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Influence of hydrological and sedimentological processes on the functioning of inland waterway transport on an example of Brdyujście Regatta Track

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Abstract

Article presents the impact of anthropogenesis on the aquatic ecosystem of the Brda River estuary. Studied section is part of the E-70 international waterway, which is connecting Central and Eastern Europe. This small section of the Brda River has very unique character, due to the hydrological transformations during the nineteenth and twentieth centuries by human race. They were happening in the "adaptation of the Brda River to the inland waterways." They were consisted in the construction of Brdyujście sluice. New hydrotechnical building created artificial water reservoir, which was used for recreational purposes, as the Regatta Track. Damming of the Brda River significantly changed water flow regime in this section. Flow has been slowed and has given nearly limnical nature to the estuary section of the Brda River. This is reflected in the transport of suspended material (total suspension) and the rate of the sedimentation in reservoir. Soundings of the bottom indicated varied thickness of the sediments. Subsequent hydrological changes in the analysed section of the Brda River, occurred at the time of closing the Brdyujście sluice and opening new inland waterway crossing to the Vistula River – Polish Czersko sluice. In this way, a significant part of the waterway (regatta track) was eliminated from the use. These changes are adversely affecting on functioning of the whole research part as an inland waterway. The dredged treatments serve not only providing proper conditions for a sporting event on the Regatta Track, but also should contribute to the improvement of navigation in this part of the Brda River. The research of the concentration of selected elements indicated the spatial variation in the rate of sediment accumulation processes. Based on available data, it is possible to propose dredged treatments as an element that enables the possibility of shipping on the Brda River section to remain at the same level.

Introduction

Estuary part of the Brda River is a key part of an international waterway E-70. The neighborhood of the city negatively affects on parameters of this waterway's section. This article presents the results of a recent hydromorphological study of the Brda River estuary section. This work is a continuation of research started in 2005 by Department of Hydrology and Water Protection Institute of Geography Kazimierz Wielki University in Bydgoszcz, now Department of Revitalization of Waterways, aimed at revitalizing the shipping function of Bydgoszcz Floodway. The first stage of the study was to identify the main sources of pollution of waters and sediments of the Bydgoszcz Canal [1]. In the following years on the basis of archival materials and other field measurements mechanisms, causes and the rate of silting the urban channel were determined [2]. In the years 2011–2012 research was conducted in a section of the Brda River from Marcinkowskiego street to the estuary to the Vistula River.

The aim of this study is to identify the mechanisms of supply and transport of sediments material in the channel of the Brda River in Bydgoszcz. For this purpose, field researches were conducted: the bathymetric surveys, geodetic measurements of water level in longitudinal profile, measurements of water's fall, 10 soundings of sediments, depth measurements in 50 cross-sections of channel. Data of water's quality collected by Regional Inspec-

