REPORT ON THE DEVELOPMENT OF FLOOD HAZARD MAPS AND FLOOD RISK MAPS FOR AREAS EXPOSED TO FLOODING IN THE EVENT OF DAM FAILURE

CONTRACTOR:

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APSFR	Area of potential significant flood risk (Polish abbreviation "ONNP")
BDOT10k	Topographic Database at a scale of 1:10 000
CZSW	Central Administration of the Prison Service
CODGiK	Geodetic And Cartographic Documentation Centre (PL: Centralny Ośrodek Dokumentacji Geodezyjnej i Kartograficznej)
DSM	Digital Surface Model (Polish abbreviation "NMPT")
DTM	Digital Terrain Model (Polish abbreviation "NMT")
DWSM	Digital Water Surface Model (Polish abbreviation "NMPW")
FHM	Flood Hazard Maps (Polish abbreviation "MZP")
FRM	Flood risk maps (Polish abbreviation "MRP")
GDOŚ	General Directorate for Environmental Protection
GIOŚ	Chief Inspectorate of Environmental Protection
GIS	Geographic Information System
GUGiK	Head Office of Geodesy and Cartography (PL: Główny Urząd Geodezji i Kartografii)
GUS	Central Statistical Office
IMGW-PIB	Institute of Meteorology and Water Management - National Research Institute (PL: Instytut Meteorologii i Gospodarki Wodnej - Państwowy Instytut Badawczy)
ISOK	IT system for Protecting the Country against Extraordinary Threats (PL: Informatyczny System Osłony Kraju przed Nadzwyczajnymi Zagrożeniami)
KE	European Commission
KG PSP	National Headquarters of the State Fire Service
LPIS	Land Parcel Identification System (PL: System Identyfikacji Działek Rolnych)
MKiDN	Ministry of Culture and National Heritage
MPHP10k	Map of Hydrographic Division of Poland at a scale of 1:10 000
MS	Ministry of Justice
MŚ	Ministry of Environment
MaxPP	Maximum water damming level of the reservoir
NFZ	National Health Fund
NID	National Heritage Board
NOBC	System of Address Identification of Streets, Real Estates, Buildings and Dwellings
NPP	Normal water damming level of the reservoir
OPGK	Cracow Surveying & Cartographic Company (PL: OPGK Kraków Sp. z o.o.)
OTKZ	Centre for Technical Inspection of Dams - unit of IMGW-PIB (PL: Ośrodek Technicznej Kontroli Zapór)
PFRA	Preliminary Flood Risk Assessment (Polish abbreviation "WORP")
PGW WP	State Water Holding Polish Waters (PL: Państwowe Gospodarstwo Wodne Wody Polskie)
PIG-PIB	Polish Geological Institute - National Research Institute
PIS-GIS	State Sanitary Inspection - Chief Sanitary Inspectorate
RZGW	Regional Water Management Authorities
UW	Voivodeship Offices
WIOŚ	Voivodeship Inspectorate for Environmental Protection

1. INTRODUCTION

The development of flood hazard maps (FHMs) and flood risk maps (FRMs) for areas exposed to flooding in the event of dam failure was carried out under the Project entitled "Review and update of flood hazard maps and flood risk maps" (hereinafter referred to as the Project), financed from the funds of the Operational Programme Infrastructure and Environment, Priority Axis II: Environmental protection, including adaptation to climate change, Measure 2.1 Adaptation to climate change including protection and improvement of resistance to natural disasters, in particular natural disasters and environmental monitoring.

This report contains the description of FHMs and FRMs for:

- 7 dams: Besko, Chańcza, Dobromierz, Mietków, Przeczyce, Słup and Świnna Poręba, developed under the task entitled: “Development of FHMs and FRMs for areas exposed to flooding in the event of dam failure (part I)” and published on 22 October 2020

  and

- 19 dams: Bukówka, Czorsztyn-Niedzica, Dębe, Dobczyce, Goczałkowice, Jeziorsko, Koronowo, Mylof, Nysa, Otmuchów, Pakość, Poraj, Porąbka, Rożnów, Solina, Sulejów, Tresna, Turawa, Włocławek, developed under the task entitled: “Development of FHMs and FRMs for areas exposed to flooding in the event of dam failure (part II)” and published on 22 June 2022.

2. LEGAL GROUNDS

Flood hazard maps and flood risk maps are developed based on the following legal acts:

1) Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks (Flood Directive);
2) Act of 20 July 2017 - The Water Law (Journal of Laws of 2021, item 624, as amended);
3) Regulation of the Minister of Maritime Economy and Inland Navigation of 4 October 2018 on the development of flood hazard maps and flood risk maps (Journal of Laws of 2018, item 2031), hereinafter referred to as the regulation.

The objective of the Flood Directive is to establish a framework for the assessment and management of flood risks in order to reduce the adverse effects of floods on human life and health, economic activity, the environment and cultural heritage. This Directive introduced the obligation to develop planning documents constituting the basis for the assessment of flood risks and to take measures to reduce the adverse effects of floods.

The provisions of the Flood Directive were implemented into the Polish legal system by the act of 5 January 2011 amending the Water Law and certain other acts (Journal of Laws of 2001 No. 32, item 159), which entered into force on 18 March 2011.

In accordance with Article 11(1)(1) of the above mentioned act, the implementation of the Flood Directive in the first planning cycle (in 2010 - 2015) was performed by the development of:

- preliminary flood risk assessment (PFRA) by 22 December 2011;
- flood hazard maps (FHMs) and flood risk maps (FRMs) by 22 December 2013 (the maps were published and submitted to the administrative authorities on 15 April 2015);
- flood risk management plans (FRMPs) for river basin districts by 22 December 2015 (Regulation on flood risk management plans of 18 October 2016).

The Act of 20 July 2017 - The Water Law (Journal of Laws of 2021, item 624, as amended), hereinafter referred to as the "Water Law", which entered into force on 1 January 2018, retains the validity of the aforementioned planning documents (Article 555(2)(4, 5, 7 and 9)) and requires their review every 6 years and, if necessary, updating.

Pursuant to Article 555(2)(4) and 5)) of the Water Law, flood hazard maps and flood risk maps are subject to review by 22 December 2019 and update if necessary.

The Water Law (in Articles 169 - 171) sets forth the general scope and manner of development of flood hazard maps and flood risk maps as well as the procedure for their evaluation and approval.

Pursuant to Article 169(1), flood hazard maps are developed for areas of potential significant flood risk identified in the preliminary flood risk assessment.

Pursuant to Article 169(2)(3)(c), flood hazard maps show the areas exposed to flooding in the event of dam failure.

Flood risk maps are developed for the areas referred to in Article 169(2) of the Water Law.

Pursuant to Article 137(1) and Article 240(2)(6) of the Water Law, draft flood hazard maps and draft flood risk maps are developed by the Polish Waters in consultation with relevant voivodes. The minister in charge of maritime economy approves flood hazard maps and flood risk maps and submits them in an electronic form to the administrative bodies indicated in Article 171(4) of the Water Law.

Detailed requirements for map preparation are contained in the Regulation of the Minister of Maritime Economy and Inland Navigation of 4 October 2018 on the development of flood hazard maps and flood risk maps (Journal of Laws 2018, item 2031), hereinafter referred to as the "Regulation”.

