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Modelling of Flood Hazard Zone for the Łęg River****

1. Introduction

Floods and their intensification in terms of the frequency of occurrence and the power of high water rises during the last century all over the world cause that they are becoming a global problem. More and more institutions are established that deal with the issue of floods.

The main objective of those institutions is to minimize the negative results of floods as regards to the economic, social, and nature-related aspects. One of such institutions is the European Exchange Circle on Flood Mapping (EXCIMAP). It was established in 2006, with its main objective being the exchange of information between particular European states about producing flood maps. Also, legal action has been initiated in order to prepare Member States for coping with flood disasters.

In November 2007 the so-called "Flood Directive" was enacted on the assessment and management of flood risks [2]. The directive determines schedules and scopes of operations and action to be undertaken by EU Member States within the framework of flood prevention. It imposes, among other things, an obligation to prepare planning documents concerning flood risk management in line within a coherent approach, uniform for the whole Europe, and to provide public access to information and results of all flood-related assessments, maps and plans. It obligates Member States to prepare and publish preliminary flood risk

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assessments, flood hazard maps, flood risk maps, as well as flood risk management plans [2, 7, 8].

As far as Poland is concerned, tasks related to the preparation of flood hazard maps are governed by the *Regulation of the Minister of Environment, the Minister of Infrastructure, and the Minister of Internal Affairs and Administration of 22 January 2013 Concerning the Preparation of Flood Hazard and Risk Maps*. According to the provisions of that regulation, areas endangered with flooding are shown as surface objects with occurrence probability values assigned to them [15]. Those areas are outlined based on water elevations calculated as a result of hydraulic modelling with the use of GIS and DTM tools. The hydraulic modelling is split into single-dimensional models, in which the velocity vector has a single component, and two-dimensional models, in which the velocity vector has two components. Two-dimensional models are produced for province and county capitals, as well as cities inhabited by more than 100,000 people. For the remaining terrains, single-dimensional models are provided [9, 15].

According to the said regulation, maps should show, among other things, the following: flood hazard zone limits, maximum water table elevations calculated through hydraulic modelling, natural water courses and canals with their names, water reservoirs, flood banks, names of localities, background map (prepared on the basis of a topographic map or an orthophotomap of terrain pixel not bigger than 50 cm) [15].

This paper presents a process of working up a flood zone for the Łęg river in the Podkarpackie province of Poland. The zone provided a basis for the preparation of a flood hazard map, and for the performance of an analyses based on which it became possible to preliminarily assess the flood risk for the selected area.

2. Study Area

The area, for which the flood hazard and flood risk map was prepared, covers a strip of the Łęg river valley (ca. 4 km long) below the water reservoir dam in the village of Wilcza Wola, in the district of Kolbuszowa (the Podkarpackie province) (Fig. 1). Land within the small distance from the river bed is used mainly for agricultural purposes, or is overgrown with bushes and single tree clumps. The river bed is unregulated. There are two bridges within the examined river section: one is a wooden bridge on reinforced-concrete supports with metal cross-beams, while the second is a wholly reinforced concrete bridge, with an asphalt surface course. Houses and buildings can be found at the whole length of the area under consideration, within average distances of 150–500 m from the river bed. However, there are a few farms located in a distance smaller than 100 m.

