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Changes of the Vistula river course and development of the flood plain in the border zone of the South-Polish uplands and Middle-Polish lowlands in historical times

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Abstract: The results of geomorphological research on the terraces of the Vistula valley have been compared with archaeological and historical evidence in this area and also with evidence of climate changes in the area of Poland. In the early Medieval times (the Medieval Warm Period), the river had a narrow channel with well-developed small meanders. This period was divided into two stages: an earlier (6th - 10th centuries) which was relatively dry and a later (11th - 13th centuries) which was relatively wet. In the first stage, the river flooded only occasionally and this favoured flood settlement. In the transitional times (14th - 15th centuries), more frequent floods started to endanger the settlements in this area; however, the meanders of the river were not significantly altered at this time. In the Little Ice Age (from the second part of the 16th to the 19th centuries) the frequency of floods was so great that the river changed its course in some channel sections and the channel itself changed from a meandering into braiding type; its width increased greatly at that time. This trend has increased considerably since the beginning of the 19th century, consequent upon climate changes and the development of agricultural land use of the Vistula catchment. To protect the fields from the floods, special protection embankments were built; the river responded in what is now the flood plain. The relationship of this plain to Medieval flood plains created by meandering river is discussed.

Key words: meandering river, braiding river, Medieval flood plains, modern flood plain, warm Medieval times, Little Ice Age

Introduction

The work concerns the area of the middle Vistula between Zawichost and Kozienice. Between Zawichost and Puławy, it belongs to the belt of South-Polish uplands, and, between Puławy and Kozienice, it belongs to the belt of Middle-Polish lowlands (Fig. 1). In the valley floors of the both sectors, settlement has been well developed since the earliest Medieval times (6th - 10th centuries). Artefacts may be thus used in analysing the character of the river and its course. Historical facts and sources are known since the 11th century; they are most prolific in the Sieciechów section of the lowland valley, i.e. the area of the Wieprz confluence with the Vistula.

Certain artefacts and historical evidence have been used in the analysis of geological-geomorphological results of flood plain investigation in both sectors of the Vistula. Changes of the river course and flood plain which have taken place since the 6th/7th centuries have been compared with the evidence of climate change trends in the second post-glacial climatic optimum (warm Medieval times) and the Little Ice Age.

The earliest Medieval times i.e. first stage of the warm Medieval period

The earliest Medieval times in the area of Poland provided a climate favourable for human activity. According to Kosiba (1962), this was the period of the "second post-glacial climatic optimum". In the West European literature it is called "a period of warm Medieval times" (Lamb, 1984). From a hydrological point of view, it should be divided into two sub-periods: the first - drier, and the second - wetter. Evidence of the dryness of the first sub-period is found not only in palaeogeographic research in Poland (Ralska-Jasiewiczowa & Starkel, 1988; Niewiarowski, 1995; Starkel *et al.*, 1996) but also in the studies of the dune areas in West Europe (Heidinga, 1984) and in the hydrological relationships in the Dniepr catchment in East Europe (Rauner *et al.*, 1983). The results of investigation in Central America (Hodell *et al.*, 1995) may even show that it was a climatic trend on a global scale.

In this first, drier sub-period of warm Medieval times, an intensive development of agricultural development took place in the flood plain of the Vistula valley, and in the Chodel Basin in particular. In this Basin, the valley floor is the widest in the whole Vistula gap through the belt of the South-Polish uplands

