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Rapid Environmental Assessment of
Kakhovka Dam Breach

Ukraine, 2023

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The full list of authors, contributors and reviewers is provided in Annex I.

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UNEP is the leading global environmental authority that sets the global environmental agenda. The organisation promotes the coherent implementation of the environmental dimension of sustainable development within the UN system and serves as an authoritative advocate for the global environment. UNEP is keeping the environment under review by providing policy advice, early warning information and promoting international cooperation. It is under this mandate and at the request of the government of Ukraine, that UNEP has undertaken this preliminary analysis of the environmental impacts of the Kakhovka dam breach, which occurred in June 2023.

Abbreviations

AP	Associated Press
ASCI	Area of Special Conservation Interest
BOD	Biological oxygen demand
CDC	Centers for Disease Control and Prevention
CEOBS	Conflict and Environment Observatory
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
DU	Depleted uranium
EPA	Environmental Protection Agency
ERCC	European Commission Emergency Response Coordination Centre
EQS	Environmental Quality Standard
EU	European Union
FAO	Food and Agriculture Organization
GICHD	Geneva International Centre for Humanitarian Demining
HRP	Humanitarian response plan
HRW	HR Wallingford
IAEA	International Atomic Energy Association
IFC	International Finance Corporation
IMB NAS	Institute of Marine Biology of the National Academy of Sciences of Ukraine
IUCN	International Union for Conservation of Nature
JEU	Joint Environment Unit
JRC	European Commission's Joint Research Centre
KSE	Kyiv School of Economics
MEPNR	Ministry of Environment Protection and Natural Resources, Ukraine
NGO	Non-governmental organisation
NNP	National nature park
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
OECD	Organization for Economic Co-operation and Development
OSCE	Organization for Security and Co-operation in Europe
PAHs	Polycyclic aromatic hydrocarbons
PAs	Protected areas
PCBs	Polychlorinated biphenyls

Abbreviations

PCDDs	Polychlorinated dibenzo-p-dioxins
PCDFs	Polychlorinated dibenzofurans
PCOs	Petroleum hydrocarbons
PDNA	Post Disaster Needs Assessment
PEEN	Pan-European Ecological Network
RDX	Research Department eXplosive (or hexogen)
RISs	Ramsar Information Sheets
SDF	Standard Data Form
TNT	Trinitrotoluene
UA	Ukraine
UK CEH	UK Centre for Ecology & Hydrology
UN	United Nations
UN RCO	United Nations Resident Coordinator's Office
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNOSAT	United Nations Satellite Centre
USD	United States dollar
USSR	Union of Soviet Socialist Republics (Soviet Union)
UXO	Unexploded ordnance
VOCs	Volatile organic compounds
ZNPP	Zaporizhzhia Nuclear Power Plant

“The environment is always a casualty of war. Always. Regardless of how wars begin or end. And when the environment is a casualty of war, people suffer long after the conflict has ended.”

Inger Andersen, UNEP Executive Director

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Key messages

- **The breach of the Kakhovka dam in June 2023 is a far-reaching environmental disaster that goes beyond Ukraine's borders;** the magnitude of which might not be clear for years or even decades to come. Hundreds of square kilometres were flooded, and thousands of square kilometres of reservoir and wetlands were desiccated.
- **While the flooding downstream caused considerable environmental loss and damage, the situation upstream of the dam is even more significant.** The desiccation of the emptied Kakhovka reservoir has rapidly transformed a mature and fully functioning aquatic ecosystem, existing since the dam's completion around 70 years ago, into a riverine type of ecosystem in an initial stage of development. Much of the damage in and around the Kakhovka water reservoir is highly likely to be irreversible, with some protected areas located within the reservoir highly probable to have been entirely damaged.
- **Downstream, the immense high-velocity flood caused losses in natural habitats, plant communities and species by washing away specimens, inundating habitats and depositing debris and sediments.** The event led to the release of chemical pollutants, including machine oil and liquid fertiliser, as a significant number of sites storing chemicals were located in the flood zone. This could negatively impact fauna and flora as well as residents in the affected area.
- **The fact that the disaster unfolded on the frontline of the war aggravates the environmental impacts** because detailed assessment, response and remediation is impossible to date due to active military combat and the presence of mines and unexploded ordnances. Without safe access, the full environmental consequences will remain unknown, but are likely to continue to worsen. While the lack of access and data makes the development of detailed recommendations challenging, some actions stand out as critical to start as soon as possible:

- **Coordination between all actors involved in conducting assessments of the various and wide-reaching consequences of the Kakhovka breach is critical and must be under the leadership of the national and regional authorities.** The sharing of information and data between actors should be encouraged and coupled with coherent and joint communication and advocacy on priorities. Planning and implementation of assessments and associated action plans for remediation shall be done in consultation with relevant stakeholders and with inclusive and effective public participation.
- **Even though affected protected areas remain inaccessible, national working groups or thematic task forces need to be established.** These groups should commence desk studies on groups of natural habitats and species to facilitate the collection of baseline data on ecosystems, habitats and species of the affected region—particularly within protected areas. Capacity building for these groups should be supported and cooperation initiated and/or continued with relevant national, regional and international entities.
- **As soon as the security conditions allow, inspections, field inventories and assessments in all affected protected areas should be undertaken to build upon baseline data collected through working groups and task forces.** Field assessments are critical for inventory of plant communities and species and should focus specifically on red-listed species, allowing a more complete understanding of the event's impact on biodiversity.
- **In the medium- and long-term, programs, action plans and remediation measures should be developed and implemented for damaged habitats and species.** This may also include the adjustment, modifications or revisions of protected area management plans. Where possible, short-term remediation measures should be undertaken. For instance, in the depleted Kakhovka reservoir, it is recommended to protect and stabilise the soil through fast growing, non-invasive vegetation such as grass species, reeds or bulrushes.
- **Downstream, identified locations of chemical storages, or 'hotspot sites', should be prioritised for on-site investigations.** Soil sampling sensitive areas, e.g. playgrounds and agricultural gardens as well as hotspots, should be undertaken as a priority. Overall, the assessment and sampling programme should support a targeted remediation programme, with a clear focus on major threats and a sound prioritisation of action.
- **In flooded areas, a disaster waste management strategy needs to be developed, new dump sites established and existing ones rehabilitated.** Waste management activities should be supported, including through provision of equipment for collection and sorting of waste. Temporary storage areas for waste should be arranged and the planning of options for the disposal of chemical waste be initiated, with the establishment of a mobile thermal waste disposal plant.
- **With the reconstruction of the Kakhovka dam a priority for the Ukrainian government, green solutions and the use of nature-based solutions should be assessed and promoted for a sustainable recovery.** The upcoming update of the Dnipro River basin management plan should also take new realities and recommendations into account. River basin management planning tools can serve as instruments for overcoming the consequences of the Kakhovka Dam breach and form a base for recovery planning and resource mobilization.
- **External financial and technical support is urgent and indispensable for the planning and implementation of remediation and restoration actions needed in the region affected by the Kakhovka environmental disaster.** Additional support to environmental monitoring should be provided, linking to existing national infrastructure, and building on existing projects. The Post-Disaster Needs Assessment for the Kakhovka dam also forms a useful base for the identification of required funding.

Photo taken on 7 June 2023 shows the breached Kakhovka dam.
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Executive Summary

The United Nations Environment Programme (UNEP) has the mandate of assisting countries, upon request, with pollution mitigation and control in areas affected by armed conflict and war. In addition, Member states adopted UNEA Resolution 3/1 to "work with national authorities and international organisations in the early identification of conflict pollution" and to "undertake field-based and post-crisis environmental assessment and recovery" in affected areas. UNEP has provided support to the Government of Ukraine in monitoring the environmental impacts of the war and has had a presence in-country since March 2023.

The Kakhovka hydroelectric dam, situated on the Dnipro River in Ukraine's Kherson Oblast, was breached in the early hours of 6 June 2023 causing extensive flooding. The Ministry of Environment Protection and Natural Resources (MEPNR) of Ukraine subsequently requested the support of UNEP to assess the environmental consequences of the breach. Through activation of its emergency response network, including through the UNEP/Office for Coordination of Humanitarian Affairs (OCHA) Joint Environment Unit (JEU), UNEP assembled a core assessment team consisting of 22 experts representing 13 institutions.

The disaster unfolded on the frontline of the war, making the work of response and assessment teams extremely difficult, with the south bank of the Kakhovka reservoir and downstream river inaccessible to date (August 2023). It was thus agreed that the UNEP assessment would be conducted remotely, with only part of the team present in Kyiv. The assessment was based on data provided by the Government of Ukraine and other national and international institutions (including civil society actors), on analysis of satellite imagery and remote sensing, consultations with key actors and expert judgement. The lack of first-hand data and access to affected territories, made it hard to confidently assess or predict the environmental impacts of the breach. Yet, efforts were made to characterise findings in terms of likelihood where some areas, such as the detailed impacts on biodiversity and species, were purposefully left out of the scope of the analysis. Throughout the assessment, accessing the baseline data collected by different actors and institutions proved cumbersome, and the lack of data and coordination between sectors may compromise the achievement of a holistic understanding of the environmental impacts of the breach.

The assessment focused on key environmental impacts of the dam breach, namely: 1) hydrological and geomorphic impacts, including sediment mobilisation; 2) chemical contamination; 3) disaster waste; and 4) ecology, including protected areas.

As a result of the breach, hundreds of square kilometres were flooded, and thousands of square kilometres of reservoir and wetlands were desiccated. While the event is one of a larger series of environmental damages caused by the war in Ukraine, it stands out in terms of scale and devastation. The dam breach impacts areas well beyond the boundaries of the affected five administrative regions, considerably affecting the coherence and ecological connectivity of the Pan-European Ecological Network (PEEN).

While the flooding downstream gained significant attention, from an environmental perspective, the situation upstream of the dam is even more significant. The desiccation of the emptied Kakhovka reservoir has rapidly transformed a mature and fully functioning aquatic ecosystem, existing since the dam's completion around 70 years ago, into a riverine type of ecosystem in an initial stage of development. Much of the damage in and around the Kakhovka reservoir is highly likely to be irreversible. Some of the protected areas located within the reservoir, like the Velykyi Luh National Nature Park, consist entirely of either water or vegetation fully dependent on water conditions, making it highly probable that they were entirely damaged. Groundwater levels in the region are already falling and leading to subsidence, as to be expected with the disappearance of a large body of water. The damage to ecosystems will have substantial and potentially permanent impacts on the region, dependent on the reservoir for drinking water and irrigation. As the burden of climate change increases, the region may be further impacted.

Downstream, the immense high-velocity flood caused losses in natural habitats, plant communities and species by washing away specimens, inundating habitats and depositing debris and sediments. Around 12,000 hectares of forest were flooded. However, there is expectation that these ecosystems, species and habitats may adapt. The sediment deposits in the lowermost Dnipro River and delta were not major but still need to be investigated, as the silt may contain increased levels of heavy metals, hydrocarbons, pesticides, fertilisers, nutrients and other pollutants. Vulnerable populations, such as women and children, are expected to face additional risks and health effects linked to chemicals exposure.

The event led to a confirmed release of chemical pollutants, including machine oil and liquid fertiliser, and a significant number of sites where releases of chemicals may have occurred are located in the flood zone. Even focusing only on large structures potentially containing significant amounts of chemicals, has led to the identification of 54 facilities that should be considered pollution hotspots.

The large discharge of river water has temporarily affected certain areas of the Black Sea, but given the area has always received freshwater intake the impact is unlikely to be consequential. However, there may be implications for the ecology in the Dnipro delta which has become accustomed to higher levels of salinity. Sediment delivery from the coastal flood water plume may reshape coastal morphology along the north-eastern Black Sea for some months or years, especially by potential deposition of fine-grained sediment. This could in turn affect transportation and economic uses of the coastal regions.

The frontline of the war cuts through territories affected by the breach, with mines, shelling and military combat hindering access and making detailed assessments dangerous, if not impossible. In certain areas, significant hazards originate from ammunition, explosive chemicals, radioactive contamination, landmines, unexploded ordnances (UXOs) and other military equipment.

The report provides recommendations for immediate action to address the impacts of the breach. These relate to the need for further coordination between actors on environmental assessments, under the leadership of the national and regional authorities, where the sharing of information and data between actors should be encouraged. Coherent communication and advocacy on the effects of the breach is important and should be used to advocate for critically needed funding for assessments, remediation and recovery actions. Additional support to environmental monitoring should be provided, linking to existing national infrastructure and building on existing projects.

It is recommended that national working groups or thematic task forces be established immediately and coordinate on the collection of baseline data on affected species and habitats, preparing the ground for on-site assessments. These groups should involve relevant expertise and authorities.

Capacity building for these groups should be supported and cooperation initiated and/or continued with relevant foreign state agencies, scientific and research institutions and individual experts. As soon as the security conditions allow, inspections, field inventories and assessments in all affected protected areas should be undertaken, which is critical for inventory of plant communities and species, with a special focus on red-listed species. In the depleted Kakhovka reservoir, it is recommended to protect and stabilise the soil through fast growing, non-invasive vegetation such as grass species, reeds or bulrushes.

When it comes to potential pollution caused by release of chemical substances, identified locations of chemical storages, or so-called hotspot sites, should be prioritised for on-site investigations as soon as the situation allows. Soil sampling sensitive areas, e.g. playgrounds and agricultural gardens as well as hotspots, should be undertaken as a priority. Overall, the assessment and sampling programme should support a targeted remediation programme, with a clear focus on major threats and a sound prioritisation of action. Identifying the location of landmines and UXOs is a priority in post-disaster clean-up efforts.

The total amount of disaster waste is bound to reach at least two million m^3, with the majority generated on the southern side of the river. Therefore, a disaster waste management strategy needs to be developed, new dump sites established and existing ones rehabilitated. Temporary storage areas for waste should be arranged and the planning of options for the disposal of chemical waste be initiated, with the establishment of a mobile thermal waste disposal plant.

When it comes to the outlook of the affected region, it is unfortunately fully dependent on the progression of the war. While a quick reconstruction of the dam could stabilise water levels and prevent colonisation of the lakebed, it is not clear when this can be initiated. Approaches suggesting that a smaller reservoir may bring benefits to nature by more closely simulating a riverine environment should be considered. With the reconstruction of the Kakhovka dam a priority for the Ukrainian government, green solutions and the use of nature-based solutions should be assessed and promoted for a sustainable recovery. The upcoming update of the Dnipro River basin management plan should also take new realities and recommendations into account and to serve as a recovery instrument for overcoming the consequences of the Kakhovka Dam breach.

External financial and technical support is urgent and indispensable for the planning and implementation of remediation and restoration actions that should be undertaken in the region affected by the Kakhovka environmental disaster. The Post-Disaster Needs Assessment also forms a useful base for the identification of required funding.

Without reservation the assessment concludes that the Kakhovka dam breach is a far-reaching environmental disaster; the scale of which might not be clear for years or even decades to come. The sooner access to, assessment of and remediation action in affected areas can start, the better. Without this, the environmental consequences will continue to worsen.

01

Introduction

Introduction

This report contains a preliminary analysis of the environmental impacts of the Kakhovka dam breach, which occurred in the early hours of 6 June 2023. It explores the environmental impacts of the breach through highlighting both potential impacts (those yet to be established) and measurable or observable changes. A detailed estimation of the full impacts on irrigation, drinking water and supply of water to industry, including the Zaporizhzhia Nuclear Power Plant (ZNPP), and associated human health impacts, fall outside the scope of this rapid assessment but pose a substantial concern.

The data used for the report has informed the Post-Disaster Needs Assessment (PDNA) conducted by the United Nations (UN) in Ukraine in partnership with the European Union (EU), the Government of Ukraine and the Kyiv School of Economics (KSE). Certain aspects have deliberately been left out of the scope of the report, even though they could be considered to fall into the topic of environment, such as the loss of cooling water for the ZNPP. Please refer to section 2.5 for details on the report scope.

The breach of the dam represents an environmental disaster of a massive scale, whose full extent and implications will only be clear in years or even decades to come. However, it is clear that it is a continuation of a wider suite of damage and environmental devastation caused by the ongoing war in Ukraine. Within each area of environmental impact, be it chemical contamination, military waste or impacts on biodiversity, the war has caused terrible damage. It will take several assessments, difficult prioritisation and significant funding to even begin to address the full scale of environmental impacts within all parts of the affected territory.

It is within this context that this report was written - an unfolding war where multiple incidents and activities are causing continuous, complex and serious damage to the environment, and where many effects may be overlooked or not addressed.

02

Context

2.1. History and characteristics of the Kakhovka dam

Built between 1950 and 1956, the Kakhovka dam and hydroelectric power station was the second largest, and southernmost, of the Dnipro cascade of six hydroelectric dams (Figure 1).

Located 12 kilometres (km) southwest of Kakhovka, the dam complex stood at a height of 30 metres (m), was 3.84 km in length and was traversed by both a highway and a railway line (Encyclopaedia of Ukraine 1988). The Kakhovka dam's construction necessitated significant investment and the relocation of approximately 50,000 people. Combined, the Dnipro cascade of dams provided water supply for domestic, industry and irrigation purposes in more than half of Ukraine's territory – approximately 35 million people, including the low-water regions of Donbas, Kryvyi Rih, the south of the country and, until 2014, Crimea (Scherbak 2019).

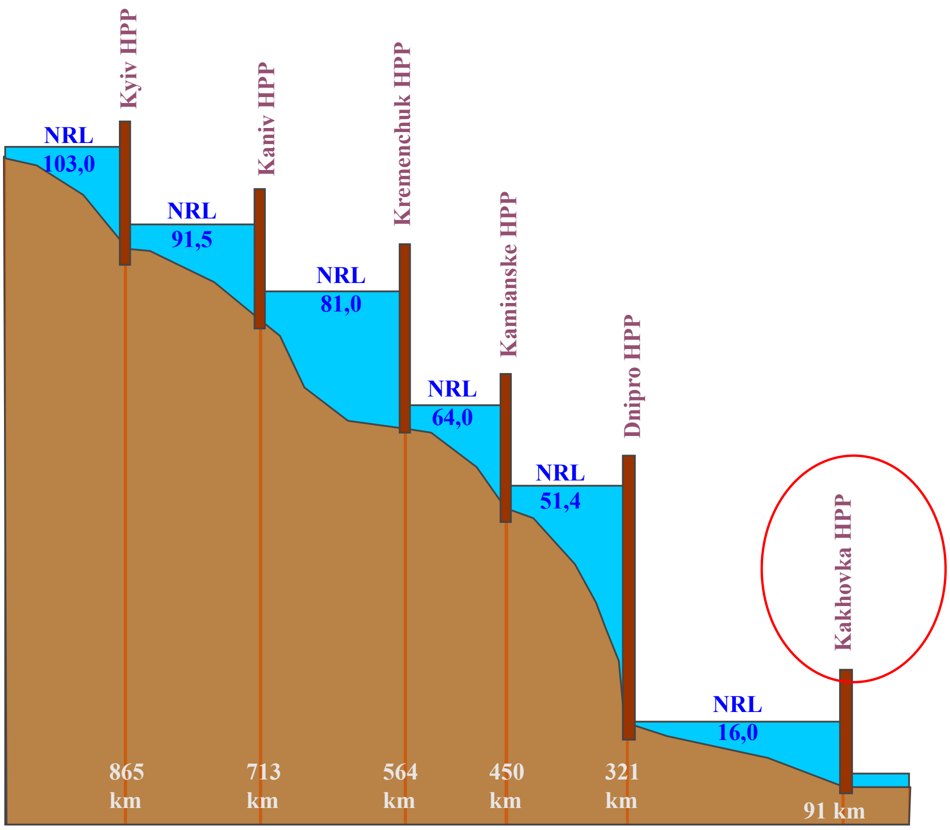

Figure 1. Cascade of six hydroelectric dams on Dnipro River *(Source: Dutch Disaster Risk Reduction and Surge Support Programme 2023) Note: NRL stands for normal retaining level in metres, HPP stands for hydropower plant.*

The Kakhovka dam held back the waters of the expansive Kakhovka reservoir that served a number of functions: supplying hydroelectric stations, industrial plants, flood protection, freshwater-fish farms, recreation, the Krasnoznamianka and Kakhovka Irrigation Systems and both the Dnipro-Kryvyi Rih and the North Crimean Canals. Additionally, the reservoir created a deep-water route, allowing sea ships to sail up the Dnipro River (Encyclopaedia of Ukraine 1988; Scherbak 2019).

The Kakhovka reservoir's flows were regulated seasonally and annually, with a normal retaining level set to 16 m. Restrictions on the reservoir's usage mandated that levels were not to fall below 14 m for ship navigability, and 15.2 m for gravity intake into the North Crimean Canal (Scherbak 2019).

Being the last in a series of reservoirs along the Dnipro River, the Kakhovka reservoir is the receiver of pollution from upstream sources as well as from tributaries and runoff. The Dnipro River and Kakhovka reservoir is subject to eutrophication from nutrients stemming from municipal and agro-industrial facilities as well as pollution from heavy industry including oil refining, metallurgy, petrochemistry and ore mining (Vasenko 1998). Bottom sediments have the ability to take up and retain toxic compounds present in the water (Vasenko 1998), and studies have indicated broad spectrum contamination of sediments in the reservoir, with a diverse range of organochlorines, hydrocarbons and metals present, as well as cesium-137 and cesium-134 in sediment layers corresponding to the period of the Chernobyl accident (Lockhart *et. al* 1998).

Downstream from the Kakhovka dam is the Dnipro-Boh estuary region, which is the largest estuarine ecosystem in southern Ukraine. It includes the combined estuary and coastal areas of two rivers – the Dnipro and the Southern Boh. Detailed information on the lower Dnipro hydrological regime can be found in Annex II.

2.2. War in Ukraine

Since the Russian Federation invaded Ukraine on 24 February 2022, the country has experienced considerable environmental destruction. Attacks on infrastructure and industry have resulted in pollution to air, water and land; waste infrastructure has been overwhelmed; debris and hazardous waste created; agricultural lands and forests burned, damaged and nature degraded (Niewiadomski 2022; United Nations Environment Programme [UNEP] 2022).

Between February 2022 and May 2023, the Ecodozor platform (Ecodozor 2023), created by ZOI and the Conflict and Environment Observatory (CEOBS) with support from UNEP and the Organization for Security and Co-operation in Europe (OSCE), has recorded more than 1,800 incidents of war damage, as well as disrupted or stalled operations of infrastructure and industry, and 917 facilities across Ukraine that may have caused environmental damage. The tracking of environmental damage caused by the war is also conducted by the Government of Ukraine (the Operational Headquarters at the State Environmental Inspectorate of Ukraine) as well as other entities. Sites that have experienced damage include heavy industry such as metallurgy, mining, chemical plants, machine building and construction; power generation facilities; food and agriculture; resources supply; and other types of environmentally sensitive facilities.

With hostilities ongoing, remote assessments and use of satellite data has become critical in assessing the damage, prior to verification from field and site assessment work, and to establish the character, magnitude and significance of conflict-related environmental impacts and remediation requirements. It is recognized that Ukraine and the wider region is at risk of being burdened with a toxic legacy long after the conflict ends (UNEP 2022).

The environmental pollution caused by the conflict, for instance as a result of infrastructure damage, present differentiated risks to women, men and children in general and to women at the reproductive age and pregnant women in particular (UNEP 2022). The war has also exacerbated the risk of gender-based violence and brought new challenges for women and men, such as reinforcing traditional gender norms and increasing the risk of economic abuse (UNDP 2023).

The Kakhovka dam has been under the control of Russian Federation forces since February 2022, which is when they restarted the water supply to Crimea that had closed in 2014 (Osborn 2023). In November 2022, the dam's sluice gates were opened resulting in the reservoir being drained to its lowest level in 30 years (14 m), compared to the average annual level of 15.8 m (Scherbak 2019). This caused public concern over the role of the reservoir water in cooling the ZNPP (Brumfiel 2023; Hydroweb 2023). From February 2023, water levels in the reservoir began to rise again (Hydroweb 2023). Alleviated concern was short lived as it became apparent that flow through the dam was not being adjusted to the Dnipro River's seasonal flow. Immediately before the breach, the reservoir had reached its highest level in 30 years (17.5 m), causing water to spill over the top of the dam (Harman and Bigg 2023; Hinnant and Stepanenko 2023; Hydroweb 2023).

2.3. Kakhovka dam breach

The Kakhovka dam breach was caused by an explosion at the dam on 6 June 2023, at around 03:00, which destabilised the massive concrete structure and caused a collapse of the wall, mainly along the spillways next to the Kakhovka hydroelectric plant, which was also destroyed. The volume of water released has been estimated to be some 30,000 m^3/sec immediately at the beginning of the breach (DHI A/S 2022), compared to a mean daily run-off of 2,600 m^3 (UK Centre for Ecology & Hydrology [UK CEH] 2023), indicating a high volume of water flow and associated force. The dam-break wave after its release was discharged into the water body of the Dnipro River body adjacent to the dam. This probably reduced the hydro-mechanic power of the flood wave, causing a fast but not torrential rise of the water levels as the flood peak magnitude attenuated downstream along the Dnipro River. Within six hours the rising water reached the eastern fringes of Kherson city, with a velocity of the deluge estimated to have been around 15 kilometres per hour (km/h).

The incident led to devastating flooding downstream, causing a wide-ranging evacuation and severe humanitarian, economic and environmental impact. Up to 4,000 people were displaced as a result of the flooding, and while the official number of deaths is yet to be confirmed (UN OCHA 2023), estimations from the Ukrainian Interior Ministry (Svoboda 2023) stand at 31 people killed in areas controlled by Ukraine, with unconfirmed accounts indicating 53 people killed in areas controlled by the Russian Federation (TASS 2023). The gradual increase of the water level is reflected in the relatively low number of casualties due to the flooding itself, and probably also thanks to the general alertness of the Ukrainian authorities and communities.

According to the Ukrainian Government, nearly 4,400 houses were flooded largely in the Kherson and Mykolaivska Oblasts in the south of Ukraine. Due to the floodwaters downstream of the dam and the desiccation of the reservoir, access to clean water emerged as a key humanitarian need (UN OCHA 2023). As of 22 June 2023, all four main canal networks, including the North Crimean Canal, had become disconnected from the reservoir (Rivault *et al*. 2023). In July, it was estimated that the depletion of the Kakhovka reservoir impacted the water supply for up to one million people. Additionally, supplies of electricity and gas were disrupted (UN OCHA 2023). The combined negative impact on water and energy supply has gendered implications, for instance, increased burden of care work for women (UN Women 2022). Throughout the humanitarian response, Ukrainian and international partners were not able to access the areas beyond the control of Ukraine, on the left/southern side of the Dnipro River, impacting the assessment of needs and provision of humanitarian assistance.

The Kakhovka dam breach affected five administrative oblasts of Ukraine (Figure 2), namely Dnipropetrovsk, Zaporizhzhia, Kherson, Mykolaiv and Odesa oblasts. The most extensive northern part of the desiccated Kakhovka reservoir is shared mainly by Dnipropetrovsk Oblast and Zaporizhzhia Oblast, the narrower southern part of this reservoir and all inundated areas along the Dnipro River downstream from Kakhovka belong to Kherson Oblast. Areas along the coastline of the Dnipro-Boh estuary and the Black Sea that mainly suffered from long-range waterborne pollution (see section 3.3.1) are located in Kherson Oblast, Mykolaiv Oblast and Odesa Oblast. However, the impact of the dam breach has a much broader spatial scale, well beyond the boundaries of these five administrative oblasts of Ukraine considerably also affecting the coherence and ecological connectivity of the Pan-European Ecological Network (PEEN).

Figure 2. Map of Ukraine, March 2014. Annotated with red star to show location of Kakhovka dam
(Source: Map No. 3773 Rev. 6, United Nations)

Due to the elevation of the area immediately downstream of the Kakhovka dam, where a cliff borders the right side of the river, the flooding mainly affected the left (south-eastern) side of the river and the low-level areas in the estuary southwest of Kherson. On the right (north-western) side, flooding also occurred mainly along the riverbed of the Inhulets River, a tributary to the Dnipro River. The Inhulets River runs north-south and enters the north side of the Dnipro river bank just upstream of Kherson (Figure 5). In addition to affecting nature reserves and natural land, the deluge impacted developed areas, including residential areas, homes, shops and roads, which took a harder hit than the agricultural areas surrounding the Dnipro River. According to UK CEH (2023), 62 per cent of the land inundated by the downstream flood from the Kakhovka dam breach is classified as herbaceous wetland; 5 per cent is classified as built-up land; cropland is less than 2 per cent (at approximately 871 hectares (ha). It should be noted that the Ukrainian Government estimated a total of over 2,000 ha of agricultural land to have been affected by flooding (Ukraine Government 2023). Additionally, flooded horticulture installations may increase the estimates of damage to crops.

Upstream of the dam, the impacted territory is vast, primarily due to the fact that the region relied on the reservoir for drinking water and irrigation. Before the war, about 5,840 km^2 of cropland on both sides of the Dnipro River could potentially be serviced by the irrigation canals, with more than half the area reliant on irrigation systems. These areas yielded about two million tonnes of grain and oil seeds in 2021, according to the Ukrainian government (BBC News 2023). Ukrainian authorities have estimated that a million and a half hectares of agricultural land will not be used to their full potential and that it will take up to seven years to restore the irrigation (Ukraine, Ministry of Agrarian Policy and Food 2023a).

2.4. UNEP assessment

Following the official request for support from the Ministry of Environment Protection and Natural Resources (MEPNR), UNEP activated its emergency response network, including through the UNEP/OCHA Joint Environment Unit (JEU) and assembled a core team consisting of 22 experts representing 13 institutions. The following entities were involved:

- UNEP (six experts)
- HKV, mobilised through the Dutch Disaster Risk Reduction and Surge Support Programme (DRRS), commissioned by the Dutch Government (three experts)
- Ministry of Water and Infrastructure Management of the Netherlands (two experts), mobilised through UCPM
- United States Environmental Protection Agency (EPA, two experts)
- United States Geological Survey (USGS, two experts)
- Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection of Germany (one expert), mobilised through UCPM
- Food and Agriculture Organization (FAO, one expert)
- Ramsar Convention on Wetlands (one expert)
- Swiss Agency for Development and Cooperation (SDC, one expert)
- Swedish Civil Contingencies Agency (one expert), mobilised through UCPM
- UNEP DHI Slovakia (one expert)
- United Nations Development Programme (UNDP, one expert)

Supported by the UNEP Senior Programme Officer based in Kyiv, a small team consisting of three experts was deployed to Kyiv to coordinate with the governmental counterparts and other on-the-ground partners on the assessment. Available data and reports from around 20 additional entities were accessed in producing this report. The assessment coincided with the development of the Post-Disaster Needs Assessment (PDNA) conducted under the auspices of the United Nations Country Team in Ukraine, the European Union, the Government of Ukraine and in cooperation with the Kyiv School of Economics. The environment chapter of the PDNA was coordinated by UNEP and drew on the analysis and findings of this assessment.

2.5. Scope of the environmental assessment

MEPNR officially requested UNEP's support to assess the environmental risks of the dam breach, with a focus on:

1. hydrological and geomorphic impacts, including sediment mobilization;
2. chemical contamination (of water and soil affected by flood waters);
3. disaster waste; and
4. ecosystem impacts, including protected areas.

The hydrological analysis of the event and resulting deluge forms the basis of estimates of sedimentation and disaster waste. The section on chemical contamination considers both potential releases from industry, infrastructure and settlements, as well as the potential contamination of sediments. A detailed understanding of these elements is vital for an in-depth analysis of the impacts on ecology downstream of the dam. The assessment focuses on the area both upstream and downstream of the Kakhovka dam. Downstream, the primary focus is the river and surrounding flooded areas. Despite the Black Sea being around 90 km downstream of the dam, impacts on the Black Sea from the water pulse and associated sediments have also been considered. Upstream, the main focus of the assessment is the ecological impacts on the Kakhovka reservoir caused by its desiccation. The reservoir was 240 km long and up to 23 km wide and had a surface area of 2,155 km^2 when the reservoir was full (Encyclopaedia of Ukraine 1988).

Other issues such as water supply and termination of supply to regions surrounding the reservoir are expected to be substantial, with Ukrainian authorities informing that almost 6,000 km^2 of agricultural land will remain without irrigation (UN OCHA 2023). However, these impacts fall within the mandate of other UN agencies, notably FAO, and are therefore not considered in detail in this report. Similarly, the assessment acknowledges the critical implications of the draining of the reservoir on the cooling water of the ZNPP, as well as the potential implications of subsidence due to groundwater reduction on the ZNPP structures, yet does not cover these elements in the report as they fall within the mandate of the International Atomic Energy Association (IAEA).

This preliminary assessment has made extensive use of other rapid assessments conducted by other agencies and actors, notably UN agencies, European Commission's Joint Research Centre (JRC) and the UK CEH with HR Wallingford (HRW). It is hoped that this report will provide a useful entry point for further studies and analysis, including an assessment that will be conducted by the Secretariat of the Ramsar Convention on Wetlands in line with Resolution XIV.20 adopted at the Ramsar Convention COP14.

The lack of first-hand data and access to the territories affected by the breach, notably the reservoir area and the north and south sides of the Dnipro River downstream of Nova Kakhovka, make it hard to confidently assess or predict the environmental impacts of the breach. Information from media and open sources has been used where official data was unavailable. Throughout the assessment, accessing the baseline data collected by different actors and institutions proved cumbersome, and the lack of data and coordination between sectors may compromise the achievement of a holistic understanding of the environmental impacts of the breach.

The assessment is based on existing data, should be considered indicative and will need verification on the ground. The authors recognize that key impacts may have been overlooked and recommend that the findings and conclusions included in this report are reassessed as data becomes available and access to the affected territories restored. It should be noted that efforts have been made to make use of the recommended UN terminology and naming of places and locations. Where maps and figures of other entities have been used, discrepancies may occur.

03

Findings

3.1. Hydrological impacts

To understand the initial and culmination phases of the flooding, it is necessary to know the detailed topography of the river valley and floodplains, the initial water level in the reservoir, the exact dimension of the opening in the dam structure (and its subsequent evolution) and the available water volume. Field measurements of the water discharge during the event were not performed due to the lack of access to the area. The hydrological impacts of the event therefore had to be assessed using numerical hydrodynamic models, coupled with verification through satellite imagery analysis, as that displayed in Figure 3. Several numerical models had been developed as early as 2022 to simulate the effects of a dam breach, and were used by the authors together with other assessments to provide information on the effects of the breach. The key models studied by the authors of this report were:

- 2D model of the lower Dnipro River from Balabyne to Stanislav, including the reservoir, the dam site and the Dnipro River downstream of the Kakhovka dam to the Dnipro - Boh estuary, set up in MIKE 21 FM modelling tool, by DHI in October 2022 and adjusted in June 2023 (DHI A/S 2022).
- 1D model of the dam breach combined with 2D model of the Dnipro River downstream of the Kakhovka dam, set up by HR Wallingford (UK CEH 2023)
- JRC model (Santini *et al.* 2023)
- Swedish 2D model, set up in HEC-RAS 2D modelling tool in October 2022 (Wilderang 2022).

This report is mostly based on the results of the DHI model in MIKE 21 FM from October 2022 and adjusted in June 2023, while the results of other models were used primarily to verify the DHI model results. It should be noted that any model will include a number of assumptions and estimations, for instance, related to the bathymetry of the Dnipro River channels and the Kakhovka reservoir. The analysis also built on monitoring data provided by government agencies, information provided through a number of consultation meetings with on-the-ground institutions and individuals, as well as expert judgement.

Figure 3: Satellite image shows the Nova Kakhovka dam breached (Image from Skysat courtesy of © 2023 Planet Labs PBC, available under a Creative Commons BY-NC 2.0 license at https://www.planet.com/gallery/#!/post/destruction-of-the-kakhovka-dam)

While the DHI model describes the initial and culmination phases of the event well, in reality the water levels dropped faster than in the model. This can be attributed to the underestimated dimensions of the river channels, invisible under water in the used digital elevation model and the enlargement of the opening in the destroyed dam during the breach. The use of more accurate hydraulic conditions evolving during the dam breach would create more detailed models. The results obtained by the DHI model are detailed below.

3.1.1. Water discharge

The Kakhovka dam breach resulted in an extremely high deluge of water. Prior to its destruction the dam was filled to an unprecedented high-water level of 17.5 m above sea level (Figure 4), the reason for which is unknown at this time.