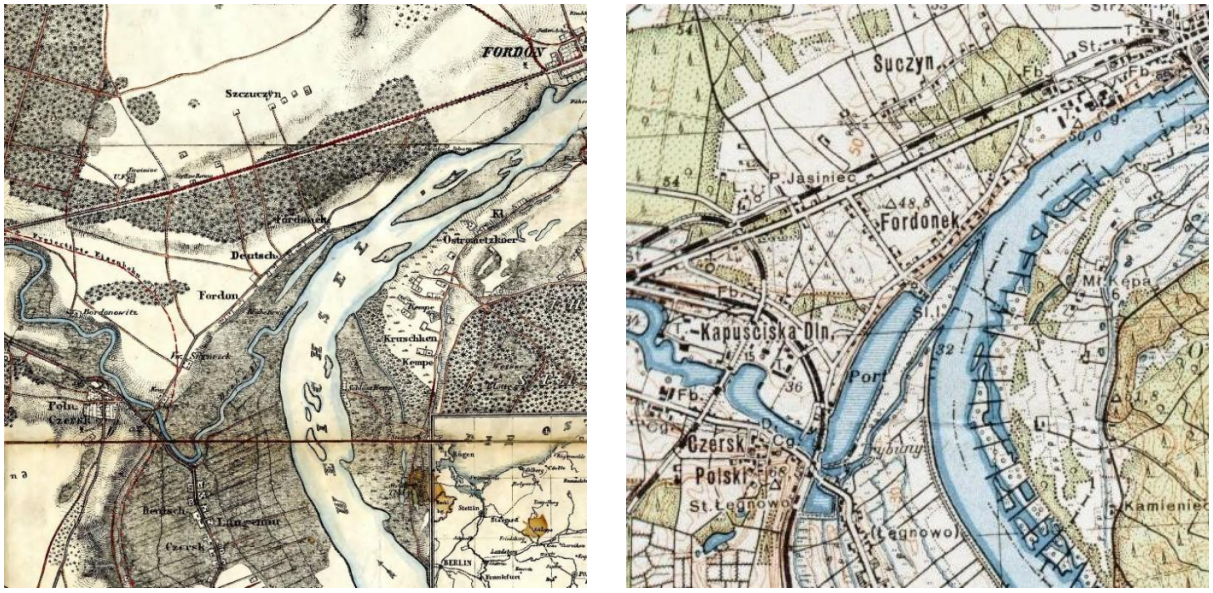

Fig. 1. Changes in the hydrographic of the estuary section of Brda River (Plan von Bromberg und Umgegend [6] and WIG Map of City Bydgoszcz [7]]

torate for Environmental Protection in Bydgoszcz from the station located above the city of Bydgoszcz (Wodowskaz Smukała) and below (Czersko Polskie) was examined. Not only the results of the quality of sediments taken from the surface layer accumulated in the Regatta Track were analyzed, but also data of the quantity of waste water discharged into the Brda River in Bydgoszcz. The Brda River, in the lower course is characterized by strong pressure from the city. A particularly important form of human impact was the damming of the river at the estuary to the Vistula River by more than four meters in the 70s of the nineteenth century (Fig. 1). The reasons for this were: the strongly growing wood industry, to maintain the shipping capacity of the Brda River and to protect the city of Bydgoszcz, before flood caused by the Vistula River [3]. Currently hydrotechnical structures: Cylinder weir Czersko Polskie, sluice Czersko Polskie opened in 1999, closed sluice Brdyujscie and hydropower plant Mewat are creating Hydro--node Czersko Polskie which might producing 36 kW electrical energy [4].

Damming of estuary section of the Brda River has caused flooding of existing valleys of length just over 1.5 km and a width of approximately 300 m. As a result water reservoir with an area of about 60 hectares was created [5]. Already in the first years of its existence the larger part was adapted for recreational purposes, as a track for water sports. Through this reservoir runs waterway connecting two basins of the Oder and the Vistula (International Waterway E-70). It is leaded along the eastern shore of the Regatta Track into the sluice Czersko Polskie (Fig. 3).

Supply of sediments material and morphology of the channel

The Brda River was a receiver of uncleaned urban, industrial waste and rainwater for 40 years. Even in 2001, 16.6% of wastewater which was discharged into the Brda River was a raw wastewater. To the Brda River had been getting 70% of the total load of waste from the city of Bydgoszcz [8]. The receivers of the rest of waste were the Vistula River and Bydgoszcz Channel. Since a completion of two large treatment plants in 2004 the Brda River hasn't been getting waste.

According to E. Jutrowska municipal management only in the section of the Brda River from stream gauge Smukała to the estuary to the Vistula River delivers about 97% of the total amount of wastewater into waters of the Brda River's basin. Along with these waste total suspension is delivered, which amount represents approximately 99% of the total suspension of waters of the Brda River's basin [9].

Sediments are created as a result of physical, chemical and biological processes which together make up the sedimentary processes. A major impact on fluvial transport plays a suspension load. Total suspension, which is a small material from the denudation and erosion of the catchment area, is often covered with a layer of toxic substances and even at low flow rate is transported. However, in the "shadow" of mainstream, in places of barriers in the channel the accumulation occurs. The accumulation may be constant, which results in the formation of "layers" silt-mule sediments or may be temporary, after which suspension is again a part of

a river transport. This process is called as a re-suspension [10].

The estuary section of the Brda River as it was indicated by measurements of water level falls in the longitudinal profile allows increased accumulation of sedimentary material. Analysis of one of the key indicators which are included when assessing the quality of water – total suspension, indicates that the water on the estuary section of the Brda River (station Czersko Polskie) is characterized by a much higher load of the lifted material than the water above the city (station Wodowskaz Smukała) (Fig. 2) [11].

