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Vistula River Mouth – History and Recent Problems

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Abstract

The history of the Vistula River mouth exhibits the development of the hydrographic system of Żuławy lowlands caused by natural phenomena and human intervention. During its history, the Vistula River has changed the location of its direct connection with the Baltic Sea three times; the first (the Gdańsk Vistula) and the second (the Brave Vistula) river outlets were created by nature, while the recent one (the Vistula Cross-Cut) was man-made. Each of these locations faced similar problems, i.e. sedimentation in the river mouth leading to flooding problem in the surrounding region, intensified in winter by ice jams. The recent outlet, made as a short cut of the river reach in 1895, requires permanent maintenance as to diminish a flood risk for the surrounding areas due to sedimentation. Since the opening, its maintenance is carried out by elongation of jetties on both sides of the river mouth, and occasional dredging of sand. Presently, further elongation of jetties is proposed, however new methods to keep the river mouth should be considered.

Key words: river mouth, sedimentation, flood risk

1. Introduction

The history of the Vistula River delta displays changes of the fluvial system of the Żuławy lowlands in the course of centuries. It is well historically documented (Makowski 1993) that natural development of the Vistula River valley had ended by the 13th century, whereas the most of later changes are related to human activity. Changeable location of the Vistula River mouth is part of this history; the location of its direct inflow to the Baltic Sea has changed three times in the course of centuries. The date of formation of the oldest location of the river mouth (the Gdańsk Vistula) is difficult to define exactly; as estimated it dates back some 6 thousand years (Augustowski 1972). Two younger outlets have well defined dates of creation, i.e. the Brave Vistula – 1st of February 1840, and the Vistula Cross-Cut – 31st of March 1895 (see Fig. 1).

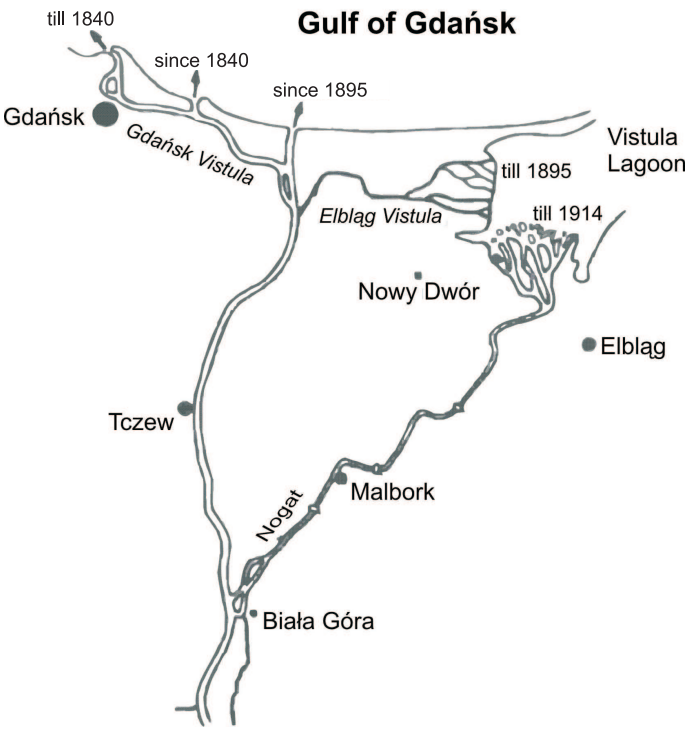

Fig. 1. Overview of the Vistula River mouth locations

2. Historical Overview

According to some hypothesis reported by Augustowski (1982), some 13 000 years ago the Pre-Vistula river flowing through the Toruń-Eberswald post-glacial valley changed its way of flow close to the city of Fordon due to a huge increase of water level estimated as 36 m. Starting from that episode, the river splitted up into two branches, one directed northward to the Gulf of Gdańsk, and the second through Noteć and Warta valleys. In the course of the next centuries, the newly created Vistula valley was deepened by the flowing water. Finally, the existing Vistula – Noteć junction was completely closed due to intensive sedimentation process.