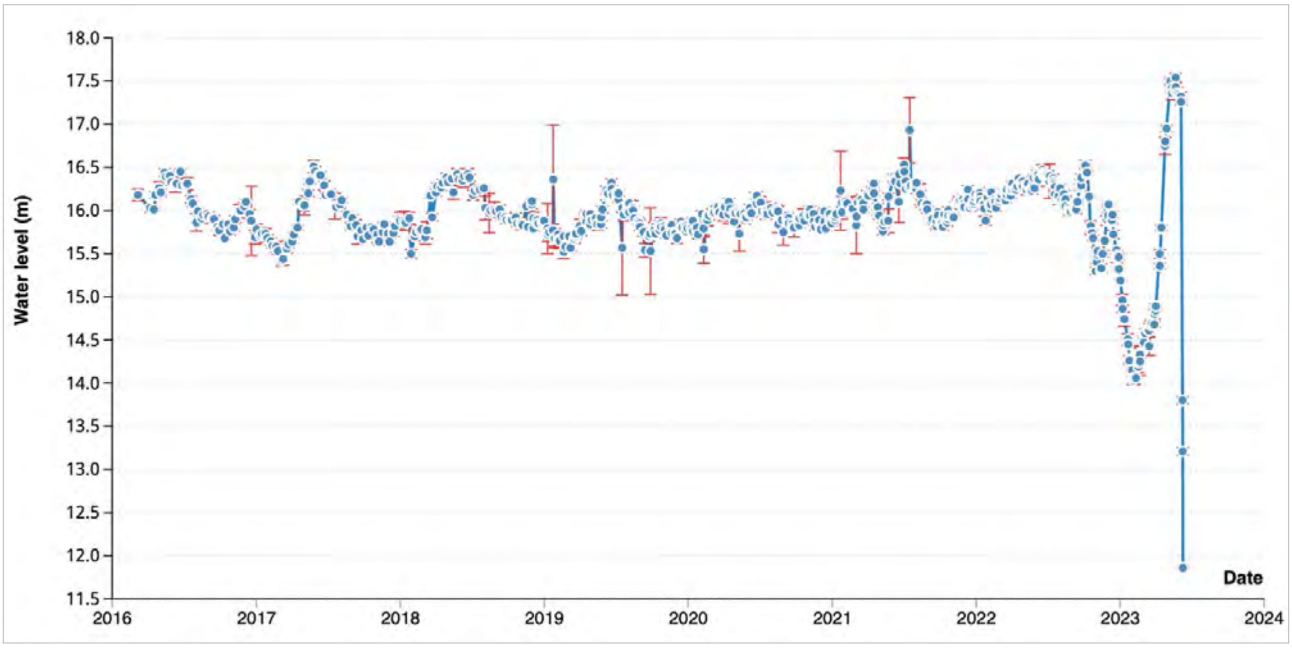

Figure 4. Water level in the reservoir from gauging station from 2016 until 9 June 2023 (*Source: Hydroweb 2023*)

The peak water discharge at the time of the event was estimated comparing the results of DHI and UK CEH numerical hydrodynamic models which gives a range of water discharge as follows:

- Kakhovka dam breach site: 30 000 - 50 000 m^3/s
- Kherson: 25 000 - 35 000 m^3/s
- Outflow to Dnipro-Boh estuary: 23 000 - 32 000 m^3/s

Comparison with usual floods

Establishing the context of this river's historical range of flow variability is important for understanding likely ecosystem impacts, because the ecosystem will have become relatively adapted to the flow regime it has experienced in historical time. Little information is available thus far on the historical flow statistics to evaluate exactly how the dam-burst flood fits into that pattern (considering both natural, pre-dam and the post-dam regulated flow history).

The severity of the dam breach event can be illustrated by comparing the peak discharge with discharges of previous floods. This analysis indicates that the estimated peak discharge at Kakhovka dam corresponded to:

- 18 to 30 times average discharge (1,680 m^3/s)
- 10 times the maximum discharge that occurred at Kakhovka dam between 2000 and 2021 (max. discharge 4,100 m^3/s recorded in April 2013) (Ukraine, State Agency of Water Resources 2023)

When comparing the flood to the flow statistics set up for the dam (see Annex II), with the caveat that it is unclear whether those annual flood probabilities were calculated with respect to only the dammed flow regime, or also to the natural flow regime, we see that the flood corresponded to:

- 3 to 5 times Q1% (100-year flood)
- 2 to 3.5 times Q 0.1% (1,000-year flood)
- 1.3 to 2 times Q 0.01% (10,000-year flood)

While this would indicate that the event corresponded to a 10,000-year flood, it should be seen as indicative only, as it is not clear whether the flow statistics cited by Scherbak (2019) were based on dam-era flows or also pre-dam (natural) era flows. Yet, from the available hydrological information, the dam-burst flood peak appears to be larger than any flow in the historical record for this lowermost reach of the river and delta.

It is estimated that the water rose from normal conditions to a devastating magnitude within minutes. In Kherson the flooding was apparent around 6 to 10 hours after the dam breach and the rise of the water to flood took several hours.

The flooding duration was approximately 14 days, during which practically the whole volume of the reservoir, 18 km^3, passed through the flooded section of Dnipro. This represents between 30 to 50 per cent of the usual total annual volume of the lower Dnipro water flow. The complete hydrographs of the simulated water discharge (DHI A/S 2022) are not displayed in this report, as satellite imagery shows that especially the later phases of the event, with descending water levels, were not correctly simulated by the model. This is due to deviations of the model from the real dimensions of the river channel bathymetry and the differences in the modelled versus real opening in the destroyed dam.

3.1.2. Flood extent

The extent of flooding was determined both in terms of metres above common levels (depth) as well as the spatial extent (area km^2). The extent was defined by the topography of the Dnipro River valley and the Dnipro-Boh estuary (refer to earlier images).

Area affected

The maximum observed water extent occurred between 6 and 9 June 2023 (Figure 5). The flood waters also raised the water levels of the Dnipro River tributary, the Inhulets, which runs from north to south and enters the Dnipro just upstream of Kherson as clearly seen in Figure 5. On 9 June, around 620 km^2 of land within the analysed area of 19,000 km^2 appeared to be flooded (United Nations Satellite Office [UNOSAT] 2023a). This figure was confirmed by MEPNR, which estimated the total flood extent to have reached over 630 km^2 (Ukraine, MEPNR 2023). Between 3 and 5 July 2023, UNOSAT observed that the flooded land had reduced to around 40 km^2 (UNOSAT 2023a).

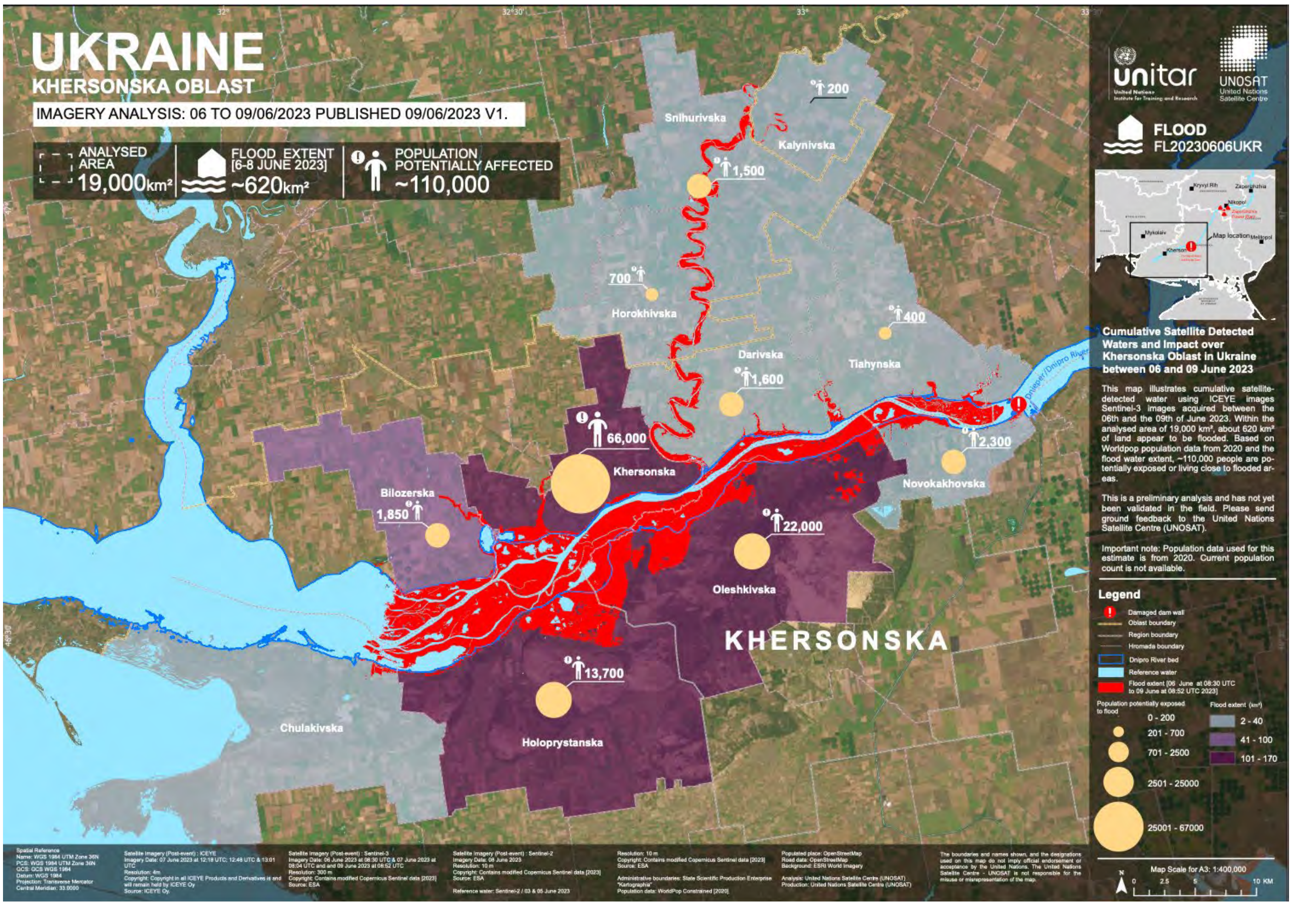

Figure 5. Satellite imagery analysis of maximum flood extent observed by UNOSAT in the downstream of the Kakhovka dam (*Source: UNOSAT 2023c*)

Water depth

In Nova Kakhovka, downstream of the dam, the maximal operational water level is defined as 4.7 m (Scherbak 2019), which was exceeded by more than 6 m at the peak of the flood, corresponding to the calculated estimate for a 10,000-year flood (P= 0.01 per cent). It should be noted that it is unclear whether this level for a 10,000-year flood was set looking at historical (pre-dam construction) or post-dam construction levels. According to information provided by the State Water Resources Agency of Ukraine, the 'critical water level' at Kherson gauging station was defined to be 1.5 m. This critical water level was exceeded by more than 4 m (culmination at 5.37 m on 8 June at 03:00).

The water depth during the culmination of the flood event in most of the floodplain and on the islands in the upper part of the section between the dam and the Inhulets River (shown as the tributary entering Dnipro River just upstream of Antonivka in Figure 6) reached between 6 m and 10 m, from the Inhulets River to Kherson 4 m to 6 m, and from Kherson to estuary 2 m to 4.5 m. The simulated water depth in the flooded area is displayed in Figure 6.

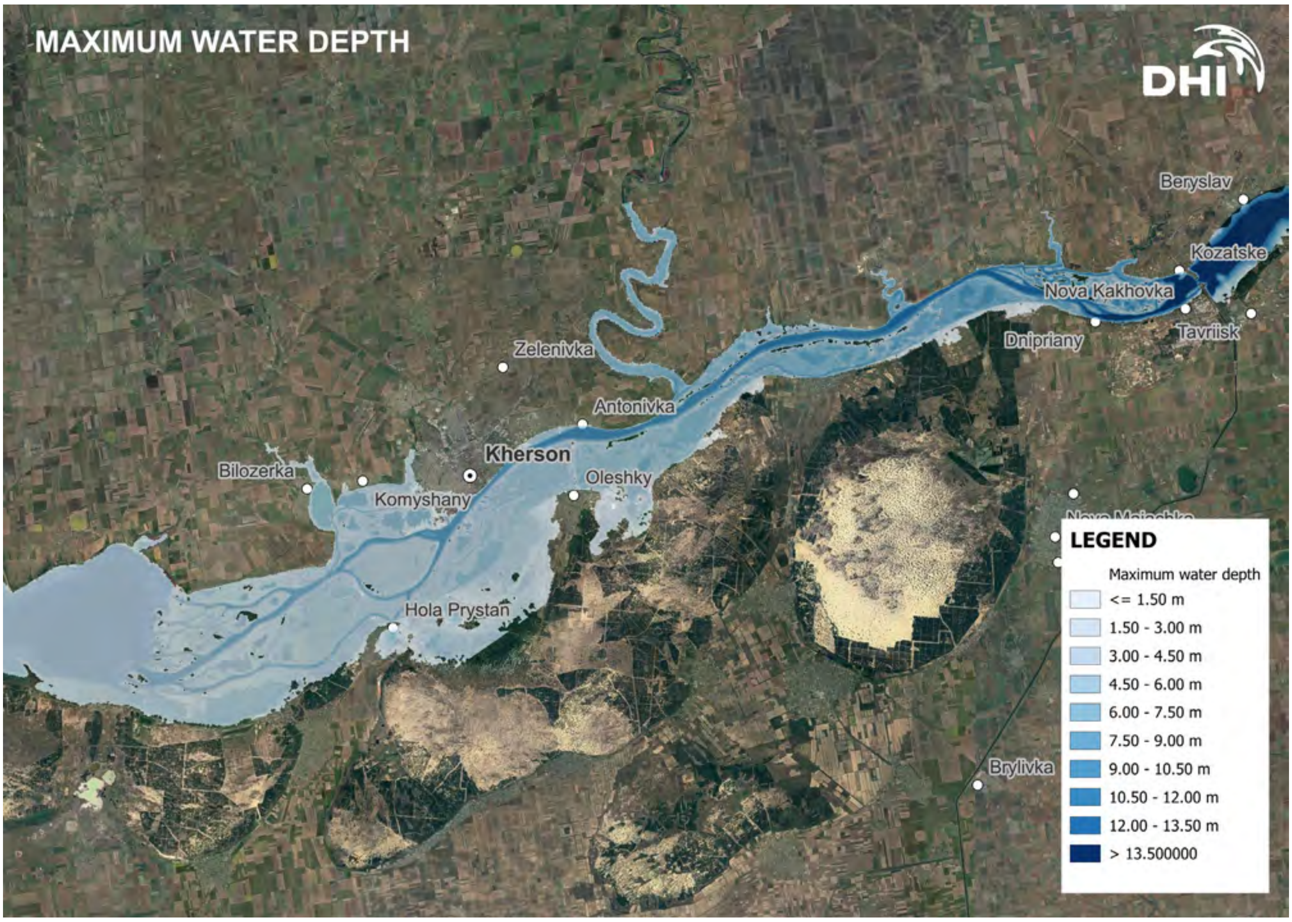

Figure 6. Water depth in flooded area (*Source: DHI A/S 2022*)

Flow velocity

An understanding of the flow velocity of the released water is important in order to evaluate the erosion and sedimentation effects (see section 4.2). The flow velocity was estimated using the DHI model (DHI A/S 2022). According to the model, in the upper section below the Kakhovka dam to Korsunka village, the flow velocities in the river channels were two to three m/s. In the section between L'vove and Kherson the flow velocities in the river channels were one to two m/s and downstream of Kherson the flow velocities in the river channels were about one m/s.

Flow velocities in floodplains and on islands were in most places between 0.3 and 1 m/s. The simulated flow velocities are indicative and based on the uncalibrated model. However, since the model results for flooding culmination are only 0.26 m below the recorded water level in Kherson, this suggests fairly reliable model results. The simulated flow velocity in the flooded area is displayed in Figure 7.

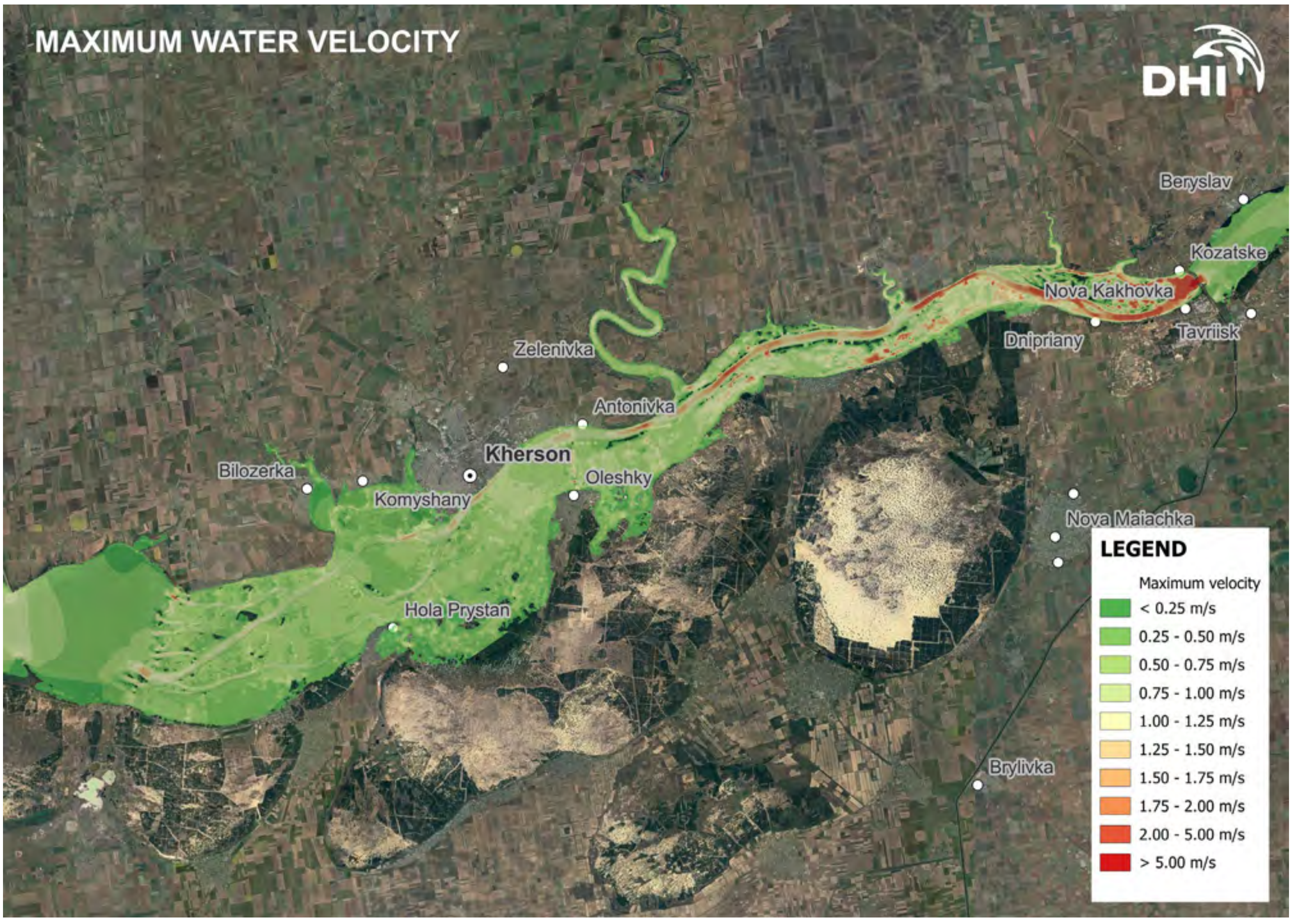

Figure 7. Flow velocity in the flooded area (*Source: DHI A/S 2022*)

Bed shear stress

The bed shear stress indicates the force per unit area exerted by water on the channel as it moves downstream. Understanding the bed shear stress is important for estimating sediment transport and for the prediction of fate and transport of environmental contaminants. The bed shear stress in the river channels was estimated using the DHI model (DHI A/S 2022) and used as inputs to the estimation of sedimentation effects of the breach (see section 4.2). The bed shear stress varied mostly from 20 to 50 N/m^2 in the upper section close to the dam breach and from 5 to 10 N/m^2 in the lower section from the mouth of the Inhulets River to the delta.

The bed shear stress on floodplains and islands varied mostly from 1–10 N/m^2 with maximums up to 20 N/m^2, with higher values in the upper part from the Kakhovka dam to the Inhulets River and lower values from the Inhulets to the Dnipro mouth. The simulated bed shear stress in the flooded area is displayed in Figure 8.

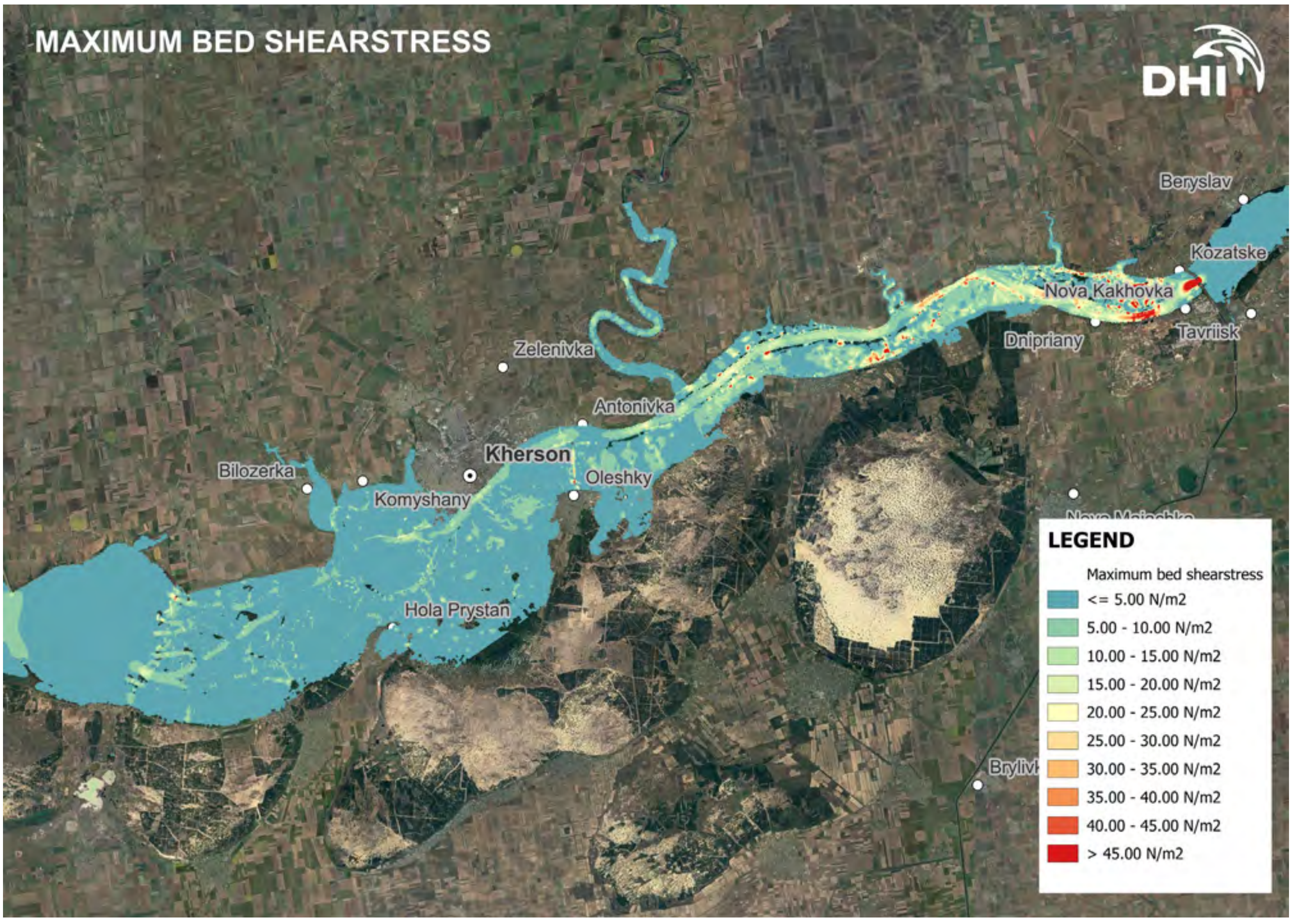

Figure 8. Bed shear stress in the flooded area (*Source: DHI A/S 2022*)

3.2. Sediment-related and geomorphic impacts

The geomorphic impacts of the dam breach detail the extent to which different layers of the riverbed and river sides were impacted by the event through erosion and the deposit of sediments. Understanding these effects is important to determine the potential mobilisation of pollutants from sediments contained in the reservoir and deposited with the floodwaters. As the grain size of the sediments was not known to the authors of this report, the above-described hydraulic characteristics (flow velocity and bed shear stress) could not be directly used for the assessment of sediment transport and analysis of erosion and sedimentation. Instead, the analysis of available satellite imagery formed the basis of the assessment of sediment-related and geomorphic impacts.

Sediment-related and geomorphic impacts are determined by the combination of flow conditions and sediment supply (including the grain size of sediment available for entrainment and transport). The flow history that determines geomorphic effects includes not only the peak magnitude but also the shape of the hydrograph, including the duration of high flows and the rate at which the flow rose (rapidly in the case of this event). All of these flow characteristics would ideally be evaluated against historical data in order to better characterise the dam-burst flood in the context of historically occurring flow patterns. This would include data on the natural and dam-regulated flow regime in the Dnipro River over the last decades to a century.

3.2.1. Amount of sediments mobilised

The Dnipro watershed terrain produces relatively little sediment, and fluvial sediment loads in the lowermost hundreds of kilometres of the river would naturally be low (compared to most other major world rivers) because of the low gradient in this setting. Milliman and Farnsworth (2011) estimated that the Dnipro's annual watershed sediment yield is in the order of tens of tons per square kilometre (<30 t/km^2/yr.), and that the annual sediment load entering the Black Sea from the river mouth is around 2.3 Mt/yr. These values account for upstream dams substantially limiting fluvial sediment export, even though human activities including agriculture will also elevate sediment yields above natural levels. This annual sediment load is far lower than for other large continent-draining rivers such as the Orinoco River (210 Mt/yr.) or the Mississippi River (400 Mt/yr.) (Milliman and Farnsworth 2011).

In view of the low sediment export from the Dnipro River, low sediment yields even upstream (in a low-gradient, low-sediment-production geography) and the fact that Kakhovka dam was the furthest downstream in a series of six large dams with no major tributaries entering the mainstem river between the final two dams, the sediment flux into Kakhovka reservoir was evidently also quite low. The value estimated by an Ukrhydroenergia official (2023) of 0.5 Mt/yr. is consistent with what could be expected in a dam located furthest downstream in a series of dams, where most of the sediment entering this cascade is likely to have been trapped in reservoirs upstream (Scherbak 2019; Ukrhydroenergia Official 2023). Similarly, the amount of sediment accumulated in the Kakhovka reservoir since its construction is expected to have been very low, and it is unlikely that a well-developed reservoir sediment delta deposit existed. It is also unlikely that any substantial amount of reservoir storage capacity had been lost to reservoir sedimentation during the reservoir's active lifespan. An exception to this would be if the next dam upstream had been operated to flush sediment deliberately at any time in the past, but presently there is no information indicating this was done.

In view of the above assessment, the amount of sediment available in the reservoir to mobilise and transport downstream during the dam-breach flood was presumably relatively small. The sediment transported to the lowermost river and delta (and Black Sea) due to the dam-breach flood was more likely to have been sourced from erosion of the pre-dam riverbed upstream of the dam, and from the river corridor downstream of the dam (entrained during the flood flow), than to have been mobilised from a reservoir sediment delta. The geomorphic appearance of the drained reservoir in recent imagery supports this interpretation, as the satellite images appear to show fluvial morphology (with meander bends and scroll bars) in the drained reservoir rather than the appearance of a newly incised reservoir delta responding to rapid, major base-level fall.

The floods washed away soil and sediment sourced from downstream of the dam, adding to what has been entrained and transported from the reservoir substrate itself. Part of this sediment load has been deposited within the flooding area, covering the area with a blanket of fine sediment. These deposits may pose a high risk to the environment, depending on the associated pollutants and their concentration, and is dependent on pollution sources upstream of the area (see section 3.3.3). Fine sediments are often more contaminated than coarse sediments because some types of pollution, which bind to the surfaces of sediment particles, are more concentrated in fine sediment because it has a higher ratio of grain surface area to volume. In areas where water is caught due to the topography of the land or the drainage is slow there will be a higher risk of severe contamination – depending on the contamination of the flood water and of the suspended solids and materials brought along by the deluge.

On the reservoir sedimentation rate, there is a high level of uncertainty. According to the Scherbak (2019) Environmental Impact Assessment, the Kakhovka reservoir receives an average of 0.5 Mt of sediments annually from upstream, which is less than in any other reservoir in the cascade. The reservoir itself produced some 22,000 megatonnes of sediment annually, originating from erosion from soils and overland flow, including from agricultural areas as well as from streambank and channel erosion and other hydrological and geomorphic processes. The reservoir traps most of the sediments, with less than one per cent discharged at the average rate of water flow of 1,340 m^3/s. In terms of particle size distribution, the mineral component of suspended solids is dominated by dusty silt soil (Scherbak 2019).

Sediment stability and resistance to erosion depends on several factors, including hydraulic conditions of the water body, the material density, grain size, content of organic materials, gas volume, consolidation time, mineralogy, temperature and biological colonisation. Additionally, erosion will depend on bed shear stress caused by water run-off. Erosion processes would have been highly variable spatially and temporally depending on localised sediment-flux gradients (and difficult to predict or model with detail in three dimensions).

However, it is likely that erosion of bed sediments did not occur in large quantities except in the immediate vicinity of the dam structure. Within the zones of increased shear stress connected to the torrential water flow at the locations of the dam breaches sediment abrasion could have happened. In contrast, it is likely that the gradual decrease of the water-surface elevation kept sediments largely unaffected in most parts of the reservoir.

This assumption is supported by the shrinking surface of the water body of the reservoir, reflecting the slow decrease in the rate of water spill from the dam. Starting at a size of 2,000 km^2, on 16 June (10 days after the dam breach) it had decreased to 60 per cent of its original size. The reservoir then further diminished by 5 per cent daily until 22 June, slowly exposing more and more of the reservoir bed. On 7 July, the surface of the remaining water area was reduced to 10 per cent, much of it reflecting what we assume (based on its morphology) to be the historical course of the Dnipro[1] (Kuchma 2023).

The possible mobilization and distribution of legacy contamination potentially deposited within the reservoir is dependent on the mobilization of sediments during the dam breach. For a full discussion on contaminants in sedeiments, please refer to section 4.3.3. The main sources of sediments mobilised during the dam breach event are:

1. **Reservoir** – mostly the area close to the dam, where the high velocity of the water is expected to have caused erosion and release of sediments close to the dam breach.

2. **Breach opening in the dam structure.** Another source of eroded sediments (and construction material debris) is the 'hole', or opening, in the breached dam, and the areas closely downstream. The final depth of the 'hole' is at the time of writing unknown and will need to be surveyed later. As the reservoir emptied faster than in the numerical models it is likely that the bottom of the opening is below the original riverbed and below the concrete foundations of the dam. A large part of the eroded sediments stem from the washed-away island between the hydroelectric plant and locks. This material can be assumed to be composed of the original soils excavated from the construction pit of the Kakhovka dam in the 1950s. This material was probably not highly contaminated.

3. **Downstream river section.** Parts of the riverbed, banks and islands downstream of the breached dam that experienced very high flow velocities and high shear stress. Most of these areas are located close to the dam, but also include areas further downstream. These locations can be reasonably well defined through analysis of satellite imagery.

4. **New erosion** – sedimentation processes in the emptied reservoir area. Sediments which are likely to have been eroded in the 'new river section' within the emptied reservoir, from banks which are exposed, bare and until now free of vegetation. Erosion is caused by flow velocities during higher discharges, either natural, or generated by hydroelectric peaking flow operations. The erosion processes are likely to occur particularly immediately downstream of the Dniprovska hydroelectric power plant, where the released water does not contain sufficient amounts of sediments and hence the so-called 'hungry water' phenomenon exists (Kondolf 1997) wherein sediment-depleted water released from a dam will begin transporting sediment entrained from the riverbed immediately downstream of the dam. It can be assumed that a significant part of these sediments will deposit within the river section in the area of the emptied reservoir. It is expected that the erosion and sedimentation processes within the new river section of the emptied reservoir will mitigate gradually over time and a state closer to dynamic equilibrium will occur.

1. By 13 June 2023, a total of 14.4 km^3 or 72.5 per cent of the water had been lost. This is equal to a third of the volume of Lake Constance, the third largest lake in middle Europe, measured both by volume and by size.

A satellite image of the lower Dnipro stretch between Nova Kakhovka and Kherson is provided in Figure 9. The photo shows the area before the dam breach (upper part of the figure) and after the dam breach event (lower part of the figure). In the north-eastern part of the lower image, part of the emptied reservoir is visible immediately upstream of the breached dam. The light brown colour indicates the dried bottom of the reservoir with exposed sediments without vegetation. The main river channel is also visible in this part. In the middle part of the lower image another patch of pale brown colour indicates erosion and sedimentation processes below the breached dam. The white spots are clouds, not relevant for the analyses.

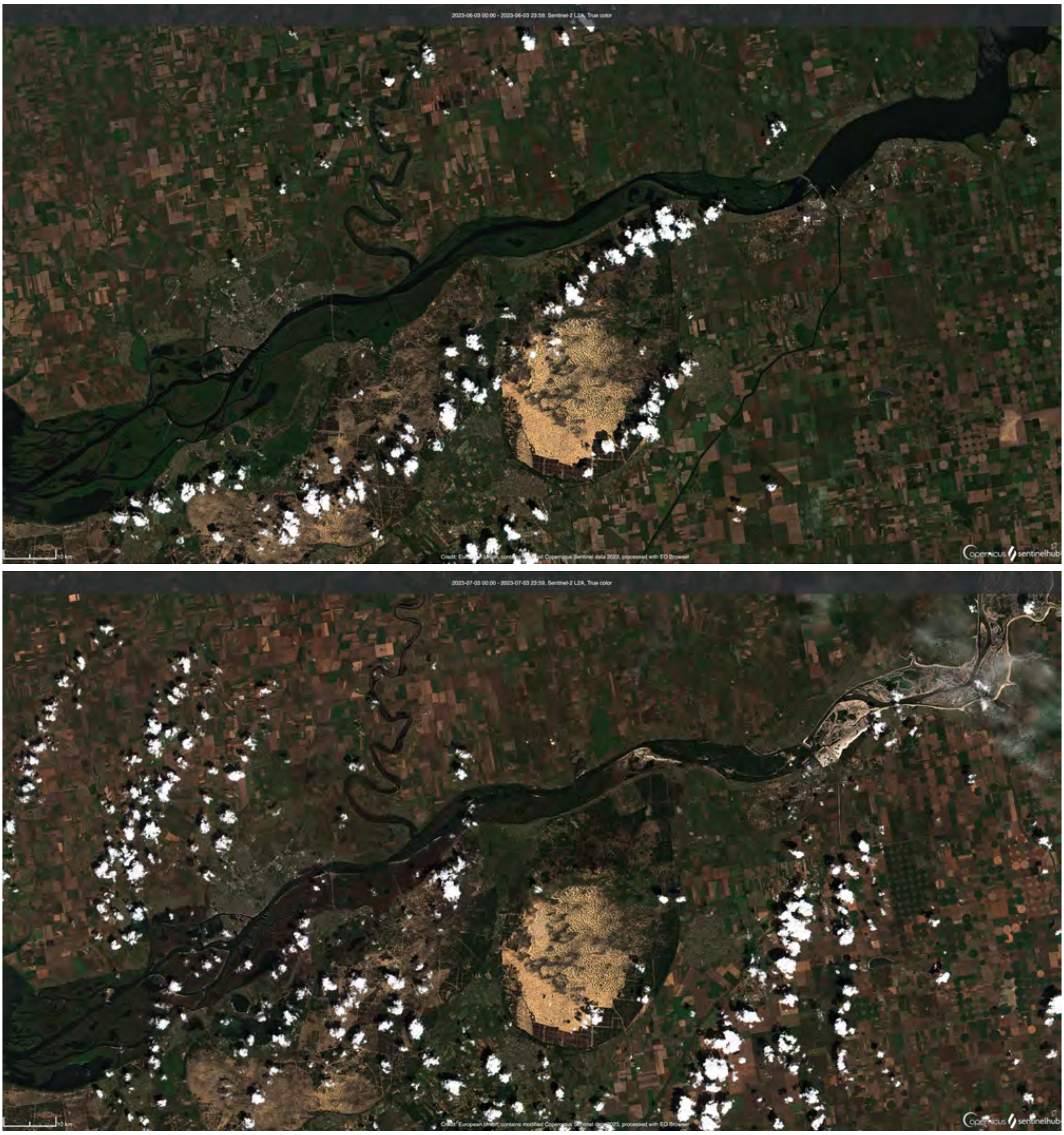

Figure 9. Situation before dam breach (top image on 5 June 2023) and after dam breach (bottom image on 4 July 2023) (*Source: Sentinel-hub EO-Browser3 2023*)

Satellite imagery was used to define the likely locations of deposited sediments. Figure 10 shows the land cover estimation where the light coloured (beige) sediments near the Kakhovka dam are likely to have a larger grain size (sand). These sediments appear near the breached dam because flow velocities were highest there, evidently removing finer materials (red in Figure 10). This sediment likely stems from erosion of the main channel upstream of the dam during the emptying of the reservoir. The darker-coloured sediments (brown/grey colours) are most probably fine sediments such as silt and clay which were transported in suspension in the water (pink in Figure 10) and settle in more quiescent flow conditions. These fine sediments are predominant in the downstream section especially around Kherson and spread over the full inundated extent.

