

**Rapid Assessment:
Impact of the Kakhovka Hydroelectric Station
Destruction**

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Yale SCHOOL OF PUBLIC HEALTH
Humanitarian Research Lab

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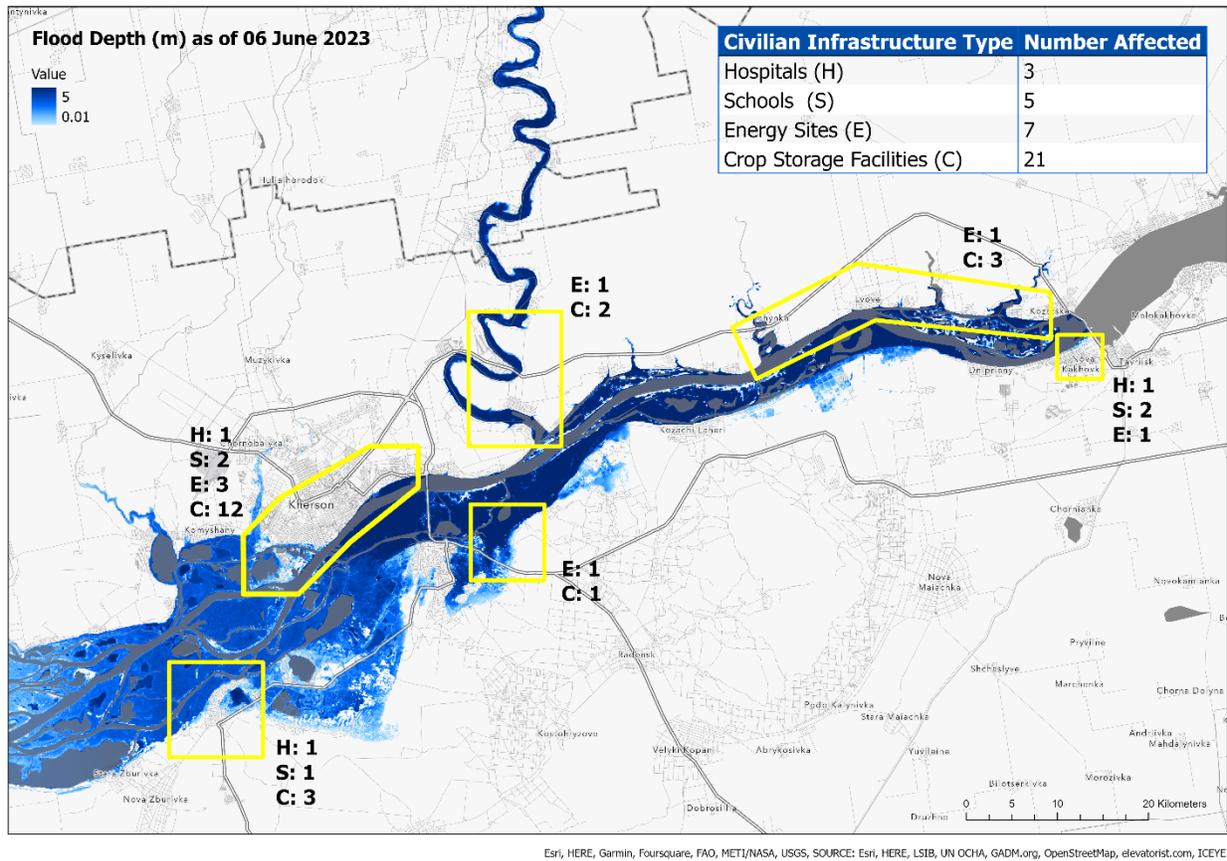
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Rapid Assessment: Impact of the Kakhovka Dam Destruction

The catastrophic failure of the Kakhovka Hydroelectric Station Dam on 6 June 2023 has flooded an estimated 520 square kilometers of southern Ukraine, including all or part of 51 towns and villages. The affected area contains at least five (5) schools, three (3) hospitals, seven (7) power and energy facilities, and twenty-one (21) crop storage facilities (river silos). Additional Protocols I and II to the Geneva Conventions forbid attacks on “installations containing dangerous forces” even if they are military objects, if such an attack may “release dangerous forces” and cause severe losses among civilians.ⁱ



Map 1. Map illustrating the extent of flooding of the Dnipro River downstream from the Kakhovka Hydroelectric Station Dam in Nova Kakhovka, as of 06 June 2023, and the numbers of civilian infrastructure sites impacted, including health facilities, schools, energy sites, and crop storage facilities, represented by the areas outlined in yellow.