The eldest historical reference to the Vistula river mouth dates back to the mid – 6th century (see Makowski 1993). In his study, the historian Jordanes mentioned three arms of the river mouth. However, it is not clear which river arms he thought about; the most commonly accepted hypothesis says that it was the Gdańsk Vistula, the Elbląg Vistula (called Szkarpawa) and the Nogat. According to hypotheses of Bindermann (1903), instead of Nogat, it could be a temporary branch called the Primislaw Vistula. There is also a third hypothesis (Bertram et al 1924) saying that the deltaic arm of the Vistula River (later called Leniwka), Tuga and Nogat were mentioned by Jordanes.

The next historical information comes from the end of 11th century from Wulfstan, the Norman sailor, reporting his expedition to the Gulf of Gdańsk. He reported three arms of the Vistula inflowing into the lagoon, and one direct outflow to the Gulf of Gdańsk. Some short written documents about the the Vistula River delta come from the 13th century, whereas graphical information (i.e. drawings, sketches, maps) come from the 16th century.

Makowski (1993) made a detailed study of historical changes in the Vistula delta showing the complexity of the system related to numerous spatial and temporal changes. Makowski cited works of Bertram (1907) who made an attempt to reconstruct the the Vistula River system as it was in the year 1300. It is estimated that by that time natural processes related to the creation of the Vistula valley had terminated, while further changes were related to more or less effective human intervention, including construction of dykes, jetties, and re-shaping of the river arms. In the further hydrographic development of the Vistula River, the following three branches: Nogat, Szkarpawa and Gdańsk Vistula played the dominant role.

After a long-lasting dispute between the cities of Gdańsk, Malbork and Elbląg with regard to the amount of water to be available to those cities, in the year 1613 the edict given by king Zygmunt III stated that 1/3 of the total Vistula discharge has to be directed towards Nogat, whereas the 2/3 of the total discharge should be directed towards Gdańsk. Based on king's Zygmunt III edict, the river regulation was executed (approx. the year 1620), and the Vistula River carried bigger amount of water than earlier. An increased Vistula discharge caused an intensification of sediment transport, and an extension of a sand bar deposited in the river mouth. This on-going phenomenon was stopped abruptly during the spring of 1840 by the break-through close to the village of Górki Wschodnie; this event started a new outlet called later as the Brave Vistula.

Starting from 1830, some works on new river regulation started. They were finalized in 1848 by the approval of a new regulation project according to which a new connection between the Vistula and the Nogat was made 4 km downstream the old one, in the Piekło village. At that time the discharge was divided between the Vistula and the Nogat in the proportion 4:1. Based on the decision taken in 1848; the regulation works on the Nogat were started in 1900; since then its discharge has reduced considerably. Presently, the Nogat carries approx. 3% of the mean the Vistula discharge (i.e. 30 m^3/s on average).

2.1. The Gdańsk Vistula River Mouth – Situation before the Year 1840

Based on the available documents, it is possible to reconstruct the historical development of the first the Vistula River outlet starting from the 16th century (Fig. 2). At the end of the 16th century no shoals in front of the river mouth were observed (Fig. 2a), while one century later some shoals on the eastern side of the river mouth were reported (Fig. 2b). Similar shoals are also reported on the western side of the

