Environment Protection Engineering

Vol. 36 2010 No. 1

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DISTRIBUTION OF GRAIN SIZE AND ORGANIC MATTER CONTENT IN SEDIMENTS OF SUBMONTANE DAM RESERVOIR

A spatial distribution of both sediments (in terms of their texture) and organic matter in the Dobczyce Reservoir (southern Poland) was studied. Texture of the sediments in a central part of the reservoir showed clay-silty character and reflected the types of soil covers in the Raba River catchment basin. Texture of the sediment was more diverse in the bank zones and reflected texture of rock and soils covering the direct basin. Organic matter content in the sediments was lower in the shallow part of the reservoir (except Wolnica Bay) compared with the deeper one. The relationships between the grain fractions, organic matter contents and reservoir depth are discussed.

1. INTRODUCTION

Texture of the reservoir sediments is related to many factors, including climate, river basin lithology, soils, and land use management. These factors influence the efficiency of chemical and mechanical weathering and erosion processes within the basin [27]. Sedimentation of material in reservoirs depends on factors which vary with time and in space, i.e. water flux that affects transport processes, the allochthonous sediment discharge, hydrodynamic flow pattern, as well as reservoir morphometry, resuspension and deposition of sediment, and abrasion processes [1], [6], [7], [10], [25], [28]. The interactions among all these factors influence the rate of suspension sedimentation and sediment texture.

Organic matter content in the reservoir sediments is influenced by many factors, e.g. allochthonous discharge of organic matter and nutrients, reservoir morphometry, current velocity (which favours creation of lentic and lotic zones), authogenic primary productivity, diagenesis processes, and resuspension [7], [26].

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The influence of particle size and organic matter content on heavy metal and contaminant content in reservoir sediment was clearly demonstrated [27]. Therefore spatial and temporal variability in the particle size composition is of a primary importance in the understanding of sediment–water interactions. There is little descripiton of a spatial distribution of organic matter and grain size composition of sediment of submontain dam reservoirs in Poland. Organic matter and grain size of the sediment in the Dobczyce Reservoir was reported by WÓJCIK [29], SZAREK-GWIAZDA [23], [24], and RECZYŃSKI et al. [20]. However, these investigations were limited to a few stations.

The aim of the present study was to determine a spatial distribution of grain size and organic matter content in the sediment of the Dobczyce Reservoir, typical of submountain part of Polish Carpathian. Sampling stations were located in the whole area of the reservoir.

