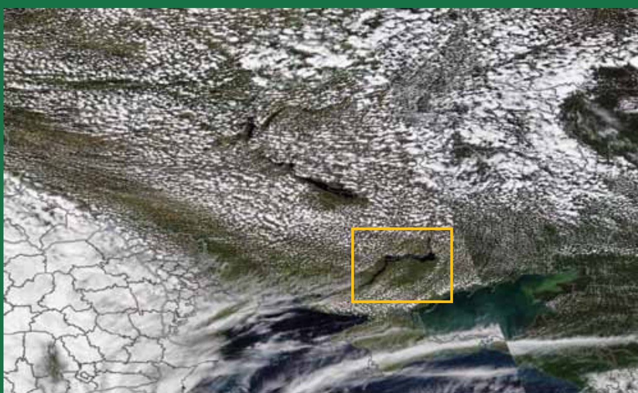
Consequently, among all major water bodies in Ukraine, water from the Kakhovka Reservoir was the least suitable for irrigation and was classified as Class II – "of limited suitability"[113]. The use of such water requires special soil flushing measures[277] that were never implemented. Furthermore, no drainage systems were ever constructed within the irrigation schemes.

16 The Water Framework Directive (2000/60/EC) requires that irrigation practices take ecological sustainability into account and that practices prevent excessive abstraction of water from natural sources. The Regulation on minimum requirements for water reuse (EU) 2020/741 provides methods for determining irrigation requirements based on the quality of reclaimed water available for irrigation. EU Member States apply their own irrigation standards and calculation methods that consider local climatic, agronomic, and technical conditions. For example, Spain uses the SIGPAC (Sistema de Información Geográfica de Parcelas Agrícolas) system, which estimates crop water requirements using satellite data. Irrigation rates therefore vary considerably across the European Union. In southern Spain, particularly in Andalusia, seasonal irrigation requirements may reach 1,000-1,200 mm for crops such as cotton and vegetables, whereas less thirsty crops, including cereals, typically require about 400-600 mm [12].

MICROCLIMATE

The Kakhovka Reservoir was created in the Steppe Zone, the driest natural region of Ukraine. The economic system developed around the reservoir reflected the technological capabilities of the Soviet Union in the mid-twentieth century, when global climate change had not yet begun to affect the economy and was therefore not taken into account in planning and decision-making. Within the area of the former Kakhovka Reservoir, a trend towards increasing average monthly water temperatures became apparent only in the last 30 years. However, this trend is not limited to the reservoir itself but characterizes the region as a whole, where the mean annual air temperature has increased by 1.5°C over the past 130 years. Agroclimatic seasons have also shifted towards a longer spring–summer period. Long-term average monthly water temperatures recorded at hydrological monitoring stations on the Kakhovka Reservoir have likewise increased[298].

These temperature changes resulted in greater water losses through evaporation[298] and an increased demand for water abstraction for irrigation. In turn, greater evaporative losses and increased water withdrawals for economic activities reduced releases from the reservoir and, consequently, river discharge in the lower Dnipro[404]. All these factors point to the growing role of global climate change in the region's water balance.



Cloud-free area above the Kakhovka Reservoir (NASA Worldview satellite imagery)

Most of the water evaporating from the Kakhovka Reservoir fell as precipitation in areas far beyond Ukraine. Meanwhile, areas adjacent to the reservoir remained within a "rain shadow" throughout the spring and summer, precisely when moisture was most needed for irrigating agricultural land. Some increase in precipitation was observed during the colder seasons, in autumn and winter[209]. Thus, the reservoir only marginally moderated the climatic conditions of southern Ukraine.

REGULATION OF RIVER FLOW

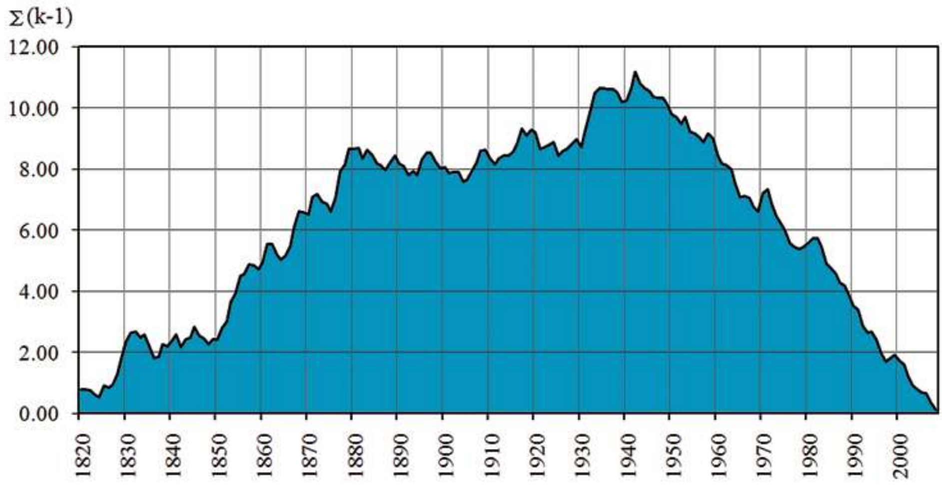
Before the cascade of reservoirs was constructed, the Dnipro River exhibited a natural seasonal flow regime: high flows occurred in spring, while low-flow conditions prevailed during summer. The seasonal development and reproduction of most living organisms in the region depended on these hydrological changes. Spring floods created temporary habitats in flooded meadows, which served as important spawning grounds for certain fish species. The resulting shallow waters also provided ideal feeding areas for migratory birds, some of which established breeding colonies in flooded vegetation that was inaccessible to predators.

The life cycles of many aquatic organisms were likewise adapted to these seasonal natural processes. This was particularly true of anadromous fish species, which migrated upstream in spring to spawn under conditions favorable for the development and growth of their young. Most species spawned in flowing river sections with firm rocky or sandy substrates. It was precisely these habitats that disappeared following the construction of the reservoirs, making successful spawning impossible.

Instead, river regulation placed the flow regime under human control. During the spring flood period, water was retained in the reservoirs so that it could later be used for irrigation during low-water months. At the same time, continuous downstream releases had to be maintained to ensure the operation of hydropower plants and river navigation by preserving the water depths required for navigation along the Lower Dnipro. Clearly, this management model failed to take into account either long-term fluctuations in river discharge or global climate change.

Cycles of Dnipro River Discharge

Scientists have identified long-term cycles in the Dnipro's river discharge that extend over centuries[235]. In 1942, the river entered a low-flow phase, the onset of which coincided with the beginning of the construction of the Dnipro reservoir cascade[238]. Following completion of the construction of the Kakhovka Reservoir and its commissioning, a clear trend towards reduced river discharge in the estuarine section of the Dnipro became apparent[236; 341]. Notably, the cumulative duration of low-flow phases has been approximately 2.1 times longer than that of high-flow phases.



Changes in river discharge in the estuarine section of the Dnipro, 1820-2010[341]

Because the Dnipro–Buh estuarine area has experienced a shortage of freshwater in recent decades, the deficit has increasingly been compensated by saline water entering from the Black Sea shelf[238]. Following the construction of the Kherson Shipping Channel[17] [18][19], during the Soviet period, the volume of saline water penetrating the freshwater ecosystems of the Dnipro Delta has increased (a phenomenon known as the "saltwater wedge"). Saltwater intrusion into the Dnipro channel is further intensified by the ongoing rise in the level of the Black Sea[170].

Effects of the Saltwater Intrusion on the Dnipro's Aquatic Biota

Because saline water is denser than freshwater, it sinks beneath it and penetrates upstream along the river channel. This phenomenon, known as the "saltwater wedge", may occur during low-flow periods in summer, particularly under conditions of global warming. Because the Dnipro has been regulated along almost its entire course, freshwater flow has been substantially reduced, allowing seawater to penetrate much farther upstream than it would under natural conditions.

In turn, increasing water salinity reduces dissolved oxygen concentrations in the Dnipro-Buh liman (a lagoon-shaped estuary) and the Dnipro River delta. Under normal conditions, oxygen deficiency is not observed, with average oxygen saturation ranging from 86% to 90%. However, during storm surges and the intrusion of saline water into the river channel network, oxygen saturation declines to 40-46% (a reduction of 2-2.5 times[238]), with the lowest concentrations recorded in areas of highest salinity. Such a sharp decline in dissolved oxygen may adversely affect biodiversity, as the Dnipro delta supports endemic aquatic species, most of which require well-oxygenated water.

At present, seawater intrusion is widespread both in the Dnipro-Buh estuary and throughout the Black Sea region. Salinity changes associated with the penetration of seawater wedges transform deltas and limans into an artificial analogue of tidal estuaries. Under such conditions, species from the Atlantic Ocean (predominantly invasive ones) gain a significant advantage over the native relict fauna[99].

It is therefore not surprising that the saltwater wedge is considered one of the principal causes of the decline of endemic and relict species in the Dnipro delta and the Dnipro-Buh liman[20], as these species are unable to adapt rapidly to the new salinity gradients.

17 The Kherson Shipping Channel (KSC) is a navigation channel located within the Dnipro–Buh liman. It branches off from the fifth bend of the Buh-Dnipro Liman Canal and extends to the entrance of the Rvach River, a distributary of the Dnipro. The channel provides access for vessels to the Kherson Sea Port and the Kherson River Port, as well as to river ports and terminals located along the banks of the Dnipro. The Kherson Shipping Canal is 40 km long, consists of three bends, and has a navigable width of 100 m [193].

18 The deep-water navigation channel was constructed to accommodate deep-draught vessels traveling from the Dnipro-Buh Liman to the Port of Kherson.

19 During the current period of martial law, regular dredging of the Kherson Shipping Canal has not occurred, as the lower Dnipro valley in southern Ukraine effectively forms the line of contact. In addition, the canal has become silted as a result of sediment transported from the former reservoir following the destruction of the Kakhovka Hydropower Plant dam. Consequently, it is currently difficult to assess the extent to which this factor contributes to changes in the salinity of the Dnipro.

ENVIRONMENTAL CONSEQUENCES

Loss of Biodiversity and Natural Habitats

Within a short period after dam construction began, natural conditions underwent profound changes that occurred in several stages. These changes can be illustrated by birds, as they are highly mobile and rapidly adapt to new environmental conditions. In other words, ecologically flexible groups of animals make it possible to trace ecological changes rather than simply document extinctions, which may be more typical of terrestrial and soil fauna.

During the first two to three years, preparations were made for filling the future reservoir basin. This involved extensive logging and the clearing of orchards[108; 243, p. 3], temporarily expanding the area of open habitats. At this stage, the principal change in bird communities consisted of the large-scale displacement of breeding species from their nesting sites to adjacent areas.

During the second stage – the filling of the reservoir bottom with water – open habitats gave way to shallow-water areas. During this period, marked changes in bird communities were observed: populations of Eurasian Coot (*Fulica atra*) increased by an order of magnitude, Black-headed Gull (*Chroicocephalus ridibundus*) by hundreds of times, or perhaps even more, and Great Crested Grebe (*Podiceps cristatus*) by several tens of times. Newly formed islands and extensive reedbeds within the future reservoir provided favorable nesting conditions for these species. At the same time, fluctuations in water level during the filling of the reservoir and the formation of waves destroyed many duck nests. As **the reservoir filled**, new temporary habitats also developed, including temporary islands, flooded forests, and reedbeds interspersed with floating peat mats[226].

The formation of the reservoir's open water surface resulted both in the destruction of some habitats and the creation of others. Changes in habitat composition were less pronounced than changes in their extent. Most terrestrial habitat types characteristic of the Dnipro floodplain landscape survived only in small areas along the reservoir margins and at the mouths of its tributaries. Likewise, some aquatic habitats also persisted, mainly in the upper part of the reservoir. However, because this section of the river lost its rheophilic conditions[259; 327], the ecological role of these habitats changed substantially for all groups of vertebrates, especially anadromous fish species[362; 363], as well as for planktonic and benthic organisms[169; 212; 258; 319; 360; 361].

The shallow waters of the reservoir began to attract larger numbers of birds during migration than had previously occurred under the free-flowing conditions of the Dnipro[226], and their stopovers for feeding and resting became longer[227]. Meanwhile, the absence of unvegetated sandy and muddy shoals on the reservoir led to a sharp decline in wading bird populations.

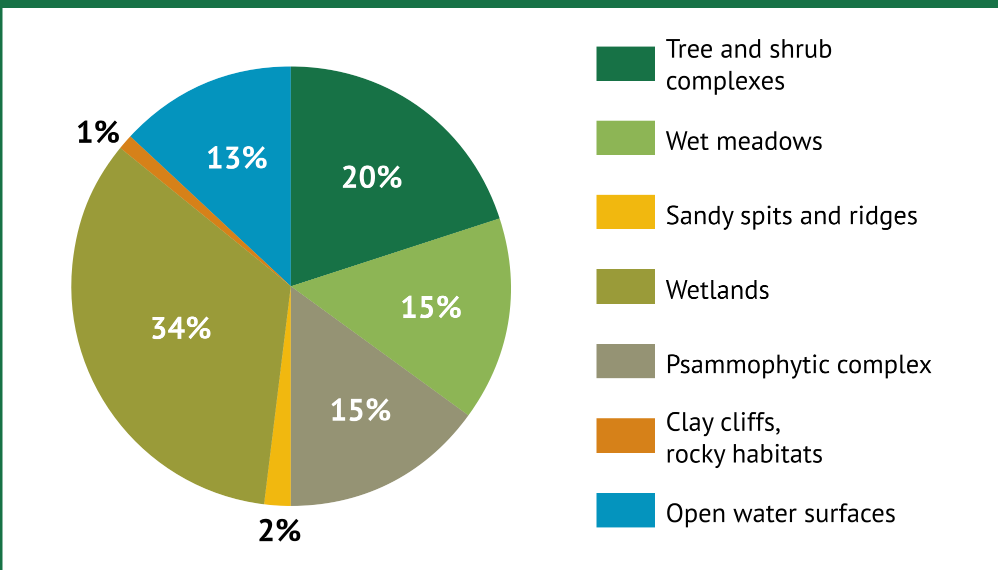
The fact that the water immediately upstream of the dam remained ice-free even during winter created favorable conditions for wintering waterbirds, which no longer needed to migrate as far as the Black Sea coast. As a result, new wintering concentrations were established[121; 126; 159; 160; 161; 175; 176; 177; 178; 179; 180; 225; 226; 228; 229; 230; 231; 232; 242; 260; 326].

Most species whose populations increased sharply during the years when the reservoir was being filled had almost disappeared again by the end of the 1950s. Among birds associated with sandy shoals, the Little Tern (*Sterna albifrons*), Eurasian Oystercatcher (*Haematopus ostralegus*), and Stone-curlew (*Burhinus oedicnemus*) declined markedly. Species inhabiting dry meadows, sandy ridges, and steppe ridges overgrown with oak scrub were likewise deprived of their traditional nesting sites[226].

Flooded Habitats of Velykyi Luh

In the 1950s, Ukrainian scientists did not yet use the concept of "habitats" and instead relied on their own intuitive classifications. Based on the scientific works of that period, it is possible to make an approximate assessment of the composition and distribution of different habitat types within the flooded area. The area flooded by the reservoir included forests, various types of grasslands, wetlands, sand ridges, rocky habitats, and open water surfaces of the Dnipro channel and oxbow lakes. A modern interpretation of these habitats is provided in **Appendix 1.**

Tree and shrub complexes were represented primarily by poplar forests (the largest in area and generally associated with river channels); riparian willow forests; alder forests (associated with depressions near floodplain terraces); and floodplain oak forests (distributed on the highest elevations of the floodplain). Following flooding, these natural complexes persisted within the reservoir area only on coastal sections and on the island archipelago in its upper part. In addition, extensive areas of the floodplains of the former Konka River were occupied by birch groves dominated by the endemic Dnipro birch, which survived only in small numbers within the Velyki Kuchuhury Island archipelago.



Distribution of habitat groups prior to the creation of the Kakhovka Reservoir

In modern terms, the “tree and shrub complex” can be assigned to at least eight habitat types, five of which are protected under Resolution No. 4 of the Bern Convention[132]. At the time of flooding, the total area of these habitats was approximately 55,000 ha[305].

Wetland habitats and meadows historically developed under conditions of periodic flooding by spring waters accompanied by the deposition of silt[117]. Their area increased substantially as a result of intensive grazing and haymaking during the Soviet period.

The former diversity of meadows and wetlands included at least 13 habitat types, six of which are protected under Resolution No. 4 of the Bern Convention. At the time of flooding, wet meadows occupied approximately 41,000 ha, while wetlands and waterlogged areas covered about 92,000 ha[305].

The sandy psammophytic complex was represented by psammophytic steppes, dry meadows, sandy spits and ridges (comprising two habitat types, one of which is protected under Resolution No. 4 of the Bern Convention). Dry meadows were associated with elevated and relatively dry sites and covered approximately 40,000 ha[305]. Psammophytic steppes were characterized by a high degree of endemism. In particular, they supported endemic species such as *Centaurea appendicata* and *Centaurea konkae*, as well as a considerably larger number of subendemics, including, in addition to the previously mentioned Dnipro birch (*Betula borysthenica*), *Dianthus platyodon*, *Achillea euxina*, *Agropyron dasyanthum*, *A. lavrenkoanum*, *Jacobaea borysthenica*, *Goniolimon graminifolium*, *Tragopogon borysthenicus*, *Jurinea paczoskiana*, *Helichrysum corymbiforme,* and others. Today, communities of psammophytic steppes occupy only very small areas on the Velyki and Mali Kuchuhury islands[234; 274]. Many of these endemic plant species are included in conservation lists. In addition to dry meadows, sandy habitats occurred along the shores of the Dnipro and its distributaries (including temporary spits formed after spring floods), as well as on the former high ridges extending along the left bank of the Konka River. The total area of sandy spits and ridges reached up to 6,000 ha[305].

The petrophytic complex (grasslands growing on rocky substrates) was represented by clay cliffs and slopes, as well as rocky outcrops (the latter habitat type is protected under Resolution No. 4 of the Bern Convention).

Rocky outcrops occupied only a limited area within the flooding zone, including the outcrops of islands located downstream of the Dnipro Hydropower Plant, the northern shore of Khortytsia Island, and adjacent sections of the bedrock banks of the Dnipro River.

Following the creation of the Kakhovka Reservoir, wave erosion led to the formation of high cliffs along at least 80% of the total shoreline length[127; 128]. The expansion of cliff and slope habitats resulted in an increase in the abundance of several bird species nesting in burrows excavated in sandy and clay riverine cliffs.

Aquatic Habitats. The remainder of the area subsequently occupied by the Kakhovka Reservoir (approximately 13%) consisted of areas of open water, including the flowing channels of the Dnipro and its branches, as well as the standing waters of oxbow lakes (representing eight different habitat types, five of which are protected). Following the filling of the reservoir, the area of these habitats increased by almost 770%. This created a substantial disproportion in favor of open water surfaces, which are not utilized by most terrestrial animals[132].

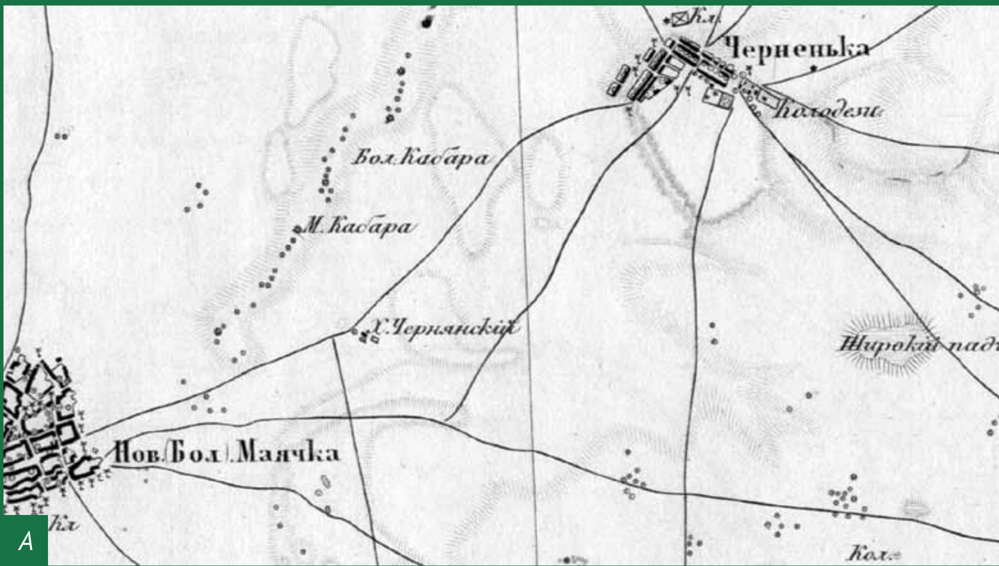
At present, it is difficult to make quantitative predictions regarding the prospects for habitat recovery within the former reservoir area, because despite the visual similarity of the relief of the Dnipro valley, the natural conditions of the territory have undergone profound changes.

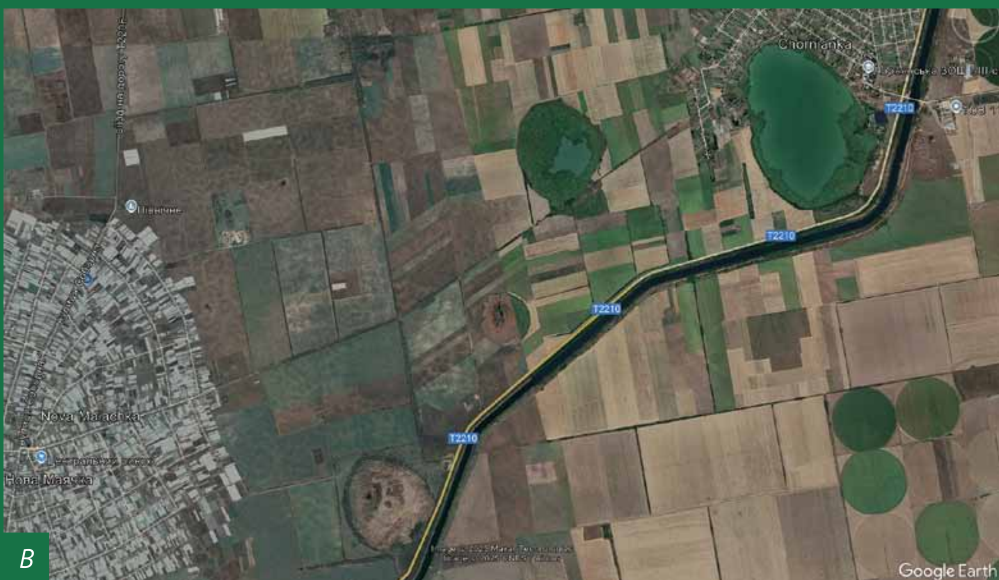
At the level of aquatic habitats, the flooding associated with the creation of the Kakhovka Reservoir represented one episode in the large-scale transformation of the Dnipro ecosystem and its biota. Historically, free-flowing river habitats (epipotamal streams (upper reaches of a lowland *streams*), corresponding to EUNIS habitat C2.31) were widespread throughout the large river basins of the Azov–Black Sea region. Under such conditions, communities developed that included both species adapted to a wide range of environmental conditions and specialized rheophilic species, i.e. species characteristic of fast-flowing waters (including the thick-shelled river mussel *Unio crassus*, which functioned as one of the most abundant filter feeders).

Following the construction of the reservoir cascade, these habitats were transformed into mesotrophic (C1.2) and eutrophic (C1.3) water bodies, while the river sections between reservoirs were converted into lowland river habitats with reduced flow velocity, namely metapotamal and hypopotamal streams (C2.32). As a result, the original conditions of the Dnipro valley were lost almost everywhere within Ukraine. Together with climate change, this led to the disappearance of a number of rheophilic species, while Ponto-Caspian species that readily adapted to the conditions of large reservoirs formed new communities. These communities became dominated by zebra mussels and other species not historically characteristic of the Dnipro.

Effects of the Kakhovka Reservoir Irrigation Systems on Native Species

The habitats of areas surrounding the irrigation canal network also underwent substantial changes. Plants characteristic of wet environments (hydrophytes and hygrophytes) spread deep into the steppe along the canals, while mesophilic species, i.e. species requiring moderate moisture and moderate temperatures, expanded along the canal corridors despite being uncharacteristic of the steppe region[275]. Some steppe depressions (*pody*) located near the North Crimean Canal were transformed into lakes after receiving water from the canal system (for example, the pody near the village of Chornianka). Irrigation of previously dry steppe areas also resulted in an increase in the abundance of insect species harmful to agriculture[254; 255]. On the other hand, extensive ploughing within irrigated areas meant that the surroundings of irrigation canals in many places became the last remaining refugia of natural habitats, although these habitats were not characteristic of the region.





