Project report

Flood detection near Kakhovka Dam
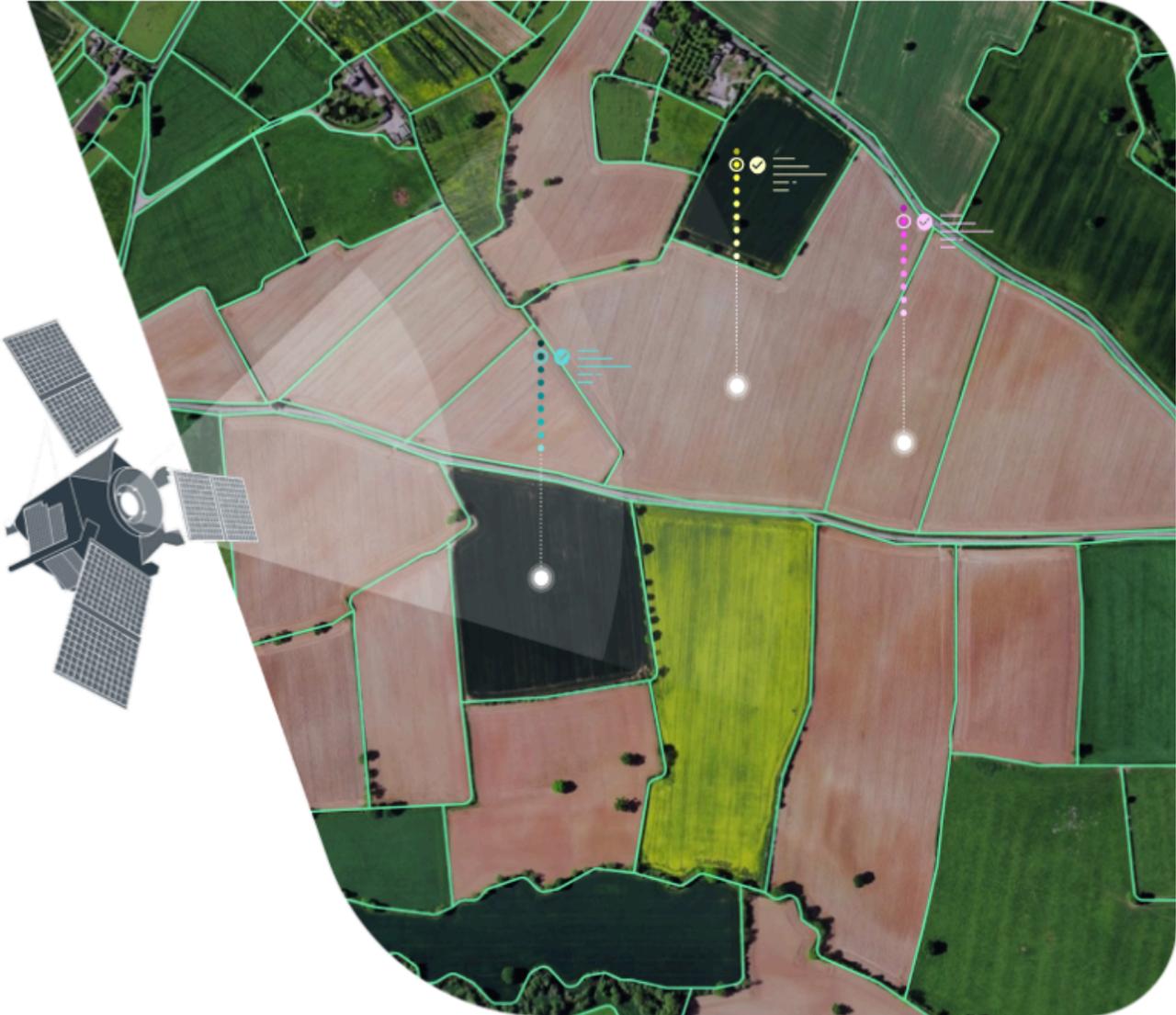
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1. Introduction

1.1. Purpose of the analysis

The purpose of the analysis is to detect and visualize the flood caused by the destruction of the Kakhovka dam, Nova Kakhovka city, Kherson region, Ukraine, based on the technologies of remote sensing of the earth using available optical and radar satellite images.

The main objectives of the analysis are:

❖ Visualization of different stages of flooding (and decline in water level in the reservoir above the Kakhovka dam) around the bed of the Dnipro River and part of its tributary, the Ingulets River for dates for which open-source optical or radar satellite images are available

❖ Analysis and calculation of the spatial (geometric) flood area of the zone below the Kakhovka dam at different stages of water movement for dates for which open-source optical or radar satellite images are available

Visualization of different stages of flooding is presented and described in this report and supplementary materials by specialists from the GIS and Data analysis departments of EOSDA. The description and interpretation are based solely on the results of the analysis of satellite images and their processing and will reflect changes in the spatial distribution of water identified on satellite images available from EOSDA during the analysis

1.2. Analysis temporal extent

The period of analysis was selected in accordance with the principle of efficient use of resources for images processing, in particular, detailed analysis was carried out only for the period when significant changes in the spatial distribution of water were observed in the project area of interest (AOI).

The starting date for the analysis is June 5, 2023, the day before the dam explosion (a small part of the territory of interest was also covered by images from June 3, 2023, but the prevailing part of the territory was analyzed specifically on images from June 5, 2023). Ths date was chosen because it is closest to the explosion date for which cloudless optical images are available.

The final analysis date is August 29, 2023. The difference between water extent on the pre-last (July 5, 2023) and last analysis dates is insignificant, but August 28, 2023, was included in the analysis to ensure that significant changes in the spatial distribution of water in the area of interest would not be missed.

Accordingly, the period of analysis within the project (analysis temporal extent) is June 5, 2023 (June 3, 2023 for minor part of AOI) - August 28, 2023. All analytics and calculations were performed only on satellite images available during the mentioned period and meeting the image selection criteria.

Also, for some small areas, high-resolution images from June 6 and 7, 2023 were used (for visualization purpose only)

1.3. Analysis spatial extent

The spatial areas of interest for the project were selected based on the principle of sufficient coverage of areas with significant water spatial distribution changes while maintaining the efficiency of data processing. This report will operate on two key concepts in relation to spatial extent: 1) Geographical scope of water movement analysis and 2) Geographical scope of flood area calculation

Geographical scope of water movement analysis

This scope is selected for a visual analysis of changes in the water mask for the target period based on available image dates for the AOI, which includes the Dnipro River bed from the city of Zaporizhzhya to the Dnipro River delta below the city of Kherson as well as additional Inhulets River zone and a buffer area near the river.