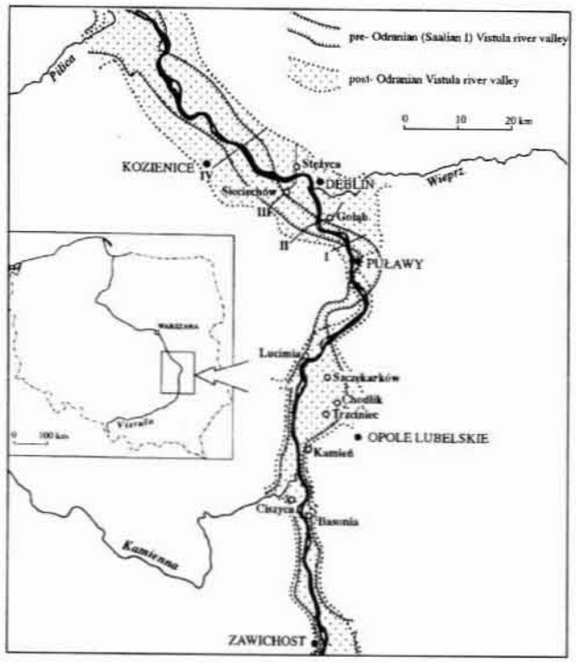

Fig. 1. The location of the area studied with towns and villages mentioned in the paper on the background of a sketch showing a belt of the South-Polish uplands (Zawichost-Puławy) and the southern part of South-Polish lowlands (below Puławy); two stages of Pleistocene valley development according to Pożaryski *et al.*, 1994.
I-II - lines of geological cross-sections shown in Figure 6.

(see Fig. 1 - the valley section in the area of Opole Lubelskie). For the most part, the Vistula flood plains are covered by sandy-silty alluvial sediments (Fig. 2B) where fertile soils developed. In the warm Medieval times, these soils were probably intensively cultivated. The settlement in this area was probably also attracted by the many different meadow and forest sites and numerous abandoned channel lakes. Also, the location of an important transport route - the Vistula itself - which maintained an even discharge and flooded only rarely, played an important role in progressive settlement of this area. The remains of an old earthwork in Chodlik, dated by archaeologists to the 7th-9th century (Gardawski, 1970) are evidence of a considerable settlement in this area. This earthwork was probably an important organisational pre-state centre, i.e. in the tribal period of eastern Poland. This settlement centre must have developed much earlier because, from the floor of the Vistula valley in the area of Opole Lubelskie, many Neolithic and Bronze Age artefacts have been found (Fig. 2), most near to Trzciniec village; this name is given by archaeologists to one of the stages of the Bronze Age in the territory of Poland (Jażdżewski, 1984; Taras, 1995). In the Neolithic and Bronze Age times, i.e. in the so called Subboreal phase of Holocene, the climate was similar to that of the earliest Medieval times - generally it was relatively dry, so it favoured the agricultural settlement in the Vistula valley floor.

There is no evidence to date to determine unequivocally the course and character of the Vistula channel in the Opole Lubelskie section in the Bronze Age. However, the river channels from Medieval times are very easy to discern, both on modern topographic maps of large scales and on the small scale map which dates from about 1830 (Fig. 3). At that time, the Vistula was a strongly meandering river with a channel many times narrower than that of today. For the needs of palaeogeographical studies on the Medieval meanders, the Vistula section below Puławy between Gołąb and Stężyca (Fig. 4) is of considerable importance. By means of historical criteria, two stages of Medieval meander development may be distinguished in this area (Fig. 5). It should be emphasised that the dimensions of Medieval meanders in both sections are very similar, as the discharge in the Opole Lubelskie section and Gołąb section (above the Wieprz confluence) was then and is also now virtually identical.

The distribution of the settlement shows that the meanders of the Medieval Vistula from the earlier stage are usually drier, rather less conspicuous and more often used now as pasture-land. In contrast, the meanders from the later stage contain numerous abandoned channels filled with water which can be clearly distinguished on a topographical map (Fig. 4). The character and dimensions of the meanders from both stages are similar. The best developed (i.e. those in an advanced phase of meandering) have a curve radius of 0.3-0.5 km. Based on cartometrical measurements, the width of the channel is about 0.1 km. The meanders of both phases comprise a valley floor zone about 2 km wide between Gołąb and Stężyca (Fig. 5).

The historical data show that the river channel with the meanders of the older stage probably existed until at least the end of the 11th century. Chronicles of war events from 1093 show that Sieciechów, an important administrational centre of a vast settlement area in the floor of Vistula valley (Dunin-Wąsowicz, 1974; Kowalczyk, 1994), was located on the left bank of Vistula on a higher flood plain (Fig. 6III). The importance of this centre was also determined by its location at an important trade route from Great Poland to Kievien Ruthenia. A crossing of the river in 1093 was not only provided by the old earthwork in Sieciechów, but also by a small defensive site, where later, in the 12th century, a Benedictine monastery, Sieciechów Abbey, became established (Wiśniewski, 1958) (Fig. 5).