Pody between the villages of Chornianka and Nova Maiachka (A – Schubert Map) that were transformed into lakes due to the construction of the North Crimean Canal (B – Google Earth, 2019).

Thus, construction of the Kakhovka Reservoir resulted in either the complete disappearance of or catastrophic reduction in surface area of several dozen habitat types. A substantial proportion of these habitats would now qualify for protection under contemporary conservation standards. They were replaced by a uniform and relatively species-poor ecosystem of slow-flowing waters represented by the water body of the Kakhovka Reservoir.

Challenges to Biodiversity Caused by Water-Level Fluctuations

One of the changes that, although local in scale, has had very important consequences is the fluctuation of water levels downstream of the dam of each hydropower plant. As a result, the living conditions of many organisms became subject to numerous new constraints. For riparian vegetation, periods of temporary flooding began to alternate with periods of exposure. The decline in the abundance of native species created opportunities for the spread of invasive flora, particularly species such as false indigo-bush (*Amorpha fruticosa*)[395], which occupies extensive areas of riparian habitats.

Animals inhabiting the water column or aquatic vegetation (for example, larvae of dragonflies and other invertebrates) become stranded due to water-level fluctuations. Where shorelines are gently sloping, water inundates floodplain areas, where isolated pools then form after water levels recede. As a result, aquatic organisms (including juvenile fish) are trapped[20].

Birds cannot build nests on aquatic vegetation, beaches, or shoals, and beavers cannot construct lodges there, because such structures would either be flooded on a daily basis or become accessible to predators[157].

The construction of the Kakhovka Hydropower Plant and the regulation of the Dnipro also substantially affected forest vegetation downstream of the dam. In the past, prolonged late-season floods resulted in the complete absence of typical forest species in the forests of the Dnipro Delta. The renowned botanist J.K. Paczoski noted in 1915 that during floods near Kherson, the Dnipro floodplain was transformed into a continuous body of water approximately four kilometers wide, above which only the tops of trees remained visible[310].

The tree layer was formed by only three species: white willow (*Salix alba*), white poplar (*Populus alba*), and black alder (*Alnus glutinosa*). Although other tree species occurred in areas adjacent to the Dnipro Delta, they did not spread into the floodplain because they could not tolerate prolonged flooding. These included pedunculate oak (*Quercus robur*), Dnipro birch (B*etula borysthenica*), European aspen (*Populus tremula*), and common pear (*Pyrus communis*). The same applied to shrub and herbaceous vegetation. Thus, the flora of the Dnipro delta was characterized by exceptional poverty and consisted almost exclusively of wetland species.

Following the construction of the Kakhovka Hydropower Plant, prolonged late-season flooding ceased, and the flora of the Dnipro delta became substantially richer. Instead of only three tree species, dozens of tree species now occur there, including alien species such as tree-of-heaven (*Ailanthus altissima*), Siberian elm (*Ulmus pumila*), and honey locust (*Gleditsia triacanthos*), among others.

SPREAD OF ALIEN SPECIES

The appearance of new animal species in the Kakhovka Reservoir that had not previously occurred there resulted in significant changes in species composition:

20 It should be acknowledged that shorebirds benefit from this situation by feeding on fish trapped in isolated pools, since zones characterized by dynamic water-level fluctuations are particularly rich in food resources.

native species adapted to rheophilic conditions began to be replaced by alien species. For example, many alien fish species are much better adapted to ecological conditions in disturbed ecosystems, are less demanding with respect to spawning habitats and water quality, and some of them exhibit parental care and protect their offspring. In general, alien species are characterized by high ecological plasticity, which facilitates their successful spread into new water bodies.

As a result of the formation of the reservoir cascade, the range of the native Ponto-Caspian fauna[21] expanded, which in some cases may be regarded as a biological invasion[58; 59]. A substantial proportion of these species appeared in the Lower Dnipro basin as a result of the deliberate introduction of forage fauna following the creation of the reservoir. This is noteworthy because relict representatives of the Ponto-Caspian fauna historically inhabited the territory of the Velykyi Luh; moreover, it was here that its most freshwater-adapted component evolved[44]. Nevertheless, this large-scale introduction of forage fauna led to a profound restructuring of biological communities within the Lower Dnipro basin[22].

As a result, mixed communities dominated by zebra mussels developed, including the widespread *Dreissena polymorpha* and the closely related *Dreissena bugensis*. Prior to the construction of the reservoir cascade, these species occurred only in the estuarine part of the basin; however, following the creation of the reservoirs, they became invasive species in many parts of the Dnipro basin.

Zebra Mussel Colonies on the Bottom of the Kakhovka Reservoir

Before the destruction of the Kakhovka Reservoir dam, the biomass of dreissenid mussels in different parts of the reservoir bottom ranged from several grams to several kilograms per square meter[107]. Dreissenids also colonized the irrigation canals supplied by the reservoir. For example, in the Kakhovka Main Canal, the combined summer biomass of *Dreissena polymorpha* and *D. bugensis* exceeded 430 g/m² on average[367].

On the one hand, filter feeding dreissenids contribute to water purification. On the other, large zebra mussel colonies can substantially deplete plankton communities, which may lead to declines in the abundance of other freshwater bivalves. In addition, the waste produced by these molluscs contains significant amounts of nutrients (nitrogen and phosphorus), which promote the intensive development of benthic algae[66]. Dreissenids are considered among the most harmful invasive species in North American reservoirs[86].

21 Ponto-Caspian fauna refers to the assemblage of aquatic organisms (fish, crustaceans, molluscs, and others) that historically evolved within the basins of the Black, Azov, and Caspian seas. These species are characterized by adaptations to brackish and freshwater environments and by high ecological plasticity, which enables them to successfully adapt to new environmental conditions.

22 For the Kakhovka Reservoir itself, the expansion of Ponto-Caspian species was generally not a biological invasion. However, the reservoir acted as a corridor for the large-scale natural expansion of species ranges and their upstream dispersal, where they "incorporated" into analogous communities and subsequently established themselves as successful invasive species.

The four alien fish species with the greatest invasive potential in the Lower Dnipro are the Prussian carp (*Carassius gibelio*), stone moroko (*Pseudorasbora parva*), pumpkinseed (*Lepomis gibbosus*)[19], and Amur sleeper (*Perccottus glenii*). Some new species entered the Kakhovka Reservoir from the Black Sea. These include, first and foremost, the black-striped pipefish (*Syngnathus abaster*)[38; 98], the Azov-Black Sea sprat (*Clupeonella cultriventris*), the three-spined stickleback (*Gasterosteus aculeatus*), and others[39; 294].

The development of the river transport corridor and the appearance of large river-sea vessels in the reservoir also affected changes in the fauna. Many organisms are transported along with water pumped into ballast tanks belonging to commercial vessels. This is how the Chinese mitten crab (*Eriocheir sinensis*) entered the Dnipro basin (it was first recorded in the Kakhovka Reservoir near the town of Nova Kakhovka in 2002[292] and near the city of Nikopol in 2003[342]).

One of the factors that promoted the spread of alien species was the discharge of warm water from the cooling pond of the Zaporizhzhia Nuclear Power Plant[60]. This resulted in the colonization of the cooling pond by new species, such as Mozambique tilapia (*Oreochromis mossambicus*)[18], guppy (*Poecilia reticulata*), and mollusc *Tarebia granifera*[27].

Due to global warming in the Kakhovka region (as well as in many other regions of Ukraine), the red-eared slider (*Trachemys scripta*)[29] is displacing the native European pond turtle (*Emys orbicularis*). The invasive red-eared slider is also a highly active predator that negatively affects native fauna. It is also worth mentioning the spread of the jellyfish *Craspedacusta sowerbii* in the reservoir, whose abundance in the Dnipro reservoirs began to increase during the twenty-first century.

Invasive Plant Species in the Kakhovka Reservoir

The flora of the Kakhovka Reservoir also changed due to the introduction and establishment of new plant species that were not characteristic of the region. In the water, Canadian waterweed (*Elodea canadensis*), a species of North American origin that causes problems in artificial water bodies throughout Europe, became particularly widespread.

A much larger number of alien plant species occurred in the coastal areas of the former Kakhovka Reservoir during the years of its existence, including tree-of-heaven (*Ailanthus altissima*), Siberian elm (*Ulmus pumila*), honey locust (*Gleditsia triacanthos*), common hackberry (*Celtis occidentalis*), box elder (*Acer negundo*), Russian olive (*Elaeagnus angustifolia*), white mulberry (*Morus alba*), green ash (*Fraxinus pennsylvanica*), false indigo-bush (*Amorpha fruticosa*), barnyard grass (*Echinochloa crus-galli*), Elbe cocklebur (*Xanthium albinum*), beggar-ticks (*Bidens frondosa*), and others.

Invasive jellyfish Craspedacusta sowerbii in the Kakhovka Reservoir, 12 July 2020[28]

Black Sea sprat (Clupeonella cultriventris) in the Kakhovka Reservoir, 8 August 2020[17]

Mozambique tilapia (Oreochromis mossambicus) in the Zaporizhzhia Nuclear Power Plant cooling pond, 4 September 2017[18]

Pumpkinseed (Lepomis gibbosus) in the Kakhovka Reservoir, 10 June 2022[19]

Black-striped pipefish (Syngnathus abaster) from the Lower Dnipro, 1 May 2021[28]

Red-eared slider (Trachemys scripta) in the Kakhovka Reservoir near Khortytsia Island[29]

CONTEMPORARY IMPORTANCE OF THE KAKHOVKA RESERVOIR FOR THE ECONOMY AND REGIONAL DEVELOPMENT

The Kakhovka hydroelectric complex and reservoir were designed as multipurpose facilities intended for electricity generation, increasing the navigable depth of the Dnipro River on the Kakhovka-Zaporizhzhia section, water supply for cities and villages, irrigation of agricultural land, and regulation of water discharge levels (flood control).

ELECTRICITY GENERATION

At the time of the destruction of the Kakhovka Hydropower Plant in 2023, it was one of ten large hydropower plants in Ukraine and one of the seven located on the Dnipro River (most of which were damaged by missile strikes in 2024). Its maximum installed capacity was 334 MW, and its average annual electricity generation amounted to approximately 1 billion kWh. On the scale of Ukraine, this represented a very small share of electricity production – less than 1%[332].

Peak use of electricity generated by the Kakhovka HPP occurred during the summer period due to the need to pump water for agricultural irrigation, supply electricity for air conditioning, and support the resort economy (before the full-scale invasion, southern Ukraine was one of the country's key domestic tourism destinations). On average, the pumps supplying water to the main irrigation canals consumed 15% of the total electricity generated by the Kakhovka Hydropower Plant annually, while during the hottest season they consumed no less than 89.5%[23].

23 During hot summer months, when the demand for irrigation water is at its highest, the total capacity of the pumps supplying water reaches 300 MW. This figure approaches the maximum capacity that the Kakhovka HPP was capable of generating under such conditions (335 MW). Thus, virtually all of the electricity generated by the hydropower plant was used exclusively to operate the pumping systems, highlighting the high energy demands of the irrigation system.

Flood Protection Measures

In some areas along the reservoir, dikes with drainage pumping stations were constructed to protect residential and industrial areas from flooding (see the section **"Construction of the Kakhovka Reservoir"**).

The creation of the reservoir and the rise in the water level of the Dnipro altered the configuration of the mouths of a number of its tributaries. To prevent the flooding of settlements, where the difference in water levels between the rivers and the reservoir reached 9-15 m, the mouths of some rivers were blocked by dams. Pumping stations were installed at these dams to pump water into the reservoir. The pumping capacity of the stations on the Bazavluk River was 30 m³/s, 20 m³/s on the Tomakivka River, and 5 m³/s on the Bilozirka River (their total capacity was 55 m³/s). The operation of all the above-mentioned pumping stations required additional long-term electricity consumption.

Role of the Kakhovka Reservoir in Balancing the Energy System

Compared to the other hydropower plants of the Dnipro cascade, the Kakhovka HPP had the lowest capacity[348]. However, it performed the critically important function of regulating water levels within the whole cascade, including storing water during the spring flood period[24].

As the last reservoir in the cascade, the Kakhovka Reservoir received significant volumes of water discharged from the upstream Dnipro HPP. Since the Dnipro HPP provided peak-load regulation within the power system, the volumes of discharged water could increase sharply depending on operational needs. Without the buffering effect provided by the reservoir, the passage of large volumes of water would have caused extensive bank erosion and flooding of adjacent areas. At the same time, the issue of ensuring electricity generation during peak loads is not so much a matter of the Kakhovka HPP itself as of the operational flexibility of the upstream Dnipro HPP.

The Kakhovka HPP also participated in balancing the output of renewable energy sources (RES), whose electricity generation depends on variable weather conditions[25]. Following the beginning of the full-scale invasion, a significant number of Ukrainian renewable energy facilities were damaged by russian attacks. According to expert estimates, by August 2022, 30-40% of the region's wind and solar power plants had already been damaged (representing approximately 1,120-1,500 MW of installed capacity)[303].

At present, a large number of renewable energy projects have already been approved for construction or are undergoing the permitting process. This indicates that, following the end of military operations in southern Ukraine, not only will damaged facilities be restored, but active construction of new wind and solar power plants will also begin.

24 Previously, the Kakhovka Reservoir functioned as a storage reservoir for the accumulation of Dnipro water during the spring flood period, with a storage volume of 3-5 km³. These reserves were gradually used throughout the year, primarily for irrigation. It is impossible to compensate for the loss of the Kakhovka Reservoir through additional water storage in other reservoirs, as they have a much smaller storage capacity intended for short-term flow regulation, hydropower generation, and meeting the needs of adjacent settlements.

25 As of 2022, the southern regions of Ukraine were national leaders in both the number and installed capacity of RES: the Dnipropetrovsk, Kherson, and Mykolaiv regions together accounted for more than 37.3% of the country's total installed renewable energy capacity.

WATER SUPPLY

Three main canals originated from the Kakhovka Reservoir: the North Crimean Canal, the Kakhovka Canal, and the Dnipro-Kryvyi Rih Canal (the only one remaining under Ukrainian control as of 2024). These canals supplied a number of irrigation systems: the Kakhovka, North Crimean, Kamianka, Pryazovia, and North Rohachyk irrigation systems. Taken together, during the summer period, these canals were capable of diverting more than half of the average long-term discharge of the Dnipro (at least 922 out of 1,670 m^3/s). Meanwhile, the reservoir had sufficient storage capacity to maintain the flow of the Dnipro through the continuous release of water via the turbines of the Kakhovka HPP.

Within Zaporizhzhia region alone[26], prior to the full-scale invasion of Ukraine by the russian federation, there were 102 registered water intake facilities on the Kakhovka Reservoir with a total capacity of 169.16 m^3/s, the majority of which were intended for irrigation or energy production.

North Crimean Canal

This canal is the largest in Europe (402.6 km in length) and supplied water from the Dnipro for agricultural and urban needs in Crimea. The canal begins near the Kakhovka Dam and ends at the wastewater treatment facilities of the city of Kerch[389] (eastern Crimea).

In the second half of the 1980s and the early 1990s, annual water withdrawals from the reservoir into the canal reached 3.5 km^3. Subsequently, with the transition to more efficient water use, annual water withdrawals decreased to 1.5 km^3 (of which 0.5 km^3 was used in Kherson region and 1.0 km^3 in Crimea)[219, p. 10], and since 2014 have amounted to 0.5 km^3.

During the construction of the canal, hydraulic engineers decided not to implement seepage protection measures in order to complete the construction of the canal to its destination as quickly as possible[314]. This resulted in a rapid increase in water losses during conveyance: between 1998 and 2003, losses increased from 23% to 52%[381]. Additional water losses also occurred due to the inefficient irrigation of agricultural crops using sprinkler systems.

The high energy consumption of the canal remained a significant challenge. Continuous water supply was maintained by pumping stations that consumed substantial amounts of electricity[389].

Following the annexation of Crimea in 2014, Ukraine stopped supplying water to the peninsula by blocking the canal with a dam. In February 2022, russian military forces occupying Kherson region unilaterally reopened the sluices. Water supply to Crimea continued until the Kakhovka disaster[240].

26 According to data from the Zaporizhzhia Regional Office of the State Agency of Ukraine for Land Reclamation Development, Fisheries and Food Programs.

Canals Associated with the Kakhovka Reservoir

Kakhovka Main Irrigation Canal

The canal was intended to provide drinking water to a number of settlements (the cities of Berdiansk, Prymorsk, and Melitopol, and the towns of Kyrylivka, Pryazovske, and others) with a total population of 493,000 (prior to the outbreak of the war). It also supplied water for the irrigation of agricultural lands in Kherson and Zaporizhzhia regions. In 2020–2021, the irrigated area amounted to 240,000 hectares, with total water consumption reaching up to 1.0 km^3.

Dnipro-Kryvyi Rih Canal

The canal was constructed between 1957 and 1961 to supply water to the industrial facilities of the city of Kryvyi Rih. Its total length is 41.3 km[239].

Using pumping stations, water from the Kakhovka Reservoir was supplied to the artificial Southern Reservoir, with a lift of 80 m. The continuation of the Dnipro-Kryvyi Rih Canal (Canal 33) connects the Southern Reservoir with the channel of the Saksahan River.

In addition to supplying water to the population and industry, water from the canal was also used for the irrigation of adjacent lands. At present, the canal operates only partially, on a section extending from the Inhulets River to the Southern Reservoir.

IRRIGATION

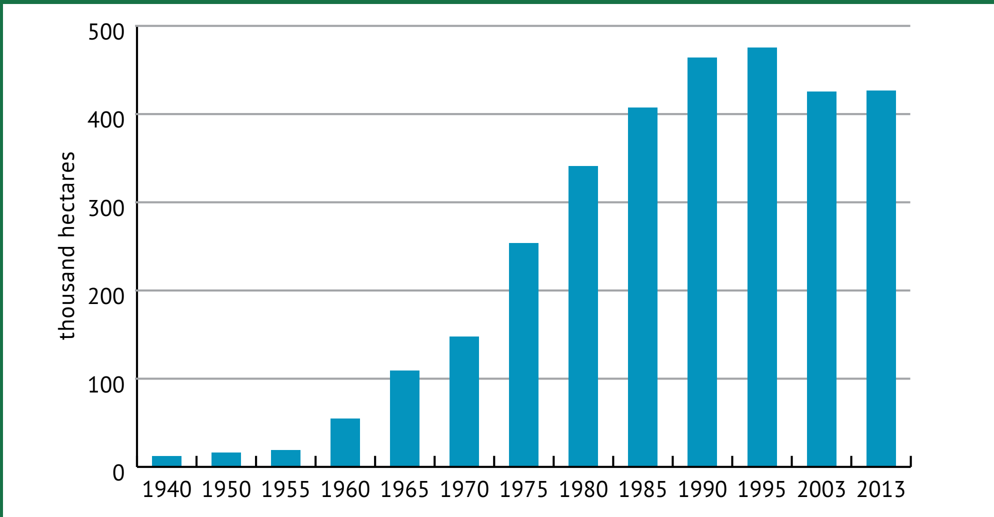
Southern Ukraine is a region with climatic conditions that are too arid for rainfed agriculture; therefore, irrigation systems began to develop here as early as the 1920s. Initially, these consisted of small irrigated areas supplied by open earthen canals using local water sources. In 1941, their total area amounted to 14,700 hectares[112].

Large-scale irrigation systems in southern Ukraine emerged with the construction of the Kakhovka hydropower complex. The projected area of irrigated lands dependent on the Kakhovka Reservoir was approximately 1.5 million hectares[27] (at that time, this represented a 100-fold increase in the area of irrigated land), while the actual irrigated area in 2021 amounted to 329,000 hectares[28].

Despite the negative environmental impacts of the reservoir and irrigation[318] (see the section **“Environmental Consequences of the Construction of the Kakhovka Reservoir. Soil Salinization”**), irrigated areas in southern Ukraine continued to increase prior to the full-scale invasion, and 94% of all water use in Kherson region was allocated to irrigation[365].

27 Letter of the State Agency of Water Resources of Ukraine No. 905/7/8/11-24, dated 16 February 2024.

28 Letter of the State Agency of Water Resources of Ukraine No. 5002/7/8/11-2, dated 29 August 2024.



Dynamics of Irrigated Land Area in Kherson region, 1940-2013[155]

Municipal Water Supply

Virtually all water intakes from the Kakhovka Reservoir have been left high and dry due to the reservoir's water level being lowered.. For the cities of Nikopol, Kamianka-Dniprovska, Enerhodar, and Nova Kakhovka, restoration did not pose a major challenge due to their close proximity to the waterline. Within two months after the disaster, the city of Nikopol restored its centralized water supply by relocating the water intake to the channel of the Dnipro River[256]. In addition, a main water pipeline to the city was constructed as part of an experimental project. However, many smaller villages, as well as the industrial agglomeration of Kryvyi Rih, Marhanets, and Pokrov, required the construction of fundamentally new water supply systems. In Marhanets, the local authorities drilled wells and also laid pipelines from the Mykolaiv Reservoir, which provided the community with technical water.

As of the end of 2024, a significant proportion of the water intakes located along the right bank of the Dnipro had already resumed operation: intake pipes were extended and water abstraction points were relocated. A of early 2025, three additional trunk water pipelines had been put into operation[272], supplying water from the Inhulets and Dnipro rivers to settlements in Dnipropetrovsk region: "Zaporizhzhia-Tomakivka-Marhanets", "Marhanets-Nikopol-Pokrov", and "Inhulets River-Southern Reservoir"[1].

The Government of Ukraine continues to finance projects for the construction of trunk water pipelines for territories affected by the destruction of the Kakhovka Hydropower Plant[29]. In addition, pilot projects are planned to identify alternative water supply sources for settlements in Mykolaiv region[355].

CONTEMPORARY IMPORTANCE

29 In April 2024, the State Agency for Restoration and Infrastructure Development of Ukraine was additionally allocated UAH 5.1 billion on a non-repayable basis (development expenditures) from the fund for the elimination of the consequences of armed aggression to finance the construction of trunk water pipelines

The development of water supply through closed pipeline systems is not associated with water losses due to evaporation; therefore, restoring water supply in this manner will be more efficient, resource-saving, and sustainable.

INDUSTRIAL WATER SUPPLY

The largest consumers of water from the Kakhovka Reservoir, apart from irrigation systems, were industrial facilities. In particular, these included the traditionally water-intensive metallurgical industry (PJSC "Zaporizhstal Iron and Steel Works") (80.818 million m³, based on 2021 data)[214], as well as the Zaporizhzhia Thermal Power Plant of PJSC "DTEK Dniproenergo"[30]. The latter operates a "once-through" cooling system, whereby water is withdrawn directly from a natural water body and returned to it immediately after use.

Water from the Kakhovka Reservoir was also used to fill the cooling pond of the Zaporizhzhia Nuclear Power Plant (300 million m³ per year[288, p. 11], equivalent to 1.65% of the reservoir's volume). Following the destruction of the Kakhovka Dam in 2023, personnel at the Zaporizhzhia Nuclear Power Plant drilled 11 wells, providing a supply of 250 m³ of water per hour[4] for reactor cooling.

Following the drainage of the reservoir, water abstraction declined significantly. However, enterprises that had not been damaged during military operations adapted to the new conditions by introducing closed-cycle water circulation systems or constructing their own water pipelines[330]. As a result, production capacities in the metallurgical industry were restored. For example, during the first half of 2024, the production of pig iron, steel, and rolled products increased by 22% compared with the first half of 2023[356].

LOGISTIC

Port Infrastructure

Ports located within the area of influence of the Kakhovka Reservoir were of significant economic importance. The Nikopol River Port of JSC "Ukrrichflot"[63] provided transportation of ore, metals, and construction materials[101], while the Kamianka-Dniprovska River Transshipment Terminal[9] was used for the transport of agricultural products (grain and oilseed crops)[102]. Following the destruction of the Kakhovka HPP and the loss of the reservoir, access to these ports became difficult or was lost altogether. In addition, due to the catastrophic flooding caused by the destruction of the Kakhovka HPP, some ports in the Dnipro delta sustained physical damage, including the Kherson[65] and Nova Kakhovka[64] river ports of JSC "Ukrrichflot" and the Dnipriany River Port[62] in the city of Nova Kakhovka. All of this led to a reduction in cargo throughput within the Dnipro transport system.

