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Szymon Kazusek (Uniwersytet Jana Kochanowskiego w Kielcach)
ORCID: 0000-0002-5430-2544

Historical Water Levels of the Nogat River and Wind Resources in Malbork in the Years 1811–1828 as an Element of the Conditions of Inland Navigation

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Summary

The article presents the historical water levels of the Nogat river on the water profile in Malbork in the years 1811–1828. In addition, the floods, low flows and ice phenomena occurring on the river are discussed, the length of shipping seasons calculated and historical wind resources characterized. These phenomena combined allowed for the reconstruction and determination of navigation conditions on the Nogat river in the Malbork area. The text is provided with rich visualization of the analyzed data, including hydrographs of daily water levels and tables.

Keywords: navigation conditions, water levels, floods, ice phenomena, wind resources, Nogat, 19th century, inland navigation.

Streszczenie

Historyczne stany wody Nogatu i zasoby wiatru w Malborku w latach 1811–1828 jako element warunków żeglugi śródlądowej

W artykule przedstawione zostały historyczne stany wody rzeki Nogat na profilu wodnym w Malborku w latach 1811–1828. Ponadto omówiono występujące na rzece wezbrania, niżówki, zjawiska lodowe, obliczono długość trwania sezonów żeglugowych i dokonano charakterystyki historycznych zasobów wiatru. Zjawiska te w połączeniu pozwoliły odtworzyć i określić warunki żeglugowe na Nogacie w rejonie Malborka. Tekst zaopatrzono w bogatą wizualizację analizowanych danych, w tym także w hydrogramy dziennych stanów wody oraz w tabele.

Słowa kluczowe: warunki żeglugowe, stany wody, wezbrania, zjawiska lodowe, zasoby wiatru, Nogat, XIX wiek, żegluga śródlądowa.

Introduction

One aspect of the study of navigable rivers is their navigability. Today, no one needs to be convinced of the necessity to characterise them, including the Nogat, in the context of navigable trade and its seasonality[1]. Such a study is based on water levels, ice phenomena that determine the winter break in navigation, and wind resources used by sailing vessels. Systematic observations of water levels on Polish rivers date back to the 18th century[2]. Regular observations of wind direction also date from this period. In the 19th century, some of the results of water level observations appeared in various editions[3]. The results of daily observations of the historical water levels of the Vistula were published several times in the post-war literature[4]. Such data can now be successfully used to characterise navigation conditions on navigable rivers. New perspectives open up, among other things, for research into navigation conditions on the Nogat during almost the entire 19th century. The results of daily observations of water levels on the Nogat and, in part, wind direction measurements at Malbork, which have been preserved from this period, make it possible to reconstruct navigation conditions on the Nogat and, indirectly, on the lower Vistula in the post-partition period. Although the course of the Nogat, within the borders of the Polish-Lithuanian Commonwealth, became part of the Prussian partitioned state after 1772, its current could still be used to transport products, also from the lands of the Duchy of Warsaw and

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1 S. Gierszewski, *Problemy dziejów Elbląga w XIX wieku*, "Rocznik Elbląski" t. 11, 1989, p. 91; J.M. Małecki, *Stan i potrzeby badań nad dziejami nowożytnego Elbląga (1466–1772)*, "Rocznik Elbląski" t. 11, 1989, pp. 77–79, 84; M. Biskup, *Potrzeby historiograficzne Elbląga i jego regionu*, "Rocznik Elbląski" R. 1, 1961, p. 26; S. Gierszewski, *Śródlądowa żegluga Elbląga w latach 1761–1820. Sezony żeglugi i przerwa zimowa*, "Zapiski Historyczne" 1955, t. 21, z. 3–4, p. 45.

2 S. Kazusek, *Spław wiślany w drugiej połowie XVIII (do 1772 roku)*, cz. 1: *Charakterystyka spławu wiślanego*, Kielce 2022, pp. 80, 81; Z. Mikulski, *Zarys historii hydrologii na ziemiach polskich*, in: A.K. Biswas, *Historia hydrologii*, Warszawa 1978, pp. 320, 321; *idem*, *O najstarszych systematycznych obserwacjach wodowskazowych na ziemiach polskich*, "Przegląd Geofizyczny" R. 10, 1965, z. 2, pp. 153, 154.

3 W. Kolberg, *Wisła, jej bieg, własności i spławność*, cz. 2, Warszawa 1861, pp. 39–213, 252–254. From this period we have surviving reports on the waterway connection between the Nogat and the port of Elbląg, as well as on the weather conditions in the region; see. R. Marcinek, *Pamiętnik Karola Glogera z pobytu na Żuławach w r. 1831*, "Rocznik Elbląski" t. 3, 1965, pp. 266, 267, 269, 271.

4 J. Makowski, A. Tomczak, *Stany wody Wisły w Toruniu w świetle pomiarów z ostatnich dwóch stuleci*, Toruń 2002, *passim*.

the Kingdom of Poland[5] and there was no shortage of ideas in the country for exploiting the potential of navigable rivers[6].

Why are the water level characteristics of the Nogat so important? Of the two larger towns, Malbork and Elbląg, which were economically dependent on the Nogat River, the latter's importance on the economic map went far beyond the region. The problem was that its potential was not fully exploited due to political and economic processes and events, as well as environmental changes. The location of the port of Elbląg on the Elbląg River, a few kilometres from the Nogat River, to which the town was connected by the Bielnicki Canal, as well as the constant changes in the bed of the Nogat, the Elbląg River and the Vistula Lagoon's roadstead, forced the navigators to use a shallow waterway. These issues have been discussed too well in the literature to be reiterated here[7]. Throughout the feudal period, also after the First Partition, attempts were made to remedy the situation by carrying out dredging and hydrotechnical works on the Nogat River,

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5 A. Groth, *Handel*, in: *Historia Elbląga*, t. 3, cz. 1: *(1772–1850)*, red. A. Groth, Gdańsk 2000, p. 46; K. Wajda, *Handel i komunikacja*, in: *ibidem*, p. 134, 135; S. Gierszewski, *Elbląg. Przeszłość i teraźniejszość*, wyd. 3, Gdańsk 1988, pp. 163–165; B. Grochulska, *Handel zagraniczny Księstwa Warszawskiego. Z badań nad strukturą gospodarczą*, Warszawa 1967, pp. 115, 184, 185, 215, 233, 235, 240, 241, 243, 250, 251; A. Jezierski, *Handel zagraniczny Królestwa Polskiego 1815–1914*, Warszawa 1967, pp. 23, 33, 36, 37, 45, 49, 53, 54–58, 61; S. Gierszewski, *Życie portowe Elbląga w XVII i XVIII w.*, in: *Szkice z dziejów Pomorza*, t. 2, red. G. Labuda, S. Hoszowski, Warszawa 1959, pp. 318, 319; *idem*, *Statystyka handlu zbożowego Elbląga w latach 1642–1795*, "Zapiski Historyczne" 1957, t. 23, nr 1–3, pp. 171–174; S. Hoszowski, *Polski eksport wiślany w 1784 r.*, "Kwartalnik Historyczny" R. 63, 1956, nr 4–5, p. 70; *idem*, *Z dziejów handlu zbożowego w Toruniu 1760–1860*, "Roczniki Dziejów Społecznych i Gospodarczych" R. 11, 1949, pp. 72, 73, 87; C. Strzeszewski, *Handel zagraniczny Królestwa Polskiego (1815–1830)*, Lublin 1937, pp. 28, 45, 49, 52, 68, 69, 150; Z. Pietkiewicz, *Drogi wodne w Królestwie Polskim i ich znaczenie gospodarcze*, Warszawa 1914, pp. 2, 17, 18. It should be added that the reality of the supply of goods from the Polish economic hinterland of the Elbląg port deteriorated due to the change in the political situation after 1806 and after the Tsar introduced high tariffs on the border with the Prussian partition in 1821; S. Gierszewski, *Elbląg. Przeszłość*, p. 165.

6 K. Karczyński, *Żegluga śródlądowa w Królestwie Polskim (1815–1830) a polityka gospodarcza ministra skarbu, księcia Franciszka Ksawerego Druckiego-Lubeckiego*, "Progress. Journal of Young Researchers" No 3, 2018, pp. 13–23.

7 It is only worth mentioning that the line of the then Nogat Delta (the Vistula Lagoon's shoreline), which was subject to constant changes every year, was more than 2.5 km away from the present one at the beginning of the 19th century, while in the second half of the 18th century it was more than 4 km away; J. Szeliga, *Zagadnienie zmian linii brzegowej Zalewu Wiślanego w świetle wybranych map XVI–XIX wieku*, "Rocznik Elbląski" t. 5, 1972, pp. 83, 84. Also see: L. Koppin, *Karte von der Weichsel Niederung welche die Danziger, Elbinger und Marienburger Werder enthält*, Elbing 1811.

the Bielnicki Canal, the Elbląg River and the Vistula Lagoon approach. Failure to carry out these works meant that the waterway was obstructed. At the end of the 18th century, ships with a draught of 4–4.5 metres could enter the port of Elbląg via the Elbląg River, while it was difficult for boats, which were used as trasshipment vessels and carrying maximum of 20 lasts of grain, to enter the port[8]. If we add to this the law in force in the port of Elbląg concerning the winter break in shipping and the observation of ice phenomena, we can see that the hydrological situation on the Nogat River also largely determined the rhythm of life in Malbork, but especially in Elbląg, which functioned in the shadow of Gdańsk and had brief periods of splendour in its history, especially after 1772, but later, more difficult years for the town followed and led to the decline in its trade[9].

The surviving sources for the study of the conditions of navigation on the Nogat River in the Malbork area were collected in four volumes and allow the analysis of some elements of the phenomenon for almost the entire 19th century. As the publication of research results based on the entire preserved source material requires a more extensive study, only the documentation from the years 1811–1828 (from the first volume) is used here[10]. That is the period before the great flood on the Lower Vistula in 1829 and the subsequent outbreak of the November Uprising, after which the prospects for navigable trade from the Polish lands changed. The caesura is marked by the moment when the measurement of the water level of the Nogat River in Malbork began. Another issue is the existence of identical documentation with data for the Mątowy profile on the Nogat, which is the subject of separate studies.

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8 S. Gierszewski, *Życie portowe*, pp. 338–342. Last of for example wheat – 2400 kg, rye – 2190 kg, oat – 1440 kg.

9 A. Groth, *Port i żegluga*, in: *Historia Elbląga*, p. 38; A. Groth, *Handel*, pp. 47–51; K. Wajda, *Handel i komunikacja*, pp. 136, 139–141; A. Groth, *Kilka uwag o pierwszych latach panowania pruskiego w Elblągu*, "Rocznik Elbląski" t. 26, 2015, pp. 40–42; *idem*, *Handel morski Elbląga w latach 1772–1815*, "Rocznik Gdański" t. 62, 2002, z. 1–2, pp. 15–24; S. Gierszewski, *Elbląg. Przeszłość*, pp. 164, 165; J.M. Małecki, *Związki handlowe miast polskich z Elblągiem w XVI i pierwszej połowie XVII wieku*, "Rocznik Elbląski" t. 5, 1972, p. 129. A forthcoming crisis in Elblag's trade at the beginning of the 19th century was signalled by the declining number of merchants and the low number of sea and coastal skippers among the citizens with voting rights according to the censuses of 1808 and 1821; M. Nadolska, *Obywatele miasta Elbląga w latach 1808–1821*, "Rocznik Elbląski" t. 19, 2004, pp. 78–81, 86–89. See: B. Łukomska, *Ludność Elbląga w latach 1815–1830 w świetle ksiąg kościelnych*, "Rocznik Elbląski" t. 23, 2012, pp. 117–119, 123, 128; A. Groth, *Ludność Elbląga w latach 1772–1815*, "Rocznik Elbląski" t. 21, 2008, pp. 87, 91.

10 Archiwum Państwowe w Gdańsku (further: APG), Naczelne Prezydium Prowincji Prus Zachodnich w Gdańsku, sygn. 7/425.

The documentation supporting these considerations consists of monthly summaries of data from daily observations of water levels (generally measurements taken once a day[11]), wind resources (once-daily measurements of winds from the 1st and 2nd direction categories) and recorded weather and hydrological phenomena (rain and snowfall, ice phenomena on the river, including ice drift, coastal ice, shuga, ice floe and solid ice). Each of these phenomena was recorded on a printed form which was divided into columns with headings. The first column recorded the name of the month, the second the consecutive days of the month, the third and fourth the water level in feet and inches[12], the fifth the direction of the blowing wind (given by full name in the first years, and by abbreviation in later years), the sixth the type of precipitation or lack thereof, the seventh the ice phenomena, and the last was dedicated to annotations. Above the head of the table was a line in which the name of the water profile and the year were entered. Prepared that way, the monthly reports were then checked and initialled in bimonthly cycles. It should be further added that in later decades the method of collecting data and the range of information on weather conditions in the Malbork area changed somewhat.