A visualization of this area of the project is provided below. The image below shows an approximate outline of the area of interest for visualization, but during the analysis only the beds of the mentioned rivers and some small buffers area around the rivers beds were analyzed in detail. For these zones, water masks are created for different stages of the flood and displayed as visualization. For this zone, only a visualization of the water mask is created (this is optimal option from the point of view of obtaining maximum informative data with minimal and efficient processing resources)
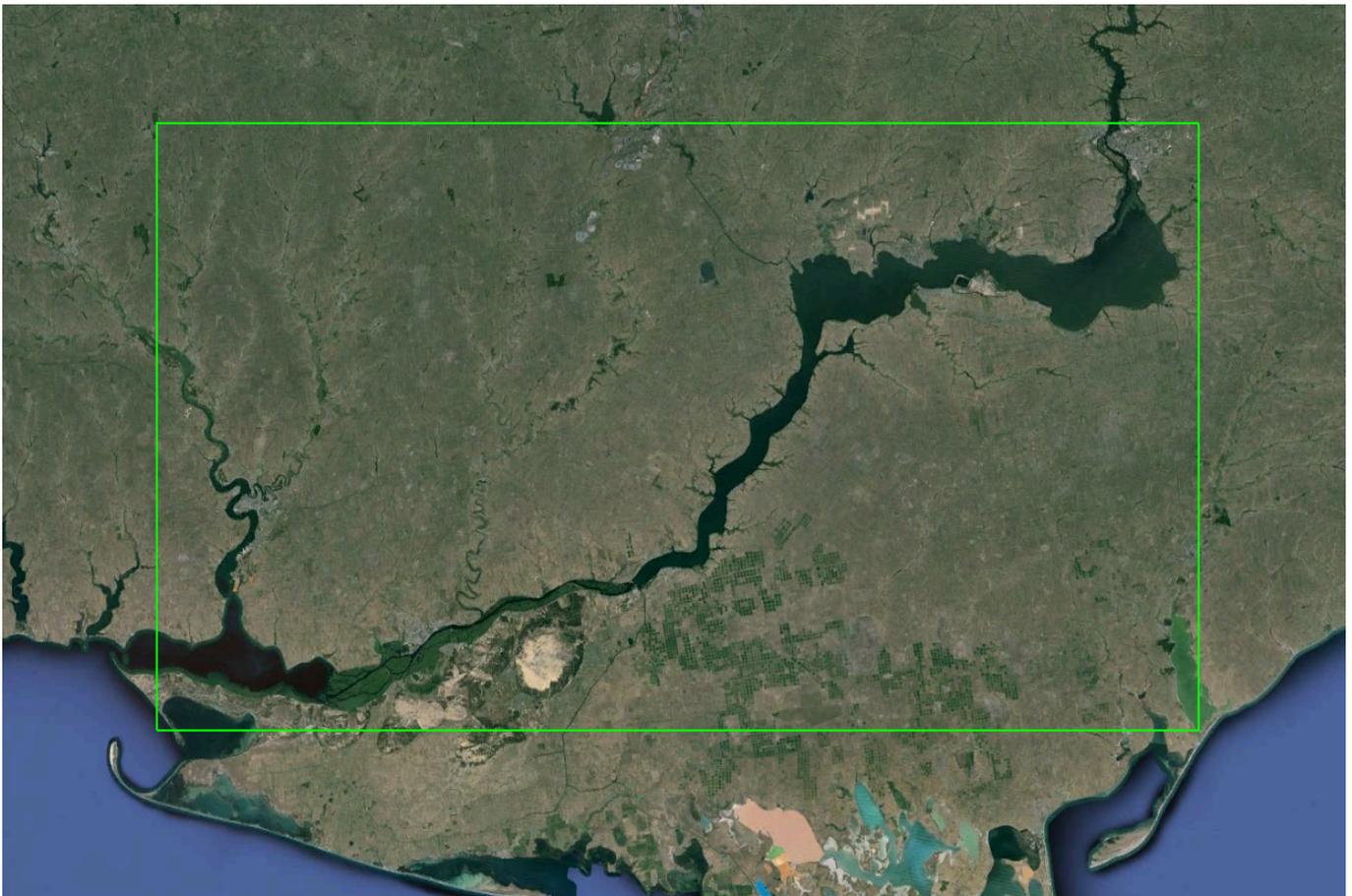
Geographical scope of flood area calculation

This scope is selected for flood spatial area calculation. Flood areas for different dates are calculated only within this spatial scope. This scope is selected as optimal from the point of view of analysis purposes and processing efficiency and includes the Dnipro River bed below the dam to the Dnipro River delta below the city of Kherson as well as additional Inhulets river zone and a buffer area near the river beds.
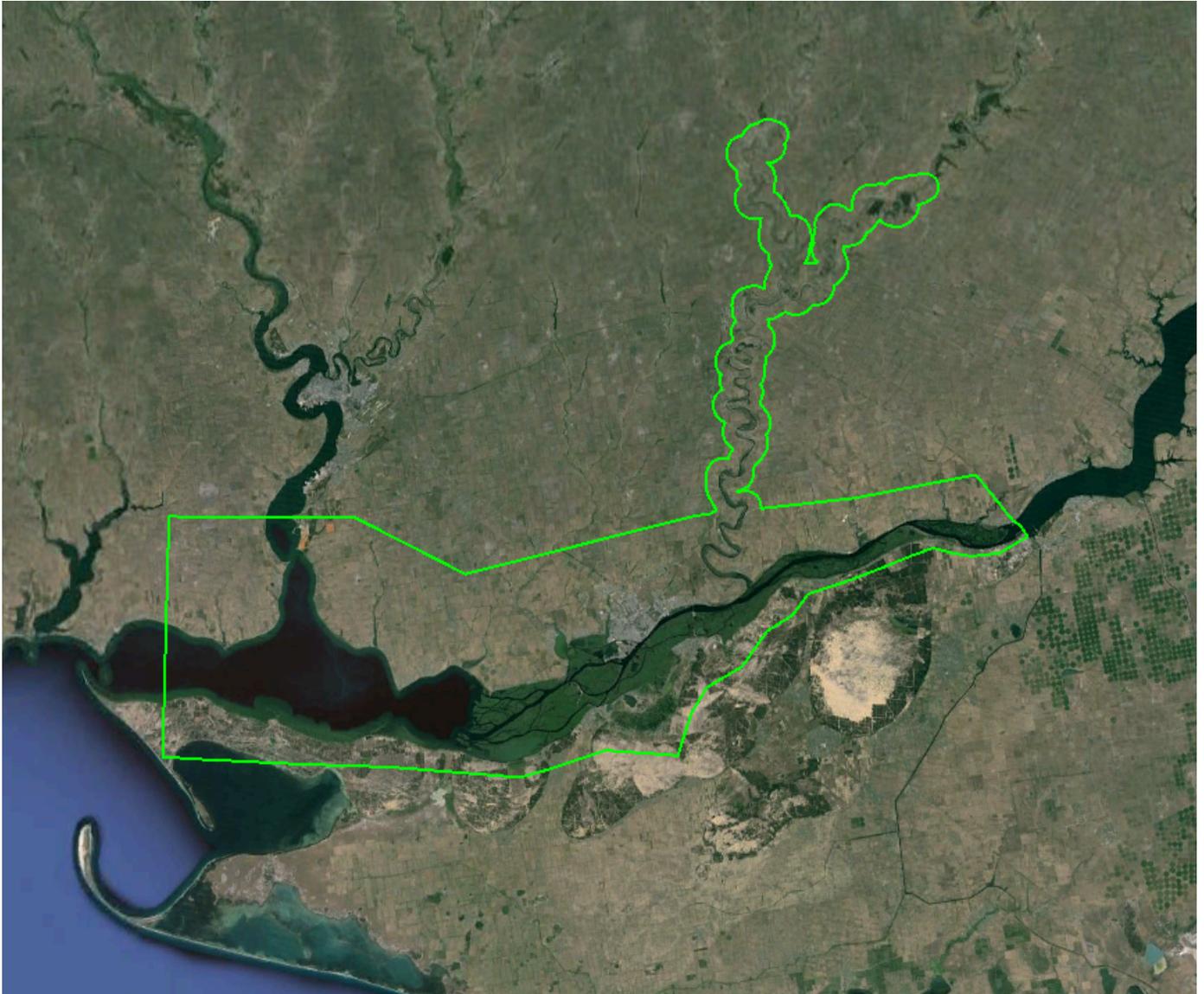
A visualization of this area of the project is provided below. The image below shows an outline of the area of interest for flood area calculation, for these zones flood areas are calculated for different stages of the flood and provided in tabular/ chart format.

During the analysis, some water bodies were excluded from the analysis for processing efficiency purposes, this is described in more detail in the following sections of this document

2. Data and methodology

2.1. Primary data used

Methodology for imagery selection

Open-source satellite images that cover the areas of interest (spatial extent) and the period of analysis (temporal extent) were used to implement the project. The following criteria were used when selecting satellite images for the project:

❖ The image covers a significant part of the area of interest of the project

❖ The date and time of the image fall into the range of analysis dates (project analysis period, temporal extent)

❖ Optical images (if available) are given higher priority since they are more optimal and informative for analysis purposes. If there are no optical images for the required zone and date, radar (SAR) images are searched and selected

❖ Higher resolution images (10x10m pixels) are given priority. If images of such resolution are not available for the required zone and date, images with a lower spatial resolution are searched and selected (for example, the Landsat satellite with a resolution of 30x30m pixels)

❖ The key factor in selecting optical images is the image cloudiness level (% of image area covered with clouds). If cloud-free images are not available for the required area and date, radar (SAR) images or images with a lower spatial resolution are searched are selected

An important complicating factor in the analysis is the high cloudiness in the area of interest in the first days after the explosion of the Kakhovka dam (6 June 2023, between 2 and 4am). The first open-source optical cloud-free image (from the Sentinel-2 satellite, 10m resolution) was available on July 5, 2023.

To level out this factor, a search and processing of radar images and images of lower resolution was performed. Sentinel-1 radar images were used. Revisit time of Sentinel-1 (the period between two flights over one point on the earth) is now from 10 to 15 days, since only one satellite operates in orbit, the second satellite, namely Sentinel-1B, left orbit on December 23, 2021 (emergency termination of satellite mission), but we were able to obtain such an image for the required range of dates in the first days of the flooding. Images from the Landsat-9 optical sensor with 30m resolution were also used. Such measures made it possible to obtain analytics in the first days after the dam explosion, namely on June 9, 2023.

