Title: Factors influencing floods in the urbanized and industrialized areas of the Upper Silesia Industrial Region in the 19th and 20th centuries (the Kłodnica catchment case study

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FACTORS INFLUENCING FLOODS IN THE URBANIZED AND INDUSTRIALIZED AREAS OF THE UPPER SILESIA INDUSTRIAL REGION IN THE 19TH AND 20TH CENTURIES (THE KŁODNICA CATCHMENT CASE STUDY)

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Abstract: The occurrence and pattern of floods in urban industrial areas depend on both the hydro-meteorological and physico-geographical properties of the catchment area and on the degree of anthropogenic transformation of land. The area selected for research is one of the largest urban mining-industrial districts in Europe, known as the Upper Silesian Industrial Region (USIR). Besides the 'typical' flood risk, which manifests itself in rivers overflowing their banks, this catchment is also threatened with floods that do not depend on meteorological factors but are caused by the formation of flood lands in areas transformed due to deep mining of hard coal. The pattern of floods in the catchment has also been influenced by changes in the forms of land use resulting from the growth of urbanized areas. Because of the increasing flood risk and the fact that it is impossible to build water storage reservoirs other possibilities of improving water retention capacity in the catchment have been indicated.

Key words: hydrology, flood, human impact, urban area, Poland.

INTRODUCTION

The occurrence and pattern of floods in urban industrial areas depend on both hydrometeorological and physicogeographical properties of the catchment and on the degree of anthropogenic transformation of land. Urban mining-industrial areas have a specific pattern of floods and inundations outside river valleys because the occurrence and pattern of this phenomenon depends to a greater extent on the effects of human economic activity than on natural factors.

The Kłodnica is a right-bank tributary of the Odra, draining a river basin area of 1085 km^2. The Bytomka, on the other hand, is a right-bank tributary of the Kłodnica, draining a river basin area of 144.5 km^2. The present study concerns the upper part of the Kłodnica river basin (catchment area A = 505 km^2).

Mean annual discharge of the Kłodnica at the Gliwice gauging station (catchment area A = 444 km^2), calculated on the basis of data from the years 1961–1999 reaches 6.41 m^3 s^{-1}, and the annual Bytomka discharge at the Gliwice gauging station (A = 136.5 km^2), calculated on the basis of data from the same period amounts to 2.61 m^3 s^{-1}. Individual discharge values amount, respectively to: 14.4 dm^3 s^{-1} km^{-2} for the Kłodnica catchment and 19.1 dm^3 s^{-1} km^{-2} for the Bytomka catchment.

Both catchments are currently urbanized to a great extent and intensive mining activity is carried out there. Due to this fact both rivers also carry foreign water, from outside the catchment (for the water supply system) and deep mining waters originating from the draining of workings in hard coal mines.

The area selected for research is one of the largest urban mining-industrial districts in Europe known as the Upper Silesian Industrial Region (USIR). Its western part lies within the Kłodnica catchment (Fig. 1), where detailed hydro-meteorological observations have been carried out since the mid 19th century. The collected material made possible the accurate evaluation of human impact on the pattern of catastrophic floods and inundations in areas located outside river valleys.

FLOODING RISK

The whole area under research is located within the Silesian Upland. The geographical location and elevation of this area above sea level were decisive factors in determining the precipitation total, which is 700 mm on average. The greatest water runoff occurs in the thaw period (March, April), while the maximum discharge occurs after long-term or torrential rains, usually in June and July

