Hydraulic and Legal Conditions for Buildings in Floodplains-Case Study of Kalisz City (Poland)

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Abstract. The 2000 Water Framework Directive (WFD) and the 2007 Floods Directive (FD) have forced the member states of EU to introduce specific regulations and rules related to the development of flood plains. An important assumption of the introduced regulations is the gradual postponement of buildings from areas endangered by flooding. This is a rational approach from the point of view of minimizing the risks associated with flooding. However, many cities are located on rivers. The growth of these cities is not possible or would be very limited without the possibility of developing areas very close to the river. Therefore, a conflict of interest arises between local self-government authorities, entrepreneurs, private persons and institutions responsible for flood protection and water management. The first group see urban areas in the vicinity of the river as economically attractive and the latter as the potential increase in the risk of flooding. The main purpose of the work is to present the scope of hydraulic analyses supporting the decision-making process on the development of flood plains. In the conducted research, a case study was used for the city of Kalisz located in central Poland on the Prosna River. It is being planned to build a housing estate in Kalisz within areas threatened by flooding. Although, inevitably, Kalisz has its residential, administrative and industrial buildings located very close to the Prosna River, the city's system of flood protection is unsatisfactory, mainly due to the lack of funds. The local water management board is very reluctant to refer to projects related to the development of areas in the vicinity of watercourses, which, in its opinion, will further increase the risk of flooding. The paper shows that carrying out detailed hydraulic, design and construction analyses significantly supports the legal process of issuing permits for the development of areas threatened by floods.

1. Introduction
The history of human and social development is inextricably linked with the use of water resources that begins with ancient Egypt and Mesopotamia (sometimes considered as hydraulic states) through the industrial revolution in the nineteenth century, and ends with the development of large urban agglomerations and highly productive agriculture of the late twentieth and early twenty-first century. The many years' works on the regulation of rivers, the construction of embankments and other hydro-technical objects has significantly changed their natural hydrological regime [1–5]. These activities have also targeted natural retention areas previously flooded with high water towards their economic use.
Areas that are a part of natural floodplains are particularly valuable within large urban agglomerations, where they were and are intended for development. The development of buildings in areas threatened by flood obviously changes the hydraulic conditions of flood flow by reducing the valley's retention capacity and changing the distribution of the velocity field of flowing water. The impact of these changes must be estimated in the initial phase of preparing and planning such an investment. Quantitative forecasting of changes in the flow regime in watercourses caused by human interference (construction of barrages, embankments, polders or changing the way of floodplain management) requires computational deterministic models that are based on the mathematical description of this physical phenomenon [6–10]. Only this type of model, commonly referred to as hydrodynamic, is able to provide a quantitative answer necessary for the conduct of engineering practice, water management, flood protection, economics of riverside areas or ecological aspects [11]. With any change in a parameter describing the watercourse, it is still possible to determine its quantitative impact on the flow transformation in a given section of the river [12].

The 2000 Water Framework Directive (WFD) and the 2007 Floods Directive (FD) in force in European Union countries attempt to provide formal and legal conditions for the development of areas threatened by floods. First of all, these directives try to minimize the threat and risks associated with flooding through the recommendation for postponement of residential housing and industrial development from watercourses flowing in areas where such facilities have not been built yet. This is a rational and logical approach, however, it significantly affects urban development directions of cities located on large watercourses. Furthermore, these directives have forced EU member countries to develop flood hazard maps and flood risk maps, which support the process of creating local land development plans passed by local government authorities.

In many EU countries (including Poland) a building permit cannot be issued without the consent of the authorised water management board, responsible for part of the watercourse and flood plains on which the investment is planned. In Poland, the authority accountable for issuing such a permit is a regional branch of the National Water Management Authority “Wody Polskie” – the Regional Water Management Board.