The above mentioned legal acts (the Flood Directive, the Water Law and the Regulation) were the basis for the preparation of the Methodology for the development of flood hazard maps and flood risk maps for areas exposed to flooding in the event of dam failure - part II (hereinafter referred to as Methodology BP), which is the basis for the development of FHMs and FRMs which are the subject matter hereof.

3. DESCRIPTION OF FLOOD TYPES

3.1 FLOOD TYPE FOR WHICH FHMs AND FRMs WERE DEVELOPED

As required under the Flood Directive, flood hazard maps and flood risk maps are developed for the areas and types of floods indicated in the preliminary flood risk assessment. As a result of the review and update of PFRA in 2018, the following significant types of floods in Poland were identified (by source):

1) fluvial flood - associated with the flooding of land by waters originating from rivers, streams, mountain streams, canals, lakes - in two scenarios:
   - natural exceedance,
   - destruction of flood embankments;
2) flood from the sea water - associated with flooding of the area by sea waters, including estuarial river sections and coastal lakes - in two scenarios:
   - natural exceedance,
   - destruction of storm control dykes;
3) flood from artificial water bearing infrastructure - associated with flooding of the area in the event of dam failure.

This report refers to FHMs and FRMs for areas exposed to flooding in the event of dam failure.

According to the classification adopted for the purposes of implementation of the Flood Directive in EU (Flood Directive Reporting Guidance 2018 v.5.0), floods resulting from dam failure are classified as follows:

- by source - flood from water and sewage infrastructure and artificial water bearing infrastructure (A15);
- by mechanism - failure of dams or technical infrastructure (A23);
- by characteristics - other rapid onset flood (A33).

3.2 DESCRIPTION OF FLOOD SCENARIOS

Pursuant to Article 169(2)(3)(c) of the Water Law, flood hazard maps should show: areas including those exposed to flooding in the event of dam failure.

There may be many probable scenarios of dam failure. Taking into account the objectives for which FHMs and FRMs are developed (flood protection, information of the public about potential flood risk, crisis management and evacuation planning), it has been assumed that flood hazard maps will present a scenario causing the maximum possible flooding of areas below the reservoir. This scenario involves complete destruction of the dam over a certain section, allowing the reservoir to be completely drained. The most probable conditions for the occurrence of a failure are the operation of dam during an extreme flood wave.

Flows with a probability of occurrence amounting to 1% and higher (scenarios with a medium and high probability of flood occurrence), taking into account the method of disposing of water discharges from the reservoir, as described in water management instructions, do not cause a sudden increase in the reservoir filling level, which could be dangerous for the facility and lead to its failure.

Therefore, dam failure is part of the scenario of extreme events referred to in Article 169(2)(1) of the Water Law and Article 6(3)(a)) of the Flood Directive.

As part of development of this scenario, different variants thereof were analysed depending on the type and class of the dam, the structure of the facility (including outlet works) and information on its technical condition.
The variants of failure defined the initial conditions and course of the very phenomenon consisting in dam failure. When developing the variants, the initial filling of the reservoir was assumed to be at the level of the maximum water damming level (MaxPP). For reservoirs in the first part of the works, a normal water damming level was also considered (apart from or instead of MaxPP). A hypothetical flood wave of maximum flow equal to the extreme design flow with a probability of exceedance ranging from 0.02% to 0.5% was assumed as the inflow to the reservoir, depending on the class of the dam (according to the Regulation of the Minister of Environment, 2007). For some reservoirs in the first part of the works (Besko, Chańcza, Świnna Poręba), hypothetical flood waves with a probability of exceedance of 0.1% or 0.01% were also considered.

In addition, failures of outlet works resulting in limited water discharge from the reservoir were assumed, but for reservoirs in the second part of the works these were assumed only for facilities for which the assumed inflow did not cause water to overflow the dam top.

Generally, two variants of dam failure were considered: water overflowing the dam or piping failure of the dam body for earth structures, and loss of stability of one or more sections as a result of damage to the dam body or water overflowing the dam top for concrete dams. In special cases resulting from technical conditions of the facilities, only one variant was considered. In the case of a cascade of reservoirs, when considering failure of the upper reservoir of the cascade, failure of the lower reservoir as a consequence of a catastrophic wave from the upper reservoir was also considered. In such a situation, the number of variants of the failure scenario could be as high as 4. For some reservoirs from the first part of the works (Besko, Chańcza, Świnna Poręba), more variants were analysed (from around a dozen to several dozen).

As a basis for the scenario of dam failures, the variant resulting in the largest area of flood hazard areas (FHAs) was selected, which was determined on the basis of model calculations and GIS analyses of modelling results (see chapter 8.1).

A detailed description of the selection and development of those variants is described in the Methodology BP (cf. "Methodology for the development of flood hazard maps and flood risk maps for areas exposed to flooding in the event of dam failure - part II").

A description of the scenarios adopted for the development of FHMs and FRMs for 26 analysed dams is presented in the table below (Table 1).

The description of the scenario includes information on:

- causes of dam failure (water overflowing the dam top or piping failure);
- probability of exceedance of the wave flowing into the reservoir;
- assumptions regarding the efficiency of outlet works.

Table 1. Flood scenarios for dams

No.	River basin district	Name of reservoir	Name of river [MPHP10k]	Description of scenario
1	2	3	4	5
Dams – part I				
1	Wisły (Vistula)	Besko	Wisłok	Dam failure of the Besko reservoir (on the Wisłok River) as a result of water overflowing the dam body during extreme design flood passage with 0.01% probability of occurrence and simultaneous failure of outlet works.
2	Wisły (Vistula)	Chańcza	Czarna (Staszowska)	Dam failure of the Chańcza reservoir (on the Czarna Staszowska River) as a result of water overflowing the dam body during extreme design flood passage with 0.01% probability of occurrence and simultaneous failure of sluices.
3	Odry (Oder)	Dobromierz	Strzegomka	Dam failure of the Dobromierz reservoir (on the Strzegomka River) as a result of water overflowing the dam body during extreme design flood passage with 0.05% probability of occurrence and simultaneous failure of outlet works.
4	Odry (Oder)	Mietków	Bystrzyca	Dam failure of the Mietków reservoir (on the Bystrzyca River) as a result of water overflowing the dam body during extreme design flood passage with 0.02% probability of occurrence and simultaneous failure of outlet works.
5	Wisły (Vistula)	Przeczyce	Przemsza (Czarna)	Dam failure of the Przeczyce reservoir (on the Czarna Przemsza River) as a result of piping failure during extreme design flood passage with 0.1% probability of occurrence and simultaneous failure of outlet works.
6	Oder	Słup	Nysa Szalona	Dam failure of the Słup reservoir (on the Nysa Szalona River) as a result of water overflowing the dam body during extreme design flood passage with 0.05% probability of occurrence and simultaneous failure of outlet works.
7	Wisły (Vistula)	Świnna Poręba	Skawa	Dam failure of the Świnna Poręba reservoir (on the Skawa River) as a result of water overflowing the dam body during extreme design flood passage with 0.01% probability of occurrence and simultaneous failure of sluices or outlets.
Dams – part II				
8	Odry (Oder)	Bukówka	Bóbr	Dam failure of the Bukówka reservoir (on the Bóbr River) as a result of water overflowing the dam body during extreme design flood passage with 0.05% probability of occurrence and simultaneous failure of outlet works.
9	Wisły (Vistula	Czorsztyn-Niedzica	Dunajec	Dam failure of the Czorsztyn reservoir (on the Dunajec River) as a result of water overflowing the dam body during extreme design flood passage with 0.02% probability of occurrence and simultaneous destruction of three spillway sections of the dam in Rożnów.
10	Wisły (Vistula)	Dębe	Narew	Dam failure of the Dębe reservoir (on the Narew River) as a result of destruction of three spillway sections of the dam during extreme design flood passage with simultaneous failure of outlet works.