The above mentioned source material has already been the subject of more general considerations[13]. It is a fragment of the documentation that once existed and was collected in connection with measurements of water levels on the Nogat and the Vistula downstream. In the first half of the 19th century such observations were carried out, among others, on the Nogat at Malbork, on the Nogat and the Vistula in the area of Szpica Mątowska, on the Vistula at Tczew and on the Vistula near the Gdańsk Head[14].

The purpose of this publication is to characterise the water levels calculated according to modern units of measurement on the basis of the above-mentioned documentation. It also contains hydrographs of the daily water levels, a discussion of the ice phenomena on the river, estimation of the duration of the navigation season, and finally, a characterisation of the historical wind resources, which in combination make it possible to reconstruct the navigation conditions on

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11 In extremely exceptional situations, between 3 December and 1 April of the study period (1811–1828), due to the accumulation of ice on the Nogat, extra measurements were taken in addition to the morning ones, at noon, in the afternoon or in the evening, including twice at 10 p.m. A total of 23 additional measurements were recorded throughout the study period.

12 1 foot (12 inches) = 0,31385 m.

13 S. Kazusek, *Spław wiślany*, pp. 117, 119.

14 At this point the water was divided into the Gdańsk Vistula and the Królewiec Vistula.

the Nogat in the Malbork area. The presented data can be successfully used for comparative studies of the hydrological conditions prevailing in the lower Vistula region, as the values of the water levels of the Nogat and the lower Vistula were characterised by a very strong correlation in the period under study. They can also be used to supplement studies carried out by hydrologists, climatologists and climate historians in connection with the seasonality of maritime and inland navigation in Elbląg in the years 1761–1820[15].

Historical Water Levels Of The Nogat

The water distribution of the Vistula and Nogat rivers in the area of the Mątowski Promontory has been subject to constant natural changes over the centuries and only partly stimulated by man. In 1830, about 66% of the water carried by the Vistula flowed into the Leniwka riverbed, and about 33% into the Nogat riverbed. As a result of further regulation works, especially in the years 1847–1853, this ratio changed so that in 1855 75% of the water flowed into the Leniwka and 25% into the Nogat[16]. In 1914, this hydrographic

[15] J. Cyberski et al., *History of Floods on the River Vistula*, "Hydrological Sciences Journal des Sciences Hydrologiques" vol. 51(5), 2006, p. 808, chart 5; S. Gierszewski, *Śródlądowa żegluga*, pp. 45–62.

[16] APG, Kolekcja gdańskich planów i map, sygn. 300, MP/327; sygn. 300, MP/383; sygn. 300, MP/539; sygn. 300, MP/851; sygn. 300, MP/976; sygn. 300, MP/1184; sygn. 300, MP/1201; *ibidem*, Kolekcja elbląskich planów i map, sygn. 1151/1; sygn. 1151/2; sygn. 1151/3; sygn. 1151/369; sygn. 1151/375; sygn. 1151/386; sygn. 1151/392; sygn. 1151/393; sygn. 1151/394; sygn. 1151/397; sygn. 1151/399; sygn. 1151/400; sygn. 1151/401; sygn. 1151/402; sygn. 1151/411; sygn. 1151/441; sygn. 1151/759; sygn. 1151/760; *ibidem*, Kolekcja pomorskich planów i map, sygn. 1126/379; sygn. 1126/380; sygn. 1126/454; sygn. 1126/464; sygn. 1126/466; sygn. 1126/468; sygn. 1126/578; sygn. 1126/579; S. Kazusek, *Spław wiślany*, pp. 54–59, 116–119; W. Długokęcki, *Zmiany koryta Wisły i Nogatu pod Białą Górą od XIII do pierwszej połowy XVI w. Przyczynek do historii*, "Rocznik Gdański" t. 53, 1993, z. 2, pp. 28–39; M. Pelczar, *Obszar doliny dolnej Wisły na mapach*, in: *Dolina dolnej Wisły*, red. B. Augustowski, Wrocław–Warszawa–Kraków 1982, pp. 10–14; J. Szeliga, *Rozwój kartografii Wybrzeża Gdańskiego do 1772 roku*, Wrocław–Warszawa–Kraków 1982, pp. 108–114; J. Cyberski, Z. Mikulski, *Stosunki hydrologiczne Żuław*, in: *Żuławy Wiślane*, red. B. Augustowski, Gdańsk 1976, pp. 242–244; M. Pelczar, *Dzieje zmian koryta Wisły i Nogatu pod Białą Górą w okresie od XV do XIX wieku*, "Zeszyty Geograficzne Wyższej Szkoły Pedagogicznej w Gdańsku" R. 8, 1966, pp. 226–233; R. Ingarden, *Rzeki i kanały żeglowne w b. trzech zaborach i znaczenie ich gospodarcze dla Polski*, Kraków 1921, pp. 127,

junction was finally tamed by the construction of a sluice at the entrance of the Nogat. Until then, the river's current and water levels depended largely on the whims of nature. Although the gradient of the Nogat riverbed was only about 0.1%[17], sedimentation processes took place constantly. At the beginning of the 19th century, there were numerous mesoforms. Just on the way between the Mątowska Szpica and the Bielnicki Canal on Koppin's map of 1811, as well as on Friedrich Leopold Schroetter's and Friedrich Bernhard Engelhardt's maps of 1802–1812, there are more than 30 islands, shoals or tufts of various sizes, not to mention shallows and side banks[18]. The whole landscape, especially the water levels, determined the possibility of navigating.

It is known from previous studies that the average annual fluctuation of the Vistula water levels in the Mątowski Promontory area (based on data from 1951–1975) was almost 6 m, with a maximum of 10 m[19]. On the basis of the data from 1811–1828, it can be concluded that the average fluctuation of water levels in the Nogat at Malbork was 4.26 m. The mean of the minima from that period was 1.24 m, while the mean of the maxima was 5.50 m. The widest range of water level fluctuations occurred in 1814 and amounted to 6.9 m. Fluctuations of more than 5 m also occurred in 1813, 1816, 1822 and 1827. The smallest annual flactuations of less than 3 m occurred in 1823 and 1826 (Table 1).

Leaving aside the explanation of the terms 'low tide', 'surge' and 'flood' in hydrological terminology, it should be noted that they are related to low surface water levels, depletion of water resources in the basin, prolonged lack of precipitation, high temperatures and evaporation, the phenomenon of hydrological drought on the one hand, and excessive recharge on the other[20]. From the findings so far, it is known that floods on the Nogat occurred in the area of its confluence

128; H. Bindemann, *Die Abzweigung der Nogat von der Weichsel*, in: *Abhandlungen zur Landeskunde der Provinz Westpreussen*, H. 12, Danzig 1903, pp. 38–69; M. Toeppen, *Beiträge zur Geschichte des Weichseldeltas*, in: *Abhandlungen zur Landeskunde der Provinz Westpreussen*, H. 8, Danzig 1894, pp. 5–6, 119; F. Neumann, *Bemerkungen über früheren Verhältnisse der Nogat*, Elbląg 1855, pp. 1–26.

17 S. Srokowski, *Prusy Wschodnie. Studium geograficzne, gospodarcze i społeczne*, Gdańsk–Bydgoszcz–Toruń 1945, p. 27.

18 L. Koppin, *Karte von der Weichsel; F.L. Schroetter, F.B. Engelhardt, Karte von Ost-Preussen nebst preussisch Litthauen und West-Preussen nebst dem Netzdistrict […]*, Berlin 1802–1812. Also see the map of Friedrich Bernhard Engelhardt; F.B. Engelhardt, *Karte von Ost--Preussen, Litthauen, West-Preussen und dem Netz-Distrikte […]*, Berlin 1819.

19 J. Cyberski, *Charakterystyka hydrologiczna*, in: *Dolina dolnej Wisły*, p. 112.

20 Z. Mikulski, *Zarys hydrografii Polski*, Warszawa 1965, pp. 156, 163.

with the Vistula Lagoon in December-January, and on the upper reaches of the river in March. Low water on the Nogat occurred in July-September, and on the lower Vistula in May-July and November-December[21]. The summer peaks and floods shown below were the result of heavy rainfall. The winter peaks were caused by rapid snowmelt. Significant water surges in the winter hydrological season were caused by ice drift or by the blockage of the river cross-section by shuga[22]. The high water levels recorded in Malbork were not caused by the damming up of water in the Vistula Lagoon as a result of the storm, although it should be added that the storm and strong north and north-easterly winds had an effect on raising the water levels of the Nogat and Elbląg Rivers at the mouth of the Vistula Lagoon.

What were the water levels of the River Nogat in the Malbork area between 1811 and 1828? From the overall visualised data of the daily records, it is clear that extremely high water levels occurred in the first months of the calendar year and much less frequently in the second half of the year. The minimum and maximum water levels were characterised by a significant range and varied greatly across all seasons (Table 1 and 4). The difference between these extremes during the study period reached a minimum of 173 cm on 27–29 April and a maximum of 594 and 591 cm on 4–5 September, respectively. High water levels on the Nogat usually occurred between December and April (Table 2). Extremely high water levels, exceeding seven metres, occurred on 3 April 1814 (785 cm) and on 20 March 1816 (764 cm). In addition, water levels exceeding six metres were recorded on thirteen occasions. Those occurred in September 1813, April 1814, March 1815, 1816 and 1821, January and February 1822, March 1827, and December 1828 (Table 1)[23]. The water levels above 2.5 m highlighted in Table 2 confirm the above conclusions.

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21 I. Dynowska, *Typy reżimów rzecznych w Polsce*, Kraków 1972, p. 19; Z. Mikulski, *Zarys hydrografii*, p. 159.

22 I. Dynowska, *Typy reżimów*, pp. 17, 18.

23 On extreme water levels in the lower Vistula up to the mid-19th century see: R. Kubus, *Gwałtowne zjawiska pogodowe oraz klęski żywiołowe na Żuławach i Mierzei w świetle kroniki kościoła ewangelickiego w Drewnicy (XVII–XVIII w.)*, in: *Ekologia w Prusach Królewskich*, ed. W. Zawadzki, Pelplin 2022, pp. 257–284; S. Kazusek, *Spław wiślany*, pp. 78–85, 91–106; P. Oliński, *Wylewy w dolnym biegu Wisły w okresie nowożytnym*, "Rocznik Elbląski" t. 29, 2019, pp. 77–87; *idem*, *Wylewy Wisły w ziemi chełmińskiej w XV–XVIII w. w świetle źródeł narracyjnych*, in: *Město a voda. Praha, město u vody. Sborník příspěvků z 22. vědecké konference Archivu hlavního města Prahy, uspořádané ve spoluprácis Institutem mezinárodních studií Fakulty sociálních věd Univerzity Karlovy ve dnech 7. a 8. října 2003*

Table 1. Elements of the descriptive statistics of the Nogat water levels in Malbork in the years 1811–1828 (in cm)

Elements of descriptive statistics	Year																	
	1811	1812	1813	1814	1815	1816	1817	1818	1819	1820	1821	1822	1823	1824	1825	1826	1827	1828
Average	122	199	234	220	232	313	291	239	230	257	286	205	191	220	226	213	210	236
Median	85	178	230	175	214	318	298	188	220	259	275	152	180	208	207	204	186	217
Range	345	314	534	690	471	569	382	429	358	381	442	573	271	322	314	262	553	456
Minimum	42	105	110	94	136	195	160	129	97	140	162	105	111	131	141	133	93	148
Maximum	387	418	643	785	607	764	541	558	455	520	604	677	382	452	455	395	646	604

Table 2. Average monthly water levels of the Nogat River in Malbork in the years 1811–1828 (in cm)

Month	Year																	
	1811	1812	1813	1814	1815	1816	1817	1818	1819	1820	1821	1822	1823	1824	1825	1826	1827	1828
January	215	139	219	305	202	372	389	372	228	272	436	357	172	240	249	242	297	205
February	193	135	201	401	191	350	389	437	189	327	395	354	163	264	334	210	306	212
March	260	228	298	343	300	408	406	373	255	293	361	297	277	248	349	237	405	276
April	183	258	200	444	268	333	323	287	362	369	330	285	252	292	249	305	326	300
May	133	218	165	218	204	334	335	223	278	229	202	225	226	219	258	293	214	196
June	82	140	143	186	151	244	298	167	203	189	187	140	250	220	204	210	181	167
July	69	145	186	158	211	296	199	192	179	198	297	111	232	283	178	165	120	261
August	52	282	181	150	256	249	219	167	203	176	259	138	162	191	206	234	118	193
September	46	186	426	117	219	242	219	173	203	167	214	138	132	151	161	161	121	247
October	63	177	264	99	197	297	171	163	156	267	294	139	117	144	144	140	96	233
November	82	205	253	103	205	284	168	144	235	262	201	130	119	175	185	150	130	221
December	87	276	274	132	376	351	382	185	269	343	261	152	186	209	201	210	214	318

* Light grey colour indicates minimum average water levels (less than 1 m), dark grey colour indicates maximum average water levels (at least 2.5 m).