The second stage of warm Medieval times and the transitional period to the Little Ice Age

Sieciechów earthwork with its Benedict monastery, situated on both banks of the river, flourished in the 12th - 14th centuries, i.e. in a wetter sub-period of the warm Medieval times. Owing to the increase of climate humidity (including an increase of the Vistula discharge), the significance of the river crossing at this important trade route increased as well. At that time, Sieciechów was the seat of a castellan who was a manager of one of the main administrational units of the Sandomierz duchy. The Benedict monastery was an important economic centre which was associated with numerous villages in the Vistula region (Wiśniowski, 1958).

In the 14th century, the first evidence of an increase in the frequency and intensity of the river floods appeared and, as a result of these, the village of Święcica, situated 3 km SSE of Sieciechów, was completely destroyed; a new village, Klasztorna Wola, has replaced it. Also destroyed was

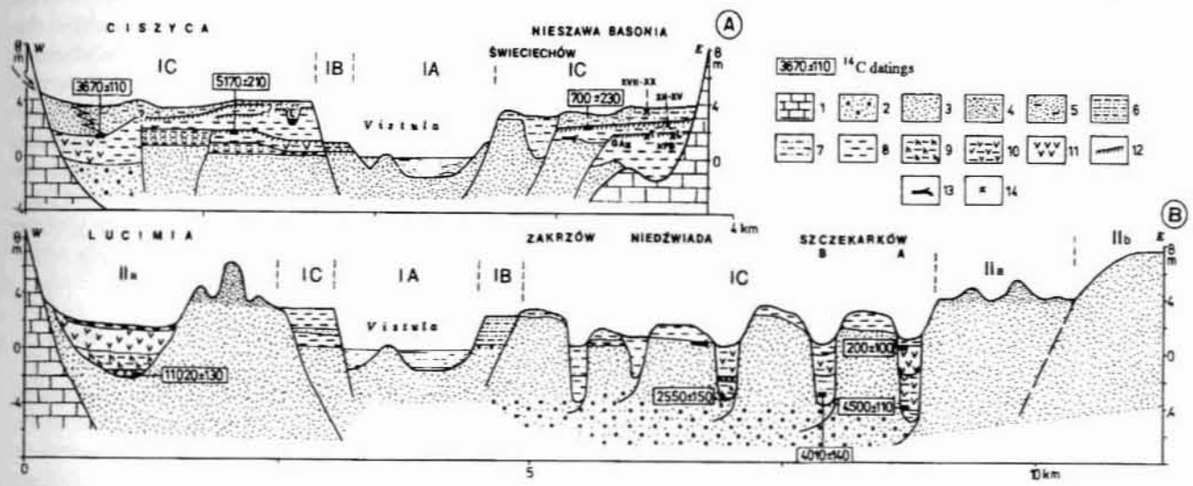

Fig. 2. Schematic valley floor cross-sections in the narrow reaches (A: Ciszyca - Basonia; compare Fig. 1) and wide reaches (B: Lucimia - Szczekarków) of the Vistula river gap through the South-Polish uplands (*cf.*Pożaryski & Kalicki, 1975). Indices of main valley floor landforms: IIb and IIa - low and middle terraces (late glacial times = late Vistulian); IC and IB - historical flood plains of the meandering river, (C) upper, (B) lower; IA - modern flood plain with accumulation sandbanks and islands in the channel of the braiding river.
1 - marl and chalk; 2 - gravel with sand; 3 - sand; 4 - aeolian sand and dunes; 5 - silty sand; 6 - sand interbedded with silt; 7 - sandy silt; 8 - silt; 9 - organic silt; 10 - silty peat; 11- peat; 12 - palaeosoil; 13 - subfossil tree trunks; 14 - archaeological artefacts (FB - Funnel Beaker Culture, GA - Globular Amphora Culture, T - Trzciniec Culture, L - Lusatian Culture /T+L=Bronze Age/, XII/XX - AD centuries).

Fig. 3. The Opole Lubelskie section of the Vistula river according to the Topographic Map of the Polish Kingdom (1839).

Fig. 4. The Sieciechów section of the Vistula river according to the Topographic Map of the Polish Kingdom (1839).

