ICE PHENOMENA IN THE WARTA RIVER IN POZNAŃ IN 1961–2010

Marika Kornaś[1,2]

[1] Nicolaus Copernicus University, Toruń, Poland
[2]Institute of Meteorology and Water Management – National Research Institute, Wrocław, Poland

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Abstract: The article presents variability of ice phenomena in the Warta River in Poznań based on data recorded in the water gauge station in Poznań – Roch Bridge in 1961–2010. The work aims to characterize and analyze ice phenomena and related hazards. First dates (freeze date), last dates (thaw date) and duration of ice phenomena and particular forms of ice, i.e. frazil ice, border ice, ice cover, ice floes and ice jam, were determined. In case of ice cover, its thickness was also analyzed. In the analyzed period, ice phenomena in the Warta River in Poznań had the maximum duration of 118 days, the earliest date appearance was on November 7 and the last on March 28. The first ice form to appear was frazil ice, the last ice floes and the longest lasting – ice floes. In the entire analyzed period, 15 winter seasons featured ice cover. The longest duration of ice cover was 29 days and its maximum thickness was 8 cm.

Key words: river ice phenomena, ice forms, the Warta River, Poznań

Address of the corresponding author: Marika Kornaś, Institute of Meteorology and Water Management – National Research Institute, Wrocław, Poland, e-mail: marika.kornas@imgw.pl

Introduction

During winter, under favourable conditions, rivers become ice covered. The type and intensity of freezing depend on the conditions in winter season. Ice coverage in rivers does not have a continuous character. Within a given winter season, shorter or longer gaps can be observed in ice phenomena occurrences. Particular ice forms can appear separately or they can occur simultaneously.

Conditions favourable to ice formation in river include temperature drop below 0°C, heat loss from water turbulent movement of cooled water masses and suspended matter in water (especially mineral suspension) of which particles act as condensation nuclei (Lambor 1948). Under such conditions, first ice phenomenon to appear in a river is frazil ice. Intense frazil ice formation creates flocculent masses of numerous small crystals adhering to each other and attached to the bottom, i.e. anchor ice (Dobrowolski 1923). Very often, the accumulated anchor ice can block the entire cross section of a river bed creating anchor ice dam (Mikulski 1965).

Ice crystals forming on supercooled water surface leads to creation of a thin layer of ice cover. This process develops in two directions: vertically – thickening the ice layer and horizontally – towards the center of a river. In its initial phase, the process first occurs along the banks forming border ice and its final effect is ice cover over the entire water surface. In some river sections characterized by high water velocity, ice free spaces or spaces with thinner ice cover can appear.

Ice cover growth occurs by crystallization of water which is in direct contact with the ice. Sometimes, as a result of the increase of water level, water which floated onto the ice cover also freezes and considerably thickens the ice cover beneath (Mikulski 1965).

Disappearance of ice phenomena in rivers is accompanied by changes of water levels during thawing, breaking the ice cover and drifting of ice floes. At the confluence of two rivers, in places with many obstacles in the river bed (closely spaced bridge piers, submerged tree trunks, shoals, still solid ice cover), in the unregulated river sections, large amounts of ice floes accumulate and create ice jam. This phenomenon is particularly dangerous because its capacity to impound water creates a major flood risk.

Freezing of rivers impacts their water levels and flow values, ratio of runoff from river basins, conditions of the entire river ecosystem, operations of hydrotechnical works, causes damages of water structures and makes navigation impossible. Freezing of rivers very often creates flood hazard.

In the climate conditions of Poland, the intensity of river freezing and its duration tend to show high variability. The differences in ice phenomena occurrences depend on the geographic location of a river, size of the river hydrological conditions, degree of contamination with industrial and domestic pollutants, and sometimes, microclimate conditions in the river valley (Gołek 1964).

There is a number of studies of ice phenomena in Polish rivers by authors such as Kolberg (1861), Słowikowski (1892), Dobrowolski (1923), Zubrzycki (1927), Łomniewski (1935), Paczoska (1938), Lambor (1948, 1959), Gołek (1957, 1964), Wokroj (1954), Wiśniewski (1975), Karabon (1980), Majewski (1985, 1987, 2009), Grześ (1991, 1999), Grześ, Pawłowski (2006), Pawłowski (2008a, b), Pawłowski, Sobota (2012).