Floods caused by intense rainfall occurred on several occasions during the study period (Tables 5–10). Of particular note is the flood at the turn of August and September 1813, which occurred first on the upper and then on the lower Vistula and, according to observations, also reached the waters of the Nogat. It was the result of heavy rainfall, which also occurred in Lesser Poland, Podhale and the Carpathians. The flood peaked in Cracow on 26 August, when the water level reached 4.95 cm (according to the scale of the 1925 water gauge). In Warsaw, the culmination reached 6.05 m on 30 August, 6.09 m in Toruń on 1 September, and 6.43 m in Tczew on 4 September[24]. On the Nogat, near Mątowska Szpica, the culminating wave reached the height of 6.36 metres on 4 September, while in Malbork the water level on the same day peaked to 6.43 metres. The 1813 flood proved to be the largest on the upper Vistula. It should be added that the largest flood on the middle Vistula took place in 1844. On 27 July, the gauge in Warsaw read 8.55 metres[25]. It is worth noting that the strong swells recorded at Malbork in March 1814 and 1827 were also recorded on the Vistula in Warsaw[26]. The data presented for the years 1811–1828 show that the last violent flood began at the end of December 1828 (Chart 10). In the early spring of 1829 there was a flood on the Vistula at Żuławy and Gdańsk. It was caused by heavy rainfall, severe frost and melting ice, which began in mid-March 1829, followed by the accumulation of water under an ice blockage and

v Clam-Gallasově paláci v Praze, ed. O. Fejtova, V. Ledvinka, J. Pešek, Praha 2005, pp. 95–109; M. Józefczyk, W. Długokęcki, *Opis przerwania wału wiślanego koło Mątów Wielkich w 1786 roku*, "Rocznik Elbląski" t. 16, 1998, pp. 95–98; A. Majewski, *Kronika powodzi w delcie Wisły*, in: *Uwarunkowania przyrodnicze i społeczno-ekonomiczne zagospodarowania dolnej Wisły*, red. Z. Churski, Toruń 1993, pp. 13–28.

24 *Wyjątki ze źródeł historycznych o nadzwyczajnych zjawiskach hydrologicznych i meteorologicznych na ziemiach polskich w latach 1601–1920*, oprac. R. Girguś, Warszawa 2022, No 850, 852; J. Szewczuk, *Kronika klęsk elementarnych w Galicji w latach 1772–1848*, Lwów 1939, pp. 84*, 56 (No 332). Por. J. Makowski, A. Tomczak, *Stany wody*, p. 9; L. Wolski, *Rys hydrografii Królestwa Polskiego z wiadomością o spławach*, "Biblioteka Warszawska" 1849, t. 2, p. 242.

25 K. Dębski, *Charakterystyka hydrologiczna Polski*, Łódź–Warszawa 1961, p. 53; Z. Mikulski, *Katastrofalne powodzie w Polsce*, "Czasopismo Geograficzne" 1954, t. 25, z. 4, pp. 383–385, 392. See: J. Makowski, A. Tomczak, *Stany wody*, p. 10. See also: A. Izdebski, K. Wnęk, *Historia klimatu Krakowa*, in: *Ekobiografia Krakowa*, red. A. Izdebski, R. Szmytka, Kraków 2018, pp. 62, 63; B. Pawłowski, M. Gorączko, *Z badań nad znakami powodziowymi w dolinie Wisły*, "Gospodarka Wodna" 2014, nr 2, p. 60; L. Opyrchał, U. Opyrchał, A. Bąk, *Tablice powodziowe na terenie Krakowa*, "Gospodarka Wodna" 2018, nr 7, pp. 213–217; P. Kuźniar, *Historia powodzi w dolinie Wisły Środkowej*, in: *Powódź w regionie Małopolskiego Przełomu Wisły w lipcu 2001*, Warszawa 2002, pp. 17, 18.

26 L. Wolski, *Rys hydrografii*, t. 2, p. 242.

the overflowing of the crest of the dikes below Tczew. On 9 April the floods inundated Gdańsk[27].

Low water levels on the Nogat were most frequent in the period from the beginning of June to the end of November (Chart 2). Monthly average of water levels not exceeding 1 m were calculated for the period from June to December 1811 and for the months of October 1814 and 1827 (Table 2, Chart 4). Exceptionally low water levels of the Nogat, not exceeding 0.5 m, occurred between August and October 1811. The lowest recorded level of only 42 cm was recorded from 20 September to 3 October 1811. The low levels observed on the Nogat in 1827 coincide with the period of low levels on the Vistula in that year[28]. Considering all water level data globally, and taking into account the small number of days with low water levels, it can be concluded that the Nogat in the Malbork area generally had relatively good hydrological conditions for inland navigation (Chart 3).

In order to determine the duration of favourable for navigation water levels, it is necessary to analyse ice phenomena. Contemporary research on the lower Vistula in the post-war period shows that the ice in the Vistula delta disappeared in the period from the end of February to the beginning of the second decade of March[29]. What conclusions can be drawn from the analysis of the data on ice phenomena on the River Nogat in the Malbork area in the years 1811–1828? The following details show that ice phenomena were observed over a very long period, depending on the season (Table 3). The first reports on the occurrence of shuga, ice or coastal ice come from the beginning of November (winter 1814/1815), more often from the second half of November or December. Seasons in which the first information on ice did not come until early January (winter 1824/1825) should be considered as exceptional. The process of the river becoming free of ice seldom began in the period from mid-February, more often in March and very rarely in early April (winter 1813/1814). The period between the first and last observation of

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27 A. Majewski, *Znaki wielkiej wody w Gdańsku i na obszarze Żuław Wiślanych*, "Przegląd Geofizyczny" R. 15, 1970, z. 1, p. 85.

28 Z. Mikulski, *Zarys hydrografii*, p. 162.

29 The longest-lasting ice phenomena in Toruń and Tczew (years 1946–1970) occurred for an average of 82 and 72 days per season, with a maximum of 122 and 121 days, respectively. A study of ice phenomena on the Vistula in Tczew shows that in the period 1960–2014 they lasted from mid-November to early April. The minimum duration was 25 days, the maximum 92 days. According to Kazimierz Dębski, the Vistula did not freeze twice between 1822 and 1877; B. Pawłowski, *Przebieg zjawisk lodowych dolnej Wisły w latach 1960–2014*, Toruń 2017, pp. 155, 158, 159; J. Cyberski, *Charakterystyka hydrologiczna*, pp. 132, 133; Z. Mikulski, *Zarys hydrografii*, p. 192. Compare: K. Dębski, *Charakterystyka hydrologiczna*, pp. 135, 139.

Chart 1. Minimum and maximum water levels of the Nogat River in Malbork in the years 1811-1828

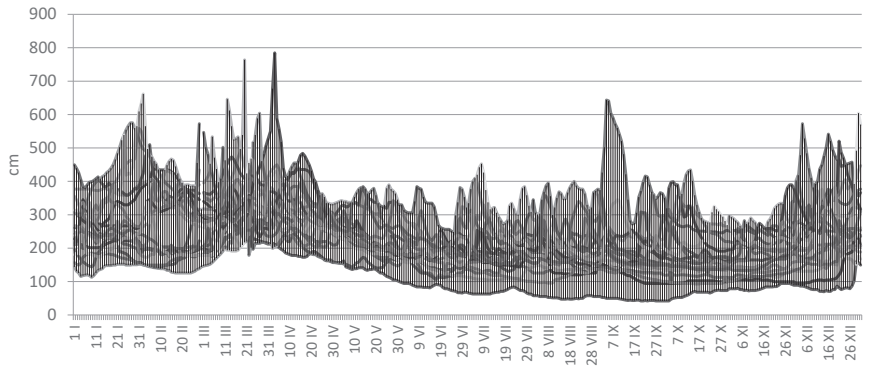
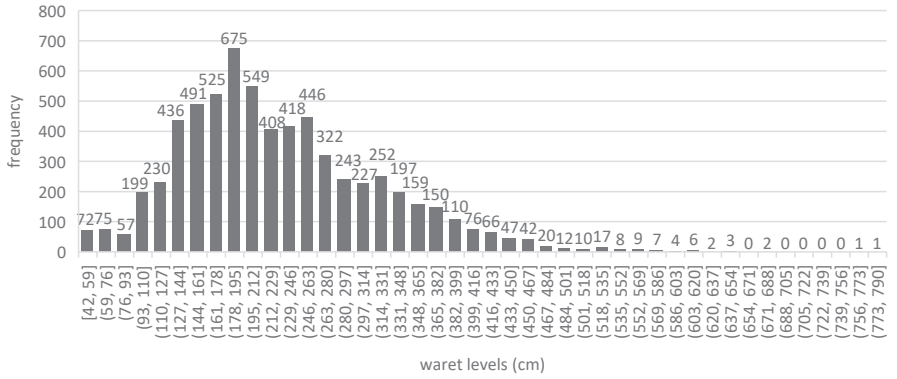


Chart 2. Arithmetic mean of water levels of the Nogat River in Malbork in the years 1811-1828

Chart 3. Frequency of appearance of water levels on the Nogat River in Malbork in the years 1811-1828



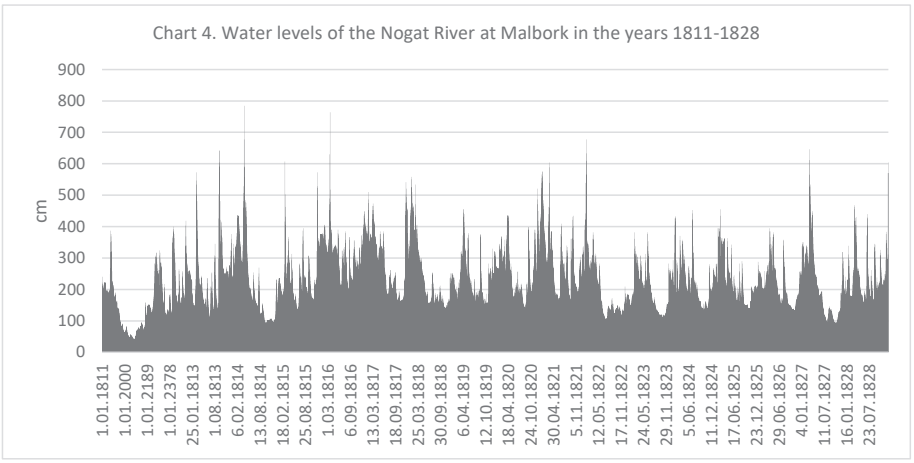


Chart 4. Water levels of the Nogat River at Malbork in the years 1811-1828
cm
900
800
700
600
500
400
300
200
100
0
1.01.1811
1.01.2000
1.01.2189
1.01.2378
25.01.1813
1.08.1813
6.02.1814
13.08.1814
18.02.1815
25.08.1815
1.03.1816
6.09.1816
13.03.1817
18.09.1817
25.03.1818
30.09.1818
6.04.1819
12.10.1819
18.04.1820
24.10.1820
30.04.1821
5.11.1821
12.05.1822
17.11.1822
24.05.1823
29.11.1823
5.06.1824
11.12.1824
17.06.1825
23.12.1825
29.06.1826
4.01.1827
11.07.1827
16.01.1828
23.07.1828

