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ASSESSMENT OF RIVERBED EROSION PROCESS OF MIDDLE ODRA RIVER ON MALCZYCE–ŚCINAWA SECTION

WŁODZIMIERZ PARZONKA

The Faculty of Environmental Engineering and Geodesy,
Wrocław University of Environmental and Life Sciences, Institute of Environmental Engineering.

RYSZARD KOSIERB

Institute of Meteorology and Water Management, Wrocław Division.

Abstract: The assessment was carried out on the basis of hydrometric parameters at the river gauging stations of Malczyce (km 304.8) and Ścinawa (km 331.8), as well as periodic measurements of the riverbed conditions performed by the Regional Water Administration in Wrocław. This analysis was supplemented by the measurement results of the Wrocław University of Environmental and Life Sciences concerning the bed load transportation on the Odra River section between Brzeg Dolny and Głogów, taking into account the erosion process of the riverbed pavement. The volume of eroded bed material in the period 1958–2005 equals about 4.5 million m^3. The continual erosion has a negative impact on the navigation in the river as well as on the environment and agriculture in the valley. The solution to the problem consists in:

- the one-time filling of the eroded areas with the appropriate material (on the section under survey),
- the systematic feeding of the Odra riverbed with bed load, just below the Malczyce Weir, after the passage of annual floods.

1. INTRODUCTION

The section of the Odra River under investigation is subject to intense linear erosion which results from the construction of subsequent weirs on the regulated section of the river. That erosion first occurred below the Wrocław Weirs (1897), then below the Rędzin Weir (1922) and finally, below the Brzeg Dolny Weir (1958). Below each of the latest weirs, a gradual increase in the extent of linear erosion was observed, along with the ongoing deepening of the riverbed, by several centimeters per year.

A lot of research work has been devoted to the issue of the erosion process assessment so far. The research concerned especially the Rędzin–Brzeg Dolny–Malczyce–Ścinawa section of the Odra River. Works that deserve attention here include, in particular, the research by KORNACKI [2], SERAFIN [11], PARZONKA [6], PARZONKA et al. [7], KASPEREK [1], MOKWA [5], PŁYWACZYK et al. [9].

The work by KASPEREK [1] provides the results of measurements of the mean bottom level T_{av} in the years of 1925, 1930, 1961 and 1992, for the section from Brzeg Dolny (282–283rd km) to Chobienia (349–350th km).

In 1994, Parzonka proposed the Conception of The Middle Odra River Modernization. It was suggested therein that the Odra River should be supplied with the bed

load, below the designed Malczyce Weir. That idea drew on the solution applied on the Rhine in Germany (the Iffezheim Weir) [12]. The assessment of the erosion process and of the transportation of bed and suspended load is included in the research report from 1995–1998 [7].

The project of feeding the Odra River with load was not, however, carried out, and degradation of the riverbed intensified significantly. Świerkosz et al., in their assessment of the impact of the Malczyce Weir construction on the environment [13], recommended that the following actions should be undertaken before the completion of the weir's construction:

- The erosion damage along the section of km 300–km 335 should be filled up (at least up to the half of its depth)
- The Odra River should be systematically supplied with the bed load below the Malczyce Weir, after each flooding.

In order to carry out this recommendation, which was confirmed by the administrative and water management authorities, it is indispensable to make an assessment of the current state of the Odra riverbed in the section under investigation and to provide the estimation of the amount of material necessary to fill up the area of erosion damage. Moreover, it is necessary to perform model testing for the purpose of determination of what type of material should be proportioned and to carry out geotechnical survey concerning the physical properties of the material to fill up the area of erosion damage [3], [4].

The authors present below their own preliminary assessment of the alterations in the Odra riverbed conditions along the section of 300–335th km, based on hydrometric measurements at the river gauging sections in Malczyce and Ścinawa.

In 1958, Polish engineers built the next weir – Brzeg Dolny (281.6th km). Gradual degradation of the Odra riverbed above and below the weir was even more intense than on the sections below the Wrocław and the Rędzin weirs described above. In the reservoir constructed above the weir, intense sedimentation processes have been taking place. In the years 1958–2000 the capacity of the reservoir decreased by about 1.0 million m^3. Right below the weir, intense local erosion occurred. In 1980, the maximum depth of the potholes reached the value of dozen or so meters, putting in jeopardy the weir's safety. Expensive protection of the potholes minimized the risk only partially, since the potholes have since then continued to expand. The weir's geology (3–4-meter-deep alluvia, and deeper – the Poznań clays) proved to be unfavourable from the point of view of the dynamic of the local erosion, which progresses on clays, sensitive to water.