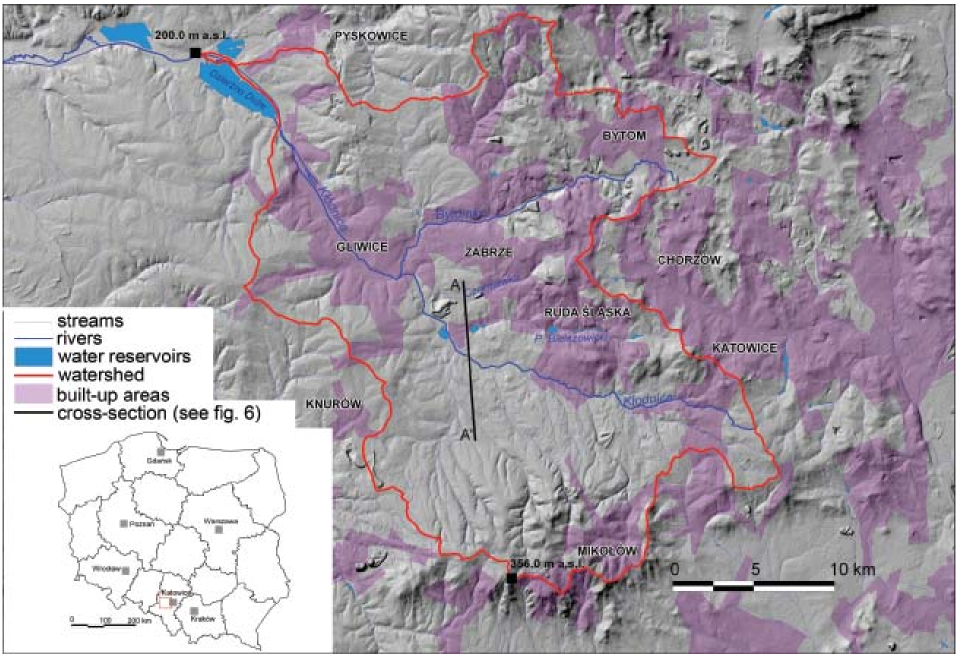

Figure 1. The Kłodnica catchment against the background of a digital terrain model

(Czaja and Jankowski 1993; Absalon *et al.* 2001). High-water stages after long-term and torrential rains pose the greatest flooding threat in the USIR area.

While evaluating the flood patterns of this area in accordance with the criterion linking the level of the high-water stage with the probability of peak discharge, the USIR district falls into the category of areas in which normal high water prevails, where the flood discharge:

$$Q_{50\%} \geq Q_{\max} \geq (\overline{Q} + Q_{50\%}) / 2,$$

and medium high water, where the flood discharge:

$$Q_{10\%} \geq Q_{\max} \geq Q_{50\%},$$

Great high-water, where the flood discharge:

$$Q_{50\%} \geq Q_{\max} \geq Q_{10\%},$$

occurs very rarely, and catastrophic floods, where the flood discharge:

$$Q_{\max} > Q_{5\%},$$

occurred only twice within the last 200 years—in 1940 and 1997 (Fischer 1915; Powódź… 1967; Powódź… 1975; Ocena sytuacji… 1997).

where:

$Q_{\max}$—maximum instantaneous discharge (peak discharge),

$Q_{p\%}$—maximum instantaneous discharge (probability p%).

Human economic activity radically transformed natural conditions of the occurrence of floods in the USIR area. Extremely intensive development of mining and industry and the urbanization of the area have taken place since the mid 19th century. This activity has resulted in distinct changes in the geographical environment of the area, on the one hand resulting in orogenic drainage in areas where drainage of coal mining floors also results in lowering of first-level water table—this usually happens in places where Quaternary surface deposits lie directly above the exploited Carboniferous level. On the other hand, water-logging due to the formation of extensive subsidence basins and hollows may occur in areas of the deep mining of hard coal. These basins are often filled with water from surface runoff or groundwater recharge. The formation of basins and hollows in river valleys also leads to local disruptions in falls of the ground.

These processes result in changes in surface and underground water retention and in the conditions for infiltration and surface runoff. A major role in modifying the conditions of water circulation and therefore in generating floods in the area in question has been played by changes in spatial development and the surface hydrographical network. In the mid 1730s forests and coppices comprised about 45% of the Kłodnica catchment area, arable land, meadows and pastures nearly 46% and ponds and reservoirs 6% (Wieland 1736). However, as early as in the 1830s, major changes in the development of this area were observed. Forests were cut down on a large scale mainly for the purposes of the mining industry, which caused the diminution of their area by nearly 40% (Czaja 1999). There were also changes in forest structure. Deciduous forests were substituted by quick-growing pines and spruces. In the 19th century the dominant forms of land use were arable lands, meadows and pastures, which constituted over 70% of the described area (Tables 1, 2).