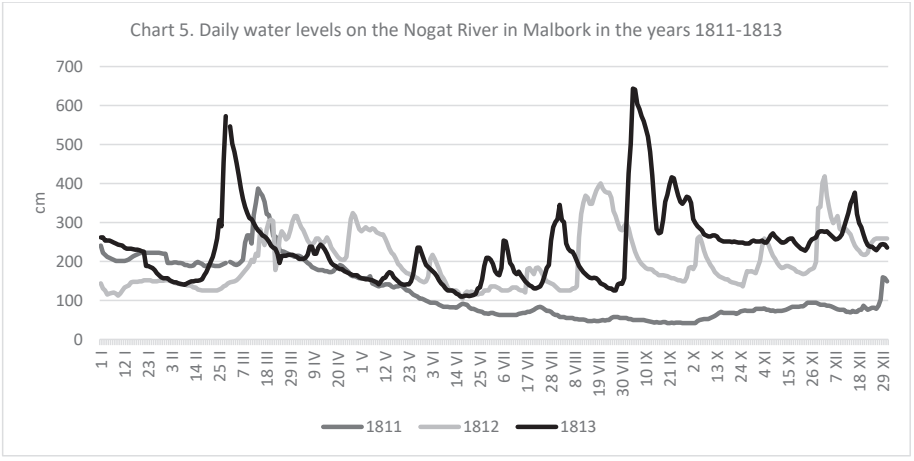


Chart 5. Daily water levels on the Nogat River in Malbork in the years 1811-1813
cm
700
600
500
400
300
200
100
0
1 I
12 I
23 I
3 II
14 II
25 II
7 III
18 III
29 III
9 IV
20 IV
1 V
12 V
23 V
3 VI
14 VI
25 VI
6 VII
17 VII
28 VII
8 VIII
19 VIII
30 VIII
10 IX
21 IX
2 X
13 X
24 X
4 XI
15 XI
26 XI
7 XII
18 XII
29 XII
1811
1812
1813

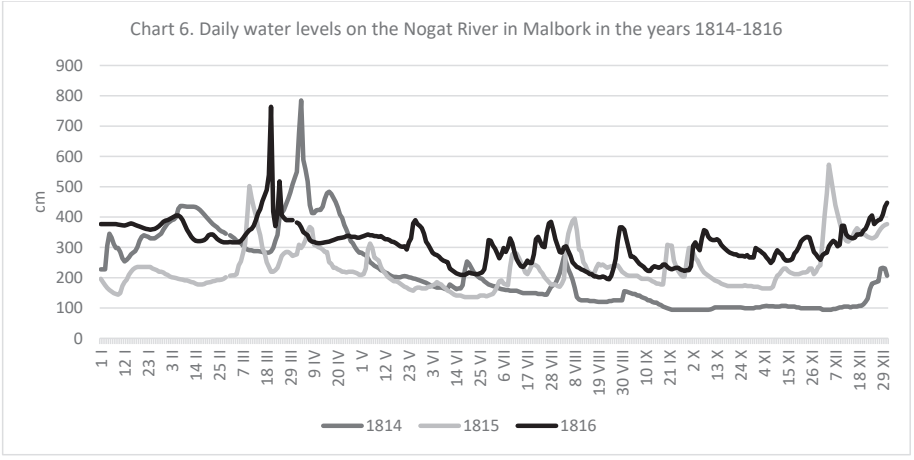


Chart 6. Daily water levels on the Nogat River in Malbork in the years 1814-1816
cm
900
800
700
600
500
400
300
200
100
0
1 I
12 I
23 I
3 II
14 II
25 II
7 III
18 III
29 III
9 IV
20 IV
1 V
12 V
23 V
3 VI
14 VI
25 VI
6 VII
17 VII
28 VII
8 VIII
19 VIII
30 VIII
10 IX
21 IX
2 X
13 X
24 X
4 XI
15 XI
26 XI
7 XII
18 XII
29 XII
1814
1815
1816

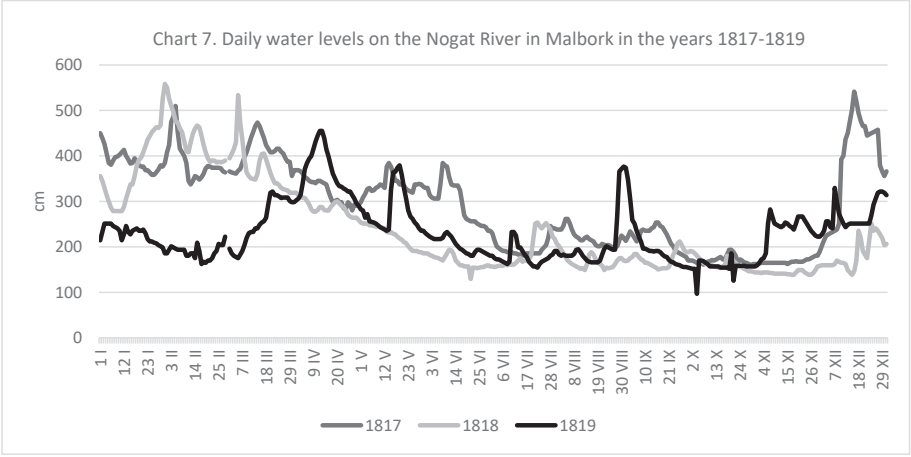


Chart 7. Daily water levels on the Nogat River in Malbork in the years 1817-1819
cm
600
500
400
300
200
100
0
1 I
12 I
23 I
3 II
14 II
25 II
7 III
18 III
29 III
9 IV
20 IV
1 V
12 V
23 V
3 VI
14 VI
25 VI
6 VII
17 VII
28 VII
8 VIII
19 VIII
30 VIII
10 IX
21 IX
2 X
13 X
24 X
4 XI
15 XI
26 XI
7 XII
18 XII
29 XII
1817
1818
1819

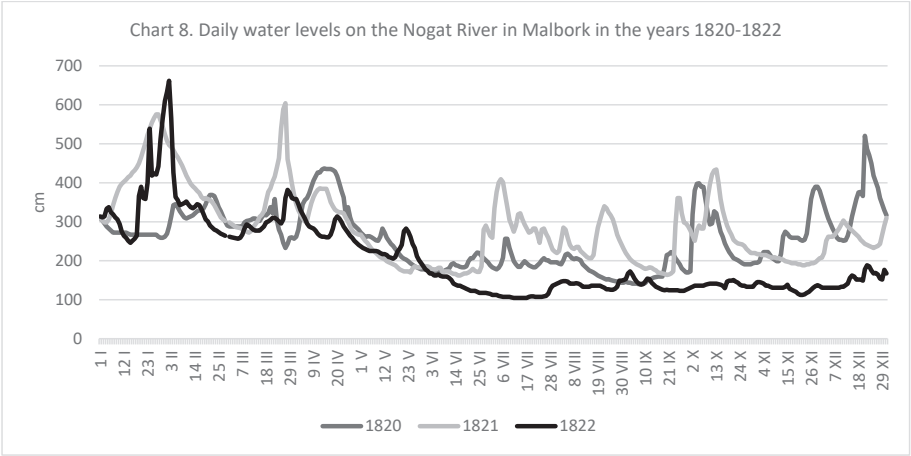


Chart 8. Daily water levels on the Nogat River in Malbork in the years 1820-1822
cm
700
600
500
400
300
200
100
0
1 I
12 I
23 I
3 II
14 II
25 II
7 III
18 III
29 III
9 IV
20 IV
1 V
12 V
23 V
3 VI
14 VI
25 VI
6 VII
17 VII
28 VII
8 VIII
19 VIII
30 VIII
10 IX
21 IX
2 X
13 X
24 X
4 XI
15 XI
26 XI
7 XII
18 XII
29 XII
1820
1821
1822

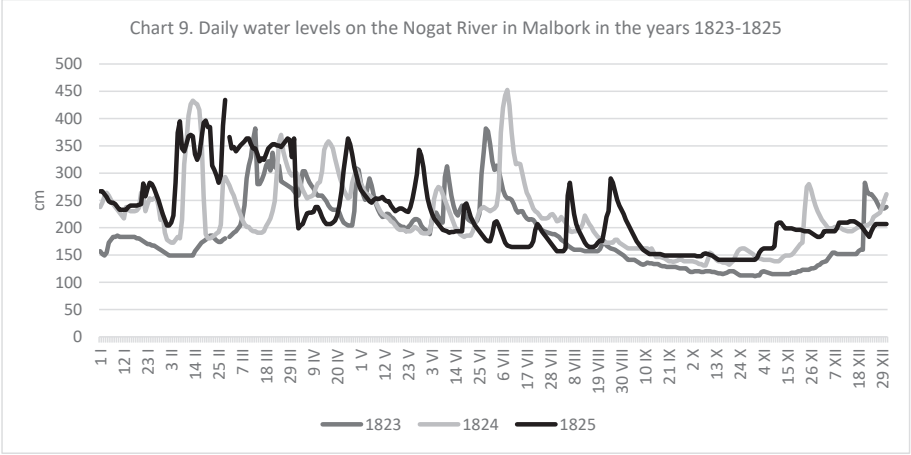
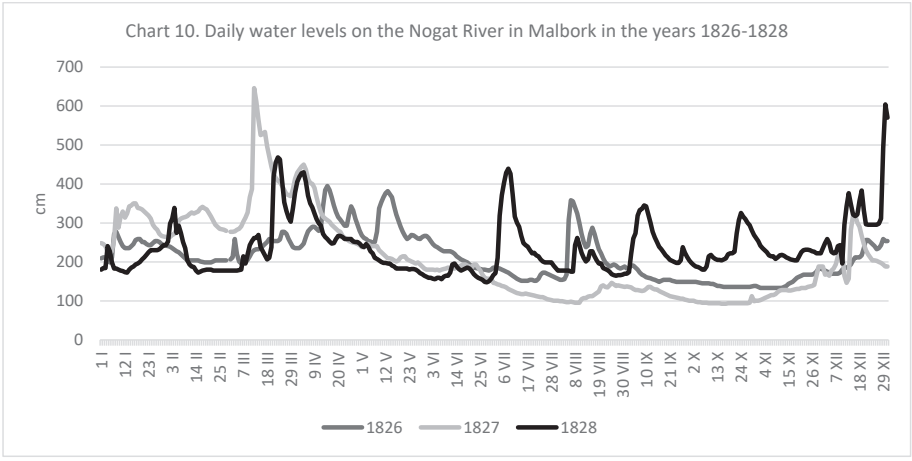


Chart 9. Daily water levels on the Nogat River in Malbork in the years 1823-1825
cm
500
450
400
350
300
250
200
150
100
50
0
1 I
12 I
23 I
3 II
14 II
25 II
7 III
18 III
29 III
9 IV
20 IV
1 V
12 V
23 V
3 VI
14 VI
25 VI
6 VII
17 VII
28 VII
8 VIII
19 VIII
30 VIII
10 IX
21 IX
2 X
13 X
24 X
4 XI
15 XI
26 XI
7 XII
18 XII
29 XII
1823
1824
1825



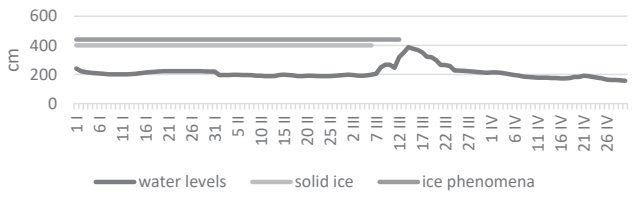
the ice phenomenon lasted from 63 to 130 days, depending on the season. It was often interrupted by thaws, longer periods of above zero temperatures and the disappearance of the ice phenomena. The ice cover stayed the shortest on the river in the winter of 1821/1822 (only 7 days), while the longest periods were recorded in the winters of 1815/1816 and 1819/1820 (107 and 105 days respectively). On average, the ice cover lasted 71.9 days over the seventeen full winter seasons studied. An important element of the data compiled is the detailed presentation of the relationship between the occurrence of ice phenomena, including coastal ice, shuga, ice floes and permanent ice, and water levels (Charts 11–29).

The data obtained on ice phenomena make it possible to determine the duration of the navigation season on the Nogat. Since in sailing practice, especially in local or even regional water transport, sailing in the late autumn and winter season was not unusual, for the purpose of calculating the sailing season, the period of one week before the first ice phenomena were seen and one week after they disappeared should be excluded. This isolated time should be reserved for sailing down the Nogat to the port of Elbląg (a distance of about 41.5 km), unloading and loading the ship, and then sailing back before the onset of more permanent frost. The one-week period after the ice had receded was the time for waiting for the flood-wave peak to go and making preparations for the voyage. On the basis of the criteria thus adopted, it may be concluded that the longest sailing season was 292 days (1824), the shortest 198 days (1814), while the average was just over 244 days (Table 4). Taking into account the occurrence of ice phenomena and the adopted criteria for measuring the length of the navigation season, it can be theoretically assumed that navigation on the Nogat could always take place between 14 April and 28 October. This time may have to be further reduced by the

number of days of heavy surges and very high water levels when navigation was suspended for safety reasons, which is difficult to determine. For comparison, the longest navigation season on the Vistula in the area of the Cracow agglomeration in the period 1674–1785 was 357 days[30].