The process of linear erosion has also been expanding intensely. The extent of erosion amounted to 50 km in 1993 and 65 km in 2007. In 1958–1993, the volume of the eroded bed load equalled $V = 3.5$ million m^3, i.e. 0.1 million m^3 per year.

Gradual wash-out of tiny grain fractions caused an increase of the average grain size of the bed load, mainly along the section of Brzeg Dolny–Malczyce–Ścinawa, and

the so called "paving" of the river bottom, which slowed down a little the linear erosion, due to the increase in the resistance of the riverbed surface layer. The eroded bed load is being deposited, in turn, on the non-degraded section below Chobienia, which causes the need for periodical river mining works.

2. ASSESSMENT OF RIVERBED CONDITION OF THE MIDDLE ODRA RIVER ACCORDING TO FORMER RESEARCH (1925–1997)

In order to analyse changes of the Odra River streamway on the section of the free flow below the Brzeg Dolny Weir, the results of the watercourse depth measurement along its length were used. The research results from the period of 72 years (1925–1997), collected by SERAFIN [11], KASPEREK [1], PARZONKA et al. [7], provided the background for an estimation of the magnitude of the river bottom alterations, as well as of the dynamics of the riverbed erosion.

The earliest measurements of the Odra River bottom were taken in 1925. The results of that survey illustrate the condition of the river in the main stream, when the Rędzin Weir (260.7th km) had been in use for 3 years. German water service carried out the measurements with the help of rod probes at every 100-meter distance. The next measurement was performed in 1930. At that time the Odra River regime on the section of Brzeg Dolny–Malczyce was stable.

Three years after the Brzeg Dolny Weir was built (1961), the Odra River bottom was investigated again by means of a stiff probe. Hydraulic and hydrological conditions of the riverbed corresponded with the low water levels and low water flow. Accumulation of water at the Brzeg Dolny Weir brought about new hydraulic conditions and the alteration of the watercourse regime.

In 1992, another measurement of the longitudinal profile of the river bottom was taken, using an echo sounder (whose operation consists in the measurement of the ultrasound wave reflected from the river bottom) installed on a watercraft.

The condition of the river bottom in 1997 was illustrated using measurements from 1995/96 and 1997, carried out as part of the KBN project [7] entitled "The Fundamentals of the Process of Bed Load Transportation in the Middle Odra River on the Section of Malczyce–Ścinawa", which entailed the following research works:

- Field tests of the Middle Odra River bed conditions – bottom material,
- Field tests of the Middle Odra River bed conditions – bed load and suspended load,
- Computer simulation of bed load transportation process in the Middle Odra River.

It must be mentioned here, however, that the measurements in 1997 were taken after the July flooding, which caused considerable deformation of the Odra River streamway and disturbed the formerly settled conditions of the bed load flow (figures 1 and 2).

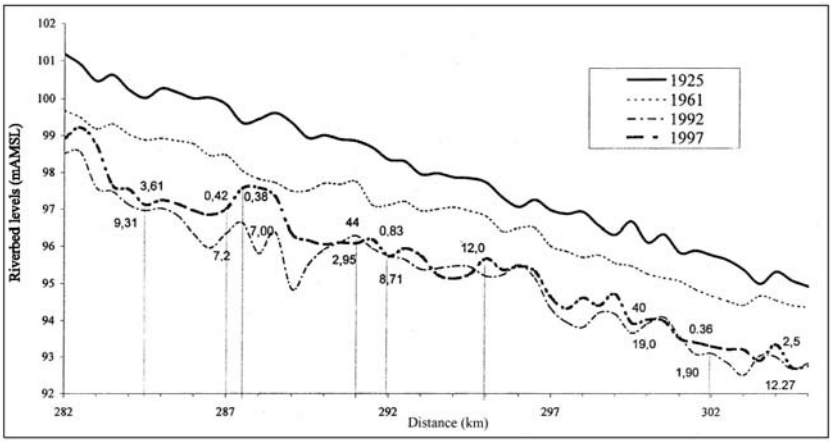

Fig. 1. The alteration in the diameter d_{50} of the bed load in 1996 and 1997 against the background of longitudinal profiles of the Odra River, section Brzeg Dolny–Malczyce