From the end of the 19th century onwards, further changes in land development of the catchment took place. The arable land, which had prevailed in the landscape, was taken over for the purposes of construction and industrial development. In the 20th century, there was a steady decrease in the area of arable land in favour of residential and industrial buildings and roads and

Table 1. Land use in the Bytomka catchment

	1827		1887		1960		2000	
Land use	km^2	%	km^2	%	km^2	%	km^2	%
Forests	35.5	24.1	27.2	18.5	21.0	14.3	26.2	19.2
Arable land	93.4	63.4	89.5	60.8	66.6	45.2	44.8	32.9
Meadows and pastures	13.5	9.2	13.8	9.3	10.2	6.9	9.2	6.8
Urban area	4.7	3.2	7.5	5.1	18.7	12.6	25.2	18.5
Industrial area	0.0	0.0	2.4	1.6	7.3	5.0	11.2	8.2
Roads and railway lines	0.0	0.0	0.3	0.2	3.0	2.0	1.8	1.3
Green areas	0.0	0.0	0.6	0.4	3.8	2.6	8.6	6.3
Wasteland and post-industrial lands	0.0	0.0	5.7	3.9	14.7	10.0	8.0	5.9
Water reservoirs	0.2	0.1	0.3	0.2	2.0	1.4	1.2	0.9
Total	147.3	100.0	147.3	100.0	147.3	100.0	136.2	100.0

Table 2. Land use in the Kłodnica catchment

	1827		1887		1960		2000	
Land use	km^2	%	km^2	%	km^2	%	km^2	%
Forests	104.1	29.0	97.6	27.3	76.7	21.4	90.4	25.2
Arable land	208.5	58.2	207.7	57.9	182.4	50.9	135.0	37.7
Meadows and pastures	35.2	9.8	35.7	9.9	32.0	8.9	28.6	8.0
Urban area	8.2	2.3	10.6	3.0	33.3	9.3	55.6	15.5
Industrial area	0.0	0.0	2.4	0.7	12.2	3.4	20.3	5.7
Roads and railway lines	0.0	0.0	0.4	0.1	2.1	0.6	1.0	0.3
Green areas	0.0	0.0	0.5	0.1	7.5	2.1	11.2	3.1
Wasteland and post-industrial lands	0.0	0.0	3.3	0.9	10.7	3.0	13.0	3.6
Water reservoirs	2.4	0.7	0.2	0.1	1.5	0.4	3.3	0.9
Total	358.4	100.0	358.4	100.0	358.4	100.0	358.4	100.0

railway lines. These processes were particularly intensive within the catchment of the Bytomka, the main tributary of the Kłodnica, draining the most urbanized and industrialized part of the Upper Silesian Industrial Region (Tables 1, 2). Until the end of the 18th century dispersed settlement prevailed here, with small villages and hamlets with farm buildings. These took up about 2% of catchment area. By the end of 19th century, the number and area of settlements had increased slightly. Rapid urban development occurred towards the end of the 19th century, when numerous residential districts for factory workers and miners were built and former villages were turned into urban settlements. By this time, such areas were comprising about 10% of the Bytomka catchment, though only 3.5% of the Kłodnica catchment. The figures at the end of the 20th century were 27% and 21%, respectively (Figs 2, 3, 4 and 5).

some of the post-industrial lands for their afforestation and the creation of parks and green areas. Urban green areas have only been playing a role since the mid 20th century. These areas currently account for over 6% of the Bytomka catchment.