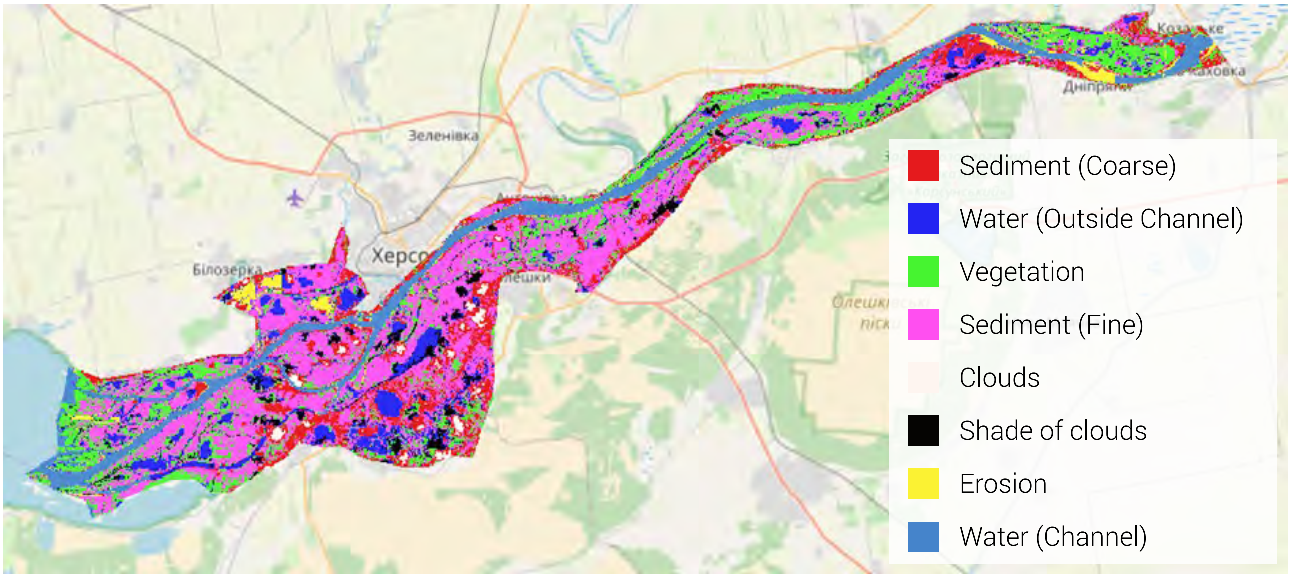

Figure 10. Land cover classification from Sentinel-2 images *(Source: Sentinel-hub EO-Browser3 2023). Note that a difference in colouring could also result from removal of vegetation due to high flow velocities in the flooded area. The red areas downstream near the delta in Figure 6 are most probably not sandy deposits but built-up areas. It is hard to distinguish in the spectra what is built up and what is sand.*

Figure 10 shows that fine sediments may have spread over 31,000 ha, while coarse sediments are to be found on 12,000 ha of land. It is estimated that almost all of the fine sediment—the exact amount is still in question—originates from the reservoir, as there is no other possible source of fine sediment in this area (Gorelick *et al.* 2023). Fine sediments are mostly deposited in the floodplains (pink in Figure 10).

Satellite imagery was used to analyse the erosion that took place downstream of the reservoir by comparing it to an image before the dam breach. These locations are mostly found near the Kakhovka dam, its islands and along the banks of the main channel (Figure 11).

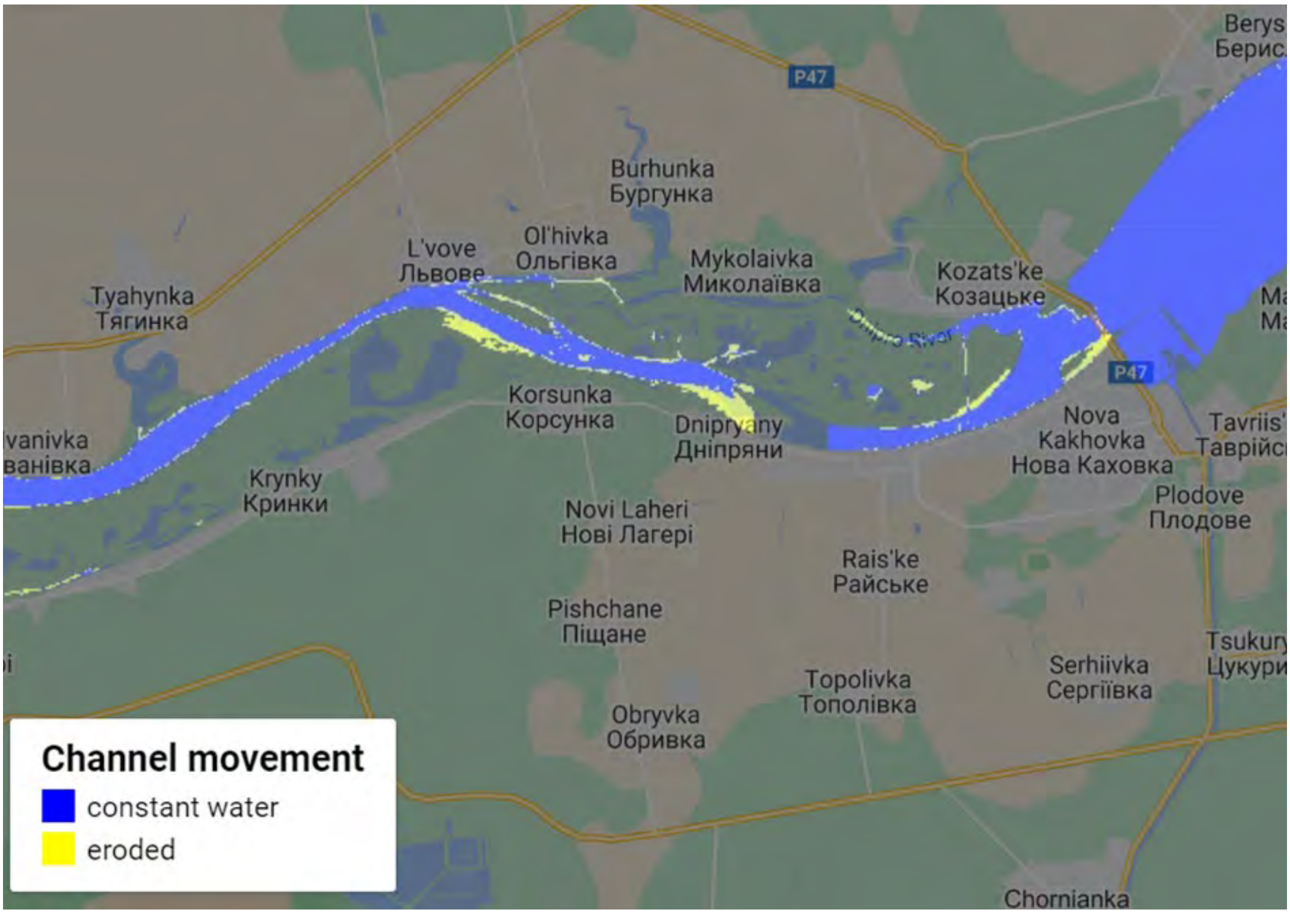

Figure 11. Constant water and eroded areas after the dam breach just below the dam. The island in the middle has suffered some erosion (*Source: Sentinel-hub EO-Browser3 2023*)

Locations with major erosion and sedimentation at the dam breach site and downstream are visible on satellite images (Figure 12)

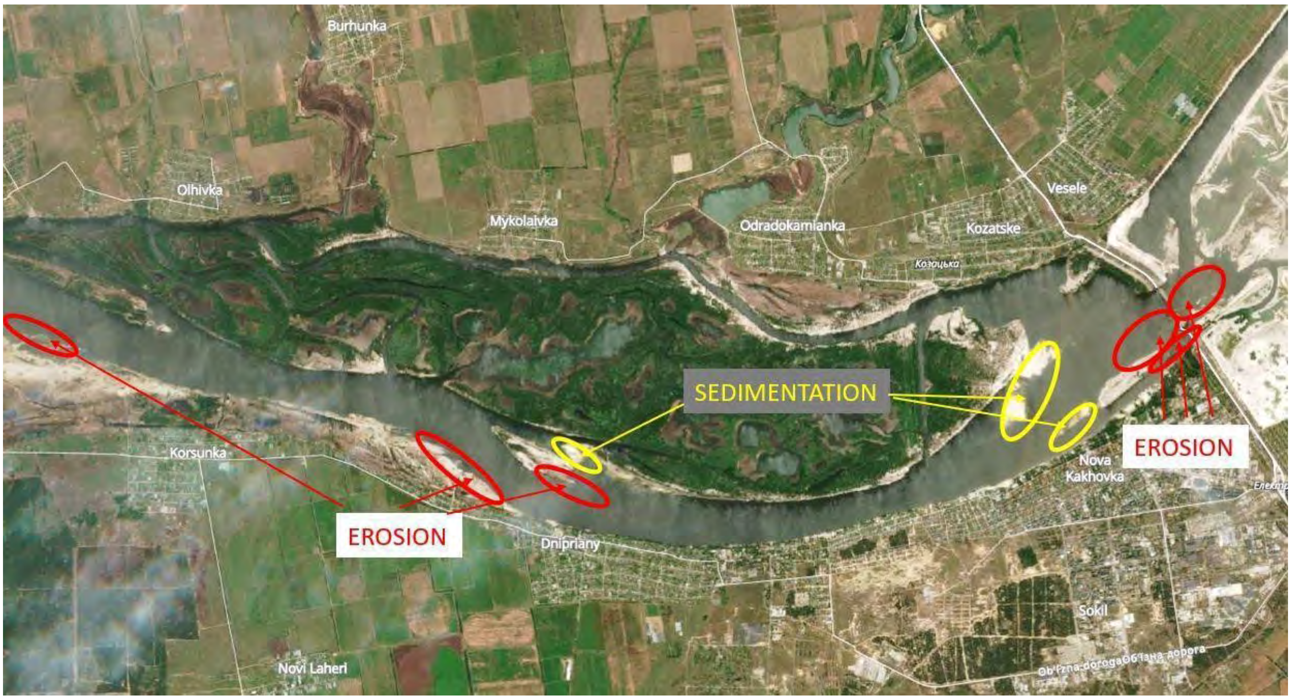

Figure 12. Localities with major erosion and sedimentation at the dam breach site and close downstream, identified on satellite images Sentinel-2 (*Source: Sentinel-hub EO-Browser3 2023*)

In the absence of a major sediment supply from the reservoir deposit, it is reasonable to expect that new sediment deposits downstream will be of limited thickness and volume, rather than a widespread massive new sediment deposition event. The authors of this report did not receive reports of widespread, thick deposition in the lower river channel or floodplain that would have substantially increased future flood risk due to bed aggradation. Therefore, the Kakhovka dam destruction does not appear to have a similar geomorphic effect downstream as other intentional large dam destructions have had, in which major sediment deposition (from erosion of large reservoir deposits) caused metres of bed aggradation and substantial changes to channel morphology as described by East *et al*. (2018) and Ritchie *et al.* (2018).

Even without major downstream sediment deposition in the lowermost Dnipro River and delta, some sediment accumulation is expected on localised spatial scales, which may require localised mitigation. As sediment deposition depends on flux gradients that can be quite variable locally, it is probable that some new bed aggradation and local sand and mud deposits will form on the downstream side of obstacles in the flow path and could require clean-up.

Geomorphic effects of the dam-breach flood will include fluvial, coastal and potentially aeolian (wind-shaped) landforms. From the satellite imagery, it appears that the June 2023 flood inundated areas that were also inundated either historically (though the assessment did not have records of floods this large in recent decades) or prehistorically well-before dam construction. That means that the geomorphic impacts are within a range that this geomorphic system can accommodate, even if the ecosystem had not recently been exposed to, and forced to adapt to, this extent of flooding.

Satellite imagery taken just before the breach (Figure 13) shows large areas of aeolian landforms on the river-left (south/east) side of the river corridor, which appear to have been formed over a long period of time by wind action on a high-sediment-supply landscape, with spatially extensive dunes. Any new sediment deposits in the lower river and delta will also be subjected to wind-reworking over time, which could create new or enlarged areas of wind-formed dunes and produce aeolian dust unless or until those deposits become vegetated.

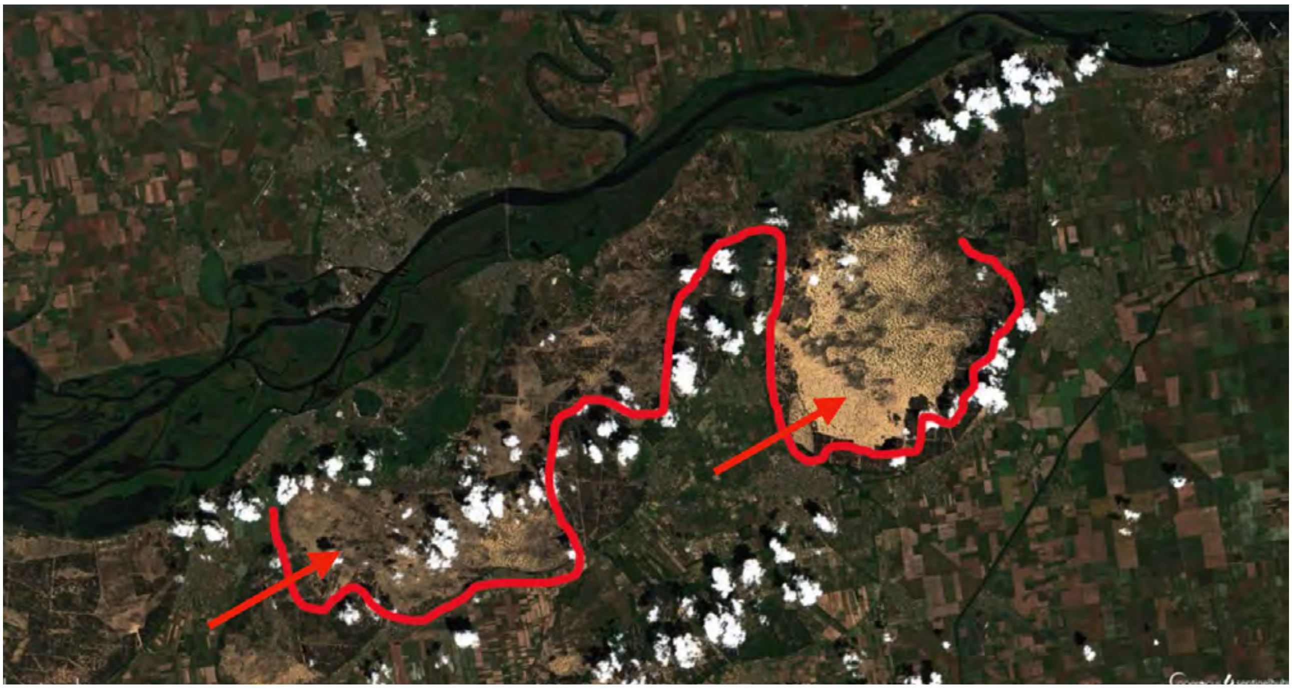

Figure 13: Satellite image of Dnipro Delta taken on 3 June 2023 (*Source: Sentinel-hub EO-Browser3 2023*)

Coastal effects of the sediment plume entering the Black Sea include temporary high turbidity, which will limit light in the coastal water column with associated ecosystem effects. The sediment from the coastal plume is expected to be predominantly fine-grained (silt and clay) and could deposit new mud drapes in coastal areas. The extent of these morphodynamic changes is presently unknown, but it is possible that nearshore deposition could impede transportation or economic uses of the shoreline for months to a year or more.

3.2.2. Future geomorphic impacts

Provided the Dnipro dam hydropeaking continues, in the medium to long term it is expected that banks in the upper part of the reservoir will be eroded. This is because the water surface area of the reservoir has decreased from a buffer of 2,000 km^2 to a channel of 200 m to 300 m in width. Therefore, increased flow velocities—changes in discharge of up to 1,000 m^3/s in several hours or days—could lead to water level differences of several metres, causing riverbanks to weaken due to seepage and undercutting. Sand banks are especially vulnerable to this type of seepage erosion. The amount of erosion depends on the soil combination of the banks (what percentage consolidated fine sediments and/or coarser sandy sediments) and the levels of hydropeaking (and the resulting flow velocities).

There is (still) little sediment coming in via the Dnipro dam. This causes 'hungry water' (Kondolf 1997), which is sediment-depleted water that will encourage new entrainment and transport of more riverbed sediment in the main river channel. This will lead to erosion of the reservoir deposits in the main riverbed starting directly downstream of Dnipro dam and working its way downstream. This is erosion in the vertical plane. Erosion of the floodplains surrounding the main channel is not to be expected, provided the top layer consists of consolidated fine sediments which are hard to erode and provided the floodplain is not subject to high flow velocities coming from the Dnipro dam. To confirm this, soil surveys will be required.

Satellite imagery of the emptied reservoir shows one main channel with large floodplains in which small creeks and ponds can be found (Figure 14). The main channel is around 200 m to 300 m wide and runs through the wide floodplains with the area covered by sediments, most of which are brown or dark grey. As the upstream dams trap most of the sediments, and because of their colour, it can be assumed that these are fine sediments (clay/silt) normally travelling as suspended sediment in the water. These new flood plains in the reservoir are likely to consist of poorly erodible clay and peat deposits, covered with a layer of consolidated reservoir mud deposits. Around the main channel, along the sides of the reservoir and near the breached Kakhovka dam lighter sediments can be found. Due to the expected higher flow velocities around the main channel and near the dam breach and due to the colour of the sediment, these sediments are expected to be sand. However, it could also be dried clay which can also have a light colour.

Figure 14. The upstream area of the breached Kakhovka dam (5 July 2023) (*Source: Sentinel-hub EO-Browser3 2023*)

When it comes to the main river channel within the former reservoir, significant changes are not expected as the river course seems relatively stable. Despite the above-mentioned bank erosion due to hydro peaking downstream of the Dnipro dam, the meandering pattern appears more or less fixed, presumably by a relatively low erodibility of the former wetlands that form the flood plains in this section. This is confirmed by the historical maps prior to construction of the dams showing that the river has, more or less, returned to its prior path (UK CEH 2023, Figure 15). Similar creeks and ponds present in the upstream part of the dam still seem to be there now. Consequently, it can be expected that a layer of fine and consolidated sediment has accumulated over the floodplains over a period of years since the dam was installed and the reservoir was formed. Under current conditions taking into account the upstream dams we do not expect the sediments from the floodplains in the emptied reservoir to erode because they will not be influenced by flow velocities high enough to transport the consolidated sediments.

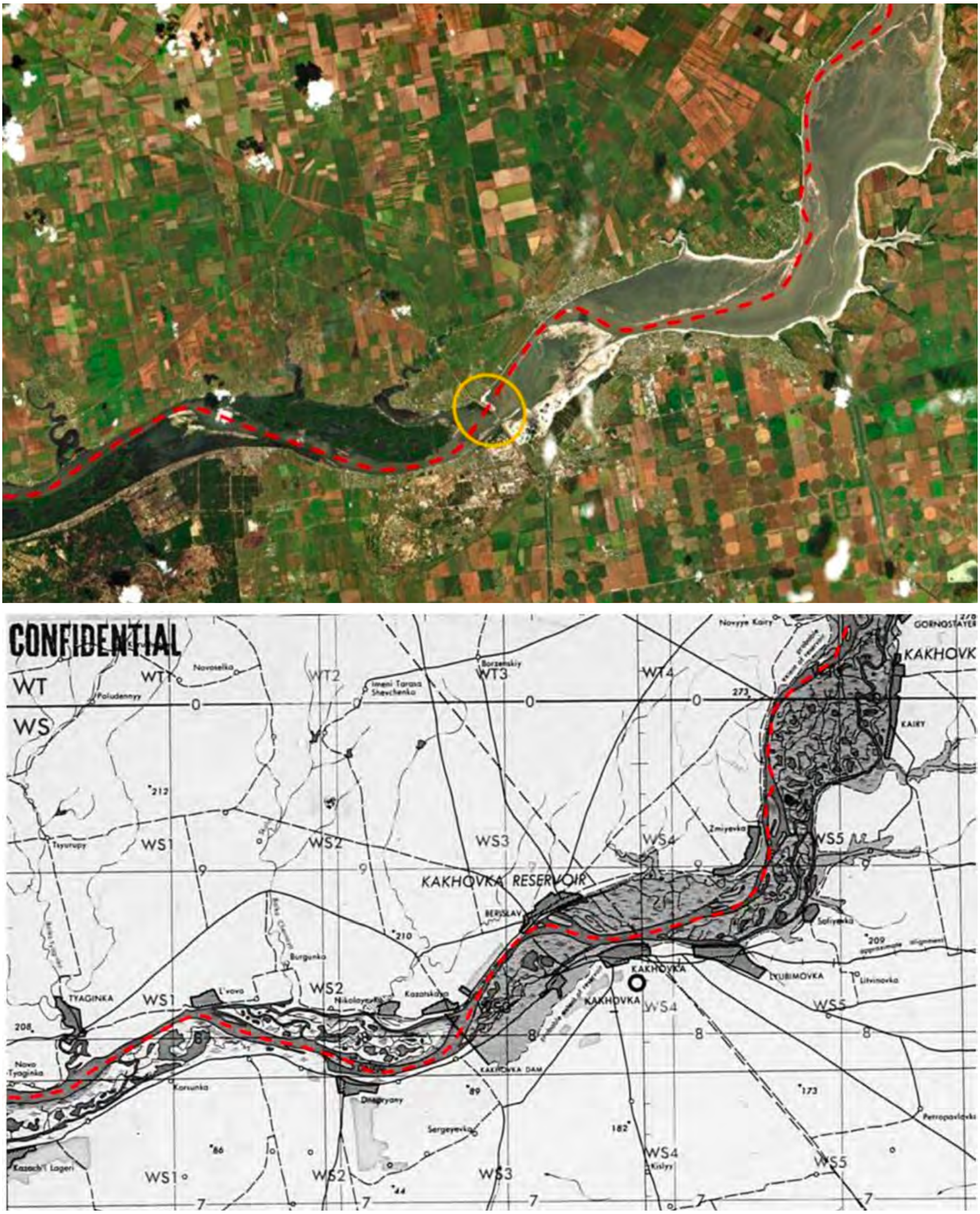

Figure 15. Main channel (dotted red line) near the dam (denoted with the yellow circle in the top image) on 18 June 2023 and from a 1940s map (before implementation of dam) (*Source: UK CEH 2023*)

Within the middle part of the reservoir, the river has returned to its original channel and therefore has more erosive power. Any sedimentation of the past decades will be eroded within the channel. The erosion wave from upstream will pass this place eventually, but there may also be a backwater effect from downstream causing it to incise. In general, this area could be an area of channel incision. Directly upstream of the dam, some sedimentation of the main riverbed can be expected, although the sediment supply arriving from upstream will continue to be relatively low. This part is already heavily eroded due to the breach and with some new sedimentation will move toward a new bed equilibrium.

Downstream of the dam, sediments were flushed from the main channel, causing incision of the channel. Provided most of the reservoir deposition was removed during this event, it will depend on the resistance of the remains of the dam structure and the water levels downstream whether this section will further incise, or will show some deposition. Due to higher flow velocity some bank erosion around the main channel could be seen. It is not expected that the channel would shift substantially over time.

Wind erosion

It has also been estimated that the destruction of the dam will affect the drainage of the Dnipro riverbed with possible consequences including sandstorms, accelerated effects of climate change (which potentially stresses vegetation that would stabilise sediment deposits) and potential desertification of neighbouring regions. These effects are most likely to be felt in Kherson, Zaporizhzhia, Dnipro and Donetsk Oblasts (Sergatskova 2023). The level of wind erosion on the now dry (drier) floodplains will depend on the type of sediment in the reservoir; a large clay content (finer but cohesive sediments) will not be mobilised as easily as coarser, less cohesive sediments. Fine sediment could now blow away easily and could be fertile if it remains in place long enough to become vegetated before it is reworked by wind. See section 4.3 for a discussion around the potential contaminants contained in the sediments. These areas may already have received seeds from the surrounding area where the next few months will indicate the extent and type of vegetation that can grow on these floodplains. While invasive species are a cause for concern, it is likely that vegetation establishing itself will be similar to the vegetation in the surrounding area. Should trees die following a decrease in groundwater levels (see section 3.2.3), wind erosion may increase further. The most common type of tree in the shelter belts of the reservoir are Crimean pine trees which do not have deep roots and may be impacted by the decrease in groundwater levels.

3.2.3. Implications on future river basin hydrological regime

In order to assess the role of the Kakhovka dam and reservoir on the fuller hydrological regime of the Dnipro River, it must be placed in context with nearby hydrological basins. Table 1 shows the surface areas of the hydrological basins relevant for this assessment and Figure 16 outlines the catchment areas of each basin on the map (Lehner and Grill 2013; HydroSHEDS 2023).

Table 1. Surface areas of hydrological basins

	Additional surface (km^2)	Total surface (km^2)
Until Dnipro	N/A	470,885
Until Kakhovka	18,317	489,202
Until Kherson	22,493	511,695

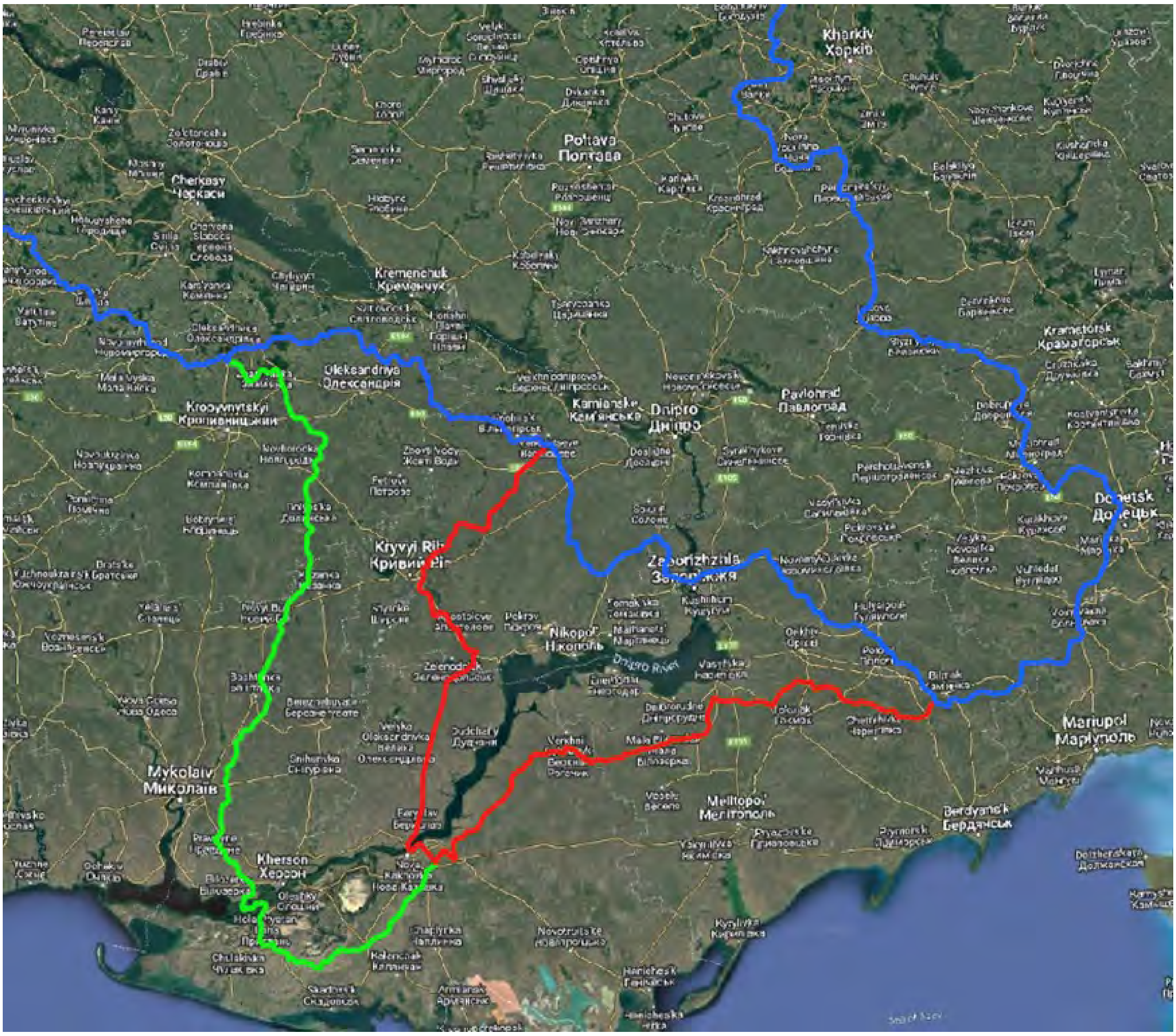

Figure 16. Dnipro River basins – the catchment up to Dnipro dam (blue), Kakhovka dam (red) and Kherson (green) (*Source: adapted from HydroSHEDS 2023*)

Table 1 and Figure 16 clearly show that the area draining directly into the Kakhovka reservoir is fairly small. Rather, most water comes from upstream (18,317 km^2 vs. 470,885 km^2). Furthermore, approximately 22,493 km^2 drains into the section of the Dnipro River located between Kakhovka and Kherson, of which the Inhulets River is the largest source of water. Most of the basin upstream of Kherson (~92 per cent) is still located behind the Dnipro dam and other reservoirs further upstream, so the Kakhovka reservoir did not represent a major influence on the hydrological regime of the lower Dnipro River.

As concluded by UK CEH and HRW, the dams upstream of Dnipro dam fulfil a mitigation function to a higher extent compared with the Dnipro dam (hydroelectric) and the Kakhovka dam (water distribution) (UK CEH 2023). As can be seen from Figures 17, 18 and 19, showing discharge measurements for dams on the Dnipro River cascade, the Dnipro dam outflow is in general the same as the Kakhovka dam outflow (the flow of each dam follows roughly the same pattern and the discharges for each station were roughly the same).

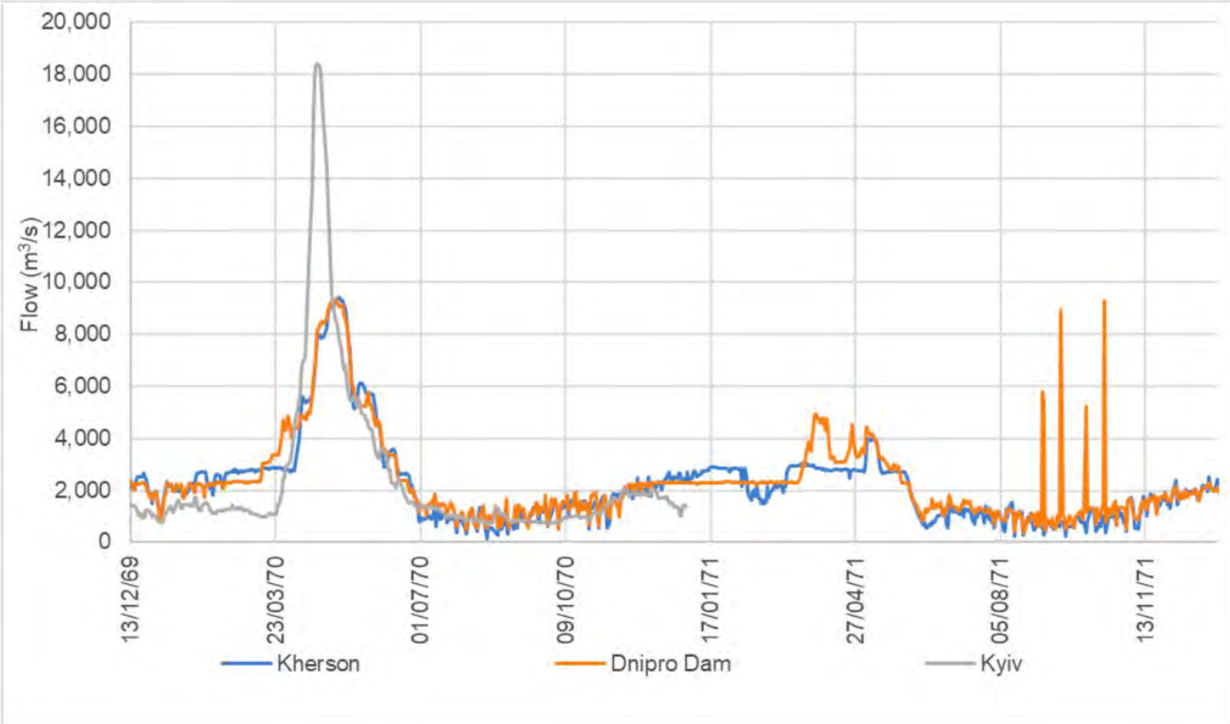

Figure 17. Discharge measurements for the year 1970–1971 for Kherson, downstream of the Dnipro Dam and downstream of the dam at Kyiv (*Source: UK CEH 2023*)

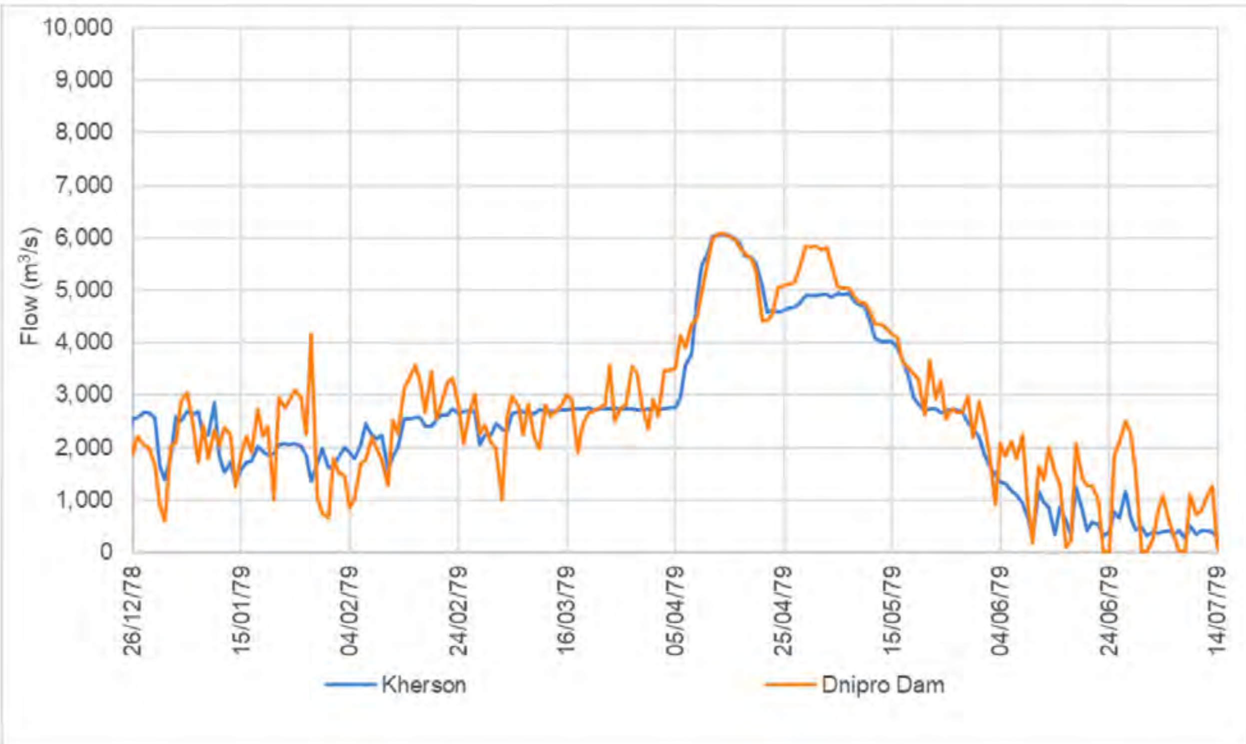

Figure 18. Discharge measurements for 1978–1979 for Kherson, downstream of the Dnipro dam and downstream of the dam at Kyiv (*Source: UK CEH 2023*)

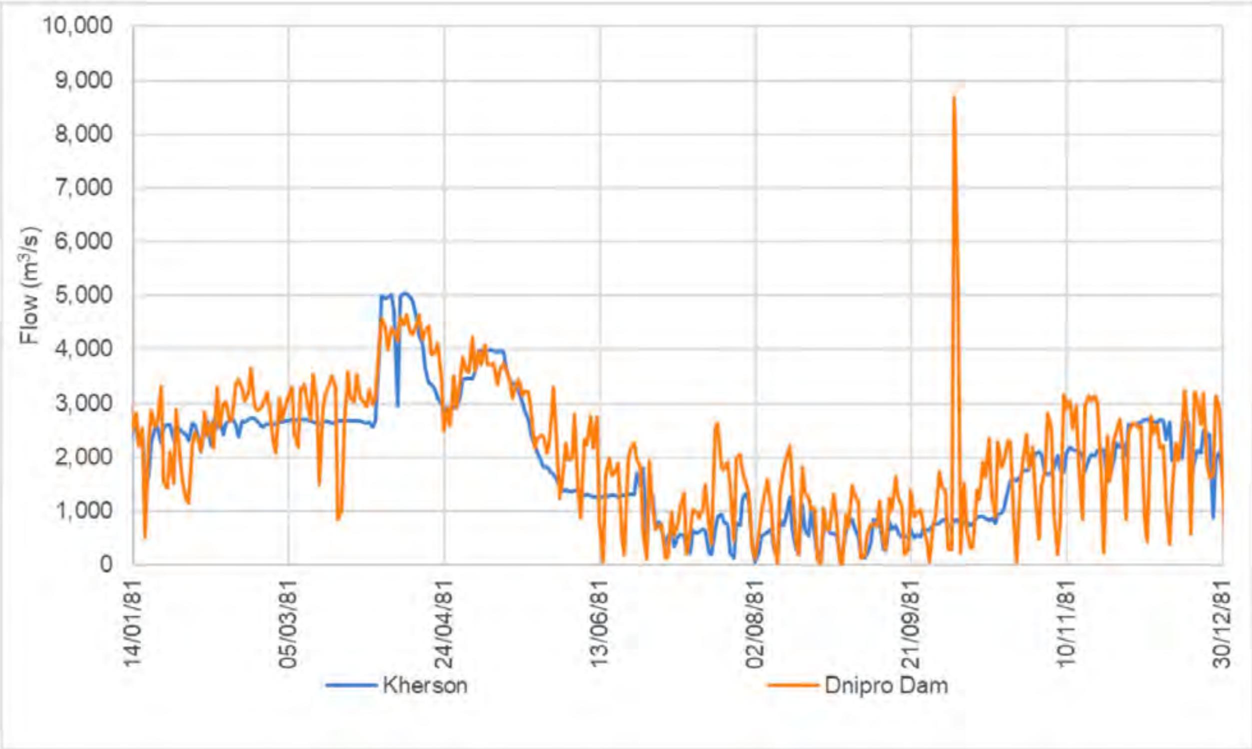

Figure 19. Discharge measurements for the year 1981 for Kherson, downstream of the Dnipro dam and downstream of the dam at Kyiv (*Source: UK CEH 2023*)

During a previous large flood, which occurred in 1970 and is referenced in the 2023 UK CEH report (Figure 19), the upstream maximum discharge was more than 18,000 m^3/s while the maximum discharge at Dnipro dam and Kherson gauging station was just over 9,000 m^3/s, clearly showing that the flood peak was reduced already upstream of the Dnipro dam. When assessing the impact of the breached dam on the future hydrological regime of the river, it can be concluded that:

- The flows in and out of the Kakhovka reservoir have historically been similar in both timing and amounts, with the Kakhovka dam providing only a small buffering function. This shows that the Kakhovka reservoir has not provided a flood reduction function. Additionally, the relative basin size covered by the Kakhovka reservoir is relatively small, supporting the conclusion that the reservoir primarily passes the flow from Dnipro dam further downstream. With the disappearance of the Kakhovka dam, it is not expected that the discharges downstream of the dam will increase substantially, as the dam primarily passes the water of the reservoir further downstream. However, it can be expected that, as of now, the discharge downstream of the destroyed Kakhovka dam will show a more pulsing behaviour typical to the flow released by the upstream Dnipro dam. The hydro peaking effect of the Dnipro hydroelectric plant may have some consequences on riverbed erosion in the upper part of the former reservoir. It is expected that this effect will gradually decrease within the new free flowing section in the empty reservoir.
- Flood peaks are historically buffered by the reservoirs upstream of the Dnipro dam and not by the Kakhovka reservoir. Therefore, the future risk of flooding downstream has not been heighted by the fact that the Kakhovka dam was breached.