An investor planning to develop a part of the floodplain must provide a conceptual plan for the development, based on which it will be possible to assess the impact of the investment on local hydraulic conditions. There are many different construction solutions that might be adapted to the conditions associated with inundation risks and prolonged impact of water. Paszczak et al. [13] presented projects of houses floating or partially immersed in water used in the Netherlands, the USA or Asian countries. Of course, the development in floodplains is more than only buildings, as it also includes road and municipal infrastructure. It is necessary to adapt it to the conditions of prolonged inundation and flooding. The recommendation applies in particular to water, sewage and electrical installations.

Figure 1 presents the schematic documentation workflow and main participants in the process of issuing consents by local water management boards. In the event of non-consent, the investment is blocked or begins appeal proceedings in accordance with applicable national administrative laws. In Poland, the regulating body is the Administrative Procedure Code. Therefore, it is important for the Investor to present a coherent and complete application including a substantive analysis of the effects of the planned investment on the hydrological regime. In practice, the local water management board will always choose the “safe” option from the point of view of flood protection, i.e. demonstrate the negative impact of the planned investment on flood protection and risk associated with flooding. The board will also rely on guidelines provided in the Water Framework Directive and the Floods Directive. The investor is entrusted with a more difficult task - to show that although the investment obviously increases the threat and risk of flooding, the risk itself is so insignificant that it does not pose a threat to other facilities and buildings located nearby.
2. Legal considerations - stages of acquiring the development consent for floodplain areas

![Diagram](image)

**Figure 1.** Schematic documentation workflow in the decision-making process of issuing development consents for floodplain areas

3. Case study – Kalisz city

Kalisz is a city with county rights in central-western Poland (figure 2), located on the Kalisz Upland, on the Prosna river, at the mouth of the Śwędrnia river. It is the second largest unit of territorial administration and local government in the Greater Poland Voivodeship, the seat of Kalisz County, one of the two main centres of Kalisz-Ostrów agglomeration and Kalisz-Ostrów Industrial District.

The main urban infrastructure is located directly at the so-called Kalisz Waterway System (KWS) consisting of the Prosna and Śwędrnia rivers and the Bernardyński and Rypinkowski channels (figure 3). Both rivers and channels flowing through Kalisz and the related hydro-technical buildings are a landscape attraction of the city and its distinctive hallmark. Unfortunately, flood protection is insufficient in Kalisz. The weakness of the system was demonstrated, among others, by a flood in May, 2010. During the passage of flood wave with \( Q_{10} \) (flood discharges with a statistical recurrence interval of 10 years), large areas of the city were flooded and inundated (figure 4). In accordance with the guidelines applicable in Poland, cities and urban agglomerations should have a flood protection system allowing a safe passage of flood wave with \( Q_{100} \) (flood discharges with a statistical recurrence interval of 100 years). This applies first of all to the outskirts of Kalisz located on the Śwędrnia River (figure 3) and over the Prosna riverbed below the strict city centre.
Therefore, it cannot be surprising that the local water management board attempts to limit further expansion of residential housing and industrial development in floodplain areas of the city.

Figure 2. Location of the city of Kalisz (Poland)

Figure 3. Kalisz Waterways System, localization of planned residential housing (red plot) and area of direct hydraulic connection (blue plot on the upper-left corner)
3.1. Location of the planned residential housing
The planned investment is located in Kalisz near Wał Bernardyński street (plot no. 22/14), and its visual location is marked on a map and presented in figure 5a. It is 2 kilometres away from the strict centre of Kalisz and 400m from the inner city ring. It is situated in the immediate vicinity of the Bernardyński Channel (15 m), from which it is hydraulically separated with use of embankments that ensure a safe passage of flood wave with HQ₁₀₀ probability. For flows lower than HQ₁₀₀, the plot is connected to the Prosna River, which is almost 450 m away.

According to the data from a simplified extract of the land register, the total area of the plot is 1.0777 ha.

Figure 5. a) Location of the planned residential housing along with marked points of field measurements b) The plot - view from the south-west side. There are visible fallen trees and varied forms of vegetation.