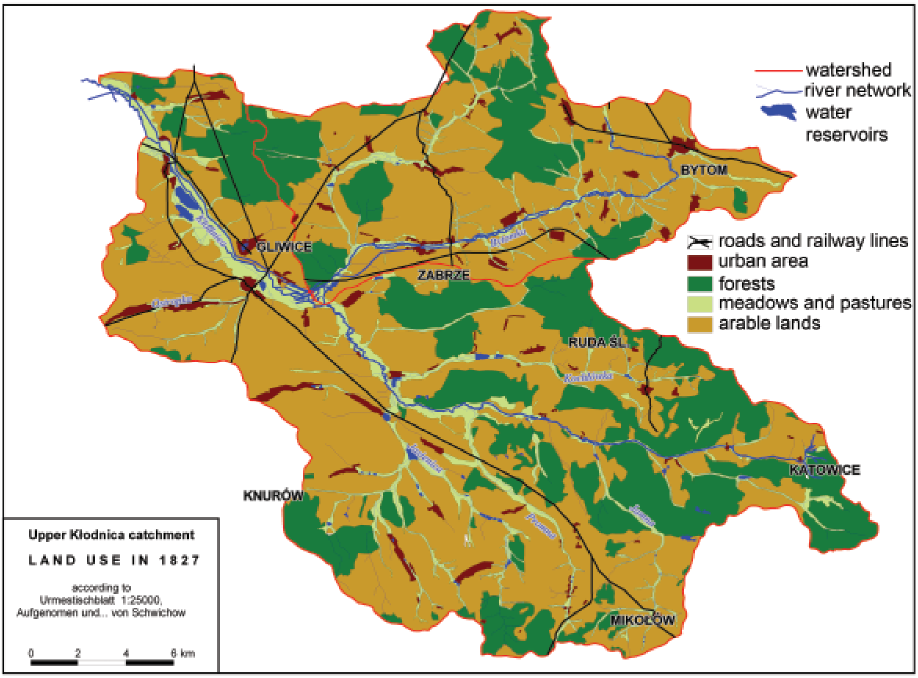

Figure 2. Land use in the upper Kłodnica catchment in 1827

With the development of industry and urbanization the research area witnessed rapid growth of degraded and post-industrial land. The main reason was storage of mining waste (barren rock) and metallurgical waste (slag and post-flotation waste) mainly on agricultural land and grassland. At the end of the 19th century, degraded areas constituted nearly 4%, and at the end of the 20th century, 6% of the Bytomka catchment area.

A positive trend in the changes in spatial development aiming at amelioration of water circulation conditions is reclamation of

The Kłodnica and Bytomka catchments are not unusual in their transformation of the land surface—as early as at the beginning of the 1970s, it was estimated that about 9% of the area of the Upper Silesian conurbation had been subject to 100% change (Żmuda 1973). In the 1980s the conurbation went through intensive transformations of water relations over an area of about 1,600 km^2 (Jankowski 1987).

Changes in surface hydrographical network are another important factor in the formation of floods in the Kłodnica valley and the valleys of its tributaries, which