Reduction in groundwater levels

A critical impact expected due to the drying out of the reservoir is a significant decrease of groundwater levels in the areas surrounding the former reservoir. Previously, the high-water level in the reservoir maintained a high ground water level in the surrounding agricultural plots. Additionally, it could cause subsidence in the area, which has already been reported (Figure 20).

Figure 20. Compressed railroad bed and landslide on the bank of the Kakhovka reservoir after its depletion (near Nikopol) (*Source: Yakovlev and Stefanyshina 2023*)

3.3. Chemical contamination

The assessment of chemical contamination relied on analysis of flooded infrastructure and industry locations conducted by UNEP partner organisations, as well as on first–hand data provided by the government and other national and international institutions, including civil society actors, and expert judgement. The assessment also includes information provided through a number of consultation meetings with on-the-ground institutions and individuals.

3.3.1. Monitoring of water quality

Surface water

The primary objective of the Kakhovka reservoir was to serve the surrounding agricultural regions with irrigation water. Furthermore, it was an important source of drinking water while energy production was a secondary, yet important, consideration. Because of its primary purpose to provide irrigation and drinking water, it can be presumed that possible contamination in the flood zone did not originate primarily from the reservoir water itself.

Nevertheless, Kakhovka reservoir, the final reservoir in the cascade, accumulates a significant amount of runoff containing pollutants. As a result, the concentrations of heavy metals in both water and sediments are generally higher than other reservoirs; for example in Kyiv reservoir, which is less affected by surrounding land uses (Scherbak 2019).

Monitoring data from the entire Dnipro basin from 2021 and the beginning of 2022 shows that the water quality of the river is generally good (see Annex III). Monitoring data of the Dnipro River, from the State Agency of Water Resources of Ukraine, after the dam breach shows that, in general, the environmental quality of the water was met with most of the criteria below the guideline values (Ukraine, State Agency of Water Resources 2023) and the large dilution in the river and Black Sea would have assisted in lowering contaminant levels. Notwithstanding these results, water quality monitoring directly after the breach and in the weeks after, showed the biological oxygen demand (BOD) in many of the samples to have exceeded the guideline values, most likely caused by organic matter content (Figure 21).

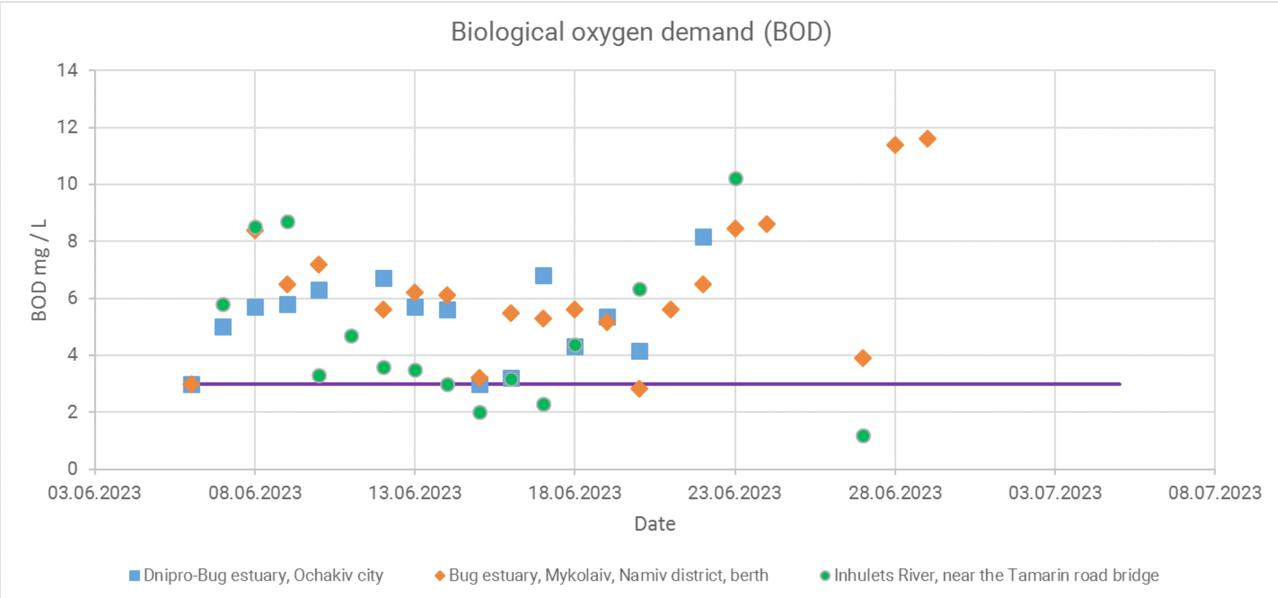

Figure 21. Biological oxygen demand in the river basin after the dam breach. Note the purple line shows the guideline value (*Source: Created by the authors using data from Ukraine, State Agency of Water Resources 2023*)

Sea Water

After the dam breach the salinity near the shores of Odesa was two to three times lower than normal due to a sudden and large inflow of freshwater, with salinity changes indicated in Figure 22. While the salinity levels will stabilise over time, a sudden decrease in salinity may lead to hypo-osmotic stress in the organisms living in the area. That means that cells will take up water, swell and eventually burst or die, causing death to the organism (Ho 2006). While some species in this estuary of the Black Sea may be adapted to a lower salinity content, other species may have suffered (Ukraine, Institute of Marine Biology of the National Academy of Sciences of Ukraine [IMB NAS] 2023).

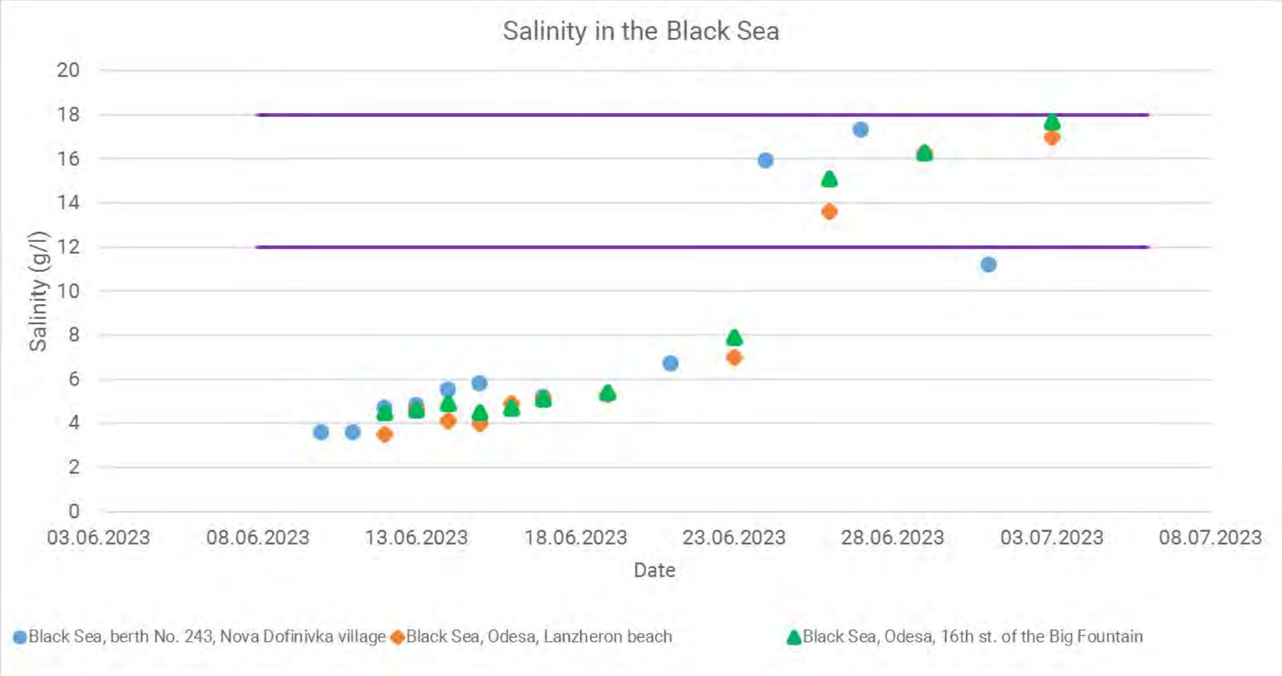

Figure 22. Salinity changes after the breach. Note normal ranges are between the purple lines
(*Source: Created by the authors using data from Ukraine, State Agency of Water Resources 2023*)

Besides nutrients and organic matter, sewage and manure discharges into aquatic ecosystems and drinking water pose a risk of microbiological contamination (Ukraine Government 2023). Waste from the flooding transported all the way to Odesa oblast is shown in Figure 23. Results of sampling carried out after the breach by the Centers of Disease Control and Prevention show that bacteria and viruses (lactose positive *E. coli, E. coli,* cholera like vibrio, amoebae, giardia, enterococci, Rotavirus, Salmonella, Astrovirus, cryptosporidium, trichocephalosis, toxocariasis, strongyloidiasis, human roundworm and staphylococci) that may cause human disease were present in the river basin and in the Black Sea (CDC 2023), yet the exact source of these contaminants is unclear. Freshwater organisms killed as a result of the dam breach have been washed upon the shores near Odesa (Ukraine, MEPNR 2023). Dying organisms can release organic matter and nutrients leading to algal blooms as well.

Figure 23: Waste from a flooded area after the Kakhovka dam breach is seen on a beach in Odesa, Ukraine 13 June 2023
(© *Keystone/imageBROKER/Andrey Nekrasov*)

Groundwater

Many groundwater wells are present in the affected region, including in the flooded area. As a result of the direct contact between the surface water and the groundwater during the flood event, chemicals and biological agents may have entered the wells and thus affected the groundwater quality. Special attention must be paid to those wells that are used for drinking water and irrigation of crops.

3.3.2. Chemical release

The release of chemicals related to the incident is primarily related to two sources: release from industry and infrastructure located in areas affected by flooding, and/or release of chemicals through the mobilisation of potentially contaminated sediments in the reservoir, where most of the impacts are expected downstream of the breach, since this is where potential contaminants and sediments were transported. The fate of contaminants will depend on the amount of chemicals released, their properties and the extent and type of inundation. When inundated soils are saturated with water, convective pollutants transport (movement of pollutants within the mass stream of water entering into the ground or within the groundwater flow) is limited.

After the breach, it is assumed that soils along the riverbanks filled up with water as the river rose and started to cover the area up to 620 km^2 downstream of the reservoir. Provided the flood water was not heavily polluted in and of itself it is expected that pollutants were released as the flooding event progressed, e.g. from flooded machinery, private homes or industrial complexes (Figure 24). As water kept arriving it carried and distributed contaminants, spreading them further from their place of origin and diluting potential contamination. As the amount of water was very large, it can be assumed that the transport rate of contaminants into the upper soil layers was rather modest, with the exception of areas with specific releases from, for example, damaged infrastructure.

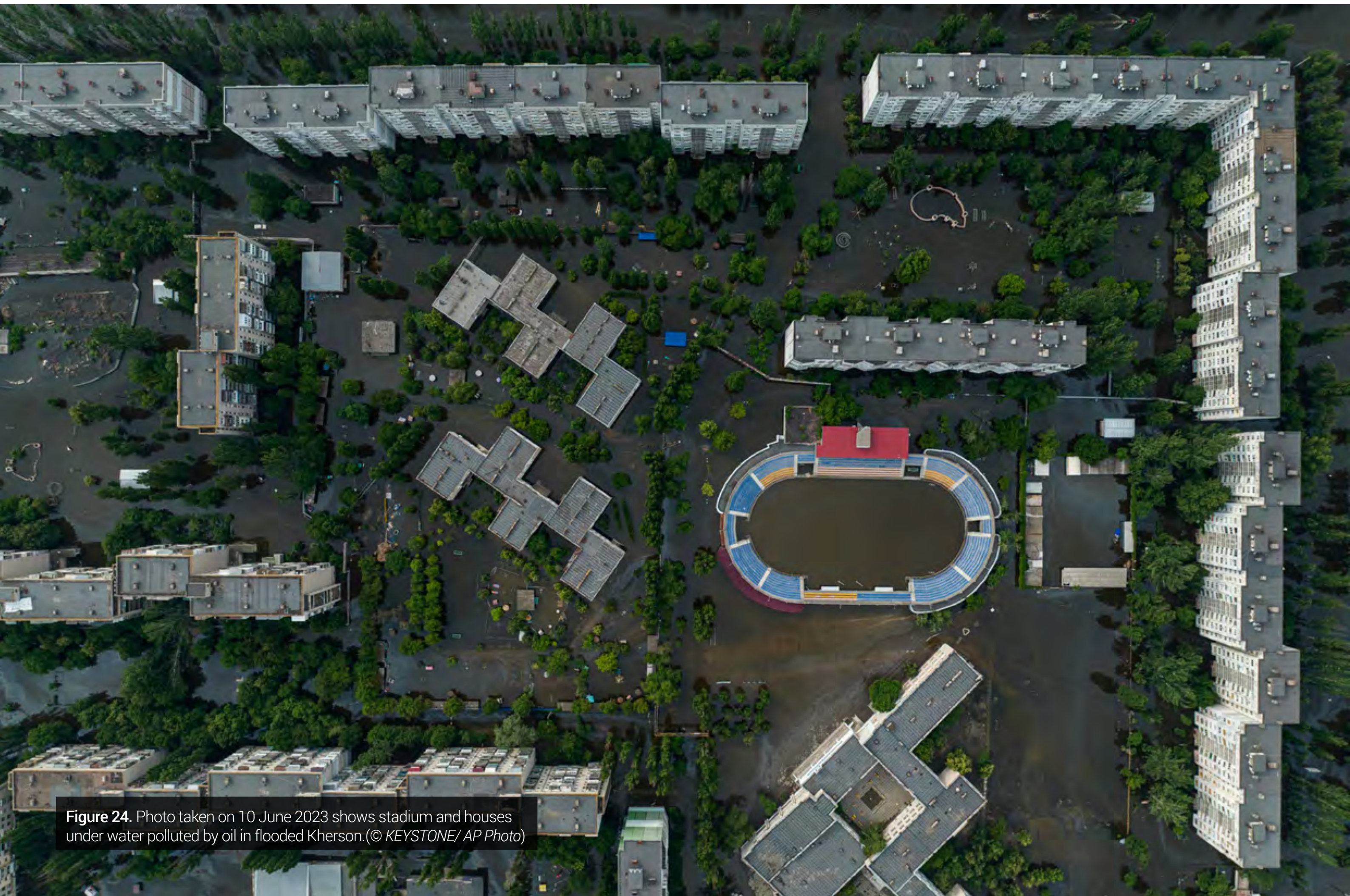

Figure 24. Photo taken on 10 June 2023 shows stadium and houses under water polluted by oil in flooded Kherson.(© *KEYSTONE/ AP Photo*)

Chemical releases from facilities

In the flooded area, chemical substances can be released from compromised structures, factories and chemical storage tanks. The greatest impacts during flooding and after the water has receded will be in the areas around sites which can release large amounts of chemicals such as solvents, petroleum hydrocarbons, pesticides and fertilisers. After a while these chemicals will be present either in the soil around the release points or will be transported further downstream the river towards the delta and the Black Sea. Chemicals can remain in the water phase or adsorb to particles and sediment. Some chemicals can be degraded over time while others are persistent and can remain in the environment for a long period of time. These chemicals can affect organisms directly or can be accumulated in the food chain and can contaminate food for human consumption. While exposures to chemicals pose a constant risk, size and physiological differences between women and men, and between adults and children, influence susceptibility to health impacts. Pregnancy and lactation are windows of susceptibility for women where they can transfer toxic chemicals to their children. Generally, women and men are exposed differently depending on their socio-economic status, professions and associated gender roles (UNDP 2011; SAICM 2017).

An overview of potential hotspots regarding the (probable) release of chemicals or biological agents into the water has been made based on existing reports and analyses, notably the lists compiled by CEOBS, containing 66 entries (facilities and infrastructure objects) (Moreland 2023), Ecodozor, containing 192 objects (Ecodozor 2023) and REACH Impact Initiatives, containing 134 objects (REACH 2023a). Information provided by the Ukraine authorities (Ukraine Government 2023) on affected industry, as well as satellite images to assess the amount of flooding of the facilities (UNOSAT 2023), were also studied.

It is expected that most of the facilities located in the flood zone had ceased operation due to their location within the area of active hostilities. However, for the assessment of possible chemical release it should be assumed that all reservoirs and tanks, and chemical substances contained therein, would have been present at the sites. For the selection of chemical hotspots the assessment has focussed on those large structures that may have contained large amounts of chemicals or those of concern (persistent, mobile and/or toxic). For biological agents the analysis has focussed on large scale livestock and poultry farming and sewage/wastewater treatment plants.

The list of chemical hotspots was assembled through:

1. Combining the list of CEOBS, Ecodozor and Reach, then checking for duplication based on facility names and locations (7 doubles)
2. Removing facilities outside the flooded area (21)
3. Removing all infrastructure and utilities, such as bridges (56)
4. Removing all facilities of a certain type, size or location (primarily those of small scale, e.g. souvenir shops or small garages, or those not located in a flooded area)
    - cemeteries (19)
    - agriculture / livestock (17) - note that small ones or those not relevant, e.g. agricultural stores selling machinery, have been deleted
    - construction (28) - note that small ones have been deleted
    - shops / markets (7)
    - ports (2) - note that any companies handling chemical substances and oil and fuel depots within a specific port area are still included
    - small to medium enterprises (71)
    - transport facilities (5)
    - waste (5)
    - other (1)

The facilities identified as potential hotspots are shown in Figure 25 and listed in Annex IV.

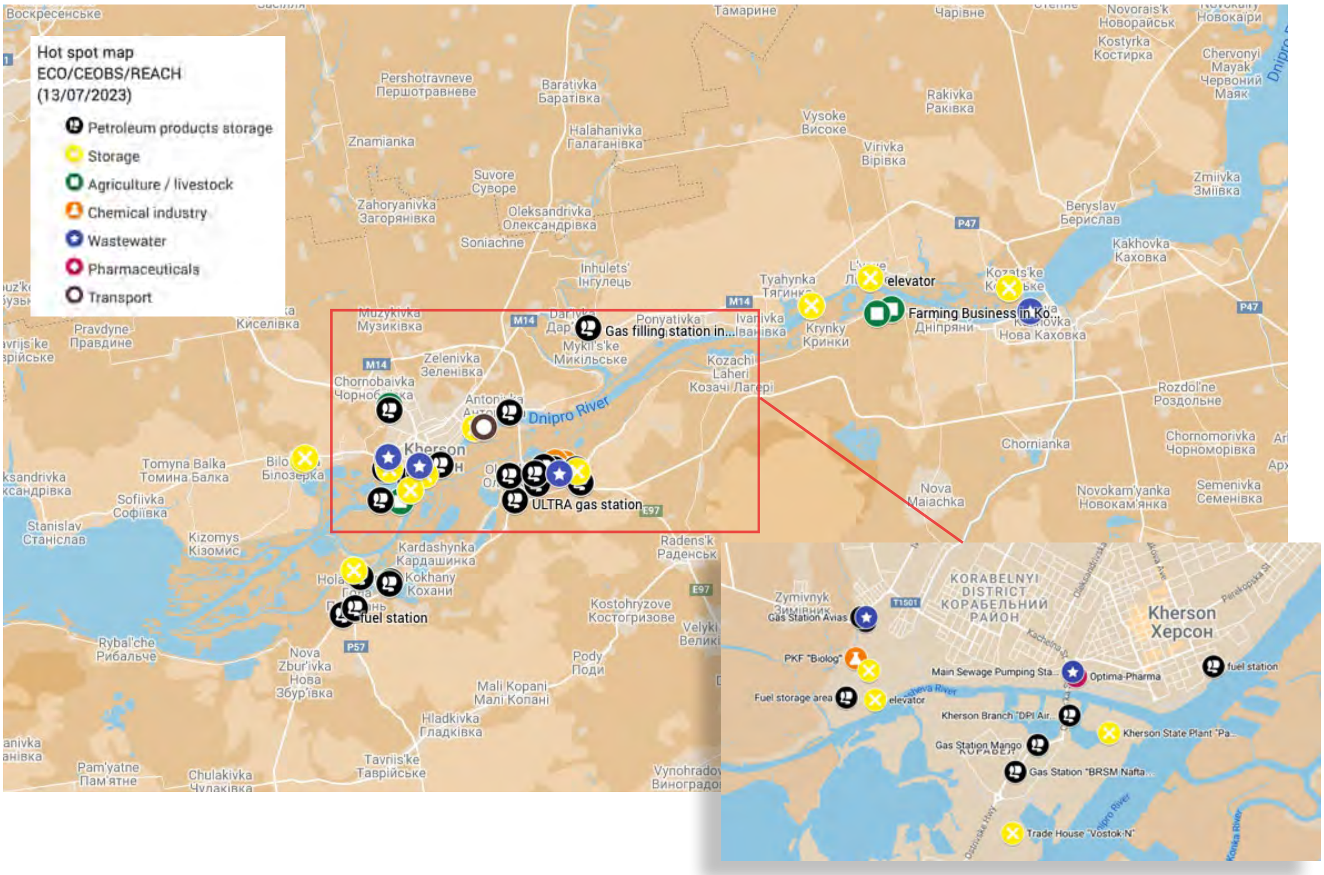

Figure 25. Map overview of the 54 selected facilities (*Source: Map data @2023 Google*)
https://www.google.com/url?q=https://www.google.com/url?q%3Dhttps://www.google.com/maps/d/edit?

Oil contamination

Oil is not a single compound but a complex mixture of hydrocarbons (alkanes, alkenes, branched alkanes, cycloalkanes, polycyclic aromatic hydrocarbons (PAH), volatile organic compounds and others) and can be light or heavy. Heavy oil tends to stick to beaches, shores, plants but also organisms like birds. Once stuck or as a floating slick on the water, oils can suffocate everything underneath. Components in oil can have effects on reproduction of organisms, mucous membranes, respiratory system, organ failure, weight loss, behavioural changes and death of aqueous organisms and plants. Compounds in oil might also bioaccumulate in the food chain. Oil may have been released from multiple facilities and locations within the flooded area downstream of the dam (Yuewen and Adzigbli 2018; Alzahrani *et al*. 2019).

Oil is likely to have been released from several locations affected by flooding, where satellite imagery shows the presence of oil slicks in Kherson (Figure 26). Around 150 tons of machine oil (corresponding to approximately 170,000 litres[2]) originating from the Kakhovka hydropower station is confirmed by Ukrainian authorities to have entered the water after the dam breach (Santini *et al.* 2023). An additional 300 tons (corresponding to approximately 340,000 litres[3]) of oil is reported to have been present at the facility and can be presumed to have been released. The exact properties of the oil is unknown but it can be estimated to possibly have caused a slick of 100,000 m^2 (assuming a density of 0.8 g/cm^3 and an average, fairly thick, slick thickness of 2 mm, where a thinner layer would lead to a larger oil slick). No oil slick has been reported either at the river or in the Black Sea yet oil slicks have been observed in the Kherson port area. All in all, it is impossible at this stage to accurately determine the fate of the released oil. Weather, flow and turbulence will all impact the behaviour of oil in water.

2. The exact amount in litres will depend on the type of oil, which was not known to the authors.
3. The exact amount in litres will depend on the type of oil, which was not known to the authors.

Figure 26. Aerial photos taken on 10 June 2023 show oil slick on flood water in Kherson area Top: Contaminated water: Gasoline can be seen next to flooded houses in a district of Kherson Bottom: Large amounts of leaked fuel are washed through the flood areas in the Dnipro (*© KEYSTONE/ AP Photo*)

Ukrainian authorities report that, besides the oil from the Kakhovka dam facility, 15 gas stations are reported to be located in the flooded area (Ukraine Government 2023). The Kherson oil depot and the ports (both sea and river) are suspect areas for release of oil into the water. REACH initially identified a total of 54 oil facilities that have been impacted by the flood (REACH 2023b), where the larger of these facilities were included in the hotspot list. The oil facilities that are expected to have the highest impact on the environmental quality are the port storage facilities in Port Naftahavan and large-scale storage facilities in northern Kherson and Glusco, a site south of the Dnipro (for further information see Annex IV). Leakage of oil from barrels located in the Korabelny district has been observed (Ukraine Government 2023).

Oil products have reportedly been discovered on the newly formed floodplains in the Kakhovka reservoir. Released oil can stick to all types of structures the water encounters on its way to the sea, including man-made structures, natural structures and soil particles. Whenever the density of the oil was higher than that of water, the oil might have disappeared visually, floating under the water level. It is also possible that, due to the impact of the breach and the force of the water, at least a part of the oil might have been dispersed in the water column, e.g. forming droplets of oil in water. It is also reported that some oil (over 20,000 m^2 of oil slick reported on 20 June) has been identified and recovered, using over three tons of sorbents (European Commission Emergency Response Coordination Centre [ERCC] 2023).

In some surface water samples taken from the Dnipro near Kherson oil products were found but only in very low concentrations. The exact extent of the contamination is unknown but estimated at some 3,700 ha of the Dnipro-Boh estuary, and a further 14,000 ha of the Black Sea coastal waters (Ukraine, IMB NAS 2023) are affected. In general, it can be noted that leaks from oil tanks or fuel spills tend to quickly dilute, evaporate, go through photo-oxidation and microbial degradation in flood disasters, usually within a few weeks and months (Alzahrani *et al*. 2019). However, some of the more persistent compounds within oils may remain in the environment for years.

Pesticides

Pesticides are biologically active compounds that can have severe effects on the ecosystems, both on individual species and community structure and function. Furthermore, these compounds can bioaccumulate in organisms, including those used for human consumption, including fish.

The South Ukrainian Sea company, which produces and stores pesticides, is located at the north shore of the Dnipro River, near Antinovka, Figure 27. The extent to which this facility has been affected is unknown, as well as its current status (type and amount of stored substances) yet given its location on the shore of the river, and the type of chemicals produced (hazardous substances), it is viewed as a high priority location.

Figure 27. Map with location of South Ukrainian Sea Company (*Source: Ecodozor 2023*)

Obsolete pesticides from Soviet times are stored as waste throughout Ukraine, including in the Kherson region (UNEP 2022). These pesticides are stored in concrete containers above ground, in smaller barrels below the surface or mixed with soil. While the Ukrainian authorities report that none of these locations were affected by flooding, this should be verified, as their existence presents a major risk to both human health and the environment and the locations may have been affected by the war (Ukrainian Authorities 2023).

Pesticides might additionally have entered the water system from flooded agricultural fields, where they may either have been adsorbed by organic matter or soil particles or dissolved in the water. Note that any large companies handling agricultural products have been included in the hotspot list, while smaller ones with expected minor quantities of chemical substances have been removed. The Ukraine Government estimates that a total of 1,066 ha of agricultural land has been flooded (309 ha arable land, 639.5 ha orchards, 45.5 ha pastures and 72 ha of private farmed land). In addition, estimates suggest that 1,058.3 ha of agricultural land has been flooded in the Mykolaiv region as well as 167.2 ha of untreated land (Ukraine Government 2023). Note that this is a higher figure than the cropland figure cited earlier (871 ha), derived from satellite imagery, which may not include all relevant plots. Nutrients, pesticides and organic matter might have been transported with the flood waters and deposited with the receding waters. On the other hand, the potentially polluted sediment might have been deposited on agricultural fields and private farmed lands.

Nutrients and organic matter

Nutrients are chemical elements that species rely on for growth, and include nitrogen, oxygen and phosphorus. Excessive amounts of nutrients and organic matter, e.g. suspended solids, are harmful to water quality and aquatic life, where they have a less visible, though not negligent, impact on the health of soil and sediments. Excess nutrients can cause harmful algal blooms. Modelling from Santini *et al*. (2023) has already shown that pollutants from the Dnipro River can end up in the Black Sea, more specifically to the north-western and western shores. It is important to understand the release and fate of nutrients in order to assess the possible ecological effects in the Dnipro delta, the Dnipro Gulf and the Black Sea.

Nutrients may stem from industry or infrastructure, including large scale livestock and poultry farms (manure). Additionally, they may have been mobilised from agricultural areas and/or through the mobilisation of sediments. The event may have caused, comparably, a peak concentration of released nutrients, as during normal times croplands are likely to have been provided with constant smaller nutrient influx caused by usual runoff. Nutrients and organic matter may also have originated from sewage, as some sewage treatment plants are reported to have been flooded. Flooding of sewage systems in towns and cities is also expected to have led to an increase of nutrients and organic matter. For instance, it is reported that sewage from the sewage treatment plant near Bilozerka has entered lake Bile. This lake is in direct contact with the Kosheva river, which is a tributary of the Dnipro (Ukraine Government 2023).

It is reported that almost 3,500 tons of liquid fertiliser (urea-ammonia) was stored at the Pallada Shipyard, Kherson Quarantine Island 1 (Ukraine, MEPNR 2023; Ukraine Government 2023). Reportedly, the integrity of the storage tanks was damaged that led to the release of chemicals to the water (Ukraine Government 2023). There is also a fertiliser factory in the flooded area (Scientific Production Enterprise '5th Element' in Hola Prystan, south of the Dnipro River).

Monitoring of water in the Black Sea shows that, as of 10 June the amount of organic matter was ten times higher than normal (Ukraine, IMB NAS 2023). Increasing organic matter might lead to a higher BOD. This might lead to lower oxygen levels in the water, even below the critical values for aquatic life. Similarly, monitoring carried out after the dam breach showed that the amount of nutrients in the Black Sea was increasing, especially ammonium (N). This may have originated from sewage (Ukraine, IMB NAS 2023).

Parallel to the inflow of reservoir water into the Black Sea an algal bloom evolved in the Black Sea, seemingly consisting mainly of cyanobacteria, species common for this region. The reported release of the urea-ammonia mixture may have contributed to an increase in algal biomass and cyanobacteria all the way to the Black Sea (Santini *et al.* 2023).

3.3.3. Sediment contamination

The Kakhovka reservoir, like the water of most rivers, has been put under stress by discharges of industrial and domestic wastewater (Scherbak 2019). The contaminants contained in these discharges, including heavy metals or organic pollutants, are mainly bound to fine cohesive particles and transported in suspension in the water of the river system. Within sites of low flow velocities, deposition of suspended solids and consequent accumulation of the contaminants in the bottom sediments takes place.

The sediments of the reservoir reflect more than 60 years of human activities and its discharge of pollutants into the environment. Sediments serve as an archive covering the time since the dam began operation in 1956. For example, north of the reservoir between Kamjanske and Zaporizhzhia there is a densely populated area and a concentration of heavy industry including iron smelting). Part of the pollution originating from these sites is likely to have ended up through surface water and riverine run-off and accumulated in the sediments. Contamination of sediments are likely to also include Cesium-137 originating from the Chernobyl nuclear accident in 1986 (Scherbak 2019).

The influence of reservoir sediments on pollution in the flood zones depends on 1) the amount of sediments carried away and; 2) on the distribution and concentration of contaminants within sediments. The pollution of sediments is typically expected to increase with depth, as pollution tended to be more prevalent before, i.e. less contaminated more recent layers have covered (or ‘buried’) more highly contaminated older sediments. Due to lack of data, it is not known if this is true in case of the Kakhovka reservoir. Studies have shown that there may be a limited mobility of heavy metals from contaminated sediments, even when total concentrations are high. Yet extreme runoff events have the potential to cause the remobilization of legacy contamination due to the resuspension of the sediment (Cappuyns and Swennen 2004).

3.3.4. Military waste

The entire area affected by the dam breach is also impacted by the presence of military waste, due to the prolonged war and presence of the frontline in this area. Military waste includes abandoned mines of various types, fuels, rocket fuels such as hydrazine nitric acid, Research Department explosive (RDX) or hexogen and ammunition containing traces of heavy metals, mercury (from mercury fulminate), lead, antimony, arsenic, strontium, asbestos, ammunition casings and other types of wastes (UNEP 2022). It is known that Soviet and Russian anti-tank mines used in the war (ranging from TM62 to PTKM-1R) are present in the affected area.

Landmines

The presence of landmines is the main military waste concern in the area downstream of the dam breach, where at least 13 types of antipersonnel mines are known to have been used and at least 13 types of anti-vehicle mines being used, with TM-62 series anti-vehicle mines appearing to be most frequently deployed (Human Rights Watch 2023). The transport of land mines due to flood waters has been reported where these risk exploding. Anti-personnel mines, on the other hand, are expected to have remained in place and are active as they are covered by a certain depth of sediment or soil (approximately 40 cm). With time, rain, movement or water may relocate or move them. It is to be expected that some of the mines will have been washed to the Black Sea where higher salt conditions speed up the corrosion. Eventually, the mines are expected to be covered by soil and sediments on the Black Sea shores or on the bottom of the sea.

It is expected that abandoned mines will degrade within a few years and will be very difficult to locate throughout the Dnipro delta. Some slow but possible methods besides conventional techniques could be the use of bees, which detect TNT/RDX better than any sensor or animal. In addition, the use of modified plants, such as the ubiquitous Arabidopsis thaliana, can indicate a higher level of N_2O by changing colour, which indicates the degradation of TNT and other explosives (Nelson 2004).

Humanitarian demining is only possible within a safe distance of the front line. Demining in Ukraine is regulated only on land and the processes of demining river channels and estuaries will need to be established. Mechanical demining by ploughing, blasting, vibrations, wave-extraction will damage ecosystems. If possible, demining with heavy equipment can be staggered to give plants and animals a chance to relocate. Without mechanical demining of the old riverbed followed by manual inspection, munitions residues, mines and southern booby traps will keep the river channel and estuarine delta very difficult to use for years to come (Geneva International Centre for Humanitarian Demining [GICHD] 2023).

Ammunition casings

Experience in Switzerland has shown that ammunition stored under water and in sediments shows a low rate of extraction of metals such as copper and zinc over time, as well as a low rate of degradation of explosive products. The degradation of casings will depend on the level of oxygen, pH and damage to the shells. Even with a high amount of partially damaged ammunition, the leaching will be low (Ramin 2020). Consequently, there would be enough time to search and recover and separate the shells from the explosives, even though the cost of this would be enormous. Different types of ammunition will see different types of metal leakage into soil including mercury (and Methyl-mercury), lead with antimony, arsenic, copper, as well as degraded products of organic ammunition loads.

3.4. Disaster waste

Following the dam breach an astonishing 14 km^3 of water flooded the land areas downstream. Immediately after the incident the water first flooded the 5 km wide delta of the Dnipro River before it started to flood human settlements. Thereby the flooding of most settlements (except those in the immediate downstream vicinity of the dam) had the characteristics of a heavy rainfall with slowly rising water levels rather than a tsunami situation where water with force destroys the settlement. The characteristic of the flooding has an impact on the waste being produced. Due to the circumstances of the flood event the waste produced is expected to mainly have consisted of household interiors and building materials destroyed from being submerged. To a lesser extent the waste is expected to have consisted of broken items and materials, mixed up with mud. The waste will thereby be easier to sort, and more materials are expected to be reused or recycled.

According to the KSE (2023) more than 60,000 buildings on the north and south banks of the river were flooded or potentially flooded. The vast majority of these buildings consist of residential buildings, see Figure 28. As the level of water reduced, many houseowners returned and, most likely, salvaged what could be saved. In this process a vast amount of waste was likely to have been produced and would have piled up within the settlements. The municipality has the ultimate responsibility to manage this waste.