Knowing the length of the navigation seasons and the calculated water levels, it is necessary to determine the navigability of the main vessels for which the draught is known, i.e. "berlinka" and "szkuta" (assuming an average value, i.e. 1 m), "dubas" (0.84 m) and "koza" (0.73 m)[31]. However, it must be stressed that the proportion of favourable time is limited by the relativity of the hydrological zero stressed by hydrologists[32], and should be treated tentatively. From the calculations it can be concluded that, among other things, ships with a draught of around 1 metre found it very difficult to navigate in 1811. For only 27.8 percent of the sailing season there were hydrological conditions suitable for them. The lack of navigability for the largest ships was most noticeable between the beginning of June and the end of the season. The largest ships may have encountered minor navigational difficulties in the last ten days of September and the first ten days of October in 1814 and 1827. For vessels with a smaller draught, the conditions on the Nogat were favourable, except in 1811 (Table 5).

Chart 11. Water levels and ice phenomena on the Nogat River in Malbork in the winter of 1810/1811*



* Only in 1811.

30 Compare: S. Kazusek, *Spław wiślany*, pp. 463–466.

31 A. Reszka, *Wiślane statki i techniki nawigacyjne od XVI do XX wieku*, Gdańsk 2012, pp. 64, 65, 96. "Berlinka" was a flat-bottomed sailing ship with a narrow hull and a probable deadweight of up to 60–100 tonnes, manned by a crew of 3 to 4 men. "Szkuta" is the largest sailing float, manned by 16–20 or even 22 rafters, with a capacity of up to about 50 lasts (about 100 tonnes). "Dubas" is a one- or two-masted floating vessel, manned by 8–16 rafters, with a capacity of up to about 24 tons. "Koza" is a small boat with a capacity of about 6–10 lasts, manned by 4–10 rafters.

32 A. Byczkowski, *Hydrologia*, t. 1, wyd. 2, Warszawa 1999, p. 34; J. Szturc, *Hydrologia stosowana w zarysie*, Bielsko-Biała 1995, p. 69; M. Ozga-Zielińska, J. Brzeziński, *Hydrologia stosowana*, Warszawa 1994, p. 242.

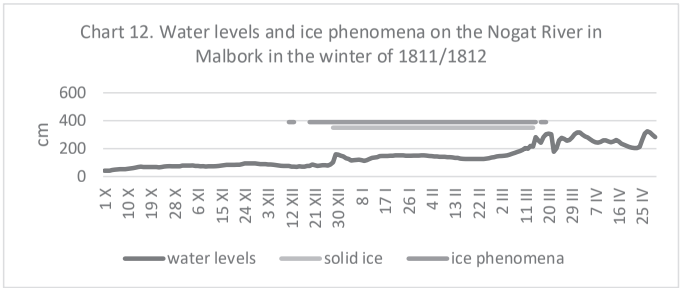


Chart 12. Water levels and ice phenomena on the Nogat River in Malbork in the winter of 1811/1812
cm
600
400
200
0
1 X
10 X
19 X
28 X
6 XI
15 XI
24 XI
3 XII
12 XII
21 XII
30 XII
8 I
17 I
26 I
4 II
13 II
22 II
2 III
11 III
20 III
29 III
7 IV
16 IV
25 IV
water levels
solid ice
ice phenomena

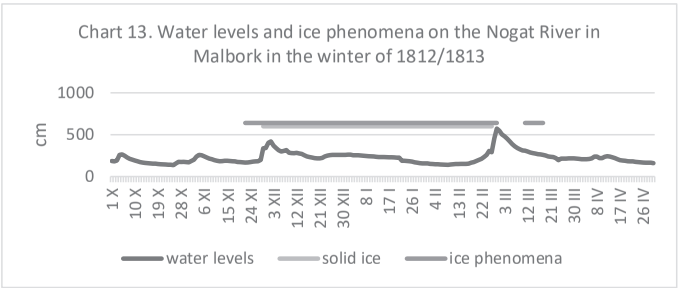


Chart 13. Water levels and ice phenomena on the Nogat River in Malbork in the winter of 1812/1813
cm
1000
500
0
1 X
10 X
19 X
28 X
6 XI
15 XI
24 XI
3 XII
12 XII
21 XII
30 XII
8 I
17 I
26 I
4 II
13 II
22 II
3 III
12 III
21 III
30 III
8 IV
17 IV
26 IV
water levels
solid ice
ice phenomena

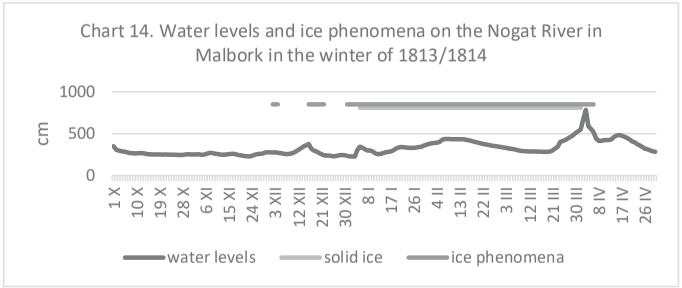


Chart 14. Water levels and ice phenomena on the Nogat River in Malbork in the winter of 1813/1814
cm
1000
500
0
1 X
10 X
19 X
28 X
6 XI
15 XI
24 XI
3 XII
12 XII
21 XII
30 XII
8 I
17 I
26 I
4 II
13 II
22 II
3 III
12 III
21 III
30 III
8 IV
17 IV
26 IV
water levels
solid ice
ice phenomena

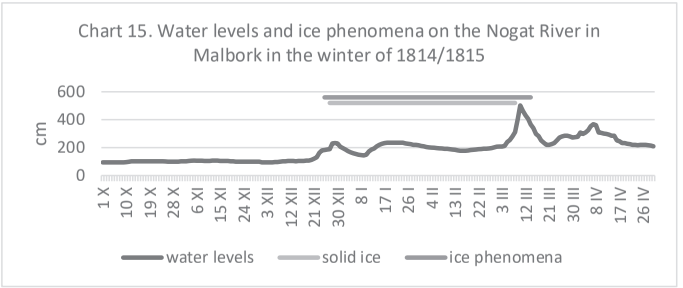


Chart 15. Water levels and ice phenomena on the Nogat River in Malbork in the winter of 1814/1815
cm
600
400
200
0
1 X
10 X
19 X
28 X
6 XI
15 XI
24 XI
3 XII
12 XII
21 XII
30 XII
8 I
17 I
26 I
4 II
13 II
22 II
3 III
12 III
21 III
30 III
8 IV
17 IV
26 IV
water levels
solid ice
ice phenomena

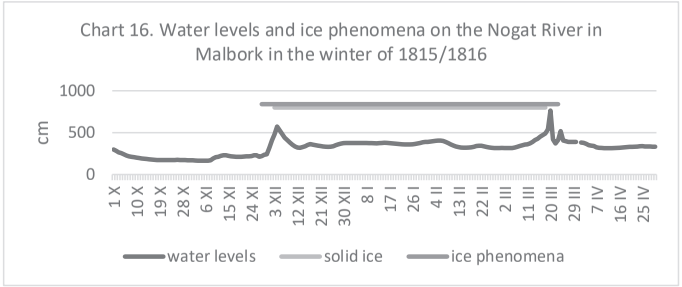


Chart 16. Water levels and ice phenomena on the Nogat River in Malbork in the winter of 1815/1816
cm
1000
500
0
1 X
10 X
19 X
28 X
6 XI
15 XI
24 XI
3 XII
12 XII
21 XII
30 XII
8 I
17 I
26 I
4 II
13 II
22 II
2 III
11 III
20 III
29 III
7 IV
16 IV
25 IV
water levels
solid ice
ice phenomena

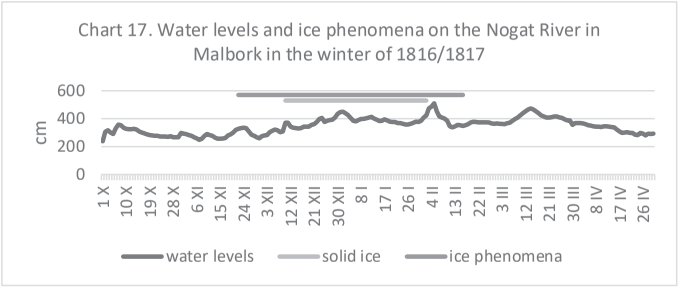


Chart 17. Water levels and ice phenomena on the Nogat River in Malbork in the winter of 1816/1817
cm
600
400
200
0
1 X
10 X
19 X
28 X
6 XI
15 XI
24 XI
3 XII
12 XII
21 XII
30 XII
8 I
17 I
26 I
4 II
13 II
22 II
3 III
12 III
21 III
30 III
8 IV
17 IV
26 IV
water levels
solid ice
ice phenomena

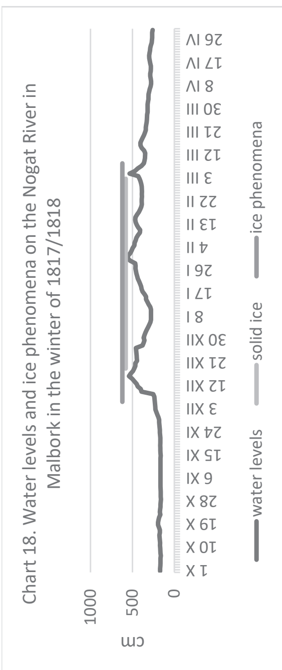


Chart 18. Water levels and ice phenomena on the Nogat River in Malbork in the winter of 1817/1818

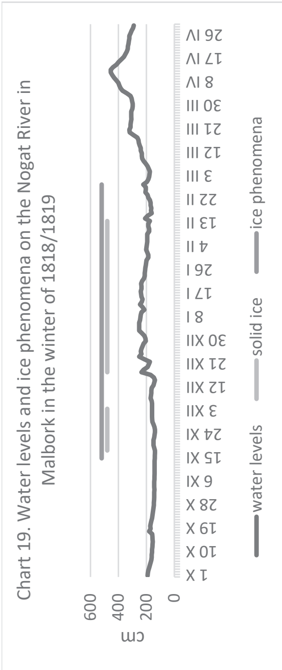


Chart 19. Water levels and ice phenomena on the Nogat River in Malbork in the winter of 1818/1819

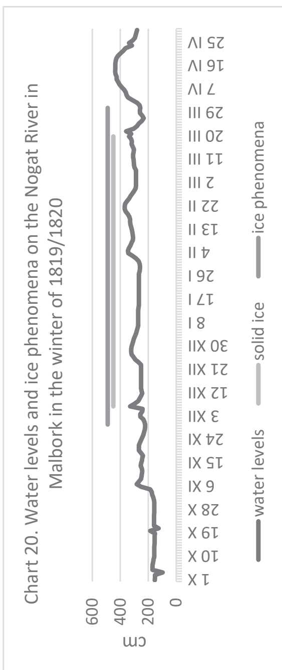


Chart 20. Water levels and ice phenomena on the Nogat River in Malbork in the winter of 1819/1820

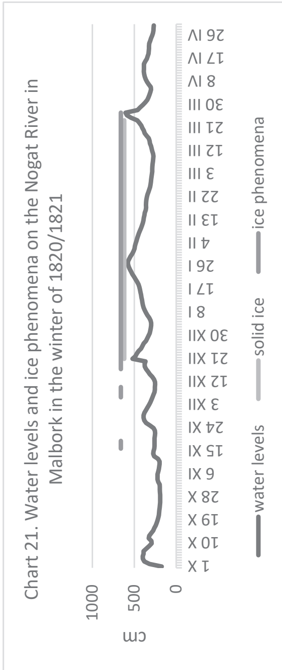


Chart 21. Water levels and ice phenomena on the Nogat River in Malbork in the winter of 1820/1821

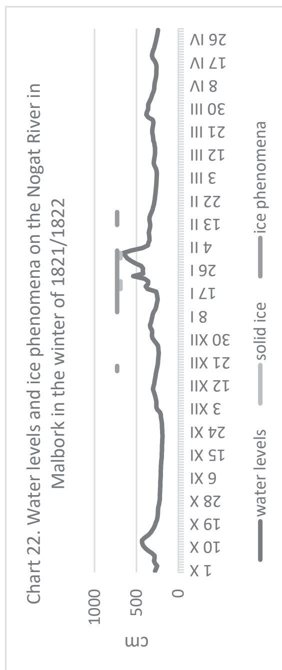


Chart 22. Water levels and ice phenomena on the Nogat River in Malbork in the winter of 1821/1822