The aim of this work is to characterize and analyze ice phenomena in the Warta River in Poznań in the five decades of 1961–2010. Possible flood hazards related to the Warta River freezing in the analyzed river section were also investigated.

Methods

The longest observations of ice phenomena and measurements of ice cover thickness on rivers in Poland have been conducted by the Institute of Meteorology and Water Management – National Research Institute. The observations and measurements are carried out on gauge stations during winter seasons (November–April).

The first water gauge station on the Warta River in Poznań was established on January 1, 1818 (PIHM 1969). The station, called Poznań – Chwaliszewski Bridge, was located on the 242.7 km of the river. The station had been operational until 1965 when the works on correction of the Warta River course in Poznań began. The project was finished in 1969. In 1920, 200 m downstream of the Cybina River inlet to the Warta River on its 241.8 km, water gauge station Poznań – Stocznia was built. By 1931, however, the station had already been closed. In 1927, water gauge station Poznań – Roch Bridge was established on the Warta River in Poznań. The station continues to work today. The station is located on 243.7 km of the Warta River and closes the 25,911 km^2 catchment.

The analysis of ice phenomena in the Warta River in Poznań was based on the data from the Poznań – Roch Bridge gauge station collected in 1961–2010, i.e. the last five decades. The characteristics of ice phenomena include first and last dates of occurrences of a given ice form and its duration. The study includes such ice phenomena as: frazil ice, border ice, ice cover, ice floes and ice jam. Moreover, thickness of ice cover measured in 5-day intervals, i.e. 5, 10, 15, 20, 25 and the last day of a month during the period of complete ice cover was also taken into account.

This allowed to establish the duration (days) of ice phenomena in each year of the analyzed period and the most frequently recorded ice phenomenon. Freeze and thaw dates were identified for each form of ice occurrence in the Warta River in Poznań in 1961–2010. The year with the thickest ice cover and its longest duration was identified. Moreover, years with no stable ice cover or no ice phenomena occurrences were also established. Special attention was given to the occurrences of ice jams because of their potential to create the risk of ice jam floods.

Results

Ice phenomena duration

The longest duration of ice phenomena in the Warta River in Poznań in the period of 1961–2010 was recorded in 1970 reaching 118 days and the shortest – 3 days in 2007. Of all the ice forms, the longest lasting was border ice – 89 days also in 1970. The second longest lasting ice form was frazil ice – 64 days in 1996 followed by ice cover – 29 days in 2006 and 2010, and ice floes – 18 days in 1969. In the entire analyzed time period, there were no occurrences of ice jam on the Warta River in Poznań.

Ice cover on the Warta River in Poznań occurred 15 times in the analyzed 50-year period. The shortest duration of 2 days was noted in 1993 and the longest, as mentioned earlier, was 29 days in 2006 and 2010. Almost equally long duration of ice cover was registered in 1979 – 27 days. Ice cover thickness reached the maximum of 8 cm in 1966, i.e. the first decade of the analyzed period (Table 1).

It is not unusual in rivers of the Polish Lowlands that ice cover appears and breaks off two and more times in the course of one winter (Dębski 1961). The ice cover formed twice in years 1979, 1980 and 2010. Year 2006 is, therefore, the year with the longest continuous ice cover duration in the period of 1961–2010.

Table 1. Ice cover on the Warta River in Poznań in 1961–2010

Year	Duration (days)	Thickness (cm)
1961	9	n
1965	10	n
1966	12	8
1970	14	n
1971	4	n
1972	3	–
1979	27	n
1980	5	n
1987	3	–
1993	2	–
1997	10	n
2003	10	n
2006	29	n
2009	15	n
2010	29	n

n – no ice thickness measurement in correct time and/or no possibility of interpolation

The highest ratio of ice cover duration in period of ice phenomena occurrences was 64.3% in 1961, and the lowest 3.4% in 1987 (the average ratio 27.9%). The summation of ice cover duration in decadal intervals shows that the longest duration of ice cover on the Warta River in Poznań occurred in the decade of 2001–2010 reaching