Fig. 5. The changes of the Vistula channel and course between Gołąb and Stężyca in the historical times (after Maruszczak, 1996).

the village of Brześce, situated 5 km NNW of Sieciechów, (Wiśniowski, 1958). A church in Regów Stary, which was built in 1390 on the upper flood plain of the Vistula, was also destroyed by floods and, at the end of the 15th century, a new church was built beyond the limits of flooding on a terrace of the river in Regów Nowy (Wiśniewski, 1913). At the beginning of the 15th century, the town of Stężyca was so badly flooded that, in 1442, it was re-built in a more elevated location (Kurzyp, 1989).

The increase of flood intensity probably determined part of the change of the Vistula course in the 14th - 15th centuries. Earlier, it flowed from Gołąb westward towards Sławczyn and Sieciechów but, since the 15th century, it has flowed northward towards Borowa and Kępice (Fig. 5). However, the characters and parameters of the new channel were similar to those of the old one. The change of the Vistula course was therefore the result of a natural migration of meanders. Further, it may be assumed that the hydrological regime of the Vistula did not change significantly; the increase of climate humidity and the role of floods must have been moderate.

The increase of flood frequency and the change of the river course caused a deterioration of the river crossing at Sieciechów and the administrational function of this setting also decreased. The seat of the castellan was transferred to Stężyca (Kowalczyk, 1994) at the confluence of the Wieprz and the Vistula and located on the terrace to protect it from floods (Figs. 5 and 6III).

Between the second part of the 14th to the end of the 15th centuries, the climatic condition of the economy was less favourable than that of the early Medieval times (11th - 13th centuries). At the beginning of the 14th century, the climate cooled; this caused an increase of food prices. By extension, it has been assumed that the cooling of the area of Poland lasted until the second half of the 15th century; in turn, this was interpreted as the first phase of the Little Ice Age (Maruszczak, 1987a, 1994). The results of the analysis of the Vistula run changes between Gołąb and Stężyca suggest that the geomorphological effects of this cooling were less dramatic than those which occurred in the economy. It may be assumed, therefore, that this was a transitional period from warm Medieval times to the Little Ice Age. Despite the changes of its course which resulted from flood frequency increase, the Vistula still had the form of meandering river on a vast flood plain and, in the section adjacent to the confluence with the Wieprz, the Vistula alluvial floor was 8 km wide (Fig. 6III).

The Little Ice Age

According to West European data, the Little Ice Age lasted from the middle of the 16th century to the second half of the 19th century (Lamb, 1984). During this time, two distinctive cold phases, each lasting about 180 years may be distinguished (Maruszczak, 1987a, 1994).

At the beginning of the first cold phase, in the last decades of the 16th century, there must have been a considerable increase of flood size and frequency in the Vistula valley (Girguś & Strupczewski, 1965). During one of the larger floods, probably in 1593 or 1595, Vistula changed its course and, in Borowa (north of Gołąb), it shifted to the confluence section of its right bank tributary, the Wieprz. This is evidenced by historical facts: until 1583, river crossings and harbours were located on both the Vistula and the Wieprz; in 1596 these were located only on the Vistula (Kurzyp, 1989). As a result, the river course between Borowa and Stężyca was shortened by 50% (Fig. 5).

This considerable change in the course of the Vistula and the much-increased bottom erosion in the section between Borowa and Stężyca probably initiated a change of the meandering channel into one which was braided. This was conditioned by a long cold period which lasted till the end of the 17th century and it must surely represent the main phase of the Little Ice Age which is known to have culminated in the middle of the 17th century; this phase is easily identified on a plot of food price changes (Maruszczak, 1994, p. 120). At about this time, the Vistula changed into an braided river with an unstable and multi-limbed channel, the floods from which were increasingly frequent. The large floods which have occurred since the middle of the 17th century have caused much damage and considerably limited any economic activity on the flood plain. After the 16th century, hardly any villages were left in the Vistula valley floor between Puławy and Kozienice despite the fact that the average population density increased 5 times in the period 1580-1980 (Maruszczak, 1987b). In the Sieciechów section of the flood plain, i.e. between Gołąb and Stężyca, only one village, Borek, was settled after the 16th century. It originated at the end of the 17th and beginning of the 18th centuries above the meander abandoned when the river cut its new course to the confluent section of the Wieprz.

The second cold period of the Little Ice Age started in the first part of the 18th century and its culmination (the climatic pessimum) occurred in the first decades of the 19th century. The Vistula floods became especially dangerous and geomorphologically-active at that time because the river came to transport ever-increasing products of soil erosion.