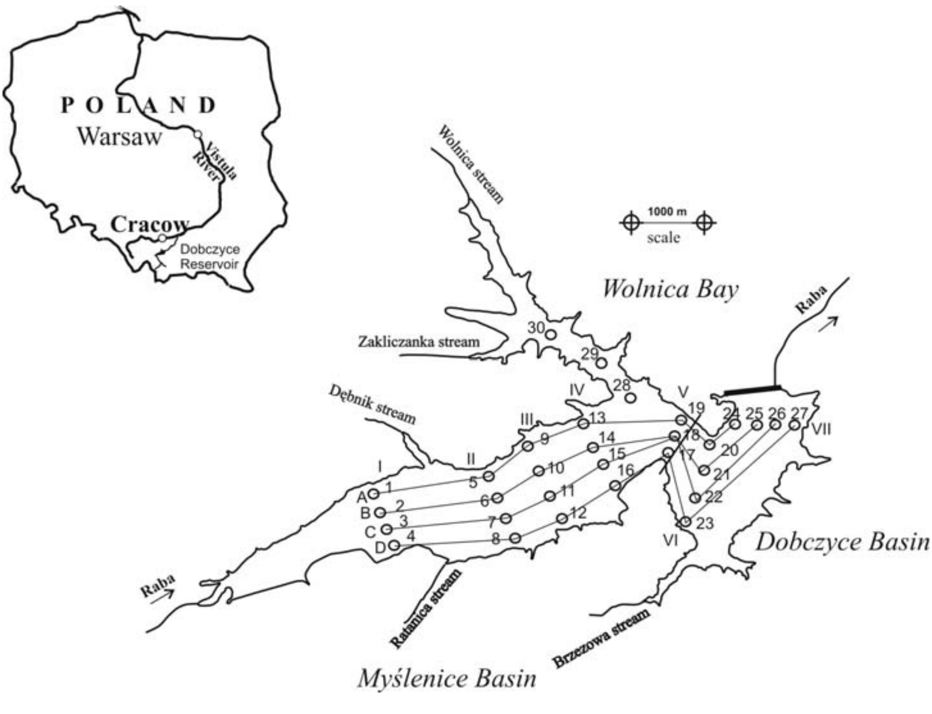
2. MATERIAL AND METHODS

2.1. STUDY AREA

The Dobczyce Reservoir situated on the Raba River (southern Poland) was put into operation in 1986. Its main function is to supply the Kraków agglomeration with potable water. The capacity of the Dobczyce Reservoir is 99.2 mln m^3, the length of about 11 km, the area of ca. 1000 ha, and average water exchange occurs 3.6 times a year [13]. As a result of a natural topografic profile the Dobczyce Reservoir consists of three distinct parts: the Myślenice Basin (steep banks prevail, mean depth of 9.9 m), the Dobczyce Basin (steep banks prevail, mean depth of 16.4 m), and Wolnica Bay (flat banks, mean depth of 4.9 m) (the figure) [2]. The Myślenice Basin has riverine character, the Dobczyce Basin – lacustrine, while Wolnica Bay – pond's one. Wolnica Bay is the most "littoral" part of the reservoir, while the size of the littoral in the Dobczyce Basin is small. Shallow part of the Dobczyce Basin is Brzezowa Bay. Left-side tributaries of the reservoirs are Dębnik, Zakliczanka, and Wolnica, while the ride-side ones – Bulinka, Trzemeśnianka, Ratanica, and Brzezówka.

The catchment basin of the reservoir has 768 km^2. The Raba River rises in the Carpathian belt of the Gorce Mountains. The Beskids part of the catchment basin of the Dobczyce Reservoir is composed of sandstone shale formations of the Magura series and of the Submagura beds. The substratum of a submontane part of the basin is built of Silesian formations of various ages and varied mosaic distribution [17]. Different types of soil were formed on the Carpathian Flysch. The Beskids part of the catchment is covered mainly with brown acid soil of silt loam or silty clay loam texture. Occasionally brown soils and leached brown soils occur there [9]. In the Pogórze

Wielickie (the left bank of the reservoir), the soils of silt, silt loam or silty clay loam texture [9] belonging to Haplic and Stagnic Luvisols are dominant. Smaller area (especially of the catchment of the Dębnik stream) is covered with loamy sand and sandy clay loam soils belonging to Podzols and Dystric Cambisols. These textures dominate also on the right bank of the Dobczyce Reservoir, i.e. in the Wiśnickie Pogórze [14]. Only in the area of Wolnica Bay loess soils prevail. In the land use of the catchment basin, fields, pastures, meadows, and orchards which constitute 51.5% of the total area predominate, while the deciduous and mixed forest occupies about 41.1% [13].



Map of the Dobczyce Reservoir with sampling points

2.2. METHODS

The upper layer (0–5 cm) of the sediment was taken from 30 stations located in the Dobczyce Reservoir in May 2007. 27 stations were situated along 7 crosswise transects (I – stations 1, 2, 3, 4; II – stations 5, 6, 7, 8; III – stations 9, 10, 11, 12; IV – stations13, 14, 15, 16; V – stations 17, 18, 19; VI – stations 20, 21, 22, 23; VII – stations 24, 25, 26, 27) and 4 lengthwise transects (A – stations 1, 5, 9, 13, 19, 20, 24; B – stations 2, 6, 10, 14, 18, 21, 25; C – stations 3, 7, 11, 15, 18, 22, 26; D – stations 4, 8, 12, 16, 17, 23, 27). Additionally, 3 stations were located in Wolnica Bay (the figure). From each station 4–5 subsamples were taken. Organic matter content was estimated by loss on ignition (LOI) at 550 ^{o}C for 2 hr. The grain fractions were determined using aerometric method [16]. There were determined the following fractions: coarse sand (1.0–0.1 mm), fine sand (0.1–0.05 mm), coarse and medium silt (0.05–0.02 mm), fine silt (0.02-0.002 mm), and clay (<0.002 mm) according to Polish Society of Soil Science [19].

The significance levels of differences in grain size between the lengthwise transect were determined using the Manna–Whitney test [22].