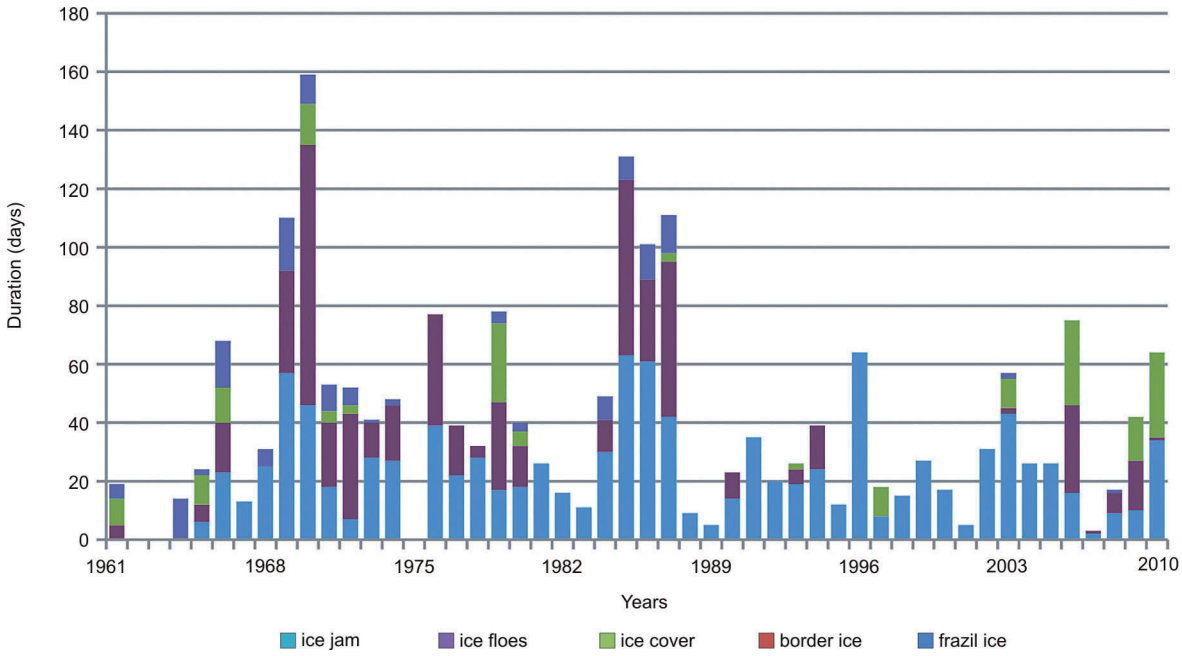

Fig. 1. Duration of ice phenomena occurrences in the Warta River in Poznań in 1961–2010

83 days, and the shortest was 3 days in the 1981–1990 decade.

The most diversified, in terms of the number of recorded ice forms, were the following years: 1965–1966, 1970–1972, 1979–1980, 1987 and 2003. In those years, four different ice forms occurred (frazil ice, border ice, ice cover and ice floes). The least varied were the following years: 1967, 1981–1983, 1988–1989, 1991–1992, 1995–1996, 1998–2002, 2004–2005 when only frazil ice occurred (with the maximum duration of 64 days in 1996) and 1964 with ice floes as the only ice occurrence (Fig. 1).

Frequency of ice phenomena occurrences

The analysis of ice phenomena in 1961–2010 showed that there was only one year with no ice in the Warta River in Poznań – the hydrological year of 1975. In 1962–1963, the observation of ice phenomena on the Poznań – Roch Bridge were not carried out.

The most frequent ice form in the Warta River in Poznań was frazil ice (Fig. 2). In the entire analyzed 50-year period, it occurred 45 times (the number of years). It did not appear five times, including two years when ice phenomena were not under observation, one year with no ice phenomena occurrences in the Warta River in Poznań and one year with only ice floes. Frazil ice did not occur also in 1961. At the time of formation of border ice, also ice floes was observed and formation of ice cover. The least frequent ice form, beside ice jam which never occurred in the studied period of 1961–2010, was ice cover – 15 occurrences.

Months with the highest frequency of ice phenomena occurrences in 1961–2010 in the Warta River in Poznań were January – 36%, followed by February – 30% and December – 21% of the total number of days in a given month. In all the months of winter season, i.e. the first half of hydrological year (November – April), ice phenomena were never registered in April (Fig. 3).

The freeze and thaw dates

The first occurrences of ice phenomena in the Warta River in Poznań in 1961–2010 were noted in the first half of November – November 7, 2003 and the last date of their occurrences was in the second half of March – March 28, 1970 (Fig. 4). The earliest ice form to appear is frazil ice and the last is ice floes.