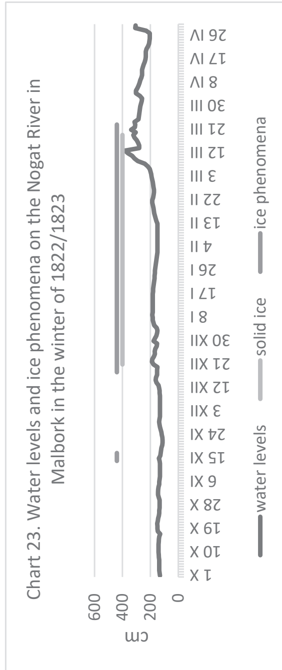


Chart 23. Water levels and ice phenomena on the Nogat River in Malbork in the winter of 1822/1823

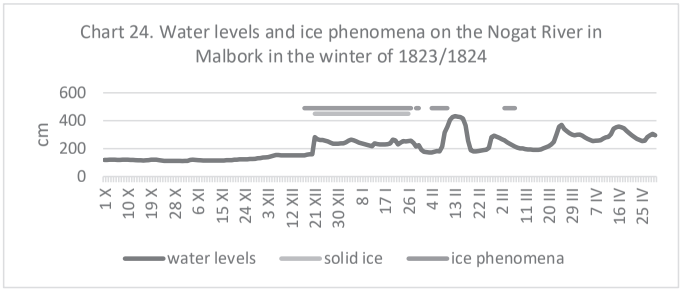


Chart 24. Water levels and ice phenomena on the Nogat River in Malbork in the winter of 1823/1824
cm
600
400
200
0
1 X
10 X
19 X
28 X
6 XI
15 XI
24 XI
3 XII
12 XII
21 XII
30 XII
8 I
17 I
26 I
4 II
13 II
22 II
2 III
11 III
20 III
29 III
7 IV
16 IV
25 IV
water levels
solid ice
ice phenomena

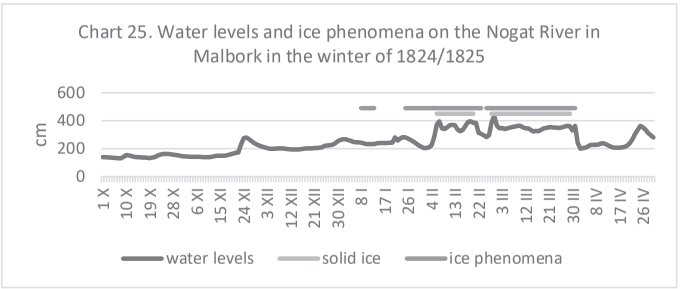


Chart 25. Water levels and ice phenomena on the Nogat River in Malbork in the winter of 1824/1825
cm
600
400
200
0
1 X
10 X
19 X
28 X
6 XI
15 XI
24 XI
3 XII
12 XII
21 XII
30 XII
8 I
17 I
26 I
4 II
13 II
22 II
3 III
12 III
21 III
30 III
8 IV
17 IV
26 IV
water levels
solid ice
ice phenomena

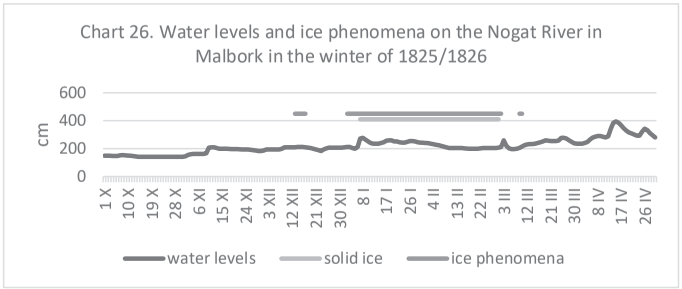


Chart 26. Water levels and ice phenomena on the Nogat River in Malbork in the winter of 1825/1826
cm
600
400
200
0
1 X
10 X
19 X
28 X
6 XI
15 XI
24 XI
3 XII
12 XII
21 XII
30 XII
8 I
17 I
26 I
4 II
13 II
22 II
3 III
12 III
21 III
30 III
8 IV
17 IV
26 IV
water levels
solid ice
ice phenomena

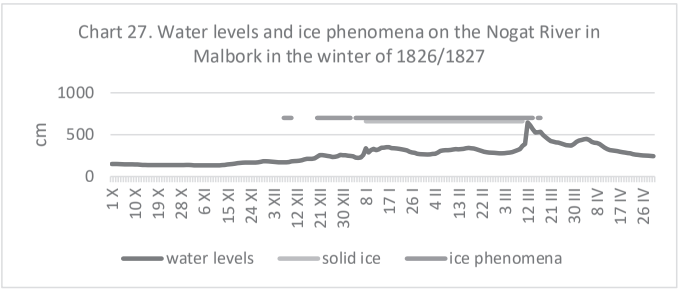


Chart 27. Water levels and ice phenomena on the Nogat River in Malbork in the winter of 1826/1827
cm
1000
500
0
1 X
10 X
19 X
28 X
6 XI
15 XI
24 XI
3 XII
12 XII
21 XII
30 XII
8 I
17 I
26 I
4 II
13 II
22 II
3 III
12 III
21 III
30 III
8 IV
17 IV
26 IV
water levels
solid ice
ice phenomena

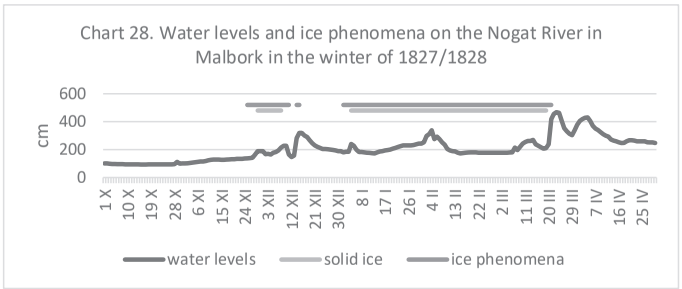


Chart 28. Water levels and ice phenomena on the Nogat River in Malbork in the winter of 1827/1828
cm
600
400
200
0
1 X
10 X
19 X
28 X
6 XI
15 XI
24 XI
3 XII
12 XII
21 XII
30 XII
8 I
17 I
26 I
4 II
13 II
22 II
2 III
11 III
20 III
29 III
7 IV
16 IV
25 IV
water levels
solid ice
ice phenomena

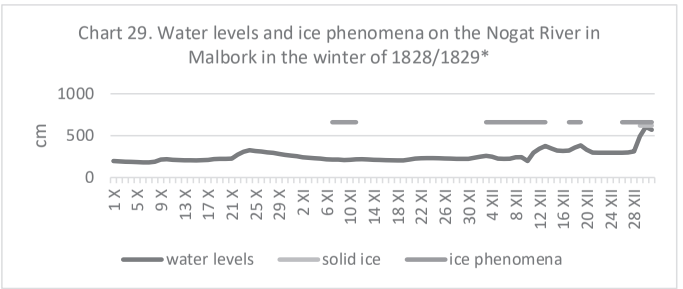


Chart 29. Water levels and ice phenomena on the Nogat River in Malbork in the winter of 1828/1829*
cm
1000
500
0
1 X
5 X
9 X
13 X
17 X
21 X
25 X
29 X
2 XI
6 XI
10 XI
14 XI
18 XI
22 XI
26 XI
30 XI
4 XII
8 XII
12 XII
16 XII
20 XII
24 XII
28 XII
water levels
solid ice
ice phenomena

* Only in 1828.

Table 3. Ice phenomena on the Nogat River in Malbork in the season 1810/1811–1828/1829

Season	Date of observation of the first ice phenomena	Date of observation of the last ice phenomena	Time span from the first to the last observation of the ice phenomena (number of days)	Number of days with solid ice	Number of days with occurrence of shuga, coastal ice, ice floe, ice drift
1810/1811	–	12.03.1811	71*	65*	6*
1811/1812	11.12.1811	24.03.1812	105	78	17
1812/1813	22.11.1812	18.03.1813	117	90	17
1813/1814	2.12.1813	6.04.1814	126	88	19
1814/1815	5.11.1814[a]	14.03.1815	130	72	9
1815/1816	28.11.1815	23.03.1816	117	107	10
1816/1817	22.11.1816	16.02.1817	87	55	32
1817/1818	6.12.1817	9.03.1818	94	75	19
1818/1819	15.11.1818	28.02.1819	106	76	30
1819/1820	30.11.1819	31.03.1820	123	105	18
1820/1821	16.11.1820[b]	27.03.1821	132	94	16
1821/1822	18.12.1821[c]	18.02.1822	63	7	27
1822/1823	14.11.1822[d]	23.03.1823	130	90	10
1823/1824	17.12.1823	7.03.1824	82	38	19
1824/1825	8.01.1825	31.03.1825	83	46	25
1825/1826	13.12.1825[e]	10.03.1826	88	54	13
1826/1827	7.12.1826	17.03.1827	101	62	29
1827/1828	25.11.1827	21.03.1828	118	86	14
1828/1829	7.11.1828[f]	–	55**	3**	22**

* Only in 1811. ** Only in 1828.

[a] Occured in 5.11.1814, next ice phenomena were observed from 25.12.1814. [b] Occured between 16–19.11.1820, next ice phenomena were observed from 6.12.1820. [c] Occured between 18–20.12.1821, next ice phenomena were observed from 10.01.1822. [d] Occured between 14–17.11.1822, next ice phenomena were observed from 18.12.1822. [e] Occured between 13–17.12.1825, next ice phenomena were observed from 2.01.1826. [f] Occured between 7–11.11.1828, next ice phenomena were observed from 3.12.1828.

Table 4. Length of the navigation season on the Nogat River in Malbork in the years 1811–1828

Year	Length of navigation season (number of days)	Year	Length of navigation season (number of days)
1811	259	1820	215
1812	228	1821	251
1813	244	1822	254
1814	198	1823	254
1815	244	1824	292
1816	229	1825	242
1817	278	1826	257
1818	236	1827	238
1819	260	1828	216

Table 5. Percentage of daily water levels of the Nogat River in Malbork allowing fully laden vessels to navigate in the years 1811–1828

Year/Years	Berlinka, szkuta	Dubas	Koza
	Full load draught (m)		
	1.0	0.84	0.73
	Percentage of daily navigable water levels within the identified navigation seasons (%)		
1811	27.8	37.8	56.0
1812–1813	100.0	100.0	100.0
1814	87.4	100.0	100.0
1815–1818	100.0	100.0	100.0
1819	99.6	100.0	100.0
1820–1826	100.0	100.0	100.0
1827	84.5	100.0	100.0
1828	100.0	100.0	100.0

Historical Wind Resources in Malbork

Let us turn to the characteristic of the wind directions. Discussion of this subject is important in view of the use of rigged vessels in inland navigation. In the past, this group of vessels included, among others, "szkuta", "dubas", "koza", "jadwiga", "bat" and, increasingly popular from the 1770s, "berlinka", while in the Elbląg region, "burdyna" and "szmaka" were also used as auxiliary vessels for navigation on the Vistula Lagoon[33]. The research shows that "szkuty" alone accounted for almost 58% of the total Vistula waterway rolling stock recorded in the Gdańsk trade emporium between 1750 and 1772[34]. Although there is no detailed data on the waterway rolling stock in the Malbork and Elbląg area in the period immediately preceding the steam era[35], it is worth looking for an answer to the question of the possibility of using the wind resource by the river fleet during the voyage up the Nogat, the distance between Elbląg and Mątowska Szpica. Among the winds that were important for river navigation in the age of sail, we should mention the full wind blowing from the stern parallel to the longitudinal axis of the ship, and the broad reach wind, i.e. the quarter wind blowing diagonally from the stern. The half-wind, blowing perpendicular to the ship's course, will also be of lesser importance. From the research carried out so far, it is known that in the years 1750–1772 in the port of Gdańsk, which is relatively close to Malbork, the decisive share of resources were taken by the westerly (31.79%), northerly (19.74%) and northwesterly (11.61%) winds, which were generally among the most favourable for sailing in the region of the lower course of the Vistula[36].

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33 "Jadwiga" was a masted ship with a sharply pointed bow, manned by 4–6 rafters. "Bat" was a small ship, often used for passenger transport, including crossings. "Burdyna" was a rigged cargo ship used for loading and unloading large ocean-going vessels in the roadstead. "Szmaka" was a vessel used for coastal and inland navigation with a capacity of 5 to 40 last.

34 S. Kazusek, *Spław wiślany*, p. 157. Compare: L. Wolski, *Rys hydrografii*, t. 2, p. 244; t. 3, pp. 266–268.

35 S. Gierszewski, *Elbląg. Przeszłość*, pp. 94, 95. Compare: S. Hoszowski, *Z dziejów handlu*, p. 88. These are supplemented by knowledge about the production of inland and coastal vessels in the Elbląg shipyards in the period before the construction of steam ships in this town, i.e. before 1828, and estimates of the size of the Elbląg inland and coastal fleet. According to the findings of S. Gierszewski, inland vessels were built and repaired here, including "bat", "szkuta", as well as "burdyna" and "szmaka". Their production peaked in the 1780s; S. Gierszewski, *Elbląski przemysł okrętowy w latach 1570–1815*, Gdańsk 1961, pp. 94, 96, 97–98, 106, 113–115, 126–129; *idem*, *Życie portowe*, p. 335–337.

