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HYDROLOGICAL CONDITIONS OF GEOMORPHOLOGIC CHANGES IN THE GAP OF THE VISTULA BETWEEN ZAWICHOST AND PUŁAWY

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A b s t r a c t.The Vistula is a river where natural flood hazard lasts all year round. Floods in the middle and lower courses of the river occur in summer. It is caused by heavy precipitation in the upper part of the drainage basin. Water levels of the Vistula recorded during the flood in July 1997 reached maximum values, higher even than in the years 1921 - 1990. The processes of surface water run-off to underground water that decreased the maximum flow values, and flood capacity was observed. It decreased the amount of drift load which was brought to a stop at the valley floor. At the same time, the river channel floor of medium and low water levels was getting low. All the processes in the river channel are caused by natural reasons remain under very strong anthropopression.

K e y w o r d s: Vistula river, drainage system, geomorphologic changes

THE VISTULA RIVER AND ITS DRAINAGE SYSTEM

The Vistula is the longest Polish river, and at the same time it is the longest river that flows into the Baltic Sea. The total area of the Vistula drainage system is 194,000 km^2, and about 87.5 % of its total territory is situated in Poland [4].

The average absolute height of the drainage basin is 270 m a.s.l. The system of the drainage area is asymmetric (Fig. 1). Its right - bank tributaries take up about 73% of the total area which is to a large extend related to the geological structures and surface relief. Density of rivers in the drainage system is very low with one exception - the mountains area [4].

Mean annual outflow of the Vistula river is 950 m^3/s.

The Vistula's length is 1047 km. The river course is naturally divided into three sub-courses: upper, middle and lower. The borders between consecutive courses are marked by the outlets of the two longest right - bank tributaries: the San and the Narew. The part of the river from its sources to the outlet of the San is called the upper course, the part to the Narew outlet is the middle course, and the last section, to the river's mouth is its lower course. The Vistula passes all the basic regions of Poland as far as surface relief is concerned which is related to the geological structure and physiographic conditions, i.e., young folded mountains, the Carpathian basins, old mountains and uplands, lowlands of middle Poland, lake district, and sea lowlands [1,4].

The sources of the Vistula are situated on the western slopes of Barania Góra in the Silesian Beskid. The main stream, the Black Vistula, flows out at the height of 1106 m a.s.l. The second stream, the White Vistula, flows out at the height of 1080 m. Both Vistulas meet at the height of 500 a.s.l. on the 97.1 km of the river length starting from the Przemsza river outlet [4].

In the beginning the Vistula is a typical mountain river with a gradient of 60 m per 1 km. After it flows into the area of the Oświęcim Basin, below the Goczałkowice Reservoir the Vistula begins to flow as a lowland river. Its gradient decreases. Near Cracow, the Vistula passes through the first gap