30 In 2021, the enterprise withdrew 732.933 million m³ of fresh water from the Kakhovka Reservoir, accounting for 73.6% of the total water abstraction in the region, or 4% of the total volume of water in the Kakhovka Reservoir. The authors were unable to determine the volume of water returned to the reservoir.

Kamianka-Dniprovska River Terminal before the destruction of the reservoir [289]

Location of the terminal after the reservoir drained[61]

The restoration of the free-flowing Dnipro means the loss of an additional function previously performed by the reservoir – maintaining stable water levels in the lower reaches of the Dnipro. The draft of vessels and the depth of the Kherson Sea Canal had been adapted to these conditions. Without the Kakhovka Reservoir, seasonal fluctuations in river water levels downstream of the Dnipro HPP dam will be restored (in contrast to the short-term daily cycles that existed previously), which will limit the use of Dnipro ports during low-water periods.

New port infrastructure constructed to replace destroyed facilities may be adapted to the transshipment of cargo from large seagoing vessels to smaller river vessels capable of passing through locks and navigating the Dnipro River channel.

Navigation

One of the main reasons for constructing the cascade of reservoirs on the Dnipro was to provide the economy with inexpensive water transport. However, despite its low cost, the volume of river freight transport has been continuously declining over the last 40 years: from 30.8 million tons in 1980[262] to 8.25 million tons in 2021. At present, only 0.15% of the total freight transport volume in Ukraine is carried by river transport. A similar trend of decline is observed in other European countries[11]. Global climate change significantly affects the flow dynamics of navigable rivers, leading to periods of extremely low water levels in certain years[91] and, consequently, to the gradual decline in the importance of river transport.

The number of passengers using water transport has also decreased: in 2013, it accounted for 0.3% of all passengers in the country[389].

At the same time, the lock of the Kakhovka HPP occupied a special place within the Dnipro cascade, as all river vessels engaged in international navigation passed through it[31]. In 2021, 43% of all cargo transported along the Dnipro passed through

31 By weight, the main category of cargo consisted of grain intended for loading onto seagoing vessels and subsequent export.

the Kakhovka navigation lock[32]. This resulted in the deterioration of hydraulic engineering structures: the technical condition of the Kakhovka lock structures in 2020 was assessed as "emergency"[173].

In addition to physical deterioration, the reservoir itself created numerous obstacles to inland water transport, including:

- the risk of wave formation during strong winds, particularly rapid in shallow waters;
- difficulties in navigation due to the need to follow the navigable channel. Significant siltation of the reservoir bottom negatively affected the guaranteed navigation depth of 365 cm[297];
- restrictions on vessel dimensions due to the size of the HPP locks. The locks at the Kakhovka HPP dam have a width of 18 m, which is insufficient for the passage of seagoing vessels;
- the impossibility of passing through the locks in winter and, conversely, delays and queues at the locks during summer.

Reasons for the rapid decline in freight transport on the Dnipro may vary; however, this fact itself refutes arguments about the decisive role of the dam and reservoir in navigation on the Dnipro River. It is entirely possible that climate change will also reduce the flow of the Dnipro, to which river transport will have to adapt.

Land Transport

For 70 years, the reservoir was the largest water body in Ukriane's steppe zone, creating significant obstacles to land transportation. Meanwhile, transport logistics played an important role in supporting the functioning of the industrial region, which included the large mining agglomeration of "Nikopol-Marhanets-Pokrov", as well as nuclear and thermal power plants, among other facilities.

The absence of bridges connecting settlements located on opposite banks created numerous logistical inconveniences. For example, travelling between Nikopol and Enerhodar required a journey of 200 km, although the cities are located only 21 km apart in a straight line, directly opposite each other on different banks of the reservoir.

These logistical challenges led to regions developing in isolation from one another. Most cities located on the shores of the reservoir became peripheral within their respective regions and subsequently experienced a degree of economic decline due to the lack of active transport connections with other parts of Ukraine.

FISHERIES

Among the predictions of the propagandists who promoted the Kakhovka Reservoir, a key argument was the expected increase in productivity across all sectors of the

32 Letter of the Ministry for Communities and Territories Development of Ukraine No. 17080/46/10-24, dated 17 September 2024.

economy, including fisheries. These promises, even before the construction of the reservoir, were accompanied by the designation of important spawning grounds as protected areas in order to increase the Dnipro River's "fish stocks"[120]. Promises were also made regarding the successful breeding of sturgeons and various predatory fish species[224]. However, these species require flowing, well-aerated water and migration routes from the sea to their spawning grounds, whereas no fish-passage facility was even planned at the Kakhovka HPP dam.

There are generally three stages in fishery development for most lowland reservoirs: initial growth in fish productivity, maximum catches, and ultimately declining catches followed by stabilization at a level significantly lower than the maximum. Subsequently, a fourth stage was identified – the destabilization of catches, including the disappearance of certain species. In the case of the Kakhovka Reservoir, long-term fisheries dynamics take the form of a curve and do not conform to these patterns[300].

Commercial Fisheries

Shortly after the construction of the Kakhovka Reservoir, fish catches reached significant levels. According to archival data, 82,380 tons of fish were caught in 1964[105]. These catches included low-value species that rapidly adapted to the new conditions, remnants of large populations of predatory species whose numbers were declining due to intensive harvesting, and introduced species.

Following the transition of the Kakhovka Reservoir to an irrigation-oriented water management regime in 1969, autumn-winter fluctuations in water levels disappeared, together with the associated seasonal drying and flooding of shallow-water areas. As a result, shallow areas with aquatic and semi-aquatic vegetation that played a key role in the reproduction of herbivorous fish species were greatly reduced or disappeared. Spawning grounds accounted for only 6% of the reservoir area, an amount insufficient to support major commercial fish species[320]. From that time onward, populations of a number of commercial fish species were maintained through the creation of artificial spawning grounds and fish stocking.

In 1971, the Kakhovka Reservoir was granted the status of an experimental-production water body of the Ukrainian Research Institute of Fisheries. Artificial spawning grounds were created there for the purpose of destroying the eggs of "low-value" native fish species, and fishing methods for these species were developed[110].

During the period 1966-1973, fish stocking was carried out using first-year fish, but this did not produce positive results. Beginning in 1974, two-year-old juveniles were used for stocking, resulting in a positive effect on commercial catches. However, this required the establishment of a network of state fish hatcheries and collective fisheries, where juveniles were reared before stocking. Stocking volumes declined sharply in the late 1990s (2.3 million individuals in 1997) due to the difficult economic situation in the country and the beginning of the transformation of the fisheries management system[174].

Formation of Fish Fauna of the Kakhovka Reservoir

Since the 1970s, ecologically adaptable generalists species have come to play the dominant role in the Kakhovka Reservoir. Among phytophilous fish species, the most important were common bream (*Abramis brama*) and common roach (*Rutilus rutilus*); dominant open-water species were the Black Sea-Caspian sprat (*Clupeonella cultriventris*) and pikeperch (*Sander lucioperca*)[136].

Beginning in 1990, the Kakhovka Reservoir, like all reservoirs of the Dnipro cascade, experienced a sharp decline in fish catches. The organization and orientation of fisheries also changed. In particular, due to the catastrophic reduction in fish stocking, the formation of commercial stocks of herbivorous fish in the reservoir almost ceased, while the fishery for Black Sea-Caspian sprat (*Clupeonella cultriventris*) was discontinued because it had become economically unprofitable[300].

In subsequent years, catches gradually increased. Thus, in 2004-2009, commercial catches in the Kakhovka Reservoir showed an overall tendency toward growth due to increases in silver crucian carp and herbivorous fish species. In 2004-2005, the average fish productivity of the reservoir amounted to 10.7 kg/ha, increasing to 12.8 kg/ha in 2009. In 2010-2014, total commercial catches declined by 67% due to decreases in catches of Black Sea-Caspian sprat, roach, bream, herbivorous fish species (silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Hypophthalmichthys nobilis*), and grass carp (*Ctenopharyngodon idella*)), as well as silver crucian carp (*Carassius gibelio*). In 2015-2018, catches began to increase again, primarily due to increased abundance of silver crucian carp. In 2019-2021, commercial catches declined once more, from 2,900-3,400 tons to 2,400-2,500 tons. The main species responsible for this decline were silver crucian carp (56.3% of the total reduction in catches), herbivorous fish species (24.4%), and, to a lesser extent, common bream (9.7%).

Intensive exploitation of fish resources eventually resulted in reduced catches and changes in population structure[105]. From the construction of the Kakhovka HPP dam (1952-1956) until its destruction, the number of fish species in the Kakhovka Reservoir declined from 42-56[400] to 39 species[295]. However, the fish productivity of the reservoir proved to be lower than under free-flowing river conditions and lower than had been expected at the time of its construction[122; 123; 124].

The structure of commercial fish catches was characterized by a certain degree of instability (at least with respect to the proportion of dominant species in the catches). From 2003 to 2010, catches consisted primarily of silver crucian carp (33.8%), common bream (17.7%), common roach (16.5%), Black Sea-Caspian sprat (14.6%), and carp species (silver carp, bighead carp, and their hybrids) (10.8%).

During the period 2010–2019, catches were dominated by the following species groups: silver crucian carp (52.8%), roach (13.1%), bream (10.4%), carp species (9.8%), and Black Sea-Caspian sprat (5.7%).

In 2020-2021, the structure of catches followed the trends described above: 61.7% of the total catch consisted of silver crucian carp, 14.5% of common roach, 8.9% of common bream, and 5.6% of carp species.[245].

Catches Prior to the Destruction of the Dam

The Kakhovka Reservoir ranked second among the reservoirs of the Dnipro cascade in terms of fish catches (after the Kremenchuk Reservoir). Commercial fisheries were based on 20 commercially valuable fish species and one species of freshwater crayfish. The largest share of catches consisted of silver crucian carp[48].

Prior to the destruction of the dam, the average annual commercial fish catch in the Kakhovka Reservoir ranged from 2,500 to 3,000 tons per year[48], accounting for 22% of fishery production[293] on the Ukrainian market.

Contribution of the Kakhovka Reservoir to Fishery Production of the Dnipro Cascade Reservoirs: 2017-2021

On average, during the period 2017-2021, the Kakhovka Reservoir accounted for 21.2% of the total catch of aquatic biological resources harvested from the Dnipro cascade reservoirs, including 38.9% of silver crucian carp catches, 34.4% of common carp (*Cyprinus carpio*) catches, 33.9% of common bleak (*Alburnus alburnus*) and Black Sea-Caspian sprat catches, 31.6% of catches of introduced "herbivorous" fish species (primarily silver carp, bighead carp, and their hybrids), 15.1% of common roach catches, 13.4% of pikeperch catches, and 10.3% of common bream catches. In addition, the Kakhovka Reservoir accounted for 48.1% of the total catch of the European crayfish (*Astacus astacus*) within the Dnipro cascade.

Recreational Fisheries

A reliable assessment of the overall productivity of the reservoir's fisheries is virtually impossible, since, in addition to legal commercial catches, substantial quantities of fish are removed by recreational fishers and poachers. Consequently, part of the catch remains unrecorded. At present, recreational fishing in Ukraine is carried out exclusively under the general-use regime and is effectively considered a component of "IUU fishing" (illegal, unreported, and unregulated fishing)[295].

In the catches of recreational fishers in the Kakhovka Reservoir (based on 2002-2013 data), 34 fish species were identified. Numerically, recreational catches were dominated by representatives of the goby family (Gobiidae) (57.0%), common roach (19.6%), and silver crucian carp (13.0%). Among representatives of the goby family, five species were recorded in recreational catches. The largest proportion of gobies in the catches consisted of round goby (*Neogobius melanostomus*) (91.6%) and toad goby (*Mesogobius batrachocephalus*) (7.6%). Among predatory species, pikeperch (*Sander lucioperca*) was recorded most frequently (1.1%), whereas European catfish accounted for the smallest proportion of catches (0.43%). Species such as chub (*Squalius cephalus*), asp (*Aspius aspius*), tench (*Tinca tinca*), vimba bream (*Vimba vimba*), blue bream (*Ballerus ballerus*), and northern pike (*Esox lucius*) were encountered only rarely. In August 2011, the European eel (*Anguilla anguilla*) was recorded in catches made with bottom fishing gear within the city of Zaporizhzhia. In the vicinity of Enerhodar, Vasylivka District, and Zaporizhzhia region, recreational fishers regularly caught channel catfish (*Ictalurus punctatus*) cultivated at the warm-water facilities of the Zaporizhzhia Thermal Power Plant, and Mozambique tilapia (*Oreochromis mossambicus*), which entered the discharge canal from the cooling pond of the Zaporizhzhia Nuclear Power Plant during the warm season[247; 295].

In addition, catches of spearfishers in the upper part of the Kakhovka Reservoir, based on competition results from 2011, included representatives of 10 fish species: silver crucian carp, common carp, chub, silver and bighead carp, grass carp, European catfish, European perch, pikeperch, and northern pike[249; 295].

The average catch per unit of fishing effort amounted to 2.4 kg. Among the recreational catches that were directly analyzed, a high proportion (20.4%) exceeded the daily catch limit.

The estimated total catch by recreational fishers in Kakhovka Reservoir in 2013 amounted to 747 tons, or 5 kg/ha, which represented 33% of the commercial catch (excluding catches of the Black Sea-Caspian sprat). This confirms the substantial impact of recreational fishing on fish abundance in the reservoir[295].

Species Composition in 2024

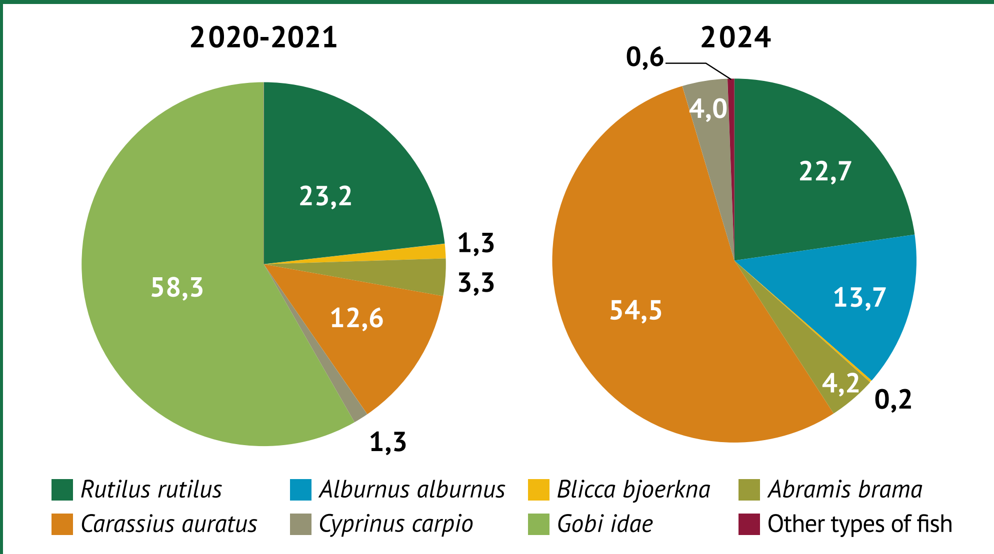
According to surveys conducted between August and November 2024 in the section of the Dnipro River and its floodplains downstream of the Dnipro HPP (within Zaporizhzhia District), the species composition of recreational catches included 11 fish species. Among the species not previously recorded in catches, the sabrefish (*Pelecus cultratus*) was documented in the section near the Dnipro HPP within the city of Zaporizhzhia. The species composition of the most popular targets of recreational fishing changed only slightly following the destruction of the Kakhovka Reservoir (**Appendix 2**).

Comparison of Species Composition of Popular Recreational Fishery Targets in 2021 and 2024

For comparison with catches in 2024, the structure of catches in the upper part of the Kakhovka Reservoir during August-September 2021 was used, when 10 fish species were identified in the catches of recreational fishers.

The study conducted by the authors showed that, in August-November 2024, the intensity of shore-based fishing was three times lower than during the corresponding period in 2021, due to the disappearance of gobies from catches. At the same time, the biomass of catches increased due to silver crucian carp and common carp, which compensated for the decline in goby catches. No significant changes were recorded for other species.

The estimated catch per completed fishing trip in 2024 noticeably exceeded the corresponding value for shore-based fishing during the previous period due to silver crucian carp (catch per unit of fishing effort increased 2.5-fold, from 0.7 to 1.72 kg) and common carp (increasing 2.2-fold, from 0.17 to 0.38 kg).



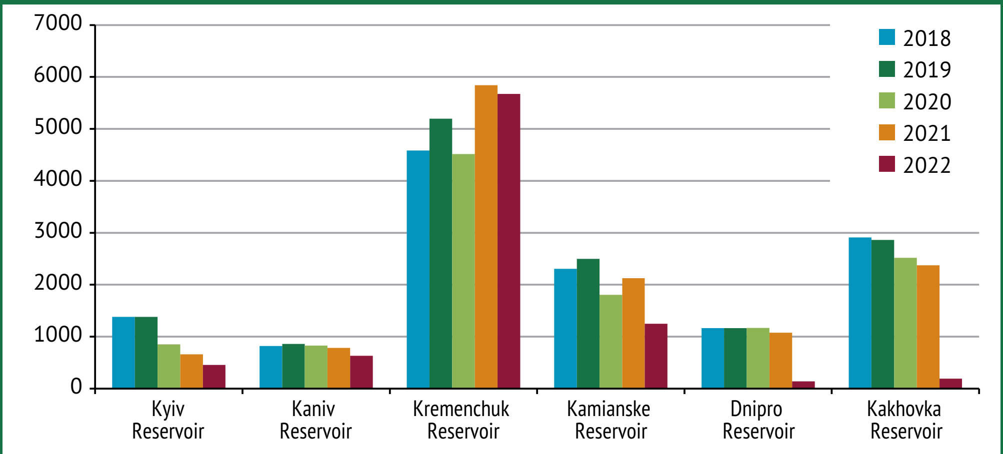
Species Composition of Recreational Fishers' Catches, August–December 2021 (before the destruction of the Kakhovka HPP dam) and in 2024

Illegal, Unreported, and Unregulated Fishing

An additional tool for studying trends in changes in the reservoir's fish fauna is the analysis of records compiled by environmental authorities, according to which 15 fish species were recorded in the reservoir prior to the destruction of the Kakhovka HPP, and 17 species after that event (**Appendix 3**).

The most interesting finding for the water bodies of the study region was the appearance of the Russian sturgeon (*Acipenser gueldenstaedtii*) in illegal fishing gear in the vicinity of the city of Zaporizhzhia. According to a report dated 15 May 2024, two individuals with a total weight of 20 kg were recorded in illegal fishing gear (gill nets) in the area of the navigation canal downstream of the Dnipro HPP in Zaporizhzhia. This area is characterized by a rocky-pebble substrate and a fast current, which may represent a potential spawning site. Notably, prior to the construction of the Kakhovka HPP, sturgeon species were recorded in the vicinity of Khortytsia Island, where they migrated for spawning.

Russian sturgeon caught in illegal fishing nets in the Dnipro River near the city of Zaporizhzhia (15 May 2024) (photo by O. Derevynskyi, State Environmental Inspectorate of the Southern District)



Commercial Fish Catches in Dnipro cascade reservoirs

Thus, according to studies conducted 2002–2021, a total of 47 fish species were recorded in the Kakhovka Reservoir, 20 of which were of commercial importance[245]. The biological status of populations of the main commercial fish species in the Kakhovka Reservoir remained stable, with the exception of common roach, whose population status had been assessed as consistently stressed over the previous ten years[216].

In March 2022, commercial, recreational, and sport fishing in the Kakhovka Reservoir were prohibited. The destruction of the Kakhovka Reservoir in 2023 eliminated the prospects for the restoration of commercial fisheries in this section of the Dnipro River for an indefinite period, even after the end of the war.

RECREATION

Beach recreation, recreational fishing, and simply spending leisure time by the water during the summer are among the most popular forms of recreation in Ukraine. The banks of the free-flowing Dnipro served as an important regional recreational resource and also attracted visitors from other parts of the country. At the beginning of the twentieth century, multi-day excursions by steamboat and motorboat were especially popular here[222; 321].

Prior to the construction of the Kakhovka Reservoir, the territory of Velykyi Luh was not only a place for recreation but also a regional tourism center.

After the construction of the reservoir, the situation changed dramatically. Although shoreline recreation remained widespread (with numerous holiday resorts and children's camps operating in the area), the quality of recreational services deteriorated substantially. This was caused by water pollution, mass algal blooms, shoreline erosion, and other adverse environmental impacts that emerged following the transformation of the natural Dnipro River.

After the reservoir's construction, tourist attractions remained only along those parts of the shoreline that had not been flooded. Although their number was limited, they continued to play an important role in the recreational and tourism sectors of the region for many years.

Numerous historical sites were located along the shores of the reservoir, including the Cossack Kamianska Sich; numerous Late Scythian hillforts (Velyka Lepetykha, Havrylivka, Hannivka, Zolota Balka, Konsulivka, Liubymivka, Sablukivka, Staroshvedske, Chervonyi Maiak, and others); the burial site of Kosh Otaman Ivan Sirko in the village of Kapulivka (incidentally, due to shoreline erosion, Ivan Sirko's remains were reburied farther from the shore on a burial mound); the Falz-Fein estate in the village of Novooleksandrivka; and others.

Local history museums in the cities of Zaporizhzhia, Kherson, Nikopol, Nova Kakhovka, Hola Prystan, and Oleshky (the latter three having suffered damage as a result of the terrorist attack on the Kakhovka HPP) contain important exhibitions dedicated to the era of the Ukrainian Cossacks and the history of Velykyi Luh.

The best-known tourist attraction is "Khortytsia" National Reserve — a historical, cultural, and nature complex located on the island of the same name near the city of Zaporizhzhia. It received its protected status in 1965 and includes archaeological sites dating from the Paleolithic to the Middle Ages. The reconstructed "Zaporizhzhian Sich" complex, which recreates the appearance of the Cossack capital and the atmosphere of the Cossack era, is also located there.

This historical and cultural reserve also includes natural areas, particularly the wetlands in the southern part of the island, which are managed by the reserve administration.

A number of historical sites that were submerged by the waters of the Kakhovka Reservoir may now become accessible for archaeological research and, in the future, may also acquire tourism value.

The creation of the reservoir also created conditions for the development of **recreational fishing**. During the Soviet period, recreational fishing was organized through public associations of hunters and fishers, which were granted designated water bodies. For some time, this practice continued in Ukraine by inertia after independence. One of the advantages of this form of recreational fisheries management was the implementation of fish fauna conservation and restoration measures in water bodies assigned to public organizations, financed through membership fees; thus, a form of targeted compensation for the impacts of fishing was provided.

The reservoir's water area created highly diverse conditions, which can be conventionally divided into three types: open water area of the reservoir, main channel of the Dnipro River, and floodplain water bodies[244; 295].

In 2013, the largest number of fishing trips in the upper and middle parts of the Kakhovka Reservoir occurred in the main open-water area of the reservoir (41%) and in floodplains (35% of the total number of fishing trips). The upper part of the Kakhovka Reservoir accounted for 28% of the reservoir's surface area; however, this part of the reservoir recorded the highest number of fishing trips — 53% of the total estimated number (3.2 fishing trips/ha).

Main channel of the Dnipro River

Main open-water area

Floodplains (bays)

Floodplains (channels)

Typical Areas of Commercial and Recreational Fishing in the Kakhovka Reservoir (photo by M. Maksymenko)

The smallest number of fishing trips occurred in the lower part of the reservoir, accounting for 19% of the total, or 1.1 fishing trips/ha[295].

Recreational fishing in the Kakhovka Reservoir was practiced in three main ways: from the shore, from boats, and on ice (during the period of ice cover in winter). For shore-based fishing, special structures – piers and fishing platforms – were occasionally constructed. Prior to February 2022, there were 43 small craft mooring facilities within Zaporizhzhia region alone, including 18 within the city of Zaporizhzhia.

The areas most popular among recreational fishers for shore and ice fishing prior to 2022 were drained following the destruction of the Kakhovka HPP dam.

Since March 2022, all fishing activities using watercraft on the Dnipro River have been prohibited under martial law. In addition, a de jure ban on access to the shoreline zone remains in force. Despite this, the number of shore-based fishing trips in certain areas increased by between 8% and 111%. Thus, the recreational function of the free-flowing Dnipro River, particularly with regard to recreational fishing, remains relevant.