36 S. Kazusek, *Spław wiślany*, p. 163.

The wind resource in Malbork in the years 1811–1828 differed from that in the Gdańsk trade emporium, which is important for the choice of the destination port by the rafting participant. Here, the largest share was held by winds from the southern (27.30%), south-western (15.04%) and western (14.04%) directions, being among the most unfavourable in relation to rafting up the Nogat (Chart 30). It should be added that the most favourable winds for river navigation from the Elbląg area towards the Mątowska Szpica, also taking into account the fact that ships have to tack, are full winds from the northeast, broad reach winds from the east and north, as well as half winds from the northwest and southeast. It is worth noting that the distribution of wind directions changed considerably over successive sailing seasons (Charts 31 and 32). The full wind, which was the most attractive for shipping (accounting for 4.66–14.75% of the total seasonal share), was most common between 1811 and 1818. The northern broad reach recorded its highest seasonal share (16.16–26.30%) between 1820 and 1827, while the eastern broad reach rarely reached more than 10% of the seasonal share (maximum 19.73% in 1815). The north-westerly and south-easterly half-winds had a much smaller share. Particularly unfavourable wind resources were recorded in the period 1811–1813 due to the westerly wind (18.85–20.55% seasonal share), in the period 1814–1819 due to the south-westerly wind (16.16–21.64% share) and in the period 1819–1826 when the southerly wind had its seasonal share of more than 30% (31.23–42.64%). The magnitude of the change in wind directions over the annual cycle for navigation is also shown in the following fixed-base dynamic index (Table 6).

Looking at the proportions of the winds in each month over the whole period under consideration, it can be seen that in January, February and March the southerly winds dominated, in April, May and June the northerly winds, in July the proportions of the northerly and southerly winds were the highest and at the same time comparable, from August onwards the southerly winds were the most frequent, reaching the level of 36.02–43.19% of the total winds in the period from October to December (Charts 33–44). By visualising the detailed wind structure over the period 1811–1828, it is possible to observe the periods in which there were particularly favourable or exceptionally unfavourable winds for navigating (Charts 45–49).

It should be added that the arithmetic mean of the northeasterly full winds from all seasons of the period under study was only 1.61% of the total winds, the westerly and easterly broad reach winds together were 16.13%, and all the winds favourable for navigating together were only 46.77%. If we assume that such unfavourable wind resources existed in earlier decades, then the more frequent

choice of the port of Gdańsk instead of Elbląg for the drifting of products and the subsequent purchase and transport of the goods up the Vistula is also indirectly attributable to this reason. For the sake of comparison, let us add that in the years 1753–1772 the average proportion of favourable winds for navigation on the Vistula from the Gdańsk trade emporium to Gdańsk Head was over 75%, while from Gdańsk Head to Grudziądz it was over 77%[37].

Table 6. Wind dynamic index at Malbork in the years 1811–1828 (annual cycle)

Year	N	NE	E	SE	S	SW	W	NW
1811	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
1812	130.30	86.21	37.50	89.29	106.06	45.59	95.83	303.45
1813	136.36	68.97	40.00	142.86	93.94	77.94	104.17	186.21
1814	124.24	179.31	105.00	142.86	69.70	116.18	54.17	89.66
1815	51.52	124.14	180.00	178.57	68.18	94.12	68.06	110.34
1816	148.48	186.21	45.00	107.14	115.15	97.06	77.78	58.62
1817	93.94	75.86	70.00	157.14	109.09	98.53	127.78	31.03
1818	136.36	58.62	110.00	117.86	153.03	86.76	41.67	124.14
1819	130.30	17.24	57.50	260.71	172.73	108.82	43.06	6.90
1820	193.94	17.24	77.50	67.86	190.91	52.94	94.44	58.62
1821	230.30	6.90	45.00	53.57	190.91	92.65	62.50	68.97
1822	178.79	31.03	62.50	89.29	213.64	64.71	75.00	27.59
1823	236.36	24.14	80.00	60.71	203.03	61.76	54.17	55.17
1824	212.12	20.69	35.00	57.14	236.36	55.88	76.39	37.93
1825	184.85	41.38	102.50	53.57	233.33	69.12	22.22	65.52
1826	290.91	10.34	75.00	96.43	195.45	47.06	54.17	31.03
1827	221.21	58.62	82.50	103.57	143.94	92.65	45.83	48.28
1828	139.39	24.14	85.00	146.43	118.18	89.71	81.94	117.24

[37] *Ibidem*, pp. 162, 192. It is worth mentioning here the wind structure in nearby Elbląg, based on contemporary studies from 1966–1990. They show that the northeasterly full wind, presented as the most favourable for sailing, had a share of 5.6%, the northerly and westerly broad reach of 12.9% and 8.5% respectively, the southeasterly and northwesterly side wind of 17.8% and 8.0% respectively, while, excluding the share of atmospheric calm, the worst for sailing upwind the southerly, southwesterly and westerly winds constituted 18.4%, 11.7% and 9.7% respectively. The contemporary data presented and calculated for the purposes of this study also testify to the climatic changes that have taken place over more than 150 years.

Chart 30. Global occurrence of winds in Malbork in the years 1811-1828

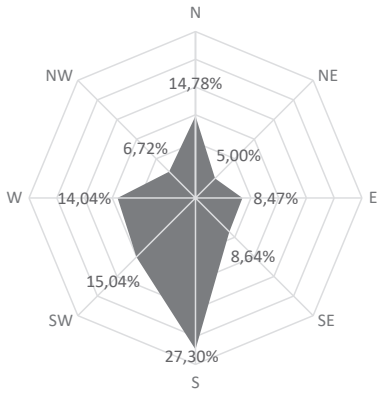


Chart 31. Annual occurrence of winds in Malbork in the years 1811-1828

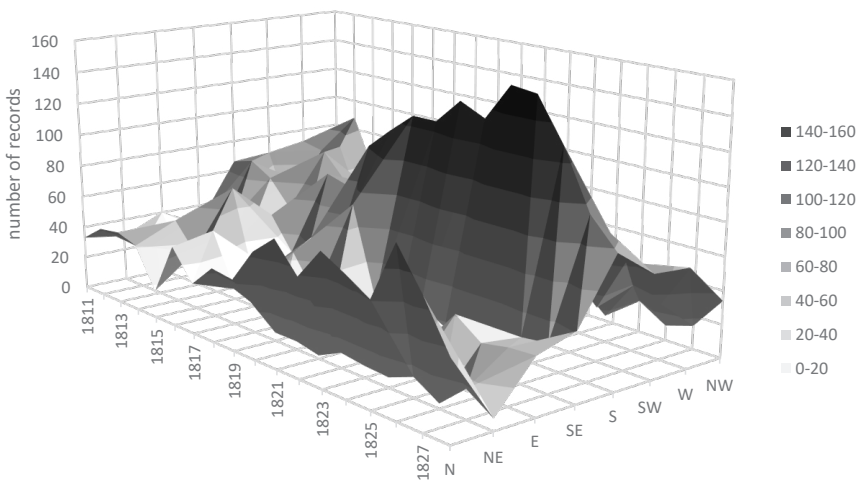


Chart 32. Annual occurrence of winds in Malbork in the years 1811-1828

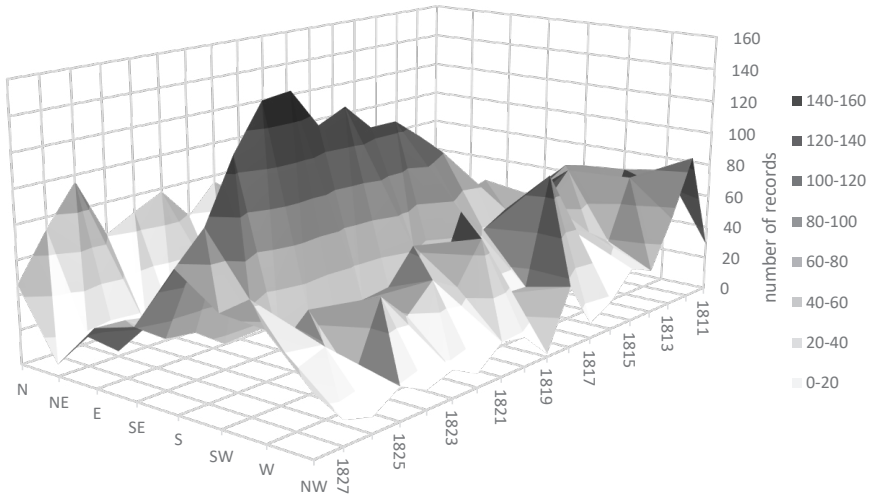


Chart 33. Wind occurence in January in the years 1811-1828 (based on measurement in Malbork)

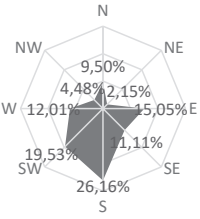


Chart 34. Wind occurence in February in the years 1811-1828 (based on measurement in Malbork)

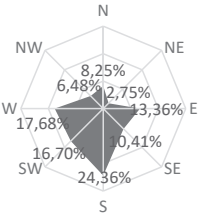


Chart 35. Wind occurence in March in the years 1811-1828 (based on measurement in Malbork)

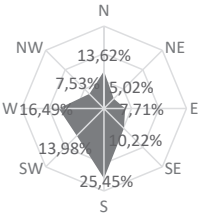


Chart 36. Wind occurence in April in the years 1811-1828 (based on measurement in Malbork)

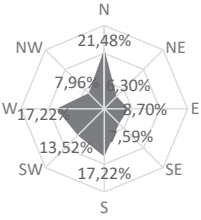


Chart 37. Wind occurence in May in the years 1811-1828 (based on measurement in Malbork)

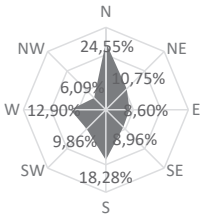


Chart 38. Wind occurence in June in the years 1811-1828 (based on measurement in Malbork)

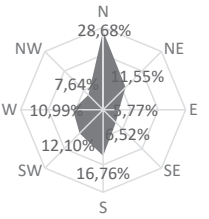


Chart 39. Wind occurence in July in the years 1811-1828 (based on measurement in Malbork)

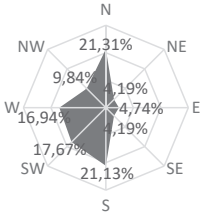


Chart 40. Wind occurence in August in the years 1811-1828 (based on measurement in Malbork)

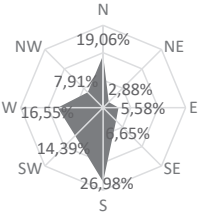


Chart 41. Wind occurence in September in the years 1811-1828 (based on measurement in Malbork)

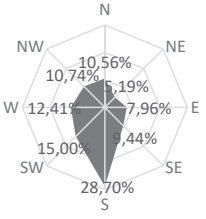


Chart 42. Wind occurence in October in the years 1811-1828 (based on measurement in Malbork)

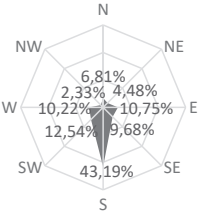


Chart 43. Wind occurence in November in the years 1811-1828 (based on measurement in Malbork)

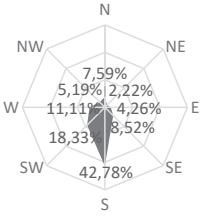


Chart 44. Wind occurence in December in the years 1811-1828 (based on measurement in Malbork)

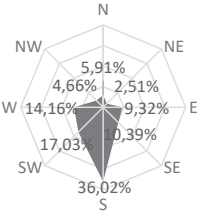


Chart 45. Monthly occurence of winds in the years 1811-1828 (based on wind measurement in Malbork)