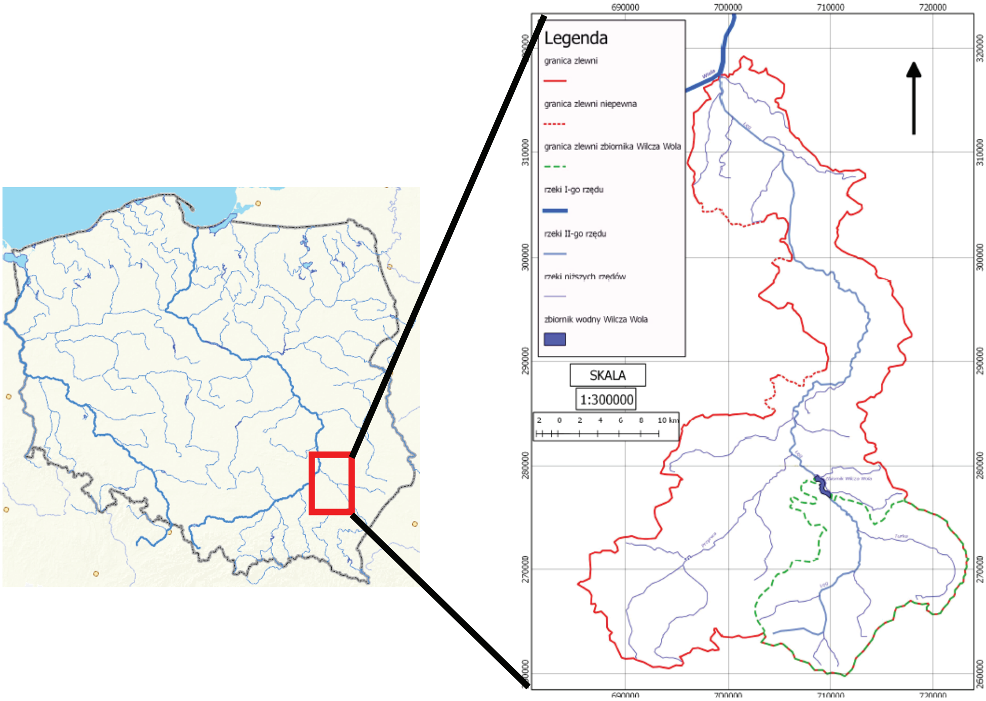

Fig. 1. Area under consideration – the Łęg river basin

3. Data

To produce the flood zone, a hydrological model was used, made in 1984 by Hydroprojekt Company from Warsaw, as well as Digital Terrain Model (DTM). The hydrological model is part of a document called *Operation Plan in Case of a Construction Disaster of Water Reservoir at Wilcza Wola* [14]. It presents a hypothetical flood scenario, with flood occurring as a result of dam construction disaster. The scenario assumes that the dam bank has been washed away or that the weir has been damaged, with the emergence of a gap in the dam bank of the assumed width of 50 m. The calculations assumed that the reservoir would be filled up to the level of 188.50 m. In case of such a level, there may be a violent maximum outflow of water amounting to Q = 967 m^3/s. Based on theoretical methods and *Awaria* software (Hydroprojekt Warsaw), flood wave elevations were calculated for cross-sections outlined along the river (Tab. 1). Those cross-sections were outlined in such a way, so that they were close to human settlements [14].

Table 1. Maximum flood wave elevations in particular localities for the area of flood hazard map preparation

Locality or name of settlement	Maximum flood wave elevation [m a.s.l.]
Maziarnia, Guściory (places close to the dam)	186.50
Zaruda, Zmysłów	182.28
Serafiny, Puzie, Suchodoły	180.08

Source: [14]

The Digital Terrain Model was obtained from resources held by the State Centre for Survey and Topographic Documentation (CODGiK). Altitude data were recorded in the PUWG 1992 Cartesian coordinate system and Kronsztad 86 altitude system. The DTM was made based on analogue aerial photos, scale 1:14000, subjected to the process of scanning with 14-μm pixels. The DTM was recorded as a regular grid of squares (25 m), supplemented with characteristic structural lines. The mean square error calculated based on model control profile and photo control points amounted to 0.28 m and 0.41 m, respectively.

In order to examine the area under consideration in terms of risk of flooding of selected surface objects, the Topographic Data Base (scale 1:10000, sheet M-34-56-D-d-3) was used. The Data Base was obtained from the resources owned by the regional centre for survey and topographic documentation (WODGiK).

The following layers were utilized for analyses:

- buildings,
- grassy and arable lands,
- permanent farming lands,
- forests or wooded lands,
- compact, dense or dispersed development lands,
- residential complexes,
- roadway sections,
- water areas,
- river and canal sections.

Orthophotomap (pixel 50 cm) obtained from the resources of the WODGiK (sheets: M-34-056-D-d-3-1, M-34-056-D-d-3-2, M-34-056-D-d-3-3, M-34-056-D-d-3-4), and a topographic map, made available as WMS layers by the Central Office for Geodesy and Cartography, were used to produce a background map.