List of used imagery

The table below provides a list of images used to cover project areas of interest for further analysis. The table contains information about image dates and sensor type, as well as original image IDs from the image providers

Date and time	Sensor	Image ID	Notes
		Medium resolution imagery	
June 05, 2023,08:36	Sentinel-2A	S2A_MSIL2A_20230605T083601_T36TVT	Optical sensor, 10m
June 05, 2023,08:36	Sentinel-2A	S2A_MSIL2A_20230605T083601_T36TWS	Optical sensor, 10m
June 05, 2023,08:36	Sentinel-2A	S2A_MSIL2A_20230605T083601_T36TXT	Optical sensor, 10m
June 05, 2023,08:36	Sentinel-2A	S2A_MSIL2A_20230605T083601_T36UXU	Optical sensor, 10m
June 03, 2023,08:45	Sentinel-2B	S2B_MSIL2A_20230603T084559_T36TVS	Optical sensor, 10m
June 03, 2023,08:45	Sentinel-2B	S2B_MSIL2A_20230603T084559_T36TVT	Optical sensor, 10m
June 08, 2023,08:46	Sentinel-2A	S2A_MSIL2A_20230608T08460_T36TVS	Optical sensor, 10m
June 08, 2023,08:46	Sentinel-2A	S2A_MSIL2A_20230608T08460_T36TVT	Optical sensor, 10m
June 08, 2023,08:46	Sentinel-2A	S2A_MSIL2A_20230608T08460_T36TWS	Optical sensor, 10m
June 08, 2023,08:46	Sentinel-2A	S2A_MSIL2A_20230608T08460_T36TWT	Optical sensor, 10m
July 05, 2023,08:36	Sentinel-2A	S2A_MSIL2A_20230705T083601_T36TVT	Optical sensor, 10m
July 05, 2023,08:36	Sentinel-2A	S2A_MSIL2A_20230705T083601_T36TWS	Optical sensor, 10m
July 05, 2023,08:36	Sentinel-2A	S2A_MSIL2A_20230705T083601_T36TWT	Optical sensor, 10m
July 05, 2023,08:36	Sentinel-2A	S2A_MSIL2A_20230705T083601_T36TXT_	Optical sensor, 10m
July 05, 2023,08:36	Sentinel-2A	S2A_MSIL2A_20230705T083601_T36UXU	Optical sensor, 10m
July 03, 2023,08:46	Sentinel-2B	S2B_MSIL2A_20230703T084609_T36TVS_	Optical sensor, 10m
July 03, 2023,08:46	Sentinel-2B	S2B_MSIL2A_20230703T084609_T36TVT	Optical sensor, 10m
August 24, 2023,08:36	Sentinel-2A	S2A_MSIL2A_20230824T083611_T36TWS	Optical sensor, 10m
August 27, 2023,08:46	Sentinel-2A	S2A_MSIL2A_20230827T084601_T36TVS	Optical sensor, 10m
August 27, 2023,08:46	Sentinel-2A	S2A_MSIL2A_20230827T084601_T36TVT	Optical sensor, 10m
August 27, 2023,08:46	Sentinel-2A	S2A_MSIL2A_20230827T084601_T36TWT	Optical sensor, 10m
August 29, 2023,08:36	Sentinel-2B	S2B_MSIL2A_20230829T083609_T36TXT	Optical sensor, 10m

Date and time	Sensor	Image ID	Notes
August 29, 2023,08:36	Sentinel-2B	S2B_MSIL2A_20230829T083609_T36UXU	Optical sensor, 10m
June 06, 2023	Landsat-9	LC09_L2SP_179028_20230609_20230611_02_T1	Optical sensor, 30m
June 06, 2023	Landsat-9	LC09_L2SP_179027_20230609_20230611_02_T1	Optical sensor, 30m
June 06, 2023,15:37	Sentinel-1A	S1A_IW_GRDH_1SDV_20230609T153657_20230609T153722_048911_05E1BA_81D1	Radar sensor, 10m
June 06, 2023,15:37	Sentinel-1A	S1A_IW_GRDH_1SDV_20230609T153722_20230609T153747_048911_05E1BA_72F1	Radar sensor, 10m
High resolution imagery			
June 07, 2023 08:06	GEOSAT	DE2_PSH_L1C_000000_20230607T080559_20230607T080603_DE2_48592_0278	Optical sensor, 0.75m
June 06, 2023 08:06	GEOSAT	DE2_PSH_L1C_000000_20230606T075217_20230606T075220_DE2_48577_628E	Optical sensor, 0.75m
June 06, 2023 08:06	GEOSAT	DE2_PSH_L1C_000000_20230606T075219_20230606T075221_DE2_48577_BFD2	Optical sensor, 0.75m
July 05, 2023 08:03	GEOSAT	DE2_PSH_L1C_000000_20230705T080334_20230705T080338_DE2_49008_8E66	Optical sensor, 0.75m
July 05, 2023 08:03	GEOSAT	DE2_PSH_L1C_000000_20230705T080332_20230705T080335_DE2_49008_8CAC	Optical sensor, 0.75m

2.2. Data processing

Preprocessing of raw imagery

To analyze and use images in pipelines, image preprocessing is required, this is relevant for both optical images and radar.

Sentinel-2 and Landsat-8\9 images are used in L2A format. The Level-2A product provides atmospherically corrected Surface Reflectance (SR) images, derived from the associated Level-1C products. Each Level-2A product is composed of 110x110 km2 tiles in cartographic geometry (UTM/WGS84 projection).

Level-1C image data (left) and associated Level-2A surface reflectance image data (right) generated using Sen2Cor processor

The atmospheric correction of Sentinel-2 images includes the correction of the scattering of air molecules (Rayleigh scattering), of the absorbing and scattering effects of atmospheric gases, in particular ozone, oxygen and water vapor and the correction of absorption and scattering due to aerosol particles.

In this project, optical images for AOI did not require significant pre-processing (for some areas of the earth's surface, L2A level images are missing and they need to be additionally processed from L1C to L2A, but this was not required in the project and ready-to-use L2A images were applied).

Radar images require more complex preprocessing. Sentinel-1 images in GRD format are used. Level-1 Ground Range Detected (GRD) products consist of focused SAR data that has been detected, multi-looked and projected to ground range using an Earth ellipsoid model. The ellipsoid projection of the GRD products is corrected using the terrain height specified in the product general annotation. The terrain height used varies in azimuth but is constant in range. Ground range coordinates are the slant range coordinates projected onto the ellipsoid of the Earth. Pixel values represent detected magnitude.

To detect water bodies, additional pre-processing is carried out based on an algorithm that was developed at EOSDA (it constitutes the company's IP and cannot be disclosed). A special polarization is used in combination with selected coefficients and the application of Speakle filters to obtain a raster mask, which can then be used for basic processing and transformed into a vector layer for editing.

The Speckle function removes speckle in radar datasets and smooths out noise, while retaining edges and sharp features in the image. Speckle is the high-frequency noise that exists in radar images. The images generated by laser, ultrasound, and synthetic aperture radar (SAR) systems are subject to speckle noise due to the interference of the returning electromagnetic waves scattered from multiple surfaces.

The Speckle function uses mathematical models to filter the bright and dark spots that are generated as a result of interference, to allow better image interpretation

Digitalization

Vectorization of water bodies is carried out in semi-automatic mode. Combinations of spectral bands were used to calculate the NDWI index based on optical satellite images Sentinel-2 and Landsat-8\9.

The Normalized Difference Water Index (NDWI) is used to highlight open water features in a satellite image, allowing a water body to "stand out" against the soil and vegetation. The NDWI is calculated using the GREEN-NIR (visible green and near-infrared) combination, which allows it to detect subtle changes in water content of the water bodies. The NDWI index was proposed by McFeeters in 1996. Its primary use today is to detect and monitor slight changes in water content of the water bodies. Taking advantage of the NIR (near-infrared) and GREEN (visible green) spectral bands, the NDWI is capable of enhancing the water bodies in a satellite image. The downside of the index is that it is sensitive to built structures, which can lead to overestimation of water bodies.

The NDWI equation:

NDWI = (Green – NIR)/(Green + NIR)

Values of water bodies are larger than 0.5. Vegetation has much smaller values, which results in distinguishing vegetation from water bodies easier. Built-up features have positive values between 0 and 0.2. The NDWI values correspond to the following ranges:

❖ 0.2 – 1 – Water surface,
❖ 0.0 – 0.2 – Flooding, humidity,
❖ -0.3 – 0.0 – Moderate drought, non-aqueous surfaces,
❖ -1 – -0.3 – Drought, non-aqueous surfaces

As a result, a raster mask with the boundaries of water bodies was obtained (with a pixel size of 10m for Sentinel-2 and 30m for areas covered by images from Landsat-8\9).