No.	River basin district	Name of reservoir	Name of river [MPHP10k]	Description of scenario
1	2	3	4	5
11	Wisły (Vistula)	Dobczyce	Raba	Dam failure of the Dobczyce reservoir (on the Raba River) as a result of water overflowing the dam body during extreme design flood passage with 0.05% probability of occurrence and simultaneous failure of outlet works.
12	Wisły (Vistula)	Goczałkowice	Wisła (Vistula)	Dam failure of the Goczałkowice reservoir (on the Vistula River) as a result of piping failure of the dam body during extreme design flood passage with 0.05% probability of occurrence.
13	Odry (Oder)	Jeziorsko	Warta	Dam failure of the Jeziorsko reservoir (on the Warta River) as a result of water overflowing the dam body during extreme design flood passage with 0.02% probability of occurrence.
14	Wisły (Vistula)	Koronowo	Brda	Dam failure of the Koronowo reservoir (on the Brda River) as a result of piping failure of the dam body during extreme design flood passage with 0.02% probability of occurrence.
15	Wisły (Vistula)	Mylof	Brda	Dam failure of the Mylof reservoir (on the Brda River) as a result of water overflowing the dam body during extreme design flood passage with 0.3% probability of occurrence and simultaneous failure of outlet works.
16	Odry (Oder)	Nysa	Nysa Kłodzka	Dam failure of the Nysa reservoir (on the Nysa Kłodzka River) as a result of water overflowing the dam body during extreme design flood passage with 0.02% probability of occurrence and simultaneous failure of outlet works.
17	Odry (Oder)	Otmuchów	Nysa Kłodzka	Dam failure of the Otmuchów reservoir (on the Nysa Kłodzka River) as a result of piping failure of the dam body during extreme design flood passage with 0.02% probability of occurrence and simultaneous water overflowing the dam body of the Nysa reservoir.
18	Odry (Oder)	Pakość	Noteć Zachodnia	Dam failure of the Pakość reservoir (on the Noteć Zachodnia River) as a result of water overflowing the dam body during extreme design flood passage with 0.3% probability of occurrence and simultaneous failure of outlet works.
19	Odry (Oder)	Poraj	Warta	Dam failure of the Poraj reservoir (on the Warta River) as a result of piping failure of the dam body during extreme design flood passage with 0.02% probability of occurrence.
20	Wisły (Vistula)	Porąbka	Soła	Dam failure of the Porąbka reservoir (on the Soła River) as a result of destruction of three spillway sections of the dam during extreme design flood passage with 0.1% probability of occurrence and simultaneous failure of outlet works.
21	Wisły (Vistula)	Rożnów	Dunajec	Dam failure of the Rożnów reservoir (on the Dunajec River) as a result of destruction of three spillway sections of the dam during extreme design flood passage with 0.1% probability of occurrence.
22	Wisły (Vistula)	Solina	San	Dam failure of the Solina reservoir (on the San River) as a result of destruction of three spillway sections of the dam during extreme design flood passage with 0.1% probability of occurrence and simultaneous failure of outlet works.
23	Wisły (Vistula)	Sulejów	Pilica	Dam failure of the Sulejów reservoir (on the Pilica River) as a result of water overflowing the dam body during extreme design flood passage with 0.02% probability of occurrence and simultaneous failure of outlet works.

No.	River basin district	Name of reservoir	Name of river [MPHP10k]	Description of scenario
1	2	3	4	5
24	Wisły (Vistula)	Tresna	Soła	Dam failure of the Tresna reservoir (on the Soła River) as a result of piping failure of the dam body during extreme design flood passage with 0.02% probability of occurrence and simultaneous destruction of one spillway section of the Porąbka dam.
25	Odry (Oder)	Turawa	Mała Panew	Dam failure of the Turawa reservoir (on the Mała Panew River) as a result of water overflowing the dam body during extreme design flood passage with 0.05% probability of occurrence and simultaneous failure of outlet works.
26	Wisły (Vistula)	Włocławek	Wisła (Vistula)	Dam failure of the Włocławek reservoir (on the Vistula River) as a result of water overflowing the dam body during extreme design flood passage with 0.3% probability of occurrence and simultaneous failure of outlet works.

4. SCOPE OF DEVELOPMENT OF FHMs AND FRMs

Flood hazard maps and flood risk maps are developed for areas of potential significant flood risk identified in the preliminary flood risk assessment i.e. areas where a significant flood risk exists or is likely to occur.

As part of the review and update of PFRA in 2018, areas exposed to flooding in the event of flood caused by dams were also indicated as significant. In total, 26 dams were identified for which flood hazard maps and flood risk maps should be developed in the 2nd planning cycle.

In the first part of the works, FHMs and FRMs were developed for 7 facilities (Besko, Chańcza, Dobromierz, Mietków, Przeczyce, Słup, Świnna Poręba), for which the results of hydraulic modelling in the form of maximum water level elevations and water depths were available, developed under earlier projects carried out by RZGW in Cracow and IMGW-PIB.

In the second part of the works, FHMs and FRMs were developed for the remaining 19 facilities: Bukówka, Czorsztyn-Niedzica, Dębe, Dobczyce, Goczałkowice, Jeziorsko, Koronowo, Mylof, Nysa, Otmuchów, Pakość, Poraj, Porąbka, Rożnów, Solina, Sulejów, Tresna, Turawa, Włocławek.

The area coverage of FHMs and FRMs divided by the river basin districts is shown in the figure below (Figure 1).