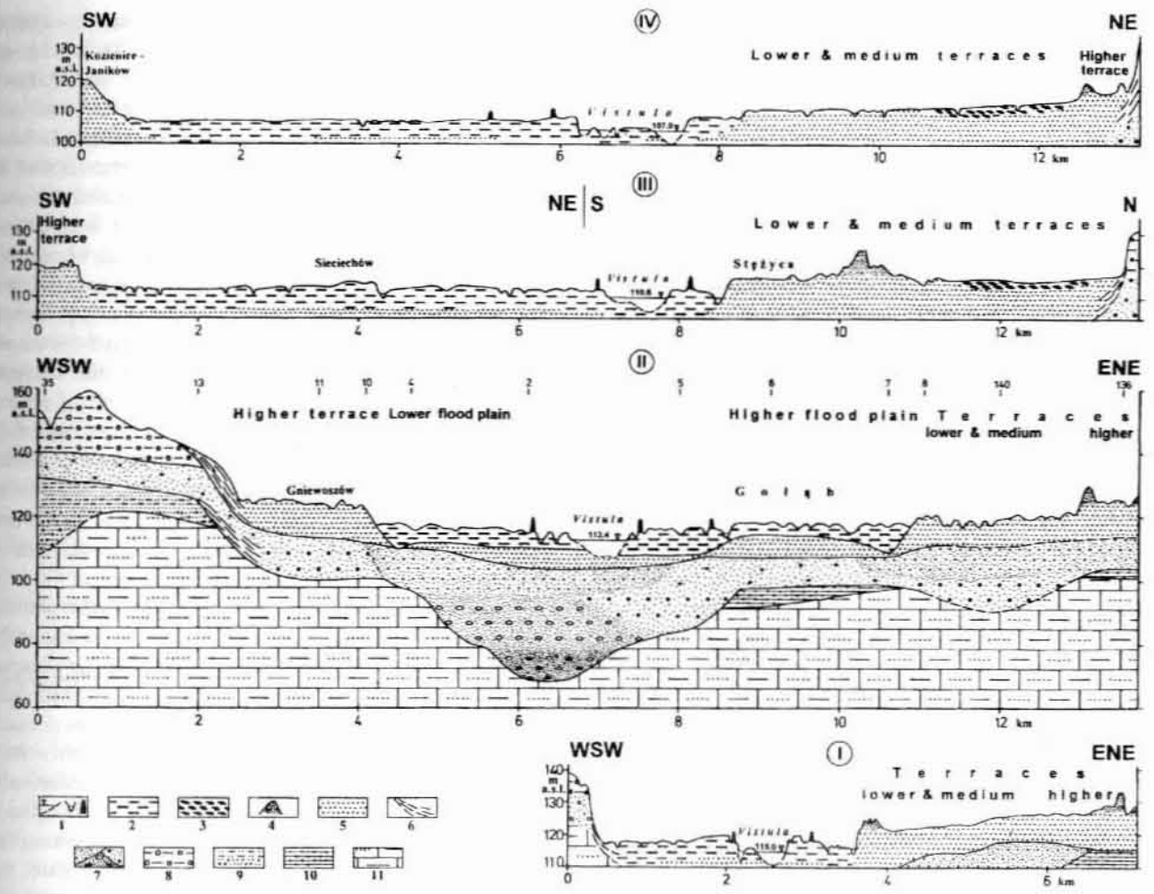

Fig. 6. Geological cross-sections of the Vistula valley floor between Puławy and Kozienice; cross-section locations as on Fig. 1. By Maruszczak, 1997 (with some data from Pawlak & Milewska, 1968 and Żarski, 1991 for the cross sections I and II; Żarski (1991, 1996) for the cross-sections III and IV).
I: Kowala - Puławy Chemia; II: Gniewoszów - Gołąb; III: Bąkowiec - Sieciechów - Stężyca; IV - Kozienice Janików - Holendry - Nadlądzie Paprotnia.
1 - the Vistula modern channel with a mean water level marked, abandoned meanders with water and flood embankment; 2 - deposits of the Holocene and modern Vistula , mainly silty and sandy alluvial clay, and within abandoned meanders alluvial clay, peat silt and peat; 3 - Holocene peat in the depressions of the lowest flood plain; 4 - dune sands (end of last glacial and beginning of Holocene); 5 - sandy river deposits (last glaciation); 6 - sandy and sandy-loam slope deposits (last and older glaciations); 7 - coarse and fine, mainly interglacial river deposits (middle and upper Pleistocene); 8 - till and other glacial deposits (Odranian = Saalian I); 9 - silty sand and sand with gravels (lower Pleistocene = preglacial); 10 - sand and sand with quartz gravels (Oligocene); 11 - gaizes and marls (Palaeocene).