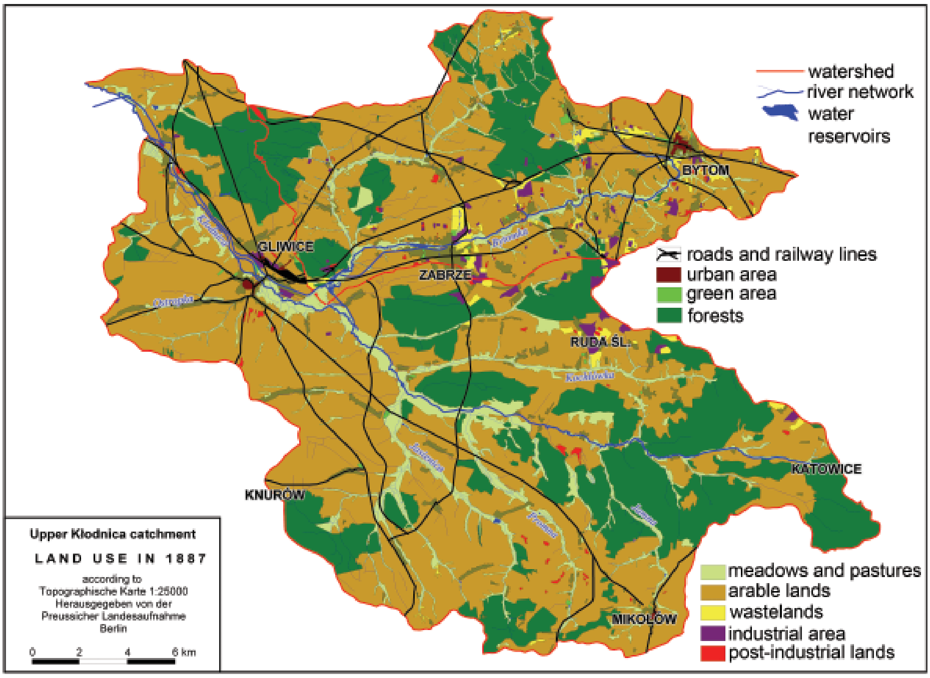

Figure 3. Land use in the upper Kłodnica catchment in 1887

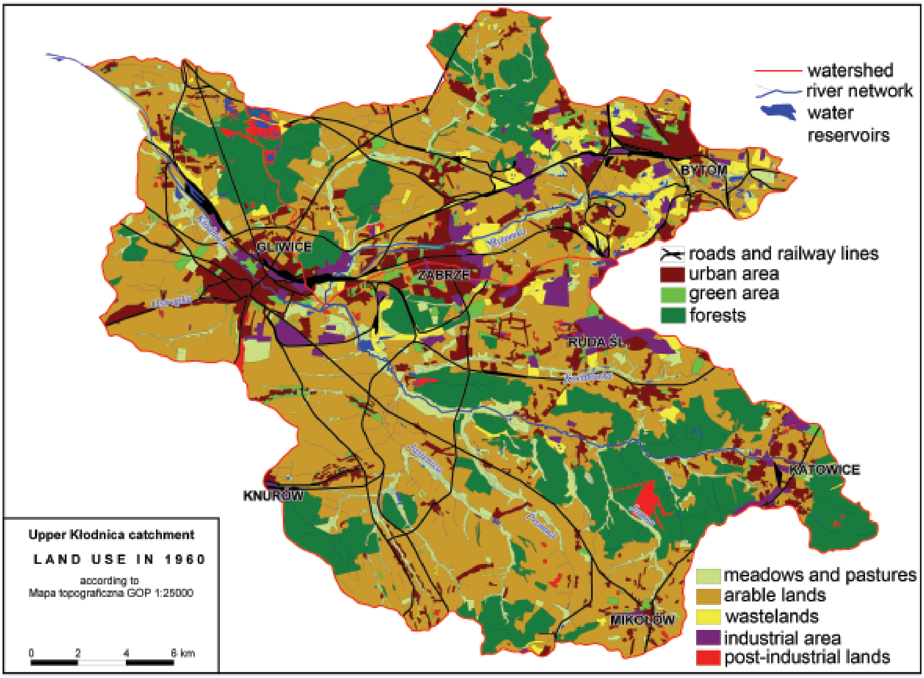

Figure 4. Land use in the upper Kłodnica catchment in 1960

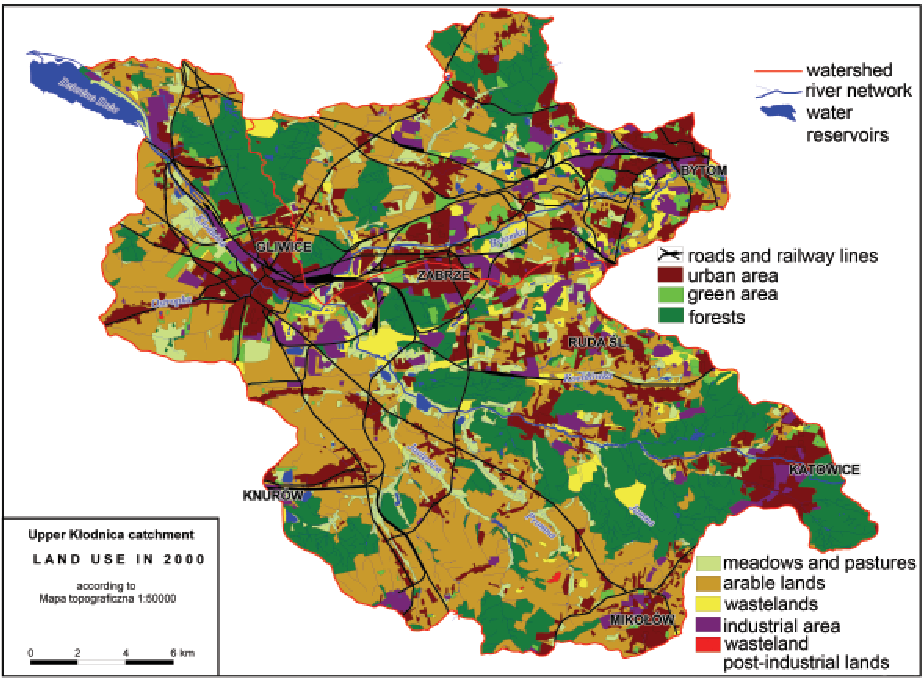

Figure 5. Land use in the upper Kłodnica catchment in 2000

are heavily transformed anthropogenically. Most of the fishponds and dam reservoirs on rivers and streams so numerous in the 18th and 19th centuries have disappeared, something that significantly diminished the water retention properties of the catchment and hurried surface water runoff. At the same time hydrotechnical works and regulation of rivers and streams have caused their shortening, making them steeper and as a consequence quickened water runoff (Czaja 1999). It follows from the analysis of historical topographic maps from the 19th and 20th centuries that the river network in the Bytomka catchment (excluding the Mikulczycki stream catchment) was 89.9 km long in 1827 and 36.4 km long in 2000.