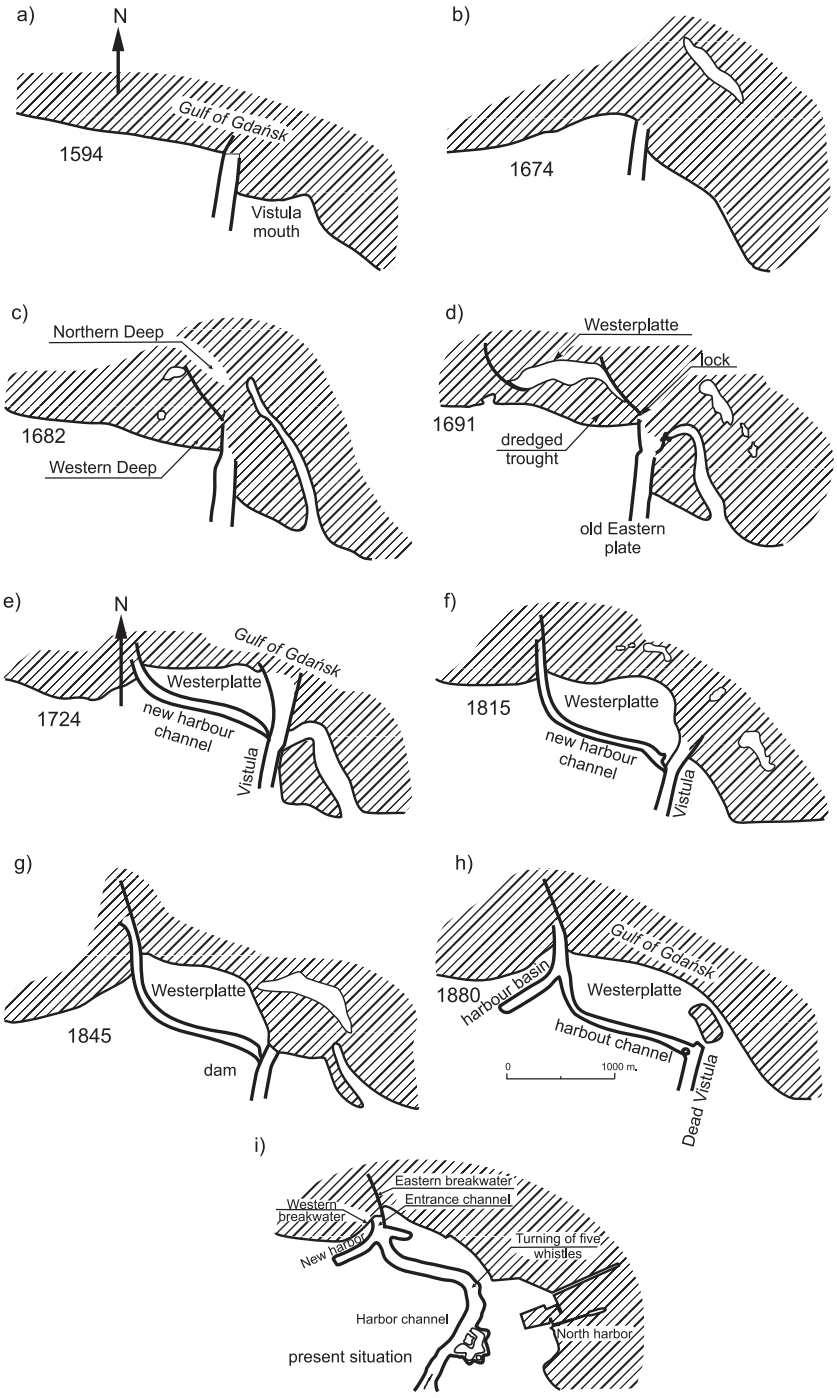

Fig. 2. History of the Gdańsk Vistula river mouth changes (based on Makowski 1993)

river mouth (Fig. 2c); in the course of time shoals started to combine, and the system of islands called "West Plaate" and "Ost Plaate" began (Fig. 2d). The natural channel created between "West Plaate" and the main land turned out to be a very useful waterway. At that time the original mouth of the Gdańsk Vistula became more and more locked by sand; for this reason the newly created channel was deepened and protected against land-slides, whereas the channel itself was elongated by construction of a pier. To protect this new waterway against sand filling, a lock was constructed (1716); as a consequence, from 1724 the Gdańsk Vistula had two outlets (Fig. 2e). In the years 1825–1845 the western outlet was again modernized by an elongation of the already existing pier, finally reaching a length of 785 meters (Fig. 2f, g). In the meantime, in 1840, a new outlet was created by the force of nature (see Fig. 1). Due to this fact a lock was constructed, which closed the river stream towards the main Gdańsk Vistula outlet and a part of the Gdańsk Vistula became dead. In the same time, sedimentation problems stopped in this outlet. Shortly (1843) this lock was removed, and a man-made channel connecting the Dead Vistula with the harbour was constructed. In the same time the northern connection of the Gdańsk Vistula was filled in with sand, and a connection of this part of land with the "Wester-Platte" island was established (Fig. 2h).