Fig. 2. Pancake ice floes and border ice in the Warta River in Poznań – view from the Roch Bridge – January 2013

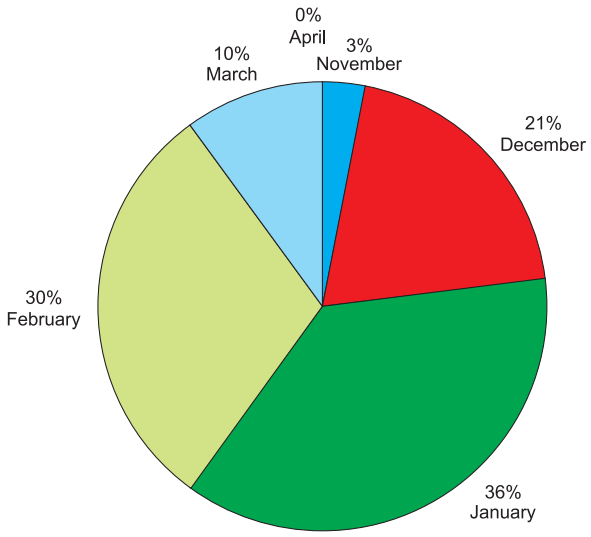

Fig. 3. Ice phenomena occurrences in the Warta River in Poznań per month in 1961–2010

The earliest date of the first appearance of ice cover was in the second half of November – November 19, 1966 as was the case with border ice – November 16, 1985. The earliest date of ice floes appearance was the beginning of December – December 1, 1966. The last dates of ice phenomena in all its forms were noted in the second half of March. The latest date of ice cover occurrence was noted in March 16, 1965, border ice – March 21, 2006, and frazil ice – March 22, 1987.

Variability of ice phenomena occurrences

The analysis of ice phenomena in the Warta River in Poznań shows that in the first half of the 1961–2010 period, their occurrences were more frequent than in its second half. Two periods can be distinguished with longer ice phenomena occurrences duration and variety of ice forms. The first period includes years from 1964 to 1974, and the second 1976–1987 (Fig. 5).

The first 11-year period includes the longest ice phenomena duration in the entire studied period (118 days in 1970). In the second, slightly longer period of 12 years, the maximum duration of ice phenomena occurrences was 88 days in 1985. In both of these periods, a higher ratio of ice forms appeared, especially border ice, than in the rest of the analyzed years.

It can be noticed that within the space of the analyzed time, especially when comparing time period before 1987 (which includes the two periods of higher variability and duration of ice phenomena occurrences) and after, the duration of ice phenomena occurrences in the Warta River in Poznań decreased (from 118 days to 75 days) while ice cover duration increased (from 87 to 95 days), although ice cover formation was more frequent in the period of 1961–1987.