Riparian zone of the main channel of the Dnipro River

A bay of the Dnipro River near the city of Zaporizhzhia used by fish fauna as wintering holes and a spawning ground.

Popular recreational fishing locations before (left) and after (right) the destruction of the Kakhovka Reservoir (photo by M. Maksymenko)

NATURE CONSERVATION ACTIVITIES

Both before the construction of the reservoir and after its filling, there were not only economic models for its use but also initiatives aimed at preserving its most valuable natural complexes. In 1926-1932, the idea of establishing a “State Wetland Reserve” or the “Velykyi Kozachyi Luh” Reserve was proposed[308], although it was never implemented.

While the reservoir existenced, several protected areas were established within its water area, including the Kamianska Sich and Velykyi Luh national nature parks, Panai Regional Landscape Park, local protected areas Kairska Balka, Ivanivskyi Bir, and Vodyanski Kuchuhury, as well as nationally significant protected areas known as Dnipro Rapids and Velykyi and Mali Kuchuhury. All of these areas were affected by the reservoir being emptied following the destruction of the Kakhovka HPP dam[276]; however, their protected status remains in force. The largest protected area in the vicinity of the former Kakhovka Reservoir is Velykyi Luh National Nature Park, established in 2006. Its total area amounted to only one-eighth of the area of the previously proposed "Velykyi Kozachyi Luh" Reserve. In 2021, conservationists developed a proposal to expand the national nature park by 10,000 hectares through the inclusion of parts of the reservoir's water area; the proposal remained under consideration until the beginning of the full-scale war.

The Proposed «Velykyi Kozachyi Luh» Reserve

The proposed reserve was intended to cover 80,000 ha (or 30% of the area of the future reservoir) within the most marshy and inaccessible part of the floodplain (from the city of Zaporizhzhia to the city of Nikopol). This territory was completely flooded during spring floods (it also experienced flooding in February 2024[70]).

Although the reserve was never established, conservationists succeeded in securing official protection for some of its areas, which were subsequently flooded: "Left Bank of the Velykyi Kozachyi Luh in the Velykyi Luh Forestry near the villages of Maiachky and Vasylivka"[379, p. 57], "Velykyi Kuchuhury" Tract near Popovo Station[379, p. 57], "Kamianski Kuchuhury" (Zaporizhzhia region)[33], "Havrylivka Reserve" ("Kachkarivka Reserve")[34], and "Wetlands of the 'Peremoha Revoliutsii' State Farm" (Kherson region)[379, p. 58]. All of these sites lost their protected status in 1934 as a result of changes in legislation.

In the past, conservation efforts were focused primarily on the floodplains — hard-to-access habitats that had experienced the least anthropogenic disturbance. Following the events of 2023, floodplain habitats are also recovering on the former reservoir bed. In the future, they may become an important source of ecosystem services[131] and will play a significant conservation role both at the local level and as Emerald Network sites and wetlands of international importance that are significant at the continental level[35].

33 Minutes No. 18 of the Presidium Meeting of the Zaporizhzhia District Executive Committee, 17 May 1928, para. 350. On declaring the Kamianski Kuchuhury a protected area of local significance [184, fols. 74–85 verso; 372, fol. 188].

34 Register of natural monuments within the Odesa Inspectorate recorded by the Ukrainian Committee for the Protection of Natural Monuments (UKOPP); letter from the Odesa Regional Inspector O. Brauner to UKOPP dated 22 April 1928, No. 64 [372, fols. 181–182].

35 In 2024, the authors of this publication prepared proposals for the establishment of three large protected areas within the territory of Velykyi Luh (specifically those parts that had not previously held protected status). Together, these protected areas are intended to cover the entire territory formerly occupied by the Kakhovka Reservoir.

FUTURE SCENARIOS

The development of agriculture, industry, and the population of southern Ukraine depended to a large extent on the Kakhovka Reservoir, constructed in the 1950s. Today, the return of the population to this region is possible only following de-occupation and restoration of the previous infrastructure model or creation of a new one.

The decision on which scenario should guide the development of southern Ukraine following the destruction of the Kakhovka HPP requires the involvement of specialists from many fields of science, transparent public discussion, and an independent environmental impact assessment. However, despite the significant public attention surrounding this issue, neither an expert platform nor an open public discussion was organized by the state in 2023-2024, although the government did finance research on the consequences of the destruction of the Kakhovka HPP[270]. Following the destruction of the Kakhovka HPP, Ukraine's publicly stated position[85] focused on assessing the damage[269] caused to the state by the terrorist attack, recognizing it as a war crime[306], and determining the amount of funding[85] required for the reconstruction of the HPP dam[36].

Meanwhile, a transparent discussion of the future of the former reservoir constitutes part of Ukraine's public commitments, including those made by partner countries. Thus, in February 2024, the Environmental Compact for Ukraine[307], developed by the High-Level Working Group on the Environmental Consequences of War operating under the Office of the President of Ukraine, included a specific recommendation: *"Consider the possibility of allowing certain d eveloped areas to return to their natural state, as well as undertaking broad consultations and involving experts in the decision-making process", accompanied by the following commentary: "Engage independent experts to conduct a thorough analysis of the options and their associated environmental consequences, given the significant scale of this project and its long-term and multifaceted impacts."*

Thus, Ukraine publicly committed itself to conducting a transparent assessment of plans for the possible restoration of the Kakhovka HPP. However, despite this public commitment, the Action Plan[268] developed in 2024 by the Ministry of Environmental Protection and Natural Resources directly contradicts the recommendations of the Environmental Compact for Ukraine itself[345].

Several possible scenarios for the future of the former reservoir area have been publicly discussed. These include construction of new hydropower plants and a new reservoir, restoration of natural ecosystems while simultaneously addressing the region's economic needs (without relying on the reservoir's resources), as well as several alternative concepts (ranging from a cascade of low-head small hydropower plants to the construction of a "narrowed" reservoir, bioenergy plantations, wind farms, and other options).

36 The reconstruction of the Kakhovka Hydropower Complex is envisaged in the Ukraine Recovery Plan [79].

Discrepancies between the Recommendations of the Environmental Compact and the Action Plan for Their Implementation

Recommendation 42 of the Environmental Compact for Ukraine establishes the mandatory application of environmental impact assessment and strategic environmental assessment procedures in relation to all projects, plans, and programs. It also explicitly states that the possible reconstruction of the Kakhovka HPP is an example of a project that requires a transparent assessment involving independent experts (indeed, this is the only example specifically mentioned in the Compact). In contrast, the Action Plan developed by the Ministry of Environmental Protection and Natural Resources states that these procedures should be waived for the possible reconstruction of the Kakhovka HPP.

Comments and proposals submitted by the public regarding the Concept Note Defining the Scope of Derogations from the Rules on Environmental Impact Assessment and Strategic Environmental Assessment[266] were not considered. The minutes of the public consultation process[271] did not even mention the comments submitted to the Ministry. Therefore, if the Concept Note leads to amendments to the legislation, such amendments will be adopted without consideration of public opinion regarding the management of the territory of the former Kakhovka Reservoir.

The first scenario (the construction of new hydropower plants and a new reservoir) requires lengthy preparatory work, including demining. Only after this can the key issues be addressed: assessing the safety of soils contaminated as a result of military activities and flooding, reconstructing settlements, and conducting an economic assessment of restoring the hydropower complex infrastructure. Undoubtedly, these processes will be prolonged, and therefore the total economic cost of regional recovery will be significantly higher than the potential cost of constructing a new hydropower plant[25]. It is highly likely that, in the coming years, only part of the population will be able to return to their former places of residence. Thus, the scenario involving the creation of a new reservoir appears to be quite realistic. However, for its implementation, it is important to assess whether such a decision would be justified from both environmental and economic perspectives. It should be taken into account that the full-scale war restricted opportunities for economic activity. Therefore, post-war recovery will likely not involve a return to the previous infrastructure model, but will require the implementation of new solutions.

There are already indications that reconstruction is developing according to the second scenario, which envisages the restoration of natural ecosystems. The bed of the former Kakhovka Reservoir is gradually transforming into a natural willow-poplar forest adapted to the specific conditions of the steppe climatic zone. The process of nature recovery is occurring spontaneously, without planning or human intervention, thereby saving human and financial resources. Funding for the recovery of the southern region is primarily being directed toward adaptation of the affected territories to these new conditions rather than restoring the reservoir, that is, towards creating an economic system that does not depend on its existence.

CONSTRUCTION OF A NEW RESERVOIR

The construction of a new HPP dam, reservoir, and irrigation systems would determine the character of the region's economy and water use at least until the end of the twenty-first century, as the service life of a hydropower complex is approximately 100 years[80]. During this period, the climate will undergo significant changes: the mean annual temperature is expected to increase by 2.68-2.98°C (compared to an increase of 1.2-1.4°C over the previous 100 years[30]), while annual precipitation may decrease by 13 mm[217]. Meanwhile, if a new reservoir is created, evaporation from its surface, from canals, and from soils irrigated by sprinkler systems will lead to a further reduction in the flow of the Dnipro River in its lower reaches.

Reduction of the Dnipro River Flow Due to Global Climate Change

The main volume of water from the Kakhovka Reservoir was used for the operation of the HPP and for irrigation (up to 15% of the annual river flow over the course of a year, and up to 30% during the summer months)[131]. During the period of operation of the Kakhovka Reservoir, the annual flow of the Dnipro River decreased by 11.2 km^3 as a result of global climate change, which represents 20% of the river's mean annual flow[153]. At the same time, the volume of water in the reservoir available for economic use also declined.

Projections of global warming indicate a likely worsening of water availability conditions. If current approaches to the use of the Dnipro's water resources are maintained, climate change may lead to an additional reduction in the river's flow by 25-30%. This means that, over the next century, the amount of water in the Kakhovka Reservoir during the summer period may become so low that it will be insufficient for both irrigation and for the operation of the HPP during the warm season.

The construction of a new dam and reservoir would require the restoration of the entire hydropower complex, including the entire irrigation system. According to estimates by the National Bank of Ukraine, the cost of restoring the hydrotechnical structures and irrigation systems amounts to approximately USD 1.5 billion for each component. Thus, the economic losses resulting from the destruction of the HPP are significantly lower than the funds required to restore the former now-outdated infrastructure complex[25].

Renewed flooding of the territory would once again lead to the problems that arose during the filling of the Kakhovka Reservoir in the 1950s, including shoreline erosion, water pollution, flooding of adjacent areas, and other impacts (see the section **"Environmental Consequences of the Construction of the Kakhovka Reservoir"**). Therefore, a comprehensive assessment of the project's cost should also take into account the expenses associated with mitigating environmental impacts and relocating people from the affected areas.

One of the key challenges associated with the construction of a new reservoir is the ongoing recovery of natural ecosystems on the bed of the former Kakhovka Reservoir. By the time such a project could potentially be implemented, the entire territory of the

Cost of Maintaining a New Hydropower Complex

Maintaining a cascade of hydropower plants requires substantial financial resources. According to the Institute of Nature Management and Ecology of the National Academy of Sciences of Ukraine, the state must invest in the maintenance of hydrotechnical structures an amount over ten times their book value[103]. The National Program for the Ecological Rehabilitation of the Dnipro River Basin and the Improvement of Drinking Water Quality [286] states that in the 1990s, the costs of maintaining the cascade of hydropower plants were 6-30 times higher than the value of the electricity they generated.

Meanwhile, the costs of maintaining a hydropower complex continue to accrue even when the hydropower plant itself is not operating (for example, due to damage caused by russian missile strikes). Maintenance costs include personnel salaries, electricity consumption, capital repairs, equipment replacement, and the provision of costly air defense systems. Without proper maintenance, any hydropower plant can become a source of technological hazards, creating risks for both the population and the environment.

former Velykyi Luh may once again become a fully developed floodplain forest. The area of young forest on this territory already exceeds by approximately twofold the total area of all forests that Ukraine has lost as a result of russian military aggression.

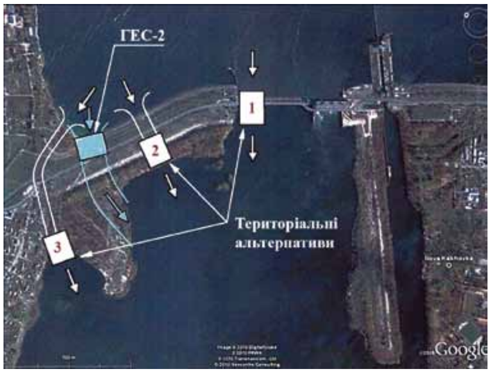
The removal of such a large area of forest (estimated by some sources at up to 40 billion trees[129]) would constitute the largest deliberate destruction of forests in the history of Ukraine. In terms of scale, it would exceed the act of ecocide committed by russian forces in 2023, when the Kakhovka Reservoir dam was destroyed.

Despite the challenges associated with the construction of a new reservoir, PJSC Ukrhydroenergo has announced plans to build at the site of the Kakhovka HPP[403] a hydropower plant with an even greater installed capacity (or to construct an additional complex of hydropower units, "Kakhovka HPP-2") in order to operate it in a peaking mode. It would have a capacity of 550-600 MW[335; 364] instead of the 335 MW lost in 2023. In some cases[377], it has even been suggested that the new HPP could have four times the installed capacity of the former plant.

It should be understood that the capacity of a hydropower plant is determined by the characteristics of the installed turbines and generators, whereas the amount of electricity generated depends on water discharge (river flow) and hydraulic head. Therefore, it is impossible to generate a larger amount of electricity without increasing the volume of available water. It is difficult to imagine the construction of a reservoir larger than the former Kakhovka Reservoir; therefore, increasing the installed capacity of the HPP would most likely require the release of larger volumes of water during periods of peak operation. This would result in greater fluctuations in water levels downstream of the dam and significant temporary flooding of the floodplain, including protected areas. At the same time, the increase in electricity generation would most likely not exceed 5%, as the flow of the Dnipro River would not be sufficient to support a larger increase.

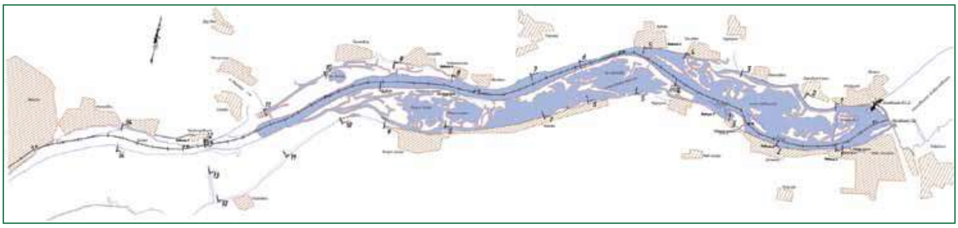
What is the Kakhovka HPP-2

The Kakhovka HPP-2 project aimed at creating additional power generation capacity based on the existing Kakhovka HPP dam. A similar approach had previously been implemented at the Dnipro HPP, where Dnipro HPP-2 was integrated into the existing dam structure in 1969-1974[354]. The planned installed capacity of Kakhovka HPP-2 was 250 MW (compared to 335 MW for Kakhovka HPP-1)[351]. The notice of intent for the new construction project was published as early as November 2014[401], and in 2017 the Cabinet of Ministers of Ukraine approved the project's feasibility study[152].



Layout of the Proposed Kakhovka HPP-2 [346]

The project required increasing the discharge capacity of the dam in the city of Nova Kakhovka, which would have resulted in greater water releases into the lower reaches of the Dnipro River. In particular, sudden fluctuations in water levels would have reached 1.94 m near the Kakhovka hydropower complex and 0.42 m near the city of Kherson[346]. Under such a hydrological regime, one-third of the territory of the Lower Dnipro National Nature Park[352] would have remained permanently flooded, while the rest of its territory would have been subject to daily water-level fluctuations[353]. Meanwhile, the entire area affected by periodic flooding is inscribed into the Emerald Network. For this reason, the project was criticized by both the public and the scientific community[7].



Flooding scheme for the territory of the Lower Dnipro National Nature Park in the event of the commissioning of Kakhovka HPP-2 [352]

BAt the same time, in 2017, the Law of Ukraine "On Environmental Impact Assessment" entered into force, requiring project developers to conduct an environmental impact assessment. Despite the obvious threat that Kakhovka HPP-2 would pose to the ecosystems of the Lower Dnipro, the scientific assessments concluded that daily fluctuations in water levels would not cause harm even to terrestrial animals[347]. In 2021, the Ministry of Environmental Protection and Natural Resources issued a positive environmental impact assessment decision for the project[265; 267], dismissing public comments. However, construction of Kakhovka HPP-2 did not begin due to the full-scale invasion by russian forces in 2022.

The recovery of fish communities would also be difficult in the event of the reconstruction of the Kakhovka Reservoir. The restoration of populations of native species to their former abundance, provided that a comprehensive program of artificial reproduction measures is implemented and fishing is completely prohibited, would take at least 10-15 years, while for some species (common carp and wels catfish) it could take up to 25 years.

In addition to its economic inefficiency and the need to destroy the largest natural forest ecosystem in the region, the announced mode of operation of the upgraded Kakhovka HPP poses a serious threat to the environment. The Kakhovka HPP had previously operated in a peaking mode (see the section **"Contemporary Importance of the Kakhovka Reservoir for the Economy and Regional Development. Electricity Generation"**), and in 60% of cases released peak flow only once per day. Under the newly proposed operating regime, however, water levels in the downstream reach would fluctuate several times a day. In such a scenario, waves generated by each water release would propagate long distances downstream. Such an operating regime for the new HPP is unacceptable because of the vulnerability of the Dnipro floodplain and its protected status.

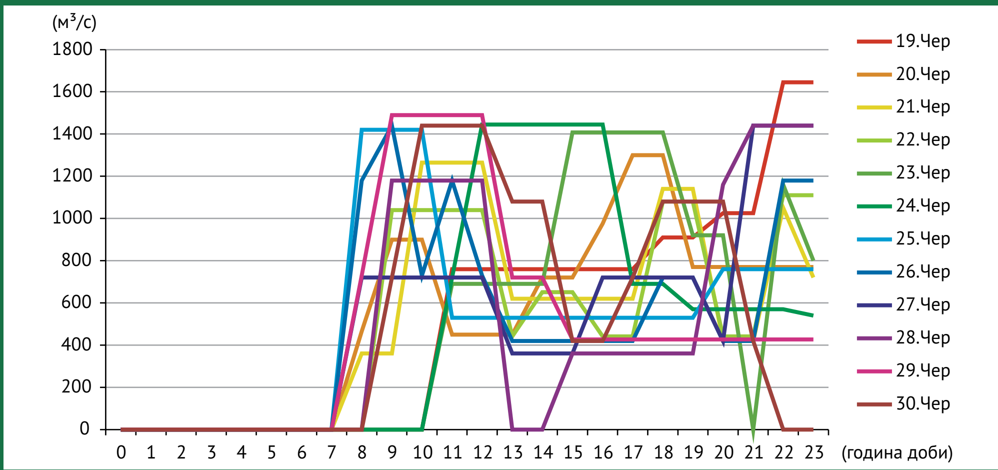
The construction of a new, more powerful HPP could cause significant damage to biodiversity in an area that, by that time, may have already recovered its natural state. Water releases would cause the water's edge to shift by tens or even hundreds of meters per hour, creating a broad erosion zone. Within this zone, which would encompass the most important natural ecosystems, biodiversity would rapidly decline.

Dynamics of the Kakhovka HPP Water Releases and Their Impact on the Ecosystems of the Lower Dnipro

Average data for the period from 1994 to 2013 indicate a sharp decrease to only 7% in the proportion of two-peak discharge regimes in the operation of the Kakhovka HPP. This means that peak water releases alternated with periods during which no water was released below the dam. Thus, even when the average daily water discharge did not exceed 500 m^3/s, peak releases could reach 1,600-1,800 m^3/s[363]. This has been a key factor in the deterioration of all components of the Lower Dnipro ecosystem over the past 20-30 years, including within the Lower Dnipro National Nature Park[75; 236; 237; 299; 338; 339; 340].

The Lower Dnipro National Nature Park was established in a territory where daily water-level fluctuations caused by HPP water releases already existed. However, if new patterns of daily water-level fluctuations were to be introduced that would affect the territory of the existing national park, Emerald Network sites, and Ramsar wetlands and would constitute a violation of legislation prohibiting changes to the hydrological regime of existing protected areas.

FUTURE SCENARIOS



Intraday distribution of water discharge at the Kakhovka HPP cross-section, 19–30 June 2018

Supporters of the Scenario

Prior to its destruction in 2023, the Kakhovka HPP was regarded by the Cabinet of Ministers of Ukraine as a promising direction for energy infrastructure development and attracting investment. In particular, the idea of the *Kakhovka HPP-2* project[351], which envisaged investments exceeding EUR 1 billion[357], was developed on the basis of the existing Kakhovka HPP dam. Following the destruction of the existing Kakhovka HPP, its supporters immediately proposed the creation of a complex of two hydropower plants, referring to it as “restoration”, although in essence it would constitute entirely new construction associated with very significant environmental risks.

Government Support

Experimental Projects for Addressing the Consequences of the Destruction of the Kakhovka Reservoir

In political declarations, the state has expressed its support for the scenario involving the creation of a new reservoir. Thus, the Cabinet of Ministers of Ukraine (CMU) adopted a number of resolutions, some of which were primarily intended to address the negative consequences associated with the destruction of the Kakhovka HPP, while others may contribute to the renewed flooding of Velykyi Luh.

On the very day of the terrorist attack, the Cabinet of Ministers of Ukraine approved the implementation of an experimental project involving the construction of a number of trunk water pipelines (Resolution No. 566 of 6 June 2023[143]). The primary objective of the project in 2023 was to restore water supply to settlements that had previously received water from the Kakhovka Reservoir. The project’s funding allocation (UAH 8.2 billion) was established by a separate Resolution No. 902 dated 22 August 2023.

At the end of December 2023, the implementation period of the "experimental project" was extended for the first time until the end of 2024 (CMU Resolution No. 1411), and its funding was subsequently increased by an additional UAH 8.4 billion (by CMU Resolutions No. 327 of 22 March 2024 and No. 1060 of 10 September 2024[148]). Finally, on 22 November 2024 (CMU Resolution No. 1333), the project completion deadline was postponed for the second time, this time until 6 June 2025. The project was also expanded to include the construction of a pipeline for the discharge of mine water from A storage facility in the Svystunova Ravine in Dnipropetrovsk region, for which an additional UAH 250 million was allocated[137].

In addition, **CMU Resolution No. 730 of 18 July 2023** initiated another experimental project: *Construction of the Kakhovka Hydropower Complex on the Dnipro River. Reconstruction Following the Destruction of the Kakhovka HPP and Ensuring the Sustainable Operation of the Dnipro HPP During the Reconstruction Period*[147]. This resolution is the most important document concerning the future of the former reservoir and hydropower complex among all those adopted by the Ukrainian authorities as of the end of 2024, as it is the only document that clearly favors one of the proposed future scenarios.

The project envisaged a sequence of steps for the design and reconstruction of the Kakhovka hydropower complex, as well as the construction of a retention pond (counter-regulator dam) in the downstream reach of the Dnipro HPP. This structure was intended to enable the Dnipro HPP dam to safely provide regulating capacity during periods of peak operation of the power system while reconstruction was underway. The resolution provides for two phases of work over a period of two years, financed by PJSC Ukrhydroenergo. No plans for this retaining structure have been made public. It may be assumed that the structure refers to a new dam in the area of Khortytsia Island (or possibly two dams). It would create a small reservoir to mitigate the destructive effects of water releases from the Dnipro HPP during periods of peak operation. The proposed construction site lies within an Emerald Network site, the Khortytsia Historical and Cultural Reserve, and the Dnipro Rapids Nature Reserve. Therefore, although this structure has a clearly defined environmental purpose, it would itself have a significant environmental impact.

Just one month after the adoption of **Resolution No. 730**, PJSC Ukrhydroenergo signed an agreement with PJSC Ukrhydroproject[296] for preparatory work worth UAH 123.81 million[54]. Approximately four months were allocated for estimating the construction costs and assessing the timeframe for implementation (completion date: 31 December 2023[54]). Within just two months, the developers presented the completed project[335], estimating the construction cost at UAH 8.98 billion, the implementation period at eight years, and identifying three stages of implementation. The adoption of Resolution No. 730 enabled financing for the design phase; however, implementation of the project would only be possible after completion of the environmental impact assessment (EIA). This, in turn, will only be possible after the de-occupation of the region and the end of martial law (without which it is impossible even to conduct the studies required by procedure). Thus, although legislative amendments that would allow the EIA procedure to be bypassed in this case are still being developed[271], the project has already received funding.