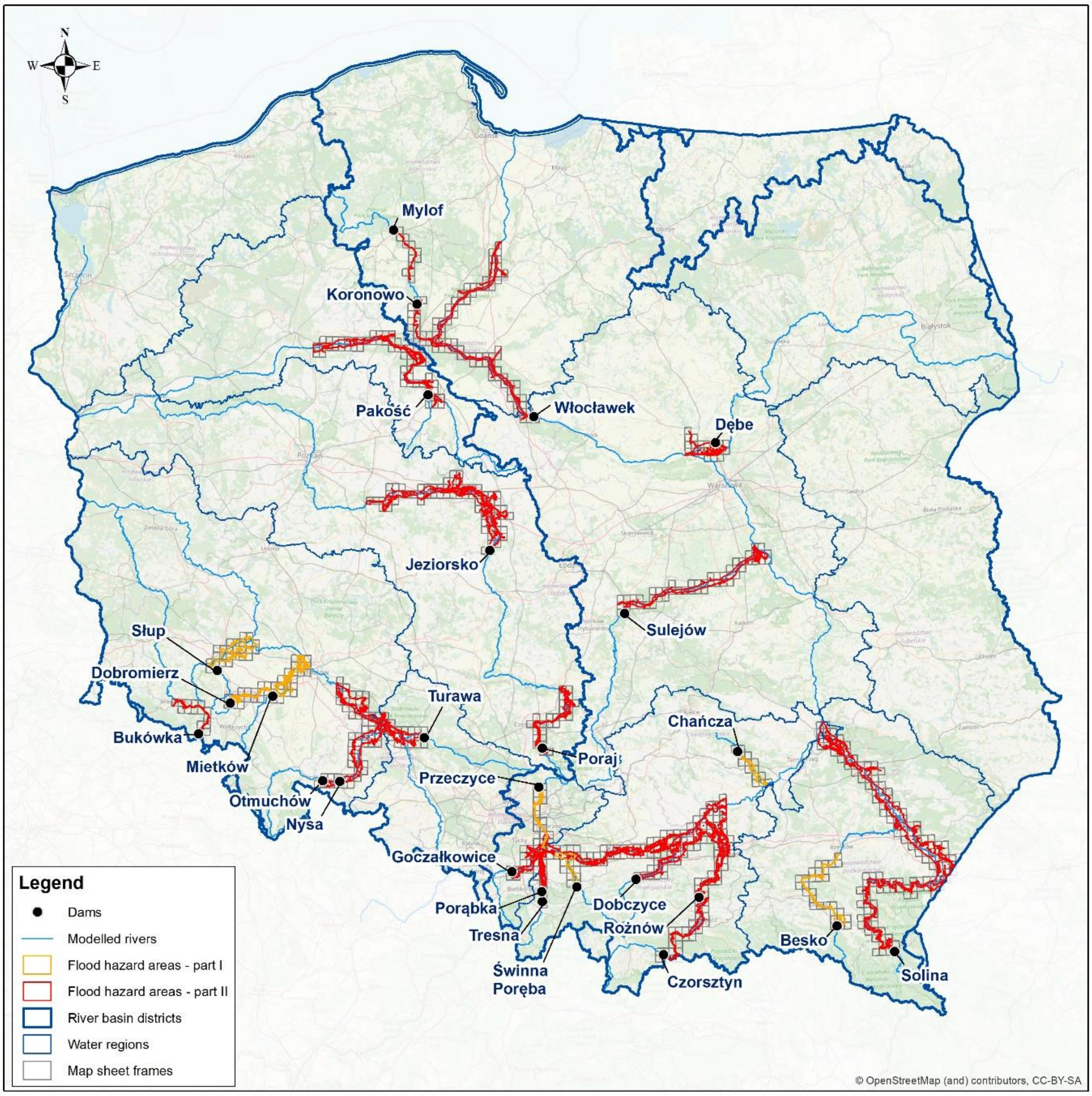

Figure 1. Location of dams and flood hazard areas for the scenario of dam failure

5. FORM OF FHMs AND FRMs

Flood hazard maps and flood risk maps for the scenario of dam failure were developed in digital form and include:

- spatial database;
- cartographic versions of FHMs and FRMs.

5.1 SPATIAL DATABASE

The FHMs and FRMs spatial database for the scenario of dam failure was prepared in shp format. It is a separate database with a structure consistent with databases for other flood types (attribute and directory structure, file naming). Differences in structure and file naming are only due to the specific nature of data and information in this scenario. FHMs and FRMs database includes:

1) **Reference layers:**
   - watercourses and canals;
   - other watercourses;
   - surface waters;
   - roads;
   - railway lines;
   - voivodeship;
   - district;
   - commune;
   - sheets of maps at a scale of 1:10 000 for PL-1992.

2) **Layers of flood hazard maps:**
   - flood hazard area for the scenario of dam failure;
   - water depth;
   - maximum water level;
   - location of dam failure;
   - dams;
   - top of flood embankment elevation in cross-sections;
   - flood embankments;
   - chainage;

3) **Layers of flood risk maps:**
   - land use with calculated potential flood damage;
   - land use;
   - buildings;
   - industrial plants;
   - water abstractions;
   - protection zones of water abstractions;
   - bathing waters;
   - forms of nature conservation;
   - areas of cultural heritage;
   - objects of cultural heritage;

- zoos;
- cemeteries (potential sources of pollution);
- landfills (potential sources of pollution);
- wastewater treatment plants and wastewater pumping stations (potential sources of pollution);
- cities.

Information about the current version of FHMs and FRMs sheet (e.g. 2019v1, 2022v1) is included in the layer containing division of map sheets (at a scale of 1:10 000).

A detailed description of the attribute structure of FHMs and FRMs database for the scenario of dam failure, layer names, layer types, layer description, data source and attributes (field name, field type, description, attribute source) are included in the methodology.

5.2 CARTOGRAPHIC VERSION

The cartographic versions of FHMs and FRMs for the scenario of dam failure are developed in the form of raster files, broken down into sheets corresponding to the sheets of topographic maps at a scale of 1:10 000, in EN-1992 rectangular flat coordinate system. Such cartographic versions were prepared in the following formats:

- pdf (version with description outside the frame, containing title, legend, scale, etc. besides the map content);
- geotiff (map content, without information outside the frame).

The map sheets in .pdf format contain information on the adopted scenario of dam failure, i.e.: causes of dam failure (e.g. water overflowing the dam top, piping failure), probability of exceedance of the wave flowing into the reservoir and assumptions regarding the efficiency of outlet works.

Orthophotomaps with a field pixel value of not more than 0.5 m provide the background for FHMs and FRMs.

Cartographic versions of FHMs and FRMs were made for the following types of maps:

1) flood hazard maps in one thematic set:
   a) flood hazard map with water depth;
2) flood risk maps in two thematic sets:
   a) flood risk map - potential adverse consequences for human life and health and the value of potential flood losses,
   b) flood risk map - potential adverse consequences for the environment, cultural heritage and economic activity.

A detailed description of all types of maps is included in Annex no. 2 to the methodology.

6. CONTENT OF FHMs AND FRMs

6.1 FLOOD HAZARD MAPS

Flood hazard maps are developed for areas of potential significant flood risk identified in the preliminary flood risk assessment i.e. areas where a significant flood risk exists or is likely to occur.

Pursuant to the Regulation (par. 5(2)), flood hazard maps are developed separately for each flood hazard area referred to in Article 169(2) of the Water Law.

Pursuant to Article 169(2)(3)(c) of the Water Law, flood hazard maps should show: **areas including those exposed to flooding in the event of dam failure.**

Only flood hazard maps with water depth are developed for areas exposed to flooding in the event of dam failure. Pursuant to par. 5(3) of the Regulation, flood hazard maps with water flow rate are not developed for floods from artificial water bearing infrastructure (par. 5(3) only applies to fluvial floods).

6.1.1 FLOOD HAZARD MAP WITH WATER DEPTH

Flood hazard maps show the depths of water in categories that determine the degree of hazard to people and the manner of impact on buildings, according to the Regulation:

1) $h \leq 0.5$ m – means low hazard to people and buildings;
2) $0.5 < h \leq 2$ m - means medium hazard to people due to the possibility of evacuation to higher floors of buildings, but high due to material damage;
3) 2 m $< h \leq 4$ m - means high hazard to people, but very high due to material damage; not only ground floors but also upper floors of buildings may be flooded;
4) $h > 4$ m - means very high hazard to people and very high hazard of total material damage.