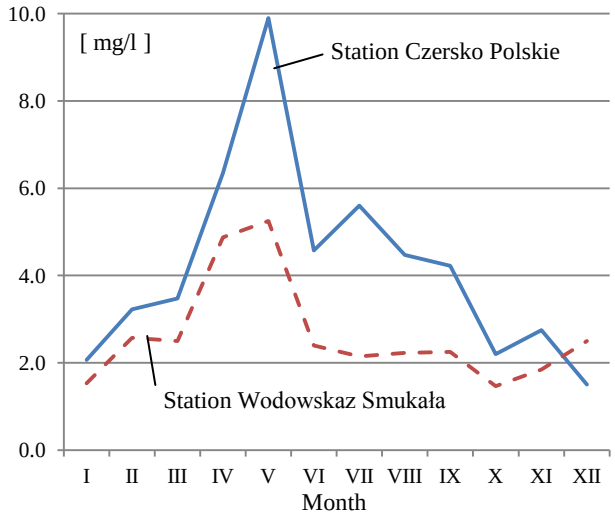

Fig. 2. Average monthly values of total suspension in selected stations of Brda River (data from the National Environment Monitoring (1995, 2001, 2005, 2011 years) [11])

The measurements of water level falls in the longitudinal profile of 12 km section of the river enabled to determine the extent of damming (backflow) of the reservoir (Fig. 4). On the basis of the analysis of longitudinal profile of the water level and the bottom of the Brda River it can be assumed that the main sedimentary basin for urban section of the Brda River is Regatta Track with a changeable backwater zone, which is reaching up to 5 km upstream (Fig. 4). However, it can be noticed that there are temporary fluctuations in the range of impact of damming, which depends on hydroenergetic water management above Bydgoszcz (three barrages below the Koronowski Reservoir).

From the analysis of morphometric measurements made on cross-sections and longitudinal profiles of the Brda River and Regatta Track, it appears that Regatta Track is characterized by a large accumulation of sediments (Fig. 3, profile E – F). Soundings of sediments indicate that its layer is strongly variable. The thickness of the accumulated material, depending on the location oscillates in the range of 0.1 m to 1.6 m (Fig. 3, sections A – B and C – D). On the basis of the thickness of sediments on Regatta Track two areas were separated:

– the southern part of the Regatta Track between the railway bridge and Cylindrical weir;
– the central and northern part of the Regatta Track.

The first zone has a small area, however, it is characterized by strong variation in morphometry and the thickness of the sediments (Fig. 3). The average depth of the Regatta Track at this point, estimated on the basis of field measurements amounts to 1.78 m and the thickness of the sediments to 0.56 m. The second part of the Regatta Track is characterized by different morphometry and the amount of the accumulated sediments. In the bottom relief two parts can be clearly difference: western – shallower with larger amounts of sediments and the eastern – deeper with smaller amount of sediments (Fig. 3). The western part has an average depth of 1.93 m and the thickness of the sediments to 0.5 m. However, the average depth of the eastern part amounts to 2.94 m and the thickness of the sediments to 0.32 m. Separation of the two parts of the reservoir can be associated with the functioning of the waterway E-70 on the eastern part of the Regatta Track and probably with conducted in 2004–2005 dredging work connected with the maintenance of a waterway.

The quality of waters and sediments

The quality of sediments from Regatta Track is presented by J. Makarewicz [13], based on the results obtained during the dredging of sediments in two parts of the reservoir. It is worth noticing that the concentration of selected heavy metals on the Regatta Track was characterized by a several times higher values, than results from the Polish Geological Institute within the State Environmental Monitoring on the station below Cylinder Weir. This indicates an increased accumulation of sediments in Regatta Track. The latest research of selected heavy metals conducted in 2012 by Regional Inspectorate for Environmental Protection in Bydgoszcz, indicated a decrease in concentration in the southern part of the Regatta Track (Table 1), while in the northern part there was an increase of the values (Table 2). The reason for this is an increased accumulation of heavy metals in the northern part of the reservoir, due to the lack of water flow. The cylinder weir, located in the southern part of the Regatta Track, by forcing the flow of water, contributes to reducing the rate of accumulation of heavy metals in sediments [14].