At the next stage, the raster mask is transformed into a vector layer and then additional semi-manual post-processing of the vector mask is performed (searching for and eliminating anomalies, smoothing the vector mask, etc.). Some of the post processing tasks are performed using the selection of coefficients for internal QGIS tools, the rest of the work is performed in manual mode (this is necessary because the boundaries of water bodies often have complex geometry and manual intervention is required to correct the mask).

A similar list (sequence and mechanics) of work was used when creating masks for Sentinel-1 radar data, but taking into account the physics of radar images, where raw preprocessed images are used to create a raster mask of water

Calculation of flooding areas

To calculate flood areas, the QGIS toolkit is used, specifically the Measure Area tool in the Advanced Digitizing toolbar. The projection is preliminarily changed according to the following parameters:

❖ Data source: EPSG:32636

❖ WGS 84 / UTM zone 36N

❖ Unit: meter

❖ Geodetic CRS: WGS 84

❖ Datum: World Geodetic System 1984 ensemble

All calculations were carried out on the basis of available water masks for dates with available images in accordance with Analysis spatial extent (namely Geographical scope of flood area calculation) and Analysis temporal extent. The flooding area was calculated as the difference in water masks for each available date compared to the date before the dam explosion. This means that each date after the explosion with an available water mask was compared with the water mask on the date before the explosion

Static water bodies that fell into the Analysis spatial extent (namely Geographical scope of flood area calculation) were excluded from the calculations since they do not affect the flood area but create additional processing efforts. By static water bodies we mean estuaries, lakes, rivers, etc., which were found in the Geographical scope of flood area calculation, but which were not affected by the explosion and the spread of water after the explosion

Regarding the assessment of a possible error in the calculation of water masks, after a long analysis we came to the conclusion that it is impossible to accurately calculate the possible deviation because this is influenced by a large number of factors, in addition, the accuracy of water masks in different AOI zones can vary significantly, in depending on the specific geometry of the river, including changing geometry on different dates due to different levels of flooding and different parts of the river.

A short list of factors that could negatively affect the accuracy of calculating the area of water masks and differences in water masks:

❖ Pixel sizes. We assume the possibility of a one-pixel error at the boundaries of the vector water mask. For Sentinel-1 and Sentinel-2 images the pixel size is 10 meters, and for Landsat-8\9 images the pixel size is 30 meters. It is technically impossible to increase the accuracy on images of such resolution, as well as to accurately calculate the error, since when creating water masks, the algorithm can distort the data both downward and upward for each pixel at the boundaries of the mask.

❖ Corregistration. Also, the accuracy can be negatively affected by inter-sensory coregistration between different images of the same satellite and between images of different satellites. For example, for the Sentinel-2 satellite there are the following accuracy parameters of image binding: 1) geolocation of Level-2A products refined with the GRI is better than 12.5 m CE95 2) multi-temporal registration performance of refined products is better than 0.5 pixels

❖ The complex geometry of water bodies also has a great influence on accuracy. The more complex the geometry of water bodies, the potentially greater the error.

Despite the high uncertainty and technical impossibility of accurately assessing the potential error, we do not expect that the error can reach more than 10-15%

3. Analysis results

3.1. Results of data processing

Processed data

The key data points (layers) that were obtained as a result of image processing for the purposes of analysis in the context of this project are water masks (vector layers) for different dates. For the efficiency of processing and for calculations, a water mask consisting of three parts was prepared.

The table below describes in more detail the key data points obtained as a result of processing, namely the names of vector water masks and their brief interpretation

Data point name	Description
Part_1_05062023.rar	Vector water masks for dates with available images in ESRI Shapefile format (zipped, the archive contains a set of files necessary to open the mask in QGIS or other GIS tools). **The first part of the mask covers the bed of the Dnipro River from the dam of the Kakhovka hydroelectric power station to the Black Sea** (namely to the westernmost point of the AOI towards the sea). The date of the mask is written in the format DDMMYYYY
Part_1_09062023.rar	
Part_1_05072023.rar	
Part_1_29082023.rar	
Part_2_05062023.rar	Vector water masks for dates with available images in ESRI Shapefile format (zipped, the archive contains a set of files necessary to open the mask in QGIS or other GIS tools). **The second part of the mask covers the part of the bed of the Ingulets river** (tributary of the Dnipro River within the boundaries of AOI). The date of the mask is written in the format DDMMYYYY
Part_2_09062023.rar	
Part_2_05072023.rar	
Part_2_29082023.rar	
Part_3_05062023.rar	Vector water masks for dates with available images in ESRI Shapefile format (zipped, the archive contains a set of files necessary to open the mask in QGIS or other GIS tools). **The third part of the mask covers the bed of the Dnipro River from the city of Zaporizhzhya to the beginning of the dam of the Kakhovka hydroelectric power station.** The date of the mask is written in the format DDMMYYYY
Part_3_09062023.rar	
Part_3_05072023.rar	
Part_3_29082023.rar	

Area of flooding calculated

The table below provides information on the total area of water for different dates for Analysis spatial extent (namely Geographical scope of flood area calculation) and flooding area for different dates (calculated as the difference in water masks for the dates after the explosion and before the explosion)

Date	Sensor	Area of water mask, sq km	Diff area of flooding, sq km*
June 05, 2023	Sentinel-2	812.8749	0
June 09, 2023	Sentinel-2	1284.9199	+405.4131
July 05, 2023	Sentinel-2	825.7846	+19.8006
August 29, 2023	Sentinel-2	817.048	+17.8368
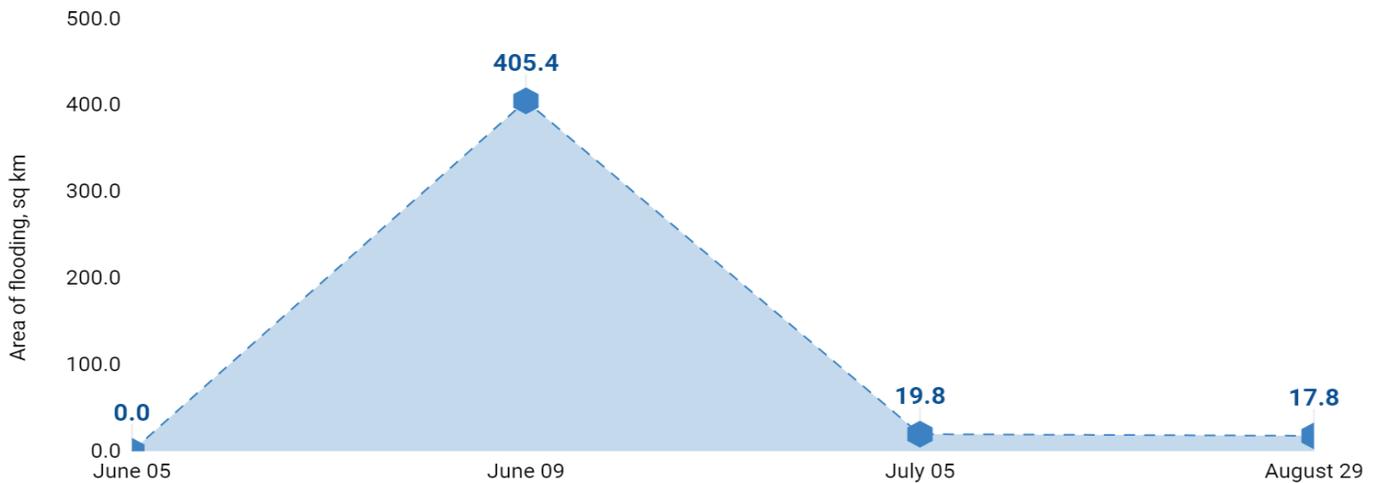
Compared to the state before the dam explosion (image from June 05, 2023)