Background

Between 2:00am and 3:00am local time on the morning of 6 June 2022, the Kakhovka Hydroelectric Station experienced a catastrophic failure, leading to uncontrolled release of water from the Kakhovka Reservoir.ⁱⁱ The Norwegian Seismic Array (NOSAR) published seismic data from a station in Romania, pointing to a blast occurring at the site at 2:54 am local time.ⁱⁱⁱ Drone footage, photographs, and videos taken soon after sunrise (4:58am) show a large gap in

the dam with two large buildings damaged and surrounded by water from the Dnipro River. Satellite imagery indicates more than 570 meters of the middle section of the dam missing. Yale HRL has not reached any conclusions regarding attribution in this report nor has any other independent evaluation been published. United States officials have told media that they have intelligence “leaning towards” Russia’s responsibility. Ukraine’s government has also claimed to have intercepted communications showing Russia’s responsibility for the failure, though

Yale HRL has not verified these assertions.^{iv} Russia's forces have occupied the dam and its control systems since 24 February 2022, the first day of Russia's full-scale invasion of Ukraine.^v In the days prior to the dam's catastrophic failure, water levels in the Kakhovka Reservoir had reached 30-year highs and there were signs of uncontrolled releases of water and apparent damage to the dam's structure.^{vi}

Impacts on Civilian Infrastructure

Flooding caused by the failure of the Kakhovka dam has destroyed and damaged homes, critical infrastructure, and protected civilian objects on both banks of the Dnipro River (Map 1). Yale HRL identified five (5) schools within the flood zone. Three (3) hospitals are also present in the affected areas. In addition, twenty-one (21) crop storage facilities (river silos) with a total storage capacity of 621,700 metric tons are present. Finally, seven (7) electrical substations and solar farms are located in the flooded areas.

The United Nations Satellite Centre (UNOSAT) has estimated that 520 square kilometers of land had been flooded by 7 June 2023, using the same ICEYE dataset analyzed by Yale HRL. Of these, UNOSAT found that 225 square kilometers fell outside of the riverbed, and that 87 impacted square kilometers were urban areas. Yale HRL has established that all or part of at least 51 towns and villages have experienced flooding.

Due to the massive population movements resulting from Russia's full-scale invasion of Ukraine, as well as limitations in available pre-invasion data, Yale HRL does not estimate the number of people impacted by flooding in the documented areas. Ukraine's Deputy Prosecutor General has estimated that 40,000 people on both banks of the river would need to be evacuated, while the United States Department of State has said that as many as 20,000 people may need to be resettled.^{vii}

Additional Impacts

Upstream from the dam, drainage of the Kakhovka reservoir is projected to cut off 31 irrigation systems supplying 584,000 hectares of agricultural land and may threaten cooling at the Zaporizhzhia Nuclear Power Plant, according to the International Atomic Energy Agency.^{viii} The floodwaters have not only displaced civilians and destroyed or damaged buildings, they have also swept large amounts of debris downstream. Open source videos have shown large objects—including a house—floating in the engorged river.^{ix} Toxic industrial chemicals, military materiel, human and animal waste, and other hazardous materials are almost certainly being displaced and carried to downstream communities. Included in this detritus is unexploded ordinance (UXO) that could include anti-personnel and anti-tank mines, artillery shells, and explosive remnants of war including cruise missiles, cluster munitions and other explosive objects that have failed to fully or partially detonate.^x The Halo Trust has already documented flooding in a minefield resulting from the dam failure and is monitoring the movement of submerged mines.^{xi}

Methodology

Yale HRL analysts used commercially available, very high resolution (VHR) satellite imagery as well as synthetic aperture radar (SAR) data provided by ICEYE to outline polygons covering the pre- and post-flood extents of the Dnipro River below (south of) the dam, the areas of which were then compared. After establishing the extent of the flooding, analysts overlaid data from OpenStreetMap,^{xii} the National Health Service of Ukraine, and the United States Department of Agriculture Foreign Agricultural Service^{xiii} to establish the number of relevant facilities within the flood area and the number of municipalities impacted.

Estimations of damage to civilian objects are based on the extent of the flood area and may be affected by local elevation variation. Given the rapidly changing situation and local topography variation, it

is possible that some structures within the flooded area may not have experienced flooding themselves. Likewise, the time of day at which satellite imagery was acquired has a significant effect on the analysis of area impacted. Ukraine government officials estimated that the river would crest on 7 June and

begin to recede within three to four days.^{xiv} In estimating the flooding's extent, UNOSAT used imagery from 7 June, while Yale HRL conducted analysis beginning on 6 June. Further civilian infrastructure was therefore almost certainly impacted after this analysis was conducted.