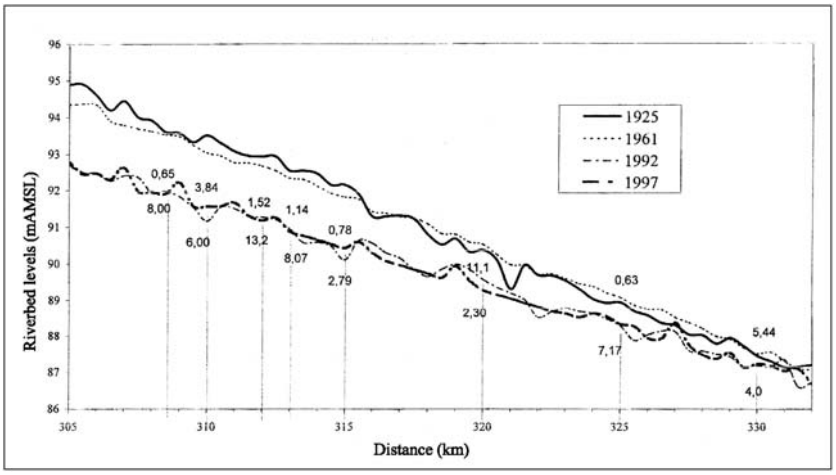

Fig. 2. The alteration in the diameter d_{50} of the bed load in 1996 and 1997 against the background of longitudinal profiles of the Odra River, section Brzeg Dolny–Malczyce

In the years 1925–1930, the river bottom lowered slightly, by about 8 cm in Brzeg Dolny and 9 cm in Malczyce, whereas in Ścinawa and Chobienia no changes in the main stream were detected. On the sections between the river gauging stations, the bottom alteration of about 15 cm was observed.

During the period of 31 years (1930–1961) the level of the bottom at the Brzeg Dolny profile lowered by 1.15 m, and in Malczyce by 0.57 m. In Ścinawa the river bottom did not change, and in Chobienia it slightly rose. On the section of Brzeg Dolny–Malczyce the bed load was significantly eroded, and, as a result, the river bot-

tom lowered by 1.04 m, and between Malczyce and Ścinawa by 0.57 m. Below Ścinawa, the Odra River bed was not subject to significant deformation.

The years 1961–1992 include the period of the Brzeg Dolny Weir operation. The impact of that weir is clearly visible on the section of Brzeg Dolny–Malczyce and Malczyce–Ścinawa. In the course of 30 years, on both of the above mentioned sections, the Odra River bottom lowered on average by 1.61 m and 1.19 m, respectively.

For the section between Brzeg Dolny and Ścinawa, a comparison was made to show the change in the graining of bottom material collected in 1996 and 1997 in the longitudinal profile of the Odra River. The characteristic values of the grain diameter d_{50} were marked on the diagrams of longitudinal profiles (figures 1 and 2). Along a several-kilometre Odra River section, from Brzeg Dolny to the 290th km, where the bottom rose distinctly after the flooding in 1997 in comparison with the year 1992, the size of an average grain decreased significantly, from 9.31 mm to 3.61 mm (285th km) and from 7.22 mm to 0.42 mm (287th km). Down below that section, despite the potholes and outwashes occurring interchangeably, the proportion of thicker particles decreased. Only at the 295th km the Odra River bottom made of clay was covered by non-cohesive material (d_{50} = 12 mm). At the 300th km, in turn, the covering bottom material thickened (the diameter d_{50} increased twice).

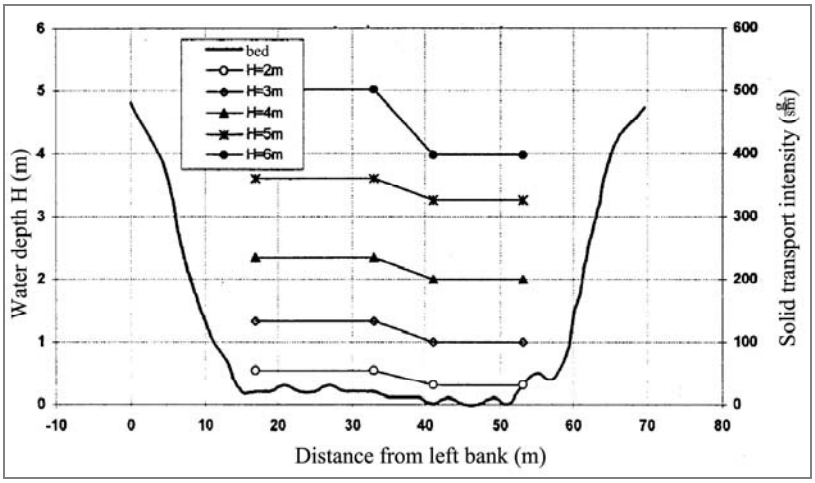

Fig. 3. The Odra River cross-section at the 302nd km (Malczyce)