Manipulation of the Environmental Impact Assessment Procedure

Most projects related to the Kakhovka issue that were planned and financed in 2023-2024 did not undergo the environmental impact assessment (EIA) procedure. These measures were classified as activities aimed at addressing the consequences of emergencies and of the military aggression of the russian federation against Ukraine. Although all of these projects are, in essence, new construction projects rather than "reconstruction" or "emergency response" measures, their implementation does not require an environmental impact assessment while martial law remains in effect (exemptions from the EIA procedure are provided for in the Resolution of the Cabinet of Ministers of Ukraine No. 1010 of 13 December 2017).

Rapid implementation of construction projects is taking place without proper assessment and consideration of alternatives. As a result, this has led to the destruction of valuable natural areas and even cultural heritage sites[131], as well as to other problems, the resolution of which has prompted the approval of additional projects that likewise bypass the environmental impact assessment procedure.

The construction of a pipeline for the discharge of mine water from the Svystunova Ravine tailings pond (Kryvyi Rih District) may serve as an example of a project that is not directly related to the consequences of the destruction of the Kakhovka HPP, but was nevertheless approved as a measure to address the consequences of its destruction. A new water intake for the city of Kryvyi Rih is located downstream from the point where the contents of the tailings pond are discharged. These discharge waters are highly mineralized and may adversely affect drinking water quality[197]. Another similar project involving the construction of a mine water discharge pipeline in the same region, but on the opposite bank of the Dnipro River (in the Pavlohrad area), is undergoing the environmental impact assessment procedure (case No. 10499[37]).

As of the end of 2024, no publicly announced updates have been provided on the implementation status of the experimental project for the reconstruction of the Kakhovka HPP. However, the Cabinet of Ministers of Ukraine approved a new project of a similar nature, which effectively represents a two-year extension of the previous one (**CMU Resolution No. 1483 of 24 December 2024**). This time, the project envisages not only the reconstruction of the Kakhovka hydropower complex, but also the restoration of other damaged hydropower facilities and energy infrastructure assets.

37 The planned activity involves the reconstruction of the pressurised mine water collector from the Blahodatna Mine to the settling pond in the Svidovok Ravine. Due to the long operational life of the existing pipeline, the increased inflow of mine water resulting from the exploitation of longwall panels at the Heroiv Kosmosu, Pavlohradska, and Zakhidno-Donbaska mines, and the need to ensure the simultaneous operation of all mine pumping stations, a decision was made to construct a new pipeline alongside the existing one without dismantling it. The corresponding Notification of Planned Activity Subject to Environmental Impact Assessment was submitted by PJSC DTEK Pavlohradvuhillia to the State Register of Environmental Impact Assessment under registration number 10499 [186].

The Rhetoric of Ukrhydroenergo Regarding the "Reconstruction" of the Kakhovka HPP

PJSC Ukrhydroenergo[38] operates and maintains all hydropower plants and reservoirs of the Dnipro cascade and therefore has a strong interest in investing in the development of the Kakhovka hydropower complex (for example, through the construction of Kakhovka HPP-2). It is therefore evident that this company has a direct interest in the "reconstruction" of the Kakhovka HPP[350]. Since the day of the dam's destruction, the management of Ukrhydroenergo has consistently emphasized the enormous importance of the Kakhovka Reservoir for the country's water supply system, also arguing that, without the HPP, water transport, the Zaporizhzhia NPP, and other facilities would allegedly be unable to function[49; 350; 358].

According to Oksana Huliaieva, PhD in Biology, Head of the Department for Environmental Support of Project Implementation at Ukrhydroenergo[344], when regulating river flow, priority was given to municipal water supply and environmental flows, while the needs of industry, hydropower generation, agriculture, water transport, and fisheries were considered secondary.

During the one and a half years following the disaster, the company not only did not change its rhetoric, but also failed to expand the range of arguments in favor of reconstructing the Kakhovka HPP.

Another Resolution supporting the experimental construction project further simplified the approval procedure for hydropower reconstruction and construction projects. It is now possible to implement such projects without complying with many of the approvals normally required in such cases[39] (although the Resolution does not mention the environmental impact assessment (EIA) procedure). Interestingly, the text of the Procedure[139] states that *"This Procedure shall not apply to territories and objects of the protected areas network"*. However, several protected areas are located within the territory of the former Kakhovka Reservoir (including Kamianska Sich National Nature Park and Velykyi Luh National Nature Park), which would undoubtedly be affected by the "reconstruction" of the reservoir.

Thus, as of the end of 2024, the Government of Ukraine was simultaneously allocating funds both for the construction of water pipelines (which effectively represent the region's adaptation to life without the reservoir) and for the design of a new HPP. If a new reservoir is eventually created, these water pipelines will lose their relevance (even though they account for the largest share of funding, amounting to approximately UAH 16.9 billion as of the end of 2024).

38 The state's corporate rights in PJSC Ukrhydroenergo are exercised by the Cabinet of Ministers of Ukraine, which adopts relevant decisions at the national level regarding the creation of a new reservoir.

39 In particular, Resolution No. 1483 allows projects financed as measures to address the consequences of the destruction of the Kakhovka HPP to proceed *without compliance with urban planning conditions and land development restrictions; without archaeological heritage investigations and obtaining an expert review report on the construction project; without obtaining authorization for construction works; without approval from the State Agency of Water Resources of Ukraine and the State Service of Geology and Subsoil of Ukraine; and without the use of the Unified State Electronic System in the Field of Construction and the registration of property rights related to cultural heritage sites*.

Restrictions on the Use of Land Beneath the Former Reservoir

Another focus area for the central authorities has been the introduction of restrictions on the use of land beneath the former reservoir. Prior to the destruction of the dam, the reservoir was classified as a water body of national significance, the operating regime of which was determined by the State Agency of Water Resources of Ukraine. However, its boundaries had not been officially marked on the ground, and the land plots had not been formally assigned to any user.

Following the destruction of the HPP dam, pursuant to the Land Code of Ukraine (paragraph 24 of the Transitional Provisions), the territory beneath the reservoir became the communal property of the 36 surrounding communities. Meanwhile, these communities acquired the right to transfer these lands into private ownership or even introduce the right of restitution[40] [392]. This would have created significant obstacles to the possible construction of a new reservoir.

In order to prevent local communities from adopting spontaneous decisions, the Cabinet of Ministers of Ukraine submitted Draft Law of Ukraine No. 10135, On Amendments to Certain Legislative Acts of Ukraine Regarding the Creation of Conditions for the Restoration of the Kakhovka Reservoir[149], as early as October 2023.

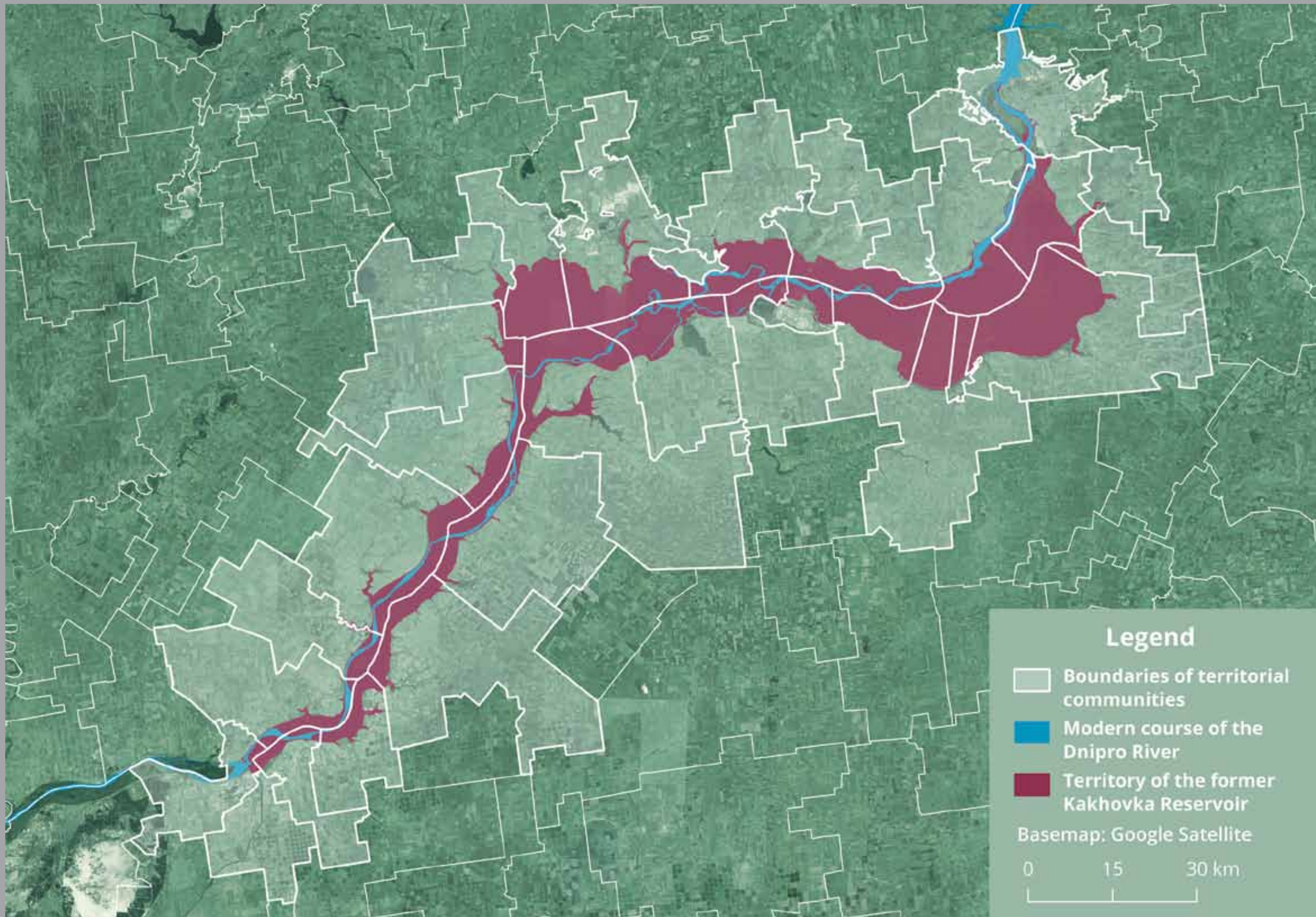
In January 2024, members of the Parliamentary Committee on Agrarian and Land Policy submitted an alternative draft law, No. 10135-d[150]. This draft law not only imposes a moratorium on the use of land beneath the reservoir (except for the purpose of restoring the hydropower complex), but also permits the establishment of protected areas on these lands. Following the registration of Draft Law No. 10135-d, the members of the Parliamentary Committee on Agrarian and Land Policy definitively rejected the government's draft law and retained their own version as the primary text for further consideration. As of the end of 2024, this law had not been adopted.

Since the Cabinet of Ministers of Ukraine did not receive support from Parliament, it independently adopted a Resolution On Preventing the Misuse of Lands Occupied by the Kakhovka Reservoir (**Resolution No. 286 of 12 March 2024**). This Resolution prohibited the transfer of land beneath the Kakhovka Reservoir into ownership or use, as well as changes to its designated purpose, *for the duration of martial law and for five years following its termination. The only exception concerned changes necessary for the restoration of the Kakhovka Reservoir and the construction of hydraulic structures*[144]. It is evident that this Resolution was adopted exclusively in the interests of constructing a new reservoir.

In order to prevent the privatization of land beneath the reservoir by local communities, amendments were introduced to the Land Code of Ukraine (Article 24-1 of the Transitional Provisions)[138]. According to these amendments, from 8 October 2024 onwards, the territory of the former Kakhovka Reservoir became state property.

40 Land restitution is the process of legally and socially restoring ownership or use rights to land that was unlawfully taken, expropriated, or confiscated, through its return to the descendants of the original owners or their lawful heirs.

United Territorial Communities Located within the Former Kakhovka Reservoir



Thus, the Cabinet of Ministers of Ukraine has chosen the path of adapting legislation to the needs of the "creation of a new reservoir" scenario. Further legislative amendments were expected to be adopted in early 2025. Draft resolutions were already published at the end of December 2024[187]. In particular, an amendment to Resolution No. 286 is being prepared that would allow decisions to be taken regarding land plots within the shoreline protection strips of the former reservoir that were established before 6 June 2023. Based on an analysis of the EIA report for the Kakhovka HPP-2 project, it may be assumed that these are the land plots required for the implementation of this project that are located within riparian protection zones[253].

RESTORATION OF NATURAL ECOSYSTEMS WHILE SIMULTANEOUSLY ADDRESSING REGIONAL ECONOMIC NEEDS (WITHOUT USING THE RESERVOIR RESOURCE)

The restoration of the Dnipro's free-flowing river has created favorable conditions for natural ecosystem development. At present, more than half of the territory of Velykyi Luh is occupied by waterlogged or wetland habitats, where the process of soil formation has only recently begun. The organic-rich bottom sediments of the reservoir, together with intensive moisture conditions (following the draining of the reservoir and during the spring flood of 2024), have created favorable conditions for the growth of young forests in its former bed.

Due to the high concentrations of toxic compounds in those bottom sediments, the economic use of these lands remains limited. At the same time, natural ecosystems retain significant value because of the ecosystem services they provide.

FUTURE SCENARIOS

Growth of young forest on the site of the former Kakhovka Reservoir: (a) photo by Vincent Mundi, 2024; (b) photo by Alessio Mamo [22]

Floodplain Forests of Velykyi Luh and the Miyawaki Forests of Japan

CThe rapid growth of trees on the site of the former reservoir may be explained by intense competition for survival. A similar nature-based approach to forest management has been proposed by the Japanese botanist Akira Miyawaki[37]. The method, named after him, involves the dense planting of native tree species in small areas, so-called "pockets". High planting density stimulates competition among plants: trees grow up to ten times faster than under traditional planting methods. The approach requires minimal human intervention after the initial establishment phase. In recent years, Miyawaki forests have become increasingly popular in cities around the world.

Although the floodplain forest of Velykyi Luh is natural rather than artificially created, and greatly exceeds Miyawaki "mini-forests" in surface area, it is easy to identify common patterns, particularly the rapid growth of trees resulting from intense competition among plants.

Ecosystem Services

The absence of intensive economic pressure on the ecosystems of Velykyi Luh has resulted in a broader range of ecosystem services than those previously provided by the Kakhovka Reservoir[131]. For example, the rapid growth of trees[41] contributes to carbon sequestration and improved air quality, while extensive areas free from human disturbance have become habitats for many species of birds, amphibians, and other terrestrial animals[279]. The restoration of the river's free-flowing conditions and water quality[42] promotes the recovery of migratory fish species populations.

Thus, the role of so-called "regulating" ecosystem services, which are important for improving the quality of life of local communities, has increased significantly. These include improved air quality, carbon sequestration, microclimate regulation, and other benefits. The habitats of Velykyi Luh are already providing these ecosystem services.

Climatic Effects of the Loss of the Reservoir

The territory of Velykyi Luh has returned to a regime close to its natural state, reducing evaporation and water losses in the lower Dnipro during low-flow periods. Although the reservoir influenced the regional microclimate to some extent[131], the forest ecosystems and wetlands that are forming in its place will have a much greater impact on the climate through carbon sequestration.

The absence of the large open water surface will no longer create a "convective shadow" (a cloud-free zone), while water temperatures in the Dnipro will become closer to their natural regime. In spring, the water will be warmer, while in autumn it will be cooler[89]. Potentially, such conditions may facilitate the cultivation of certain early crops before the onset of the summer drought season.

Economic Activities

The scenario of natural ecosystem restoration does not exclude the possibility of addressing the region's economic needs. Economic development will likely become less dependent on the territory of the former reservoir and will contribute to decentralization. Such an approach would make it possible to actively implement innovative solutions, including construction of water pipelines, development of solar and wind power plants, drip irrigation systems, introduction of agricultural crops adapted to the new conditions, and other measures.

Electricity Generation

This scenario envisages the creation of new energy capacities to compensate for the loss of the Kakhovka HPP, because, in addition to balancing the power grid, the electricity generated by the plant was used to supply water to the canals. Even if irrigation is abandoned, it will still be necessary to provide electricity for pumping water into canals and pumping stations. This will require a substantial increase in pumping head, an increase in pump capacity and, consequently, a 1.5-fold increase in energy consumption.

To ensure the electricity supply of pumping stations during the summer period, when water demand is highest, it would be advisable to use solar power plants. This would make it possible to provide the system with a stable energy supply without creating an additional burden on the regional power system.

Electricity Consumption for Canal Operation

Several important factors must be taken into account when considering water supply to the canals directly from the Dnipro River instead of the Kakhovka Reservoir.

Before the destruction of the reservoir, water was supplied to the North Crimean Canal by gravity flow, whereas pumps were used for the Kakhovka Canal and the Dnipro-Kryvyi Rih Canal. The pumping head was 25 m and 83.6 m, respectively, and the total installed capacity of the pumping stations exceeded 300 MW. The total annual electricity consumption required for the operation of these pumping stations exceeded 200 million kWh, accounting for 15% of the annual electricity generation of the Kakhovka HPP.

Following the destruction of the reservoir, water must be supplied directly from the Dnipro River channel, which means an increase in pumping head: 17 m for the North Crimean Canal, 41 m for the Kakhovka Canal, and 95 m for the Dnipro-Kryvyi Rih Canal. Altogether, this will require a 1.5-fold increase in pumping capacity, resulting in additional annual electricity consumption of up to 100 million kWh[41], bringing total annual consumption to approximately 300 million kWh.

As of the end of 2024, the water intakes of the Dnipro-Kryvyi Rih Canal and the Nikopol water supply system have already been modernized. However, modernization of the North Crimean Canal and the Kakhovka Canal will only be possible after the end of the war.

This will require both substantial modifications to pumping equipment and the introduction of renewable energy sources.

41 The calculation of pumping capacity takes into account the volume of water supplied, the pumping head, the density of water, gravitational acceleration, and the pump efficiency coefficient, which is assumed to be 0.9. An increase in pumping head has a directly proportional effect on the increase in energy consumption.

Renewable energy generation in the vicinity of the former Kakhovka Reservoir (or even within its former boundaries) represents a more efficient use of land than hydropower generation. If the amount of electricity generated is compared with the area occupied, the Kakhovka HPP was the least efficient of all hydropower plants in the Dnipro cascade, with an output of 6,590 kWh per hectare. It would require 1/100 of the area of the reservoir to be covered with solar panels to generate the same amount of electricity.

From an economic perspective, this is a fully viable option, as the cost of solar panels fell by almost half during 2023[31]. Consequently, solar power accounted for 73% of newly installed renewable energy capacity in Ukraine. Owing to this, solar energy became the global leader[55] among all renewable energy sources in terms of installed capacity. At present, Ukraine also has a large number of projects for the construction of new solar and wind power plants..

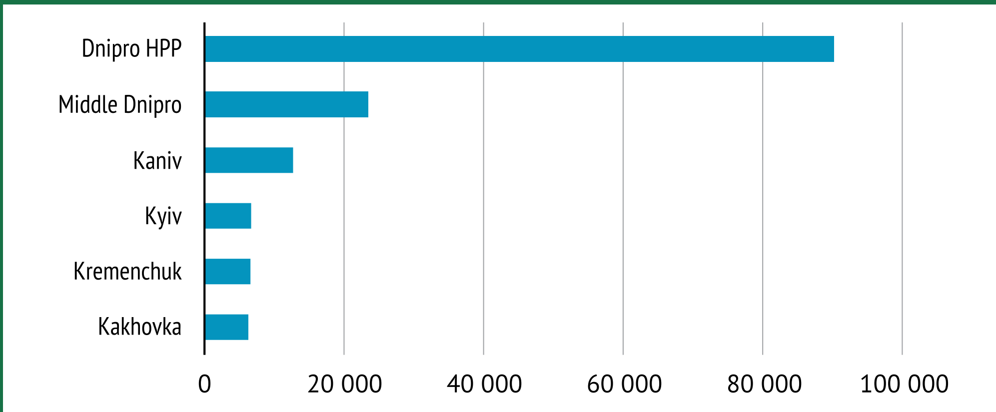
Restoring Electricity Generation in Southern Ukraine in the Context of the European Green Deal

The European Union, for which the war has also raised the issue of energy security, has taken a number of radical steps to accelerate the deployment of renewable energy technologies. In particular, the EU expects that by 2030 at least 42.5% of its energy consumption will be provided by renewable energy sources. This means almost doubling the current share of renewable energy in the EU[13]. Consequently, by 2050, renewable energy installations occupying an area equivalent to that of Sweden will be required to meet the EU's energy needs[34].

Unlike the European Union, Ukraine can use land damaged by military activities for the deployment of solar power plants. Examples of such areas include buildings that cannot be restored, agricultural land irreversibly contaminated as a result of shelling, or even part of the drained territory of the Kakhovka Reservoir. The loss of such areas can be turned into an opportunity for the "green transition", making Ukraine a European leader in the development of solar power[134].

Meanwhile, it should be taken into account that, in contrast to the deployment of renewable energy facilities in anthropogenic landscapes degraded by human activities, the construction of such facilities in natural areas is unacceptable and requires a thorough assessment of potential impacts on biodiversity.

The development of a network of solar power plants equipped with battery energy storage systems may prove to be a more economically efficient option, also from the perspective of assessing potential losses (thermal and hydropower plants remain potential targets for missile strikes, which increases the risk of repeated losses)[56]. Cases of deliberate missile attacks on solar power plants have also been documented; however, their restoration requires significantly less time and financial resources compared with other types of energy infrastructure, as it is sufficient to replace damaged standard modules with new ones.



Average Annual Electricity Output of the Dnipro Cascade Reservoirs (kWh/ha)

The new model must consider the full range of functions previously performed by the Kakhovka HPP, including not only electricity generation but also power system balancing (see the section **"Contemporary Importance of the Kakhovka Reservoir for the Economy and Regional Development. Electricity Generation"**). Efforts to address this issue began in July 2023, when the Cabinet of Ministers of Ukraine instructed that construction of a retention pond (counter-regulator reservoir) downstream of the Dnipro HPP[42] should begin[56]. This facility may play an important role, since following the destruction of the Kakhovka HPP, water-level fluctuations downstream of the Dnipro HPP dam (the next facility in the cascade) have reached amplitudes of up to 3 m[311, p. 37].

The creation of a regulating basin downstream of the hydropower plant can be complemented by other technologies, including large-scale battery energy storage systems, biogas power plants using energy willow[43] [43], capable of operating independently of weather conditions and time of day[44], and demand-side management measures (for example, by introducing time-of-use electricity pricing)[133].

Wherever possible, compensation for lost electricity and heat generation through the combustion of wood biomass should be avoided. This technology, which originated in the pre-industrial era, cannot be regarded as an important component of a modern energy sector. It does not comply with environmental principles and is incapable of meeting contemporary demand for electricity and heat.

Thus, under the scenario of natural ecosystem restoration, energy generation will be possible only in a decentralized form, with a much stronger emphasis on distributed renewable energy than existed previously.

42 The construction of such a basin is provided for by the Resolution of the Cabinet of Ministers of Ukraine No. 730 of 18 July 2023, On the Implementation of the Pilot Project "Construction of the Kakhovka Hydropower Complex on the Dnipro River. Reconstruction Following the Destruction of the Kakhovka HPP and Ensuring the Sustainable Operation of the Dnipro HPP During the Reconstruction Period" [264].

43 Such facilities accumulate biogas throughout the day and use it for electricity generation during periods of electricity shortage.

44 Increasing the share of livestock production and feeding biogas digesters with a mixture of plant and animal residues would substantially increase biogas yields (synergy with the argument concerning livestock production).

Road Transport

The destruction of the Kakhovka HPP resulted in the loss of land transport connections between the right and left banks of the Dnipro. Restoring these connections will become one of the priority tasks following de-occupation.

Possible logistical solutions include the construction of a bridge crossing in the area of the former dam in Nova Kakhovka and the construction of a bridge between the cities of Nikopol and Kamianka-Dniprovska[45]. The latter could serve as an effective replacement for the ferry service that operated during the existence of the reservoir.

An upgraded transport network would improve connectivity between the left and right banks of Zaporizhzhia and Kherson regions and stimulate their economic development. The construction of a bridge crossing on dry land is technologically less complex and requires less funding and time than construction works within the reservoir basin. However, the initiation of such construction would automatically preclude the creation of a new reservoir.