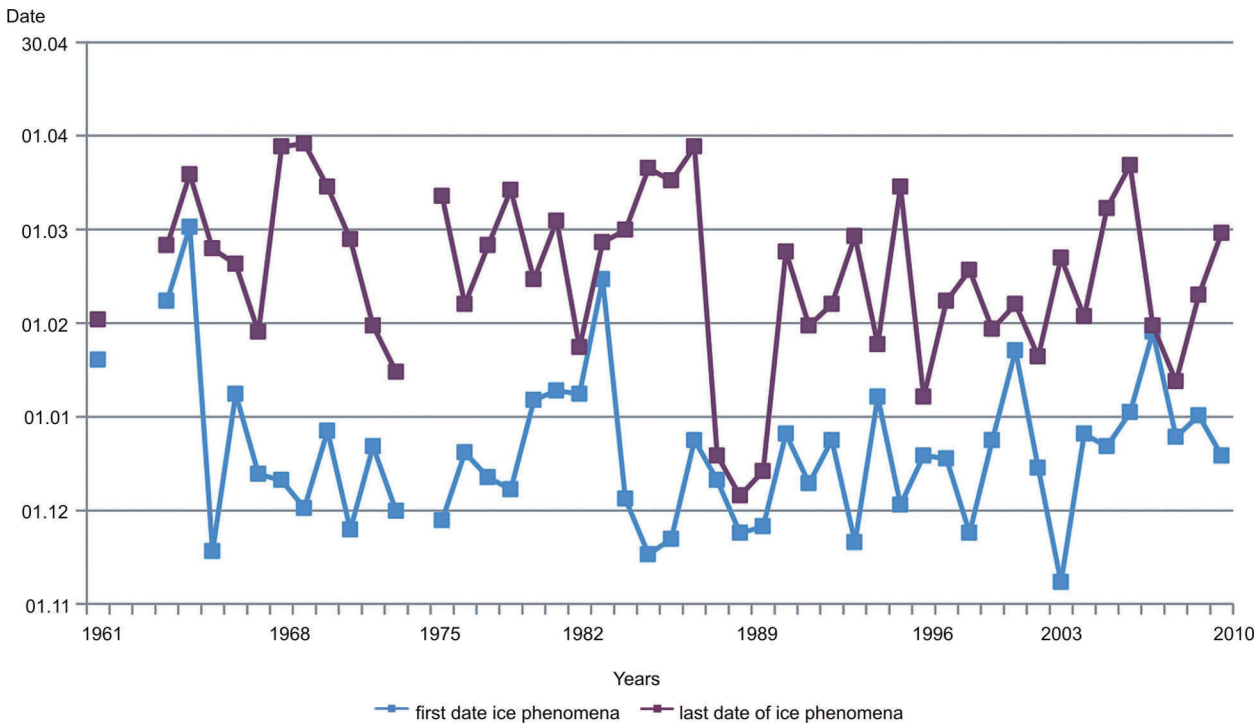

Fig. 4. Freeze and thaw dates in the Warta River in Poznań in 1961–2010

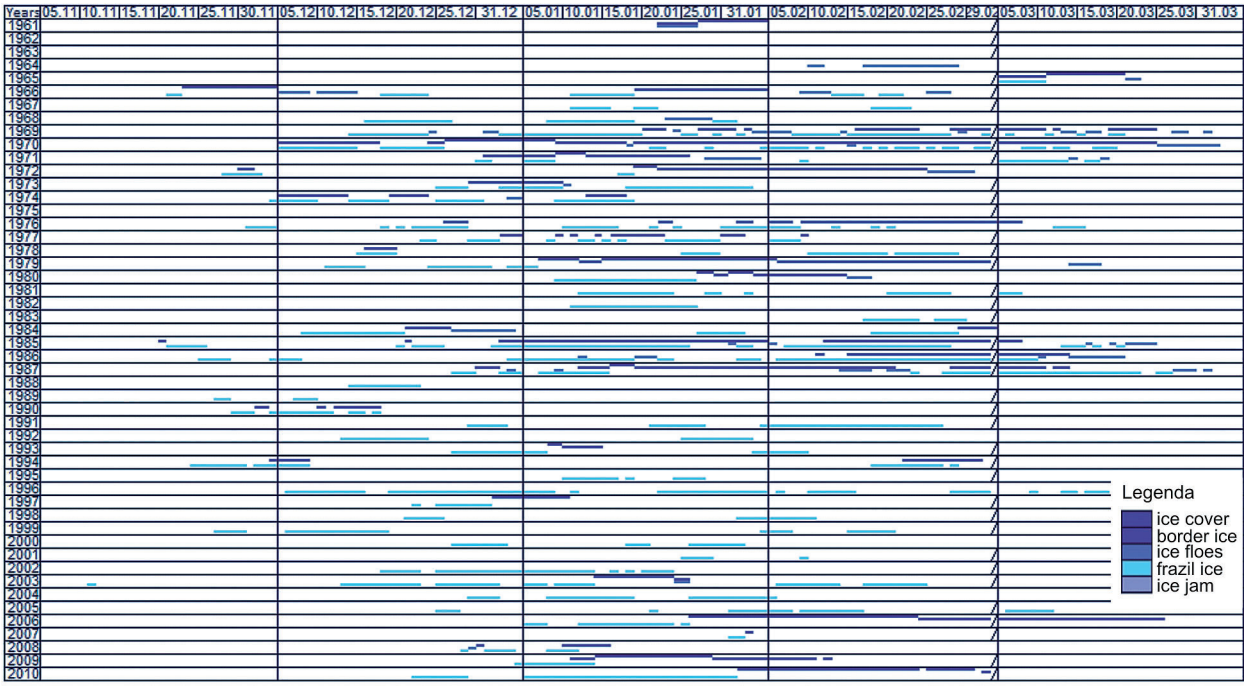

Fig. 5. Ice phenomena in the Warta River in Poznań in 1961–2010

Summary

The maximum duration of ice phenomena in the Warta River in Poznań was 118 days in 1970. Border ice was the ice form with the longest duration – 89 days, also in 1970. During the entire analyzed period of 1961–2010, there were no ice jam occurrences in the Warta River in Poznań. The maximum duration of ice cover was 29 days, noted twice in 2006 and 2010. Ice phenomena in the Warta River in Poznań were not under observation in 1962–1963 and in 1975 they did not occur at all. Ice cover was noted 15 times in the studied 50-year period. Only once – in 1966 – it was possible to measure ice cover thickness which had the maximum of 8 cm. The highest ratio of ice phenomena occurrences in 1961–2010 was observed in January (36%) while April had no ice forms of any kind. The earliest date of freeze in the Warta River in Poznań in 1961–2010 was November 7 (in 2003) and the latest date of freeze was March 28 (in 1970). The first ice form to appear was frazil ice and the last ice floes. The earliest first date of ice cover formation was November 19 (in 1966) and it could be observed until March 3 (1965). The analysis of ice phenomena occurrences variability allowed to distinguish two periods of their longer duration and diversity i.e. 1964–1974 and 1976–1987. In the Warta River in Poznań, a decreasing trend of ice phenomena duration and increasing trend of ice cover duration could be observed.

Discussion

The original character of the Warta River valley in Poznań has been significantly transformed as the result of human economic activities. Both, the river network and the landform have been altered. Deliberate human activities had changed the landform to such a degree that it is nearly impossible to recreate the previous landscape and the original river network (Kaniecki 2004).

The regulation and land improvement works in the valley of the Warta River began in the 18th century. Watercourse regulation works such as the river straightening, rechanneling, reinforcing banks for military and flood protection and damming for the industrial purposes were conducted in 18th, 19th and 20th centuries. In the 20th century, the Warta River was regulated twice within the Poznań city borders (Kaniecki 2004).

In 1911, the realization of the project of the Warta River course regulation in Poznań authored by S. Schultz was initiated. It proposed