The plot is covered with various vegetation, in different developmental stages (figure 5b). It was probably used for gardening and horticultural activities. There are a large number of fruit trees, shrubs of blackberries and raspberries as well as remains of greenhouses or hotbeds.

Terrain features are varied, and the maximum difference in altitude calculated according to DEM based on LIDAR is 1.91 m. The highest elevations of the area are in the northeast part, directly on Wał Bernardyński Street. The ground lowering with ordinates less than 100.10 m is located inside the plot.
3.2. Conceptual design of the planned housing estate

According to the conceptual design in the form of a schematic arrangement of individual buildings and their basic contour dimensions as well as the information obtained from the Investor, the plot will completely change its existing form of development. The area will be developed with residential buildings and pavements while ensuring that rainwater is to be drained from the property. It is being planned that the ordinate of floors on the first level of buildings will be 102.5 m a.s.l. exceeding the water table ordinate by 0.9 m with HQ100 probability given by the Regional Water Management Board in Poznań. If the ordinates of buildings are elevated, it will avoid significant losses during the passage of high water. The proposed solution refers to terps (artificial dwelling mounds situated in areas threatened by flooding) used by Dutch settlement groups called Olęders as early as in the 16th century [14]. Adapting buildings to threats posed by the passage of flood waters allows for carrying out economically and socially justified land management policy in floodplain areas. This applies in particular to the areas where the value of municipal, industrial and residential infrastructure makes the construction of flood embankments uneconomical.

4. Hydraulic analysis of the impact of the Planned Investment on hydraulic conditions of the flow

4.1. Materials and methods

The basic reservation expressed by the local water management board to the planned investment was that it would reduce the retention of flood plains resulting from the Investor's proposal to elevate the terrain ordinates in the area of the plot. It was necessary to determine with an utmost precision the volume of lost valley retention and its impact on the distribution of states and flows in the immediate vicinity and in the entire Kalisz Waterways System.

The following materials were used for the purpose of the research and analysis: a Data Elevation Model (DEM) based on LIDAR (Light Detection and Ranging); flood hazard and flood risk maps developed under the ISOK project (Polish IT System Against Extreme Hazards) available at www.isok.gov.pl, the orthophotomap and data on bathymetric and valley cross sections held by the Institute of Construction and Geoengineering of Poznań, the University of Life Sciences. The basic test tools were: one-dimensional SPRUNER flow modelling system based on de Saint-Venant equations [7], GPS Sokkia surveying system enabling measurement of terrain ordinates, and QGIS - geographic information system software (https://www.qgis.org).

The DEM accuracy and correction evaluation methodology described by [15] and [16] was applied in the study. It uses a small number of direct measurements of terrain ordinates to estimate a terrain mapping error in DEM.

4.2. Field measurements

For the purpose of assessing the mapping accuracy of the plot and its adjacent areas in DEM based on LIDAR, there were made 74 measurements of terrain ordinates within the research facility and its adjacent areas. The location of measuring points is shown in figure 5a.

The measurement data was compared to the values read from DEM. By using the QGIS tools, the measurement points were assigned with the ordinates read from DEM to interpolate altitude values by means of the nearest neighbour's method. Two sets of data were obtained and provided the base for calculating the average difference in altitude between the values measured and taken from DEM. Table 1 shows the basic statistical characteristics of the analysed database. The average difference in altitude ΔRT between the ordinates measured (RTp) and interpolated from DEM (RTDEM) was -0.23 m. The result indicates that terrain ordinates in DEM are higher than real ones. By applying the DEM correction methodology described by [15] and [16], all DEM points within the plot and the direct hydraulic connection area illustrated in Fig. 8 were reduced by the ΔRT value.
Table 1. Results of statistical analysis of the set of terrain measurements compared with data interpolated from DEM based on LIDAR

|                     | Average elevation from field measurements $RT_p$ [m n.p.m] | Average elevation from DEM $RT_{DEM}$ [m n.p.m] | Average difference in elevation $\Delta RT = RT_p - RT_{DEM}$ [m] | Standard deviation of elevation differences [m] |
|---------------------|----------------------------------------------------------|------------------------------------------------|---------------------------------------------------------------|-----------------------------------------------|
|                     | 100.69                                                   | 100.93                                         | -0.23                                                         | 0.13                                          |