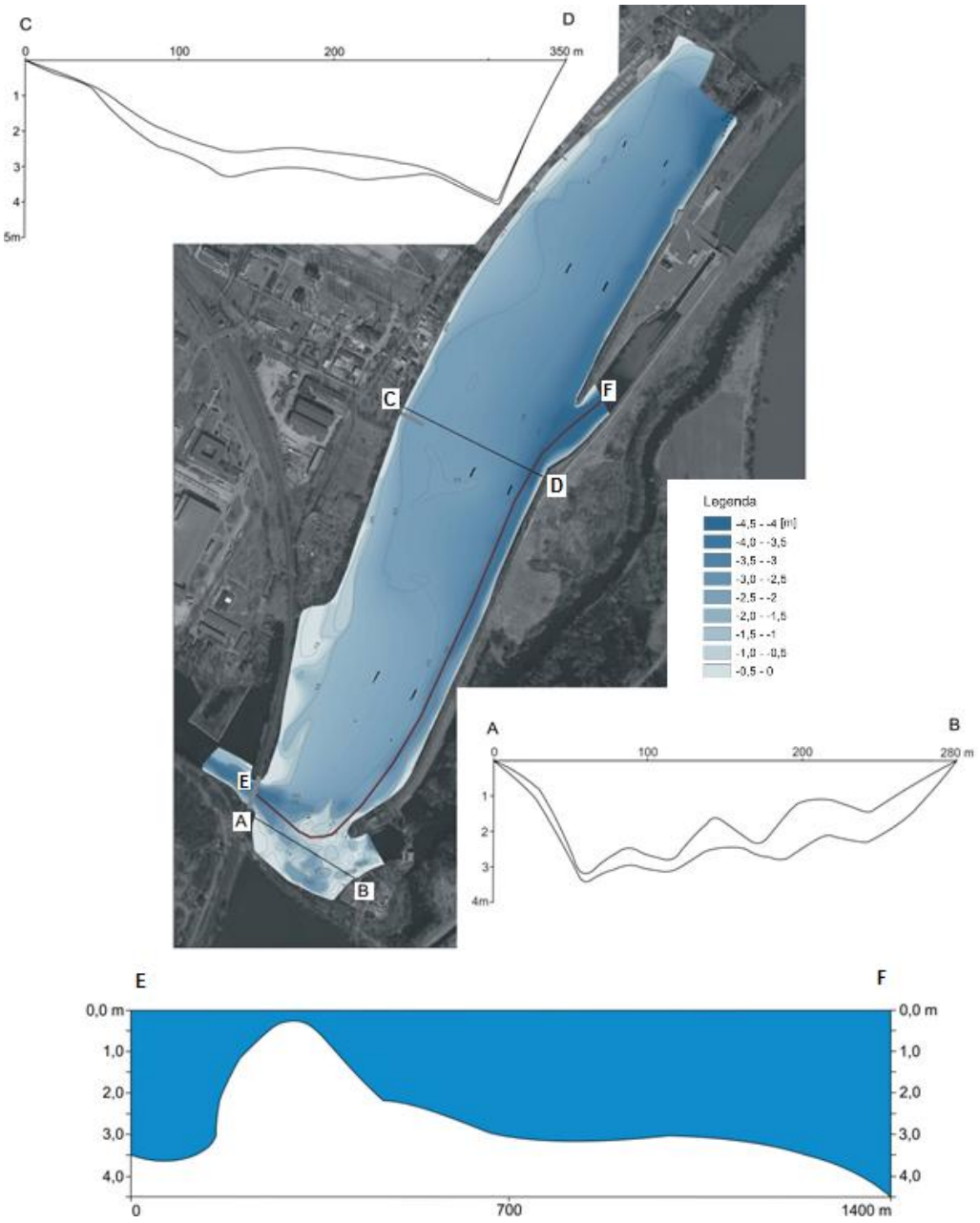

Fig. 3. Bathymetry of the Regatta Track with selected profiles of thickness of sediments A – B and C – D and longitudinal profile of the bottom of the waterway E – F (measured 28.10.2011); (bathymetric map prepared by: Z. Babiński, M. Habel, D. Szumińska, P. Twaróg; Profiles with thickness of sediments prepared by J. Dąbrowski)