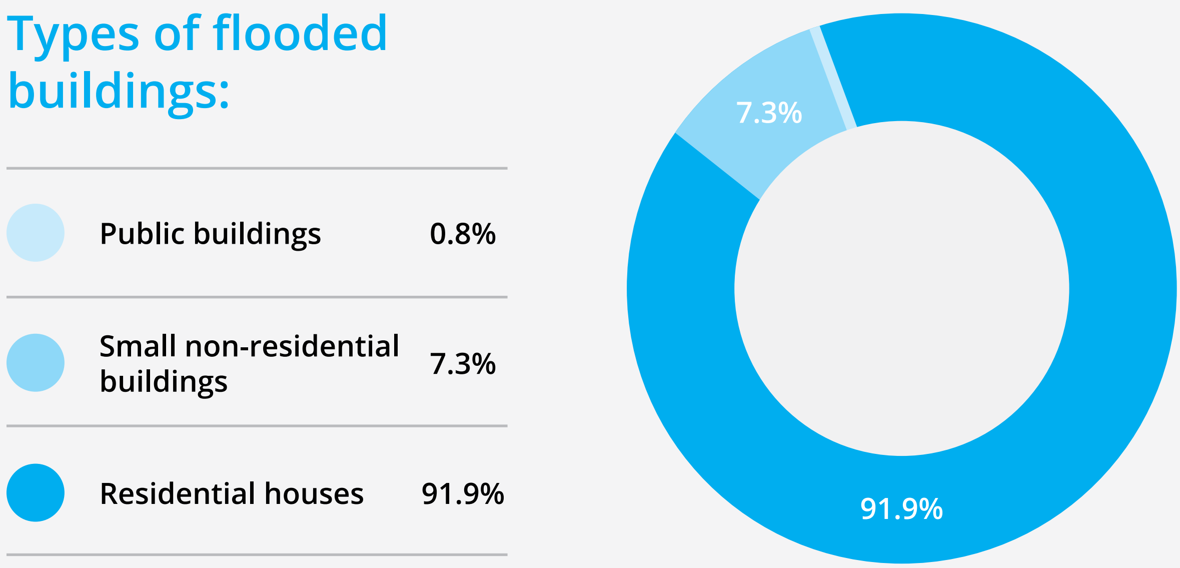

Figure 28. Division of potentially damaged buildings (*Source: KSE 2023*)

The assessment of disaster waste was conducted remotely. The main sources of information were satellite images, images from the press and the modelled extension of the flood area. The assumed flooded area applied for the analysis was the one used in Ecodozor, developed by the Institute of Mathematical Machines and Systems Problems of the Ukraine National Academy of Science and the Ukrainian Hydrometeorological Institute (Ecodozor 2023). Information provided by the oblast and partner organisations has also been used (KSE 2023).

Biological hazards related to dead domestic or wild animals is not considered in detail here, even though it was considered a significant concern following the dam breach (Figure 30). This is due to the fact that biological waste is not considered by various disaster waste conceptual models, and the information on biological waste was unavailable. No reports of larger deposits of mud have been found and the post disaster handling of mud will probably not require significant management responses. Neither will this report focus on other types of natural materials such as dead trees. Assessment of waste within this report is mainly focused on inert debris (concrete, wood and metal) from residential buildings. While the potential chemical waste from companies and operations is considered in section 3.3.2, the creation of debris waste from industries and operations is considered to a lesser extent. This is considered warranted as:

- The majority (92 per cent) of the affected buildings are residential buildings (where the exact type of housing, e.g. multi storey or individual, is unknown)
- It is not possible within this assessment to receive information on amounts of waste from the operations due to the security situation.

Similarly, the potential of contamination of debris by chemicals, e.g. from spilled oil, is not considered in detail in the report. The estimations and the recommendation on disaster waste from households is within this assessment based on the conceptual model below, Figure 29.

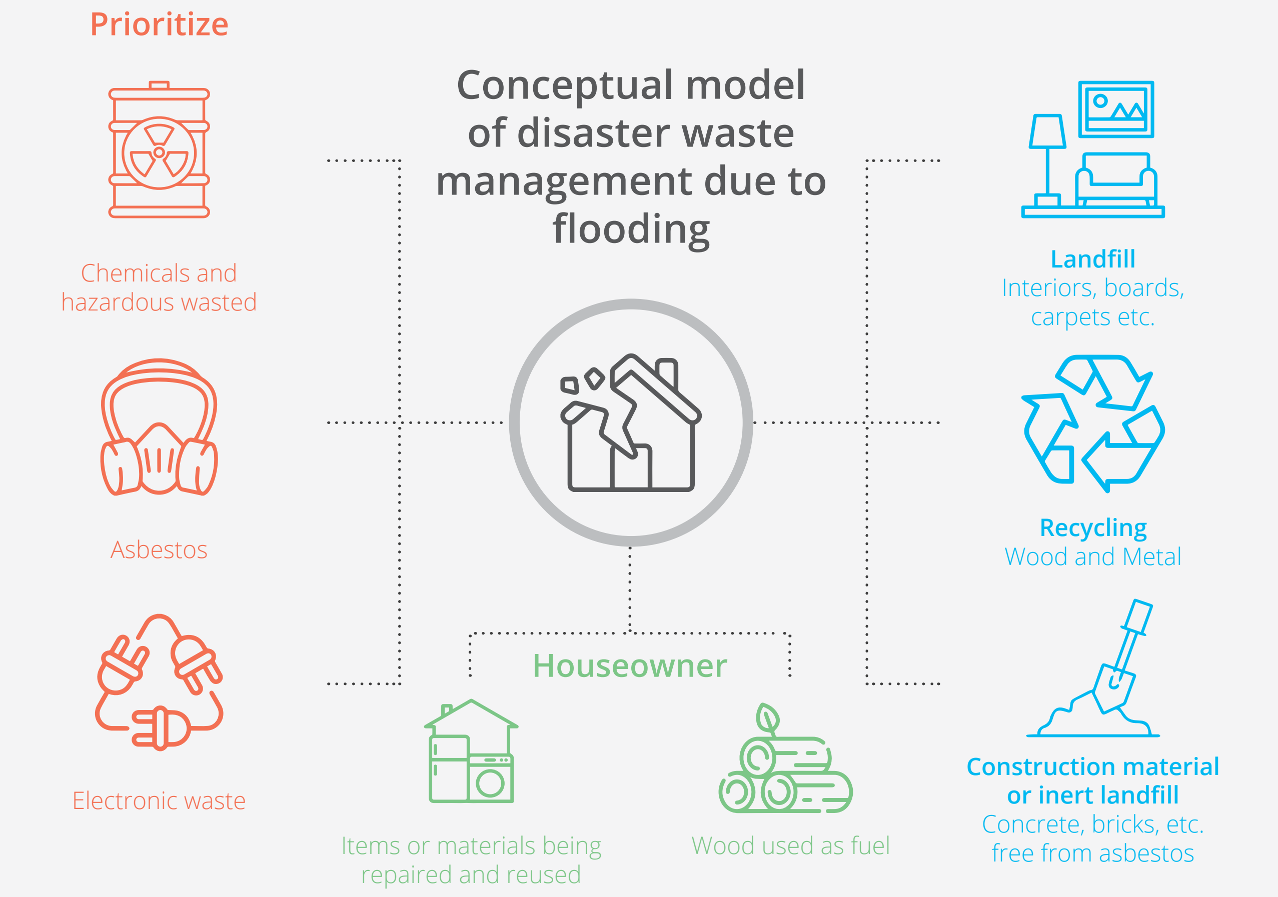

Figure 29. Conceptual model of disaster waste management due to flooding (*Source: Original infographic by report authors*)

Given the ongoing war it is assumed that affected households have a reduced availability of new goods to buy and are thereby likely to repair and reuse more materials within the household rather than discarding them. For the same reason it is likely that construction materials of wood are cut up into firewood rather than discarded, at least in the rural areas and smaller settlements, as the availability of other sources of energy is scarce.

For management of carcasses, including the 11,000 tons of dead fish reported (Ukraine, Ministry of Agrarian Policy and Food 2023b), FAO has produced estimations and guidance in line with the national legislation.

Figure 30. An animal rescue volunteer moves among floating debris on a boat in floodwaters at Kherson on 8 June 2023 (*© 2023 Aleksey Filippov/AFP via Getty Images*)

3.4.1. Characteristics of affected areas from a waste management perspective

The northern and southern banks of the river have many differences which affect waste generation. The riverbank of the northern side is generally higher and the flooding has not spread as far outside the river channel as it has on the southern side where entire settlements flooded. On the other hand, several water courses join the Dnipro from the north, leaving settlements upstream of these watercourses also affected by the rising water levels.

Figure 31. The photo taken on 10 June 2023, shows flooded area west of Kherson on the northern side of the river. Heavy industry and residential areas are located close together (© *KEYSTONE/ AP Photo*)

The northern shore, where the city of Kherson is situated, contains areas of heavy industry such as the wharf and the former brick work in close proximity to residential buildings (Figure 31). Downtown Kherson contains larger, higher buildings, surrounded by suburban quarters, which were mainly unaffected by flooding. Meanwhile, the southern side is more rural with less industry, smaller settlements as well as smaller buildings with mainly one storey and more dependent on farming (Figure 32). In several settlements, Korsunka for example, every household has its own greenhouse of several hundred square metres. The three larger towns in the affected area, Nova Kakhovka, Oleshky and Hola Prystan contain more residential areas without farming, but still consist of mainly smaller buildings.

Figure 32. The photo taken on 10 June 2023, shows a flooded settlement of Oleshky on the southern side of the river. The buildings are smaller and the settlements more rural on the south side of the river (© *KEYSTONE/ AP Photo*)

The disaster waste on the southern side is expected to consist mainly of waste from small residential buildings and from greenhouses. Many buildings will have been fully flooded but it is difficult to estimate the extent to which greenhouses have been damaged. Within the delta, a couple of smaller settlements with small buildings are located on the waterfront by the river and have been heavily affected by the flooding.

3.4.2. Estimated amounts of waste

Estimates of household disaster waste have been carried out after several larger disasters caused by natural hazards during the last 20 years and have resulted in several different calculation models. The produced amounts of waste within this assessment have been modelled using two different approaches where one is based on the number of affected households and the other is based on the number of affected buildings. Given the different operational realities, separate estimates have been made for the north and south sides of the river.

The model primarily used within this report is the Incident Waste Decision Support Tool (I-WASTE DST) developed by the United States Environmental Protection Agency (US EPA) (2023). The model I-WASTE DST was developed based on experience of disaster management in the United States of America. The situation at Kherson has both similarities and differences from this American scenario. The most obvious difference is the ongoing war, so there is a lack of goods and fuel as a result. The citizens are probably more likely to recycle materials damaged by flooding instead of discarding them, such as wood as fuel stored for winter. As a consequence of this the results from the model have been adjusted.

Information about the model is presented in Annex V, and includes the site-specific adjustments made to meet the situation at the Kakhovka dam breach. Calculations are based on 4,377 households on the north side and 12,844 households on the southern side. Background information to these figures is found in Annex V.

Results from the modelling are outlined in Table 2 below. The total amount of waste expected to have been generated by the flood amounts to 1,077,000 m^3.

Table 2. Estimated amounts of disaster waste

	Per household m^3	North side m^3	South side m^3
Total structural building materials (50 per cent of households affected)	33	72,221	211,934
Total non-structural building materials (75 per cent of households affected)	26	85,352	250,467
Total interior (divided as below)	27	116,148	109,178
Furnishing	*9.0*	*39,393*	*115,600*
Items (kitchen and personal)	*8.8*	*38,299*	*112,389*
Electric equipment	*8.5*	*37,205*	*109,178*
Tanks and cylinders	*0.19*	*832*	*2,440*
Asbestos	*0.075*	*328*	*964*
Household chemicals	*0.021*	*92*	*270*
TOTAL AMOUNTS OF WASTE m^3	*112*	*273,720*	*803,242*

Note the USEPA model adjusted after site specific conditions.

The amount of waste has also been calculated by UNDP using another approach based on estimations by KSE (2023) for the assessment of flooded buildings. The UNDP model is based on the number of buildings found within the flooded area and the footprint of these buildings. The amount of waste is then assigned per square metre depending on the degree of flooding.

This model also takes operations into account, as the assessed footprint of buildings doesn't differentiate between the purpose of the building. Results using the UNDP modelling are compiled in the Table 3 below. Using this model, the total amount of waste expected to have been generated by the flood is higher at 2,894,000 m^3.

Table 3. Estimated amounts of disaster waste using UNDP model based on size of potentially flooded buildings

		North side		South side
		Mykolaiv Oblast	Kherson Oblast	Kherson Oblast
Completely flooded	Number of buildings pcs.	208	3,737	7,474
	Footprint of buildings m^2	15,132	353,927	712,413
	Waste produced 1 m^3/m^2	15,132	353,927	712,413
Partially flooded	Number of buildings pcs.	366	2,408	6,245
	Footprint of buildings m^2	27,422	366,353	606,025
	Waste produced 0,5 m^3/m^2	13,711	183,177	303,013
Potentially flooded	Number of buildings pcs.	923	10,529	31,155
	Footprint of buildings m^2	101,732	1,754,513	4,705,002
	Waste produced 0,2 m^3/m^2	20,346	350,902	941,000
TOTAL AMOUNTS OF WASTE / m^3		937,195		1,956,426

There is a significant difference in the results between the two methods of calculation. Both methods have their strengths and their weaknesses, and both include multiple unknown parameters and assumptions. When the predictions are extrapolated over the vast number of affected buildings and settlements the remaining degree of uncertainty is extremely high.

Waste which should be added but is not included in any of the estimations are:

- Public environments, such as material from parks, squares etc.
- Cars
- Boats and marine vessels

Waste which is included but will not be managed is:

- Buildings and household waste washed away with the river into the Black Sea.

The amount of disaster waste is difficult to estimate due to lack of information. The output of the two models applied vary between 1 million m^3 and 2.8 million m^3. The total amount can be estimated at 2 million m^3 as an average of the two models, with the majority of waste generated on the southern side of the river.

This waste amount can be put into perspective:

- If all disaster waste from households is put into one 5-metre-high landfill on either side of the river, this would equal 15 football fields on the northern side, and 40 football fields on the southern side.
- If 20 trucks drive every day of the week to remove disaster waste, it would take one year to transport all the waste from households on the northern side, and three years to transport all the waste on the southern side.

3.4.3. Existing capacities and needs

Solid waste management has been neglected in Ukraine even before the war (International Finance Corporation [IFC] 2015; UNEP 2022). Less than a handful of sanitary landfills exist and most waste has ended up in dumpsites in the outskirts of settlements. There is therefore a low baseline of working safely and in an environmentally sound manner on solid waste management.

The presence of Russian Federation military forces in Kherson between 2 March and 11 November 2022 further reduced the capacity for solid waste management.

Against this background, the existing capacity of managing vast amounts of disaster waste is limited, to say the least. Nothing is known about the capacities or needs on the southern side of the river as this is still under Russian Federation control.

According to a Kherson Oblast official (2023) the existing dumpsites outside Kherson were not affected by the flooding and are still receiving waste. Equipment has been borrowed from neighbouring oblasts, and while staff are capable of handling the immediate situation, it could become unbearable when homeowners reclaim their houses during summer and autumn. They are unlikely to be equipped to manage this waste sustainably, leading to a risk of contamination of nearby land and groundwater.

The rotation of staff within the oblast, due to the war, is a factor as more qualified staff are needed to plan and carry out waste management. Education and continuous support to staff at all levels working on waste management is much needed in order to secure environmental and human health in the long run.

Kherson Oblast has a list of needs which is updated weekly and shared with the humanitarian organisations active in the area, and includes equipment for waste management (see Annex VI). Additional equipment recommended by UNEP has been added in a separate table within the annex. The additional equipment is needed to meet the recommendations of this assessment and would enable an isolation of hazardous wastes, an improved recycling of materials like wood and metals and also ensure optimal landfilling procedures.

The most important needs regarding waste management within the Kherson oblast:

- Equipment according to list in Annex VI
- Support to municipal staff on planning and management of waste
- Rehabilitation of existing dumpsites and planning of new areas for waste management

3.4.4. Strategy and plan for waste management

The Ukrainian government has passed a new law on waste management, effective as of 9 July 2023 (Ukraine, Verkhovna Rada 2023). This is part of several ongoing projects in Ukraine to raise the level of waste management and to approach European legislation and practices. These projects are very ambitious and will not be fully operational for decades. In the meantime, vast amounts of waste will be produced and will need to be managed.

This assessment focuses on the waste produced by the Kakhovka breach, with focus on the downstream areas affected by flooding. It should, however, be noted that the amount of waste generated by the dam breach is very limited when compared to the huge volumes of waste generated by the war. Once the war ends and the reconstruction of the society begins in earnest, it is expected that enormous amounts of construction waste will be generated, creating a need to address the cumulative concern of conflict waste.

It is, therefore, not possible to consider the flooding as an isolated event. The war and the future reconstruction of the country will need to be taken into account while designing waste management strategies in the short term. Environmental and human health will be better protected by robust plans being implemented than by ambitious plans still under development.

3.5. Impacts on ecology

This section reviews the impacts of the breach on protected areas, followed by an assessment of the impacts on wetland and riverine ecology and biodiversity, as well as an outline of the impacts on fisheries, forestry and ecosystem services. Through the review of affected protected areas (section 3.5.1) the scale of the damage on ecosystems and biodiversity (section 3.5.2) can be estimated. Impacts are outlined for both downstream (flooded) and upstream (desiccated) areas. As affected sites were inaccessible due to their location on the front line and/or the fact that they were still inundated and/or due to the presence of UXOs, it was not possible to conduct reconnaissance field inspections nor post-disaster nature inventories and field research to base the analysis of ecosystem impacts on. These field assessments would have been indispensable for preparing a rough assessment of the scale of damage to the ecosystems, habitats and species. Consequently, this part of the assessment intentionally does not include any descriptions of biodiversity values of protected areas concerned, although there is available research and documentation. This report also does not attempt to estimate the possible number of affected habitats and species as these damages need to be thoroughly researched and validated in the future.

3.5.1. Protected areas

This assessment relied on publicly available information on protected areas (PAs). Detailed information on ecosystems, biomes, habitats and plant communities as well as species of flora, fungi and fauna in the affected areas is generally available. This data is gathered in the 'Chronicles of Nature' regularly published by Ukrainian protected area administrations, scientific monographies, as well as in the National Red Data Book of Ukraine and in regionally adopted lists of plant and animal species subject to special protection in particular administrative units (e.g. 'The Red List of Kherson Oblast'). Standard Data Forms (SDFs) related to each Area of Special Conservation Interest (ASCI) include detailed information on the natural values of a particular Emerald Network site, including Resolution No. 4 (1996) listing endangered natural habitats requiring specific conservation measures and Resolution No. 6 (1998) listing the species requiring specific habitat conservation measures and other important species of flora and fauna. Similarly, Ramsar Information Sheets (RISs) available for each Ramsar site always include detailed information on plant and animal species, and ecological communities whose presence relates to the international importance of the particular site (including the occurrence of endemic species, species listed in the Red Data Book of Ukraine, International Union for Conservation of Nature (IUCN) Red List, Appendices to the Bern Convention and CMS, CITES Appendix I) as well as on the ecosystem services provided by a particular Ramsar site.

In addition to this information, satellite imagery was analysed to determine the extent of the damage on PAs located both upstream (desiccation) and downstream (flooding). Last, but not least, the report benefited from analyses conducted for the elaboration of the Scherbak's EIA (2019) for the planned hydroelectric capacity expansion at Kakhovka dam, where all important habitats and species occurring in nearby protected areas were considered.

Affected sites of biodiversity conservation importance

The breach directly affected as many as 59 nationally-designated PAs and areas of different legal protective categories, as well as ten Areas of Special Conservation Interest (Emerald Network sites) established under the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention), five Wetlands of International Importance designated under the Convention on Wetlands of International Importance Especially as Waterfowl Habitat (Ramsar Convention on Wetlands) and one UNESCO-MAB Biosphere Reserve. Some of these areas were either partly or almost entirely destroyed, causing irreversible consequences for their biological diversity, and the loss of the multiple services the biodiversity and ecosystems provided to people. For more detail on the legal framework of PAs in Ukraine, please refer to Annex VII, which outlines the protected area categories included within the Ukrainian legal framework.

Annex VIII lists the nationally and internationally designated and established PAs in the affected region. It should be noted that many sites bear multiple designations, for example, a nationally designated reservation can constitute part of the strictly protected core zone of a national nature park, but also be recognized as a Ramsar site and simultaneously part of an Emerald Network site.

In general, affected protected areas can be broadly divided into four groups, according to their geographical location and main impact/s expected:

1. Protected areas located downstream from the Kakhovka dam — in the river corridors of the Dnipro River and the lower section of Inhulets River. Most of these were directly affected but to a varying extent by the inundation, sediments and potential chemical pollution mobilised by the deluge.
2. Protected areas located downstream — either along the coastline of the Dnipro-Boh estuary, at the Black Sea coast or in the Black Sea marine area, rarely flooded but affected by waterborne pollution, sediments and temporal reduction of the sea water salinity.
3. Protected areas located upstream from the Kakhovka dam — directly affected by the desiccation of the Kakhovka water reservoir and/or the resulting lowering of ground water level in surrounding areas.
4. Protected areas located in the region surrounding the dam — which in the future may be indirectly affected by the desiccation of the main irrigation channels supplying water to their location.

Although no nature reserves of IUCN protected area management category were affected, it should be noted that several strictly protected national nature park core zones and three protected sites were either completely inundated for a long period, or destroyed as a result of the Kakhovka reservoir desiccation.

While the full list of affected protected areas is provided in Annex VIII, some highlights are provided below.

Affected areas downstream

As shown on satellite photos (Figure 33), immediately after the breach the flood wave directly hit and partly washed away the soil, tree stands and all other vegetation on the Kozatsky Island on the Dnipro River, part of the strictly protected core zone of the Lower Dnipro National Nature Park located in Kherson Oblast. This protected area encompasses the whole Dnipro River delta, stretching from the Kakhovka dam to the Dnipro-Boh estuary. According to the administration of this national nature park (NNP), its entire area was inundated.

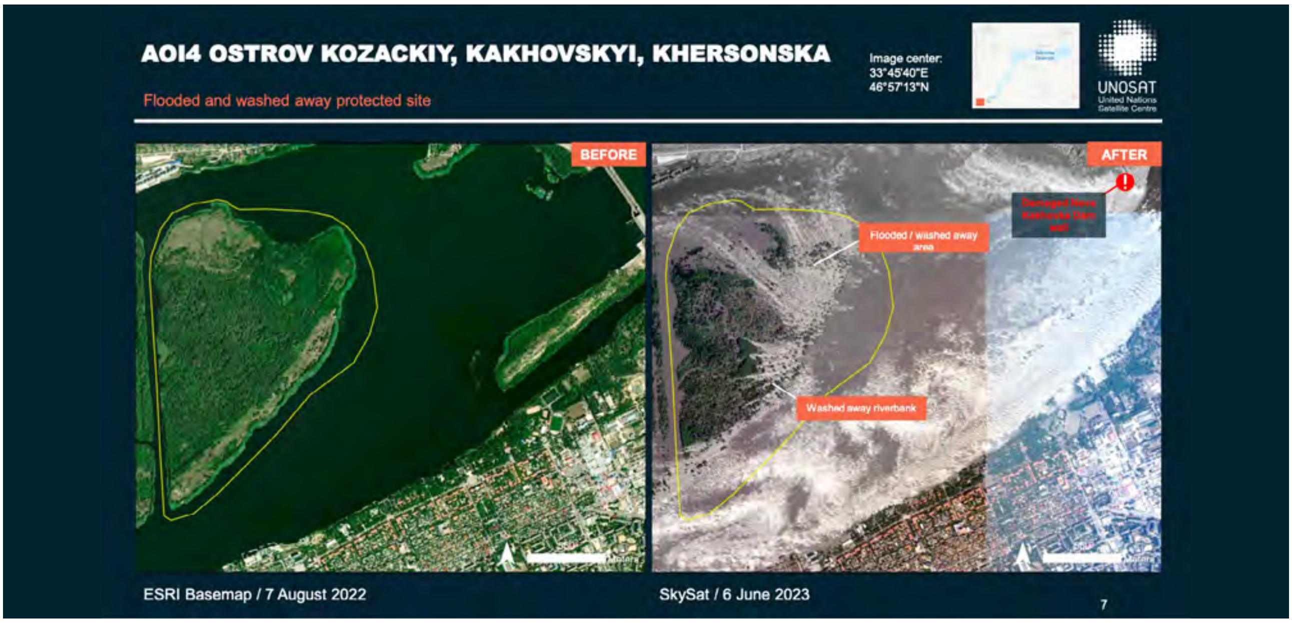

Figure 33: Satellite imagery shows damage to an island, part of the strictly protected core zone of the Lower Dnipro National Nature Park, downstream of the Kakhovka dam (*Source: UNOSAT 2023d*)

The flooding also inundated four other nationally-designated PAs located within the boundaries of the Lower Dnipro NNP, either in the main Dnipro River corridor or in the Dnipro River delta, including Inhuletsky Liman, Bobrove Ozer, Bakai, and Bakai Zholob.

The flooding of the Inhulets River, caused by an inflow of water and blocking of the river's outflow, impacted Lower Inhulets River valley ASCI shared by Kherson Oblast and Mykolaiv Oblast as well as two botanical reservations of local importance. Six natural monuments located along the Dnipro River on its right bank under Ukraine Government control were affected by the flooding.

Several nationally-designated PAs located in Kherson Oblast on the lower left bank of the Dnipro River in areas beyond the control of the Government of Ukraine were inundated for several weeks, including three reservations: Korsunsky, Sagy, and Solyane Lake. Further, nine natural monuments located on the left bank of the Dnipro River were flooded and thus impacted.

Affected PAs on the lower left bank of the Dnipro River, beyond the control of the Government of Ukraine, also include three protected sites of local importance as well as two parks— monuments of horticultural art.

Some sources mention the left-bank Oleshky Sands National Nature Park constituting part of Oleshkivski Pisky ASCI among the inundated PAs. Yet, the impact of the dam breach on this particular site (located well above the Dnipro floodplain) has not been confirmed through satellite imagery or reports, and Ukrainian officials indicate that this PA avoided flooding. Pollution could still possibly affect the lower located outskirts of this park.

PAs located along the coastline of the Dnipro-Boh estuary, at the Black Sea coast or in the Black Sea marine area, are expected to have been primarily affected by waterborne pollution, sediments and temporal reduction of the sea water salinity.

According to official Ukrainian sources, on 15 June 2023 some 2,530 ha of the Kinburn Peninsula (including 1,472 ha inside the Biloberezhzhia Sviatoslava NNP) was still flooded, which also raised the groundwater level, potentially threatening plant communities. Furthermore, in late June 2023 the pollution of waters of the Dnipro-Boh estuary by petrochemical products was detected (and later confirmed by analyses of water samples) (Ukraine, IMB NAS 2023). The extent of contaminated water areas inside this NNP was estimated at some 3,700 ha of the Dnipro-Boh estuary, and a further 14,000 ha of the Black Sea coastal waters.

Another area highly likely affected by pollution, sediments and temporal reduction of the sea water salinity is the vast marine PA, Zernov's *Phyllophora* field designated in the Ukrainian exclusive economic zone in the Black Sea near Odesa Oblast. According to the European Red List of Habitats the unique *Phyllophora* biocenosis occurs solely in this single location in the north-west Black Sea. It was additionally designated as an Emerald Network site, Zernov *Phyllophora* Field Zakaznyk ASCI.

Some sources also mention the Berezanskyi ASCI located in Mykolaiv Oblast, to the north of the mouth of the Dnipro-Boh estuary, as affected by the breach. However, any significant impact of the breach on this particular site is neither likely, nor confirmed by satellite imagery.

Affected areas upstream

Another main group of affected PAs are those located upstream from the dam and directly affected by desiccation (Figure 34) and/or the lowering of ground water levels. The vast majority of these PAs are located either on the southern or the eastern coast of the Kakhovka water reservoir, remaining in areas beyond the control of the Government of Ukraine at the time of this assessment.

Only three 'upstream PAs' were under Ukraine Government control at the time of the event and assessment, the largest of which is the Kamianska Sich National Nature Park. Some terrestrial parts of Kamianska Sich NNP have already been de-mined, which allowed conducting several field inspections (first in November 2022), establishing four biodiversity monitoring plots on the exposed lakebed and collecting samples for further analysis.

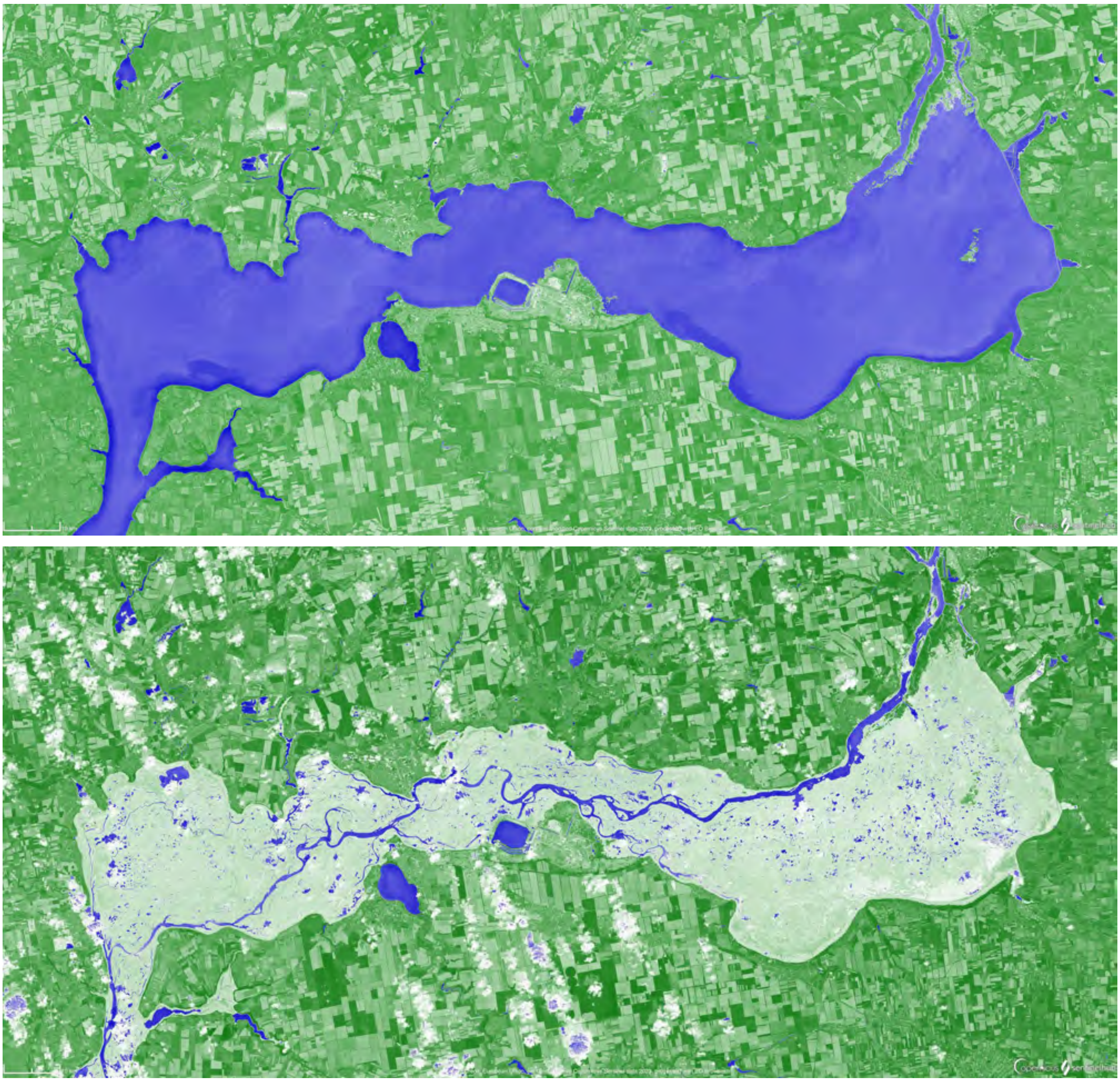

Figure 34: Satellite images show the water level of Kakhovka reservoir before (05 June 2023) and after the dam breach (15 July 2023) (*Source: Sentinel-hub EO-Browser3 2023*)

Like all other important parts of the Dnipro ecological corridor and of the Pan-European Ecological Network, the whole Kakhovka water reservoir, together with several valleys of inflowing streams and adjacent coastline wetland and riparian forest areas, is covered by the two Emerald Network sites: Kakhovske Reservoir ASCI and Velykyi Luh National Nature Park ASCI. Both ASCIs were heavily damaged by desiccation of the former water reservoir. Their aquatic ecosystems and coastal habitats were destroyed with adverse effects on species (such as the lack of feeding grounds or nesting places) expected to worsen in the near future.

The latter ASCI encompasses the nationally-designated Velykyi Luh National Nature Park. Taking into account that the waters of the Kakhovka water reservoir account for 14,898 ha (thus almost 89 per cent of the NNP total area), while the remaining NNP areas include riparian vegetation fully dependent on the water conditions provided by the presence of this extensive water body, it is highly probable that this NNP was entirely damaged by the desiccation of the reservoir. Further, it should be noted that the strictly protected core zone (8,084 ha) of Velykyi Luh NNP includes an archipelago of some 13 small islands in the Kakhovka reservoir, constituting an important nesting and resting sites for waterfowl. This reservation, together with surrounding waters is also designated as a wetland of international importance, Archipelago Velyki and Mali Kuchugury. All these interlinked PAs were equally affected by the Kakhovka dam breach (Figure 35).

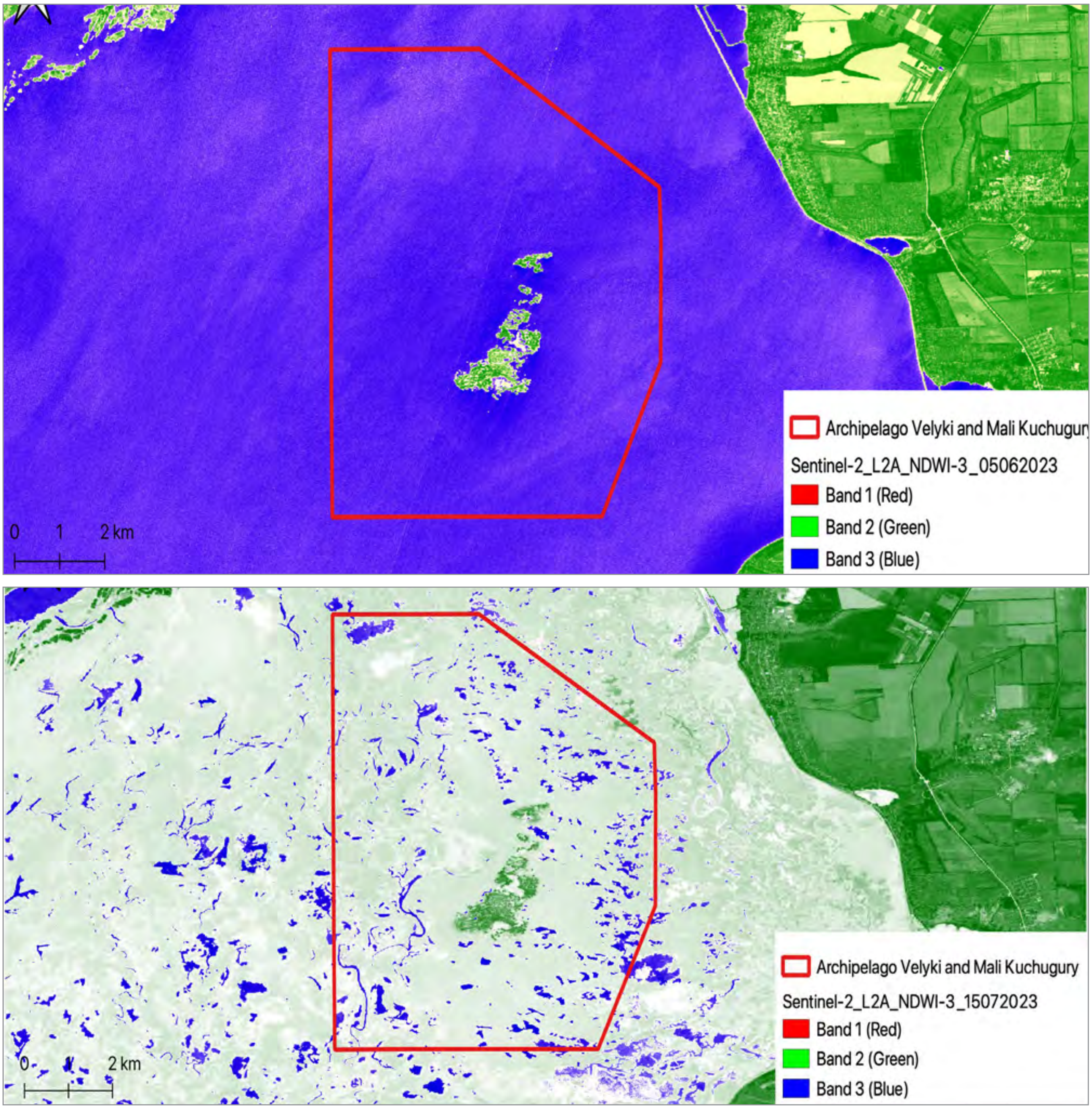

Figure 35. Satellite images show the water level of Kakhovka Reservoir before (05 June 2023) and after the dam breach, showing the area which includes the Ramsar site 'Archipelago Velyki and Mali Kuchugury' (15 July 2023) (*Source: Sentinel-hub EO-Browser3 2023*)

Several other nationally-designated PAs (adjacent to each other or/and partly overlapping) were established at the same section of the Kakhovka water reservoir southern coast, some of which are also included in another wetland of international importance designated in the same section of the reservoir coast, Sim Maiakiv Floodplain.

Further to the west, two other nationally-designated PAs surround the city of Enerhodar and the ZNPP, Ivanivsky Bir and Vodyanski Kuchuhury.

The other group of PAs located upstream of the dam and likely to be affected by changed conditions in the coming months, are those located in the larger surrounding region whose vegetation depends on water provided by irrigation channels, previously supplied by the Kakhovka reservoir. The desertification of larger areas due to the lack of water, e.g. the North Crimean Canal, and the lowering of the groundwater level is highly likely to threaten not only the agricultural production in the region, but also its PAs, regardless of their distance from the Kakhovka dam. A photo showing the decrease in water levels is provided in Figure 36.

Figure 36. Water levels decreasing at Kamianska Sich National Nature Park immediately after the dam breach (© *Serhii Skoryk*)

An illustrative example of such an indirectly threatened area, and probably the most suitable for future monitoring of threats to biological diversity, is one of the most prominent PAs in Ukraine, Biosphere Reserve Askania, established in 1898. This site is also designated as a UNESCO-MAB Biosphere Reserve and an Emerald Network site. This PA is at the time of writing located in an area beyond the control of the Ukrainian Government.