Flood hazard maps with water depth show the following elements:

- water depth [m] - in four categories, as described above;
- maximum water level;
- elevation of the top of flood embankments or side dams;
- river chainage marked every 500m (for sections of modelled rivers within the limits of map sheet);
- flood hazard area for the scenario of dam failure;
- watercourses and canals and their names;
- surface waters;
- flood embankments;
- side dams;
- dams;
- location of dam failure;
- names of cities;
- commune boundaries;
- district boundaries;

– voivodeship boundaries;
– country border.

6.2 FLOOD RISK MAPS

Pursuant to Article 170 of the Water Law, flood risk maps are developed for flood hazard areas, for which flood hazard maps were made.

Flood risk maps specify the values of potential flood damage and show areas and structures exposed to flooding in the case of a flood with a certain probability of occurrence. Those are areas and structures that allow for the assessment of flood risk to human health and life, the environment, cultural heritage and economic activity, i.e. the four groups for which the adverse consequences of floods should be reduced in accordance with the objectives of the Flood Directive.

On the basis of the Regulation (par. 12(2)), flood risk maps are developed separately for each flood hazard area in two thematic sets described below.

6.2.1 FLOOD RISK MAP - POTENTIAL ADVERSE CONSEQUENCES FOR HUMAN LIFE AND HEALTH AND THE VALUE OF POTENTIAL FLOOD DAMAGE

Flood risk maps showing potential adverse consequences for human health and life and the value of potential flood damage show the following elements:

– estimated number of residents who are likely to be affected by the flood - given under the name of the city or village;
– residential buildings in the flood hazard area [water depth in m] less than and more than 2 m,
– buildings of social importance in the flood hazard area [water depth in m] less than and more than 2 m,
– buildings of social importance are marked as follows:
  - police stations - P,
  - nursery – żłb.,
  - kindergarten – przedszk.,
  - school – szk.,
  - fire stations - rem.,
  - border guard - SG,
  - hospital - szpit.,
  - health resort - san.,
  - social care centre, nursing home, hospice - d.op.,
  - shopping and service centre - c. han.,
  - hotel – H,
  - resort – d.wyp.,
  - educational care facility – d. wych.,
  - penitentiary, correctional or custodial facility – z. kar.,
– values of potential flood damage [PLN/m^2];

- river chainage (for sections of modelled rivers within the limits of map sheet);
- flood hazard area for the scenario of dam failure;
- watercourses and canals and their names;
- surface waters;
- flood embankments;
- side dams;
- dams;
- locations of dam failure;
- names of cities;
- commune boundary;
- district boundary;
- voivodeship boundary;
- country border;

6.2.2 FLOOD RISK MAP - POTENTIAL ADVERSE CONSEQUENCES FOR THE ENVIRONMENT, CULTURAL HERITAGE AND ECONOMIC ACTIVITY

Flood risk maps showing potential adverse consequences for the environment, cultural heritage and economic activity show the following elements:

- land use types:
  - residential areas,
  - industrial areas,
  - transportation areas,
  - forests,
  - recreational areas,
  - arable land,
  - grassland,
  - surface waters;
  - other areas,
- groundwater abstraction;
- surface water abstraction;
- abstraction protection areas;
- bathing waters;
- zoos;
- areas and objects of cultural heritage;
  - area, object of cultural heritage,
  - UNESCO World Heritage Site,
  - extermination monument,
  - open-air museum, museum,
  - library, archives;
- forms of nature conservation:
  - national park,
  - nature reserve,

  - Natura2000 site:
    - Special Protection Area (birds),
    - Special Area of Conservation (habitats);
- potential sources of pollution:
  - industrial plants:
    - installations which may, in the event of flood, cause significant pollution to some parts of the environment or the environment as a whole, for the operation of which it is required to obtain an integrated IPCC permit referred to in Article 181(1)(1) of the Environmental Protection Law, in the following categories of industrial activity:
      - energy industry,
      - production and processing of metals,
      - mineral industry,
      - chemical industry,
      - waste management,
      - other activities,
    - industrial plants with installations that do not require the permit referred to in item 1 and which may cause hazards, including plants with high and increased risk of major industrial failure within the meaning of Article 248(1) of the Environmental Protection Law;
  - (municipal, industrial, mixed) landfills;
  - wastewater treatment plants;
  - wastewater pumping stations;
  - cemeteries;
- river chainage (for sections of modelled rivers within the limits of map sheet);
- flood hazard area for the scenario of dam failure;
- watercourses and canals;
- names of watercourses and canals;
- flood embankments;
- side dams;
- dams;
- location of dam failure;
- names of cities;
- commune boundaries;
- district boundaries;
- voivodeship boundaries;
- country border.

Detailed information on the content of FHMs and FRMs in the digital version is given in Annex no. 1 to the methodology.

A description of the cartographic version of FHMs and FRMs including elements outside the frame and graphic symbols is given in Annex no. 2 to the methodology.

7. INPUT DATA FOR FHMs AND FRMs

The input data for the development of flood hazard maps and flood risk maps are listed in the tables below (Table , Table).

Table 2. List of input data for the development of FHMs

No.	Data	Name of institution/Database	Format	Data update
1	Orthophotomaps (pixel field size: 0.5 m; 0.25 m, 0.1 m)	Head Office of Geodesy and Cartography	tif	2010-2020
2	National Register of Boundaries and Areas of Territorial Division Units of Poland (PRG)		shp	2018
3	National Register of Geographical Names (PRNG)		shp	2018
4	Topographic Database BDOT10k		shp	2013-2018
5	Digital Terrain Model (DTM) and Digital Surface Model (DSM), pixel field size: 1 m		xyz, asc, tif, las, TIN	2010-2018
6	Map index 1:10 000		shp	nd
7	National Official Register of the Territorial Division of the Country (TERYT)	GUS	*xml, *csv	2017
8	Hydrological and meteorological data	Institute of Meteorology and Water Management - National Research Institute	doc, xls, pdf, tif, jpg and other	1926-2016[1]
9	Hydraulic models developed for fluvial floods for rivers with reservoirs	State Water Holding Polish Waters	sim11, couple, nwk11, xns11, bdn11, dfs0, hd11, dfs2, res11	2015, 2019
10	Map of Hydrographic Division of Poland MPHP10k		shp	2017, 2021
11	Updated instructions for water management in reservoirs		doc, xls, pdf, tif, jpg and other	2002-2017
12	Bathymetric measurements of reservoirs		txt, xls and other	2003-2008
13	Data on flood embankments - developed under the project uFHMs and FRMs and earlier		shp and other	2009-2019
14	Channel and valley cross-sections of rivers and civil engineering structures - developed under the project uFHMs and FRMs and earlier		shp, xls, jpg and other	2003-2019
15	Assessment of technical condition of dams	IMGW-PIB National Service for the Safety of Dams, MGMiŻŚ	doc, pdf, xls	2019

[1] start and end dates of data periods, on each reservoir these periods were different