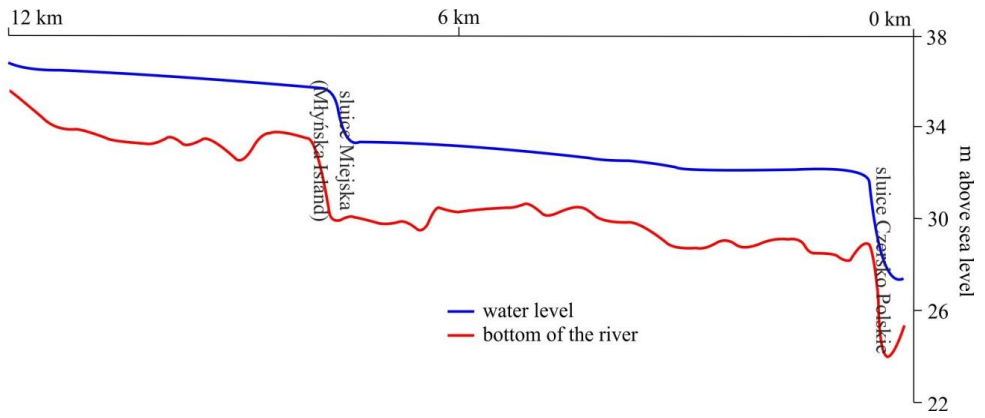

Fig. 4. Longitudinal profile of the water level and the bottom of the estuary section of the Brda River measured in September 2012 [12]

Table 1. Concentration of selected metals in the bottom sediments of the start position on regatta track (monitoring data Voivodship Inspectorate for Environmental Protection in Bydgoszcz [14])

Metals / Year	Arsenic (As)	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Nickel (Ni)	Lead (Pb)	Zinc (Zn)
2003	8.26	8.35	166.28	144.08	50.74	116.49	894.50
2004	9.70	20.10	424.90	230.70	91.50	188.40	1004.60
2012	6.40	6.37	253.00	145.00	63.70	132.00	906.50

Table 2. Concentration of selected metals in the bottom sediments of the finish position on regatta track (monitoring data Voivodship Inspectorate for Environmental Protection in Bydgoszcz [14])

Metals / Year	Arsenic (As)	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Nickel (Ni)	Lead (Pb)	Zinc (Zn)
2003	2.58	2.87	48.47	32.07	20.58	30.67	190.93
2004	5.00	1.04	19.97	10.60	14.40	14.94	53.60
2012	2.98	3.46	88.65	37.00	21.55	40.50	262.50

High concentrations of selected heavy metals in sediments of Regatta Track are evidenced for the strong anthropogenic pressure on the estuary section of the Brda River. Comparsion of geochemical ratings of sediments conducted by Polish Geological Institute and State Environmental Monitoring at the two stations of the Brda River, located above and below the city of Bydgoszcz, indicates the negative impact of the city, during the historical times and confirms the accumulation of heavy metals in sediments of Regatta Track. On the station Smukała, geochemical evaluation indicates, that the sediments are uncontaminated, while on the station below the city geochemical rating is characterized by the contaminated class [15].

Also other indicators classifying state waters are characterized by higher values of the station Czersko Polskie, than below the city of Bydgoszcz. The load of organic matter in the Brda River on the station located in the northern part of the city (Wodowskaz Smukała) is low. The recorded values oscillate in the range of 0.9 mgO_2/l in 2011 to 4.5 mgO_2/l in 1995. (Fig. 5). On the station Czersko Polskie values of five daily biochemical oxygen demand oscillate between 0.8 mgO_2/l in 2011 to 7.1 mgO_2/l in 1995 years (Fig. 5). Comparing the average values of the analyzed indicator, it can be noticed, that the station Wodowskaz Smukała is characterized by much lower values, than water tested on station Czersko Polskie. This indicates accumulation of organic matter in the urban section of the Brda River. In the discussed period (1995–2011) at both studied stations the load of organic matter is decreasing. The annual average value is systematically decreasing from 2.2 mgO_2/l (station Wodowskaz Smukała) and 4.7 mgO_2/l (station Czersko Polskie) to 1.6 mgO_2/l and 1.8 mgO_2/l [11].