2.2. The Brave Vistula River Mouth – Situation in the Years 1840–1895

Hydrological and meteorological situation at the end of January 1840 was very difficult for the city of Gdańsk due to a threat of a strong flood. On the Upper Vistula snow melting had already started, whereas on the Lower Vistula winter conditions were still present. At that time Nogat and Szkarpawa (the Elbląg Vistula) were completely filled with ice; in such circumstance the total amount of water melted with ice was directed towards the sea through the Gdańsk branch of the Vistula. In those days ice locked the outlet and penetrated up to km 947.5. Due to such unfavorable conditions, a water level increase occurred, leading to breaks of embankments on the right bank of the river. In the area of Górki Wschodnie, i.e. in the area where the sandbar was the narrowest (Fig. 3a), a new opening was formed by natural processes. It was due to soil subsidence and an increase of water level estimated as 5.6 m. During the night 31.01/1.02.1840 the new outlet reached the width of 200 m; during the first month its width was enlarged up to 600 meters. The creation of the new outlet shortened the river by 13.8 km (Fig. 3b). In 1851 the Polish geographer Wincenty Pol named this new outlet as the Brave Vistula (in Polish Wisła Śmiała); the history of its development is quite well documented as regular bathymetry measurements were carried out every year.

The naturally started new river mouth settled a dispute over the sedimentation of the channels in the harbor of Gdańsk, which continued between the members of the harbor authority starting from 1810. By taking advantage of this new situation, an old the river bed was closed by new embankments, and a new river bed was formed