This increase of soil erosion was undoubtedly caused by the considerable increase of plough land area which was necessary to fulfil the needs of a growing population in the Vistula catchment and by cultivation of root crops (such as potatoes and sugar beet) which became very popular at the end of the 18th and beginning of the 19th centuries (Szumański, 1982; Maruszczak, 1987b). The increase of erosion products, especially the suspended load transported by the river, accelerated its capacity to cause devastation and the course became a multi-limbed or braided system (Falkowski, 1982). Numerous small islands and channel bars built from alluvia originated in the channel. They favoured winter freezing which resulted in the development of ice-jam on some river sections, thereby causing dangerous local floods. On 1 April 1845, an ice ridge in Stężyca created a river level which was actually higher than that caused by one of the largest summer floods recorded, that in July 1844. In 1852 and 1854, large ice jams caused considerable damage to plough land and changes to the Vistula channel over a 10 km- long section below the Wieprz confluence (Kurzyp, 1989).

The flood hazard was so serious that it was considered necessary to construct protective embankments in Strężyca as early as in the 1760s. On a larger scale and in the longest sections, more flood embankments were built in the first decades of the 19th century e.g. in the river section from Gołąb to Borowa and from Sieciechów to Kozienice; these are shown in the former topographical map (Fig. 4). The construction of the embankments had the effect of limiting the possibilities of river course changes and, along its braiding channel, a modern flood plain about 1-2 km wide started to develop. On the map dating from the first part of the 19th century, this plain is distinguished and described as "fresh sand deposits" (Figs. 3 and 4). Contour lines of present large-scale topographical maps reflect many abandoned sections of braiding channel within this plain. Two older Vistula flood plains, i.e. a lower and an upper, contain numerous traces of river channels with small meanders.

The modern flood plain, as contained between flood embankments, in the section from Puławy to Kozienice often rises above the level of the upper flood plain (Fig. 6I, II). Despite this, it is distinguished on many geomorphological and geological maps (not very logically) as the "lower flood plain" (Żarski, 1996). Only within the section between Gołąb and Stężyca is it situated below the level of Holocene flood plains. This is one of the consequences of bottom erosion of the Vistula channel, which was caused by shifting of Vistula river into a confluence section of the Wieprz at the end of the 16th century. At first, this section must have extended from the village of Borowa to Brześce (Fig. 4), and then, owing to upstream erosion, it moved up the river run. At present, the most dramatic example of channel erosion and the lowest location of a modern flood plain are to be observed near the village of Gołąb (Fig. 6II).

The modern, frequently-changing braided channel of the Vistula is much wider than the stable meandering channel of early Medieval times. It is now from 0.3 to 0.8 km wide. Locally, it is divided into branches, among which small islands and channel bars occur. These forms, which depend on the rate of suspended load accumulation, are significantly less numerous than in the first half of the 19th century (compare Figs. 5 and 4). This results from the protection now afforded to the Vistula by the flood embankments and the several regulation works, especially those of the second part of the 20th century. As a result of these works, the accumulation of the alluvium is now limited to the zone between the flood-embankments (Łajczak, 1997). In this way, the modern flood plain with its multi-channel flow originated. Outside these embankments, occurs a Holocene alluvial plain which has well preserved and numerous traces of meandering channel (Fig. 7). Because this plain is beyond all but the most disastrous of floods now, the term "flood plain" is of no more than historical importance. Therefore, in Figure 2, it is distinguished as a "historical flood plain".

Conclusions

1) In the earliest Medieval times (6th - 11th century), the Vistula river between Puławy and Kozienice, was represented by a well-developed meandering channel; this was indicative of a relatively dry climate in which the river did not flood very often. These conditions favoured agricultural land use of this broad, Holocene flood plain which contained fertile and easy-to-cultivate alluvial soil and variety of terrestrial and water habitats. The upper levels of the flood plain i.e. those beyond the limit of flooding, were eminently suitable for settlement. Sieciechów became the economical and administrational centre of this Vistula settlement region and it served to protect the river crossing along the important trade route from Great Poland to Kievian Ruthenia. This crossing was even more important in the early Medieval times (12th -14th centuries), when, owing to a more humid climate, the discharge of the Vistula river became greater.