3. RESULTS

3.1. GRAIN SIZE

The spatial distribution of grain size differed considerably in the reservoir sediment. The distributions of coarse and fine sands (1.0–0.1 and 0.1–0.05 mm) in the sediment were similar. Their amount in the sediment collected from 17 stations was very low (in total <10%). Those stations were situated in the upper (stations 3 and 4) and middle parts of the Myślenice Basin and in the Dobczyce Basin (except stations 23 and 24) as well as in Wolnica Bay. Higher amount of sands was found in the sediment at stations 1 (18%) and 2 (37%) situated along in the transect 1, stations 5 (61%), 9 (46%), and 13 (21%) on the left bank and stations 8 (33%), 12 (46%), and 16 (28%) on the right bank of the Myślenice Basin, in the narrowest part of the reservoir (stations 17, 18, 19), and at stations 23 (Brzezowa Bay) and 24 in the Dobczyce Basin.

Similarly, the amount of coarse and medium silt (0.05–0.02 mm) was low (< 10%) at the stations situated in the middle part of the Myślenice Basin and in the Dobczyce Basin (all stations near the dam). Its higher amounts (10–30%) occurred along the transect 1 (stations 1–4), on the left-bank and right-bank of the Myślenice Basin (stations 5, 6, 12, 17, 19), in Brzezowa Bay of the Dobczyce Basin (station 22), and in Wolnica Bay. The highest amounts of coarse and medium silt (30–37%) were found in the sediment near the shore line of the Myślenice Basin (stations 8, 9, and 13) and at station 23 (Brzezowa Bay, the Dobczyce Basin).

The amount of fine silt (0.02–0.002 mm) was characterized by considerable differentiation (11–80%) in the sediment of the reservoir. Its lowest amount (10–30%) occurred in the sediment near the banks of the the Myślenice Basin and in Brzezowa Bay (station 23, the Dobczyce Basin), while in higher amount (30–50%) it was found in the sediment of the Dobczyce Basin and at stations 1, 16, 17, and 18 in the Myślenice Basin. The amount of fine silt ranged from 50 to 60% in Wolnica Bay. Its higher amount (50–70%) was found in the sediment in the upper (stations 3 and 4) and middle parts of the Myślenice Basin, where it also reached the highest amount (71%, station 7).

Smaller amounts (0–20%) of clay (<0.002 mm) occurred in the sediment along the transect 1 (stations 1–4) and near the shoreline of the Myślenice Basin, at station 23 (Brzezowa Bay, the Dobczyce Basin), and in Wolnica Bay (except station 30). Greater amount of this fraction (20–50%) was measured in the sediment of a deeper part of the Myślenice Basin, in the Dobczyce Basin, and at station 30 in Wolnica Bay. The greatest amount of clays occurred at stations 25 (51%) and 26 (53%) near the dam.

To sum up, fine silt (0.02–0.002 mm) dominated in the sediment in 19 stations of the Dobczyce Reservoir. These stations were situated in the middle part of the Myślenice Basin (11 stations), Wolnica Bay (3 stations), and the Dobczyce Basin (5 stations). Coarse and fine sands as well as coarse and medium silt prevailed in the sediment of 7 stations situated on the right and left banks of the Myślenice Basin and in Brzezowa Bay (the Dobczyce Basin), while clay at 4 stations located at Dobczyce Bay, three of them were near the dam.

Table 1

Means, standard deviation (SD), and coefficients of correlation (CV) of grain size content along crosswise transects of the Dobczyce Reservoir

Transect		Grain size (mm)				
		Coarse sand (1.0–0.1)	Fine sand (0.1–0.05)	Coarse and medium silt (0.05–0.02)	Fine silt (0.02–0.002)	Clays (<0.002)
I	Mean (%)	6.5	9.8	20.3	49.5	14.0
	SD	5.8	10.1	5.4	17.3	2.9
	CV	0.89	1.04	0.27	0.35	0.21
II	Mean (%)	14.5	11.3	15.5	42.8	16.0
	SD	15.5	13.1	12.4	28.0	6.4
	CV	1.07	1.16	0.80	0.65	0.40
III	Mean (%)	18.5	9.3	15.0	37.3	20.0
	SD	18.0	11.2	14.3	27.6	11.1
	CV	0.97	1.21	0.95	0.74	0.55
IV	Mean (%)	10.0	4.3	11.5	42.3	32.0
	SD	8.6	4.0	15.9	11.2	13.2
	CV	0.86	0.95	1.38	0.27	0.41
V	Mean (%)	18.0	11.7	10.7	30.3	29.3
	SD	10.6	1.5	9.3	9.0	10.7
	CV	0.59	0.13	0.87	0.30	0.36
VI	Mean (%)	7.3	7.0	17.3	39.8	28.8
	SD	7.3	7.8	15.5	14.1	16.5
	CV	1.00	1.11	0.90	0.36	0.57
VII	Mean (%)	4.3	2.5	5.0	41.5	46.8
	SD	6.6	2.5	3.7	5.7	6.8
	CV	1.54	1.01	0.73	0.14	0.14