to build a new navigation channel along the 1st relief channel, i.e. between the Ostrów Tumski (meaning *Cathedral Island*) and the Chwaliszewo district (Kaniecki 2004). The old Warta River channel, cut off by a levee equipped with a lock, was to provide water exchange in the river-harbour, built in 1901–1905 (Lewandowski, Rembeza 1972), and located along the left bank of the Warta River between the Chwaliszewski Bridge and the railway bridge in the Garbary district. In 1911, the construction of the Saint Roch Bridge on the Warta River had begun in the location of the Great Bridge destroyed in 1780. The Roch Bridge was completed in 1913 (Kaniecki 1993).

As the part of developing a new urban road network in 1964, the *Hydroprojekt* prepared a new plan of regulation of the Warta River in Poznań. The plan proposed to build a new riverbed for the Warta River in the area of the Chrobry Bridge and to remove the 600 m long Chwaliszewo river arm (Kaniecki 2004).

The decision to close the Warta River riverbed around the Chwaliszewo district was mostly motivated by the flood protection and economic concerns. Regulation of the Warta River in Poznań was to reduce flood risk in the city and to improve navigation in this section of the river (the river course bent forming a very acute angle near the Chwaliszewski Bridge).

Floods in Poznań were discussed in many publications such as: Łukaszewicz (1838), Warschauer (1890), Pawłowski (1929), Pasławski (1956), Olejnik (1989) and Kaniecki (1993, 1995, 2004). Warschauer (1890) counted 40 large flood events in Poznań in the period from 1501 to 1785. Pawłowski (1929), who analyzed a longer period of 1500–1925, concluded that the Warta River inundated Poznań 61 times, giving an average of one flood event in 7 years. The largest flood occurred in Poznań in July 1973 when the flood wave reached over 9.47 m above its mean level. According to Pasławski (1956), the frequency of flood events increased while the high water culminations showed decreasing trend, especially after 1761. Pasławski explains the increase of flood frequency by deforestation of the Warta River catchment and lower culmination of high water due to the removal buildings that obstructed flow of water in the Warta riverbed in the 18th century, and then by the regulation of the Warta riverbed section, i.e. downstream of the Prosna River inlet to the confluence of the Warta River and the Odra River, in the 19th century (Kaniecki 2004).

Of all the registered flood events, 87% occurred in spring and were caused by snow melting, and 13% were summer or fall floods resulting from rainfalls (Kaniecki 2004). Among the historical flood events in Poznań, there were also floods caused by ice jams on the river. Extremely high water levels resulting from ice phenomena occurrences in the Warta River in Poznań were observed in 1850, 1855, 1888, 1889, 1924 (Olejnik 1995). During the great flood in 1888–1889, the ice jam blocking the Great Lock in Poznań had to be blasted and crushed (Fig. 6, 7).