Water Transport and Logistics

The Kakhovka Reservoir served not only as a segment of Ukraine's inland waterway system, but also maintained year-round water levels in the Lower Dnipro region, particularly near Dnipro ports. However, the full-scale war has brought significant changes to transport logistics. Some Ukraine's export flows have been redirected to ports on the Danube, while another portion has shifted to land transport routes to European countries[116]. Nevertheless, up to 90% of Ukraine's exports are still transported through seaports, which have adapted rapidly to the new conditions[125]. Maintaining and further developing this new model in the future may reduce the importance of Dnipro River ports, particularly in the context of the economic reorientation of southern Ukraine.

The restoration of navigation on the Dnipro does not require the reconstruction of the Kakhovka HPP[56]. The absence of large-scale water withdrawals for irrigation will ensure stable river discharge most of the year (except during the spring flood period), supported by the upstream reservoirs of the Dnipro cascade. This will create conditions suitable for navigation in the area of Dnipro ports.

The new model of river logistics could potentially prove more efficient than the system that existed during the operation of the reservoir. The problems of lock congestion and winter navigation closures would disappear (see the section **"Contemporary Importance of the Kakhovka Reservoir for the Economy and Regional Development. Logistics"**). Navigation along the free-flowing Dnipro channel would require only periodic dredging of the navigation channel along the fairway on the Nova Kakhovka-Zaporizhzhia section and the development of a fleet of modern, highly maneuverable (potentially autonomous) vessels.

Dredging of the navigation channel is considerably less expensive and less environmentally destructive than the construction of a new reservoir. This approach would ensure the efficient use of river resources without creating additional pres-

45 In the past, this location had already been identified as the most suitable site for a bridge crossing over the Dnipro. Even before the filling of the Kakhovka Reservoir, German engineers constructed a freight aerial ropeway here in 1943 and began bridge construction works [213].

sure on ecosystems, while preserving the natural dynamics of the Dnipro River. This strategy was also supported by Yurii Tereshchenko, Deputy Financial Director of Ukrrichflot. In an interview with the NGO Urban Coalition Ro3kvit[56], he stated that restoring navigation on the Dnipro does not necessarily require the reconstruction of the Kakhovka HPP in its previous form.

Water Supply

Restoring water supply in populated areas will be one of the priority tasks following de-occupation. It would be advisable to begin planning water pipelines[25] from the Dnipro River to the cities of Skadovsk, Henichesk, and Melitopol. These cities are expected to become major population centers after de-occupation. Subsequently, the water pipeline network should be expanded through additional systems to supply water to smaller settlements. However, such a water supply model may prove insufficient to restore the pre-war population level. Therefore, other decentralized solutions should also be implemented, including:

- storage of up to 4 km^3 of water in reservoirs and ponds covering an area of up to 8,000 ha[359];
- closed-loop water use in industrial production and the introduction of modern water treatment technologies;
- seasonal water pricing, with the lowest tariffs during the spring flood period and the highest during low-flow periods[359], as well as differentiated tariffs for businesses and household consumers.

As regards the operation of the Zaporizhzhia NPP, its sustainable functioning depends not on the existence of the reservoir but on the cooling pond. Water can also be supplied to the cooling pond from a branch of the Dnipro River that extends directly to the pond, or from the alluvial aquifers of the Dnipro floodplain.

Following improvements in the security situation, the former water intake facilities of populated areas and part of the canal system may be reused, since annual discharge in the Lower Dnipro is expected to increase following the loss of the Kakhovka Reservoir due to reduced losses from evaporation and irrigation. This will require the modernization of former water intake facilities, their relocation to the newly formed river channel or branches of the Dnipro, as well as the construction of new pumping stations and pipelines. At the same time, increased river flow is expected to result in a substantial improvement in water quality, particularly during the summer period.

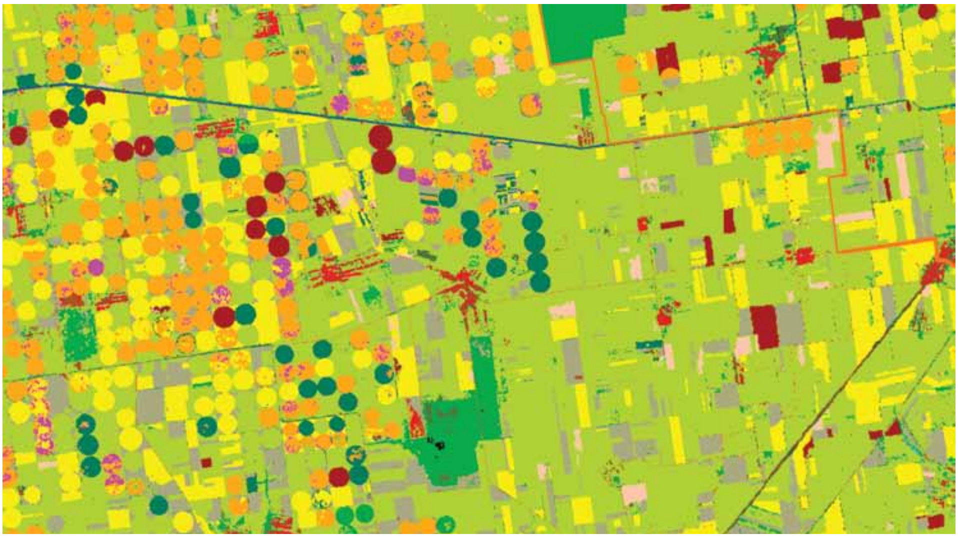
Agriculture

The restoration of agriculture is one of the key challenges in the public discussion of post-war recovery scenarios for southern Ukraine. A rational approach to economic activity in this region without the reservoir would be the introduction of alternative practices based on the principles of sustainable development.

Sustainable agricultural development involves the creation of a complex mosaic of land uses in accordance with modern environmental standards, the application of environmentally safe technologies, and the provision of high levels of employment. Each of the possible adaptation options would be applied locally, in combination with other solutions, depending on the specific features of the area.

Monoculture Agriculture in Southern Ukraine

For a long time, agriculture in southern Ukraine was based on centralized irrigation and gradually evolved into a monoculture grain production system. This model is profitable for large agricultural holdings but not for local communities, as it requires very little labor input[46]. In addition, monoculture agriculture is not environmentally friendly, as it relies on large volumes of agrochemicals.



Example of agricultural land use in Kherson region in 2019: light green areas represent winter wheat, brown areas represent soybean, dark red areas represent rapeseed, and dark green areas represent pastures and protected areas [78].

Changing Irrigation Technologies. Traditional resource-intensive irrigation methods based on sprinkler systems can be replaced by modern, water-efficient drip irrigation technologies.

With the modernization of irrigation systems (through the reduction of evaporation and drainage losses and the direct delivery of water to plants), substantially less water will be required per unit area. Calculations show that, for example, the cultivation of transplanted tomatoes under drip irrigation in southern Ukraine would yield 4.5 times more production per unit area than would be achieved through the restoration of traditional irrigation technologies[396].

Changing Agricultural Crops. Consideration should also be given to replacing currently cultivated crops with varieties that do not require irrigation. For part of the territory, this would eliminate the need for irrigation altogether.

Development of Pasture-Based Livestock Farming. At present, it is premature to consider the return of grazing to the territory of the former Kakhovka Reservoir, although historically the territory of Velykyi Luh served as the principal area for meat

46 From a presentation by I.O. Pylypenko [349].

and dairy farming in the region. At present, this is constrained primarily by the level of contamination of the bottom sediments and by the lack of studies on the transfer of pollutants into plant biomass.

In addition, field studies conducted in 2023 and 2024 did not demonstrate the formation of grassland vegetation on the bed of the former reservoir. Therefore, it is still too early to consider this territory suitable for grazing. Meanwhile, many species of perennial herbaceous plants characteristic of pasture ecosystems have already appeared on the former reservoir bed, making it possible to predict the future development of grassland ecosystems.

In the long term, pasture-based livestock farming should also be considered as an alternative land-use option for the areas surrounding the reservoir that were previously irrigated. This approach would be supported by the natural conditions of the climatic zone, where grassland ecosystems are native and can persist even under conditions of soil salinization. Under current climatic conditions, natural grazing in the steppe zone is possible up to ten months per year.

The development of this particular branch of livestock farming would also create broad opportunities for the development of the light industry sector. Prior to the full-scale invasion, Ukraine focused on the cultivation of grain crops and the export of low-value agricultural commodities. The principal importers were countries that successfully developed meat and dairy production based on feed imported from Ukraine. As a result, the global cost of livestock production increases due to the long-distance transportation of feed.

By increasing water-use efficiency and expanding domestic meat and dairy production (while reorienting it towards pasture-based systems), Ukraine may be able to make its rural economy more resilient and reduce the cost of livestock products both on the domestic market and globally.

Fisheries

As of the end of 2024, the water area downstream of the Dnipro HPP dam consists of the former channel of the Dnipro River and a system of lake-like water bodies of relatively shallow depth, which are largely unsuitable for fish communities, especially in the long term. Therefore, relatively favorable conditions for most fish species will remain only within the river channel itself.

Almost 70 years of reservoir operation have caused irreversible changes in the ecosystems of this section of the Dnipro, and the river ecosystem is unlikely to recover fully. The principal prerequisite for recovery is a hydrological regime approaching natural conditions, including prolonged spring flooding (lasting 50-60 days).

Unlike the Lower Dnipro, with its extensive system of floodplain water bodies, the section of the Dnipro River between Zaporizhzhia and Nova Kakhovka lacks natural spawning habitats. Based on data on the fish communities that remained in the Dnipro River following the destruction of the Kakhovka Reservoir (the total number of mature individuals of species spawning at intermediate depths is estimated at

9 million), it can be concluded that natural fish reproduction requires approximately 6,000 ha of shallow-water areas with depths of 0.5-1.0 m and a stable water-level regime throughout the spawning and egg incubation period (approximately from 20 April to 10 June). This area is approximately twenty times smaller than the area flooded by the Dnipro during the spring flood of 2024.

The need to provide increased discharge to simulate natural spring flooding is complicated by the requirement to maintain stable discharge downstream of the Kakhovka HPP dam (at approximately 1,500 m³/s in summer months). Thus, meeting the needs of fisheries management would require both releasing water from the entire Dnipro cascade in spring and storing water to maintain discharge during summer, which are mutually incompatible objectives. Therefore, creating conditions suitable for fish spawning would require changes in the operating regime of the entire Dnipro cascade of reservoirs.

Nature Conservation

As of early 2026, Velykyi Luh still formally retains the legal status of a reservoir. It would be advisable to legally recognize the newly formed habitats of Velykyi Luh as naturally regenerated forest and transfer them to the category of state forest land. Such a decision would contribute to the implementation of the objectives of the State Strategy for Regional Development 2021-2027 related to the conservation of naturally regenerated forests and the expansion of forested areas. In addition, the same Strategy provides for the introduction of special mechanisms for the recovery and development of territories affected by the destruction of the Kakhovka HPP dam[142].

To preserve the emerging ecosystem, it will be necessary to adopt appropriate management decisions and grant this territory protected status.

Reduced Development Pressure on Riparian Protection Zones

An interesting side effect of the loss of the reservoir has been the reduction in the number of spontaneous violations of environmental legislation in the region. Construction within riparian protection zones, unauthorized wastewater discharges into the river, and illegal water abstraction have largely lost their relevance, as these facilities are now mostly located at a considerable distance from the river channel.

Ecosystem Management Measures for Velykyi Luh

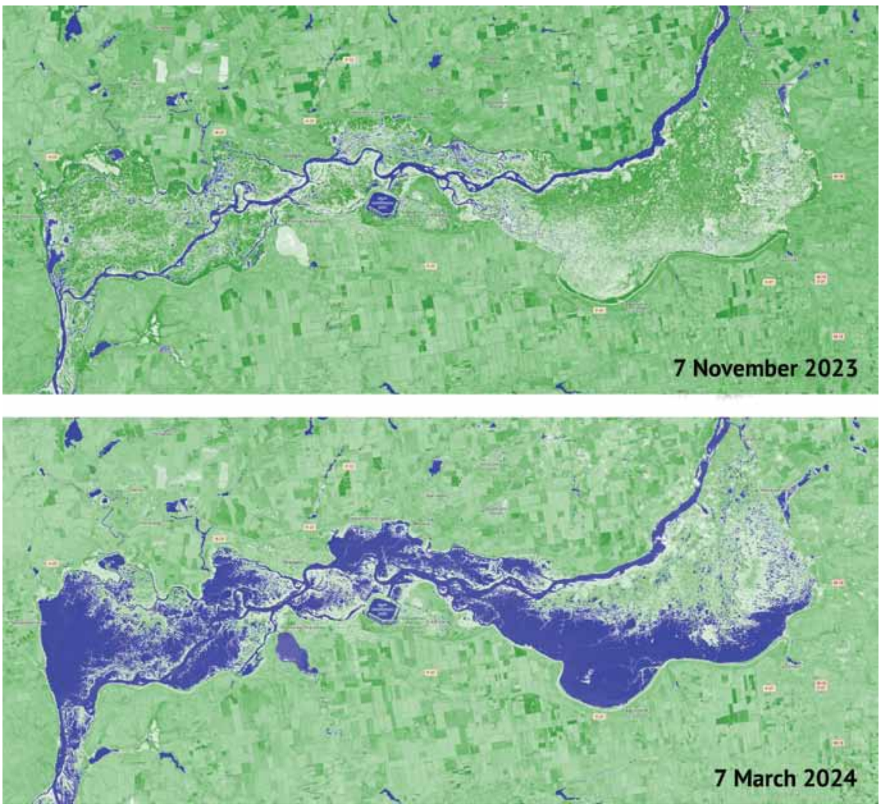
To preserve the recovering habitats and the biodiversity characteristic of these ecosystems, it is necessary to maintain the river's natural hydrological regime.

Until recently, the Kakhovka Reservoir mitigated the destructive effects of water releases from the Dnipro HPP on the section between Khortytsia Island and the dam (see the section **"Environmental Consequences of the Construction of the Kakhovka Reservoir. Loss of Biodiversity and Natural Habitats"**). In the absence of the reservoir water body, water releases may lead to various erosion processes, and a reduction in the rate of vegetation recovery. This pattern is already evident: the farther from the Dnipro HPP, the faster the recovery of vegetation.

Unlike in the 1940s and 1950s, when the reservoir was designed on waterlogged and wetland areas, the landscape today will most likely be considerably more dynamic: it will be flooded during the spring flood period and dry out during the second half of the year[304]. This is because, during the period of the reservoir's existence, both the overall discharge of the Dnipro and the capacity of this territory to retain moisture have decreased, primarily due to erosion and removal of silt deposits, infilling of bottom depressions, loss of peat deposits, and other processes.

Natural Spring Flooding in Velykyi Luh, Spring 2024

In the spring of 2024, the first natural spring flood in a long time occurred in Velykyi Luh. In March and April, the area of wetlands and temporarily flooded shallow-water habitats on the bed of the former reservoir (excluding river channels and oxbow lakes) reached approximately 60% of the area that existed before the construction of the Kakhovka Reservoir. Throughout the spring and summer period, large areas retained a high level of moisture, which has a positive effect on ecosystem recovery in the region.



Extent of flooding of Velykyi Luh during the 2024 spring flood (map: H. Kolomytsev)[70]

Above all, maintaining floodplain ecosystems will require the development of a new operating regime for all of the Dnipro cascade's reservoirs. Prior to 2023, this regime was based on the need to maintain the normal retention level required for hydropower generation, prevent the flooding of populated areas, and ensure the maximum storage capacity of the Kakhovka Reservoir. Under these new conditions, part of the objectives of the revised operating regime could be focused on maximizing the restoration of a natural spring flood regime in the Lower Dnipro.

Assigning Protected Status to the Territory

The absence of economic use across such a large natural area as Velykyi Luh creates opportunities for the establishment of protected areas throughout its entire territory. This could be achieved either through the creation of wildlife reserves covering the entire area of the former reservoir or through the expansion of existing protected areas (primarily national nature parks).

At present, the Protected Areas Network covers only a small part of the former reservoir area. In particular, the wildlife reserves Velykyi and Mali Kuchuhury and Dnipro Rapids are located entirely within the former reservoir area, while Velykyi Luh and Kamianska Sich National Nature Parks overlap partially. Naturally, the expansion of national nature parks would require increasing their staff and establishing additional local branches. However, this approach would provide the best framework for the territory's protection, study, and management.

The establishment of a protected area in this territory would represent a step towards fulfilling the requirements of a number of international conservation conventions and agreements ratified by Ukraine, including the European Landscape Convention and the Bern Convention.

The entire former Kakhovka Reservoir already has the status of an Emerald Network site[47] [45], while a small part of its area is also protected as a Wetland of International Importance (a Ramsar site). At the time the Ramsar site was designated, areas containing islands and riparian vegetation that played an important role in bird migration and nesting were selected. Following the loss of the reservoir, these areas became part of the shoreline, while a single large wetland complex is now forming across much of the former reservoir area. Therefore, rather than maintaining the existing small Ramsar areas, it would be reasonable to designate a single Ramsar wetland covering the entire area of Velykyi Luh[41].

Restoration of Velykyi Luh and the European Green Deal

Spontaneous ecological restoration of the former reservoir area may prove beneficial for Ukraine not only environmentally, but also politically.

47 The dramatic changes in the quantitative characteristics of natural habitats in this area will require updating the site's data in the Emerald Network database maintained by the Standing Committee of the Bern Convention.

International Ecosystem Restoration Strategies

In recent years, European and international organizations have increasingly adopted ambitious long-term strategies aimed at mitigating global climate change. The United Nations General Assembly proclaimed the period 2021-2030 as the UN Decade on Ecosystem Restoration[83] (hereafter the UN Decade). Within the framework of the UN Decade, initiatives are aimed at restoring degraded ecosystems and promoting the protection of intact ecosystems[84].

In May 2020, the European Commission presented the **EU Biodiversity Strategy for 2030: Bringing Nature Back into Our Lives**[334]. In 2021, the Standing Committee of the Bern Convention adopted the Convention's Vision and Strategic Plan. According to these strategic objectives, at least 30% of terrestrial and marine areas should become protected areas; at least 10% of agricultural land should be withdrawn from intensive use and restored to natural ecosystems; pesticide use should be reduced by 50%; and at least 25,000 km of rivers should be restored to a free-flowing state[133].

In 2022, the **Kunming-Montreal Global Biodiversity Framework** was adopted. It established 23 global targets for 2030 and 4 global goals for 2050. Among other objectives, it calls for halting the loss of areas important for biodiversity and restoring at least 30% of degraded ecosystems by 2030 in order to improve biodiversity, ecosystem functions, and ecological connectivity.

Some of the most ambitious conservation targets can be found in the **EU Nature Restoration Law**[14], adopted by the European Parliament in 2024. Under this legislation, EU Member States will implement effective restoration measures across all ecosystems covered by the Regulation on at least 20% of terrestrial and marine areas by 2030, while all ecosystems in need of restoration should be restored by 2050[133]. Thus, ecosystem restoration is becoming a new era in the relationship between humans and nature.

Achieving the ambitious goals set out in these strategic documents remains a major challenge both for individual European countries and for the European Union as a whole. This is particularly evident given that, on average, European countries already have a substantially higher proportion of protected areas than Ukraine. At the same time, Ukraine has considerable potential to increase the share of protected and restored ecosystems, especially in view of the need to align with European standards.

Until the beginning of the full-scale invasion by russian forces, reservoir decommissioning was virtually unknown in Ukraine. The destruction of the Kakhovka HPP dam represents the largest dam removal and reservoir drainage event in recorded history. The destruction of numerous smaller dams occurred only as a direct consequence of military actions in 2022-2024.

In Western countries, dam removal has become part of public policy. In North America and Western Europe, more dams are currently being removed than built.

Decision-making priorities are increasingly shifting toward the restoration of rivers and wetlands as more sustainable and beneficial water management solutions, particularly in the long term, despite continued population growth and increasing demand for food and energy[21].

The restoration of Velykyi Luh ecosystem could become Ukraine's most significant contribution to ecosystem restoration in Europe. Abandoning plans to rebuild the reservoir would allow the restoration of up to 1,800 km^2 of natural ecosystems (of which at least 1,000 km^2 would consist of climate-resilient forests[23]) and approximately 250 km of free-flowing Dnipro River[182]. This project could become the largest ecological restoration project ever implemented in Europe, and moreover, it would require only minimal financial investment[41].

Potential for Carbon Credit Projects

Young forests developing on the bed of the former reservoir actively sequester carbon in their biomass. Carbon compounds are among the principal greenhouse gases driving global climate change. Therefore, the preservation of Velykyi Luh could become an important contribution to climate change mitigation.

Given the extent of the floodplain forests, it is reasonable to assume that international carbon credit projects could be developed in the area. Such initiatives do not require major capital investment; on the contrary, they can become a source of investment. This, in turn, could provide an economic incentive for Ukraine while creating attractive investment opportunities for partner countries.

Recreation

The floodplain developing on the site of the former reservoir will likely gradually acquire ecosystem characteristics similar to those of the Dnipro floodplain downstream of the Kakhovka HPP dam. Accordingly, recreational use of these territories may follow a similar pattern.

Before the war, the Dnipro floodplain on the islands and along the riverbanks downstream of the Kakhovka HPP supported extensive recreational use. Numerous summer cottage communities, recreation centers, children's camps, and water sports facilities were located there.

Summer cottage communities were by far the most widespread form of recreational use. More than 5,000 summer cottage plots were located within the Lower Dnipro National Nature Park alone. Every year, around 50,000 people regularly visited these properties for recreation, while the total number of visitors, including guests, approached one million. Most of these cottages were situated on river islands.

The popularity of this area was determined both by the geomorphological characteristics of the islands (a typical island in the Lower Dnipro consists largely of reedbeds, with only a narrow shoreline strip suitable for construction) and by its recreational attractiveness and logistical accessibility. Thousands of families in Kherson region owned summer cottages on the riverbanks. These properties could only be reached by boat.

The existence of a vast number of summer cottages on the islands of the Lower Dnipro floodplain was one of the defining features and major advantages of the city of Kherson. No other large city in southern Ukraine had such a concentration of riverside cottages located on islands. The development and prosperity of Kherson were likely linked to the existence of this extensive recreational area in the Lower Dnipro floodplain, as the city was located directly adjacent to its own recreational and health resort area. By all indications, this territory could have qualified as a resort area, were it not for the lack of infrastructure. Unfortunately, the vast majority of these summer cottages were destroyed by the catastrophic flooding following the destruction of the Kakhovka HPP and by military actions.

Thus, the territory of the former Kakhovka Reservoir has significant recreational potential as a local recreation and health resort area. However, there are a number of serious challenges to realizing this potential (see the section **"Environmental Risks of the Restoration of Velykyi Luh"**).

Historical and Cultural Heritage

In the 1950s, when the reservoir was being planned, archaeological work was limited by a lack of time and resources. The authorities assigned archaeologists the task of rapidly identifying and documenting sites that would be flooded, without providing opportunities for detailed excavations[343]. Consequently, numerous archaeological sites from different historical periods, including settlements, burial mounds, and other monuments, were submerged beneath the waters of the Kakhovka Reservoir.

Following the destruction of the Kakhovka HPP in June 2023 and the subsequent drop in water levels, archaeologists and historians discovered numerous artefacts dating from the Stone Age to the twentieth century, including ceramics, tools, and even the remains of wooden structures[323].

A dugout canoe carved from a single oak trunk, nearly 7 meters long, discovered on a previously submerged section of the shoreline of Khortytsia Island on the Dnipro River. It was identified as a monoxylon (dugout canoe) dating back 300-500 years[323]

Finds made by residents of the Nikopol area following the destruction of the Kakhovka HPP by russian occupying forces [337]

Chance discoveries of historical artefacts from the Cossack period [171]

Jawbone of a southern elephant discovered on the exposed bed of the Kakhovka Reservoir [171]

Many discoveries are made not by professional archaeologists, but by local residents. During the brief period before the reservoir bed became overgrown with young forest, residents of villages adjacent to the former reservoir published a large number of photographs of chance finds. As a result of the redeposition of silt, some artefacts became buried beneath additional layers of sediment, while others, on the contrary, emerged at the surface.