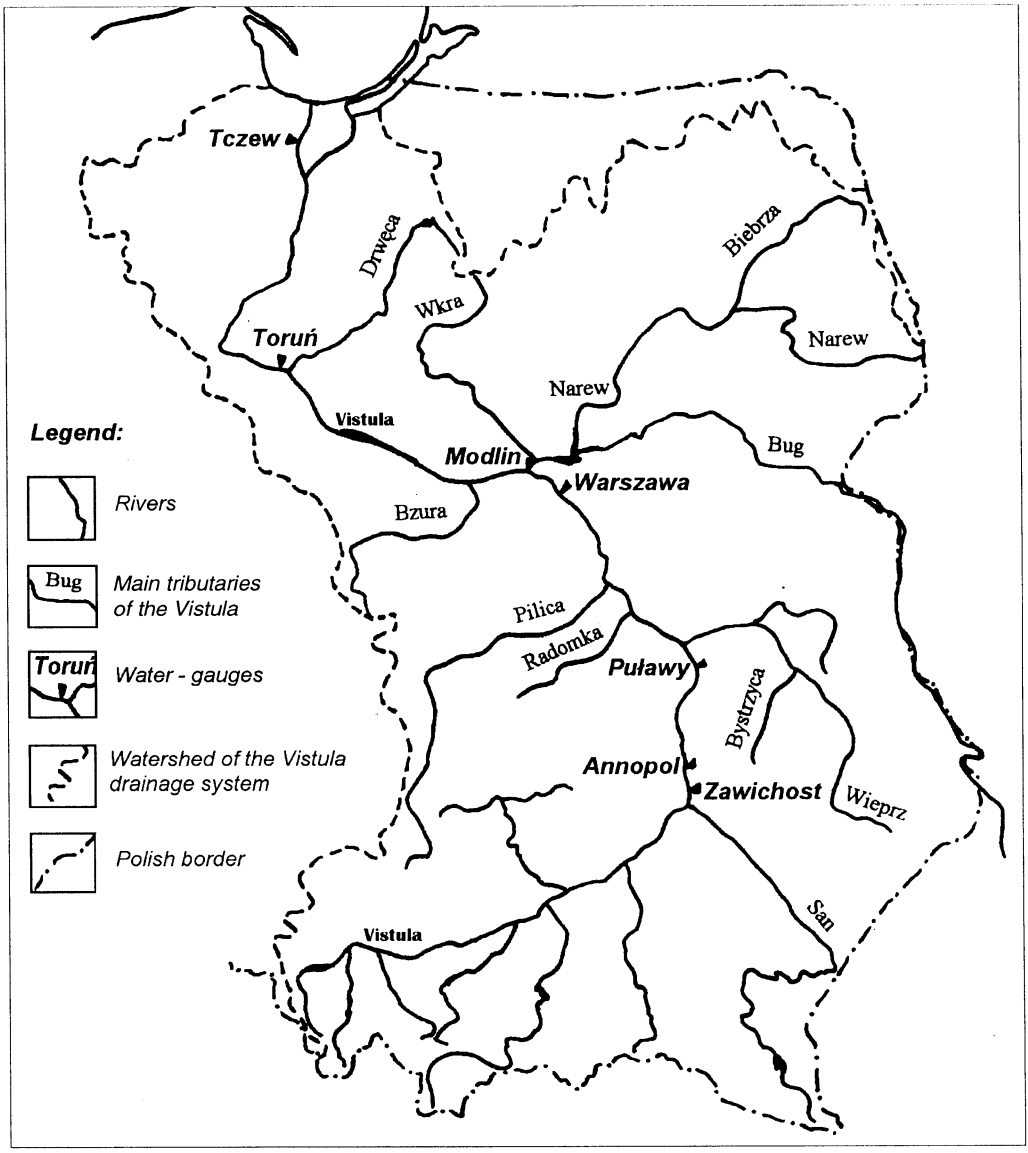

Fig. 1. The Vistula river drainage system in Poland.

of Jurassic limestone. Then it flows into the Sandomierz Basin, and at the San outlet the Vistula upper course ends. The middle course of Vistula is characterised by the gradient of 0.3 - 0.2 ‰. The part of the middle course where the Vistula passes through the Polish Uplands is called the Little Poland Vistula Gap (Małopolski Przełom Wisły). Its lower course is characterised by the gradient below 0.2 ‰. In that part the Vistula passes through the third gap in the lake district. The Vistula's mouth is situated near Świbno [4].

THE LITTLE POLAND VISTULA GAP (MAŁOPOLSKI PRZEŁOM WISŁY)

The gap of the Vistula in the Upland area is situated between Zawichost and Puławy. The length of this part of the river valley is 80 km, and its width varies from 1.5 to 10 km. The area of the valley is 300 km^2. The height of the valley between Zawichost and Puławy decreases from 135 to 115 m a.s.l. The river mean gradient is 0.25 ‰ and the mean width its water table is 250 m [2].

The gap of the Vistula as it flows through the plateaux is divided into three parts: from Zawichost to Solec, from Solec to Janowiec, and from Janowiec to Puławy. The last part of the Vistula river is a typical gap with a small width of the river floor and big denivelation between the valley floor and upland.

Western slopes of the Vistula gap are built from Cretaceous and Palaeocene rocks and belongs to the physiographic unit of the Radom Plateau. Its eastern part belongs to the Nałęczów Plateau and is characterised by the loessial cover with the thickness of 30 m.