In general, fine silt (0.02–0.002 mm) dominated along both lengthwise and crosswise transects (except transect VII, table 1). Taking into consideration the crosswise transects, the highest mean amount of coarse sand (18.5%) was found along the transect III (causing its high amount at bank stations 9 and 12), and that of coarse and fine sands – along the transect V in the narrowest part of the reservoir (table 1). The highest mean amounts of silts (0.05–0.02 mm and 0.02–0.002 mm) were measured along the transect I (stations 1–4) near the place where the Raba River flows into the reservoir. Greater amount of clays (<0.002 mm) occurred in the sediment of a deeper part of the Dobczyce Reservoir (transects IV–VII) and they dominated near the dam (transect VII).

Table 2

Means, standard deviation (SD), coefficients of correlation (CV) of grain size content along lengthwise transects of the Dobczyce Reservoir

Transect		Grain size (mm)				
		Coarse sand (1.0–0.1)	Fine sand (0.1–0.05)	Coarse and medium silt (0.05–0.02)	Fine silt (0.02–0.002)	Clays (<0.002)
A	Mean (%)	17.6	13.4	19.3	28.1	21.6
	SD	12.8	8.3	10.7	13.5	13.0
	CV	0.73	0.62	0.55	0.48	0.60
B	Mean (%)	6.6	4.9	7.1	47.9	33.6
	SD	5.8	8.4	9.0	13.6	14.4
	CV	0.88	1.73	1.26	0.28	0.43
C	Mean (%)	5.4	2.7	6.1	53.1	32.6
	SD	4.3	3.6	8.3	12.9	13.6
	CV	0.79	1.32	1.35	0.24	0.42
D	Mean (%)	15.0	10.6	20.3	33.4	20.7
	SD	14.2	7.1	11.8	15.2	13.5
	CV	0.95	0.67	0.58	0.46	0.65

Taking into consideration the lengthwise transects, the higher mean amounts of coarse and fine sands as well as coarse and medium silt were recorded on the left bank (transect A) and the right bank (transect D) of the Dobczyce Reservoir in comparison with centrally laid transects B and C. Radically different situation arose in the central part of the reservoir (transects B and C) where the amounts of fine silt and clays were higher compared with those on the bank one (transects A and D). Statistical calculations show that the texture of sediment on the left bank and right bank (transects A and D) as well as in the central part of the reservoir (transects B and C) was similar (table 2). Greater amount of fine sand was measured in the sediment along the transect A (left bank) than along the transect C (central part; $U = 8$, $p < 0.05$), and also along the transect

D (the right bank) compared with the transect C ($U = 8$, $p < 0.05$). The amounts of coarse and medium silt in the sediment along the bank transects A and B were greater than those along centrally laid transects B and C (transects: A–B and A–C: $U = 7$, $p < 0.05$; transects D–B: $U = 7$, $p < 0.05$; transects D–C: $U = 6$, $p < 0.05$). The sediments along transects B and C were richer in fine silt than those along transect A ($U = 7$, $p < 0.05$; $U = 3$, $p < 0.05$, respectively). The amounts of coarse sand and clays in the sediment of the transects studied were similar. The variability of the amounts of fine silt and clays in the sediment was lower compared with that of sands and coarse and medium silt both along the lengthwise and crosswise transects (tables 1 and 2).

Statistical calculations showed the positive correlations between the reservoir depth and the amount of clays for all the stations ($r = 0.92$) and for the transects: A ($r = 0.87$), B ($r = 0.94$), C ($r = 0.99$), and D ($r = 0.93$). Negative correlations were found between the reservoir depths and the amount of coarse and medium silt for all the stations ($r = -0.72$) and the transects: A ($r = -0.62$), B ($r = -0.86$), C ($r = -0.63$), and D ($r = -0.81$) as well as between the reservoir depth and the amount of fine sand in the transects A ($r = -0.76$) and B ($r = -0.58$), and fine silt in the transect C ($r = -0.75$).

3.2. ORGANIC MATTER

The sediments in the Dobczyce Reservoir were poor in organic matter (2.1–8.5%). Its lowest amount (2–4%) occurred in the sediment at the station on the right and left sides of the Myślenice Basin and the Dobczyce Basin. In the upper part of the Myślenice Basin and in the central part of the Dobczyce Basin, its amount ranged between 4 and 6%. Higher amount of organic matter (6–8%) was measured at 11 stations in a central part of the Myślenic Basin along the long axis of the reservoir and in Wolnica Bay (station 29). The sediment at station 30 (Wolnica Bay) was the richest in organic matter (8.5%).