The project made also use of the open-source software: QGIS and GRASS, which enabled us to prepare hydrological analyses that employed both vector and raster data, as well as Geomedia Professional software. The said programs are able to cooperate with external databases, to provide 2D and 3D visualizations, and to present analysis results.

4. Flood Hazard Map Preparation Methodology

Cross-sections of identified flood wave altitude elevations provided grounds for works related to flood zone modeling [13]. Based on information from the hydrological model, cross-sections were plotted on the map. Next those cross-sections were densified by means of two additional auxiliary cross-sections that were located in half of the distance between the already existing ones. The flood wave altitude for those auxiliary cross-sections was calculated by averaging altitude elevation values for neighbouring cross-sections. River kilometre values for particular cross-sections were determined on the basis of measurements performed directly on the map, and the known river kilometre value for the dam. The distribution of cross-sections is shown below (Fig. 2), where cross-sections were additionally provided with flood wave altitude elevation values and river kilometres.

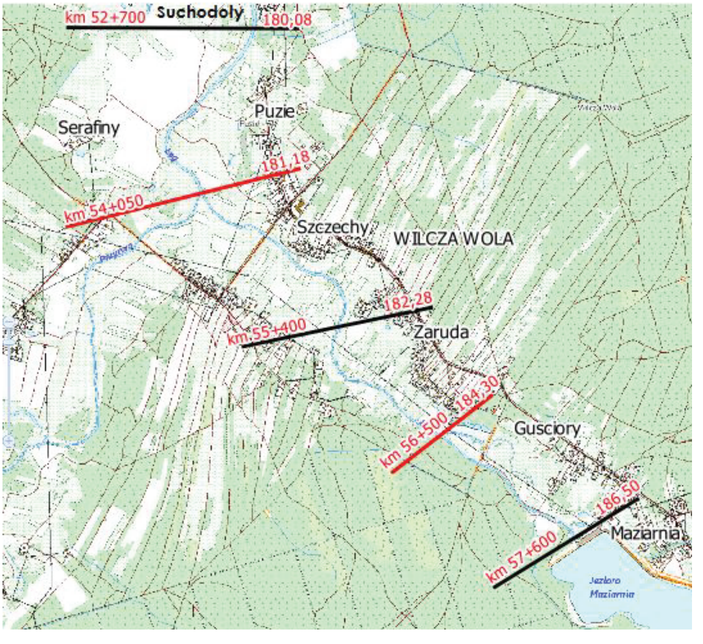

Fig. 2. Determining main (black colour) and auxiliary (red colour) cross-sections
Source: [12]

The elevation of flood wave rise in the flood area under examination is systematically dropping down, as the distance from the dam grows. This is proved by elevations at next cross-sections. Based on the DTM and flood wave elevations, "partial flood zones" have been generated, as a difference between the DTM and digital model of water surface. There were five such zones for the area around each of cross-sections established. Flood zones were generated for the following high water levels: 186.50 m; 184.30 m; 182.28 m; 181.18 m; 180.08 m. Particular partial zones were plotted based on wave damming elevations at particular cross-sections, that is why it was assumed that the error of determination of flood zone limit point at the intersection of the cross-section with its corresponding partial zone equalled zero. The so generated "partial zones" of various flood wave altitudes provided the basis for the interpolation of the total flood zone. Flood limits between neighbouring cross-sections were interpolated based on overlapping partial zones. During interpolation, also distances between interpolated points of flood limits and the adjacent were considered. The way of interpolating is shown on the longitudinal profile of the river (Fig. 3).