3.1. Visualization of flooding (based on medium-resolution images)

General plan of the entire area of interest with water masks for all available dates, showing water movement for the period from June 5, 2023 to August 29, 2023. The most severe flooding of the area below the dam is observed in the image from June 9, 2024, then the water gradually recedes, at the same time a gradual decrease in the water level in the reservoir is observed.
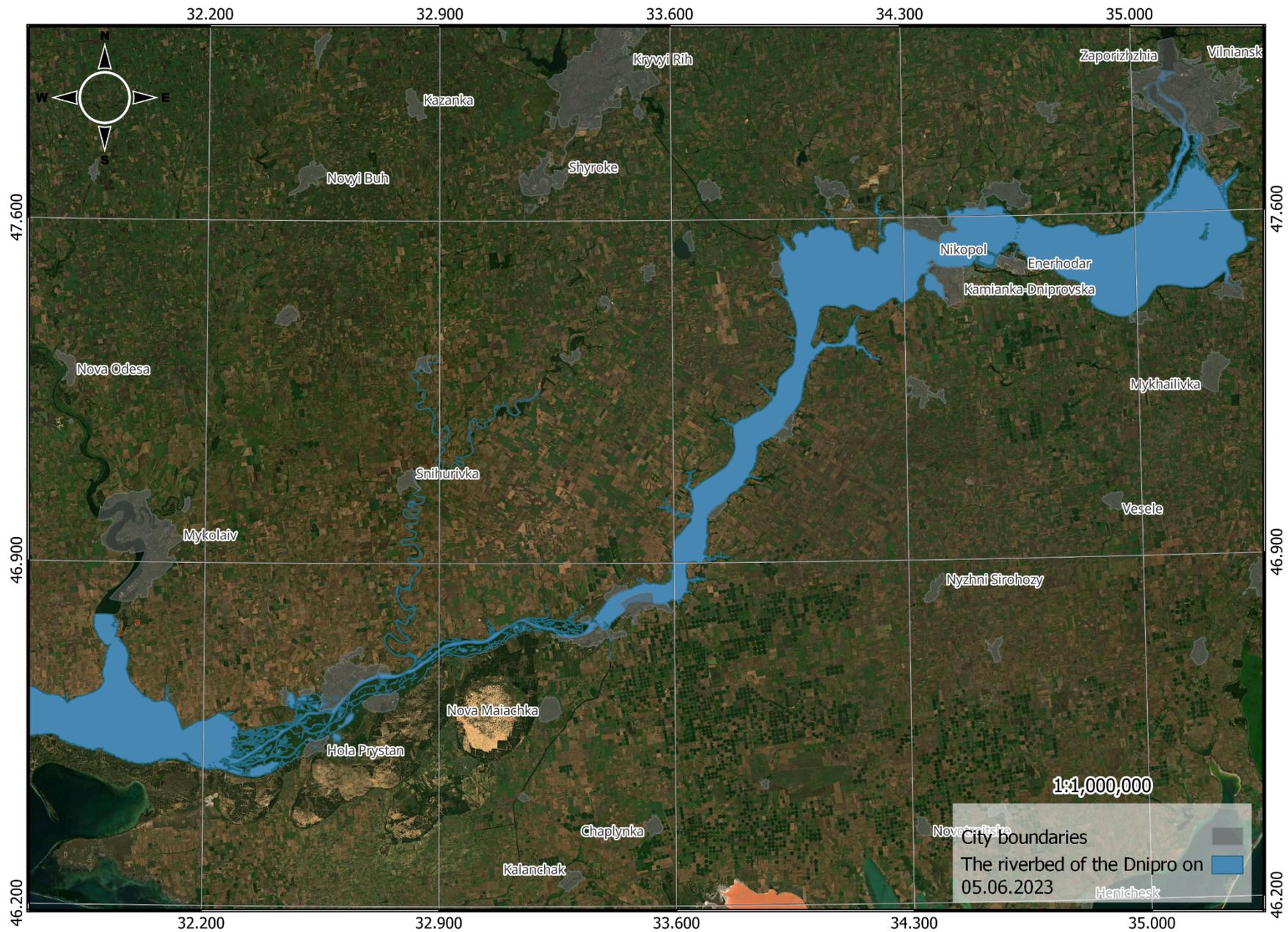
Water mask for the entire territory of interest (Geographical scope of water movement analysis) based on the image from June 5, 2023, the exposure of the dam. Images of all target locations are provided as supplementary materials to report

Water mask for the entire territory of interest (Geographical scope of water movement analysis) based on the image from June 9, 2023, 3-rd day after the exposure of the dam. Significant flooding is observed in the buffer zone of the Ingulets river and the area below the dam, and in the area near the city of Kherson and the city of Oleshky
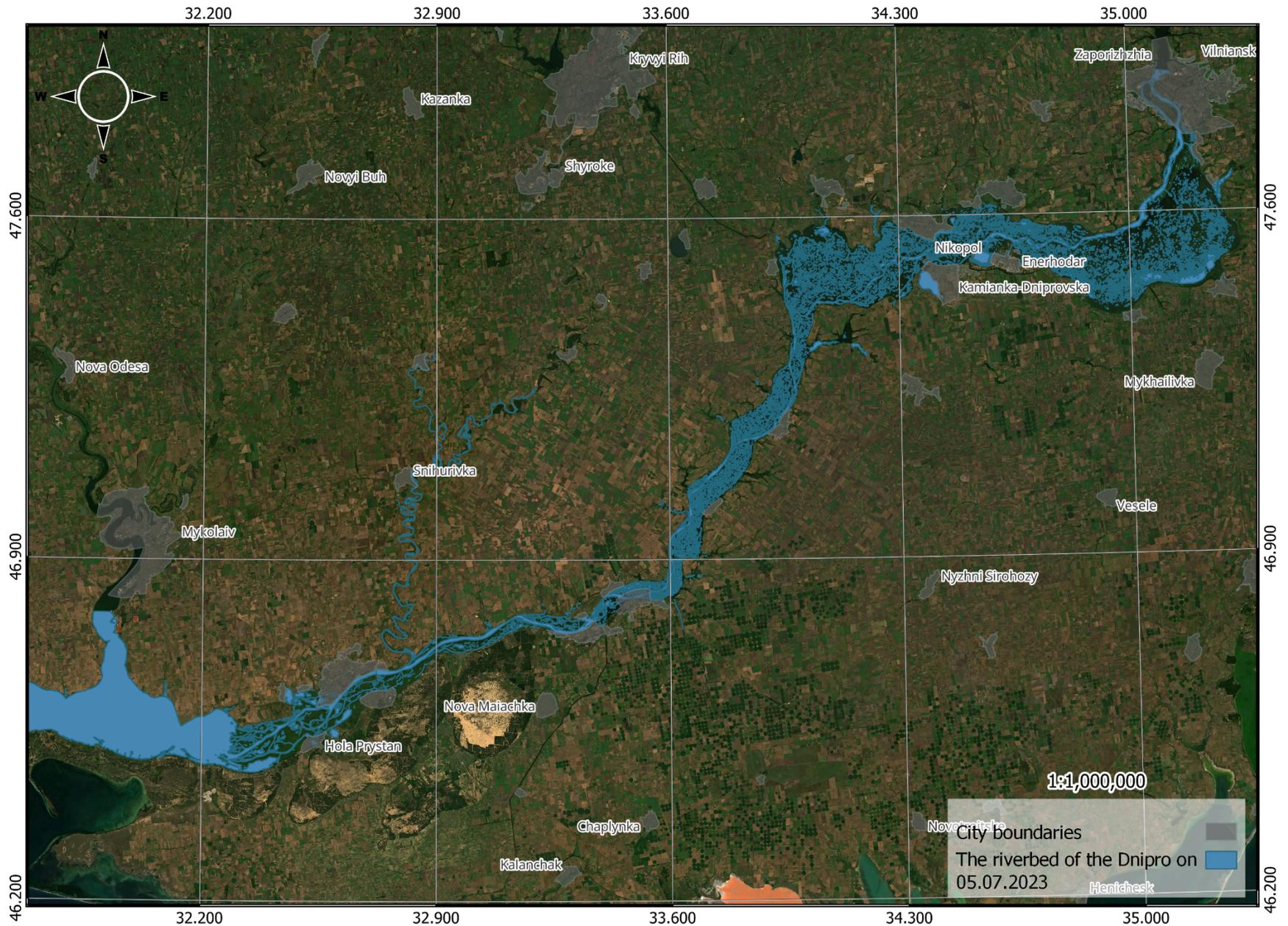
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Water mask for the entire territory of interest (Geographical scope of water movement analysis) based on the image from July 5, 2023. Satellite images show a drop in water level below the dam almost to the level before the explosion, and also a further gradual decrease in the water level and shallowing of the Kakhovka reservoir and the Dnipro River bed above the dam in general
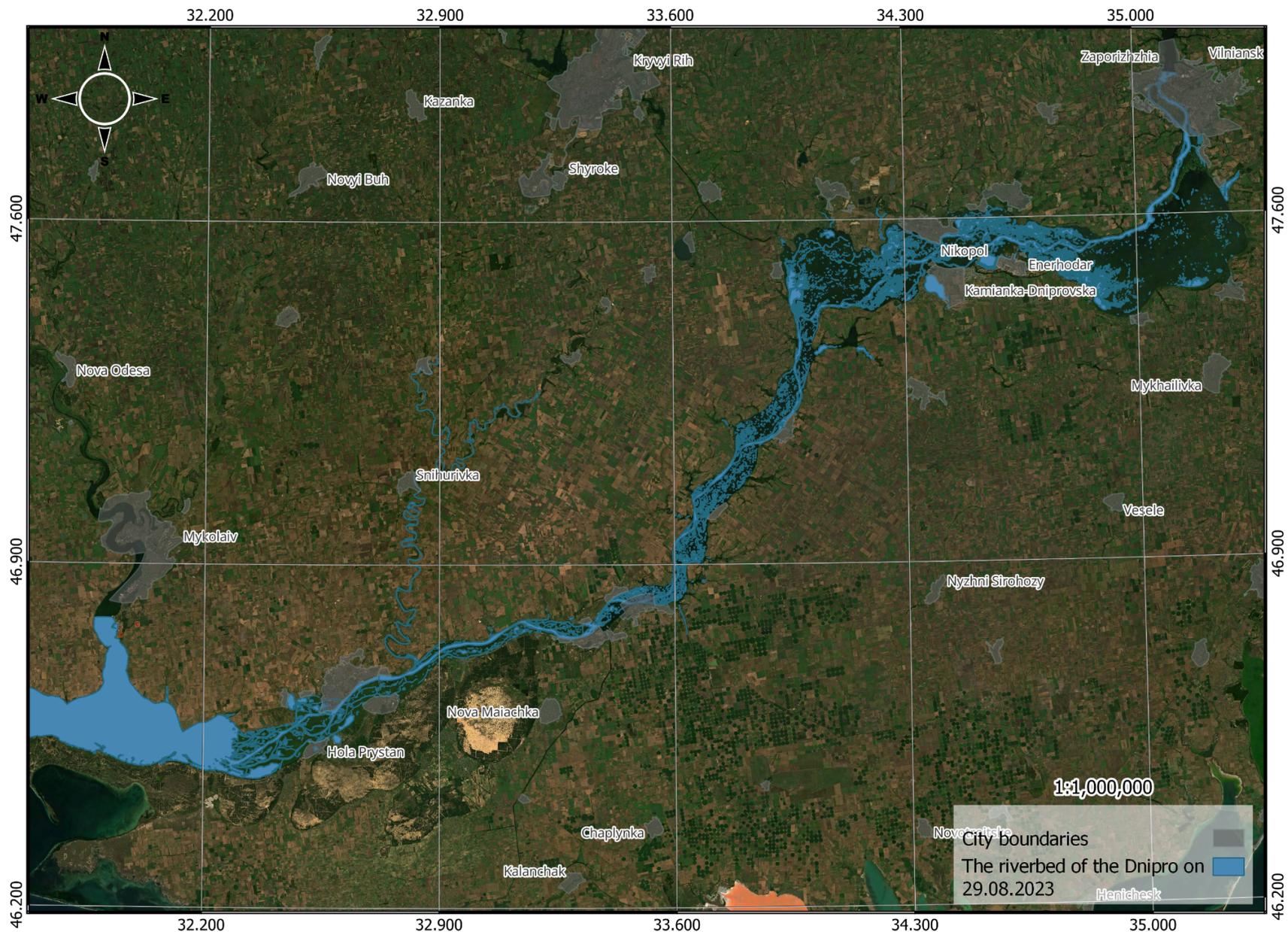
Water mask for the entire territory of interest (Geographical scope of water movement analysis) based on the image from August 29, 2023. Satellite images show further decrease in the water level and shallowing of the Kakhovka reservoir and the Dnipro River bed above the dam