Mining activity and the development of the sewerage network in the urbanized areas located in zones crossed by watersheds result in major changes in catchment area, something that influences the magnitude of calculated hydrological parameters. Depending on the extent of subsidence, its location off the centre of the basin or hollow and the location of major sewerage collector outlets areas came to be included into or excluded from one catchment or another. This phenomenon was observed in the Bytomka catchment, which lost 11 km^2 (7.5% of total catchment area) in the years 1960–2000.

The present occurrence of floods and inundations in the USIR part of the Kłodnica catchment area is connected mainly with land deformations due to open pit and deep mining. Numerous subsidence basins and hollows are formed, both within active mining fields and on their edges. Subsidence basins and hollows are formed within mining fields as the result of the exploitation of resources carried out using the roof-fall method. Land surface deformations in mining subsidence zones often cause changes in the direction of surface and underground water runoff, leading in consequence to flooding of land located beyond river valleys (Fig. 6).

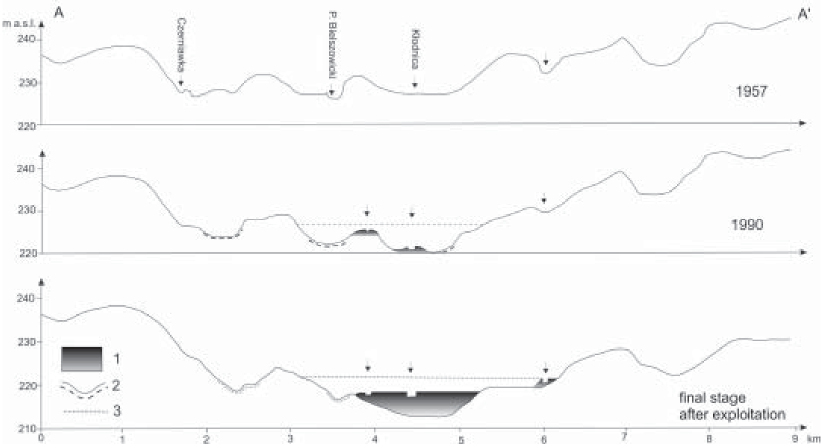

Figure 6. Changes in surface features in the Kłodnica valley (transverse section):
1—flat waste heaps of barren rock, 2—local subsidence basins,
3—potential level of water in land depressions.
Source: Szczypek, Wach (1987)

The specific character of the described area results from the fact that, in natural conditions, normal and medium-sized floods prevailed there. Changes in geological structure (as the result of mining activity) caused great ground subsidence, which in turn brought permanent inundations of river valleys. This phenomenon is particularly dangerous in the built-up areas of the region. In times of flooding, inundations of considerable areas can be observed in mining subsidence zones, mainly in connection with obstructed flow of surface and ground waters (Szczypek and Wach 1987; Wach and Szczypek 1996; Czaja and Wach 1999).

Besides inundations due to the subsidence and sinking of ground, the USIR area is threatened with flooding caused by the obstructed flow of surface waters into the river network. These obstructions result from rivers and streams draining areas within the zones of hollows and extensive subsidence basins. The riverbeds have been sealed by building stone and concrete troughs and flood embankments. Intensive ground subsidence made it necessary to raise embankments, which has resultedraised the surface of water in rivers much above valley-floors. In many cases the level of water in an embanked riverbed is a few metres higher than the valley-floor beyond the embankments. This often causes the formation of wide flood-lands collecting precipitation waters in river valleys. Flood-lands forming along the embankments of rivers and streams are particularly dangerous when it rains. The scale of flooding risk in river valleys in the USIR area can be proven by the extent of flooded land during the July 1997 flood. In some sections of the Kłodnica and its tributaries and other rivers of the region the extent of flooding was wider than the theoretical range of inundation of these valleys with the probability of peak discharge of $Q_{0.1\%}$.

THE HISTORY OF FLOODING

In the 19th and 20th centuries floods on the upper Kłodnica were quite frequent. The 1803 flood caused considerable loss to property, destroying quite a long section of the newly-built Kłodnicki Canal. Water in the river in the Gliwice area reached the level of 2.0—3.3 m, as was the case in 1803, 1903, 1913, 1915, 1925 and 1930. Unfortunately no discharge data are available for the period before 1911 (the gauging station was installed in 1908) and we only know the descriptions of the magnitude, extent and effects of the floods from historical sources (Mann 1905, Fischer 1915, Knothe 1939).