Table 3. List of input data for the development of FRMs

No.	Data	Name of institution/Database	Format	Data update
1	Population	GUS/ System of Address Identification of Streets, Real Estates, Buildings and Dwellings (NOBC) GUS/ Local Database	xlsx,txt, docx,shp, pdf xlsx	2018 2018
2	Address points	GUGiK/Geoportal/Dictionary services	xml	2018
3	Residential buildings and facilities of particular social importance (hospitals, schools, kindergartens, nurseries, hotels, shopping centres, nursing homes, care homes, hospices, prisons, correctional facilities, detention centres, police units, firefighting units, border guard units)	GUGiK/BDOT10k database	shp	2018
4	Care homes, nursing homes	Voivodeship Office (UW)	shp, xlsx, docx	2018
5	Hospices	National Health Fund (NFZ)	xlsx	2018
6	Penitentiaries, custodies	Central Board of Prison Service (CZSW)	xlsx	2018
7	Correctional facilities	Ministry of Justice	xlsx	2018
8	Groundwater abstractions	PIG PIB PGW WP (Identyfikacja presji[1])	xlsx, shp	2019 2018
9	Surface water abstractions	GUGiK/zasób BDOT10k PGW WP (Identification of pressures)	shp shp	2018 2018
10	Protection zones of water abstractions	PGW WP	shp	2018
11	Bathing waters	PIS-GIS	shp	2018
12	Boundaries of Natura 2000 areas, including boundaries of Special Protection Areas for bird and Special Areas of Conservation	General Directorate for Environmental Protection (GDOŚ)	shp	2018
13	Boundaries of national parks	General Directorate for Environmental Protection (GDOŚ)	shp	2018
14	Boundaries of nature reserves	General Directorate for Environmental Protection (GDOŚ)	shp	2018
15	Fixed monuments	National Heritage Board (NID)	shp	2018
16	UNESCO World Heritage Site	National Heritage Board (NID)	shp	2018
17	Extermination monuments	The Act, Regulations of Ministry of Culture and National Heritage	pdf	2019
18	Open-air museums and museums listed in the National Register of Museums	Ministry of Culture and National Heritage	xlsx	2018
19	Libraries forming the national library resources	Regulation of the Ministry of Culture and National Heritage	pdf	2019
20	Archives forming the national archive resources	Ministry of Culture and National Heritage	pdf	2018
21	Zoos	GUGiK/BDOT10k database	shp	2018
22	Industrial plants	GUGiK/BDOT10k PGW WP (Identification of pressures)	shp shp	2018 2018
23	Industrial plants with high and increased risk of major industrial failure	Chief Inspectorate of Environmental Protection (GIOŚ) Voivodeship Inspectorate of Environmental Protection (WIOŚ) National Headquarters of the State Fire Service (KG PSP)	xlsx xlsx, docx, pdf, rtf pdf	2018 2018 2018

No.	Data	Name of institution/Database	Format	Data update
24	IPPC installations (register of installations with integrated permits)	register of installations with integrated IPCC permits	xlsx	2018
25	Cemeteries	GUGiK/BDOT10k database	shp	2018
26	Landfills	GUGiK/BDOT10k database PGW WP (Identification of pressures) Voivodeship Inspectorate of Environmental Protection (WIOŚ)	shp shp shp, xlsx, mdb, docx, pdf	2018 2018 2018
27	Wastewater treatment plants	Voivodeship Inspectorate of Environmental Protection (WIOŚ) PGW WP (Identification of pressures) GUGiK/BDOT10k database	shp, xlsx, pdf shp shp	2018 2018 2018
28	Wastewater Pumping Stations	GUGiK/BDOT10k database	shp	2018
29	Potential flood damage values calculated based on potential damage coefficients for each land use class in 2016	Consortium of IMGW-PIB/ARCADIS/MGGP	shp	2019
29	Cities	GUGiK/BDOT10k database	shp	2018
30	Land use	GUGiK/BDOT10k database	shp	2018

[1] Identification of pressures in water regions and river basin districts, 2018 (works carried out for PGW WP)

The key input data for the development of FHMs for dams are as follows:

- data on dams included in the maps (water management instructions, monographs of dams, technical condition assessment sheets of facilities);
- hydrological and meteorological data (data of IMGW-PIB: historical measurement data, hydrological characteristics, probable flows, flow curves, hypothetical waves);
- basic geodetic data (cross-sections, embankments and other civil engineering structures such as: bridges, dams, weirs, barrages, developed under the aMZPiMRP project, the ISOK project and previous studies);
- digital elevation data (DTM and DSM from the resources of GUGiK or separate studies).

In the modelling of dam failure, data from models prepared in the course of development of flood hazard maps for river scenarios were used i.e.: cross-sections, civil engineering structures, flood embankments and hydrological data (internal boundary conditions i.e. concentrated and distributed lateral inflows). These data needed to be supplemented with:

- new or extended valley cross-sections (the extent of flooding for dam failure exceeded the extents for the 0.2% scenario) which were determined based on the latest available digital terrain model;
- hydrological data required to calculate hypothetical waves flowing into the reservoirs (data collected during the development of flood scenarios for rivers were used);
- detailed data on dams required for modelling of failure of these facilities, such as: geometric parameters of the dam (including cross-section, location of benches and outlet works), material of the dam body and its technical parameters, information on the technical condition of the facilities - these data were obtained from current water management instructions for the reservoirs, technical condition assessments of dams and from information obtained directly from reservoir administrators.

8. SUMMARY OF THE METHODOLOGY FOR THE DEVELOPMENT OF FHMs AND FRMs

8.1 METHODOLOGY FOR THE DEVELOPMENT OF FHMs

The flood hazard maps for the scenario of dam failure show flood hazard areas with information on water depths.

8.1.1 METHODOLOGY FOR HYDRAULIC MODELLING

The basis for determining the extent of flood risk areas was a hydraulic model based on unsteady flow i.e. based on hydrographs of flood waves with a specified probability of peak flow occurrence. A hydraulic model based on steady flow was used only for the section of the Oder River affected by the failure of the Turawa, Nysa and Otmuchów reservoirs.

In most cases, the models developed for the purposes of FHMs and FRMs for fluvial floods were used. Calculations were based on 1D model (Mike 11) or, in certain cases, a combination of 1D and 2D models (hybrid model, Mike Flood). The model of water reservoir was an integral part of the hydraulic model.

Hydrodynamic model of dam failure

Mapping of the reservoir storage area and dam geometry

The description of geometry of the reservoir storage area was based in most cases on the reservoir storage curve and in some cases on cross-sections derived from bathymetric measurements (Mietków, Chańcza). The reservoir storage was calibrated for at least characteristic damming levels: NPP, MaxPP and for the level corresponding to the elevation of the dam top, taking the current reservoir storage curve as the reference.

The front dam of the reservoir was implemented as a spillway with a wide top with parameters corresponding to the real characteristics of the facility.

Rules for controlling outflows from the reservoir

The operation of the reservoir is described in accordance with the water management instruction during flood and the assumptions made about the failure of outlet works. The rules of control were introduced to 1D model using the CONTROL STRUCTURE function.

Model of dam failure

For individual variants of the failure, assumptions were made about hydrological conditions, initial filling level of the reservoir (cf. chapter 3.2) and parameters of simulated dam failure.