3.3. Visualization of specific flooded zones in the first days (based on high-resolution images)
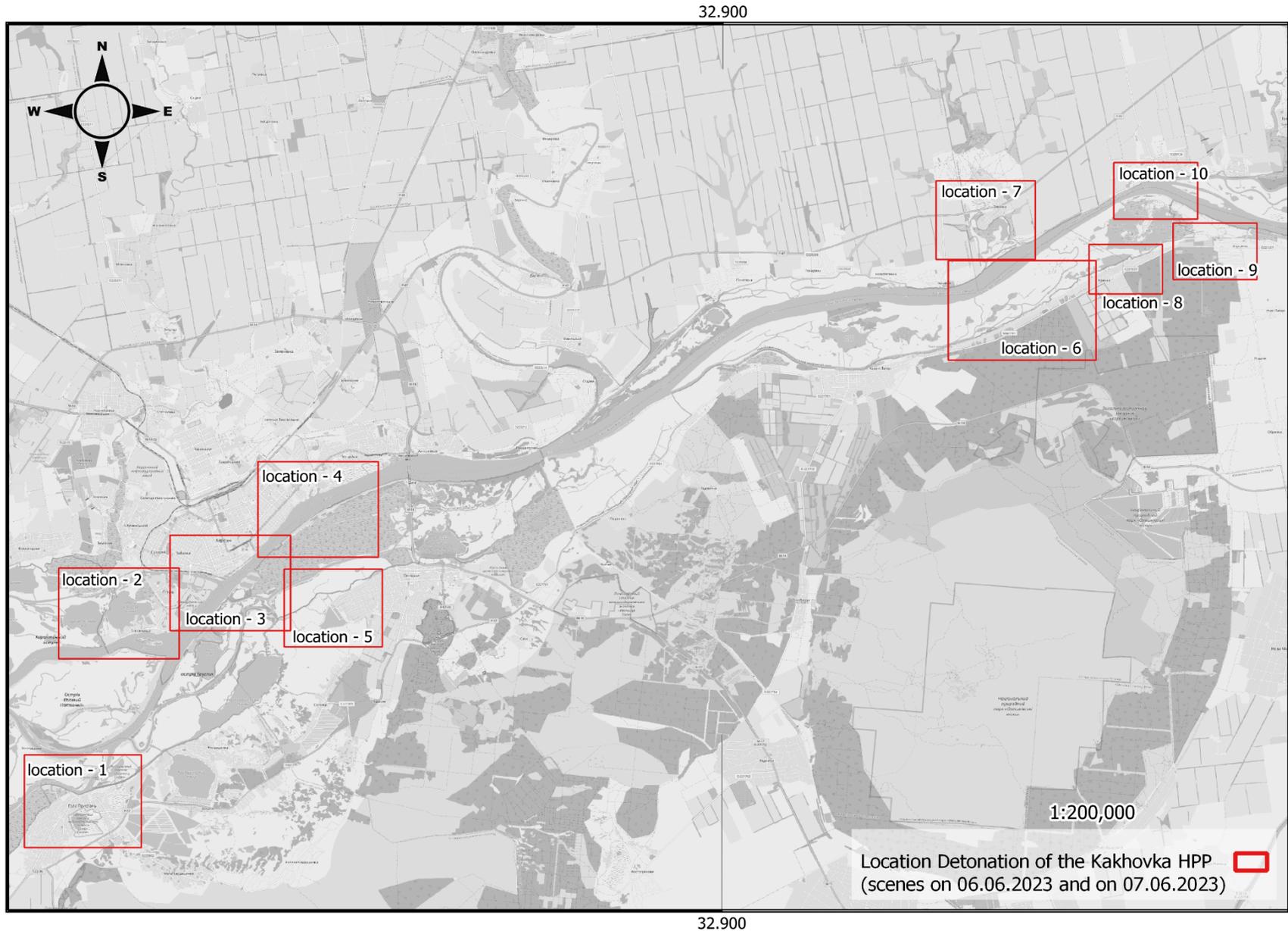
General plan with designated areas for which high-quality and cloud-free high-resolution images are available. Some of the zones (locations) are presented in detail below (as an RGB image). Images of all locations are provided as supplementary materials to report
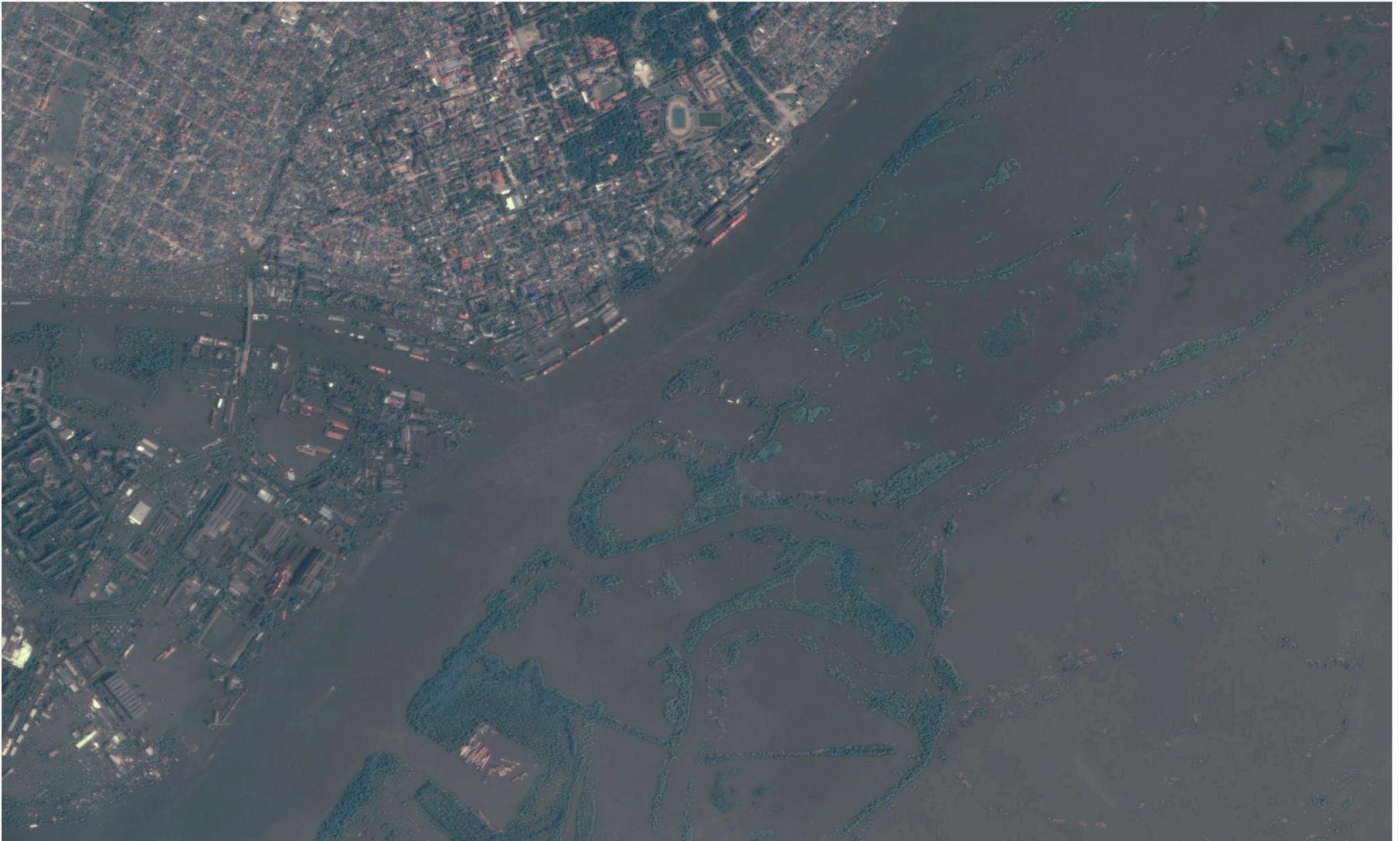
Flooding in Location 1, Geosat image from June 7, 2023, resolution 0.75 meters