The analysis of the Odra riverbed geometry, together with the measurement of bed load transportation, on the section under investigation shows that the width of the strip of the rubble traction changes from 40 m to 60 m and its mean value equals 50 m. On the basis of the analyses carried out as part of [1] and [7], as well as the assessment prepared by the ecologists [13], it was assumed that the river bottom should be raised by at least half the value of its lowering in recent years, by means of filling it up with

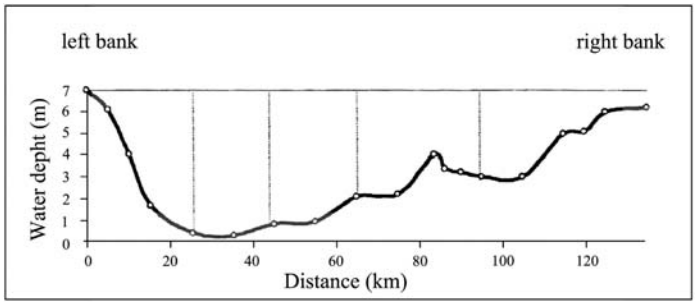

Fig. 4. The Odra River cross-section at the 332nd km (Ścinawa)

the rubble of suitable granulation. Figures 3 and 4 display sample geometry of the Odra River bed at the 302nd and 332nd km, as well as some characteristics of the bed load transport intensity.

3. INDIRECT ASSESSMENT OF BOTTOM EROSION PROCESS OF THE ODRA RIVER BED IN POST WAR YEARS OF 1956–2008 ON THE BASIS OF HYDROMETRIC TESTS OF WATER LEVEL AT MALCZYCE AND ŚCINAWA RIVER GAUGING STATIONS

The assessment of change in the water level in the Odra River at the gauging stations of Brzeg Dolny and Malczyce was prepared by, among others, PŁYWACZYK et al. [9]. Their analysis concerned mainly the relationship between the water level of the river and the groundwater level in the adjacent valley. According to Pływaczyk et al., below the Brzeg Dolny Weir in the years 1956–2003 the groundwater level decreased by about 0.44 m at a distance of 550 m from the river and by 0.65 m at a distance of 120 m from the river. That had a negative impact on the meadows, arable lands and riparian forests.

In the above-mentioned period, the average water level at the river gauging station in Brzeg Dolny according to [9] decreased from 101.76 m AMSL (above the mean sea level) to 99.81 m AMSL, that is, by 1.95 m. A similar reduction of water level was observed at the Malczyce gauging station, which amounted to 1.8 m.

The lowering of the average annual water level in the period under investigation is not, in our opinion, a sufficient measure of the riverbed erosion process. The alterations of that level are caused by both the deformation of the proper streamway's bottom and the alteration of the mean annual rate of flow in the Odra River at the gauging stations under survey. The authors have made an evaluation of the erosion process at those stations for the comparable mean annual flow rate values Q. By means of that analysis it was observed that the mean multiannual flow rate was altering significantly, in general decreasing in the course of time (table 1).

Table 1

Mean multiannual flow rate in 1958–2007 at the Brzeg Dolny, Malczyce and Ścinawa river gauging stations

Period	Mean multiannual flow rate SSQ (m^3/s) at the river gauging station		
	Brzeg Dolny	Malczyce	Ścinawa
1961–1990	170.5	170.0	198.0
1991–2007	150.0	142.0	167.0
1958–2007		165.0	184.0

Table 2 presents chosen synthetic results of that analysis, for similar mean annual flows equal to 150–160 m^3/s in the period 1956–2007 for the Ścinawa gauging station.

Table 2

The alteration of mean annual water levels and the ordinates as a function of the average flow SQ in the Malczyce and Ścinawa river gauging stations in 1956–2007

Year	SQ (m^3/s)	Malczyce	Ścinawa	
		Datum (m AMSL)	T_{av} (cm)	Datum (m AMSL)
1956	154	96.83	256	89.28
1960	159	96.77	257	89.29
1973	159	96.19	240	89.12
1984	160	95.24	201	88.73
1992	156	95.33	219	88.91
1994	154	95.27	219	88.91
1995	157	96.15	225	88.97
2000	160	95.38	228	89.00
2007	150	95.02	206	88.78

On the basis of table 2 it may be concluded that the lowering of the mean datum of the water level, in the conditions of similar mean annual flows, equalled:

- 1.81 m at the Malczyce river gauging station,
- 0.50 m at the Ścinawa river gauging station.