2) It seems likely that similar conditions for agricultural development and settlement occurred in this area earlier, i.e. in the Subboreal phase of Holocene. As evidence of this, numerous Neolitic and Bronze Age artefacts have been found near Opole Lubelskie in the river gap section of Vistula through South-Polish uplands between Zawichost and Puławy. Preliminary analysis of these sites shows that they were also associated with a meandering river, as in the earliest Medieval times. In the Opole Lubelskie Vistula section, the width of the river floor is similar to that of the lowland section between Puławy and Kozienice. A comparison of the lowland and upland sections of the valley suggests that a typical, meandering channel development in Neolithic and Bronze times was ubiquitous in the valley extensions. In the river gap section, where the valley floor was less than 3 km, well-developed meanders did not occur. The importance of this becomes obvious, if one considers the stream gradient which is more or less the same in both the narrow and wide parts of the valley, e.g. Zawichost-Kamień (relatively narrow valley) - 0.285‰, Kamień-Lucimia (wide valley) - 0.245‰ and Lucimia Puławy (very narrow valley) - 0.252‰. By comparison, the stream gradient in the lowland section of the Vistula between Puławy and Kozienice is from 0.212 to 0.286‰.

3) In the transition period from the warm Medieval times to the Little Ice Age (second part of the 14th to the end of the 15th centuries), the Vistula flowed in a meandering channel, as it did in the earliest Medieval times. But it flooded more often and, during large floods, it repeatedly destroyed not only adjacent farmland but also whole villages and towns. As a result of such floods, the river course changed so drastically between Gołąb and Stężyca, that the Vistula abandoned Sieciechów and this settlement thereby lost its importance as the main flood centre of the Vistula plain region. Thus, the economic results of the hydrological regime change were, in a sense, rather more significant than the geomorphological ones, for the parameters of meanders did not change materially.

4) The frequency and size of the Vistula floods considerably increased during the Little Ice Age (from the second half of the 16th to second half of the 19th century). During one of the larger floods, at the end of the 16th century, an important change of the river course between Borowa and Stężyca took place. The Vistula then shifted into a confluent section of its tributary, the Wieprz, and, as a result, the river course at this section was shortened by half the distance. This provoked intensive channel erosion and transformed the meandering channel into an braiding one. The typical braided Vistula channel developed in the 18th century not only in the lowland section (Puławy - Kozienice), but also in the upland section (Zawichost - Puławy) of the river. The Vistula, overloaded with the products of soil erosion, especially since the beginning of the 19th century when root crop cultivation was initiated, formed a channel with numerous banks and islands of fresh alluvium. These, in turn, certainly since the beginning of the 19th century, have led to the development of large ice jams which have caused considerable damage and local floods which have proved to be even more widespread than the more catastrophic of the summer floods. To protect this area from flooding, protective embankments have been built here since the middle of the 18th century. These constrained the river, so a modern flood plain, which is locally higher than the Holocene upper flood plain, started to develop along its braided channel. Only in the section of intensive bed erosion, caused by the shortening of the Vistula river run at the end of the 16th century, is the modern flood alluvial plain situated below the level of the Holocene flood plains.

5) In the lowland section, where a modern flood alluvial plain is situated below the level of the Holocene flood plains, the arrangement of valley floor landforms is similar to those from the narrowest parts of the river gap section through the South-Polish uplands, where the valley floor is up to 3 km wide and the modern flood plain represents the lowest morphological surface of the Vistula valley. In the floors within the narrow sections, where meandering processes are limited, the Holocene morphological surfaces occur in a falling sequence. By contrast, in the wide part of the river gap valley, as with the lowland section of the river course between Puławy and Kozienice, a modern alluvial flood plain is usually situated above the level of the Holocene flood plains. The flood plain built from the youngest alluvia also shows traces of former channels of the braiding river. In contrast, the Holocene alluvial plain, i.e. historical flood plains, contains numerous traces of meandering channels despite the fact that they have been cultivated for a long time.

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