Affected prospective PAs

The effects of the breach on planned but not yet formally designated PAs should also be considered.

According to the Ukrainian Nature Conservation Group (a non-governmental organisation), as many as 22 prospective nationally-designated PAs were affected in result of the Kakhovka dam breach. The full list is included in Annex VIII.

Despite no detailed information on these prospective PAs having been made available for the purposes of this report, it is highly likely that at least in some cases the natural values determining their expected designation as PAs were seriously affected as a result of the Kakhovka dam breach.

It should be noted that none of the 162 proposed potential Emerald Network sites were directly impacted as a result of the dam breach. The proposed Bazavluk site adjacent to Kakhovske Reservoir ASCI from the north, stretches in the river basins of the Right-bank Steppe Podniprov’ya, which feed the Kakhovka reservoir with water, hence is unlikely to be threatened by the desiccation of the reservoir. The potential impact on two other, much smaller proposed sites (i.e. Garbuzy depression and Ozerianskyi steppe) located in the surrounding region to the south from the reservoir, possibly dependent on water previously supplied by the network of irrigation channels, is yet to be determined.

3.5.2. Impacts on wetland and riverine ecology and biodiversity

The scale and intensity of potential environmental impacts cannot be properly estimated before more thorough studies and assessments in the field are undertaken. Similarly, at this preliminary stage, it cannot easily be determined which of the damages are irreversible, and which can possibly be at least partly mitigated through future remediation activities.

It should be noted, that although the natural habitats (in particular aquatic, riverine and riparian) together with their plant communities and wildlife species generally are well adapted to both dry and wet seasons, including spring flooding, the breach took place during a particularly 'naturally sensitive' season of the year. Vegetation was undergoing intensive growth, and many fish species were spawning, while other animal species (including waterfowl, amphibians and small mammals) were breeding.

Downstream effects

The breach had a catastrophic effect on the ecosystems of many downstream areas, causing rapid habitat destruction and mass die-off of numerous wildlife (plant, fungi and animal) species. While it was a massive disaster, it was a short-term event, lasting only several weeks, after which the water level stabilised, allowing a slow but constant regeneration of the damaged areas, even prior to any human intervention. Some of the damages are highly likely to be irreversible. But, even if not all-important habitats, plant communities and threatened species survived, the combined forces of nature and humans could, at least partly, remediate some of the disaster effects. It should also be noted that this was an environment modified by humans e.g. any restoration and remediation could be an opportunity to restore the Dnipro River system closer to its natural state.

A tentative (but not exhaustive) list of the main impacts specific for downstream areas is as follows:

- The high-velocity water washed away the soil, vegetation and specimens of aquatic and terrestrial species, causing them to drown or be dragged downstream and potentially perish due to changed environmental conditions. Evidence gathered after the breach includes well-documented cases of animals deployed as far as into the Black Sea, where the higher salinity of waters was lethal for the specimens of freshwater species (Figure 37).
- Long-term inundation of habitats can affect even those habitats comparably well-adapted to flooding over short periods, like wetland, coastal and riparian habitats (Figure 38). This includes losses in plant communities and animal species, for instance due to loss of their breeding/nesting and/or feeding grounds.
- Deposition of debris and sediments mobilised by the flood in the river corridor or delta may alter the terrain morphology and the spatial configuration of habitat patches, including submerged habitats (important for aquatic species) and habitats protruding from the water (important for semi-aquatic and terrestrial species).
- Habitats and their species may also be affected by biological and chemical contamination, including oil, nutrients as well as by military waste including UXOs, the effects of which have been described earlier in the report.

Figure 37: Around 150 rare newts are reported dead following the Kakhovka dam breach (*Source: Ukraine, MEPNR 2023*)

Figure 38. Satellite imageries from 5 and 6 June 2023 shows the extent of flood in the riverine area at Korsunka town (*Source: Sadler 2023; © 2023 Planet Labs PBC*)

Upstream effects

The scale of the catastrophic effects of the breach on the ecosystems of almost all upstream areas, with the possible exception of those in the larger surrounding region, is incomparably higher than downstream. Upstream, the desiccation of the emptied Kakhovka reservoir resulted in a rapid transformation of its mature and fully functioning aquatic ecosystem (that gradually evolved over almost 70 years) into a riverine type of ecosystem in the early initial stage of development. This new riverine ecosystem consists of a narrow main watercourse, currently without concurrent riparian vegetation, and several remaining disconnected shallow ponds surrounded by the dried-up barren muddy lakebed, on the vast area of 2,155 km^2. The intensity and pace of ecosystem transformation processes triggered by the rapid desiccation of the Kakhovka reservoir within just a few weeks was such that it cannot be compared to other slow-onset drying out of lakes. The radically changed water conditions have already now caused long-term consequences, where effects will only aggravate over the time. The coming dry summer months will add to the losses already incurred by the environment of this part of the region concerned, and impact habitats over the next few years. A tentative (but not exhaustive) list of the main impacts specific for upstream areas is as follows:

- Water run-off and desiccation of the Kakhovka reservoir, resulting in the rapid emersion of its littoral and benthic habitats, which is highly likely to have caused the immediate mass die-off of their stranded aquatic plant and animal species (including numerous fish species).
- Lowering of the water level (both of the reservoir and of groundwaters) resulting in the destruction or considerable (and constantly aggravating) degradation of wetland, coastal and riparian habitats, constituting important habitats for rare flora and fauna species, leading to the destruction of plant communities and species and mass die-off of semi-aquatic and terrestrial animal species, in particular waterfowl.
- Desiccation of vast areas of the exposed lakebed of the Kakhovka reservoir, which can enhance its colonisation by pioneer vegetation, including invasive species.
- Increased levels of chemical pollution and biological contamination of water in the new Dnipro River watercourse that remained on the desiccated bottom of the Kakhovka reservoir, resulting from the much lower water purification capacity of the recently emerged narrow watercourse compared to the immense capacity of the former Kakhovka reservoir.
- Biological contamination of water in disconnected shallow ponds remaining on the exposed bottom of the Kakhovka reservoir by toxins released by algal blooms.
- Lowering of the water level in the Kakhovka reservoir resulting in the disconnection of the network of several main irrigation channels (including the North Crimean Canal) resulting in impacts on habitats surrounding the reservoir.
- Lowering of the water level in the Kakhovka reservoir resulting in the enhanced ecological connectivity of previously secure isolated island habitats This impact is specific for the northernmost part of the reservoir where a long archipelago previously stretched out (south from the city of Zaporizhzhia and Khortytsia Island, and its geological reservation Dniprovski Porogi), as well as for the Velyki and Mali Kuchuhury archipelago and small islands close to the Ivanivsky Bir reservation near Enerhodar. Due to the rapidly decreasing water level these previously isolated habitats are now accessible from the mainland, so that e.g. small predatory mammals can easily reach bird nesting sites.

International impacts

As a result of the breach, a 240 km long section (the length of the Kakhovka reservoir) of the 'Dnipro Natural Longitudinal Corridor' has become much less permeable for a significant number of species. This ecological corridor constituted an important part of the Pan-European Ecological Network and the largest meridional eco-corridor in Ukraine, running southward from the state border with Belarus, mainly along the Dnipro River valley (as one of the three main migration routes for birds) linking the transboundary Polesie region (shared by Belarus, Poland, the Russian Federation and Ukraine) with the Black Sea coast. Due to its natural values, and its pan-European and transboundary importance, the 981 km long Ukrainian section of the Dnipro ecological corridor is almost entirely covered by several Emerald Network sites. With the desiccation of the reservoir, the ecological connectivity along the Dnipro ecological corridor is now seriously threatened (Ukraine, MEPNR 2022; Emerald Network 2023).

Future outlook

De-mining activities are expected to be particularly challenging on the left bank of the Dnipro River and the southern coast of the Dnipro-Boh estuary and it is likely that PA demining will be undertaken last, after the clean-up and de-mining of infrastructure objects, residential or commercially used areas. It could thus take months or years before more accurate data concerning PAs is available.

The downstream part of the affected region is expected to slowly recover. As soon as the affected areas become accessible, the thorough planning and implementation of remediation works and ecosystem restoration measures will be possible. Provided adequate funding is mobilised, this can substantially enhance the recovery of the biological and landscape diversity. The number of possible different scenarios for the downstream areas seems to be quite limited, mostly depending on whether and when the Kakhovka dam will be reconstructed. As long as the Dnipro River flow remains non-regulated, both the natural recovery processes and implemented restoration works would need to cope with the seasonally fluctuating water level in the river channel and its extensive river delta.

The number of possible scenarios for the upstream part of the affected region depend on the scale and pace of ongoing large-scale ecosystem alterations and are yet to be carefully monitored and assessed. A resolution on a pilot project to rebuild the dam was adopted by the Government of Ukraine on 18 July 2023. The project is estimated to last for two years and is to be initiated as soon as possible (Ukraine, Cabinet of Ministers 2023).

Under an estimated 'Upstream scenario No 1' it is envisaged that, as long as the ongoing reservoir desiccation process continues, the coastal and riparian vegetation at the former coastline will vanish. This will have adverse consequences for the provision of its important filtering ecosystem service, while some new riverine and semi-wetland ecosystems will gradually evolve on its exposed lakebed, colonised by pioneer vegetation, including some riparian vegetation belts or patches along the current narrow Dnipro River watercourse/s and around the bigger shallow ponds that can retain enough water for a longer period. These processes are likely to be dynamic and subject to periodic fluctuations in the river flow. However, if the desiccation processes intensify (e.g. as a result of the globally ongoing climate changes, or due to unfavourably dry weather conditions, e.g. low precipitation and thin snow cover), desertification processes can modify this scenario. Either way, should the reservoir desiccation process continue, the natural values of all nearby protected areas will be threatened considerably.

'Upstream scenario No 2' envisions that the Kakhovka dam is either provisionally repaired or fully reconstructed within the first few years after the breach, and that some of the coastal ecosystems survive (although in a much worse state than prior to the disaster) until the Kakhovka reservoir is again gradually filled with water. This may allow the water levels to stabilise, preventing full colonisation of the lakebed, for example by invasive species, and allow remediation works and ecosystem restoration measures to be implemented. This could support the continued provision of ecosystem services, which is important also for the larger surrounding region and foster the maintenance of some remaining natural values of the existing protected areas in the 'upstream part' of the concerned region. However, it should be noted that during and soon after the refilling of the reservoir, the previously accumulated sediments (some of them polluted or contaminated) and algae bloom toxins would be gradually released to the rising waters of the restored Kakhovka reservoir.

'Upstream scenario No 3' has been advocated for by some scientists and environmental non-governmental organisations (NGOs) in Ukraine, which proposes the Kakhovka reservoir should not necessarily be restored to its previous size. In this scenario, the narrow Dnipro River watercourse would be left for shaping by natural processes where it is believed that the re-naturalization of some parts of the remaining exposed lakebed could be more beneficial than inundating the entire reservoir area. However, it is unlikely that this scenario would be seriously considered, taking into account the importance of the Kakhovka reservoir for agriculture in the larger surrounding region, and its function as a source of hydro energy and drinking water. Moreover, should the capacity of the reservoir be reduced and its water level lowered, neither the spontaneous regeneration of the natural values of nor any ecosystem restoration works in all affected (and later desertificated) upstream PAs will be feasible.

To conclude, many of the damage to ecosystems and biodiversity in and around the Kakhovka reservoir are highly likely to be irreversible. At the same time, one must recall that most of the recently destroyed aquatic and coastal habitats of the Kakhovka reservoir did not exist before 1955, and gradually evolved throughout the last 68 years. Hence, at least some badly damaged habitats can probably be restored by nature within e.g. 30 to 40 years, alternatively new types of habitats created.

3.5.3. Fisheries

The dam breach has been catastrophic for marine life and national authorities report that tens of thousands of kilograms of fish have been affected, including commercial species, with the majority affected by the desiccation of the Kakhovka reservoir (Figure 39). The Ukrainian Government has confirmed the loss of 11,388 tons of fish (Ukraine, Ministry of Agrarian Policy and Food 2023b). As the breach occurred during the spawning season, fisheries have been impacted for coming seasons.

Figure 39. Dead fish are seen on the drained bottom of the Kakhovka reservoir (*© KEYSTONE/AP Photo/ Mstyslav Chernov*)

Specialists of the State Ecological Inspectorate from the Zaporizhzhia and Kherson regions collected samples of surface water for analysis of pollutants in the Dnipro River at several locations. The results of these studies found that the concentration of several compounds exceeded permissible levels for the continued operation of fisheries. Dissolved oxygen, organic substances, suspended solids, iron and sulphates were each found to exceed the maximum permissible concentrations several times over in different locations. As of 25 June 2023, despite the elevated pollution, there have been no reports of suffocated bioresources (Ukraine Government 2023).

3.5.4. Forestry

As per spatial analysis conducted by FAO utilising satellite imagery provided by ICEYE Oy, a significant 11,294 hectares of forested area experienced flooding as of 7 June 2023. The type of forest is mostly pine where young trees are more vulnerable. It is crucial to note that considering the maximum flood extent occurred after the date of the satellite imagery, the total flooded forest area could potentially be greater. Experts believe that the total flooded area should be considered fully lost, due to the extended inundation period.

In addition, the affected oblasts experienced an escalation in water stress compared with previous years, despite the absence of a significant rainfall anomaly (FAO 2023). This phenomenon is believed to be associated with the desiccation of the Kakhovka reservoir, raising concerns about potential impacts on forest health and ecosystem stability in the coming future.

The Government considers it likely that 17 tree nurseries have been destroyed (Ukraine Government 2023). To better understand the scale and extent of damage to forested areas by the Kakhovka dam breach, in-depth and on-the-ground assessments are required.

3.5.5. Ecosystem services

Almost all ecosystem services have been impacted throughout the whole affected region, e.g. not only in affected protected areas. For example, the vast area of the desiccated Kakhovka reservoir can no longer ensure rendering a number of important provisioning ecosystem services (e.g. water supply, provision of hydro energy for the industry and households, but also of biomass, including freshwater plants and fish for human and animal nutrition) as well as regulating ecosystem services (including climate, air quality and water quality regulation, flood control, water purification and waste treatment and sediment retention).

For obvious reasons, all affected PAs can no longer guarantee the same level of provision of supporting and habitat ecosystem services (such as nutrient cycling, habitat maintenance and gene pool protection) of fundamental importance for safeguarding their formerly rich biodiversity. Last, but not least, affected PAs (only temporarily inaccessible) will no longer provide the same level of cultural ecosystem services (e.g. recreation and ecotourism opportunities, aesthetic values, scientific and education values, inspiration for culture and art). Figure 40 shows local residents fishing in an area affected by flooding on 9 June, highlighting the importance of the area’s ecosystems for local livelihoods.

Figure 40. Residents fishing in Chornobaivka, Kherson region on 9 June in an area affected by flooding (*© Keystone/AFP Photo/Aleksey Filippov*)

However, it is obvious that damages to the directly affected natural ecosystems will in turn affect the state of all ecosystems in a larger surrounding region, impairing their ability to provide numerous ecosystem services specific for these indirectly affected parts of the region concerned. For example, the likely desertification of vast areas previously supplied with water by the network of irrigation channels, fed by the Kakhovka reservoir, can largely impact provisioning ecosystem services particularly important for ensuring the continuity of agricultural practices and food production (such as erosion prevention, soil fertility maintenance and support of pest and disease control).

Based on initial estimations using global unitary values, ecosystem services provided by only 333,000 ha of impacted protected areas (five sites listed under the Ramsar Convention and seven sites listed under the Emerald Network) is estimated at USD 8.5 Billion (in 2023 Constant US Dollars) (Davidson *et al.* 2019). The scale of impact of the Kakhovka dam breach on the capacity of the concerned region to continue providing particular ecosystem services is yet to be thoroughly studied and assessed.

04

Recommendations

4. Recommendations

It is recognized that the situation in the affected area is changing rapidly given its location on the frontline of the war, and the implementation of any recommendations will be challenging. It should be noted that the recommendations below are based on a remote assessment with acknowledgment of current information gaps. This section outlines the recommendations related to various thematics and activities, followed by an overview of key actors relevant for follow-up actions.

It is recommended that working groups on the areas described below be established and start detailing the specific activities to be taken to address the impacts of the breach in various domains. The composition of these working groups will depend on the topic but it is recommended that they include local and national stakeholders, composed of government and local authorities, scientific entities as well as civil society organizations. External technical and financial support is essential for the planning and implementation of remediation and restoration actions where the recommendations of the working groups can guide fundraising efforts. The below described recommendations can form a base for working groups' discussions on activities to be undertaken.

4.1. Hydrology

It is recommended to implement the following:

- Install new stream gauges within and downstream of the Kakhovka reservoir, to monitor water-surface elevation (stage) and river discharge above or near the Kakhovka dam and also downstream at the city of Kherson. Monitoring of flows is important to better understand the conditions the downstream ecosystem is experiencing in the aftermath of this major flood. This could be done in conjunction with monitoring for turbidity and water quality, if equipment to monitor those parameters is installed at the same locations as stream gauges.
- Using data from any remaining existing and the recommended/new stream gauges, determine new exceedance probability curves downstream (that is, peak-flow statistics) of the Dnipro dam to assess the changes in flood probability caused by the dam destruction.
- To use numerical modelling to establish the new regime of water levels and water flow in the new river section of the former reservoir, which can guide the decision-making on potential dam adjustments upstream and possible reconstruction of the Kakhovka dam.
- Assess the possibility of changing the operational rules of all dams in the cascade to fully make use of their potential in accommodating the former flood reduction functionalities of the Kakhovka dam.

The foreseen update of the Dnipro River basin management plan presents an opportunity to take new realities and recommendations into account and to serve as a recovery instrument for overcoming the consequences of the Kakhovka Dam breach.

4.2. Erosion

Erosion processes directly downstream of the Dnipro dam can be managed through:

- Ramping: operating turbines and gates in a way which releases water more slowly or, preferably, by abandoning hydropeaking
- Creating a regulation pond directly downstream of the dam, which consists of a small impoundment with sufficient storage to dampen the rapid fluctuations from hydropeaking
- Diverting extra water into the floodplain for example, through an existing channel on the left bank, using control structures

- Stabilising river banks
- Controlling weirs and river training (e.g. by widening eroding sections)

It should be noted that while the above may carry environmental benefits, these mitigation measures may have auxiliary negative consequences. For example, ramping will affect the hydroelectric efficiency of the Dnipro dam, and creating a regulation pond would require a high investment in an auxiliary dam. Any measures should therefore be carefully weighed against potentials for negative effects.

4.3. Chemicals and sediments

Assessment

The environmental impacts relating to pollution hazards are to be further investigated and the hotspot sites should be prioritised for on-site assessments. Identifying zones of accumulation for contaminants will aid in post-disaster clean-up efforts. Detailed assessment, including sampling and analysis, of high-risk areas is required.

As surface water is already monitored by government entities, the primary gap identified in terms of contamination by the assessment team is soil sediment contamination and chemical releases (with surface water contamination possible in places without outlets and groundwater contamination possible in places with significant contamination). Consequently, in order to support actors and authorities willing to undertake soil sampling, a soil sampling proposal for the flooded area downstream of the dam was drafted in parallel to writing the environmental impact assessment. This programme proposal was delivered to the MEPNR at the beginning of July 2023 to inform a targeted approach and to support first measures to be taken; this document is available in Annex IX. It was later complemented by suggestions of chemical parameters to analyse and locations where sampling should take place.

Overall, the assessment within this report and the sampling programme should support a remediation programme, with a clear focus on major threats and a sound prioritisation of action. For agricultural areas, this would include, inter alia, conducting an agrochemical survey of agricultural and horticultural land that was flooded and perhaps contaminated, with a focus on food safety. The monitoring of surface water quality should continue. UNDP, through its EU4EMBLAS project is analysing twelve water samples including two sea water samples, one ground water sample and nine freshwater samples as well as eight samples of sediment, for the content of a wide range of organic pollutants. This round of monitoring will not include biological monitoring and or chemicals pollutants in biota samples, as bioaccumulation takes time. However, it is recommended that at least two rounds of sampling and analysis, including biological monitoring and biota sampling, is conducted as a follow-up action.

Delivery of equipment in need

A required short-term action includes delivery of equipment needed to support the work of the responsible agencies for soil and water contamination, including, but not limited to, the State Environmental Directorate and Water Resources Agency.

To date, Ukrainian authorities have expressed need for:

- Mobile laboratories
- Laboratory equipment (spectrometers, analysers and portable refrigerators)
- Test kits for determination of pollutants
- Reagents for laboratory analysis

Containment of sediments

To avoid the mobilisation of contaminants from the now dried-up reservoir bed it would be advisable to protect and stabilise the soil (muddy or sandy sediments) through fast growing, possibly not invasive vegetation, where Ukrainian authorities have suggested to sow alfalfa, clover, oatmeal, wheatgrass and other species. Sowing of grass species, tolerant to the harsh condition, would be advisable, and plants adapted to floodplains and floodplain soils, such as reeds or bulrushes. The root system will help to avoid run off after heavy rainfall and far-reaching distribution through wind erosion. Furthermore, it will help to build up a more stable soil structure tolerant to higher levels of mechanical stress and supporting site accessibility. Tree species with deep root systems should be selected for restoration of protective shelter belts to reduce the risk of wind erosion. Innovative practices and technologies, like water reuse from the municipal wastewater treatment plants for irrigation should be explored (Weir 2023).

As long the level and the variety of contamination within the empty reservoir is unknown there should be no, or only limited, use of the site for food production. Wherever feasible, focus should be on planting energy and industrial crops such as fibre crops, in the contaminated areas. Another option to prevent release of pollutants from the now exposed sediments could be building a temporary overlay of decent height (some metres) to stabilise the dam at the location of the breach, thereby retaining a certain level of reservoir water. By ensuring a minimum percentage of the reservoir is covered with water would protect it from drying out and minimize wind erosion.

Concerns have been raised regarding the potential contamination of mud left behind after the flood water receded. Caution should be exercised when cleaning up flood-affected areas, where environment and health sectors can provide advice on the clean-up process and any short- and long-term risks to health from flood contaminants.

Remediation

Wherever possible, remediation measures should be considered to reduce the number of contamination hotspots. The extent to which this is feasible would depend on the number of contaminated sites, their location (close to residential areas or not) as well as their future use (residential, industrial and waste sites). Remediation would be conducted through excavation and appropriate treatment and disposal of waste. As an alternative, the mobility of contaminants can be limited, e.g. through amendments with active carbon. Phytoremediation would be another option to clean up certain types of soil contamination in a controlled and soil conserving manner.

Active biomonitoring

Analyses of contaminant uptake by representatives of forage and food crops (bioindicators at the beginning of the food chain to animals and humans) can serve as active biomonitoring of contaminant transport and environmental risks. Pollutants such as dioxins and furans, polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) are deposited on the leaves; lipophilic substances (substances soluble in fat) accumulate in the wax layer of the leaf surface. The typical contamination path is via the air in gaseous form or bound to dust particles. For example, grass cultures are also suitable for monitoring metals, in addition to the investigation of organic pollutants. Besides air transport, active biomonitoring can also be applied to monitor the availability of soil contaminants.

4.4. Military waste

The contamination of affected territories by military waste, notably mines, is extremely challenging and hindering the work in other areas. It is critical to continue with ongoing de-mining efforts. While experience exists in how to manage landmines, e.g. from the former Yugoslavian war, these operations are lengthy and costly. The presence of landmines makes it impossible to take samples or conduct assessments before clearance by local demining teams or organisations. It can be assumed that even the clean-up of known minefields will take more than 10 years and incur huge costs (Military Feodal 2023; Osmolovska 2023). It is estimated that the demining of Ukraine would take decades and cost more than USD 37 billion (UN News 2023). It could be expected that some areas (e.g. along the tourist trails in Lower Dnipro park) would probably be demined manually as this is a more accurate method using traditional mine detection using metal detectors and prodders. Most likely, some areas will probably remain inaccessible for decades.

Military waste should be appropriately accounted for, isolated, collected and managed, where the collection and re-use especially of metals, e.g. from armoured vehicles, is possible (Marchenko *et al.* 2022). The recommendations provided in section 4.5 on disaster waste also, to a large degree, apply to military waste.

4.5. Disaster waste management

Commercial waste from companies and operations has been impossible to determine during this assessment. This is a large gap in information and an assessment needs to be done by local staff. The main recommendation to officials in charge of waste management is to develop a structured waste management strategy.

The recommendation to international stakeholders is to allocate equipment for waste management to Kherson Oblast as soon as possible, which should cover both collection and sorting of waste. Equipment needs to be complemented by technical expertise on sustainable and efficient waste management

The following actions are recommended:

- Inform the concerned population, including both women and men, of how to handle their waste: The better the waste is handled early on the chain of collection, the easier it is to manage. Informational campaigns to homeowners are important, and the information should emphasise management of hazardous waste.
- Map operations and companies able to manage commercial waste due to the flooding: This mapping needs to be done by local staff within existing waste management structures where companies responsible for waste management should be informed, supported and coordinated with.
- Arrange curb side collection of the following wastes:
  - Electronic waste
  - Chemicals and hazardous substances
  - Asbestos
- Hire contractors to manage collection and recycling of hazardous wastes: Ensuring hazardous waste is handled separately and by trained staff will reduce negative effects on human health and the environment.
- Arrange temporary storage areas for waste: Final deposit of the different types of waste will take time to organise. In the meantime, the waste needs to be stored in a serviceable site where it also is possible to manage by sorting and crushing/shredding. Hazardous waste needs to be stored safe from weather conditions.
- Establish strategy for sustainable management of non-hazardous waste: Such a long-term strategy is to be outlined and implemented by the oblast and cover waste management in the short- and midterm.
- Conduct an inventory of companies and operations producing waste: More work to accurately determine the amounts and types of disaster waste from operations should be undertaken, where municipalities can provide support to the companies on how to manage their waste in a sustainable way.
- Rehabilitate existing dump sites and create new engineered landfills: An unknown number of dumpsites have been damaged by flooding. These need to be investigated and rehabilitated. Most of the disaster waste should be deposited in new, engineered landfills.

- **Plan for on-site destruction of persistent chemical waste and pharmaceuticals:** Historical storage sites of pesticide waste are located near Kherson and pesticides may have leaked into soil either as a result of the flooding or due to earlier mismanagement of legacy contaminants. A mobile thermal destruction plant should be placed in the vicinity of Kherson once the war ends with the purpose of remediation of soil and destruction of chemical waste and pharmaceuticals.

4.6. Mitigation of ecological impacts

Effective biological and landscape diversity conservation requires committed staff and adequate funding as well as the implementation of several actions. First, baseline data on species and habitats should be acquired, gathered and compiled. This data should then be analysed to assess their current status and identify the main threats to their preservation or recovery. This would allow prioritization of interventions in light of available operational capacities and financial resources. Action plans and programmes could then be elaborated and adopted, leading to the implementation of conservation or ecosystem restoration measures. Implementation phase should be coupled with regular monitoring of the effectiveness of the actions, followed by adjustment of action plans and programmes. The adoption of an ecosystem restoration action plan must be coupled with mobilization of adequate funding for their implementation.

In the case of the Kakhovka breach, the collection of data is especially complicated, given the inaccessibility of the affected areas and it could be months or even years before accurate data concerning protected areas is available.

Additionally, it should be noted that the thorough elaboration of remediation or restoration plans will take time, during which some of the adverse effects on 'upstream areas' are expected to aggravate. Thus, it is highly likely that the overall picture will change during the planning phase. Any remediation works should therefore be adaptive to changing situations on the ground.

Outlined below are recommendations concerning ecosystem restoration and biodiversity recovery.

Short term:

- Establish national working groups or task forces, involving relevant experts[4] to initiate desk studies on particular groups of natural habitats and species. They will need effective communication means, administrative staff support and adequate working conditions such as the formal allocation of work hours.
- Retrieve all available data on ecosystems, habitats and species of the affected region, in particular those occurring in protected areas from accessible public databases and archives[5], and store in a single database to be made accessible for the members of the above groups.
- Gather and store on a single database all available data on the environmental impacts of the Kakhovka dam breach, including data deriving from remote sensing/satellite imagery.
- Facilitate communication and coordination between different working groups/thematic task forces.
- Where necessary, ensure capacity building for working groups / thematic task force and their supporting staff.
- Establish, where necessary, cooperation with relevant foreign state agencies, scientific and research institutions and individual experts.

4. For example, representing regional departments of ecology and natural resources, scientific and research institutions, relevant faculties of academic institutions, members of protected area Scientific and Technical Councils, protected area administrations and State Forestry units, as appropriate
5. Including data available in 'Chronicles of Nature' published by protected area administrations, scientific monographies, the National Red Data Book of Ukraine, the Green Book of Ukraine and regional Red Lists of species subject to special protection in particular administrative regions (Standard Data Forms and Ramsar Information Sheets can also be used for comparisons and harmonisation of data).

Short to medium term

- Prior to undertaking any actions in the field, conclude waste and sediment removal and mine clearance works, allowing access to affected areas.
- Conduct further remote sensing/monitoring of the territory with the objective to assess the conditions (e.g. current state of inundation or desiccation) in affected areas, and conduct areas with varying degrees of transformation and damage for further long-term monitoring.

Medium term

- Restore damaged or destroyed biodiversity research infrastructure and office buildings in protected areas, including those belonging to scientific and research institutions, and supply with necessary equipment.
- As soon as the security conditions allow, undertake inspections, field inventories and assessments in all affected protected areas (ideally in spring 2024), with a special focus on red-listed species.
- Enter data derived from inspections, field inventories and assessments in affected protected areas into the single database on habitats and species, and make data accessible for the members of the national working groups/thematic task forces.
- Based on available data, agree upon the most urgent conservation and restoration priorities, and share information with other working groups/thematic task forces.
- Based on available data, prepare programs or action plans determining recommended measures for the restoration of damaged natural habitats and plant communities, for the preservation, reproduction (if necessary also re-introduction) of plant and animal species affected by the dam breach. In particular, redlisted species as most threatened by extinction and other important species (not included in any of the applicable Red Lists, but listed in Appendices I and II of the Bern Convention and in Bern Convention Resolution No. 6 (1998) listing the species requiring specific habitat conservation measures and Appendices I and II to CMS), and identify potential source populations for the re-introduction of affected species. The plans should also cover measures for the prevention of alien invasive species colonisation.
- Relevant groups should submit, as appropriate, species recovery and habitat restoration action plans for the adoption of the relevant nature conservation authorities.
- Relevant groups should propose adjustments, modifications and/or revisions of PA management plans, including necessary changes in their functional zonation to allow active ecosystem restoration measures, but leaving some parts (e.g. those with high potential for regeneration) to natural regeneration to be able to compare effects of both approaches (active and passive), limit interventions and decrease overall costs.

Long term

- Implement adopted remediation actions and restoration measures.
- Monitor and assess the effectiveness of the applied remediation actions and restoration measures.
- Regularly monitor the transformations of the riparian vegetation belt along the former Kakhovka reservoir coastline.
- Adjust and revise adopted action plans and programmes, according to the changing situation on the ground.

4.7. Monitoring

The environmental monitoring infrastructure of Ukraine is of critical importance when it comes to monitoring the impacts of the war. Systematic monitoring of different environmental areas is essential, where the information-exchange between different authorities should be supported, and the data should (where feasible) be made publicly available. The need for coordination on assessments has been highlighted before, including at the 2022 Environment for Europe Ministerial Conference held in Nicosia, Cyprus organised by the United

Nations Economic Commission for Europe (UNECE), UNEP and Organization for Economic Co-operation and Development (OECD). The Nicosia conference affirmed the need to assess the environmental consequences of the war in Ukraine for both the country and the surrounding region (UNECE 2022). The following parameters are of importance:

- Hydrology (water levels and water discharge on new locations within the empty reservoir, and water turbidity)
  - It is advised to include multiple stream-gauging stations on the newly created river in the former Kakhovka reservoir to monitor water level (stage) and discharge
- Hydrography and digital elevation data (topography of river channels and floodplains)
- Biology (hydrobiology, vegetation cover and fauna)
- Contaminants, expanding on existing programmes
- Erosion: to be monitored downstream of the Dnipro dam to be able to take action if hydropeaking causes hazardous erosion
- Ecosystems and biodiversity, as part of existing monitoring and PA activities

4.8. Coordination on assessments and remediation action

Multiple efforts are ongoing to assess the environmental dimensions of the war. Throughout the Kakhovka breach environmental assessment, it became evident that there is a lack of coordination between various actors and ongoing activities. For instance, where several actors are conducting sampling and analysis, but for different purposes and using different methodologies and approaches. It is important to ensure adequate coordination between actors, to reduce duplication of efforts and ensure that resources are directed to key gaps. The sharing of information and data between actors should be encouraged, while noting potential sensitivities associated with ongoing investigations of damage caused by the war. Planning and implementation of assessments and associated action plans for remediation shall be done in consultation with relevant stakeholders and with inclusive and effective public participation.

Internationally, the informal inter-agency group established by UNECE, UNEP and the OECD and joined by multiple other actors can fulfil this role (UNECE 2022). Nationally, the environment working group established by UNEP/OCHA during the start of the war could be further strengthened, where the inclusion of national actors would be important. Information-exchange whether for response or recovery options would benefit all actors involved.

4.9. Communication and advocacy

The environmental consequences of the Kakhovka dam breach are devastating and were acknowledged globally when the event occurred. As time passes, there is a risk that the attention of the global community will focus elsewhere. It is thus critical to, as information becomes available and the impacts become clearer, communicate on the effects and advocate for more funding to assessments, remediation and recovery. Coherent and joint messaging by key national and international actors would be important, backed up by independent and scientific evidence.

4.10. Future outlook

On 18 July 2023, in response to the breach of the Kakhovka dam, the Government of Ukraine adopted a resolution on a pilot project to rebuild the dam. It was estimated that the project would last for two years and be initiated as soon as the Government of Ukraine regains control of the area (Ukraine, Cabinet of Ministers 2023).

During the assessment process, UNEP was requested to provide some principles, considerations and preliminary ideas for the green recovery of the area affected by the dam breach. It is recognized that the rebuilding of the dam is a complex and far-reaching project, the environmental details of which are outside the scope of this report. However, some general considerations are provided below.

The planning and decisions regarding the reconstruction or replacement of the Kakhovka dam should be based on strong scientific grounds, results of monitoring, research studies and feasibility studies where different alternatives should be considered. The need to maintain an overall diversified energy mix for the country is important. The principles of 'build back better' should be followed, where sustainability should be a major criteria of recovery. Out of the three pillars of sustainability (environmental, economic and social sustainability) the environmental pillar of the original technical set-up of the dam was especially weak and would benefit from major improvements and enhancements.

Environment

Within the environmental pillar of sustainability, different topics should be carefully considered, notably the opportunities for:

- Restoration of free-flowing river ecosystems and habitats containing natural geomorphic features and development. It would also be important to consider restoring a section of limited length of free-flowing river section. If and as the Kakhovka dam is reconstructed, it should be considered to reduce its head in order to restore free-flowing river sections.
- Ensuring migration and passage of fish, other organisms, sediments and nutrients. The new or reconstructed hydraulic structures should contain a fish pass or bio corridor.
- Connection of the river channel with side channels and natural floodplains.
- Establishment of natural banks, floodplains and floodplain vegetation.

Especially for the above listed measures, but also for some listed below, it would be important to understand the ecosystems services that could be provided under the new flood regime, and which may be able to substitute or complement built infrastructure in the delivery of various services, for example water management for irrigation, safe drinking water provision, flood protection, as well as multiples additional non-infrastructure related benefits (e.g. for biodiversity). The natural elements that deliver these services can be considered as nature-based infrastructure assets (NbI), a specific kind of nature-based solutions. Understanding the potential for service delivery by NbI can help to make the case for their inclusion as part of the infrastructure rebuild.

Economic activities

Different economic areas should be carefully considered, notably:

- Irrigation: Irrigation systems used in Kherson oblast were widely dependent on the Kakhovka reservoir and new, more efficient irrigation methods should be considered that take climate change projections into account.
- Water supply canals for surrounding areas: The redesign and reconstruction of inflows to canals should be considered, so that they would work with lower water levels. Alternative sources of water supply for Crimea should be also considered e.g. desalination stations.
- Hydroelectricity: Guidelines for sustainable hydroelectricity recommend that production of electricity should be considered within the river basin scale, meaning that in river basins with large production of electricity, free flowing river sections should be left or recreated. In case of the Dnipro River, the hydroelectric production on upstream hydroelectric plants is high and a reduction of hydroelectric on the Kakhovka dam may be considered. From this perspective, the hydroelectric production on Kakhovka could be reduced, or even fully abandoned. In case of reduced hydroelectric production, reduced head

should be considered, for restoration of free-flowing river sections. Use of modern technology with high efficiency (turbines, generators) could partly compensate for the reduced water head.

- Cooling water for nuclear power plant Zaporizhzhia: Explore the redesign and reconstruction of the nuclear power plant cooling system to allow for efficient and safe operation with lower water level elevation.
- Inland navigation: Consider possibilities of river navigation on the lower Dnipro in free-flowing state, without impoundment. Sensible application of river regulation measures for creation and maintenance of navigable fairways should be considered applying groins, chevrons and dredging. Best practice examples from the Danube River could be studied as inspiration. Alternatively, reduced impoundment by one or more structures (weirs with locks) could be considered.