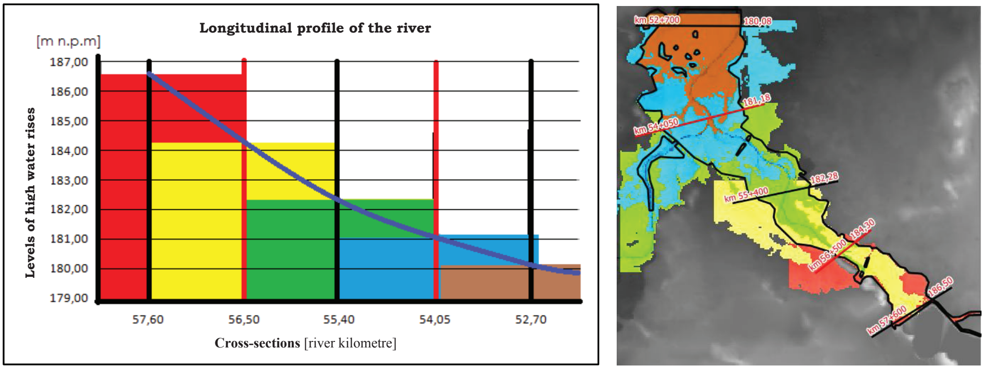

Fig. 3. Longitudinal profile of the Łęg river section below the water reservoir dam in the village of Wilcza Wola showing flood wave pattern, as well as levels of high water rises and ranges of determined partial flood zones

Source: [12]

The framework of research work as presented herein also included performing an analysis to assess flood risk in terms of inundation hazard posed to selected land surface objects [11]. The GIS analyses for the outlined flood zone were performed with the utilization of the Topographic Data Base. Following a detailed study of topography of the area under consideration, all operations were repeated in relation to three zones there were created as a result of the basic zone extension by 25 m, 50 m, and 100 m, respectively (Fig. 5). As a result of the operations performed, surfaces of inundated areas were obtained, with division into specific land surface forms (forests, agricultural land, developed areas). Additionally, a risk analysis was performed in relation to developed areas in terms of need to evacuate local residents [1, 10]. To that purpose, the number of real estates and buildings was analysed, for which there exists a direct exposure to flood. Taking into account their functions, the buildings were divided into three types: residential, farming, and other buildings (including public buildings).

5. Results

The obtained map shows a hypothetical flood scenario. According to assumptions, flood would be caused by the construction disaster of the water reservoir dam. The study presents the maximum reach of the flood wave, without describing the depth and flow velocity of water in the point (Fig. 4). On the map, the PUWG 1992 system cartographic grid was plotted, with grid crosses at distances of 1,000 m.