The parameters of dam failure were implemented in the calculation structure responsible for failure mapping (DAMBREAK STRUCTURE in 1D model). The implementation consisted in the introduction of calculation parameters concerning:

- the location of damage to the body in relation to the dam i.e. location of the breach (in the case of earth dam) or damaged sections of the dam (in the case of concrete dam);
- the geometry of damage (maximum width at the bottom, target elevation of breach bottom, inclination of side walls);
- the coefficients of resistance to the flow of water through the damaged part of dam body;
- the moment or conditions that determine the start of dam failure process (e.g. failure when the reservoir reaches a certain level of damming);
- the way in which the phenomenon of formation and spatial development of damage is described (time series - in the case of damage to concrete dams, erosion formulas – in the case of damage to earth dams);
- the causes that initiate failure (overflowing the top, piping failure).

In case of simulation of earth dam failure using erosion formulas, it was also necessary to determine the basic physical and mechanical characteristics of the soil of dam body.

Moreover, due to the necessity to define the initial boundary conditions for the calculations of breach formation or piping failure fissure over time, it was necessary to define the initial parameters of these structures i.e. the initial width and elevation of breach bottom in the dam body or the initial diameter of piping failure fissure and its elevation.

Hydrodynamic model of the valley below the dam

Diagram of the valley

The schematisation in 1D model is aimed at taking into account those features of the river valley that would influence the transformation of extreme flows, while neglecting insignificant details like small embankments, meanders and bends. This process was carried out for the reservoirs from the first stage of the works. In the second stage, the models developed for the purposes of FHMs and FRMs for fluvial floods were used.

Cross-sections

Cross-sections of the river bed and adjacent areas were obtained by means of geodetic measurements. DTM was used to obtain valley cross-sections. Cross sections were located perpendicularly to the main direction of the valley i.e. perpendicularly to the course of contour lines on the main slopes limiting the river valley. In hybrid models, combining elements of one-dimensional and two-dimensional modelling, cross-sections from 1D model were connected with the calculation grid of the two-dimensional model. Cross-sections prepared for fluvial flood simulation purposes were used, supplemented based on DTM if necessary.

Identification of hydraulic parameters

The basis for the determination of roughness coefficients were land cover classes determined at the stage of surveying or separated on the basis of BDOT10k, orthophotomaps and other available materials. Appropriate values according to Ven Te Chow were assigned to land cover classes. Due to high flow and rating values directly below the dam, the Manning roughness coefficient of n = 0.1 was assumed, in certain cases, for the section of 10 km directly below the dam.

The roughness coefficients, implemented in the model, were verified during the calibration process.

Civil engineering structures

The impact of artificial water bearing infrastructure such as: weirs, barrages, bridges or culverts, especially those located near the dam on the catastrophic flows resulting from dam failure is not significant. However, due to the calibration and verification of the model on historical waves, these structures were introduced into the model. For the purpose of hydraulic model construction, information on civil engineering structures surveyed during land surveying works was used.

Boundary conditions

In the developed models, the hydrograph of inflows to the reservoir, generally a wave with culmination equal to the extreme design flow of the dam, was taken as the upper boundary condition. The hydrograph of water levels or flow rating curve was the lower boundary condition closing the model, depending on modelling assumptions. Internal boundary conditions (concentrated and distributed lateral inflows) were assumed in most cases identical as in the $Q_{0.2\%}$ scenario. In some cases, lateral inflows on the river recipient, on which the analysed dam was located, were assumed as in the $Q_{10\%}$ scenario (lateral inflows of the Oder River in models of steady flow for the following reservoirs: Nysa, Otmuchów and Turawa).

Calibration and verification

In the case of hydraulic models created for the purpose of the analysis of flood wave transformation caused by dam failure, the process of calibration and verification of the model is performed only for the purpose of checking the general principles of its operation i.e. to determine whether the model properly transforms the flows down the valley and whether the relation between the values of water levels and flows at individual control points (river gauges) is maintained. Flows caused by dam failures are many times higher than the flows associated with typical floods caused by rainfall. Therefore, calibration of the model for such high flows is not possible due to the lack of appropriate historical waves.

Due to the use of models developed for the purposes of FHMs and FRMs for fluvial floods, in most cases the calibration process was carried out as part of the works concerning fluvial floods. The calibration and verification of the models were performed on large historical flood waves, selecting 2 flood waves for each reservoir.

The table below (

Table) shows the types of modelling used for individual dams.

Table 4. Type of hydraulic modelling for individual dams

No.	Reservoir	Name of river	Modelled section	Type of modelling[1]
1	Besko	Wisłok	76.9 – 183.9	1D
2	Chańcza	Czarna (Staszowska)	23.0 – 40.3	1D/2D
			0.5 – 23.0	1D
3	Dobromierz	Strzegomka	0.0 – 61.6	1D/2D
4	Mietków	Bystrzyca	16.3 – 44.8	1D
			0.0 – 16.3	1D/2D
		Strzegomka	0.0 – 24.5	1D
		Czarna Woda	0.0 – 5.4	1D
		Odra (Oder)	492.2–504.4	1D
5	Przeczyce	Przemsza (Czarna)	48.5 – 52.8	1D
			36.0 – 48.5	1D/2D
			0.0 – 36.0	1D
6	Słup	Nysa Szalona	0.0– 8.7	1D
		Kaczawa	0.0 – 42.3	
7	Świnna Poręba	Skawa	0.0 – 26.5	1D
8	Bukówka	Bóbr	208.4 – 269.5	1D
9	Czorsztyn-Niedzica	Dunajec	0 – 175.4	1D
		Wisła (Vistula)	740.7 – 775.6	1D
10	Dębe	Narew	0 – 29	1D
		Wisła (Vistula)	382.8 – 389.2	1D
11	Dobczyce	Raba	0 – 60.4	1D
		Wisła (Vistula)	768.8 – 816.9	1D
12	Goczałkowice	Wisła (Vistula)	788.7 – 960	1D
13	Jeziorsko	Warta	334.3 – 489.3	1D
14	Koronowo	Brda	0 – 49.1	1D
		Stare Koryto Brdy	0 – 10.3	1D
		Wisła (Vistula)	165.7 – 176	1D
15	Mylof	Brda	68.7 – 133.7	1D
16	Nysa	Nysa Kłodzka	0 – 65	1D
		Odra (Oder)	531.6 – 594.3	1D
17	Otmuchów	Nysa Kłodzka	0 – 77.2	1D
		Odra (Oder)	531.6 – 594.3	1D
18	Pakość	Noteć[2]	135.4 – 287	1D
19	Poraj	Warta	681.1 – 757.5	1D
20	Porąbka	Soła	0 – 34.1	1D
		Wisła (Vistula)	910.3 – 917.8	1D
21	Rożnów	Dunajec	0 – 82.2	1D
		Wisła (Vistula)	740.7 – 775.6	1D
22	Solina	San	0 – 340.3	1D
23	Sulejów	Pilica	0 – 137.7	1D
24	Tresna	Soła	0 – 41.7	1D
		Wisła (Vistula)	788.7 – 933.5	1D
25	Turawa	Mała Panew	0 – 18.4	1D
		Odra (Oder)	569.3 – 605.8	1D
26	Włocławek	Wisła (Vistula)	80.9 – 266.6	1D

[1] Type of modelling marked as: 1D - one-dimensional model, 1D/2D - hybrid model

8.1.2 DETERMINATION OF FLOOD HAZARD AREAS AND DEVELOPMENT OF FHMs

The final effect of the calculations simulating the dam failure is the development of maps on which flood hazard areas with water depth are presented.