Flooding in Location 4, Geosat image from June 7, 2023, resolution 0.75 meters

Flooding in Location 6, Geosat image from June 6, 2023, resolution 0.75 meters. The image is post-processed with contrast filters filters for information content, since on this day the worst image quality is observed due to the weather

Flooding in Location 8, Geosat image from June 6, 2023, resolution 0.75 meters. The image is post-processed with contrast filters for information content, since on this day the worst image quality is observed due to the weather

ANNEX 1. CONSOLIDATED LIST OF PRIMARY AND PROCESSED DATA

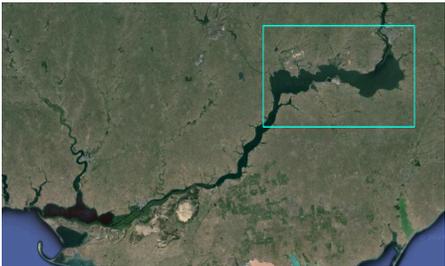| #	Name	Description
Raster images (path to files on Google Drive: Results -> Raster images)	
1	Contains_Copernicus_Sentinel_data_2023_Sentinel_2_0705_T36TVT	**Folders with raw images of the Sentinel-2 satellite**, used in the project in the format received from the provider. Each folder contains a set of metadata and raster images (separate bands, combination of bands)
2	Contains_Copernicus_Sentinel_data_2023_Sentinel_2_0605_T36TVS	
3	Contains_Copernicus_Sentinel_data_2023_Sentinel_2_0605_T36TVT	Interpretation of the folder name: Contains_Copernicus_Sentinel_data_2023_[satellite name]_[image date in DDMM format]_[tile ID]
4	Contains_Copernicus_Sentinel_data_2023_Sentinel_2_0605_T36TWS	
5	Contains_Copernicus_Sentinel_data_2023_Sentinel_2_0605_T36TWT	Path to files on Google Drive: Results -> Raster images -> Sentinel-2
6	Contains_Copernicus_Sentinel_data_2023_Sentinel_2_0605_T36TXT	
7	Contains_Copernicus_Sentinel_data_2023_Sentinel_2_0605_T36UXU	
8	Contains_Copernicus_Sentinel_data_2023_Sentinel_2_0608_T36TVT	
9	Contains_Copernicus_Sentinel_data_2023_Sentinel_2_0703_T36TVS	
10	Contains_Copernicus_Sentinel_data_2023_Sentinel_2_0703_T36TVT	
11	Contains_Copernicus_Sentinel_data_2023_Sentinel_2_0705_T36TVT	
12	Contains_Copernicus_Sentinel_data_2023_Sentinel_2_0705_T36TWS	
13	Contains_Copernicus_Sentinel_data_2023_Sentinel_2_0705_T36TWT	
14	Contains_Copernicus_Sentinel_data_2023_Sentinel_2_0705_T36TXT	
15	Contains_Copernicus_Sentinel_data_2023_Sentinel_2_0705_T36UXU	
16	Contains_Copernicus_Sentinel_data_2023_Sentinel_2_0705_T36UXU	
17	Contains_Copernicus_Sentinel_data_2023_Sentinel_2_0827_T36TVS	
18	Contains_Copernicus_Sentinel_data_2023_Sentinel_2_0827_T36TVT	
19	Contains_Copernicus_Sentinel_data_2023_Sentinel_2_0827_T36TWT	
20	Contains_Copernicus_Sentinel_data_2023_Sentinel_2_0829__T36UXU	
21	Contains_Copernicus_Sentinel_data_2023_Sentinel_2_0829_T36TXT	

#	Name	Description
22	Contains_Copernicus_Sentinel_data_2023_Sentinel_1_0609_05E1BA_72F1	**Folders with raw images of the Sentinel-1 satellite**, used in the project in the format received from the provider. Interpretation of the folder name: Contains_Copernicus_ Sentinel_data_2023_[satellite name]_ [image date in DDMM format]_[tile ID]
23	Contains_Copernicus_Sentinel_data_2023_Sentinel_1_0609_05E1BA_81D1	Path to files on Google Drive: Results -> Raster images -> Sentinel-1
24	Contains_USGS_data_2023_Landsat_0609_179027	**Folders with raw images of the Landsat-8\9 satellite**, used in the project in the format received from the provider. Interpretation of the folder name: Contains_Copernicus_ Sentinel_data_2023_[satellite name]_ [image date in DDMM format]_[tile ID]
25	Contains_USGS_data_2023_Landsat_0609_179028	Path to files on Google Drive: Results -> Raster images -> Landsat-8\9
26	Location_1_Before.jpg	**High resolution RGB images** for the first days after the dam explosion. Presents different zones (locations) for which images are available.
27	Location_1_After.jpg	Path to files on Google Drive:
28	Location_2_Before.jpg	Results -> Raster images -> High-resolution images -> June 6, 2023
29	Location_2_After.jpg	Results -> Raster images -> High-resolution images -> June 7, 2023
30	Location_3_Before.jpg	
31	Location_3_After.jpg	
32	Location_4_Before.jpg	
33	Location_4_After.jpg	
34	Location_5_Before.jpg	
35	Location_5_After.jpg	
36	Location_6_Before.jpg	
37	Location_6_After.jpg	
38	Location_7_Before.jpg	
30	Location_7_After.jpg	
40	Location_8_Before.jpg	
41	Location_8_After.jpg	
42	Location_9_Before.jpg	
43	Location_9_After.jpg	
44	Location_10_Before.jpg	
45	Location_10_After.jpg	
46	Images location_OSM basemap.png	**General plan** with all designated areas for which high-quality and cloud-free high-resolution images are available Path to files on Google Drive: Results -> Raster images -> High-resolution images