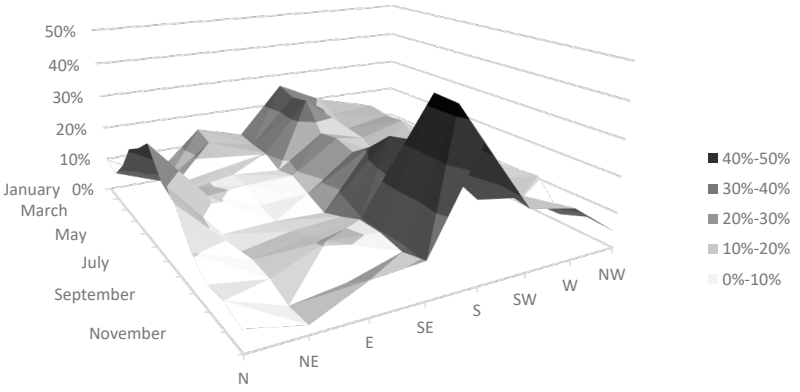


Chart 46. Monthly occurence of winds in the years 1811-1828 (based on wind measurement in Malbork)

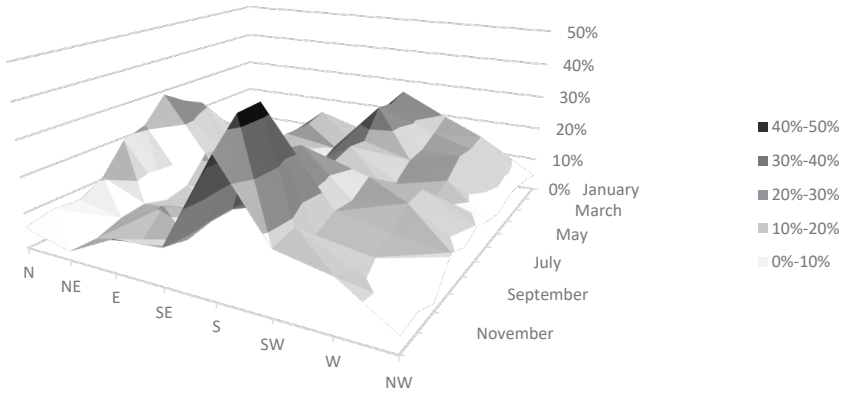


Chart 47. Percentage of winds in the years 1811-1819 within a month (based on wind measurement in Malbork)

Chart 48. Percentage of winds in the years 1820-1828 within a month (based on wind measurement in Malbork)

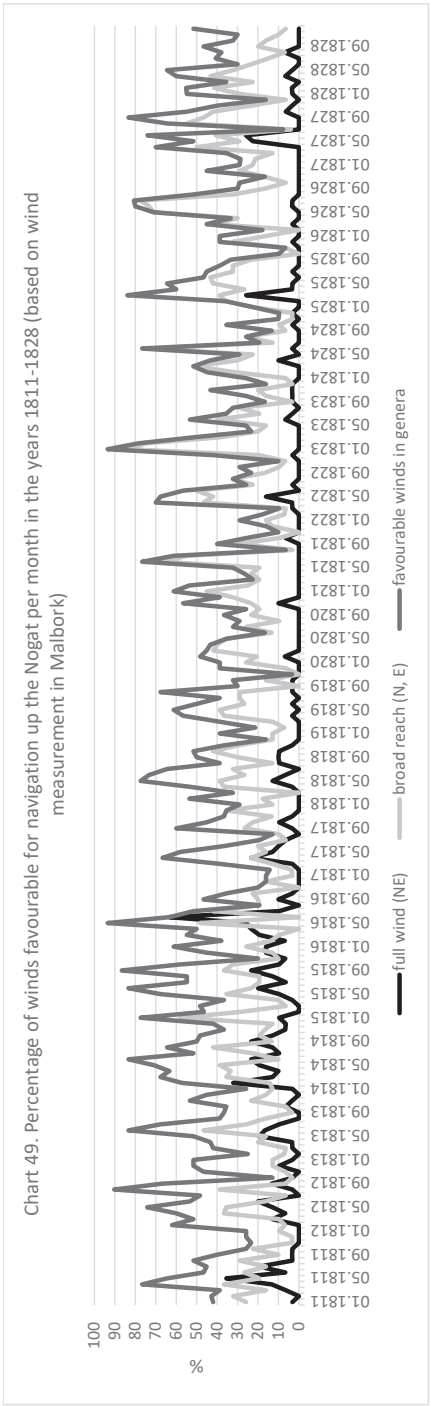


Chart 49. Percentage of winds favourable for navigation up the Nogat per month in the years 1811-1828 (based on wind measurement in Malbork)
%
100
90
80
70
60
50
40
30
20
10
0
full wind (NE)
broad reach (N, E)
favourable winds in genera
01.1811
05.1811
09.1811
01.1812
05.1812
09.1812
01.1813
05.1813
09.1813
01.1814
05.1814
09.1814
01.1815
05.1815
09.1815
01.1816
05.1816
09.1816
01.1817
05.1817
09.1817
01.1818
05.1818
09.1818
01.1819
05.1819
09.1819
01.1820
05.1820
09.1820
01.1821
05.1821
09.1821
01.1822
05.1822
09.1822
01.1823
05.1823
09.1823
01.1824
05.1824
09.1824
01.1825
05.1825
09.1825
01.1826
05.1826
09.1826
01.1827
05.1827
09.1827
01.1828
05.1828
09.1828

We do not know the strength of the wind in this area at the beginning of the 19th century, but on the basis of contemporary research we can conclude that in the nearby Elbląg it averaged between 3.2 and 4.0 m/s between 1966 and 1990. The absence of atmospheric calm lasting more than 5 hours is also characteristic[38]. On the basis of research into the life of the Elbląg port, it should be added that in the feudal times the frequent north winds were particularly hard on ships sailing from the Elbląg port to the roadstead, to which sea vessels could withstand with difficulty, but smaller sailing transhipment vessels such as "burdyna", "szmaka" and "bat" required horse-drawn trawling (until the appearance of the steam ship)[39].

Conclusion

Having characterised the water levels, the length of the navigation season and the wind resources, it is worth answering the question regarding the most optimal time for inland navigation in the years 1811–1828. For this purpose, a classification of the three phenomena mentioned was made, for which a measure of the length of a month cycle was taken. In cycles of this length, average monthly water levels, as well as wind resources, were calculated. For the classification of winds, a five-class scale was adopted, describing the resource from the least favourable winds (class 1) to the most favourable for navigation up the Nogat (Table 7). The objective division into classes and their lengths does not present a challenge here, unlike the classification of water levels, for which a five-class scale was also used. In order to identify the most favourable mean water levels, the following criteria had to be applied. Mean water levels in the ranges 0–46 cm and 402–442 cm were excluded from the classification as extreme and not navigable. Mean monthly water levels between 204 and 244 cm (class 5) were considered

[38] H. Lorenc, *Struktura i zasoby energetyczne wiatru w Polsce*, Warszawa 1996 (*Materiały badawcze IMGW*, Seria: *Meteorologia*, nr 25), pp. 32–34, 38, 45, 63; *eadem*, *Zasoby wiatru w Polsce*, Warszawa 1992 (*Materiały badawcze IMGW*, Seria: *Meteorologia*, nr 18), p. 26. Also see: A.B. Adamczyk, *Charakterystyka wiatrów silnych i bardzo silnych w Polsce*, "Zeszyty Instytutu Geografii i Przestrzennego Zagospodarowania PAN" 1996, nr 37, pp. 8–11, 21; A. Woś, *Zarys klimatu Polski*, Poznań 1995, pp. 48–53; *Atlas współzależności parametrów meteorologicznych i geograficznych w Polsce*, cz. 5: *Z badań klimatu Polski*, red. M. Stopa-Boryczka, J. Boryczka, B. Kicińska, E. Żmudzka, Warszawa 1989, pp. 177–191.

[39] S. Gierszewski, *Życie portowe*, pp. 334, 335.

to be the most favourable. One reason for specifying this value is the fact of the relativity of the hydrological zero and the assumption that this favourable water level for navigation could in fact be well above the height of 1 m at the gauge. A second, equally important criterion used to adopt this range is the fact that the most intensive navigation on the lower Vistula (based on studies for the second half of the 18th century) took place between April and July. Therefore, the average of the water levels of these months should be taken into account when looking for an objective criterion for the optimum water level for navigation. In addition, the average of all records and, with its right asymmetry (see Chart 3), also the median should be taken into account.

Table 7. Classification of navigational conditions on the Nogat River in Malbork in the years 1811–1828

Category	Range of average monthly water levels (cm)	Range of proportion of favourable winds per month (%)
1	[46–86]; [363–402]	[3.3–21.4]
2	[86–125]; [323–363]	[21.4–39.4]
3	[125–165]; [284–323]	[39.4–57.5]
4	[165–204]; [244–284]	[57.5–75.5]
5	[204–244]	[75.5–93.5]

All these values (April-July average – 227 cm; average of all Nogat water levels – 229 cm; median of all levels – 216 cm) are within the accepted range. The remaining average water levels were classified into the classes shown in the table below. The last criterion needed to indicate the most favourable conditions for navigation is the length of the navigation season.

It was established by identifying as cycles those months in which the number of navigable days free of ice phenomena was greater than 50% (over the month). This gave a notional length of 142 monthly cycles (65.7% of the total of 216 monthly cycles) in which navigation was possible. The most favourable navigation season was determined by summing the classified monthly water levels and the number of months used for navigation and, in the case of upstream navigation, also the wind resource over the season.

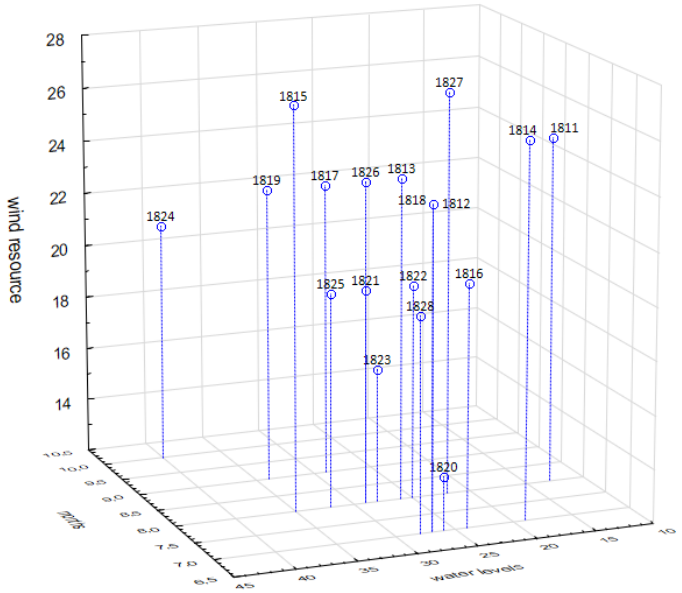
On the basis of the criteria thus adopted and the calculations of wind resources, water levels and space-time used for sailing, it can be concluded that the most favourable conditions for sailing on the Nogat river prevailed in 1824 and the most difficult in 1811 (Table 8). The most favourable wind conditions for sailing were in 1815 and 1827, and the least favourable in 1820 and 1823.

The most favourable conditions for upstream navigation prevailed in 1815, 1817, 1819, 1824 and 1826, while the worst conditions were recorded in 1811, 1814, 1816, 1820, 1822 and 1823 (Chart 50).

Table 8. Most favourable conditions for navigation down the Nogat River in the years 1811–1828

Year	Number of months used for navigation	Results of classification	Year	Number of months used for navigation	Results of classification
1824	10	40	1812	7	27
1815	8	35	1818	7	27
1819	9	34	1813	8	26
1825	8	32	1820	7	26
1817	9	29	1822	8	25
1821	8	29	1816	7	24
1826	8	29	1827	8	22
1823	8	28	1814	7	19
1828	7	28	1811	8	13

Chart 50. Navigation conditions on the Nogat River in the years 1811-1828



Taking into account the aspect of seasonality of navigation, it should be noted that on the studied water profile the most favourable water levels for navigation occured in the period from May to August, while very low water levels were noted in late autumn and early spring. This picture seems to fit in with the regularity of the intensity of inland navigation on the Lower Vistula in the light of previous studies. The results of the research, carried out according to the adopted procedure, may be one of the elements of further studies on navigation on the Vistula not only in the first half of the 19th century, but also, due to their chronological proximity, at the end of the 18th century. They will also enable further research into the conditions of inland navigation on the Vistula.

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O autorze:

dr hab. Szymon Kazusek – Instytut Historii Uniwersytetu Jana Kochanowskiego w Kielcach. Autor kilku książek i kilkudziesięciu artykułów.

Zainteresowania badawcze: historia gospodarcza XVI–XVIII w., w tym dzieje handlu w Rzeczypospolitej i jego uwarunkowania polityczno-prawne, spław wiślany, system celny w Koronie, kupiectwo w dawnej Polsce, a także klęski elementarne w dobie wczesnonowożytnej, edytorstwo źródłowe i geografia historyczna.

e-mail: szymon.kazusek@ujk.edu.pl