ⁱ International Committee of the Red Cross (ICRC), Protocol Additional to the Geneva Conventions of 12 August 1949, and relating to the Protection of Victims of International Armed Conflicts (Protocol I),” Article 56, 1977, <https://archive.ph/bfNpl>, <https://ihl-databases.icrc.org/en/ihl-treaties/api-1977/article-56?activeTab=undefined>.

ⁱⁱ “Russian Offensive Campaign Assessment, June 6, 2023,” Institute for the Study of War, accessed June 9, 2023, <https://perma.cc/X7UB-YXJG>, <https://www.understandingwar.org/backgrounder/russian-offensive-campaign-assessment-june-6-2023>.

ⁱⁱⁱ “Norwegian Seismologists Say Data Shows Explosions at Time of Ukraine Dam Blast,” Reuters, June 9, 2023, <https://archive.ph/88Hff>, <https://www.reuters.com/world/europe/norwegian-seismologists-say-data-shows-explosions-time-ukraine-dam-blast-2023-06-09/>.

^{iv} “Ukraine and Russia Accuse Each Other of Blowing up Nova Kakhovka Dam,” NBC News, June 6, 2023, <https://archive.ph/T81Wm>, <https://www.nbcnews.com/news/world/live-blog/khakovka-dam-live-updates-ukraine-russia-blew-up-kherson-rcna87855>;

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^v Дмитро, “‘Мешканці Каховки Прагнуть Показати Світові, Що Вони – Українці і Що Їх Не Треба Ні Від Кого Визволяти’. Інтерв’ю Каховського Міського Голови,” Децентралізація, accessed June 8, 2023, <https://archive.ph/v3ya2>, <https://decentralization.gov.ua/news/14796>.

^{vi} Sabbagh, Dan, and Julian Borger, “Thousands Flee Homes as Collapse of Dam Is Blamed on Russian Forces.” The Guardian, June 6, 2023, <https://archive.ph/e8PRj>, <https://www.theguardian.com/world/2023/jun/06/ukraine-accuses-russia-of-blowing-up-nova-kakhovka-dam-near-kherson>;

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; Telegram, Accessed June 8, 2023, <https://archive.ph/QPqvY>, <https://t.me/investigatorua/5552>.

^{vii} Binley, Alex, and Paul Adams, “Ukraine Dam: Thousands Flee Floods after Dam Collapse near Nova Kakhovka,” BBC, June 6, 2023 <https://archive.ph/FYRHI>, <https://www.bbc.com/news/world-europe-65819591>.

; “Department Press Briefing – June 7, 2023,” U.S Department of State, June 7, 2023, <https://archive.ph/QyZbD>, https://www.state.gov/?post_type=state_briefing&%3Bp=92333.

^{viii} “Update 162 – IAEA Director General Statement on Situation in Ukraine,” IAEA, June 7, 2023,

<https://archive.ph/wZ3fN>, <https://www.iaea.org/newscenter/pressreleases/update-162-iaea-director-general-statement-on-situation-in-ukraine>.; Polityuk, Pavel, “Dam’s Destruction May Cause ‘much Bigger’ Problem for Ukraine Farming -Minister,” Reuters, June 8, 2023, <https://archive.ph/kKVID>, <https://www.reuters.com/world/europe/dams-destruction-may-cause-much-bigger-problem-ukraine-farming-minister-2023-06-08/>.

^{ix} “Video: House Floats after Ukrainian Dam Collapse,” CNN, June 7, 2023, <https://archive.ph/7pBuA>,

<https://www.cnn.com/videos/world/2023/06/07/ukraine-dam-collapse-house-floating-lon-orig-na.cnn>.

^x John Bacon, Kim Hjelmggaard, and Jorge L. Ortiz, “Floating Mines, Contaminated Water, Dead Fish among Threats from Dam Breach: Ukraine Updates,” USA Today, accessed June 8, 2023, <https://perma.cc/25MS-GXNG>, <https://www.usatoday.com/story/news/world/2023/06/07/ukraine-dam-breach-un-warns-of-grave-and-far-reaching-consequences/70296400007/>;

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^{xi} The HALO Trust, Twitter, June 6, 2023, <https://archive.ph/mrbfO>,

<https://twitter.com/TheHALOTrust/status/1666119369968037903>.

^{xii} OpenStreetMap, Accessed June 8, 2023, <https://archive.ph/yILMS>,

<https://www.openstreetmap.org/#map=4/38.01/-95.84>.

^{xiii} Data certified crop storage locations scraped from the Elevatorist website in 2019 was provided to Yale HRL by the US Department of Agriculture. It is no longer publicly available.

^{xiv} Al Jazeera, “Ukraine’s Zelenskyy Says Dam Blast Will Not Stop Military Plans,” June 7, 2023, <https://archive.ph/VxZLg>, <https://www.aljazeera.com/news/2023/6/7/ukraines-zelenskyy-says-dam-blast-will-not-stop-military-plans>.