WATER CONDITIONS IN THE AREA OF THE LITTLE POLAND VISTULA GAP

The Little Poland Vistula Gap (especially the environment of Kazimierz Dolny) is characterised by a strong hydraulic connections between underground and surface waters. Water conditions in this area depend on its geological structure, tectonics, surface relief, climate, and anthropogenic changes.

Density of the river system is very low in this area. Most of tributaries are situated on the left bank of the Vistula: the Kamienna, the Krępianka, the Iłżanka, and the Zwoleńka. Rivers: the Sanna, the Wyżnica, the Chodelka, the Grodarz, and the Bystra are right - bank tributaries.

Differentiation of water conditions in the area of Kazimierz Dolny results from its environmental features. Groundwater appear at a very shallow level in deeply dissected valleys of the Vistula, the Grodarz, and the Bystra. At the same time floors of the valleys are the bottom of the local drainage system. The process of surface waters runoff to underground was observed in the outlet section of these rivers.

Two water-bearing levels related Cretaceous and Quarternary rocks were found. Water table of the underground waters is located at various levels. Water storage takes place in pores and fissures, but lateral flow is only observed in fissures. This type of water is often referred to as fissure-stratum type.

The deeply dissected Vistula valley plays an important role in the underground water circulation. The river drains natural groundwater resources and upsets the course of water table. There is hydraulic connection between Cretaceous groundwater and alluvial water of the Vistula valley. The depth at which water-bearing formations appear varies from several meters in the area of valley ridge to 40 - 60 m in the uplands adjoining the valley.

Differentiation in the appearance of groundwater is influenced by the stratification of layers with the anisotropic conditions of filtration related to vertical and horizontal lithological difference among the Cretaceous and Quarternary rocks. Precipitation is the main source of groundwater recharge. Fissured Cretaceous rocks covered by weathering waste, sandy materials, loesses, and water storage capacity of soils provide for the interception of water by the basement. Rocks with the conductivity of 10-2 to 10-5 m/s occur at the depth of 150 - 170 m.

Due to the increasing depths, water content is getting low, and rocks fissures and Cretaceous rocks become impermeable. Cretaceous rocks are of very good quality: colourless, hard and medium hard. Their temperature is about 9°C, and chemical analysis shows HCO_3^- and Ca^{++} (carbonates and calcium) ions. Their mineralisation varies from 300 to 500 mg/l.

Water that infiltrates through grevels, loesses or sandy rocks sometimes cannot reach the main groundwater reservoir, but is stopped by the impermeable boulder clay. These are perched Quarternary waters that appear at the depth that depends on the location of impermeable rocks. Quarternary waters are characterised by

small storage capacity and dependence on precipitation. Water bearing formations are recharged by river water and groundwater of the uplands. Sands and grevels can conduct water, and the first aquifer has free water - table, others are confined.

FLOOD IN THE MIDDLE COURSE OF THE VISTULA IN JULY 1997

The middle course of the Vistula river is characterised by the occurrence of floods in summer caused mostly by precipitation. The highest flood hazard is observed during snow-melt periods (March, April under condition of huge snow retention in the drainage basins) in the middle and lower courses. Amount of water retained in the snow cover in the Vistula upper course, and its lowland tributaries during spring period is of crucial importance [6].

Heavy rainfalls that caused flood in the drainage basin of the Odra and the upper Vistula took place in July 1997 (in the south part of Poland). Isohyet of 50 mm (counted for 4th - 8th, July 1997) surrounded most of Poland, and reached 100 mm and more in the Sudety and the Carpathian Mountains, and in the upland area [3].

Flood wave that was formed in the upper course of the river exceeded all the levels of water table recorded before; e.g., for example in Zawichost the level of 804 cm was observed on 11th, July. This level was higher than the maximum level observed in March of 1855 by 10 cm. The level of 710 cm was recorded in Annopol which was higher than in July 1980. However, in Puławy water level never exceeded the maximum [6].

Analysis of the Vistula hydrograms from its middle course showed flattening of flood wave. It probably resulted from the lack of recharge in the middle part of the drainage system. Water levels in the right - bank tributaries reached the border line between the medium and low water. Rainfalls that appeared in that area in July, caused river swells to medium levels, but did not result in the excessive increase of the flood wave culmination as it was flowing in the middle and lower courses of the Vistula. The highest level that surpassed the level of alert occurred in the middle Vistula course in Annopol by 210 cm, and values of water level decreased with the water course down the river to Warsaw (Fig. 2).