It is interesting to note the large number of flood events in Poznań after 1830 when the city became a fortress and several water damming structures were built (the Great Lock, the Cathedral Lock, the Berdychowo Dam, the Garbary Dam) which obstructed the flow of high waters of the Warta River in Poznań. The presence of these hydrotechnical structures increased the duration of high water levels of the Warta River in Poznań. The removal of these structures in 1905 considerably improved the flow of water in the Warta River decreasing flood risk in Poznań (Kaniecki 1995).

For centuries, the population of Poznań has been fighting against floods by raising the terrain

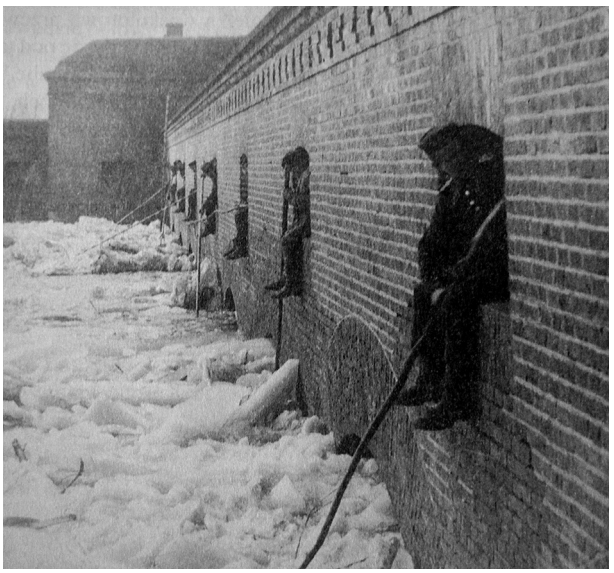

Fig. 6. The Great Lock on the Warta River in Poznań during the flood in 1888 (Kaniecki 2004)

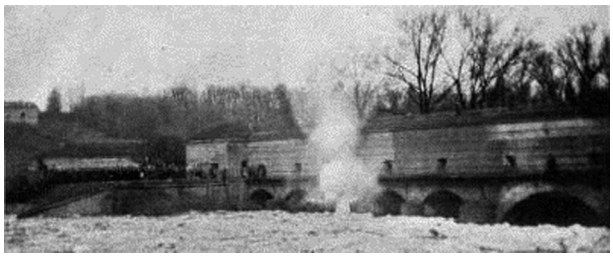

Fig. 7. Ice blasting at the Great Lock on the Warta River in Poznań during the flood in 1888

level, eliminating wetlands, rechanneling watercourses, reinforcing river banks, constructing levees and embankments.

When it was no longer possible to raise terrain level, the decision was made to develop the city on the other i.e. left riverside, of the Warta River. It is estimated that after the flood in 1253, the decision was made to construct a levee to cut off the river arm encircling Ostrów Tumski from the west and to redirect the riverbed toward the Chwaliszewo river arm. The Chwaliszewo river arm had operated up to 1969 (Kaniecki 2004).

Flood hazard was also created by timber bridges with closely spaced piers, water mills and ice jams. For the construction of the Poznań–Gniezno railway, completed in 1880, three rail-bridges were built which obstructed the flow of water. This resulted in narrowing the Warta River and consequently contributed to development of many floods (Kaniecki 1993).

River regulation, which includes narrowing and straightening the riverbed and closing all the river branches, reduces the risk of ice jam floods. Has, therefore, the Warta River regulation influenced the formation ice phenomena and consequently flood risk? Was the lack of any noted ice jams in the Warta River in Poznań in the last 50 years the result of the eliminating the Chwaliszewo river arm and opening the new riverbed in the area of the Chrobry Bridge? Based on the analyzed data on ice phenomena in the Warta River in Poznań in 1961–2010, it can be concluded that no risk of ice jam floods existed during that period.

It must be added that, for a quite some time, works to create a comprehensive plan of land development along the Warta River banks, especially within the city borders, have been under way (Dyliński 2011). The concepts proposed last year by Strategia... (2012) include the idea of restoring the river to the city, excavating the old Warta riverbed and activating the old Chwaliszewo river arm. It remains to hope that the Strategy takes into account the analysis of hydrological conditions in this section of the Warta River and all the impacts that those changes may cause.

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