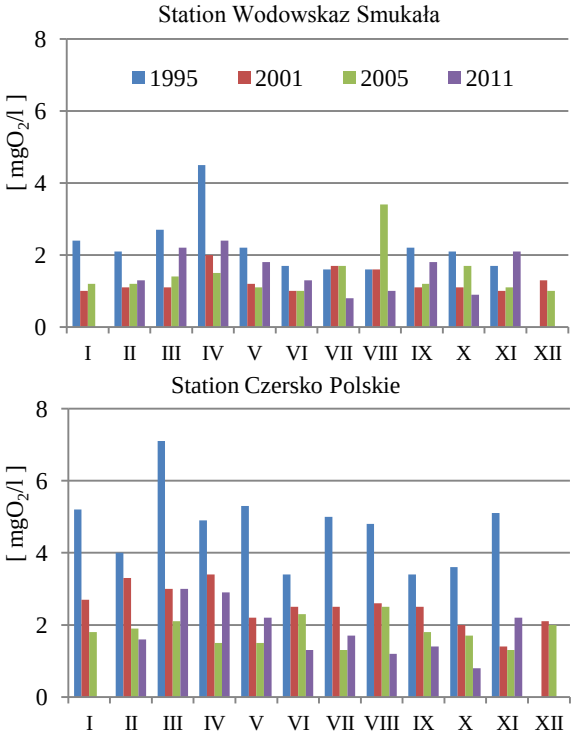

Fig. 5. Concentrations of five daily biochemical oxygen demand in the waters of the Brda River in the stations above and below Bydgoszcz (data from the National Environment Monitoring (1995, 2001, 2005, 2011 years) [11])

The load of biogenic substances for example total phosphorus in the Brda River on the station Wodowskaz Smukała is twice lower than on station Czersko Polskie. The recorded values in Wodowskaz Smukała oscillate in the range of 0.030 mgP/l in 2001 to 0.330 mgP/l in 2005 (Fig. 6). On the station Czersko Polskie concentrations of the total phosphorus oscillate in the range of 0.046 mgP/l in 2011 to 0.490 mgP/l in 1995 (Fig. 6).This diversity demonstrates the accumulation of biogenic substances in the estuary section of the Brda River. In the analyzed period (1995–2011) the load

of biogenic substances is decreasing on the station Czersko Polskie. The annual average value is decreasing from 0.270 mgP/l in 1995 to a level of 0.110 mgP/l in 2011. On the station Wodowskaz Smukała average values of total phosphorus oscillate throughout the period on the same level – 0.100 mgP/l [11].

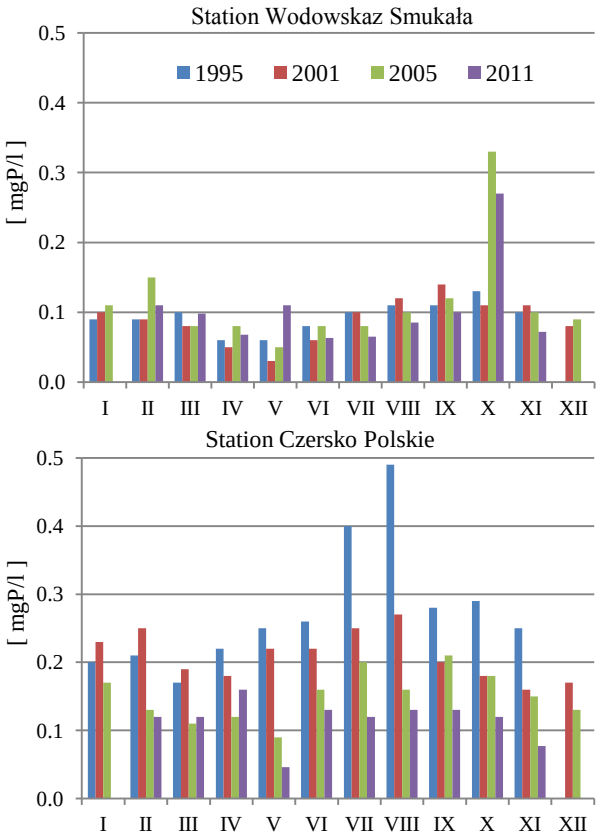

Fig. 6. Concentrations of total phosphorus in the water of the Brda River in the stations above and below Bydgoszcz (data from the National Environment Monitoring (1995, 2001, 2005, 2011 years) [11])

Conclusions

For many centuries estuary section of the Brda River, underwent strong anthropogenic pressure. Starting from the regulatory procedures at the end of the nineteenth century, which led to increasing the area of the water surface, as a result of water backpressure in weir Czersko Polskie. It also caused a change of water's flow character from fluvial (which was under strong influence from the Vistula River) to relimnical (reservoir). These changes created suitable conditions in Regatta Track for accumulation of material from the catchment (until 1965) and the collectors of urban waste and rainwater. In conjunction with the further development (industrial and demographic) of the city, this process determined the accumulation of pollutants in sediments, which were classified according to the geochemical criteria as contaminated. At about 3 km of the Brda River above the weir Czersko Polskie an intense accumulation of sediments had occurred. In 2004–2005 only a part of Regatta Track was dredged. Recent studies suggest, that it is necessary to dredged once again the southern part of the Regatta Track in order to provide the minimum depth in the navigation route International Waterways E-70.

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