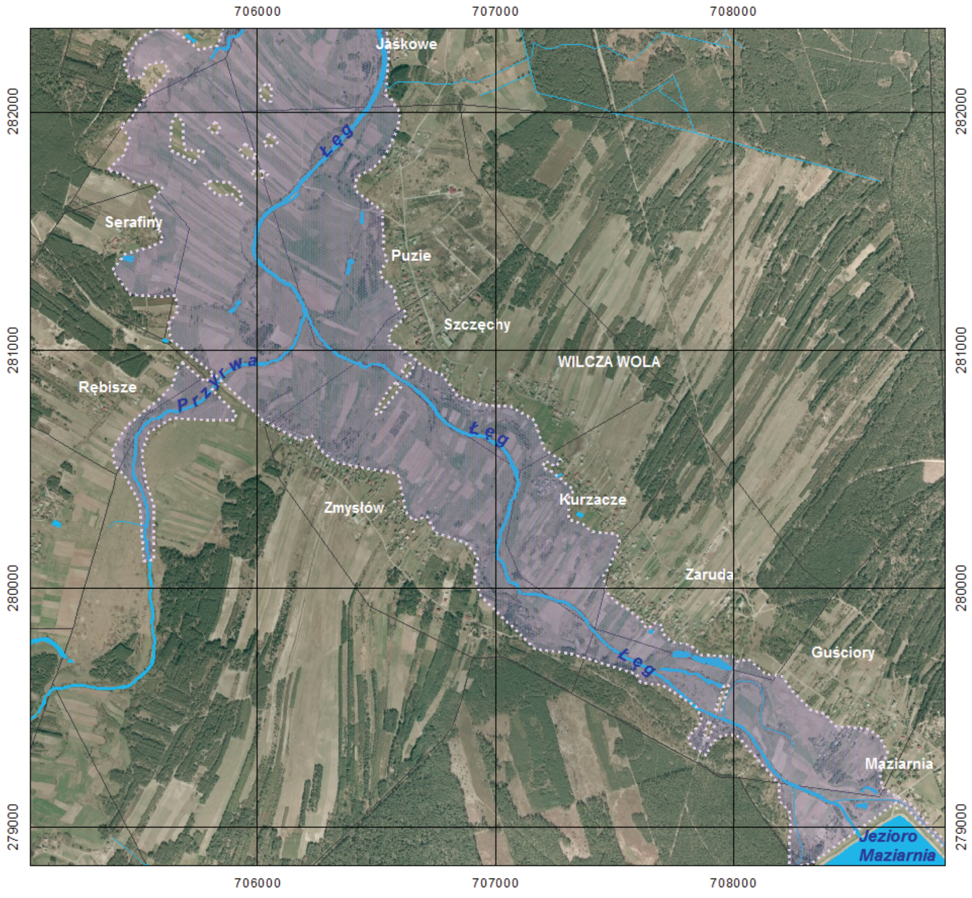

Fig. 4. Flood zone for the Łęg river on the orthophotomap background

Based on a GIS analyses, an estimated impact of possible flood on inhabitants of the examined area and on selected land surface objects was assessed [1, 7]. As the charts below show (Tabs 2, 3), the projected flood will result in the fact that a large part of inundated areas (250 ha out of total 284 ha) will be arable land (ca. 88%). Due to the poor level of afforesting of the river valley, the surface area of forests endangered with the direct inundation hazard constitutes only 6% (18.2 ha) of the total flood zone area. On the other hand, the total length of road sections within the flood zone amounts to 8,517.40 m. The actual surface area of developed land (surface area of 60 real estates) is 4.9 ha (2%). There are 108 buildings within the basic flood zone, including 34 residential buildings and 74 farming buildings. For the analysis of risk that directly impacts upon human life, the results of GIS analyses were utilized that provided information on the number of residential buildings within the basic flood zone limits, as well as data from the Central Office of Statistics (GUS) on the average number of persons per single household. According to the GUS 2011 data, that number is 2.87 persons per 1 household [3].

Table 2. List of surface areas and lengths of land surface objects in the areas of outlined flood zones

Zone	Surface area [ha]			
	zone	forests	agricultural land	developed land
Flood zone	283.9	18.2	249.4	4.9
+25 m	331.5	28.6	276.2	10.2
+50 m	375.2	39.3	296.0	17.2
+100 m	461.9	61.3	331.7	32.6

Table 3. List of the number of inundated buildings and real estates in the areas of outlined flood zones

Zone	Number					
	real estates	total buildings	residental buildings	farm buildings	other buildings	persons to be evacuated
Flood zone	60	108	34	74	0	136
+25 m	108	218	61	155	2	244
+50 m	138	340	104	233	3	416
+100 m	212	553	221	326	6	884

Taking into account the fact that the area under consideration is a rural one, where the average number of persons per single household is higher than in the cities, the average number of 4 persons per household was assumed for the needs of this study. Given such an assumption, the number of 136 persons that need to be evacuated was obtained. It is noteworthy that with the extension of the basic zone by only 25 m, the number of examined land development objects increases twofold. Accordingly, in the risk zone there will then be 108 real estates (61 residential buildings and 155 farming ones, 2 educational and sports buildings) of the total surface area of 10.2 ha (Fig. 5). Therefore, also the number of persons to be evacuated from the hazard zone will considerably increase to reach 244. That fact demonstrates that calculations and operations related to the outlining of flood zones are crucial for results of assessing the potential risk that may affect human life [4, 5].

Fig. 5. Flood zone for the Łęg river on the orthophotomap background

The extension of the flood zone by 50 m and by 100 m has also caused a large increase in the surface areas of developed land endangered with flooding to 17.2 ha and 32.6 ha, respectively. Accordingly, there will be 340 and 533 buildings in the risk zones (Fig. 5). The number of persons to be evacuated increases twofold with each extension of the flood zone, to reach 416 and 884 persons, respectively. The surface area of inundated forests will increase more than three times (18.2–61.3 ha), and the same about the total length of roads endangered with flood (8–24 km).

6. Summary

The determined flood zone may become a basis for the performance of various flood-related GIS studies. Combining the project with GIS databases concerning the area under examination makes it possible to assess potential material losses or may provide auxiliary material for the preparation of crisis management plans in case of flood [16]. Those combined data may also be used in the preparation of local area development plans. It should be stressed that the correctness of assumptions, the proper correctness of data, as well as the correctness of performing calculations and operations related to the flood zone determination highly affect results of analyses the of the potential flood risk occurrence.

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