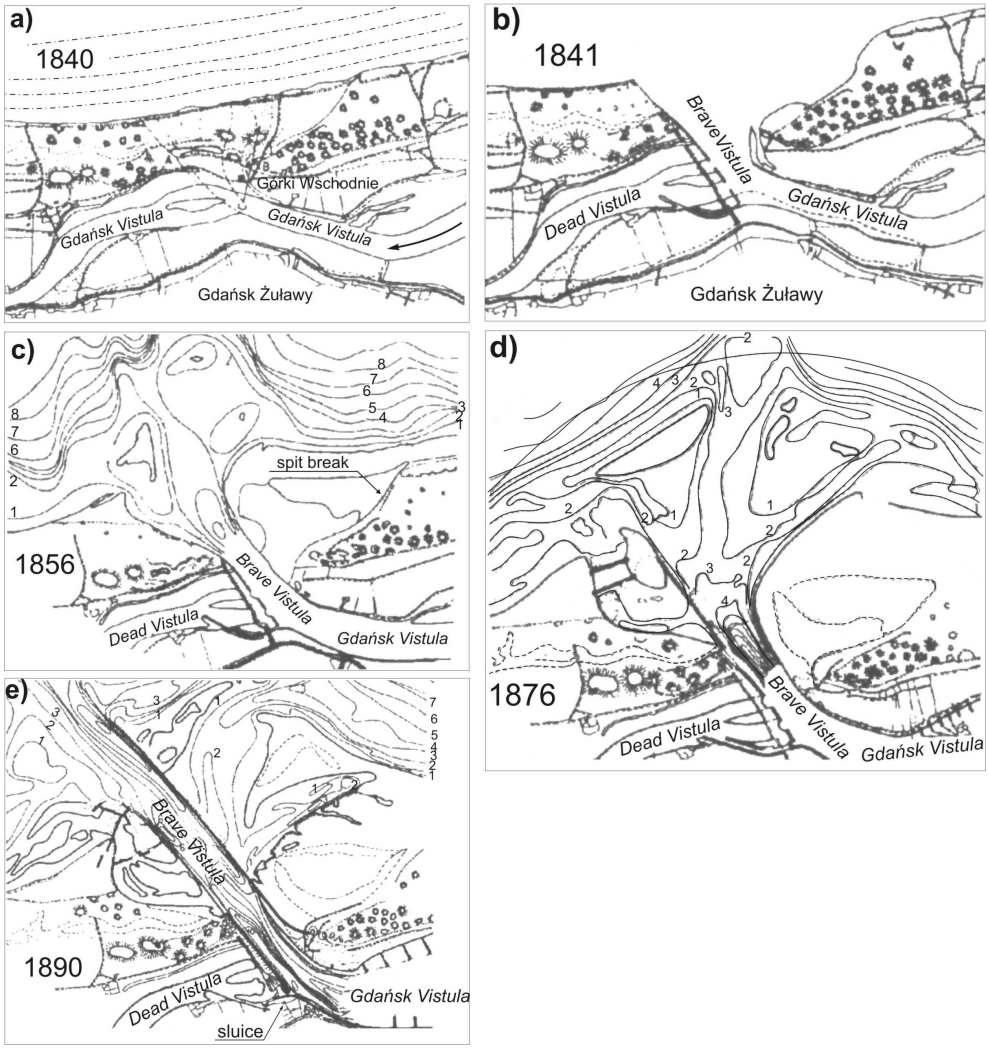

Fig. 3. History of the Brave Vistula river mouth changes (based on Makowski 1993)

by the construction of jetties. A connection between the river and the harbour was made possible through the new sluice (Fig. 3c). The new outlet changed the hydraulic conditions in the river mouth significantly.

Shortening of the river reach by 13.8 km caused an increase of the water level gradient; during the low water the increase of the water level gradient reached ΔH = 0.75 m, while during the high water reached ΔH = 2.50 m. Such changes intensified the flow and sediment transport considerably; in a consequence it caused the lowering of the river bed position and relative water levels. Due to the changed conditions of the flow in the whole system, the Elbląg branch of the Vistula River became so shallow that finally it was completely closed, and soon an artificial channel was constructed

(1845–1850) to maintain the navigation between the Vistula River and the Vistula Lagoon. During the first few years the river mouth of Brave the Vistula was quite stable. In the following years the sediment deposits started to cumulate in the form of sand bars and small islands, being the starting point for bigger forms. To keep the river mouth navigable, its regulation was carried out by constructing jetties (Fig. 3d, e). The Brave Vistula mouth was active for a short period, as 55 years after its natural start a new artificially created outlet was opened.

2.3. The Vistula Cross-Cut River Mouth – Situation since the Year 1895

Execution of a new Vistula River outlet was preceded by a long-lasting discussion and dispute between the local community and administration. The main goal of this huge investment was to shorten the distance to the sea in order to facilitate the outflow of high water. A project of the comprehensive regulation works was prepared by Alsen and Fahl (1877) (see Makowski 1993, 1995). Due to the scope of the works and their costs the project execution was divided into three steps:

1. executed based on a statute of 20.06.1888 – execution of the artificial connection between the river and the sea, damming the Gdańsk Vistula and the Szkarpawa, construction of sluices to keep the navigation between the Dead Vistula and the Brave Vistula with the Szkarpawa (Fig. 4);
2. executed based on a statute of 25.06.1900 – regulation of the Vistula on high water on the river stretch from km 889 (Piekło) to km 922,5 (Giemlice);
3. executed based on a statute of 20.07.1910 – damming of the Vistula – Nogat channel, connecting the Vistula with Nogat by the sluice in Biała Góra (km 884.4); creation of three steps to dam up the water.