The subsequent growth of forest across almost the entire area of the former reservoir has once again made the territory largely inaccessible for research. An additional, and currently almost insurmountable, obstacle to archaeological investigations is the extensive contamination of the area by landmines, as well as its status as an active combat zone. The possibility of conducting such studies in the future will largely depend on the development scenario chosen for the region. In particular, if Velykyi Luh is preserved, the possibility of conducting archaeological research will also be preserved. Moreover, as noted above, Cabinet of Ministers Resolution No. 1483 allows projects financed as part of the response to the destruction of the Kakhovka HPP to proceed without conducting investigations of archaeological heritage sites.

Environmental Risks Associated with the Restoration of Velykyi Luh

The restoration of Velykyi Luh may contribute both to the ecological restoration of landscapes and biodiversity and to the emergence of new environmental risks.

One such risk is the degradation and loss of water bodies in the Dnipro delta, whose hydrological regime was previously maintained by artificial water releases that are now entirely absent[36]. Consequently, the regulation of environmental conditions beneficial to certain species (for example, filter-feeding molluscs) has also been lost.

Following the cessation of daily water releases from the Kakhovka HPP, water exchange rates in oxbow lakes have decreased by a factor of 8-10. Consequently, over the next few years, a complete transformation of trophic conditions and habitats is expected, together with the shallowing and eventual disconnection from the river system of a large group of water bodies covering a total area of approximately 75 km². Therefore, many of these water bodies may disappear. Exceptions include several lakes located at the lower edge of the delta, where water level fluctuations are driven by wind-induced surges from the sea (including Krasniukove, Zolote, and Didove lakes)[36].

Delta water bodies constitute an important component of the ecological, economic, and cultural landscape of the region and are protected within Lower Dnipro National Nature Park and the Emerald Network.

A possible solution to this problem could involve local artificial water exchange systems (pumping stations) supplying water to individual water bodies, similar to those used in the Lower Danube basin. This approach would likely increase economic costs, as it would require continuous expenditures for operation and management. Meanwhile, such measures could receive international support, which may become an important component of the long-term management strategy of the Lower Dnipro National Nature Park.

Heavy metals and other toxic compounds accumulated in woody biomass and plant residues may be released again during wildfires or as a result of human-induced burning. Similar concerns apply to the potential cultivation of agricultural crops within Velykyi Luh. At present, these challenges remain insufficiently studied; there is also insufficient information regarding the possible transfer of toxic compounds into livestock products (through contaminated vegetation consumed by animals) and into honey produced by apiaries located adjacent to Velykyi Luh.

Development of recreation along the shores of Velykyi Luh may also involve certain risks. Before such activities can be expanded, it will be necessary to assess the extent to which contamination of bottom sediments may affect safe recreational use of beaches. Large-scale recreational use of the territory in the future may also conflict with its conservation value.

Thus, the restoration of Velykyi Luh requires an integrated approach involving careful planning and consideration of multiple environmental factors in order to avoid potential risks to both people and biodiversity.

Supporters of the Scenario

At present, no official government plans exist for implementing this scenario, although it is actively supported by many scientists and civil society organizations and has attracted considerable interest from the international community. In addition, some local residents, particularly older people who remember the period before the construction of the reservoir, recreational fishers, historians, local history researchers, and archaeologists express support for this scenario. At the same time, this does not apply to local authorities, whose public position regarding the restoration of natural ecosystems remains unknown.

Non-governmental organizations. The scenario focused on the restoration of Velykyi Luh while simultaneously addressing the region's economic needs is supported by a number of non-governmental organizations (NGOs). These include Ukrainian organizations such as the Ukrainian Nature Conservation Group[130], Environment-People-Law[201], and Ecoaction[200]; international organizations such as Bankwatch International[87], International Rivers[35], and the Ukraine War Environmental Consequences Work Group[182]; and networks of civil society organizations, including the Ukrainian Climate Network[81] and the Kakhovka Platform[203]. Support for this scenario has also been expressed by the Dnipropetrovsk Regional Institute Of Public Administration[185] and the Kyiv School of Economics[25].

During the year following the attack, as photographs of the young forest spread and public discussion of the topic intensified[48], public attitudes towards the events at the Kakhovka HPP began to change noticeably. Support for the preservation of Velykyi Luh has grown, while thematic YouTube channels[93, 95] and dedicated sections in leading independent Ukrainian media outlets[69] have been created.

Non-Governmental Platforms for Discussion of the Kakhovka Issue

In August 2023, the GIS Experts Club community[15] organized a seminar dedicated to the Kakhovka issue[96], and on 6-7 June 2024, Kherson State University hosted the first international conference "Kakhovka Reservoir Disaster: One Year 'After Tomorrow' and Future Prospects"[241]. The conference became the only discussion platform to officially publish the outcomes of its work[251].

On the part of non-governmental organizations, the Kakhovka Platform[202] was established at the initiative of the International Charitable Organization Environment-People-Law (EPL). In autumn 2024, the Platform hosted the Community Forum[203; 204; 205; 206; 207], the first public event dedicated to the Kakhovka issue that involved not only experts but also other stakeholders.

The scientific community of the National Academy of Sciences of Ukraine (NAS of Ukraine)[278] also established a working group to analyze the consequences of the destruction of the Kakhovka HPP dam. The group was intended to coordinate the preparation of analytical materials on Kakhovka-related issues for state authorities[283], with its most intensive activities taking place during the period of reservoir drainage and subsequent flooding[285]. In September 2023, the Presidium of the NAS of Ukraine adopted the resolution "On the Environmental Consequences of the Destruction of the Kakhovka HPP Dam"[284], in which the preferred scenario involved the creation of a narrower reservoir confined by a special long dyke (saddle dam). At the same time, the views of individual members of the NAS of Ukraine[162] who advocated for the restoration of Velykyi Luh[281] were subject to criticism. Thus, the scientific community of the NAS of Ukraine was also unable to develop a unified position on the Kakhovka issue. The analytical report prepared by the NAS of Ukraine for the first anniversary of the attack in June 2024 entirely avoided addressing the question of whether the reservoir should be restored[280].

48 Among the supporters of this scenario are Academician Yakiv Didukh of the M.G. Kholodny Institute of Botany, Kyiv [72]; Yurii Kvach, PhD (Biology), Odesa [324]; Vadym Maniuk, PhD (Geography), Dnipro [22; 92]; Olha Helevera, PhD (Geography), Kropyvnytskyi [71]; the EOS communities [10]; and others.

Official Government Position. No government body has publicly expressed support for any scenarios that do not rebuild the Kakhovka HPP. One possible reason for this may be the desire to provide psychological support to Ukrainians remaining in the occupied territories who hope for the restoration of their former way of life.

Among high-ranking officials, the strongest support for the restoration of Velykyi Luh has been expressed by Volodymyr Omelian, former Minister of Infrastructure. In an interview given as early as the beginning of 2024, he stated that *"the economic feasibility of rebuilding the Kakhovka HPP is zero. This means that economic, social, and ecological systems are functioning without the Kakhovka Reservoir. It is much more effective for businesses, civil society organizations, and researchers to develop scenarios under which the reservoir is not restored"*[74].

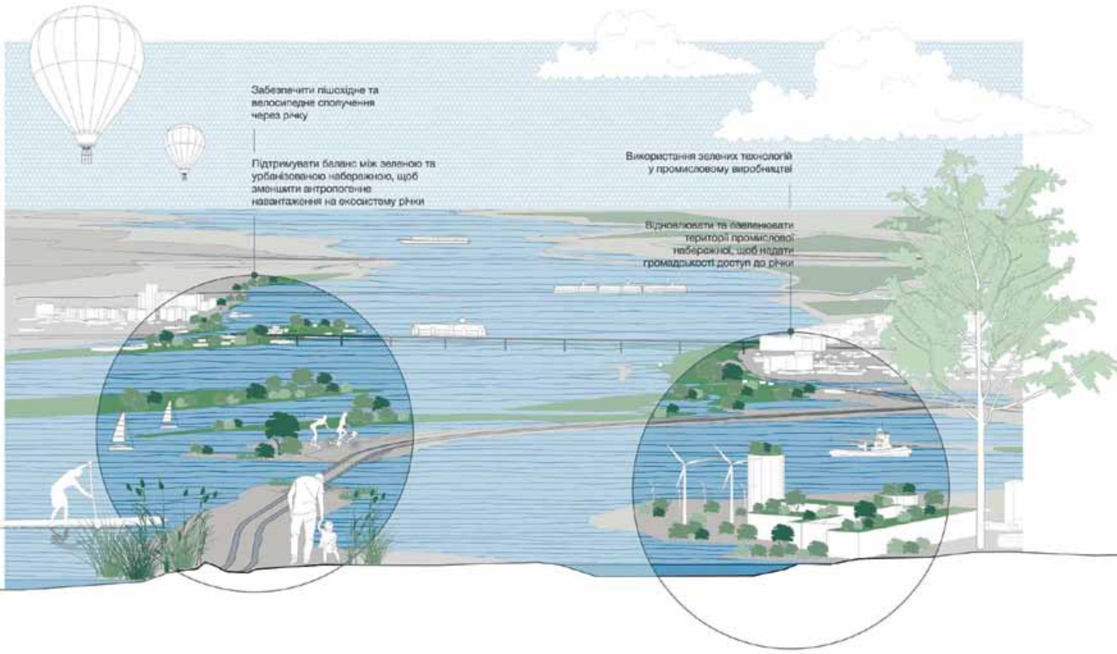
State Agency for Water Resources. Some government institutions indirectly indicate support for this development scenario. Since the destruction of the Kakhovka HPP, the State Agency for Water Resources of Ukraine (SAWR) has developed the Dnipro River Basin Management Plan[190] (approved by the Resolution of the Cabinet of Ministers of Ukraine of 1 November 2024 No. 1077-r[151]) and the State Target Program for Integrated Water Supply for Territories Most Affected by Military Operations (currently undergoing interagency approval[189]). These documents provide for the reconstruction of water supply systems for cities that previously relied on water from the Kakhovka Reservoir, as well as the creation of reserve water storage facilities, rather than the restoration of the reservoir itself[111].

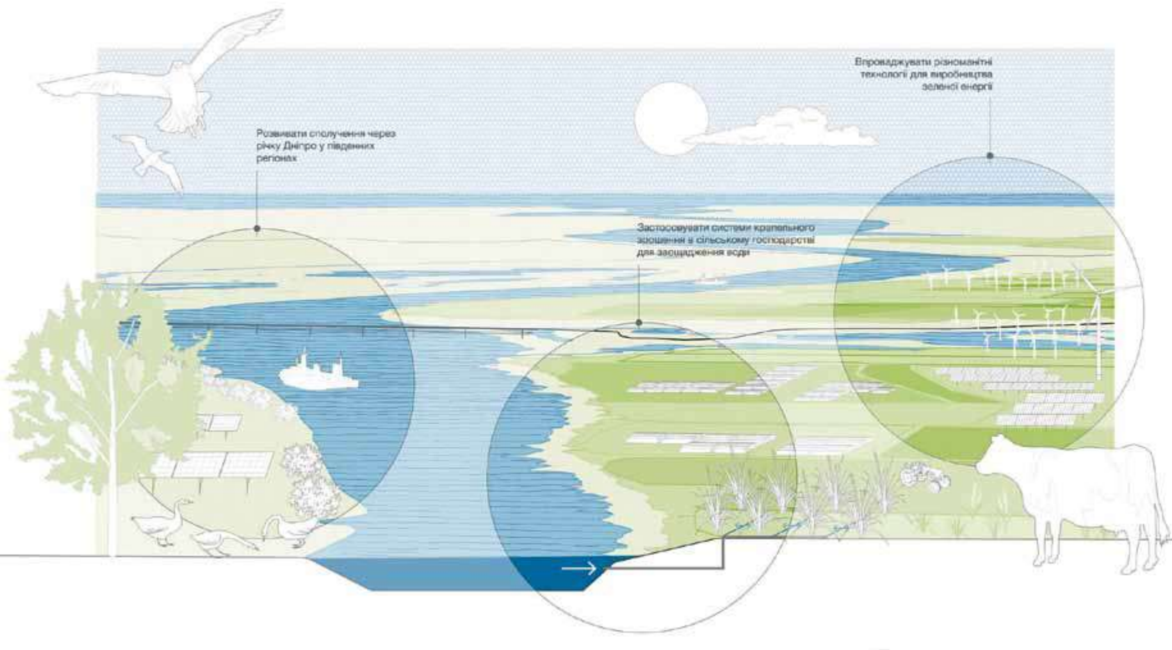
Most likely, the scenario of rebuilding the Kakhovka Reservoir was not considered in either document because of institutional and administrative factors: government agencies prepare plans based on requests from the sectors under their jurisdiction. Consequently, the restoration of the HPP, which falls within the competence of the Ministry of Energy, is not considered in the planning documents of other government bodies. In addition, Ukraine's future financial priorities remain uncertain, as other hydropower plants on the Dnipro were also severely damaged by russian attacks[208]. Their restoration will likely take priority over the construction of a new Kakhovka HPP.

In addition, in 2024 the large-scale project Integrated Vision for the Dnipro River, organized by the NGO Urban Coalition Ro3kvit and Greenpeace, was presented. Representatives of the State Agency for Water Resources participated both in the presentation of the project[56; 76; 191] and in the preparation of the report. The report recommends against rebuilding the Kakhovka HPP dam in its previous form and instead proposes reconsidering its relevance under current conditions.

Verkhovna Rada of Ukraine. Parliamentary committees did not support the draft law initiated by the Cabinet of Ministers of Ukraine that would have created the conditions necessary for the restoration of the Kakhovka Reservoir. Moreover, members of the Verkhovna Rada Committee on Agrarian and Land Policy submitted an alternative draft law[150], which not only provides for restrictions on the use of lands within the former reservoir area but also makes it possible to designate parts of the territory for nature conservation purposes: *"The restrictions on land use established by subparagraph 1 of this paragraph shall not apply to the formation of land*

A spatial vision of the landscape following the restoration of natural ecosystems [76]





plots, their transfer for use, or changes in land designation for the purposes of restoring the Kakhovka Reservoir and navigational hydraulic structures, implementing land protection measures, or establishing protected areas and objects of national importance." Although this draft law had not been adopted by the end of 2024, the fact that it was developed by the Verkhovna Rada's agrarian committee may indicate a degree of support among members of parliament for the scenario of ecological restoration and the development of a new economic model for the region.

In June 2024, the Verkhovna Rada Committee on Environmental Policy and Nature Management held an off-site meeting in the city of Kherson, where committee members discussed the prospects for constructing new water supply pipelines in the region, as well as the climate resilience of the forests developing on the bed of the former reservoir. To some extent, this suggests that even government initiatives are gradually becoming oriented towards the development of a new economic model for the region.

Armed Forces of Ukraine. Despite the absence of official statements on the matter, the restoration of Velykyi Luh may also offer potential advantages for the Defense Forces of Ukraine. In its current state, the Dnipro Valley remains a formidable obstacle to crossings by russian forces[77]. On the first anniversary of the attack, the State Border Guard Servic e of Ukraine published a video report demonstrating how the newly formed wetland impedes the movement of infantry, military vehicles, and even boats[94].

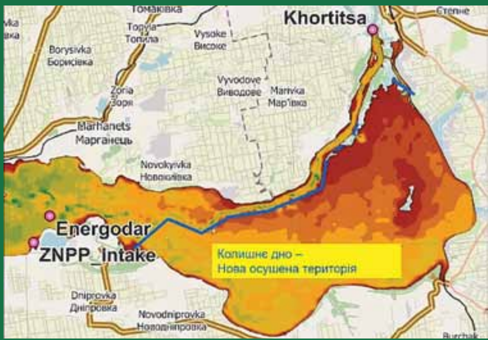
«COMPROMISE» AND «ALTERNATIVE» DEVELOPMENT SCENARIOS

Possible future scenarios for the territory of the former Kakhovka Reservoir include several "compromise" options, which involve restoring the Kakhovka hydroengineering complex in a modified form, as well as scenarios based on a complete shift in approach and the abandonment of the existing paradigm. In most cases, such proposals are driven primarily by economic considerations.

Construction of a Smaller Reservoir

At various times, a number of scientific institutions have proposed limiting the Kakhovka Reservoir to its deep-water section by constructing a 35-km-long dyke. In essence, this scenario envisages the creation of a smaller reservoir with greater average depths. According to the proposal, the d am would create a "protected zone" (similar zones exist around other reservoirs of the Dnipro cascade), while the useful storage capacity of the reservoir would remain sufficient to meet water demand and maintain environmental flows in the Lower Dnipro[198].

Since the 1950s, similar ideas have repeatedly reappeared in the literature[369; 371], often being presented as new and original proposals. Today, this concept continues to be promoted by institutions of the National Academy of Sciences of Ukraine, including the Institute of Hydrobiology and the Institute of Telecommunications and Global Information Space[107; 349].



Embankment scenario
proposed by M. Zhelezniak [97]

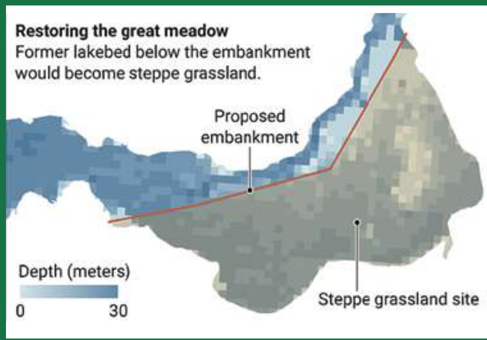


Illustration from Science [67]

"Protected zones" in the upper reaches of the Kaniv Reservoir: island archipelagos occupied by meadow ecosystems (satellite image, 1985; source: Google Earth)

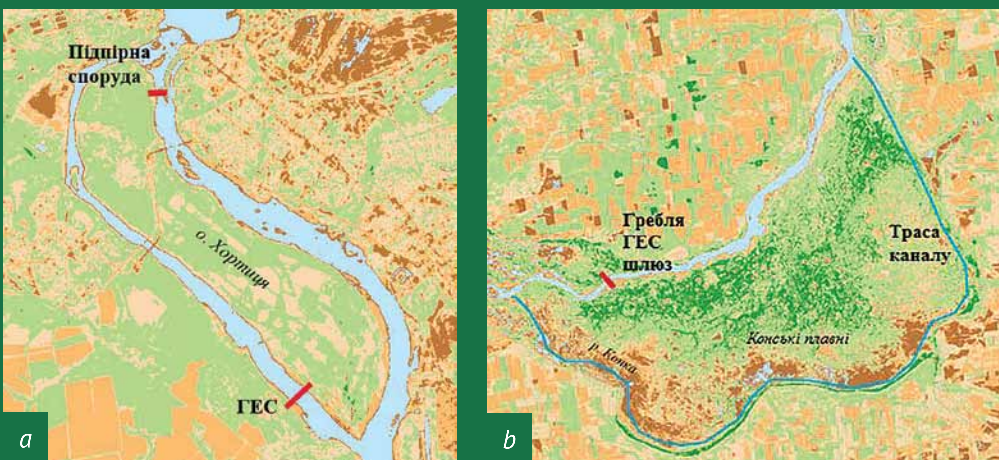
The construction of a 35-km dam would require up to 16 million m^3 of soil. This volume would first need to be extracted from the environment elsewhere and subsequently transported to the construction site. The implementation of such a project would likely require substantial investments in infrastructure development, including the construction of railways and roads[389].

Today, the territory proposed for conversion into a "protected zone" consists predominantly of wetlands and young forests growing on substrates contaminated with toxic substances. This effectively precludes its use for agriculture or forage production, as envisaged by the proposed scenario. Most likely, draining these areas would require raising the land surface by adding large quantities of soil, which would not represent an efficient use of natural resources[49]. This would require tens of times more soil than the construction of the dam itself.

The reduced storage capacity of the reservoir[50] may be insufficient to simultaneously ensure the efficient operation of the hydropower plant and satisfy irrigation demands. At the time when the concept of a smaller reservoir was first proposed, the discharge of the Dnipro River was substantially higher than it is today: in 2022, water availability in the reservoir was barely sufficient to support the operation of the hydropower plant. For this reason, the proposed project is unlikely to be economically efficient.

Cascade of Low-Head Hydropower Plants

The construction of a cascade of small or floating low-head hydropower plants (LHPPs) on the Dnipro has been considered as a possible alternative in a German Agency for International Cooperation report[349]. This concept was also proposed by representatives of the Institute of Telecommunications and Global Information Space of the National Academy of Sciences of Ukraine in 2024. The project involves constructing a dam across one or even both branches of the Dnipro River in the vicinity of Khortytsia Island[349]. This option entails lower environmental risks, as LHPPs do not require the flooding of large areas and have only a limited impact on river morphology. In addition, LHPPs may offer greater energy security because their generation capacity is distributed across multiple facilities, making simultaneous disruption more difficult.



Options for the construction of small hydropower plants (based on a presentation by Dmytro Stefanyshyn [349]): a) on the main channel of the Dnipro River in the vicinity of Khortytsia Island; and b) on an embanked section of the Dnipro River downstream of the Konski Plavni wetlands, with the construction of a bypass channel.

49 All "protected zones" established around other reservoirs in the Dnipro cascade were located in their upper reaches. In most cases, these were meadows suitable for grazing rather than wetlands.

50 In the event of the construction of Kakhovka HPP-2, water use for electricity generation would nearly double.

The proponents of this scenario argue that although the initial investment costs of low-head hydropower plants (LHPPs) are higher, their operating costs are lower. Consequently, the overall life-cycle costs of such projects are reduced. These plants can also be commissioned more rapidly than large hydropower facilities while providing a comparable level of electricity generation due to lower transmission losses[349].

However, the concept of constructing a cascade of small hydropower plants on the Dnipro has several limitations. Its implementation would require substantial investments because of the complexity of constructing multiple infrastructure facilities and protective embankments, potentially exceeding the costs of rebuilding a single large hydropower plant. While small hydropower plants are capable of generating electricity, they do not address the irrigation, water supply, and other services previously performed by the Kakhovka HPP. In addition, their operation depends on natural hydrological fluctuations, which affects the stability of electricity generation.

Restoring Irrigation through Water Transfer from the Danube

In 2024, the O.N. Sokolovsky Institute for Soil Science and Agrochemistry National Scientific Center published a study[183] that considered the possibility of restoring and refilling the Kakhovka Reservoir by transferring water from the Danube River. Under this proposal, 3-5 km³ of water would be diverted from the Danube Biosphere Reserve to the reservoir through large pipelines[51] [331]. Although this scenario does not comply with the principles of sustainable development, the project received approximately UAH 4 million in government funding during the full-scale war[290].

Conceptual design for the transfer of water from the Danube River to the Kakhovka Reservoir proposed by the O.N. Sokolovsky Institute for Soil Science and Agrochemistry (2023)[291]

51 Similar ideas have also been proposed by researchers of the Institute of Climate-Smart Agriculture of the National Academy of Agrarian Sciences of Ukraine, who consider it appropriate to transfer water from the Danube not only to the Dnipro but even to the city of Mariupol [290].

Interbasin Water Transfers

Projects to transfer water from the Danube River to supply the southern regions of Ukraine were already being considered during the Soviet era[317; 329]. In particular, the final destination of the proposed water transfer scheme was to be the lower reaches of the Dnipro River. The project was initiated in the waning years of the Soviet Union but was immediately abandoned due to the catastrophic consequences of the desalination of the Sasyk Lagoon, the first of the lagoons that hydraulic engineers had planned to convert into freshwater reservoirs.

The dam separating the Sasyk Lagoon from the Black Sea was constructed between 1971 and 1978. This resulted in the degradation of biodiversity within the lagoon, soil salinization in adjacent areas, the collapse of commercial fisheries, and a deterioration in water quality.

Restoring the lagoon to its natural state and re-establishing natural water exchange with the Black Sea proved to be a complex task. It required large-scale engineering interventions, which themselves could have resulted in additional environmental impacts.

The Government of Ukraine continued efforts to address the consequences of the desalination of the Sasyk Lagoon[140] until 2010. However, in 2015, the commission responsible for this issue was dissolved[141], and restoration efforts were subsequently discontinued.

Cultivation of Energy Crops on Selected Areas of the Former Reservoir

This scenario, proposed by the German Agency for International Cooperation (GIZ) [349], considers the potential use of lands within the former Kakhovka Reservoir for agricultural purposes. The authors propose cultivating energy crops (particularly energy willow) on up to 20% of the area of the former reservoir. The cultivation of such crops may be advantageous because they do not require fertile soils (the territory is currently undergoing natural colonization by willows) and are therefore well suited for areas exposed following the drainage of the reservoir. In addition, this scenario could simultaneously contribute to land reclamation and phytoremediation, as willows are known to efficiently remove heavy metals from soils.