The corrected DEM was used to calculate the volume excluded from the flood plain area due to the planned investment and to determine the volume of the area designated for direct hydraulic connection for the ordinate of 101.40 m a. s. l.

4.3. Retention capacity

The area of the research facility is protected against flooding by embankments from the Bernardyński Channel side. According to data presented on the flood hazard map available at http://www.isok.gov.pl – M34001Ca4.ZG.1 - the water table ordinate in the Bernardyński Channel at the plot no. 22/14 is approx. 101.81 m a. s. l. The height of embankments is between 102.46 and 102.59, as stated in the same sheet of map. The values of ordinates for embankments might have been designated only on the basis of DEM LIDAR, which is burdened with over 20 cm mapping error (see table 1). The measured value of terrain ordinates for the Bernardyński Channel embankments at the plot no. 22/14 is 102.05 m a. s. l. There is a greater risk associated with flooding from the Prosna River side, since the area is not protected with embankments. Thus, if the flow has a value close to HQ100, the plot may be flooded from the northwest side. As already mentioned, despite the fact that the plot no. 22/12 is located directly at the Bernardyński Channel, it is hydraulically connected to the Prosna riverbed. The distance from the Prosna river (465 m) and specific terrain coverage characteristics (high grass vegetation, bushes and trees) make the river transform the flow only through the possibility of water retention.

During the passage of flood wave in May 2010, the plot was flooded with Prosna waters (figure 6), which spilled exactly from the northwest side. Water entered floodplains through the ground lowering below the bridge on the national road no. 25. Subsequently, the area was filled with water in its lowest places. The photograph shown in figure 6 was taken during the culmination of flood wave, and it illustrates that water within the plot was not flowing but just stagnating. It confirms the assumption that in the case of flood waves, the key parameter affecting the flow transformation is the retention volume [17] and its influence on the momentum transfer is negligible.

Figure 6. The plot no. 22/14 during the flood in May 2010. Photo taken on behalf of the Municipal Office in Kalisz on May 23, 2010.
The volume of stored water within the plot no. 22/14 for the ordinate of 101.40 m a. s. l. (corresponding to the flow p=1%) is 7727 m$^3$. The value was calculated on the assumption of a horizontal water table using the corrected DEM LIDAR data. Using the same DEM, the authors calculated the volume of retention water for the direct hydraulic connection area (figures 3 and 5a). The volume is 179249 m$^3$. The authors also calculated that as a result of development of the plot – the adjacent areas connected hydraulically reduce their retention volume by 4.3%. Undoubtedly, the percentage share of the plot no. 22/14 in the retention capacity of the entire floodplain located northwest of the national road 25 (DK 25) to the mouth of the Bernardyński Channel to the Prosna river is negligibly small. It is necessary to point out that with the inflow of 1 m$^3$/s, it will take 2 hours to fill the volume of 7727 m$^3$. Such inflow can occur even with slight damage to flood embankments.