Some preliminary works were started already in 1889, i.e. three possible routes of the short-cut were demarcated and the gathering of necessary equipment started. The earth works started in 1891. The beginning of a new outlet of the length of 7.1 km, starting from the Gdańsk the Vistula embankments towards the sea, was dug with the width of 250– 400 m; its depth was 1.3–1.93 m below the mean sea level. The ending part of the new outlet (1.4 km long) was dig as a narrow and shallow channel (50 m wide; depth = 0.0 m). At the very end a barrier of a height of 6 m was left. The main idea was to allow the river to wash-out the sand from the short-cut by the use of natural forces in the moment of its opening. During the preparatory works some 7.2×106 m^3 of material was removed from the river mouth under construction. In November 1894 the water from the Vistula River was already purred into the prepared channel, however its opening was delayed till spring 1895. It was assumed to allow the water during a spring increase in 1895 to pass through the old river mouth for the last time. Winter conditions of 1895 made the situation more complicated due to a huge ice jam on the Lower the Vistula (km 909 – km 939); the threat of flooding of Żuławy Gdańskie and Elbląskie accelerated the decision to open a new outlet. Its opening

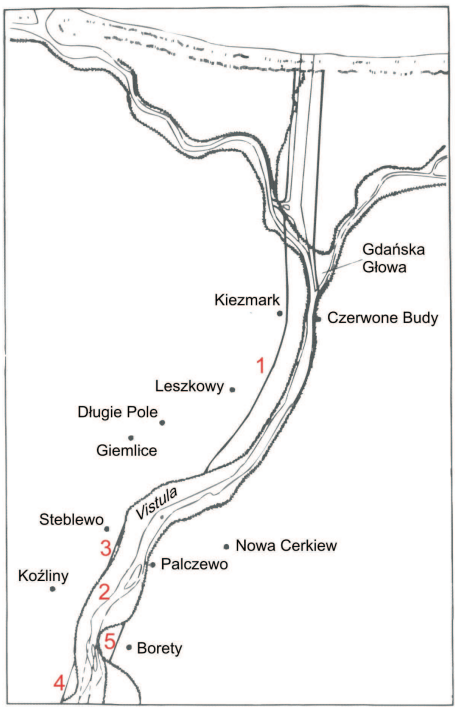

Fig. 4. Plan of regulation works of the Vistula River Cross-Cut according to the statute of 20.06.1888; numbers 1–5 indicate embankments to be reconstructed according to this plan (based on Makowski 1993)

took place on the 31st of March 1895 at 15:45. During the first hour the ending part of the new river mouth widened up to 100 m, while after 16 hours the river mouth width was already 300 m. During the first 16 hours approx. 2×10^6 m^3 of sand was washed out to the sea.

The evolution of the new river mouth is quite well documented, starting from its beginning (e.g. Makowski 1995, Franz et al 2005). The available archival bathymetry data enable tracing of the formation and changes of the sand bar in front of the river mouth. Based on those data, some estimates with regard to the amount of accumulated sand have been done. According to some older estimates (e.g. Makowski 1995), till the autumn 1895 approx 9.08×10^6 m^3 were removed from the newly created river mouth; this intensive sediment transport can be related to the shortening of the river reach by 10 km. Newer calculations carried out by using a uniform geodetic network indicate even higher values, up to 13.1×10^6 m^3 (Franz et al 2005). Those discrepancies are related to the accuracy of both location and water depth measurements; an estimation of these errors is rather difficult.

Already two years after the creation of the new river mouth, regulation works started by the construction of jetties, at first the eastern, and in the next year also the western one (Tab. 1). Since 1897 the eastern jetty has reached the length of 2350

m, while the western – 2251 m. In the meantime (1991) the top of the eastern jetty was elevated by 0.6 m above the mean sea level. The last modification of the western breakwater was carried out in 2002, and a further extension of jetties is considered by Regional Water Board in Gdańsk.