Among the risks associated with this approach are the potential spread of invasive species and the release of heavy metals accumulated in plant biomass. Most fast-growing energy crops are invasive species. Such plants may spread beyond managed areas and adversely affect native flora and fauna. During combustion, heavy metals, other toxic substances, and combustion products may be released into the atmosphere, posing risks to both human health and ecosystems. Additionally, the cultivation of energy crops requires a substantial labor force.

Deployment of Combined Renewable Energy Sources (Solar, Wind, and Others)

This scenario may prove to be one of the more promising development options. Approximately 10 GW of solar and wind generation capacity have already been installed in Ukraine, about half of which is located in occupied territories. The contribution of these energy sources to the country's overall energy balance amounts to 7-10% of final energy consumption, which is comparable to the total electricity generation of all hydropower plants in Ukraine, including the Dnipro HPP (which, as of the end of 2026, remains out of operation due to damage).

Only 8-10% of Ukraine's solar and wind energy potential has been utilized, although this figure is somewhat higher in the southern parts of Dnipropetrovsk, Kherson, and Zaporizhzhia regions. The main reason is the implementation of large-scale projects such as the Nikopol and Pokrov solar power plants, with a combined installed capacity of 440 MW.

Under current legislation, the bed of the former Kakhovka Reservoir may be used for the construction of solar or wind power plants[52]. To achieve electricity output comparable to that of the Kakhovka HPP using solar and wind generation, a renewable energy complex with an installed capacity of 1,000-1,100 MW would be required, occupying approximately 1-2% of the reservoir area (around 4,000 ha), with investments estimated a t EUR 2.5-2.8 billion without energy storage and up to EUR 4.5 billion with storage capacity. The use of 10-20% of the former reservoir bed (20,000-40,000 ha) would make it possible to achieve a capacity of up to 20 GW and annual electricity generation of 9-12 TWh (without storage) or 20-24 TWh (with storage). The cost of such projects is estimated at EUR 27-36 billion, including expenditures on infrast ructure, drainage works, and flood protection measures[349].

This scenario appears relatively realistic. However, considering the flooding observed during the spring flood of 2024, it should be recognized that more than half of the territory of the former reservoir is likely to be flooded in springtime. This factor would significantly affect the possible configuration of energy generation facilities and their cable connections to substations located on the banks.

The highest areas of Velykyi Luh are located in its central part. Therefore, if energy generation facilities are to be developed without disrupting the hydrological regime of the territory, their construction would require either elevated structures or roads built on embankments. In the former case, construction costs would increase substantially, whereas in the latter case the hydrological conditions of the territory would be altered.

SPECIFIC FEATURES OF SCENARIO IMPLEMENTATION FOR LOCAL COMMUNITIES

The residents of all settlements located along the shores of the reservoir (primarily rural communities) were strongly dependent on the reservoir. During its construction, many settlements in the basin were relocated over relatively short distances. As a result, villages often ended up being situated directly on the reservoir shoreline.

52 Pursuant to Resolution No. 35 of the Cabinet of Ministers of Ukraine of 19 January 2022, the construction of solar and wind power plants may be carried out on land plots contaminated by hazardous chemicals as a result of emergencies and/or armed aggression and military operations during the period of martial law.

The new environmental conditions created in the 1950s led to the adaptation of local livelihoods to the presence of the reservoir, including adjustment to higher groundwater levels and, consequently, easy access to water for irrigating household plots. In addition, a considerable proportion of local residents were engaged in commercial fisheries.

Following the loss of the reservoir, most villages found themselves located far from the Dnipro River or its branches. At the same time, the traditional forms of natural resource use familiar to local communities also disappeared. It is therefore understandable why, for many local residents, the destruction of the Kakhovka HPP represents not merely the loss of infrastructure but the collapse of an entire way of life.

Meanwhile, elderly residents who remember the period before the creation of the reservoir recall a wide range of traditional uses of Velykyi Luh landscape, including timber harvesting, reed harvesting, fishing, hunting, livestock grazing, and beekeeping[336]. Preserving the natural ecosystems of Velykyi Luh would make it possible to restore the historical coexistence between local communities and the ecosystems of the Dnipro valley, with the exception of livestock grazing and beekeeping, which may currently pose significant environmental risks due to the potential transfer of heavy metals and other toxic substances into agricultural products.

In addition, the extensive natural colonization of the former reservoir bed by willows creates economic opportunities for the development of willow weaving. This includes the production of furniture, containers, woven reinforcement structures for camouflage systems, and military fortifications. The selective thinning of willow stands may facilitate the development of forest habitats while providing high-quality raw materials available in substantial quantities. Willow weaving could become a viable small-scale business with local markets in Zaporizhzhia, Kryvyi Rih, and Kherson, contributing both to sustainable resource use and local employment.

The abandonment of the reservoir may lead to insufficient water resources for large-scale monoculture agriculture. In contrast, small family farms may assume a more prominent role. Thanks to their flexibility and adaptability, such farms currently have greater opportunities to establish themselves in the market than do large agricultural holdings. Moreover, during the war, small family farms have already demonstrated considerable resilience and an ability to adapt to changing conditions[40]. They also play a more significant role in supporting local communities by providing a substantial share of employment. European Union policies, particularly the European Green Deal, are also likely to favor support for small-scale farms as more environmentally sustainable and resilient forms of agriculture.

It is difficult to identify a single development scenario that would be most beneficial for local communities among those currently under consideration. One reason is that the proposed scenarios differ substantially in their implementation timeframes. For example, the restoration of Velykyi Luh could provide benefits in the short term, although taking advantage of these opportunities would require a transformation of existing economic practices. Reconstructing the reservoir, by contrast, would require fewer changes to the established economic model but would entail a lengthy implementation period. Such a scenario requires an unreasonably long a wait for any family, as even a generational change could occur during this time.

CONCLUSIONS

The construction of the Kakhovka Reservoir in the 1950s pursued both military and economic objective that took precedence over consideration of the environmental risks associated with the project. Consequently, the natural environment of southern Ukraine underwent a profound transformation: vast areas of valuable floodplain ecosystems were flooded, the free-flowing character of the Dnipro River was lost along a stretch of approximately 250 km, and with it the river's importance for the spawning of many valuable fish species, as well as for bird migration and reproduction. At the same time, the largest irrigation system in the region was established across extensive areas surrounding the reservoir, fundamentally transforming the regional economy and contributing to significant population growth. In addition, the creation of the reservoir reshaped the entire transport infrastructure of the region, urban water supply systems, and the energy sector. Most contemporary Ukrainians cannot imagine life without the Kakhovka Reservoir, as their ancestors settled in the region only after its construction.

In 2023, russian forces committed an act of ecocide unparalleled among the environmental consequences of the full-scale invasion. The reservoir ceased to exist; territories downstream suffered devastating destruction caused by catastrophic flooding, and the marine environment experienced unprecedented pollution and desalination. The large-scale destruction of infrastructure, flooding of entire cities, and loss of human life generated international attention and led to discussions of the disaster at all levels, including at the United Nations. After 6 June 2023, the term ecocide ceased to be perceived merely as a rhetorical concept and became widely used in reference to the Kakhovka disaster[131].

Within days of the catastrophe, biologists began investigating its environmental consequences. Within a few months, they documented the rapid regeneration of floodplain forests and other vegetation across the former reservoir bed. These forests are highly resilient to climate change, and their emergence indicates the possibility of returning the former reservoir area to a natural state.

This unexpected ecological recovery triggered a public debate about the future of the destroyed Kakhovka hydroengineering complex. Public opinion largely divided between supporters of restoring the former reservoir, advocates of reviving the floodplain ecosystems of the Lower Dnipro and Velykyi Luh, and proponents of several compromise scenarios requiring fundamentally new technical solutions.

The occupation of nearly the entire region dependent on the Kakhovka hydroengineering complex in 2022 followed by the destruction of the Kakhovka HPP created conditions for a paradigm shift. Making hasty decisions without studying international experience, carefully weighing the advantages and disadvantages of each scenario, and conducting a strategic environmental assessment could prove to be an unacceptable mistake[133].

Most of the proposed “compromise” or “alternative” projects primarily address the interests of individual sectors of the economy and are therefore likely to divert valuable resources away from the comprehensive recovery of the region. Any proposed scenario should instead be evaluated based on its ability to address the needs of the environment, local communities, and key sectors of the economy, while recognizing that agricultural practices, economic priorities, and patterns of land use may need to change.

Time is working against the scenario of restoring the hydroengineering complex. With each passing month of war and occupation on the left bank of the Dnipro, the area covered by young forests continues to expand, while public support for preserving Velykyi Luh grows stronger. Meanwhile, the infrastructure sectors that are critically dependant on the reservoir are not sufficiently resilient to remain idle while waiting for its restoration[133]. The costs required to restore the entire system, including water supply and irrigation infrastructure, appear disproportionate to the needs that can only be met through the reservoir itself. Compensating for its loss through modern technologies and adaptation of the regional economy is likely to be more effective than rebuilding a system that loses nearly half of its water during transportation.

The sediments of the former reservoir are contaminated with heavy metals, which are already being accumulated in the biomass of trees growing across the former reservoir bed. As a result, pollutants located in deeper sediment layers are effectively being transferred to the surface. If the area were to be flooded again, hazardous substances contained in accumulated leaf litter and dead plant material would likely be transported downstream. Consequently, the creation of a new reservoir would further increase the spread of heavy metals beyond the boundaries of the contaminated area of the former reservoir[131].

Based on the evidence reviewed in this study, the scenario with the greatest potential is the preservation of the emerging ecosystem of the new Velykyi Luh, combined with the development of alternative approaches to meeting the region’s economic needs without reconstructing the reservoir. This implies not merely identifying alternative water sources for irrigation, but creating a new economic model for the region that is better adapted to contemporary environmental and socio-economic conditions. At the same time, this scenario is not without risks: the mechanisms governing the migration of heavy metals within woody biomass and soils of the former reservoir remain insufficiently understood. It is possible that timber from Velykyi Luh will not be suitable for energy production and that soils from the former reservoir area will be unsuitable for agriculture, as their use could result in the redistribution of pollutants.

Since the first day of the disaster, Ukraine has invested substantial resources in restoring the functionality of the affected region, including the construction of new water supply systems and the adaptation of all sectors of the economy and local communities to the new environmental conditions. In practice, this amounts to the creation of a new economic model. This model appears more resilient both under conditions of geopolitical instability and in the context of accelerating climate change. Should the construction of a new reservoir nevertheless proceed in the future, it would result in the destruction of the largest floodplain willow-poplar forest in Europe and the largest forest ecosystem in southern Ukraine, eliminate the possibility of establishing a sustainable regional economy, and ultimately lead to enormous waste, as investments are already being directed toward a different recovery pathway. Equivalent investments in more resilient renewable energy sources and improved energy efficiency are more justified under current conditions[56] than rebuilding the hydroelectric power plant. Likewise, modern agricultural technologies are capable of supporting the production of diverse agricultural products without relying on outdated irrigation systems and the continued large-scale salinization of soils.

The studies reviewed here indicate that even if the reservoir had been preserved, global climate change would likely have resulted in the eventual salinization of irrigated lands and increasing shortages of water for irrigation, water supply, and electricity generation in the coming decades. Thus, abandoning the Soviet development model based on constructing a new reservoir and further expanding irrigated agriculture in southern Ukraine creates opportunities for establishing a more resilient and modern regional economy than that envisioned under Stalin's Plan for the Transformation of Nature.

The unexpected restoration of Velykyi Luh, whose memory Soviet ideologues sought to erase for decades, may become a symbol of Ukraine's post-war recovery. The study of the archaeological heritage of this territory may reveal new chapters in the history of Ukrainian statehood and the pre-Cossack period. The unique experience of the Kakhovka disaster may ultimately enter the history of the russian-Ukrainian War as a turning point after which Ukraine emerged stronger than before[133]. Moreover, the restoration of Velykyi Luh is likely to become the largest ecological restoration project ever undertaken in Europe.

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APPENDICES

Appendix 1. List of habitat types of Velykyi Luh according to the National Habitat Catalogue of Ukraine and Resolution No. 4 of the Bern Convention

Habitat types of the National Habitat Catalogue of Ukraine[53]	Habitat types of Resolution No. 4 of the Bern Convention
Woody and Shrub Natural Complex	
*Д1.6.1. Заплавні вербові і тополеві ліси	G1.11 Riverine Salix woodland / Прирічкові вербові ліси;
Д1.6.2. Вологі та періодично вологі ліси з домінуванням дуба звичайного або видів в'яза	G1.22 Mixed oak – elm – ash woodland of great rivers / Мішані дубово-в'язово-ясенові ліси великих рік.
Д1.6.4 Рівнинні незаболочені ліси вільхи чорної і ясена	G1.21 Riverine Fraxinus-Alnus woodland, wet at high but not at low water / Заплавні періодично мокрі ліси з домінуванням Alnus або Fraxinus.
Д1.4.7 Ліси берези дніпровської, дуба звичайного, осики на піщаних терасах степової зони	-
Ч7.1 Вербові чагарникові зарості піщаних і суглинкових берегів	F9.1 Riverine scrub / Прирічкові чагарники.
Ч7.3. Заболочені чагарники	-
!Ч7.4. Зарості аморфи кущової	-
*Ч8 Псамофітні чагарникові угруповання	F9.1 Riverine scrub / Прирічкові чагарники
Wetland and Grassland Complexes	
Т3.1.1 Вологі евтрофні і мезотрофні сінокісні луки	E3.4 Moist or wet eutrophic and mesotrophic grassland / Мокрі або вологі евтрофні і мезотрофні луки.
Т3.2 Вологі луки пасовищного використання	E3.4 Moist or wet eutrophic and mesotrophic grassland / Мокрі або вологі евтрофні і мезотрофні луки.
Т3.3.1 Мокрі луки з домінуванням злакоподібних трав	E3.4 Moist or wet eutrophic and mesotrophic grassland / Мокрі або вологі евтрофні і мезотрофні луки.
Т3.3.2 Мокрі луки з домінуванням високотрав'я	E5.4 Moist or wet tall-herb and fern fringes and meadows / Мокрі або вологі високотравні та папоротеві узлісся і луки.

53 https://www.researchgate.net/publication/331935396_NATIONAL_HABITAT_CATALOGUE_OF_UKRAINE

Habitat types of the National Habitat Catalogue of Ukraine[53]	Habitat types of Resolution No. 4 of the Bern Convention
!В2.1.1 Алювіальні ділянки та днища пересохлих водойм з однорічною земноводною рослинністю	C3.51 EuroSiberian dwarf annual amphibious swards (but excluding C3.5131 Toad-rush swards) / Євро-сибірські низькорослі однорічні земноводні угруповання (за винятком C3.5131 угруповань ситнику жаб'ячого);
Б2.2.1 Болотні та підтоплені ділянки з угрупованнями високих гелофітів	-
Б2.2.2 Болотні та підтоплені ділянки з угрупованнями високих кореневищних осок	D5.2 Beds of large sedges normally without free-standing water / Зарості крупних осокових переважно без застою води.
Б2.2.3 Болотні та підтоплені ділянки з угрупованнями високих купинних осок	D5.2 Beds of large sedges normally without free-standing water / Зарості крупних осокових переважно без застою води.
*В4.1.1 Прибережні та підтоплені ділянки з угрупованнями високих гелофітів	C3.2 Water-fringing reedbeds and tall helophytes other than canes / Літоральні угруповання високих гелофітів (крім очерету)
В4.1.2 Прибережні злаково-різнотравні зарості вздовж водотоків	-
В4.1.4 Прибережні угруповання невисоких гелофітів на мулистих субстратах	-
*В4.1.5 Угруповання нітрофільної однорічної рослинності на мулистих берегах річок та обмілинах	-
!В4.1.6 Високотравні окрайкові нітрофільні біотопи низинних річок	E5.4 Moist or wet tall-herb and fern fringes and meadows / Мокрі або вологі високотравні та папоротеві узлісся і луки.
Psammophilous Complex	
Т1.1.2 Псамофітні трав'яні біотопи на нейтральних субстратах	E1.9 Open non-Mediterranean dry acid and neutral grassland, including inland dune grassland / Незімкнені несередземноморські сухі кислі та нейтральні трав'яні угруповання, у тому числі континентальні трав'яні угруповання на дюнах; X35 Inland Sand Dunes / Континентальні піщані дюни.
Т2.1 Ксеромезофітні алювіальні луки	-
Petrophilous Complex	
*К3.4 Лесові відслонення	-
*К1.3 Силікатні скелі та осипища Українського кристалічного щита	H3.1 Acid siliceous inland cliffs / Кислі силікатні внутрішньоконтинентальні скелі.

Habitat types of the National Habitat Catalogue of Ukraine[53]	Habitat types of Resolution No. 4 of the Bern Convention
Open Waters	
1.1.2 Мезотрофні та евтрофні водойми з макрофітною рослинністю	C1.222 Floating Hydrocharis morsus-ranae rafts / Вільно- плаваючі скупчення Hydrocharis morsus-ranae; C1.32 Free-floating vegetation of eutrophic waterbodies / Вільно- плаваюча рослинність евтрофних водойм; C1.33 Rooted submerged vegetation of eutrophic waterbodies / Вкорінена занурена рослинність евтрофних водойм; C1.3411 Ranunculus communities in shallow water / Угруповання водяних жовтеців на мілководдях
В1.3 Ділянки постійних непроточних водойм без вищої водної рослинності	-
В2.1.1 Алювіальні ділянки та днища пересохлих водойм з однорічною земноводною рослинністю	C3.5131 Toad-rush swards) / Євро-сибірські низькорослі однорічні земноводні угруповання (за винятком C3.5131 угруповань ситнику жаб'ячого);
В2.1.2 Алювіальні ділянки та днища пересохлих водойм з багаторічною земноводною рослинністю	C3.4 Species-poor beds of low growing water-fringing of amphibious communities / Маловидові угруповання низькорослих біля водних або земноводних рослин.
*В2.1.3 Мілкі стоячі та тимчасові водойми з макрофітною рослинністю	
В3.2.1 Мезотрофні та евтрофні водотоки зі швидкою течією	C2.27 Mesotrophic vegetation of fast flowing streams / Мезотрофна рослинність швидких водотоків; C2.28 Eutrophic vegetation of fast flowing streams / Евтрофна рослинність швидких водотоків.
*В3.2.2 Мезотрофні та евтрофні водотоки з повільною течією	C2.33 Mesotrophic vegetation of slow-flowing streams / C2.33 Мезотрофна рослинність повільно текучих водотоків; C2.34 Eutrophic vegetation of slow-flowing streams / Евтрофна рослинність повільно текучих водотоків.
*В3.3 Ділянки водотоків без вищої водної рослинності	

* Here and throughout this appendix, habitat types confirmed by recent studies are indicated by an asterisk (*), whereas habitat types also recorded by recent studies but whose occurrence prior to the creation of the reservoir remains uncertain are indicated by an exclamation mark (!).

Appendix 2. Species composition of recreational anglers' catches in the Kakhovka Reservoir before June 2023 and in the Dnipro River section corresponding to the upper part of the destroyed reservoir in August-December 2024.

Species	Species conser-vation status	Recorded in recreational anglers' catches before June 2023	Recorded in recreational anglers' catches in 2024
Anguilla anguilla (Linnaeus, 1758)	CITES-2, BO-2	+ [295]	-
Clupeonella cultriventris (Nordmann,1840)		+	-
Alosa pontica (Eichwald, 1838)		+	-
Squalius cephalus (Linnaeus, 1758)		+	-
Rutilus rutilus (Linnaeus, 1758)		+++	+++
Scardinius erythrophthalmus (Linnaeus, 1758)		++	+
Alburnus alburnus (Linnaeus, 1758)		++ [295]	++
Vimba vimba (Linnaeus, 1758)	BE-3	+ [295]	-
Blicca bjoerkna (Linnaeus, 1758)		++	+
Abramis brama (Linnaeus, 1758)		++	++
Aspius aspius (Linnaeus, 1758)	BE-3	+ [295]	-
Aspius aspius (Linnaeus, 1758)	BE-3	+	+
Hypophthalmichthys molitrix (Valenciennes, 1844)		+ [295]	-
Hypophthalmichthys nobilis (Richardson, 1845)		+ [295]	-
Pelecus cultratus (Linnaeus, 1758)	BE-3	-	+
Rhodeus amarus (Bloch, 1782)	BE-3	+ [295]	-
Pseudorasbora parva (Temminck et Schlegel, 1846)		+	-
Ctenopharyngodon idella (Valenciennes, 1844)		+ [295]	-
Cyprinus carpio (Linnaeus, 1758)		++	++
Carassius auratus (Linnaeus, 1758)		+++	+++
Tinca tinca (Linnaeus, 1758)		+	-
Cobitis taenia Linnaeus, 1758	BE-3	+	-
Ictalurus punctatus (Rafinesque, 1818)		+ [295]	-

Species	Species conser-vation status	Recorded in recreational anglers' catches before June 2023	Recorded in recreational anglers' catches in 2024
Silurus glanis (Linnaeus, 1758)	BE-3	++	+
Esox lucius (Linnaeus, 1758.)		+ [295]; ++	+
Lepomis gibbosus (Linnaeus, 1758)		++	-
Sander lucioperca (Linnaeus, 1758)		++	+
Perca fluviatilis (Linnaeus, 1758)		++	-
Percarina demidoffii Nordmann, 1840		+ [295]	-
Gymnocephalus cernua (Linnaeus, 1758)		+ [295]	-
Neogobius melanostomus (Pallas, 1814)		+++	+
Neogobius fluviatilis (Pallas, 1814)	BE-3	++	-
Neogobius kessleri (Günther, 1861)	BE-3	+ [295]	-
Mesogobius batrachocephalus (Pallas, 1814)		++	-
Proterorhinus marmoratus (Pall.)	BE-3	+	-

Note: "–" – species not recorded in the catches;
"+" – rare species in the catches (up to 1% of the total number of individuals in the catch);
"++" – common species (1–10%);
"+++" – abundant species (>10%).

BE – Convention on the Conservation of European Wildlife and Natural Habitats:
"II" – strictly protected fauna species (Appendix II);
"III" – protected fauna species (Appendix III).

Appendix 3. BFish species composition in the Kakhovka Reservoir and adjacent water bodies before and after the destruction of the Kakhovka Hydroelectric Power Plant, based on records of environmental enforcement authorities

Species	Recorded before June 2023	Recorded after June 2023	Species conservation status
Acipenser gueldenstaedtii Brandt et Ratzeburg, 1833	-	+	RBU – 3K, BO-2, CITES – 2
Rutilus rutilus (Linnaeus, 1758)	+	+	-
Scardinius erythrophthalmus (Linnaeus, 1758)	+	+	-
Blicca bjoerkna (Linnaeus, 1758)	+	+	-
Abramis brama (Linnaeus, 1758)	+	+	-
Hypophthalmichthys molitrix (Valenciennes, 1844) + *Hypophthalmichthys nobilis* (Richardson, 1845)	+	+	-
Hypophthalmichthys nobilis (Richardson, 1845)	+	+	-
Ctenopharyngodon idella (Valenciennes, 1844)	+	+	-
Cyprinus carpio Linnaeus, 1758	+	+	-
Carassius gibelio (Bloch, 1782)	+	+	-
Tinca tinca (Linnaeus, 1758)	+	+	-
Silurus glanis Linnaeus, 1758	+	+	BE-3
Esox lucius Linnaeus, 1758	+	+	-
Lepomis gibbosus (Linnaeus, 1758)	+	+	-
Sander lucioperca (Linnaeus, 1758)	+	+	-
Perca fluviatilis Linnaeus, 1758	+	+	-
Gobies *	-	+	-

Note. RBU – *Red Data Book of Ukraine*. The following conservation categories are included: **EX** – extinct; **EN** – endangered; **VU** – vulnerable; **R** – rare. Categories not requiring protection are not included: **NE** – not evaluated; **DD** – data deficient.

BE – *Convention on the Conservation of European Wildlife and Natural Habitats*: **Appendix II** – strictly protected fauna species; **Appendix III** – protected fauna species.

CITES – *Convention on International Trade in Endangered Species of Wild Fauna and Flora*: **Appendix I** includes species threatened with extinction; **Appendix II** includes species that are not necessarily threatened with extinction but may become so unless trade is subject to strict regulation.

BO – *Convention on the Conservation of Migratory Species of Wild Animals*: **Appendix I** includes migratory species threatened with extinction; **Appendix II** includes migratory species that have an unfavorable conservation status and require or would significantly benefit from international cooperation.

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