Social effects and implications

Within the social pillar of sustainability, different areas should be carefully considered, notably:

- Ensuring sufficient drinking water supply
- Flood protection: Hydrological, hydraulic and flood hazard analyses should assess flood regime in new conditions without the Kakhovka dam and reservoir. The newly emerged land in the area of the empty reservoir, which is a natural floodplain, should not be developed. No new structures and investments, no economic activities, other than compatible with the new flooding regime, should be allowed.
- Gender dimensions and implications should be considered in all aspects and at all levels of reconstruction efforts, making inclusive efforts to ensure women's full participation in decision making, as well as the application of gender responsive budgeting.
- Employment
- Recreation and aesthetics

4.11. Funding

Taking into account the current situation in Ukraine, urgent external support is indispensable for the planning and implementation of remediation and restoration actions that should be undertaken in the region affected by the Kakhovka environmental disaster. The PDNA forms a useful base for the identification of required funding. Annex X briefly describes the relevant European Union and global strategic context for the future recovery/restoration initiatives to be undertaken in the affected region (also in all other regions impacted by this war).

4.12. Stakeholders

National and local actors are on the ground and have since the start of the war in Ukraine been instrumental in assessing the environmental consequences. The actors listed in Annex XI are considered critical for implementing the recommendations and actions proposed within this report and it is recommended that further consultations with these take place, as the planning of assessments and remediation continues. Instruments such as the Lower Dnipro Basin Council and the Dnipro River Basin Management Plan can be used to involve and cooperate with the relevant stakeholders.

It should be noted that the operational capacities of several key scientific, regional and local stakeholders are likely to be seriously limited, due to the losses and damages caused by the war to offices, equipment and staff, which should be considered when advocating for their involvement in the follow-up of recommendations.

05

Conclusions

5. Conclusions

The Kakhovka dam breach that occurred on 6 June 2023 is an environmental disaster that inundated hundreds of square kilometres and desiccated thousands of square kilometres of reservoir and wetlands. The destruction of the dam represents the most significant individual cause of environmental damage in the Russian Federation's war on Ukraine to date. Yet, it should not be viewed as an individual event, but rather placed within the continuum of the ongoing war, where the environment is a silent victim of multiple and repeated man-made emergencies and incidents. Together they are causing release of contamination, creation of debris and hazardous waste and destruction of habitats and protected areas. The war, and the conflict that preceded it, have undermined environmental monitoring and governance functions and led to loss of related equipment and services. It has also exacerbated the risk of gender-based violence and brought new challenges for women and men, such as reinforcing traditional gender norms and increasing the risk of economic abuse (UNDP 2023). In this context, even the execution of normal environmental governance and monitoring functions is proving difficult without even beginning to account for the significant additional burden of the war.

The destroyed dam and depleted reservoir are situated on the front line of the ongoing war, where mines, shelling and active combat make access and detailed assessments impossible. The left/southern bank of the affected area downstream remains inaccessible. The context is rapidly evolving and operationally extremely challenging. The movement of mines will make huge areas downstream of the dam inaccessible for years to come, hampering assessments, studies, mitigation and remediation almost impossible to implement.

While the catastrophic flooding released by the dam was an environmental and humanitarian disaster in itself, the situation upstream of the dam must be considered even more severe. Ecosystems, species and habitats have been destroyed downstream but may adapt. Upstream, adaptation of species within the existing wetlands habitats is not feasible unless some type of dam is reconstructed. Alternatively, riverine and steppe ecosystems take the place of the reservoir, creating new habitats and ecosystems. It should be noted that the impact of the dam breach has an international spatial scale, well beyond the boundaries of the affected five administrative regions, considerably affecting the coherence and ecological connectivity of the Pan-European Ecological Network (PEEN).

Upstream, the desiccation of the emptied Kakhovka reservoir resulted in a rapid transformation of its mature and fully functioning aquatic ecosystem, that had evolved over the past 70 years, into a riverine type of ecosystem in early initial stage of development. Many of the damages in and around the Kakhovka reservoir are highly likely to be irreversible. Some of the protected areas located within the reservoir, like the Velykyi Luh National Nature Park, consist fully of either water or vegetation fully dependent on water conditions, making it highly probable that they were entirely damaged.

Groundwater levels in the region are already falling, as to be expected with the disappearance of a large body of water, which already has led to subsidence. The reservoir is now dry with the level of wind erosion dependent on the type of sediment and the level of protection by new grown vegetation or rewetting of parts of the reservoir. Exposed areas are likely to have received many seeds from the surrounding area and the next few months will indicate the extent and type of vegetation that can grow on these floodplains. Irrigation water, drinking water and supply of water to industry, including the ZNPP, is a key concern.

Downstream, the flooding lasted approximately 14 days, during which practically the whole volume of the reservoir, up to 18 km^3, passed through the flooded section of the Dnipro river. This represents between one third and half of the usual total annual volume of the lower Dnipro water flow. The immense flood caused losses in natural habitats, plant communities and species by washing away specimens, inundating habitats and depositing debris and sediments. Around 12,000 ha of forest was impacted. While the dam breach did not lead to major sediment deposits in the lowermost Dnipro River and delta, nearshore deposits could impede transportation or economic uses of the shoreline. The sediment load will need to be investigated, as the silt may contain residues of heavy metals, pesticides, fertilisers, nutrients and other pollutants, given that they have accumulated in the Kakhovka reservoir for more than six decades since the dam was built. Additionally, sediments may cover moved landmines, making them harder to detect.

The event led to the release of hazardous chemical pollutants, either confirmed or to be assumed based on a thorough risk analysis. Even focusing on larger structures containing huge amounts of chemicals and especially chemicals of great concern has led to the identification of more than 50 facilities that should be considered pollution hotspots. The release of nutrients from sewage facilities is confirmed and poses a localised risk of water-borne disease. While monitoring of Dnipro River surface water downstream in general shows the water to be of acceptable quality, the lack of information and analysis from multiple locations and for multiple parameters, make a comprehensive analysis impossible at this stage. The total amount of disaster waste is estimated to reach at least two million m^3, with the majority generated on the southern side of the river.

The large discharge of river water has temporarily desalinated certain areas of the Black Sea. Given that this area has been receiving freshwater intake for long, this impact is unlikely to be consequential. However, there may be implications for the ecology in the Dnipro delta, where species for the last 70 years have become accustomed to higher levels of salinity. Sediment delivery from the coastal flood water plume may reshape coastal morphology along the north-eastern Black Sea for some months to years, especially by potential deposition of fine-grained sediment. This could in turn affect transportation and economic uses of the coastal regions.

When it comes to the future outlook of the region, it is fully dependent on the progression of the war. While a quick reconstruction of the dam could stabilise water levels and prevent colonisation of the lakebed, it is not clear when this could start. It should also be noted that a smaller reservoir that would simulate a riverine environment has been advocated for as an alternative solution. With the reconstruction of the Kakhovka dam a priority for the Ukrainian government, green solutions and the use of Nature-based Solutions should be assessed. When it comes to the effects of the breach on the hydrological regime of the river, it should be noted that flood peaks historically are buffered by the reservoirs upstream of the Dnipro dam and not by the Kakhovka reservoir. Therefore, it is unlikely that the dam breach in and of itself would contribute to a large increase in flood risk downstream of the Kakhovka dam.

While it is impossible to, at this stage, fully assess the environmental impacts of the Kakhovka breach, the breadth of the damage shows that they are massive in size, particularly in the area of ecosystems and habitats, with corresponding impacts on species and biodiversity. At this stage, it cannot be determined which of the damages are irreversible, and which can possibly be at least partly mitigated through future remediation activities. The full consequences are likely to become clear only decades from now.

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Annexes

Annex I: List of authors

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Annex II: Lower Dnipro hydrological regime

The information on the lower Dnipro hydrological regime has (Figure 41) been extracted from Scherbak (2019), an Environmental Impact Assessment (EIA) conducted for a planned expansion of the hydroelectric capacity at Kakhovka dam, released in 2019.

Figure 41: Esri basemap showing the downstream region of the Kakhovka dam; accessed through the United Nations Satellite Office (UNOSAT) Webmap (*Source: UNOSAT 2023b*)

The formation of the modern water regime of the Dnipro River and most of its ecosystem components took place between 1947–1976, when the Dnipro cascade of reservoirs were gradually created. At that time, irreversible water withdrawals increased (up to 10–15 km^3/year). The average runoff decreased to 40–44 km^3/year and the share of runoff in the spring decreased to 36.3 per cent. The period of stabilisation of the Dnipro's hydrological regime, including in the lower reaches, began after the last reservoir in the Kaniv cascade was filled. It consists of two cycles: low-water (until 1993) and close to average water content (the last 25 years). The Dnipro River is fed mainly by snowmelt – the share of meltwater averages 60 per cent of the runoff, and in snowy years can reach up to 85 per cent.

The catchment area of the Dnipro River from the beginning of the Kakhovka reservoir to the mouth of the Black Sea is 482,000 km^2. In natural conditions, the Dnipro River in the lower reaches was characterised by an average flow of 51.9 km^3/year with fluctuations from 22 to 96 km^3/year (Figure 42). During the spring floods, 50–54 per cent of the annual runoff passed through to the Black Sea.

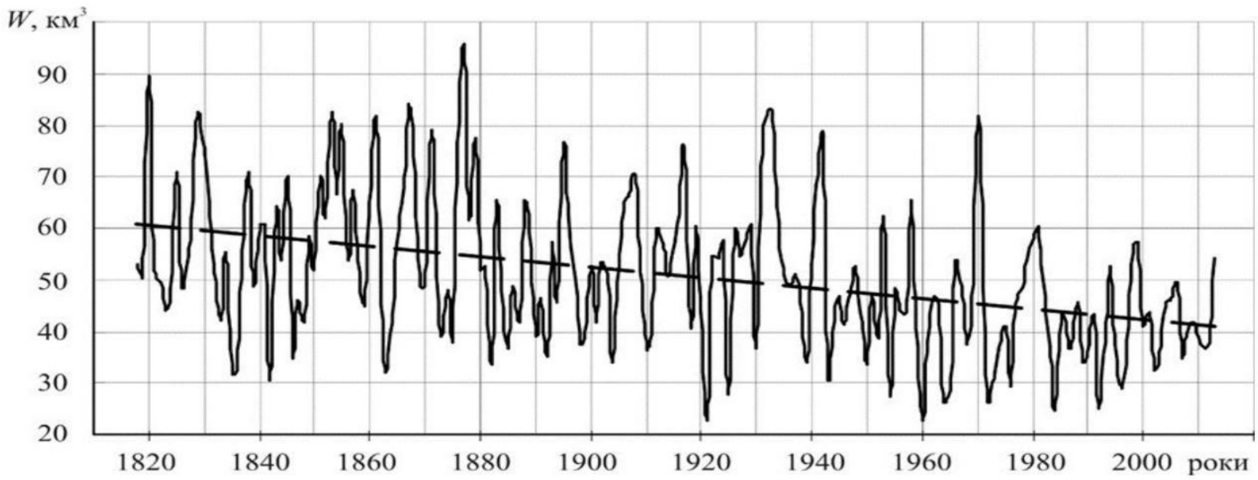


Figure 42. Average Dnipro River flow through the Kakhovka dam location (*Source: Scherbak 2019*) *Note the dam was constructed in 1956.*

The cascade of reservoirs has a significant impact on the water regime of the lower reaches. From 1977 to 2018 the maximum runoff values have not exceeded 57.3 km^3/year. Currently, there are three main hydrological periods in the intra-annual flow distribution: a weakly pronounced spring flood, the summer-autumn low water mark, and the winter period. Spring floods occur from March to early June, with an average discharge of 1,665 m^3/s at the Kakhovka dam, which is 2.8 times less than before the regulation (water regime post-dam construction). The summer-autumn high water mark is observed from July to September, with an average flow of 773 m^3/s during these months. In winter (from October to early March), water flows are higher than average and amount to 1,379 m^3/s.

The water discharge statistics (recurrence intervals and annual probabilities of certain flood magnitudes) for the Dnipro River at Kakhovka are provided in Table 4 (Scherbak 2019). It is not clear whether these discharge statistics calculated by Scherbak (2019) were based on a full suite of natural and regulated flows, or only on the post-dam-construction flow peaks. If the statistics were derived from only flow peaks since dams were built, then they should not be considered truly representative of the historical range of flow variability. Defining the recurrence interval and annual exceedance probability of a certain size flood peak (e.g. 1,000 or 10,000 years) is of importance when determining the level of adaptation of downstream ecosystems to high flows, yet the full suite of such data was not available to the assessment team.

Table 4. Characteristic water discharges of the Dnipro River for the Kakhovka dam location (Scherbak 2019)

Mean annual discharge	1,680 m^3/s
Minimal sanitary discharge	500 m^3/s
100-year flood (P = 1%)	9,200 m^3/s
1000 -year flood (P = 0.1%)	14,000 m^3/s
10000-year flood (P = 0.01%)	23,200 m^3/s

Note 'P' refers to the annual exceedance probability, the chance of such a flood magnitude occurring in any given year.

River and estuarine section of the Dnipro River downstream of Kakhovka dam

The Dnipro-Boh estuary region is the largest estuarine ecosystem in southern Ukraine. It includes the combined estuary and coastal areas of two rivers – the Dnipro and the Southern Boh. The information on the lower Dnipro section, floodplains and estuary has been extracted from the Environmental Impact Assessment (EIA) undertaken for a planned expansion of the hydroelectric capabilities at Kakhovka dam (Scherbak 2019).

The 106-km-long coastal section of the Dnipro River is located in the Black Sea South Steppe Zone. By its structure, the coastal section of the river is divided into the near-coastal and the estuary sections. The estuarine section is located from Kakhovka dam to the city of Kherson. In the upper part of the near-coastal section, the Dnipro River flows in a relatively narrow valley, mostly in a single channel. The width of the floodplain varies from 3 to 4 km. In the lower, deltaic section, the floodplain expands to 7–10 km. There are about 60 islands, more than 65 branches, channels and rivulets, and 160 lakes along the floodplain. The total area of the lower reaches of the Dnipro River is about 550 km^2, with the estuary area accounting for 151 km^2 and the mouth area for 399 km^2. About 70 per cent of the delta's area is covered by floodplains. The delta is 47 km long and 13 km wide along its leading edge. In the floodplain terrain, there are riverbed low-wave sandy plains with sod and meadow soils, flat and undulating areas of the central floodplain with sandy loam and silt deposits, on which meadow and marshy meadow soils are formed, and flat and low-lying terraced areas of the floodplain with meadow-bog and marsh soils. Alluvial and estuarine deposits lie on the eroded surface of the Upper Sarmatian and have a total thickness of 35 to 40 m (Scherbak 2019).

Annex III: Monitoring data from the entire Dnipro basin

Before the dam breach, a large pollutant screening of Water Framework Directive priority substances was performed in the Dnipro River basin (EUWI+ 2021), where water samples were taken from all parts of the river basin at its tributaries. Pollutant screening of the Dnipro water (EUWI+ 2021) was conducted at 27 sampling locations. Some priority substances (atrazine, cadmium and nickel) in concentrations above environmental quality standard (EQS) limits were recorded in surface water samples; as well as mercury and diphenyl ethers in biota samples. The target and suspect screening revealed 161 and 440 organic pollutants, respectively, to be present in at least one sample. Cadmium exceeded its environmental quality standard at seven sites, with the highest concentration at the sampling site below Zaporizhzhia city. Some pesticides were also found in concentrations representing a potential threat for the Dnipro River basin ecosystem and should be further monitored. Brominated flame retardants and pesticides (mainly terbuthylazine, nicosulfuron, fipronil and carbendazim) exceeded EQS at some samples, also in biota. All of these compounds can have negative effects on biota, both in freshwater and in seawater.

According to Scherbak (2019), the main pollutants of the Kakhovka reservoir and the lower reaches of the Dnipro River are municipal and industrial enterprises, which account for almost all pollutant discharges. In 2017, a total of some 13,000 tonnes of minerals (by dry weight) were discharged into the reservoir via wastewater, containing a cocktail of organic and inorganic pollutants (Scherbak 2019). Currently, most information on pollutants in surface water is on heavy metals with limited data on other pollutants. The presence of metals is where most of the metallurgical enterprises are located (Osadcha *et al*. 2021).

The radiation status of water bodies in the Dnipro basin has been determined mainly by radionuclides that are washed away from sites contaminated by the Chernobyl accident. The main route for radionuclides to enter the Dnipro River is via the Pripyat River, flowing into Kyiv reservoir with further migration through the Dnipro reservoir cascade. Along the length of the Dnipro cascade in the reservoirs, the radionuclide content is decreasing due to sedimentation processes and dilution of Dnipro water with cleaner waters of lateral tributaries. In the Kakhovka reservoir, in 2018, the average concentrations of strontium-90 and cesium-137 for six months were 26 and 0.40 Bq/m^3, respectively (in 2013, the same indicators were 29 and 0.43 Bq/m^3) (Scherbak 2019). These levels are fairly low for Ukraine and far below drinking water intervention levels (125 Bq/l for Sr-90 and 1,000 Bq/l for Cs-137).

Annex IV: Selection of potential chemical hot spots

This annex contains a selection of potential hotspots regarding the release of chemicals or biological agents into the water.

This selection has been made based on the following sources;

- CEOBS – Partial analysis of potentially polluting industrial and infrastructure facilities within the flood-affected territory of the Kakhovka dam, Ukraine (66 spots)
- Ecodozor lists and maps (192 spots)
- REACH list: hazardous_facilities_in_flood_zone_kahovka
- Information from Operational situation regarding the consequences of the destruction of the dam of the Kakhovka hydroelectric power plant
- Satellite images to assess the amount of flooding of the facilities

It is expected that most of the facilities located in the flood zone will have ceased operation already before the dam breach due to the location of the facilities within the area of active hostilities. However, for the assessment of possible chemical release it was assumed that all reservoirs and tanks, and chemical substances contained therein, would have been present at the sites. For the selection of chemical hotspots the assessment has focussed on those large structures that may have contained large amounts of chemicals or chemicals of great concern. For biological agents the analysis has focussed on large scale livestock and poultry farming and sewage treatment plants.

The list of hotspots has been then filtered by:

- Combining the list of CEOBS, Ecodozor and Reach, then checked for doubles based on their name and GPS location (7 doubles)
- Removing facilities outside the flooded area (21 outside)
- Removing all infrastructure and utilities (56)
- Removing all facilities on type or size of business
    - Cemetery (19)
    - Agriculture / livestock (17)
    - Construction (28)
    - Shop / market (7)
    - Port (2)
    - Small to medium enterprises (71)
    - Transport (5)
    - Waste (5)
    - Other (1)

There are 54 facilities remaining and selected as potential hotspots.

The following hotspot locations pose a particular concern:

1. Port storage facilities at Kherson

The large port storage facilities located at the eastern part of the island south of Kherson (Figure 43) have been identified as a hotspot for both primary and secondary pollution. Almost 3,500 tons of stored liquid fertiliser is also present, at the Pallada Shipyard. Besides being a potential location of historical pollution, this part of Kherson was flooded for many days which may have caused historical pollution to re-enter the water column. Residential areas are located west of this port area.

Figure 43. Industrial area in Dnipro delta, in the southern part of Kherson (*Source: Map data @2023 Google*)

At Port Naftohavan (Figure 44, located at 46.599076; 32.548313) large quantities of oil have been stored. It is unknown whether this oil was still present during the flood and what the integrity of the tanks was before or after the flood.

Figure 44. Figure 44 Port Naftohavan (*Source: Map data @2023 Google*)

2. Fuel storage facilities

At the Glusco fuel storage area (Figure 45 located at 46.625226; 32.789267) located beyond the control of Ukraine fuels were stored. It is unknown whether this oil was still present during the flood and what the integrity of the tanks was before or after the flood.

Figure 45. Glusco fuel storage area (*Source: Map data @2023 Google*)

At a site located in northern Kherson several huge storage tanks for fuel were located (Figure 46 located at 46.675692; 32.559648). It is unknown whether this oil was still present during the flood and what the integrity of the tanks was before or after the flood.

Figure 46. Fuel storage area in northern Kherson (Source: *Map data @2023 Google*)

3. Large scale livestock and poultry farming

Large scale livestock and poultry farms can pose a double risk, if the animals were still present during the flood. Drowned animals pose a risk to human health as well as through large amounts of manure entering the surface water. Manure in the water poses a biological hazard due to microorganisms present in the manure and can also cause eutrophication due to the large amounts of nutrients present. Large scale farms located in the flooded area are shown in Figure 47 and Figure 48.

Figure 47. Farm area in Korsunka located in the area beyond the control of Ukraine (*Source: Map data @2023 Google*)

In the northern part of Kherson a large poultry farm is located (Figure 48, location 46.67994; 32.55953). This part has been temporarily flooded. It's unknown whether poultry was still present at the time of flooding and what the damage to the area was.

Figure 48. Chernobaiv poultry, PJSC (*Source: Map data @2023 Google*)

4. Diffuse pollution due to sewage

Sewage treatment plants are reported to have been flooded with the Oleshki wastewater treatment plant (location 46.622327; 32.769576) shown in Figure 49.

Figure 49. Oleshki wastewater treatment plant (Source: Map data @2023 Google)

Bilozerska wastewater treatment plant

The Bilozerska wastewater treatment plant (location unknown) was included in a Ukraine Government (2023) report but not included in the different lists of flooded installations yet sewage was reported to have entered the lake Bile.

It is expected that, in addition to affected treatment plants, sewage structures will have been damaged as a result of flooding. This can lead to diffuse pollution by microorganisms, organic matter and nutrients from faeces. In addition to causing disease in humans this may cause eutrophication of the aquatic environment.

5. Potential additional sources with unknown precise locations

Obsolete pesticides from Soviet times are stored as waste in the region of Kherson, either in concrete containers above ground, in smaller barrels below the surface or mixed with soil. The exact location of these storages is unknown and it is unknown whether they have been affected by flooding. The environmental effects of these pesticides, if released in the environment, can be devastating both in the short- and long-term. Obsolete pesticides are highly hazardous substances which can bioaccumulate in organisms and enter the human food chain for example through the consumption of fish.

Annex V: Estimated amounts of waste – Modelling using I-WASTE-DST

The model used for estimating the amount of disaster waste is I-WASTE-DST by US EPA (2023). The model is developed with background in estimations of waste produced by previous disasters caused by natural hazards in the United States of America.

The model can predict amounts of waste produced from several different parts of the society. Information on companies and operations around Kherson is too limited, and the uncertainty due to the war is too great to make any modelling possible. Therefore, only waste from households is considered and thereby only this module of the model is used. Note that the model is based on United States constructed buildings which may vary to buildings in Kherson and Mykolaiv Oblasts.

As input to the calculations are the number of affected households. Table 5 below shows the estimates of flooded households on each side of the river. For the northern side the administrations of the oblast of Kherson and the oblast of Mykolaiv have produced lists of affected households and those numbers are used in the calculations. The total number of households on the north side is set to 4,377.

For the southern side there is a lack of official information. The number of affected households is calculated by assessing the settlements within the flooded area out of satellite images, and to estimate the degree of flooding of each settlement between 0-100 per cent.

Table 5. Estimations of flooded households in major settlements on the south side of the river

	Inhabitants	Households	Degree of flooding	Flooded households
Bilohrudove	239	100	100%	100
Hola Prystan	14,755	6,148	80%	4,918
Velyka Kardashynka	1,443	601	80%	481
Kardashynka	1,303	543	100%	543
Solontsi	1,051	438	100%	438
Oleshky	24,639	10,266	50%	5,133
Sahy	804	335	100%	335
Krynk	991	413	80%	330
Korsunka	1,478	616	100%	616
Nova Kakhovka				50
Total				**12,844**

Calculations in the model are based on the following estimations, introduced into the model.

- 140 m^2 median house footprint
- 30 per cent of buildings with brick/masonry-faced exterior walls
- 50 per cent residences constructed pre-1980

The model is run on one household and the results presented in Table 6 below. Thereafter the results are extrapolated on the number of households estimated to be flooded on either side of the river. Results showing a total of a little more than two million m^3 of waste.

Table 6. Amounts of waste calculated by I-WASTE-DST

	Amounts per household I-WASTE-DST	Amounts of waste without adjustments	
		North side	South side
		Households: 4,377	Households: 12,844
Total Structural Building Materials	33	144,441	423,867
Total Non-Structural Building Materials	51	227,604	667,912
Total interior (divided over the following)	44	193,840	568,830
Electronic Equipment	*8.5*	*37,205*	*109,178*
Furnishings	*18*	*78,786*	*231,200*
Items	*23*	*76,598*	*224,778*
Asbestos	*0.75*	*328*	*964*
Household hazardous waste	*0.021*	*92*	*270*
Tanks/Cylinders	*0.19*	*832*	*2,440*
TOTAL	**174**	**565,885**	**1,660,609**

Due to the circumstances around Kherson it is not entirely correct to use data input from the United States of America in the report. As mentioned in the report several factors contribute to the theory that a substantial part of the material damaged by flooding will be reused or recycled by the houseowner. To an extent that would not be in question for an American houseowner after a flooding disaster.

Because of this, site specific adjustments are made to the results from the I-WASTE-DST model and presented in Table 7 below.

The reduction due to conflict is an adjustment which covers the possibility that houseowners probably will reuse a larger part of the damaged items, simply because new items are not available in stores or are too expensive to buy. The fact that supply of energy is unreliable in the region means that houseowners probably will see the value of wooden construction material as firewood and store it rather than discard it. This theory results in the adjustment that half of the non-structural building material, furnishers and items are reused or recycled by houseowners, and not discarded for landfilling.

The reduction due to only partially flooded buildings covers the possibility that houseowners whose houses are not completely damaged will repair them as much as possible, rather than demolishing the entire building. This assumption is based on the same considerations as above, that new building material is not available, and it is better to have a damaged house rather than no house at all. Nor will many houseowners dare to invest in a new house, due to the uncertain security situation. The result is thereby adjusted and half of the affected buildings are assumed to not be entirely demolished and 25 per cent of the buildings are assumed to keep the non-structural building materials even though they are damaged. Non-structural building materials are considered interior framework, drywall carpets etc.

The adjustments lead to a reduced amount of waste which needs to be managed. This material is still damaged and will turn into waste once the security situation and financial situation improves in the region (with the exemption of wood which may be used as fuel).

Table 7. Amounts of waste calculated by I-WASTE-DST and adjusted according to site specific conditions.

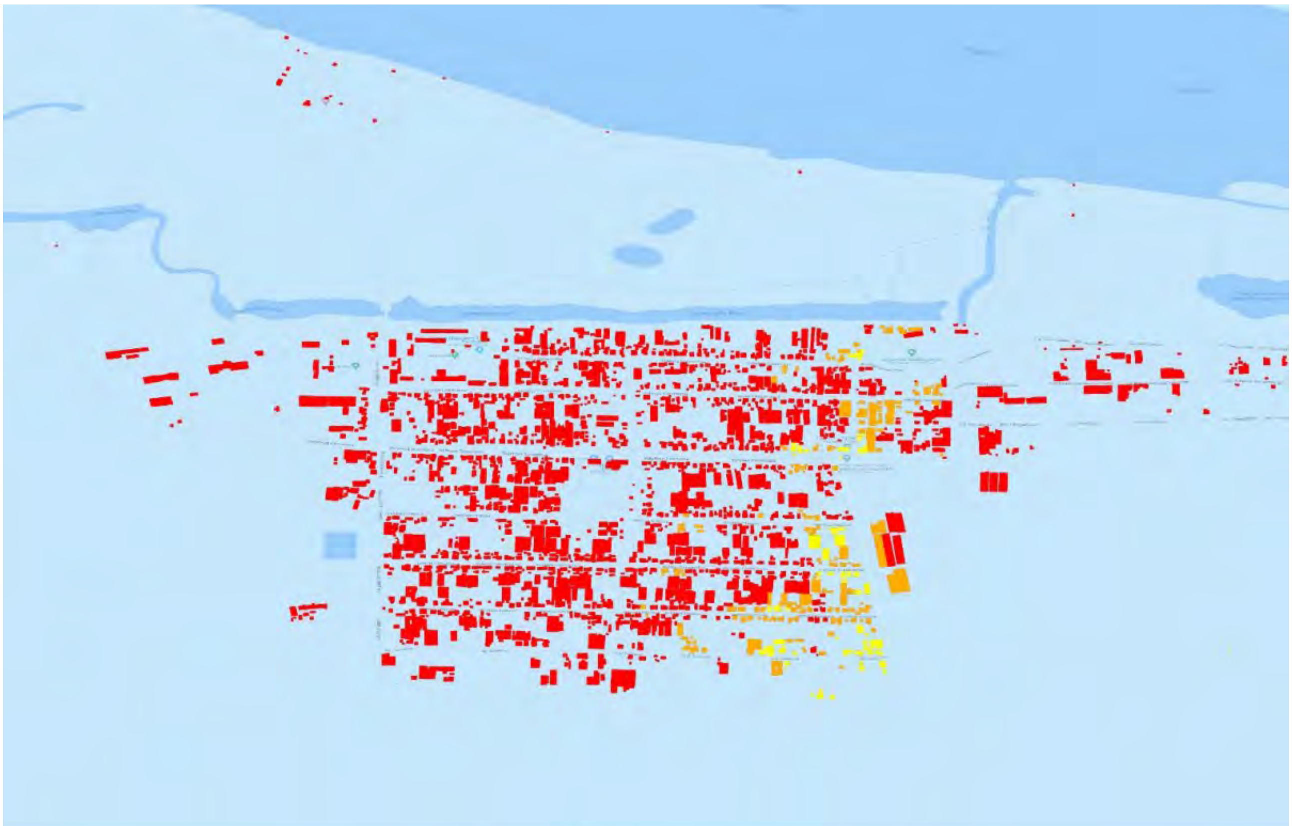
	Reduction due to conflict	Reduction as a result to only partially flooded buildings	Amounts of waste adjusted figures	
			North side	South side
Total Structural Building Materials		50%	72,221	211,934
Total Non-Structural Building Materials	50%	25%	85,232	250,467
Total interior		0 %	116,148	340,841
Electronic Equipment		0%	37,205	109,178
Furnishings	50%	0%	39,393	115,600
Items	50%	0%	38,299	112,389
Asbestos		0%	328	964
Household hazardous waste		0%	92	270
Tanks/Cylinders		0%	832	2,440
TOTAL			273,720	1,076,962

The final estimation of waste production based on the I-WASTE-DST is 1,351,000 m^3.

Modelling by UNDP

UNDP additionally produced calculations of the expected amounts of disaster waste due to the flooding. The calculations were based on the footprint of flooded buildings within the settlements along the river, and also far up along the adjacent watercourses joining both sides of the river.

The source of information for the calculations is the mapping from KSE (2023). Within the mapping modelled water levels after flooding are compared with topography, and size and locations of buildings. Due to the depth of the water level the buildings are assumed to be completely, partially or potentially flooded. Figure 50 below shows the settlement of Korsunka on the southern side of the river. The normal water level is darker blue while the flooded area is light blue – which is the entire settlement. The buildings are marked with colour, where red indicates completely flooded.



The settlement of Korsunka after the flooding.

Figure 50. Example of the results from KSE mapping of flooded settlements, the settlement of Korsunka (KSE 2023).

The total number of fully, partially or potentially flooded buildings are presented by settlement in Table 8.

Table 8. The total number of flooded buildings in Mykolaiv and Kherson Oblast.

Kherson						Mykolaiv	
Antonivka	328	Korsunka	2,672	Raiske	868	Berezan	31
Berehove	36	Kozachi Laheri	2,437	Rybalche	263	Chornomorka	61
Bilohrudove	412	Kozatske	255	Sadove	902	Halytsynove	433
Bilozerka	108	Krynky	3,165	Sahy	62	Ivanivka	35
Burhunka	22	Lvove	5	Sofiivka	8	Lupareve	149
Darivka	288	Mala Kardashynka	461	Solontsi	530	Lymany	54
Dnipriany	3,634	Mykilske	65	Stanislav	200	Mykolaiv	160
Dniprovske	17	Mykolaivka	73	Stara Zburivka	300	Novobohdanivka	20
Fedorivka	311	Nova Kakhovka	6,243	Tiahynka	269	Ochakiv	112
Heroiske	20	Odradokamianka	425	Tokarivka	16	Parutyne	75
Hola Prystan	5,003	Oleksandrivka	4	Ulianovka	10	Pokrovka	10
Inhulets	362	Oleshky	7,943	Veletenske	85	Pokrovske	235

Kherson						Mykolaiv	
Ivanivka	38	Olhivka	148	Velyka Kardashynka	1,037	Soniachne	99
Kardashynka	2,083	Pidstepne	14	Vynohradne	17	Stara Bohdanivka	11
Kherson	1,3662	Poima	916	Yantarne	7	Vasylivka	10
Kizomys	327	Poniativka	6	Zabaryne	98	Yaselka	2
Kokhany	2700	Prydniprovske	78	Zarichne	90		
				Zymivnyk	117		

No consideration is made of the use of the building. Residential and commercial buildings are thereby considered the same. Instead a differential factor is added to the degree of flooding of the building. If the mapping indicates the building to be fully flooded it is assumed that one m^3 of waste is produced for every m^2 of the building. If the building I partially flooded the waste production is 0.5 m^3 per m^2 and if the building is only potentially flooded the factor is 0.2 m^3 per m^2.

Especially for the south side of the river, the settlements contain a large number of greenhouses. In some settlements like Korsunka almost every household contains a greenhouse which is many times larger than the residential building. The consequence is an overestimation of produced waste, as greenhouses don't produce very much waste. This is however a good approach to consider both residential and commercial buildings.

Information on number of affected buildings, and the footprint of these are presented in Table 9 below. Out of the footprint the amount of waste is calculated. The total amount of waste is calculated to 2,894,000 m^3.

Table 9. Results from mapping of flooded buildings in the oblasts of Mykolaiv and Kherson – both sides of the river.

		Kherson	Mykolaiv	Grand Totals
Number of flooded buildings (pieces)	Completely flooded buildings	11,211	208	11,419
	Partially flooded buildings	6,245	366	6,611
	Potentially flooded buildings	41,684	923	42,607
	Total Buildings	59,140	1,497	60,637
Size of flooded footprint area (m^2)	Completely flooded footprint area	1,066,340	15,132	1,081,471
	Partially flooded footprint area	972,378	27,422	999,800
	Potentially flooded footprint area	6,459,515	101,732	6,561,247
Amount of waste produced (m^3)	Completely flooded debris	1,066,340	15,132	1,081,471
	Partially flooded debris	486,189	13,711	499,900
	Potentially flooded debris	1,291,903	20,346	1,312,249
	Total debris	2,844,432	49,189	2,893,621

Annex VI: Waste management needs Kherson Oblast

List of needs received from Kherson Oblast 6 July 2023

6 July Segment of equipment	Type of equipment	Specification	Number
Excavators and loaders	Mini Excavators	Cat 302/303, JCB 8030/8035, Bobcat E27/E37 or equivalent	2
	Wheeled backhoe loaders		15
	Wheel excavator middle class	JCB JW 160/175, Hyundai R180 or analogues	1
	Front loader		9
	Bucket loader		1
	Wheel Loader		7
	Front telehandler	Cat 642/943, JCB 535/540 or equivalent	1
	Telehandler	MANITOU	3
	Crawler skid steer loader	Cat 289, Bobcat T650/T770 or equivalent	3
	Mini-loader		5
Waste handling equipment	Mobile Buccal Crusher	Keestrack Granite Crushing	1
	Construction waste shredder		1
	Crusher - shredder		3
	Electric chip cutter		3
	Medium Bulldozers	Cat D4/D5/D6 or equivalent	1
Lifting equipment	Truck crane	lifting capacity of 16 tons with a boom reach of up to 40 m	6
	Middle class truck cranes		2
	Forklift	Linde E18C-02 2006 11 280 m/h	1
Transport equipment	Truck		16
	Dump truck	capacity of 20 - 25t	17
	Dump truck	capacity of 4-5t	3
	Bunker truck portal		2
	Garbage truck	capacity of up to 12 m^3	5
	Refuse-collection vehicle	with side mechanised loading SV-701.2	10

Transport equipment	Rear loaded refuse-collection vehicle		6
	Tractor with trailer		3
	Low power tractor	John Deere 6095, New Holland T4.85/ T4.95 or equivalent	2
	Medium power tractor	JCB 2155, CASE 110/125, John Deere 6110/6135 or equivalent	4
	Trailer for tractor, 6-8 tons	2TSP-6/2TSP8 or analogues	6
	Trailer-roslet	PRL-0512	2

List of needs suggested from UNEP			
Segment of equipment	**Type of equipment**	**Specification and purpose**	**Number**
Waste handling equipment	Material handler	Volvo EW200E, Cat MH3024 or equivalent For sorting of waste before landfilling. Removal of recyclable materials as wood and metal	2
	Truck with load changer	Several different models. With the purpose to create curb side collection of hazardous waste.	5
	Load charger beds		20
	Landfill compactor	Volvo LC450H, Cat 836K or equivalent For compaction of waste at landfill	2
	Medium Bulldozers Additional to list from Oblast	Cat D4/D5/D6 or equivalent	2

Annex VII: Basic information on the legal framework for biodiversity conservation in Ukraine

The conservation of biological and landscape diversity in Ukraine is regulated by several laws, including the 1999 Law 'On the plant world', 2001 Law 'On the animal world', 2002 Law 'On the Red Data Book of Ukraine', 1992 Law 'On the Nature Reserve Fund of Ukraine' and 2004 Law 'On the ecological network of Ukraine', as well as by the 2002 Resolution of the Cabinet of Ministers of Ukraine 'On approval of the Regulation on the Green Book of Ukraine'.

In accordance with the 1999 Law 'On the plant world', rare and endangered species of plants and fungi growing in natural conditions are subject to special protection and are listed in the Red Data Book of Ukraine. Other plants and fungi species not listed there but rare or endangered in the territory of the Autonomous Republic of Crimea, regions (oblasts), or cities of Kyiv and Sevastopol, may be included in the list of plant species subject to special protection in these territories (like e.g. the Red List of Kherson Oblast). Further, rare, endangered and typical natural plant communities are subject to protection throughout the territory of Ukraine and are entered into the Green Book of Ukraine, that summarises information on their protective status, and provides the basis for the development of protective measures for the preservation, reproduction and use of those natural plant communities. Planning such measures will be indispensable for the restoration activities to be undertaken in the region affected by the breach.