Table 1. History of the Vistula River regulation since 1895

date	works done	date	works done
1895	opening of the new outlet	1933	extension of western jetty to 1700 m
1897	beginning of regulation works; construction of eastern jetty of 180 m	1936	extension of eastern jetty to 960 m
1898	extension of eastern jetty to 240 m	1937	extension of eastern jetty to 1300 m
1902	extension of eastern jetty to 360 m	1938	extension of eastern jetty to 1600 m
1906	extension of eastern jetty to 400 m	1954	dredging works to keeping navigation depths
1907	construction of western jetty – 300 m	1958–1960	extension of eastern jetty to 1900 m
1908–1915	dredging works – keeping navigation dredging works – depth 4–5 m	1963–1967	extension of western jetty to 2070 m
1912	extension of western jetty to 520 m and eastern jetty to 480 m	1968–1971	extension of eastern jetty to 2200 m
1923–1938	dredging works – keeping navigation depth 3–4 m	1986	extension of eastern jetty to 2350 m
1930	extension of western jetty to 600 m and eastern jetty to 540 m	1999	reconstruction of eastern jetty (increased height +0.6 m)
1931	extension of eastern jetty to 720 m	2002	extension of western jetty to 2251 m
1932	extension of eastern jetty to 760 m	2003, 2010	proposed extension of both eastern and western jetties

3. Present Situation and Future Activities

At present the Vistula River mouth requires regular observations in order not to allow the navigation to be hampered by insufficient water depth. Such circumstances can be especially dangerous during the severe winter conditions, since in the presence of ice the river mouth can be locked, and break and/or overtopping of the embankments and flooding of the surrounding lowlands can occur. Such a scenario can be avoided when the navigation of ice breakers is possible without obstacles.

The Regional Water Board (RZGW) in Gdańsk is responsible for the flood protection in the Vistula River delta. In order to improve the navigation conditions in the river mouth, it is the intension of RZGW to elongate the eastern and western jetties, similarly as it was done in the previous decades (Tab. 1). In 2003 an analysis with regard to a necessary extension of jetties to keep the river mouth navigable for the period not shorter than next 10 years was carried out (Majewski et al 2003). Numerical modeling of the hydrodynamics and sediment transport was applied in the analysis

of various options for the length of jetties. Based on this analysis, it was proposed to extend the eastern jetty by 760 m, and the western jetty by 560 m. The proposed investment was not executed due to financial reasons; therefore a similar analysis was repeated in 2009 (Ostrowski et al 2009) by taking into account the changes in bathymetry and hydro-meteorological data in the meantime. As shown in Fig. 5, the bathymetry in the Vistula River mouth changed substantially between the years 2003 and 2009. In 2003 we observed the main outflow channel directed eastward, while in 2009 it was directed to the north. Based on those maps, the increase of the sediment volume of underwater sand bar was calculated; it was estimated to be 0.2×10^6 – 0.25×10^6 m^3/year. This amount of deposited sediment is smaller than it was estimated for earlier periods: for 1920–1945 it was estimated as 1.0–1.4 $\times 10^6$ m^3/year, while for 1970–1995 as 0.4–0.6 $\times 10^6$ m^3/year.

A numerical analysis carried out for the changed conditions in the river mouth in 2009 has shown that both breakwaters should be extended even more then it was proposed in 2003; it was proposed then to extend the western breakwater by 1170 m, and the eastern by 900 m.

The elongation of breakwaters is a rather expensive way of maintenance of the river mouth, and does not assure the long-lasting positive consequences, because the hydrological and meteorological conditions are of a random character. In unfavorable conditions the sedimentation can proceed faster than estimated on the basis of multi-year average conditions. For this reason it is recommended to search for new solutions to reduce sedimentation in the river mouth.

It is well known that the amount of sediment in the river mouth depends on the intensity of the river bed erosion along the river reach. It is rather difficult to reduce a run-off substantially, however, it is possible to reduce a sedimentation in the river mouth by decrease of the bed erosion along the river reach, i.e. a reduction of the material available for deposition. This goal can be achieved using different methods, like a decrease of the flow velocity by an elongation of the river leading to a decrease of the river slope, a division of the discharge into branches, or a retention of water in reservoirs, polders. All those solutions require expensive investments, preceded by a detailed analysis of water management of the whole system; they also require changes in the spatial planning in the region to be accepted by the appropriate administration and the local community. All those methods, having a technical character, in practice mean re-naturalization.

The other option deals with a controlled removal of sediment from the river bed, i.e. by sand mining. The removed sediment, as the raw material, could be used by construction industry or for coastal protection. The basic task for such a solution is a choice of the best location and technology for mining; also some plans to distribute the sediment should also be made. Sand mining can be applied as an additional method which is not in contradiction with the previous option; both of them could be applied in a balanced way.