A related point to consider is the passage time of flood wave as it goes through Kalisz for 2-3 days. Water velocities presented on the flood hazard map – M34001Ca4_ZP_1- take values below 0.5 m/s. This is the lowest velocity value marked on the map and indicates a low probability of occurrence of scouring. However, it is worth noting that the two-dimensional flow model (2D) from which the velocity distributions were derived was based on DEM and mapped only terrain features, excluding other elements such as buildings, sheds, fences, etc. The plot no. 22/14 is fenced which significantly disturbs the water flow to and within it. Therefore, the actual directions as well as velocity values may differ significantly from those presented on the map M34001Ca4_ZP_1 Impact of the investment on the hydrological regime of Kalisz Waterways System

In order to examine an adverse impact of development of the plot no. 22/14 on the flow transformation in the KWS, the authors applied a one-dimensional numerical model describing transient flows for the Prosna River from 70+000 km to 45+903 km cross-sections. The model included 153 cross-sections connected with 154 sections, 18 bridges, 4 hydrotechnical constructions (weirs), 3 flow distribution nodes and 3 boundary cross-sections. It was tarred for the 2013 flood data and verified for the flood flow of 2010. The model was used to calculate the flood area for the flow with HQ$_{100}$ probability, and the results of calculations were published in the article: [18]. The model was updated for the purposes of expertise by introducing two cross-sections located within the plot no. 22/14.

The upper boundary condition in 70+000 cross-section was a flow hydrograph with a maximum value of 199 m$^3$/s (flow p=HQ$_{100}$ for the Piwonice gauge-station). The second upper boundary condition in Sw_1+043 cross-section (boundary cross-section in the Swędrnia River) was a flow hydrograph with a maximum value of 25 m$^3$/s, while the lower boundary condition in 45+903 cross-section was a hydrogram of states with a constant ordinate of 92.60 a. s. l. The lower boundary condition was moved away from the Kalisz Waterways System at a distance that ensured no impact on the distribution of states and flows in the analysed river network.

Two calculation variants were used to determine the effect of change in terrain characteristics within the research facility on the distribution of water table ordinates.

I. The plot is hydraulically linked to the Prosna river and the ordnates within the future development remain unchanged (existing status),

II. The plot is hydraulically linked to the Prosna River and the ordnates within the future development are elevated to the designed value of 102.50 m a. s. l. (status after implementation).

The ordinates were determined in a numerical model using the SPRUNER system with an accuracy of 1 cm [19]. It was assumed that the range of action would end if the differences in the ordinates between individual variants were less than 2 cm (with an accuracy of 1 cm, the error band was ±2 cm).

The biggest differences in water table ordinates between variant I and II did not exceed the permissible value and were 0.2 cm in the cross-sections located in the immediate vicinity of the future development.
5. Conclusion

The above analyses of both – the research facility and calculation results – indicate that the change in development of the plot no. 22/14 will minimally affect the flood risk of adjacent areas and the entire Kalisz Waterways System. The research facility area is connected hydraulically to the Prosna riverbed for flows with up to HQ100 probability. Despite the proximity of the Bernardyński Channel, the plot is protected with embankments and hydraulically separated from the channel’s surface water. Due to the fact that the plot no. 22/14 is distant from the Prosna riverbed, the river transforms the flow only through water retention. Exclusion of the plot from the valley retention system will not significantly affect the flow transformation of adjacent areas.

The planned elevation of terrain ordinates up to 102.50 will secure buildings located on the plot no. 22/14 against the direct impact of floodwater, and hence – minimize the risk of losses and reduce insurance costs. Location of the plot close to the Bernardyński Channel embankments and situating the plot entry from the Wał Bernardyński street side will enable residents to be safely evacuated in case of flows equal or higher than HQ100, since the roadway ordinates of the aforementioned street are higher than the water table ordinates given on the flood hazard maps published on the website (http://www.isok.gov.pl).

In the design and implementation phase, it is highly recommended to take into account the fact that buildings on the plot no. 22/14 will be located in the area threatened by floods. Materials, installations and construction solutions should be resistant to prolonged contact with water, inundation or flooding. Future owners and tenants should be informed about the risk occurring in the area.

The hydraulic analysis presented in the work significantly influenced the positive decision issued by the local water management board. The results were verified in an independent expertise conducted by researchers from the Institute of Meteorology and Water Management, who confirmed both the scope of research as well as its substantive correctness.

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