Since the moment when systematic observations of water stages started to be carried out at the Gliwice gauging-station the peak flood discharges recorded in different years were: 1913—61.0 m^3s^{-1}; 1915—83.0 m^3s^{-1}; 1925—66.6 m^3s^{-1}; 1930—64.7 m^3s^{-1}. The lar-gest flood was recorded on the Kłodnica in late May and early June 1940. In Gliwice, the recorded water stage was H = 505 cm and discharge Q = 121.5 m^3s^{-1}. Within 22 hours there was an increase in discharge from 11.0 m^3s^{-1} to 121.5 m^3s^{-1}, the result being flooding in large areas of Gliwice, mostly in the vicinity of the present Silesian Technical University (Figs. 7, 8).

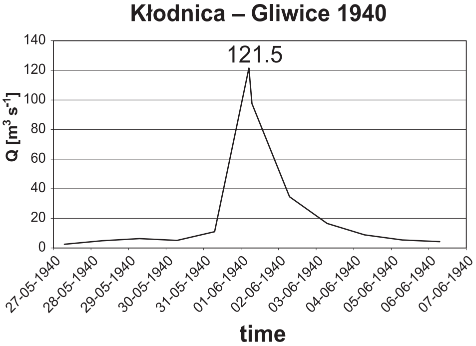

Figure 7. The pattern to peak high water along the Kłodnica in 1940

Figure 8. Gliwice during the 1940 flood – Krakowska Street area.

Such a rapid increase in discharge attests to a considerable intensity of rainfall over a comparably small area, because the time of discharge concentration should be taken into account. The flood of 19–20 August 1854 was quite similar. It follows from interpolation of flood marks that the discharge of the Kłodnica in Gliwice might then have equalled 80 m^3s^{-1}. Since those floods there have been other large events, the next major one being the flood of July 1997. The estimated discharge of the Kłodnica on the Gliwice gauging-station was 88.1 m^3s^{-1}. Slightly smaller discharges were recorded during floods in: 1968—52.1 m^3s^{-1}, 1972—50.3 m^3s^{-1} and 1985—48.2 m^3s^{-1} (Kompleksowy program… 1998).

The origin of most floods in the Kłodnica and Bytomka catchments may be sought in the spring thaw period. Only the largest floods resulted from storm rainfall, as in May/June 1940.

An analysis of the peak high water observed on the largest tributary of the Kłodnica—the Bytomka—was also carried out. The Bytomka catchment, as has been shown before, is one of the most urbanized and transformed areas in the Kłodnica catchment. Unfortunately, as regards this catchment, hydrological data are confined to the last 50 years, since the gauging-station was only installed in 1955. Due to smaller catchment area, the observed peak discharges are lower (Figs. 9, 10 and 11). The analysis points to the Bytomka flood wave usually being part of the Kłodnica flood wave, since its peak is observed over a dozen hours (12—18 hours) before the peak on the Kłodnica. The flood of 1997 was different because the Kłodnica peak occurred 12 hours earlier than the Bytomka one (Fig. 12).

The last 40 years has have also witnessed larger increases in discharges along the Kłodnica than the Bytomka. This is due to much more major changes occurring in the upper Kłodnica as compared to the Bytomka. These changes mainly include river control works resulting in the strengthening and shortening of the river network and changes in land use in the catchment area in the direction of urban development, and the resulting development of a storm-water drainage network. A similar situation was

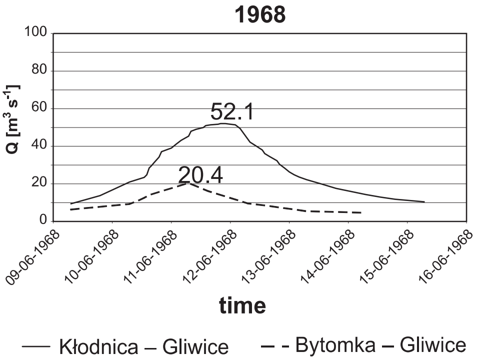

Figure 9. Patterns to peak high water on the Bytomka and Kłodnica in 1968.