^{xv} BBC News Україна, Telegram, accessed June 8, 2023, <https://archive.ph/Iod8T>, <https://t.me/bbcukrainian/17129>.

^{xvi} Alex Kokcharov, Twitter, June 7, 2023, <https://archive.ph/O3Y9N>,

<https://twitter.com/AlexKokcharov/status/1666344749891035138>.

^{xvii} *Херсон Обстановка Херсонщини*, YouTube, 2023, 0:37, <https://ghostarchive.org/varchive/zb1yyuhf1kM>,

<https://www.youtube.com/watch?v=zb1yyuhf1kM>.

Annex I: Visuals of Dnipro Flooding Impact

TYAHYNKA, KHERSON OBLAST

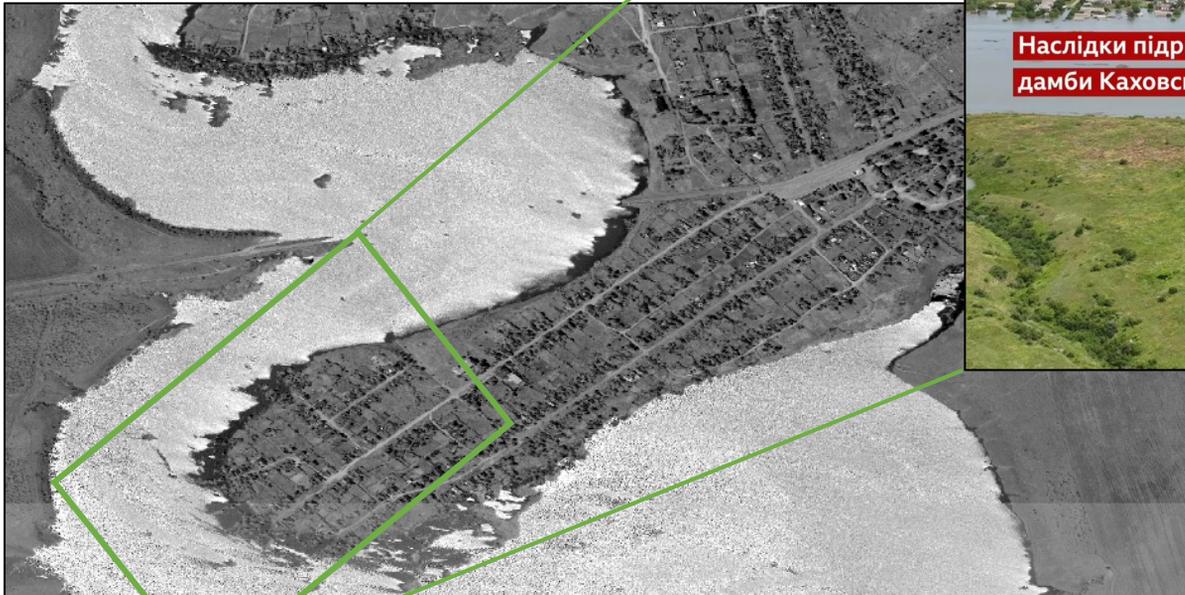


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Image 1. Satellite imagery from 23 May indicates the appearance of the town prior to the destruction of the flood.



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Image 2. Satellite imagery from 6 June 2023 after the collapse of the Kakhovka Dam showing heavy flooding of Tyahynka town. The Beryslavske Highway, the main ingress and egress route to and from the town, is completely covered in standing water where it crosses the river. Drone footage published 6 June by the BBC documents the Tyahynka flooding.^{xi}

OLESHKY, KHERSON OBLAST



Image 3. Satellite imagery captured 31 May 2023 indicates the appearance of structures and roadways on the northeast side of the town of Oleshky prior to the Kakhovka Dam's destruction. © 2023 Maxar



Image 4. Satellite imagery captured 6 June 2023 indicates heavy flooding over the banks of the Dnipro River and inundation of structures on the northeast side of the town of Oleshky. A 600-meter section of the M14 Highway in northeast Oleshky, the main ingress and egress route from the town, is visibly covered in standing water.

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Open source non-attributed drone footage shows flooding along Highway M14 in Oleshky.^{xvi}



HOLA PRYSTAN', KHERSON OBLAST

IMAGE 7. Satellite imagery captured 15 April 2023 indicates the appearance of part of the town of Hola Prystan' prior to the destruction of the flood.



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Image 8. Satellite imagery captured 8 June 2023 indicates the scale of flooding in the town of Hola Prystan', approximately 21 kilometers downstream from the Kakhovka Dam. An open source video of the flooding of Hola Prystan' shows civilians evacuating by boat.^{xvii}