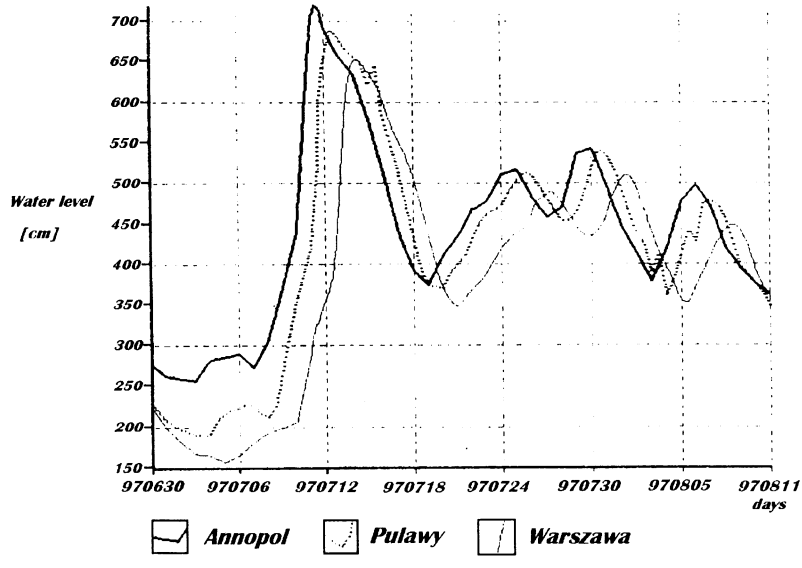

Fig. 2. Hydrogram of the water level in the middle course of the Vistula river.

A decreasing maximum flow (Q_{max}) was observed during the summer flood from 6900 m^3/s in Zawichost to 6730 m^3/s in Puławy, and 5150 m^3/s in Warsaw. In the middle Vistula course between Zawichost and Puławy the values of maximum flow decreased from 7450 m^3/s to 6580 m^3/s between 1921 and 1990, and values of the mean flow were less diversified in the same period of time. An increase of the mean flow value down the river from 433 m^3/s in Zawichost to 458 m^3/s in Puławy was observed. The recorded values of the mean flow during the summer 1997 were close to the highest in the years 1921 - 1990, and probability of their appearance was about 2 - 8% [6].

Total capacity of the flood (from 4th July to the end of the month) was 5593 10^6 m^3 in Zawichost, and 4666 10^6 m^3 in Puławy. Retention of the river channel was 927 10^6 m^3 [5].

A mass of drift load was recorded, too. It reached the amount of 1504 10^3 t in Zawichost, and 1254 10^3 t in Puławy. A decrease in the amount of load marks the process of sedimentation of a part of drift load (249 10^3 t in exact values - 17% of the total drift load) in the river channel and between embankments [5]. Research on the stability of the Vistula channel showed a process of lowering process of the channel floor of medium level water and water table (erosion). The river channel of flood water, despite vertical erosion, can increase because of load sedimentation in the area of flood plain.

During the last 58 years (1939-1997) a reduction in the flow capacity of flood water in the river channel by 1870 m^3/s, and 0.45% in one year was observed. The above process takes place continuously. However, the Vistula channel shows a permanent process of floor decrease at the rate that depends on the location of cross - profiles. For low levels of water it is 0.60 - 2.86 cm per year, and 0.26 - 2.64 cm per year for annual medium water level. The river channel has decreased by about 97 cm in Zawichost, and 101 cm in Puławy since 1939. The above mentioned values point out to the influence of canalisation of the Upper Vistula on the stability of the river channel. Development of vertical erosion in a part of the river below dams causes the lowering process of ground water table in the areas in the immediate vicinity of the river [5].

CONCLUSIONS

1. All the processes observed in the Vistula river channel are caused by natural reasons and strong anthropopression.
2. The summer flood in 1997 caused geomorphological and hydrological changes in the Vistula river channel between Zawichost and Puławy. It decreased the amount of drift load which was brought to a stop at the valley floor. The processes of surface water runoff to underground water that decreased the maximum flow values, and flood capacity was observed.

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