Similarly, in accordance with the 2001 Law 'On the animal world', one of the measures for the protection of animal species is the establishment of a special regime for the protection of animal species listed in the Red Data Book and in the lists of animal species subject to special protection in the territory of the Autonomous Republic of Crimea, oblasts, or cities of Kyiv and Sevastopol. This law also constitutes the legal basis for the development and implementation of programs (action plans) for the preservation and reproduction of wild animal species that are under threat of extinction. Again, the development of such single species recovery action plans will be indispensable for the mitigation of damages in the affected region.

The fourth edition of the National Red Data Book of Ukraine currently includes 858 plant and fungi species, and 687 animal species. Many of these species are also listed in the European Red Lists of species, and the IUCN Red List of Threatened Species.

Since the entry into force of the Ukraine – European Union Association Agreement on 1 September 2017 Ukraine is successfully transposing the EU environmental acquis into its national legislation, including the Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds (commonly abbreviated as the 'Birds Directive'), the Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (abbreviated as the 'Habitats Directive'), and the Regulation (EU) No 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species. The EU candidate status granted to Ukraine on 23 June 2022 is expected further accelerate the harmonisation of biodiversity conservation-related Ukrainian national legislation with the above Directives.

Moreover, Ukraine is party to several relevant multilateral environmental agreements, including the 1971 Convention on Wetlands of International Importance, especially as Waterfowl Habitat (abbreviated as Ramsar Convention on Wetlands), the 1979 Council of Europe's Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention), the 1979 UN Convention on the Conservation of Migratory Species of Wild Animals (CMS) and the Convention on Biological Diversity (CBD). Most species occurring in Ukraine that are listed in Appendices I and II of the Bern Convention and in Bern Convention Resolution No. 6 (1998) listing the species requiring specific habitat conservation measures, as well as Appendices I and II to CMS, are listed in the Red Data Book of Ukraine, which further enhanced their protection.

In the light of the expected accession of Ukraine to the EU, several important synergies between the Bern Convention and the EU environmental acquis should be emphasised. Bern Convention Resolution No. 4 (1996) listing endangered natural habitats requiring specific conservation measures corresponds to Annex I of the 'Habitats Directive', while Resolution No. 6 (1998) listing the species requiring specific habitat conservation measures corresponds to Annex II of the 'Habitats Directive', and to Annex I of the 'Birds Directive'. Further, Parties to the Bern Convention contribute to the development of the Emerald Network of Areas of Special Conservation Interest (further as ASCIs). EU Member States fulfilled this obligation by designating sites of the Natura 2000 network (perceived as the EU's contribution to the Emerald Network).

Ukraine considerably progressed in the designation of ASCIs, according to the updated list of officially adopted Emerald Network sites (December 2022), the Standing Committee of the Convention on the Conservation of European Wildlife and Natural Habitats adopted 377 ASCIs in Ukraine, while other 162 proposed potential ASCIs in Ukraine are currently being verified. Therefore, due to the compatibility of above networks, ASCIs of the Emerald Network can, upon the accession of Ukraine to the EU, become sites of the EU Natura 2000 network.

Ukraine is also Party to the Convention on Wetlands of International Importance Especially as Waterfowl Habitat (Ramsar 1971), stipulating the designation of Wetlands of International Importance (commonly known as Ramsar sites). According to the Ramsar Sites Information Service (RSIS), Ukraine harbours 50 wetlands of international importance (Ramsar sites) jointly covering a total area of 930,559 ha.

However, it should be noted that both in the case of Emerald Network sites and of Ramsar sites, it is the duty of the sovereign Party to ensure the legal protection and efficient management of each internationally-recognized site accordingly to its own national legislation in force. In other words, regardless of their international recognition, Emerald Network and/or Ramsar sites remain non-protected unless granted a legal protective status in accordance with the national legislation of the respective country, Party to the Bern Convention and/or Ramsar Convention.

Designation and management of PAs is one of the most effective means towards either the conservation or active protection of ecosystems, habitats and species. The 1992 Law No. 2457-XII 'On the Nature Reserve Fund of Ukraine' defines seven national 'natural' PA categories:

- nature reserves (*природні заповідники*), 'nature zapovednik' term derives from the former USSR PA categorization system, meaning a strict nature reserve of IUCN PA management category I
- biosphere reserves (*біосферні заповідники*) of IUCN category II
- national nature parks (*національні природні парки*) of IUCN category II
- natural monuments (*пам'ятки природи*) of IUCN category III
- reservations (*заказники*), 'zakaznik' term derives from the former USSR categorization system and implies active management of the area, thus IUCN category IV
- regional landscape parks (*регіональні ландшафтні парки*) of IUCN category V
- protected sites (*заповідні урочища*) of IUCN category I

In addition to 'natural' PA categories the 1992 Law also defines five categories of 'artificially created' protected objects: botanical gardens (*ботанічні сади*), dendrological parks (дендрологічні парки), zoological parks (*зоологічні парки*) and parks monuments of horticultural art (*парки-пам'ятки садово-паркового мистецтва*). Further, reservations can be classified as landscape, forest, botanical, general zoological, ornithological, entomological, ichthyological, hydrological, general geological, paleontological and karst-speleological. Natural monuments can be classified as complex, primaeval forest, botanical, zoological, hydrological and geological. Natural monuments can occur within the boundaries of other areas of the nature reserve fund. Reservations, natural monuments, botanical gardens, dendrological parks, zoological parks and parks-monuments of horticultural art may be of national or local importance.

Annex VIII: List of affected protected areas

The protected areas are below listed in alphabetical order.

A. Located downstream from Nova Kakhovka, in the river corridors of Dnipro and the lower section of Inhulets River:

National Nature Parks

- Lower Dnipro National Nature Park/НПП Нижньодніпровський (80,177.8 ha, designated in 2015) – the lower part of the Dnipro delta and part of the Dnipro-Boh estuary inside this NNP were also designated as a wetland of international importance (Ramsar site) – see below

Reservations

- Bakai/Бакайський (forest reservation of state importance, 420 ha, 1974) located inside the strictly protected core zone of the Lower Dnipro NNP on the Great Island (eastern coast of the Dnipro-Boh estuary);
- Bakai Zholob/Бакайський жолоб (general zoological reservation of local importance, 1,680 ha, 1978) located on several islands of the lowest part of the Dnipro River delta, also constituting part of the strictly protected core zone of the Lower Dnipro NNP.
- Bobrove Ozero/Боброве Озеро (landscape reservation of local importance, 50 ha, 2008) located on the left bank near Gola Prystan village;
- Elizavetivka/Єлизаве́тівка (27 ha, 1995)
- Inhuletsky Liman/Інгулецький лиман (botanical reservation of local importance, 50 ha, 1983) located at the confluence of the Inhulets River with the Dnipro River;
- Ivano-Kepine/Іва́но-Ке́пине (25.5 ha, 1987)
- Korsunsky/Корсунський (general zoological reservation of local importance, 3,357 ha, 1978) located downstream from Kakhovka to the south from Krynky village
- Sagy/Урочище Саги (landscape reservation of state importance, 500 ha, 1977) located to the east from Oleshky
- Solyane Lake/Озеро Соляне (hydrological reservation of state importance, 120 ha, 2016) located in the outskirts of Gola Prystan

Natural Monuments

- Ancient Plane-Trees/Вікові платани (botanical, 0 ha, 1983)
- Memorial Oaks/Меморіальні дуби (botanical, 0 ha, 1983) in Kakhovka
- Krynkyvsky Beaver Settlement/Кринківське поселення бобрів (zoological, 5 ha, 1983) located in Dnipro floodplain near Krynky village (within the boundaries of the Lower Dnipro NNP)
- Acacia Tree Stand/Деревостій акації білої (botanical, 0 ha, 1983) located to the south from Oleshky, as well as two natural monuments in Gola Prystan
- Ancient Oaks/Вікові дуби (botanical, 0 ha, 1983)
- Part of Lake Hopri/Частина озера Гопри (hydrological, 5 ha, 1983),
- two in the proximity of Gola Prystan, Ancient Pines/Вікові сосни (botanical, 0 ha, 1983)
- Curtain of Oaks/Куртина дубів (botanical, 0.5 ha, 1983),
- Poplars/Тополі (botanical, 0 ha, 1983) located in Stara Zburivka village to the south-west from Gola Prystan

- Kozatske Spring/Козацьке джерело (hydrological, 0 ha, 1983) in Kozatske village (next to the dam)
- Shilova Balka Spring/Джерело Шилової балки (hydrological, 0 ha, 1975) north of Kozatske
- Ponyativske Snake Settlement/Понятівське поселення змій (hydrological, 5 ha, 1983) near Ponyativka village
- Mykilske Snake Settlement/Микільське поселення змій (hydrological, 4 ha, 1983) near Mykilske village
- Quercus robur/Дуб черешчатий (botanical, 0 ha) consisting of seven trees in the city of Kherson
- Bilozerski Springs/Білозерські джерела (hydrological, 0 ha, 1983) located in Bilozerka village, on the bank of the Bilo Ozero lake

Protected Sites

- Goloprystansky Acacia Forest/Голопристанський акацієвий ліс (42 ha, 1972) south from Gola Prystan
- Starozburivsky Acacia Forest/Старозбур'ївський акацієвий ліс (14 ha, 1972) in Stara Zburivka village;
- Tsyurupinsky Pine Grove/Цюрупинський сосновий бір (290 ha, 1972) in the southern outskirts of the completely flooded Oleshky

Parks Monuments of Horticultural Art

- Dendrological Park of Nizhnedniprovsk State Pedagogical University/Дендропарк Нижньодніпровської НДС (3 ha, 1964) in Oleshky
- Park of the 'Hopri' Sanatorium/Парк санаторію 'Гопри' (18 ha, 1964) in Gola Prystan

Wetlands of International Importance (Ramsar sites)

- Dnipro River Delta (34,425.8 ha, 1997, Ramsar site No 767 RIS)

Emerald Network sites

- Lower Dnipro ASCI (52,386.0 ha, 2016, site code UA 0000192 SDF)
- Lower Inhulets River valley ASCI (13,570.98 ha, 2020, site code UA0000321 SDF)

B. Located downstream, outside the Dnipro River corridor, either along the coastline of the Dnipro-Boh estuary or at the Black Sea coast / marine area:

Biosphere Reserves

- Black Sea Biosphere Reserve/Чорноморський біосферний заповідник (106,513.8 ha, 1927), also designated under Emerald Network and UNESCO MAB (see below)

National Nature Parks

- Biloberezhzhia Sviatoslava National Nature Park/НПП Білобережжя Святослава (35,359.34 ha, 2009), also designated under the Bern Convention (see below under Emerald sites). This NNP includes the Kinburn Spit Regional Landscape park (see below), which is also part of Kinburnska Kosa ASCI (see below under Emerald sites)

Regional Landscape Parks

- Kinburn Spit Regional Landscape Park/РЛП Кінбурнська коса (17,890 ha, 1992)

Reservations

- Berezovi Kolky/Березові колки (forest reservation of state importance, 1,312 ha, 1974)
- Krestova Saga/Хрестова сага (botanical reservation of local importance, 30 ha, 1983)

- Shaby/Шаби (botanical reservation of local importance, 20 ha, 1983)
- Yagorlytsky/Ягорлицький (ornithological reservation of state importance, 30,300 ha, 1974)
- Zernov's Phyllophora field/Філофорне поле Зернова (botanical reservation of state importance, 402,500 ha, 2008)
- Sofiivskyi/Софіївський (botanical reservation of local importance, 194 ha, 1998);
- Shyroka Balka/Широка Балка (botanical reservation of local importance, 116 ha, 1998);
- Stanislavskyi/Станіславський (landscape reservation of state importance, 659 ha, 2002); and
- Oleksandrivskyi/Олександрівський (landscape reservation of state importance, 996 ha, 2002).

Natural Monuments

- Curtain of Ancient Oaks/Куртина вікових дубів (botanical natural monument, 0.1 ha, 1983)

Wetlands of International Importance (Ramsar sites)

- Tendrivska Bay (55,022 ha, 1997, Ramsar site No 768 RIS)
- Yagorlytska Bay (39,692.7 ha, 1997, Ramsar site No 116 RIS)

Emerald Network sites

- Biloberezhzhia Sviatoslava National Nature Park ASCI (35,242 ha, 2016, site code UA 0000097 SDF)
- Black Sea Biosphere Reserve ASCI (115,873.0 ha, 2016, site code UA 0000017 SDF)
- Dniprovsko-Buzkyi Lyman ASCI (71,276 ha, 2016, site code UA 0000109 SDF)
- Kinburnska Kosa ASCI (46,588 ha, 2016, site code UA 0000215 SDF)
- Loess outcrops of the Dnipro estuary ASCI (589.2 ha, 2020, site code UA 0000336 SDF)
- Zernov Phyllophora Field Zakaznyk ASCI (403,997.0 ha, 2016, site code UA 0000139 SDF)

UNESCO MAB Biosphere Reserves

- Chernomorskiy Biosphere Reserve (89,129 ha, 1984)

C. Located upstream from the Nova Kakhovka hydroelectric dam:

National Nature Parks

- Kamianska Sich National Nature Park/НПП Кам'янська Січ (12,261.14 ha, 2019), of which almost 78 per cent is included in the Emerald site Kakhovske Reservoir (see below)
- Velykyi Luh National Nature Park/НПП Великий Луг (16,756 ha, 2006)

Regional Landscape Parks

- Regional Landscape Park Panai/РЛП Панай (1,025 ha, 1998)

Reservations

- Kam'yansky Forest Massif/Кам'янський лісовий масив (landscape reservation of local importance, 239 ha, 1998)
- Kayirska Balka/Каїрська балка (landscape reservation of local importance, 664.9 ha, 2001)
- Floodplain of the Bazavluk River/Заплава р. Базавлук (ornithological reservation of local importance, 48.6 ha, 1990)

- Forest Massif na Lisiy Hori/Лісовий масив на Лісій Горі (landscape reservation of local importance, 700 ha, 1998)
- May Hora site/Урочище Май Гора (landscape reservation of local importance, 68 ha, 1984)
- Velyki and Mali Kuchuhury/Великі та Малі Кучугури (ornithological reservation of state importance, 400 ha, 1974)
- Vodyanski Kuchuhury/Водянські кучугури (landscape reservation of local importance, 1,237.5 ha, 1998)
- Steep slopes of the Kakhovka reservoir/Крутосхили Каховського водосховища (landscape reservation of state importance, 522.2 ha, 2002);
- Virgin area/Цілинна ділянка (botanical reservation of local importance, 2 ha, 1980)
- Ivanivsky Bir/Іванівський бір (landscape reservation of local importance, 793.3 ha, 1998)

Protected Sites

- Stoyany/Стояни (15 ha, 1983)
- Malokakhovsky Bir/Малокаховський бір (177 ha, 1979)

Dendrological Parks

- Dendrological Park of Kakhovka Forestry/Дендропарк Каховського лісгоспзагу (15 ha, 1964)

Wetlands of International Importance (Ramsar sites)

- Archipelago Velyki and Mali Kuchugury (7,740 ha, 2013, Ramsar site No 2282 RIS)
- Sim Maiakiv Floodplain (2,140 ha, 2013, Ramsar site No 2273 RIS)

Emerald Network sites

- Kakhovske Reservoir ASCI (218,119.0 ha, 2016, site code UA 0000106 SDF)
- Velykyi Luh National Nature Park ASCI (16,755.0 ha, 2016, site code UA 0000037 SDF).

D. Located in the surrounding region:

Biosphere Reserves

- Askania - Nova named after Friedrich Falz-Fein/ Біосферний заповідник 'Асканія-Нова" імені Фрідріха Фальц-Фейна (33,307 ha, established already in 1898)

Emerald Network sites

- Askaniia-Nova Biosphere Reserve (33,398.0 ha, 2016, site code UA0000016 SDF).

UNESCO MAB Biosphere Reserves

- Askaniya-Nova Biosphere Reserve (33,008 ha, 1985)

E. Prospective Protected Areas:

- Dolina Kurganiv/Долина Курганів (proposed as a regional landscape park or national nature park)
- six landscape reservations of state importance (Burgunska Balka/Бургунська балка, Vyazemsky/В'яземський, Donchikha/Дончиха, Zabarinye/Забарине, Korovodynsky/Короводинський and Tyahynska Balka/Тягинська балка)
- one botanical reservation of state importance (Kardashynske Bog/Кардашинське болото)
- one landscape reservation of local importance (Lesovyi Canyon/Лесовий каньйон)

- two botanical reservations of local importance (Vilkhovi Sagi/Вільхові Саги and Orlovsky/Орловський)
- one geological natural monument of local importance (Miocene Sediment Outcrops near Lvove Village/Відслонення відкладів міоцену біля села Львове)
- one complex natural monument of local importance (Baydi-Bombanderi/Байди-Бомбандери)
- seven botanical natural monuments of local importance – old trees (Ivanivsky Oak/Іванівський дуб, Mariykin Oak/Марійкин дуб, Mstyslav and Oleksiy Nestruiev Poplars/Тополі Мстислава та Олексія Неструєвих, Oleksiy Nestruiev Senior Poplar/Тополя Олексія Неструєва старшого, Sophia Faltz-Fein Poplar/Тополя Софії Фальц-Фейн, Starozburivska Poplar/Тополя Старозбур'ївська and Olga Ash/Ясен Ольги)
- two botanical natural monuments of local importance (Kurgan near Bratske/Курган біля Братського and Kurgan near Ochakivske/Курган біля Очаківського)

Annex IX: Soil investigation programme for the area along the Dnipro River affected by the Kakhovka dam break

This programme was drafted by Thomas Strassburger (Federal Ministry for the Environment, Germany) on 3 July 2023 and updated on 12 July 2023. It was subsequently shared with MEPNR and other partners.

This proposal greatly profited from contributions from Dr. Josef Backes (Ministry for Climate Protection, Environment, Energy and Mobility of the State of Rhineland-Palatinate), Dr. Michael Gierig (Bavarian State Agency for Environmental Protection), Stefan Schroers (Ministry for the Environment, Nature Conservation and Transport of the State of North Rhine-Westphalia) and the UK Centre for Ecology & Hydrology (peer-review)

Introductory remarks

This proposal follows the principle 'As little as possible but as much as necessary'. It considers the difficult situation due to the conditions of war, stretched resources as to sampling and coordinating. Presently there are still knowledge gaps. Depending on new findings the concept is to be adapted.

The release of up to 18 kilometres of water from the Kakhovka reservoir into the Dnipro River over a couple of days, following an explosion within the dam's structure on June 6, caused tremendous flooding of the downstream area, a stretch of some 90 km of length, ruining settlements, industrial zones, land used to produce food and fodder and also to a great extent numerous areas of high ecological value. A week after the dam broke, districts located near the river were still dealing with the consequences as the waters had not yet receded completely. The release of all sorts of unwanted chemicals, some of them toxic, could mean long term harm for the whole region; including the ecology of the Black Sea.

As to the aspects of contamination, the following concept is proposed to support identifying risks and to assess the scope of pollution[6]. The sampling strategy is designed to outline a procedural approach to inform the development of a targeted sampling programme. It sets the frame to support the work of, for example, local authorities. It is a pragmatic approach, but should not necessarily be considered comprehensive across all potential hazards. It should be placed into context of what could be considered a fully comprehensive post-disaster environmental and human health monitoring and assessment approach, to be developed in a later phase.

Underlying assumptions for a risk-based sampling approach

The following assumptions as to pollution sources have been taken:

<u>Mobilisation/transport of pollutants from within the flooding zone (high risk)</u>

- Serious pollution occurred via mechanical destruction of objects and facilities due to the hydro-mechanic power of the water released from the dam and, secondly, through the impact of flooding, releasing pollutants from facilities within residential and industrial areas, e.g. from oil tanks, storages of chemicals etc. It also caused mobilisation of contamination already existing before the dam break. The last one includes diffuse pollution of nutrients (mainly N and P) caused by erosion of topsoil or set off of fertilisers. This will have a negative impact mainly on the ecology of natural areas, including the sensitive estuary, and the Black Sea. It will be of less importance as to direct and indirect human health impacts and will not be considered here.

6. At the time of finalisation of this concept, 12 July 2023, no sufficient data is available to UNEP/EU's expert team on the real scope and intensity of contamination in the affected area downstream, nor on the legacy pollution of reservoir sediments; partly, due to war inflicted restrictions in the flow of information. Despite existing and available data to map possible high-risk sources, some openly available data may be of uncertain quality – including knowledge on the specific local impact of flooding. Thus, this concept is not into addressing specific sites of concern but rather framing a longer-term programme of monitoring and assessment.

Mobilisation/transport of compounds typical for explosives (medium risk)

- Depending on their polarity – some are quite water-soluble - explosive type compounds could have been further spread beyond the site of explosion; this might have caused additional contamination of soil and, following infiltration into the soil, will threaten groundwater quality. On the other side, the vast amount of reservoir water and the dilution factor could also have been of a beneficial impact rinsing some type of chemicals from the land to certain extent.

Water and sediments from the Kakhovka reservoir acting as source of pollution (lower risk)

- Due to the quality of the water itself, that is also used for irrigation and drinking water, this is not considered to play an important role despite the load of the water with some pollutants; reservoir sediments could play a major role, but it is assumed that the amount of sediments carried away by the outflowing water has been limited and could be reduced to the area in the vicinity of the dam breach(es). Furthermore, it could be assumed that the sediment load did reduce over time since most sediments were carried away by the pull of the water rather at the beginning. If so, some of the sediments from the reservoir were gradually carried away by the following water further towards the estuary. Nonetheless, sediments can pose a threat as to the remobilization of its contaminants.

Scope of contaminants

Sampling should include petroleum hydrocarbons (PCOs), polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins (PCDDs) polychlorinated dibenzofurans (PCDFs), polycyclic aromatic hydrocarbons (PAHs) and heavy metals. The scope of analysis could be extended to include volatile chlorinated hydrocarbons and compounds typical of explosives, depending on the local situation and the distribution of possible sources of contamination and, of-course, actual findings on the spot.

Considering Chernobyl and the nuclear power plant at Kakhovka reservoir, it is also recommended to screen for Cesium-137.

If there are indications of specific pollution, the parameter spectrum must be expanded. This applies in particular to the immediate vicinity of commercial and industrial sites/industrial operations that handle substances hazardous to water. For example, agricultural chemicals that might have been released by the flooding (e.g. from pesticide stores, warehouses) could be included in the parameter spectrum, where appropriate. Insecticides are of particular concern as they are hazardous even in very low concentrations.

Risk-based sampling approach

To limit the expense of soil testing, a step-by-step approach can be taken (use-related consideration). Areas of sensitive use are to be investigated as a matter of priority. Areas that are subject to a non-acute need for investigation due to their use are placed in a lower investigation priority.

Limiting the sampling area (temporary):

In general, sampling could exclude wide stretches of the riverbank to the north, as the steep cliff will not have allowed deposition but rather suffered from erosion. Natural areas, reserves and forest areas could be excluded from sampling as well. There is no need to invest scarce resources, since these areas must cope with the situation, unfortunately, and will need to recover over time. Surely, under present conditions there is limited chance for immediate action to be taken, not only but also due to dispersed live munitions across the assumed target sampling area.

Not into addressing specific sites of concern but rather framing a long-term programme of monitoring and assessment

A longer-term sampling strategy (i.e. post conflict) should provide the opportunity to set out a sampling strategy addressing the wider environmental and non-direct human exposure issues. Contamination of habitats may represent both a short-term and long-term exposure risk to humans; especially in an area where most of the impacted flood zone carries designation for conservation. As such, these habitats should be identified and the pollutant load both in soil and biota confirmed as soon as capacities will be available. This should also inform responses and guidance on consumption of potentially contaminated species.

Agricultural areas affected by flooding are mainly located south of the river. Due to the geography of the area sampling could be reduced to a small number of samples, as it is expected that contaminants including nutrients (fertilisers) and pesticide have been more or less equally distributed by the flood. As these sites are not too far from the estuary it might also been, that parts of the contaminants have been washed off. An analysis of some flood deposits and some samples of the underlying topsoil would be advisable. Due to the problems of unexploded ordnances and personal mines, access to the land will be restricted at present. Sites must be cleared first from debris too. Thus, sampling of agricultural sites can be postponed, but should be done as there is a high risk of contaminants entering the food chain from the fields.

Due to the relatively high organic carbon content of most soils in Ukraine, contaminants entering the soil will be immobilised to greater extent than in soils with a lower organic matter content. Still, even a fraction of the pollutant load would represent a potentially important exposure route, both for metals (including radionuclides) and organic pollutants.

Areas recommended to be sampled first:

Prioritisation of the areas to be investigated by the responsible authorities or supporting competent organisations is necessary. For example, a distinction is made between children's play areas, residential areas, industry/commercial space and agricultural land.

It is suggested to focus mainly on the area of Nova Kakhovka, the villages along the Dnipro, the flooded parts of Kherson, and if possible agricultural sites. Sampling along the Inhulets River should be done based on the use of affected sites. Initial sampling for the total area could be limited to a few but representative samples (a suggestion and subject to professional assessment is around 50 samples for an inital first response sampling).

First priority should be given to:

- Investigating sensitive areas, e.g. flooded children's playgrounds
- Investigating hot-spot areas:
    - sites of commercial-industrial operations from which hazardous substances could have been released while flooded (focus on those with certainty or high probability)[7]
    - still-water areas or slow flow zones, in which sedimentation of fine-grained sediments takes place at low/low flow and therefore higher contents can be assumed, and
    - other sites of high risks (waste sites, known contaminated sites, sites affected by ammunition etc.)

The initial limitation to children's playgrounds or gardens of residential areas and other sensitive sites will reduce the need for sampling in less sensitive sites, provided the results will show contamination of low concern. If sensitive sites are ok, there is no need to be worried about less sensitive areas in general. And only if the analyses confirm high levels of contamination in sensitive areas, there will be a need to investigate other sites too.

In case of flooding of sites with a higher risk of a release of contaminants, samples are to be taken to assess the situation on site and the risk exposure in the affected area. In general, on site-decisions have to be made to reduce or extend sampling, for example in case of sludge deposits or oil deposits.

7. Based on a list of critical facilities, received 30 June 2023 from the Ukrainian authorities, a further prioritisation and possible narrowing of the number of sampling sites will be done. Additionally, any data on background contaminants i.e. prior to the flood would be of use to adopt the sampling scheme.

Depending on source location, chemical properties and hydrology, the distribution pattern of pollutants may result in a rather even or more heterogeneous distribution of pollutants. To understand spatial trends in pollution levels, higher sampling rates would of course be helpful, but should be subject to a later phase of a soil investigation programme.

Localised anomalies of varying magnitude with mineral oil hydrocarbons, individual heavy metals or other contaminants will specify the need for action. Presently it is expected (depending on measured concentration) that there will be no need for remediation in the majority of cases.

If only small areas are affected or if alluvial material can be spatially delimited, a soil investigation may not be necessary. The material must then be disposed of in an appropriate manner.

Sampling of soil and sediments/flood deposit

To be able to assess the local situation in order to adapt the scope of analyses, samples of alluvial deposits should be taken and screened first - as far as they will be available; this will support better understanding of what has to be expected at all along the river.

Sampling of alluvial sediments (flood sludge) could be supplemented by limited additional sampling of the underlying 'pre-flood soil' to learn about the previous situation and to assess the significance of the additional chemical burden imposed. A selection of some reference points to distinguish between 'new and old problems' would be advisable.

Soil samples should be done as composite samples, whereby the sampling depth of the soil can initially be limited to the uppermost horizon (usually 10 cm), since we don't expect deep infiltration during the limited time of flooding.

If possible, despite all limitations due to the conditions of war, it could also be of an advantage to send screening samples - for non-target screening too - to different laboratories with different methods (liquid or gas chromatography / mass spectrometry). This procedure could help to indicate contamination; only very small sample quantities would be needed.

Given the size of the affected area, it would also be worth considering using pool samples, i.e. combining individual samples from larger areas (e.g. 5–10 each). Based on the results, further sampling would not be necessary if no contamination is detected. Only in case of contamination individual sample analysis would be advisable (follow-up investigation).

As to 'pooling' it should be noted though, that this may risk losing valuable information on depth profile and on average and worst-case scenarios. Similarly, knowing the heterogeneity of high and low concentrations and deposited depths will be important to confirming average and worst-case exposure scenarios and what solutions are necessary and/or possible to address the identified major problems. Thus, a sound ratio of pool samples and single location sampling would be advisable.

Reserve samples

The number of samples should exceed the number of samples to be initially analysed (suggestion: by a factor of 3). This will allow limiting the scope of contaminants at the beginning, avoiding follow-up sampling in risk or sensitive areas.

Reserve samples should be kept frozen or at least stored in a refrigerator and in the dark as air-dried samples. Under given circumstances, volatile and readily degradable substances should not be of main concern. Otherwise, a targeted, second sampling based on the first exploratory results is preferable.

Further comments

Sampling and analysing should be carried out—if possible—by one company and one laboratory in order to obtain results that are as comparable as possible. If different laboratories are to be involved to analyse common determinants, for example, to increase analytical capacity by using laboratories from other countries, then samples from defined geographic zones could be allocated to a dedicated laboratory to reduce interlaboratory bias. Preferably, laboratories involved should submit methodological reports and method quality assurance documentation and conduct inter-calibration testing to allow quantification of analytical uncertainty.

Additionally, to the aforementioned sampling aspects, it should be recalled at this point that the distribution of contaminants (e.g. metals including mercury, persistent organic pollutants) from remobilized sediments and other sources may render species unsuitable for human consumption, for example, in downstream fisheries or within hunting areas. This should also be taken into consideration as to a longer-term assessment.

Signed Thomas Strassburger

12 July 2023

Federal Ministry for the Environment, Germany

Annex X: Potential funding sources for biodiversity assessments and action

External financial support for assessments and remediation is urgent. Depending on the targeted financial institution, the documents referred to below can be used to determine potential funding sources.

In the light of the EU candidate status granted to Ukraine on 23 June 2022, the expected accession of Ukraine to the EU, as well as the availability of LIFE Programme funding allocation for Ukraine, future applications should probably first and foremost refer to the EU Biodiversity Strategy for 2030, expressing an explicit commitment towards the restoration of ecosystems, further enhanced by the recent (on 13 July 2023) approval of the EU Nature Restoration Law by the European Parliament, which will require Member States to submit National Restoration Plans to the Commission within two years of the Regulation coming into force.

References to the Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds ('Birds Directive', and its Annex I), the Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora ('Habitats Directive' and its Annexes I and II), and the Regulation (EU) No 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species could additionally strengthen the application.

Furthermore, the recently adopted CBD Kunming-Montreal Global Biodiversity Framework has set the Global Targets for 2030, among which the most relevant for the Kakhovka case would be Target 2 (expressing the requirement for the effective restoration of at least 30 per cent of areas of degraded terrestrial, inland water, and coastal and marine ecosystems by 2030) and Target 4 (concerning measures aimed at halting the extinction of threatened species and at their recovery, mentioning also the in situ and ex situ conservation of native wild species).

The reference to the above CBD GBF can further be strengthened by referring to the text of the 1992 UN Convention on Biological Diversity (CBD), in particular to its Article 8 (f) concerning in-situ conservation, which obliges the Parties to rehabilitate and restore degraded ecosystems, inter alia, through the development and implementation of plans or other management strategies, and Article 9 (c) concerning ex-situ conservation, stipulating the adoption of measures for the recovery and rehabilitation of threatened species and for their reintroduction into their natural habitats.

On 1 March 2019 the United Nations General Assembly declared 2021–2030 the UN Decade on Ecosystem Restoration, which could focus much more attention of the whole global society and its decision-makers on the protection of natural ecosystems, and measures aimed at their effective restoration, than it was the case in the past decades. The above initiative aims to drastically scale up the restoration of degraded and destroyed ecosystems, while the response to the Kakhovka environmental disaster will most probably include extensive ecosystem restoration works and measures.

It should also be mentioned, that numerous Targets set by the UN 2030 Agenda for Sustainable Development are quite relevant here, namely Target 6.6 (concerning the protection and restoration of water-related ecosystems, which include forests, wetlands, rivers, aquifers and lakes), Target 14.2 (concerning the protection of marine and coastal ecosystems to avoid significant adverse impacts, and taking actions for their restoration), Target 15.1 (concerning the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services), Target 15.2 (concerning, inter alia, the restoration of degraded forests), Target 15.3 (concerning, inter alia, combating desertification, and restoration of degraded land and soil, including land affected by floods), and Target 15.5 (concerning actions aimed at the reduction of the degradation of natural habitats, and preventing the extinction of threatened species).

Another particularly relevant strategic document is the Fourth Strategic Plan for 2016–2024 of the Ramsar Convention (adopted at Ramsar COP12 in June 2015) which also includes several relevant targets: Target 5 (addressing the need for the maintenance or restoration of the ecological character of Ramsar sites, through effective planning and integrated management), Target 7 (emphasising the need for addressing threats to sites that are at risk of change of ecological character), Target 12 (explicitly mentioning the restoration of degraded wetlands, with priority to wetlands that are relevant for biodiversity conservation), Target 15 (concerning the reinforcement of Ramsar Regional Initiatives), Target 17 (concerning the mobilisation of funds for implementation of this Ramsar Strategic Plan), Target 18 (emphasising the need for strengthening international cooperation at all levels), and Target 19 (concerning capacity building for implementation of the Convention and its 4th Ramsar Strategic Plan 2016–2024).

Last, but not least, in the Ministerial Declaration, adopted as an outcome of the Ninth Environment for Europe Ministerial Conference October 2022), European countries called for coordinated assessments of the war's impact on the environment and called for further support of Ukraine's post-war reconstruction.

Annex XI: Key national stakeholders for the implementation of recommendations

State authorities at the central level and specialised state agencies and services:

- Ministry of Environmental Protection and Natural Resources of Ukraine
- Ministry of Communities, Territories and Infrastructure Development of Ukraine
- Ministry of Internal Affairs of Ukraine
- Ministry of Economy of Ukraine
- Ministry of Finance of Ukraine
- Ministry of Reintegration of the Temporarily Occupied Territories of Ukraine
- Ministry of Agrarian Policy and Food of Ukraine
- Ministry of Family, Youth and Sports
- Ministry of Social Policy
- Ministry of Culture and Information Policy of Ukraine
- National Police of Ukraine
- Administration of the State Border Guard Service
- State Ecological Inspection of Ukraine (and its regional branches)
- State Emergency Service of Ukraine
- State Agency for the Restoration and Development of Infrastructure
- State Agency of Water Resources of Ukraine
- State Agency of Land Reclamation and Fisheries of Ukraine
- State Forest Resources Agency of Ukraine
- Armed Forces of Ukraine

Regional authorities:

- Regional Councils
- Heads of the Regional State Administration
- Regional Departments of Ecology and Natural Resources (subordinate to the Head of the respective regional state administration)
- Regional Departments of Forestry and Hunting
- Mykolaiv Regional Military Administration
- Dnipropetrovs'k Regional Military Administration
- Kherson Regional Military Administration
- Zaporizhizhia Regional Military Administration

Relevant funding institutions:

- State Fund for Environmental Protection
- Regional Funds for Environmental Protection

Scientific and research institutions, academic institutions and scientific advisory bodies:

- National Academy of Sciences of Ukraine (NAS of Ukraine), and its specialised institutes, e.g.:
    - M.G. Kholodny Institute of Botany of NAS of Ukraine
    - Kherson Hydrobiological Station of NAS of Ukraine
    - Schmalhausen Institute of Zoology of NAS of Ukraine

- Institute of Marine Biology of NAS of Ukraine in Odesa
- National Science and Natural History Museum of NAS of Ukraine
- Institute of Fisheries of the National Academy of Sciences of Ukraine
- Scientific Research Institution 'Ukrainian Center for Marine Ecology' (UkrSCME)
- National Research Center 'A.N. Sokolovsky Institute of Soil Science and Agrochemistry' of the National Academy of Sciences of Ukraine
- State Environmental Academy of Postgraduate Education and Management of the Ministry of Ecology
- Scientific Research Institution 'Ukrainian Research Institute of Ecological Problems'
- Institute of Evolutionary Ecology of the National Academy of Sciences of Ukraine
- Institute of Environmental Geochemistry of the National Academy of Sciences of Ukraine
- Institute of Geological Sciences of the National Academy of Sciences of Ukraine
- State Scientific Institution 'Center for Problems of Marine Geology, Geoecology and Sedimentary Ore Formation of the National Academy of Sciences of Ukraine'
- Institute of Telecommunications and Global Information Space of the National Academy of Sciences of Ukraine
- Institute of Water Problems and Land Reclamation of the National Academy of Sciences of Ukraine
- Kyiv Agrarian University of the National Academy of Sciences of Ukraine
- Institute of Geography of the National Academy of Sciences of Ukraine
- State Institution 'Institute of Environmental Economics and Sustainable Development of the National Academy of Sciences of Ukraine'
- H.M. Vysotsky Ukrainian Research Institute of Forestry and Agroforestry;

- Universities:
  - relevant faculties of the Kherson State University
  - relevant faculties of the Zaporizhzhia National University
  - relevant faculties of the V.O. Sukhomlynskyi National University of Mykolaiv
  - relevant faculties of the Odesa I. I. Mechnykov National University
  - relevant faculties of the Oles Honchar Dnipro National University
  - Educational and Scientific Center 'Institute of Biology and Medicine' of the Taras Shevchenko National University of Kyiv
- Scientific and Technical Councils of particular protected areas (biosphere reserves and national nature parks)

Key local stakeholders:

- Protected area administrations (e.g. biosphere reserves and national nature parks)
- District Councils
- Territorial Defence units
- State Forestry units.

Others:

- All-Ukrainian Environmental League
- Association of Environmental Professionals 'PAEW'

UN
environment
programme