4. INDIRECT ASSESSMENT OF RIVERBED BOTTOM EROSION PROCESS OF ODRA RIVER ON THE BASIS OF HYDROMETRIC TESTS OF MEAN RIVER BOTTOM LEVEL AT MALCZYCE AND ŚCINAWA RIVER GAUGING STATIONS

The authors have carried out a similar evaluation of the erosion process of the riverbed bottom on the basis of the analysis of the measurements at the river gauging

stations under survey, that is, Malczyce and Ścinawa. The changes of the bottom's mean datum at these stations have been illustrated by table 3 and figures 5.

Table 3

Mean datums of the riverbed bottom levels in line with selected measurements (Institute of Meteorology and Water Management) in 1956–2008 at the Brzeg Dolny, Malczyce and Ścinawa gauging stations

Year of mesurement	Brzeg Dolny	Malczyce	Ścinawa
1956	99.49	94.41	87.20
1957			
1958			
1959	99.15		86.95
1960			87.18
1961		94.25	87.22
1962	99.29	94.58	87.56
1963			87.37
1964	99.25	94.78	87.24
1965			87.14
1966		94.63	87.38
1967	98.92		87.48
1968		94.45	87.68
1969		94.15	87.15
1970	98.73		87.59
1971		94.13	
1972			87.34
1973	98.6	93.97	87.11
1974		94.28	
1975			87.3
1976		93.98	
1977			87.53
1978			87.24
1979	98.32	93.79	
1980			87.39
1981		93.75	
1982	98.23		87.24
1983		93.14	
1984		93.18	87.12
1985	98.26		
1986			
1987		93.31	
1988			87.66
1989		92.96	87.22
1990	97.83		86.86
1991		92.82	86.88

Table 3 continued

1992			86.85
1993		92.84	86.83
1994	97.88		87.11
1995		92.93	86.83
1996		93.47	86.99
1997		93.01	86.98
1998			86.79
1999	97.75	92.79	86.75
2000			86.78
2001			86.37
2002	97.59	92.45	
2003			86.44
2004	97.03	92.78	86.24
2005	97.57	92.71	86.84
2006	96.39		
2007		92.75	86.59
2008	96.39	92.37	86.72

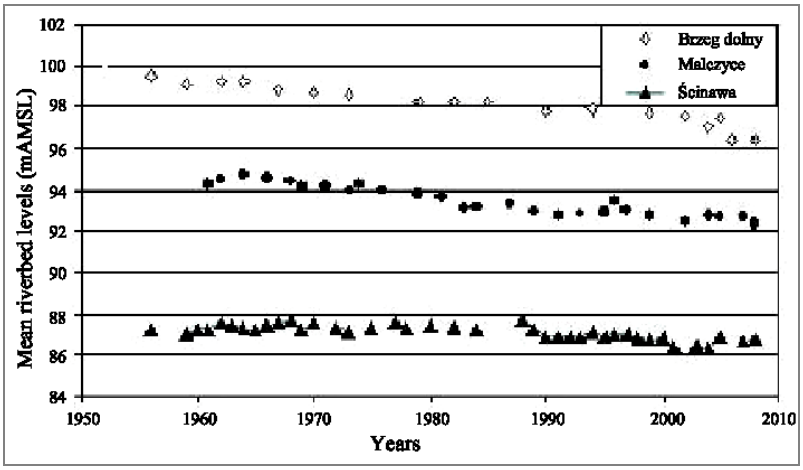

Fig. 5. Changes of the riverbed bottom's datum T_{av} (m AMSL) at the river gauging stations of Brzeg Dolny, Malczyce and Ścinawa according to the Institute of Meteorology and Water Management in the years 1956–2008

Table 3 and figure 5 imply that in the period of 1956–2008 the bottom T_{av} lowered at particular river gauging stations in the following way:

- in Brzeg Dolny – from 99.49 m AMSL to 96.39 m AMSL, i.e. by 3.10 m,
- in Malczyce – from 94.41 m AMSL to 92.37 m AMSL, i.e. by 2.04 m,
- in Ścinawa – from 87.20 m AMSL to 86.72 m AMSL, i.e. by 0.48 m.

5. SUMMARY

Once the results of the approximate evaluation of the erosion process have been compared, it may be stated that between 1956 and 2008 the following decrease of levels occurred at the Malczyce and Ścinawa river gauging stations:

- the mean annual datum of the water level lowered by 1.81 m in Malczyce and by 0.50 m in Ścinawa,
- the mean annual datum of the riverbed bottom lowered by 2.04 m in Malczyce and by 0.48 m in Ścinawa.

The values are comparable and they make it possible to prepare a preliminary estimation of how much material is necessary to fill up areas of the erosion damage.

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