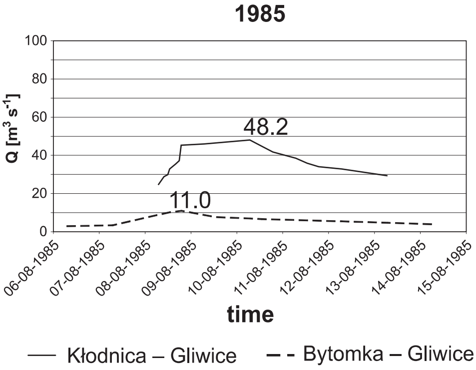

Figure 11. Patterns to peak high water on the Bytomka and Kłodnica in 1985.

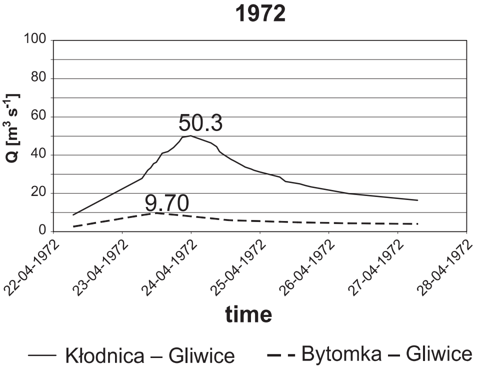

Figure 10. Patterns to peak high water on the Bytomka and Kłodnica in 1972.

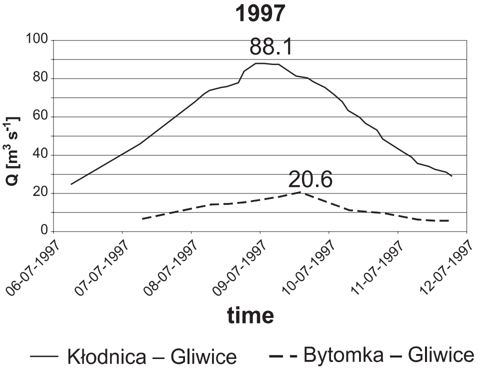

Figure 12. Patterns to peak high water on the Bytomka and Kłodnica in 1997.

observed in the Ruhr Area (Ruhrgebiet), where channelling of rivers and streams and the building of embankments resulted in larg-scale inundations between the embankments and the Emscher Valley escarpment (Brüggenmeier, Rommelspacher 1992; Emschergenossenschaft 1910).

The assessment of the impact of small man-made reservoirs on the pattern of floods in the Kłodnica catchment is a very difficult task requiring individual research. In the second half of the 20th century two opposing tendencies were in conflict in this catchment. On the one hand, due to the deterioration of water quality and economic transformations many fishponds disappeared. On the other hand an unintended effect of deep mining was the formation of subsidence basins, these becoming filled with water under certain morphological and hydrogeological conditions. We are currently unable to define the relative proportions of these two phenomena, particularly because the situation of water-filled depressions is subject to dynamic change, these often becoming filled up with waste barren rock from coal mining. In a situation of diminishing natural water retention in the catchment, retaining some of the water-filled depressions should be considered, in order to improve retention. One of the largest water-filled post-mining depressions in the Kłodnica Valley played a positive role, e.g. during the flood of 1997.

CONCLUSIONS AND FINAL REMARKS

The area of the Upper Silesia Industrial Region has been heavily transformed as the result of long-term mining activity, urbanization and industrialization. A minor flood risk resulting from natural conditions has been multiplied mainly by mining activity and urbanization. The main rivers draining the region have been controlled and prepared to carry flood waters with a probability of peak discharge of even 0.3—0.1%. However, most of the USIR areas are threatened by floods caused by surface flow and underground runoff, which leads to flooding not only of river valleys but also of considerable areas located beyond them. Very often these are highly developed areas, such as areas of urban and industrial development, railway lines, etc. This threat overlaps with the location of the ground subsidence zone. Because it is impossible to restore the natural water retaining capacity of the catchment, and practically also impossible to build water storage reservoirs, the use of some of the transformed mining areas and in particular water-filled depressions forming as a result of ground subsidence should be considered to improve water retaining capacity of the catchment. Other flood prevention activities in the catchment should aim at:

- the afforestation of wastelands,
- the proper irrigation and drainage of agricultural lands,
- limiting the construction of flood embankments outside densely built-up urban areas,
- improving water retention of riverbeds, e.g. by building multipartite channels.
- limiting the urbanization in river valleys.

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