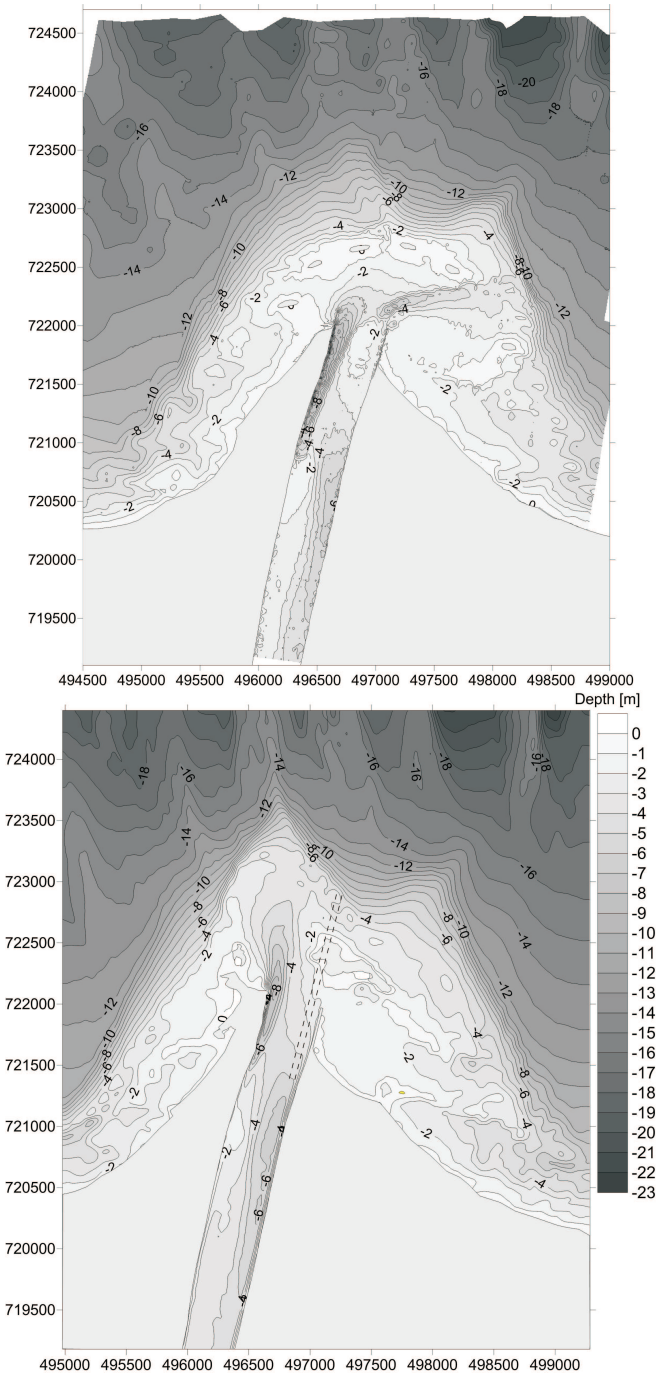

Fig. 5. Bathymetry in the Vistula River mouth: left – 2003, right – 2009

4. Conclusions

The historical documents make it is possible to trace changes in the Vistula River mouth and the sedimentation problems in the course of centuries. It is well documented that ice jams in the river mouth played a crucial role in geomorphological changes in this region, a formation of the Brave Vistula mouth is a clear evidence. The present location, a short-cut of the river reach artificially made in 1895, did not solve all the problems known from the past; both the sedimentation and ice jams are those phenomena which still endanger the river mouth. The construction of jetties was started only few years after the creation of the new outlet, and is continued up till now. This technical solution is supported by occasional dredging works. Taking into account the high costs of the continuous elongation of jetties and presumable changes in the water circulation pattern outside the jetties, it is recommended to search for other solutions in order to decrease the sedimentation process in the present river mouth.

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