The determination of flood hazard areas was based on the development of a digital water surface model (DWSM) on the basis of hydraulic modelling results. Combining the digital water surface model with the digital terrain model in GIS systems allows us to determine the flood hazard areas and the distribution of water depth.

The flood hazard maps for the scenario of dam failure were made in accordance with the methodology for fluvial floods (Methodology for the development of flood hazard maps and flood risk maps in the 2nd planning cycle. Version 7.00. IMGW-PIB, ARCADIS sp. z.o.o., 2020, works carried out for PGW WP). The specific nature of the scenario of dam failure was taken into account in terms of, among others, map names, legend content, database structure and catalogue structure.

8.2 METHODOLOGY FOR THE DEVELOPMENT OF FRMs

Flood risk maps present the potential negative consequences associated with flooding by specifying:

- negative consequences for human life and health;
- types of economic activities;
- protected areas;
- facilities that pose threats to the environment in the event of a flood, including those that may also have a negative impact on human health;
- cultural heritage areas and sites;
- value of potential flood damage.

The flood risk maps for the scenario of dam failure were made in accordance with the methodology for fluvial floods (Methodology for the development of flood hazard maps and flood risk maps in the 2nd planning cycle. Version 7.00. IMGW-PIB, ARCADIS sp. z.o.o., 2020, works carried out for PGW WP). The specific nature of the scenario of dam failure was taken into account in terms of, among others, map names, legend content, database structure and catalogue structure.

9. NON-TECHNICAL DESCRIPTION OF THE METHODS OF READING, SCOPE AND CONTENT OF MAPS

The flood hazard maps and flood risk maps for areas exposed to flooding in the event of dam failure were developed on the basis of the Act of 20 July 2017 - The Water Law (Journal of Laws of 2021, item 624, as amended) and the Regulation of the Minister of Maritime Economy and Inland Navigation of 4 October 2018 on the development of flood hazard maps and flood risk maps (Journal of Laws of 2018, item 2031).

Draft flood hazard maps and flood risk maps for the scenario of dam failure prepared by the State Water Holding Polish Waters in consultation with relevant voivodes were approved by the minister competent for water management (part I in 2020 - the Minister of Maritime Economy and Inland Navigation, part II in 2022 - the Minister of Infrastructure).

Maps for this scenario are developed for dams identified as areas of potential significant flood risk in the review and update of the preliminary flood risk assessment in 2018. These are dams closing large water reservoirs with damming levels generally above 15 m.

Dam failure is part of the scenario of extreme events, with very low probability of occurrence, referred to in Article 169(2)(1) of the Water Law and Article 6(3)(a)) of the Flood Directive.

Flows with a medium and high probability of flood occurrence, taking into account the method of water management in reservoirs, as described in water management instructions, do not cause a sudden increase in the reservoir filling level, which could be dangerous for the facility and lead to its failure.

These maps provide information for residents and local authorities about the potential risk of flooding in the event of dam failure. They can also be used as the basis for information in the planning of activities such as flood protection and crisis management.

However, it should be remembered that FHMs and FRMs for this scenario refer to an extreme situation in which the occurrence of a flood wave coincides with a technical failure of outlet works or damage to dam body. As a result, the dam is destroyed and the reservoir is drained rapidly, which makes the coverage of flood hazard areas for this scenario very wide.

Therefore, the areas presented in FHMs and FRMs for the scenario of dam failure are not flood hazard areas with significant flood risk within the meaning of the Water Law, so they do not constitute the basis for the reconciliation of planning and spatial development documents referred to in Article 166 of the Water Law.

FHMs and FRMs for this scenario present different variants of dam failures depending on the type and classes of buildings and structure of the facility.

The cartographic version of those maps includes a brief description of the failure variant adopted for each structure. This description contains information on:

- the probability of flood wave occurrence that was adopted to the simulation of dam failure;
- the assumptions regarding the efficiency of outlet works;
- assumed cause of dam failure (water overflowing the dam top or piping failure).

FHMs and FRMs were prepared in electronic form in the form of: spatial databases and in a cartographic version (in the form of pdf and geotiff files), divided into sheets corresponding to the sheets of topographic maps at a scale of 1:10 000.

The spatial database includes vector layers in shapefile format, on the basis of which it is possible to conduct spatial analyses in geographic information systems.

The cartographic version of maps in pdf format is a complete map containing the legend, including information on the adopted variant of dam failure.

The cartographic version of maps in geotiff format contains only the content of the map with a specific spatial reference, which enables their use in spatial information systems.

Flood hazard maps show areas which include areas exposed to flooding in the event of dam failure, with water depth (h) assigned to these areas in classes determining the degree of hazard to people and the way the water affects buildings:

- $h \leq 0.5$ m – indicating low hazard to people and buildings;
- $0.5 < h \leq 2$ m - indicating medium hazard to people due to the possibility of evacuation to higher floors of buildings, but high due to material damage;
- 2 m $< h \leq 4$ m - indicating high hazard to people, but very high due to material damage; not only ground floors but also upper floors of buildings may be flooded;
- $h > 4$ m - indicating very high hazard to people and very high hazard of total material damage.

Flood risk maps identify the values of potential flood damage and show facilities important for human health and life, the environment, cultural heritage and economic activity that are exposed to flooding in the event of dam failure.

Flood risk maps show in particular:

- estimated number of residents who are likely to be affected by the flood;
- residential buildings and facilities of particular social importance, the operation of which may be impeded or rendered impossible by flooding (i.e.: hospitals, schools, kindergartens, nurseries, hotels, shopping and service centres, social care centres, nursing homes, hospices, penitentiaries, correctional facilities, custodial facilities, police stations, fire stations, border guard), with a water depth zone assigned to them;
- types of economic activities performed in flood hazard areas, in the form of land use classes (residential areas, industrial areas, transportation areas, forests, recreational areas, arable land and permanent crops, grasslands) and the values of potential damage for particular land use classes;
- areas and objects of cultural heritage;
- protected areas, including: water abstractions, bathing waters, Natura2000 sites, national parks, nature reserves, zoos;
- potential sources of water pollution in the event of flooding i.e. industrial plants, wastewater treatment plants, wastewater pumping stations, landfills, cemeteries.

Flood risk maps are prepared in two thematic sets:

- potential adverse consequences for human health and life and values of potential flood damage;
- potential adverse consequences for the environment, cultural heritage and economic activity.

Flood hazard maps and flood risk maps form the basis for the development of flood risk management plans that include measures aimed at reducing the adverse consequences of floods for human health and life, economic activity, the environment and cultural heritage.

More information about FHMs and FRMs can be found at: www.powodz.gov.pl.

Maps in cartographic version in pdf format are available at: http://mapy.isok.gov.pl.

Maps in digital (vector) version are available at: https://isok.gov.pl/hydroportal.html.

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