#	Name	Description
	Vector layers (path to files on Google Drive: Results -> Vector layers)	
47	Part_1_05062023.rar	Vector water masks for dates with available images in ESRI Shapefile format (zipped, the archive contains a set of files necessary to open the mask in QGIS or other GIS tools). **The first part of the mask covers the bed of the Dnipro River from the dam of the Kakhovka hydroelectric power station to the Black Sea** (namely to the westernmost point of the AOI towards the sea). The date of the mask is written in the format DDMMYYYY Path to files on Google Drive: Results -> Vector layers -> Water masks_part_1
48	Part_1_09062023.rar	
49	Part_1_05072023.rar	
50	Part_1_29082023.rar	
51	Part_2_05062023.rar	Vector water masks for dates with available images in ESRI Shapefile format (zipped, the archive contains a set of files necessary to open the mask in QGIS or other GIS tools). **The second part of the mask covers the part of the bed of the Ingulets river** (tributary of the Dnieper river within the boundaries of AOI). The date of the mask is written in the format DDMMYYYY Path to files on Google Drive: Results -> Vector layers -> Water masks_part_2
52	Part_2_09062023.rar	
53	Part_2_05072023.rar	
54	Part_2_29082023.rar	
55	Part_3_05062023.rar	Vector water masks for dates with available images in ESRI Shapefile format (zipped, the archive contains a set of files necessary to open the mask in QGIS or other GIS tools). **The third part of the mask covers the bed of the Dnipro River from the city of Zaporizhzhya to the beginning of the dam of the Kakhovka hydroelectric power station.** The date of the mask is written in the format DDMMYYYY Path to files on Google Drive: Results -> Vector layers -> Water masks_part_3
56	Part_3_09062023.rar	
57	Part_3_05072023.rar	
58	Part_3_29082023.rar	
59	View_small.zip	**The final AOI vector layers** used for the project (corrected to optimal size and aspect ratio according to requirements) Path to files on Google Drive: Results -> Vector layers -> AOI_edited
60	View_reservoire.zip	
61	View_upstream.zip	
62	View_downstream.zip	
	Visualization files (path to files on Google Drive: Results -> Visualization)	
63	Overall scheme.png	**General plan of different zones to visualize those selected for the project according to the requirements** Path to files on Google Drive: Results -> Visualization
64	05062023_Water extent_Sentinel (300 dpi).png	**Maps of water masks and maps of the difference in water masks on a large scale 1:1 000 000** for AOI for different dates for which images are available. All maps are presented in high (300 dpi) and very high (1200 dpi) resolution for different use cases
65	05062023_Water extent_Sentinel (1200 dpi).png	
66	09062023_Water extent_Sentinel (300 dpi).png	
67	09062023_Water extent_Sentinel (1200 dpi).png	
68	09062023_Difference mask_Sentinel (300 dpi).png	
69	09062023_Difference mask_Sentinel (1200 dpi).png	

#	Name	Description
70	05072023_Water extent_Sentinel (1200 dpi).png	
71	05072023_Water extent_Sentinel (1200 dpi).png	
71	05072023_Difference mask_Sentinel (300 dpi).png	
73	05072023_Difference mask_Sentinel (1200 dpi).png	
74	29082023_Water extent_Sentinel (300 dpi).png	
75	29082023_Water extent_Sentinel (1300 dpi).png	
76	29082023_Difference mask_Sentinel (300 dpi).png	Path to files on Google Drive:
	29082023_Difference mask_Sentinel (1200 dpi).png	Results -> Visualization -> 1:1 000 000 -> Maps_Sentinel-2 basemap -> June 5, 2023
		Results -> Visualization -> 1:1 000 000 -> Maps_Sentinel-2 basemap -> June 9, 2023
		Results -> Visualization -> 1:1 000 000 -> Maps_Sentinel-2 basemap -> July 5, 2023
		Results -> Visualization -> 1:1 000 000 -> Maps_Sentinel-2 basemap -> August 29, 2023
77	05062023_Water extent_Sentinel (300 dpi).png	Maps of water masks and maps of the difference in water masks on a **medium scale 1:400 000 for the Kakhovka Reservoir zone** for different dates for which images are available. All maps are presented in high (300 dpi) and very high (1200 dpi) resolution for different use cases
77	05062023_Water extent_Sentinel (1200 dpi).png	
79	09062023_Water extent_Sentinel (300 dpi).png	
80	09062023_Water extent_Sentinel (1200 dpi).png	
81	09062023_Difference mask_Sentinel (300 dpi).png	
82	09062023_Difference mask_Sentinel (1200 dpi).png	
83	05072023_Water extent_Sentinel (1200 dpi).png	
84	05072023_Water extent_Sentinel (1200 dpi).png	
85	05072023_Difference mask_Sentinel (300 dpi).png	
86	05072023_Difference mask_Sentinel (1200 dpi).png	**Path to files on Google Drive:**
87	29082023_Water extent_Sentinel (300 dpi).png	Results -> Visualization-> 1:400 000 -> Reservoir -> Maps_Sentinel-2 basemap -> June 5, 2023
88	29082023_Water extent_Sentinel (1300 dpi).png	Results -> Visualization-> 1:400 000 -> Reservoir -> Maps_Sentinel-2 basemap -> June 9, 2023
89	29082023_Difference mask_Sentinel (300 dpi).png	Results -> Visualization-> 1:400 000 -> Reservoir -> Maps_Sentinel-2 basemap -> July 5, 2023
90	29082023_Difference mask_Sentinel (1200 dpi).png	Results -> Visualization-> 1:400 000 -> Reservoir -> Maps_Sentinel-2 basemap -> August 29, 2023
91	05062023_Water extent_Sentinel (300 dpi).png	Maps of water masks and maps of the difference in water masks on a **medium scale 1:400 000 for the Narrow part of Kakhovka reservoir and Inhulets zone** for different dates. All maps are presented in high (300 dpi) and very high (1200 dpi) resolution for different use cases
92	05062023_Water extent_Sentinel (1200 dpi).png	
93	09062023_Water extent_Sentinel (300 dpi).png	
94	09062023_Water extent_Sentinel (1200 dpi).png	
95	09062023_Difference mask_Sentinel (300 dpi).png	

#	Name	Description
96	09062023_Difference mask_Sentinel (1200 dpi).png	
97	05072023_Water extent_Sentinel (1200 dpi).png	
98	05072023_Water extent_Sentinel (1200 dpi).png	
99	05072023_Difference mask_Sentinel (300 dpi).png	
100	05072023_Difference mask_Sentinel (1200 dpi).png	
101	29082023_Water extent_Sentinel (300 dpi).png	
102	29082023_Water extent_Sentinel (1300 dpi).png	
103	29082023_Difference mask_Sentinel (300 dpi).png	**Path to files on Google Drive:**
104	29082023_Difference mask_Sentinel (1200 dpi).png	Results -> Visualization-> 1:400 000 -> Upstream -> Maps_Sentinel-2 basemap -> June 5, 2023
		Results -> Visualization-> 1:400 000 -> Upstream -> Maps_Sentinel-2 basemap -> June 9, 2023
		Results -> Visualization-> 1:400 000 -> Upstream -> Maps_Sentinel-2 basemap -> July 5, 2023
		Results -> Visualization-> 1:400 000 -> Upstream -> Maps_Sentinel-2 basemap -> August 29, 2023
105	05062023_Water extent_Sentinel (300 dpi).png	Maps of water masks and maps of the difference in water masks on a **medium scale 1:400 000 for Black Sea – Nova Kakhovka zone** for different dates for which images are available. All maps are presented in high (300 dpi) and very high (1200 dpi) resolution for different use cases
106	05062023_Water extent_Sentinel (1200 dpi).png	
107	09062023_Water extent_Sentinel (300 dpi).png	
108	09062023_Water extent_Sentinel (1200 dpi).png	
109	09062023_Difference mask_Sentinel (300 dpi).png	
110	09062023_Difference mask_Sentinel (1200 dpi).png	
111	05072023_Water extent_Sentinel (1200 dpi).png	
112	05072023_Water extent_Sentinel (1200 dpi).png	
113	05072023_Difference mask_Sentinel (300 dpi).png	
114	05072023_Difference mask_Sentinel (1200 dpi).png	**Path to files on Google Drive:**
115	29082023_Water extent_Sentinel (300 dpi).png	Results -> Visualization-> 1:400 000 -> Reservoir -> Maps_Sentinel-2 basemap -> June 5, 2023
116	29082023_Water extent_Sentinel (1300 dpi).png	Results -> Visualization-> 1:400 000 -> Reservoir -> Maps_Sentinel-2 basemap -> June 9, 2023
117	29082023_Difference mask_Sentinel (300 dpi).png	Results -> Visualization-> 1:400 000 -> Reservoir -> Maps_Sentinel-2 basemap -> July 5, 2023
118	29082023_Difference mask_Sentinel (1200 dpi).png	Results -> Visualization-> 1:400 000 -> Reservoir -> Maps_Sentinel-2 basemap -> August 29, 2023