The relationship between organic matter content and grain fraction and the reservoir depth was established. The amount of organic matter was found to be negatively correlated with the amount of coarse sand ($r = -0.79$), fine sand ($r = -0.72$), and coarse and medium silt ($r = -0.62$). The positive correlations were established between the amount of organic matter and the amount of fine silt ($r = 0.75$), clay ($r = 0.63$) and reservoir depth ($r = 0.60$). In the last case, only stations 1–27 laid along the long axis were taken into consideration.

4. DISCUSSION

In general, the sediment in a central part of the Dobczyce Reservoir has silty clay character reflecting the geological conditions and soil texture, mainly of silt loam and silty clay loam, prevailing in the Raba River catchment basin. The catchment geology and thus the particle size composition of suspended sediment were of fundamental importance in its fluvial transport [27]. According to [27] the relationship between grain size characteristics of suspended sediment and those of its source material is modified by the selectivity of erosion and delivery processes. Grain size of sediment in dam reservoirs related to soils texture of the catchment basin was earlier reported by JASIEWICZ and BARAN [8], LIGĘZA and SMAL [10]. Loess soils in the catchment basin of the Dłubnia River are responsible for a silty character of the sediment of the Zesławice Reservoir [8]. According to these authors silty loam and silty clay loam soils which dominate the main part of the catchment basin of the Wisłoka River affect fine fraction (<0.02 mm) predomination in sediment of the Krempna Reservoir. Silty fraction which dominates in the granulometric fractions of the sediment of the Zemborzyce Reservoir reflects the loess and loess-like soils that prevail in the Bystrzyca catchment basin [10].

Texture of the sediment in the bank zone of the Dobczyce Reservoir was more diverse compared with that in the central zone and reflected texture of rock and soils covering direct catchment basin. In the Myślenice Basin and in the part of the Dobczyce Basin (Brzezowa Bay), greater amount of sands was found. In the catchment basin of the left-bank tributary (Dębnik stream, the Myślenice Basin), loamy sand and sandy clay loam soils [14] rich in sands dominated. The catchment basin of the Ratanica stream (right-bank tributary, the Myślenice Basin) is covered mainly with sandy loam soil (72.7%) [14] consisting mainly of sands (1.0–0.1 mm; 60–89%). Near this area (stations 5, 8, 9, and 12) high amount of sands in the reservoir sediments was found. The similar amount of sands (36%) was also observed in the sediment of Brzezowa Bay (the Dobczyce Basin). In the catchment basin of the Brzezówka stream (right-bank tributary, the Dobczyce Basin), silt loam (87.6%) soils prevailed [14] which can comprise higher amount of sands (25–64%) and clays (36–50%). Such a relation indicated that sediment texture was influenced by abrasion, erosion, and resuspension processes taking place in bank zone. Due to large and irregular water level fluctuations most sediments of the Dobczyce Reservoir are inundated which prevents the establishment of littoral flora. Lack of submerged vegetation did not reduce local resuspension influenced by wind-generated waves. Erosion and resuspension of floodplain sediment increase high loadings of suspended material from drainage basin sources [6]. The relation between soil texture in the direct catchment basin and the sediment is well seen in the case of Wolnica Bay. Loess soils that have texture of clay and silty clays and occur in the basin (84.4% in the basin of the tributaries of Wolnica stream and Zakliczanka stream) [9] affect silty character of the sediment of Wolnica Bay (stations 28–30). This is confirmed by an earlier study by NACHLIK and BOJARSKI [15] who report that the part of Wolnica Bay and bank zone are not affected by water mass movement of the Dobczyce Reservoir. These authors indicate also that under selected conditions of water flow, wind-induced wave, temperature etc., a few of water circulation zones may occur in the reservoir.

The sediment distribution in terms of its texture in crosswise section of the Myślenice Basin, i.e. larger amounts of coarse fractions (sands and coarse and medium silt) in the shallow part (except stations 1–4) and fine fractions in the deeper part, is similar to those found in other dam reservoirs [1]. In shallow erosion zone, the sediment is usually sandy, in deeper profundal zone clay-silty, while in sublittoral one, where the transport of suspended sediment occurs, its grain size may vary. Both resuspension of fine particles from a shallow area and its secondary deposition in a deeper part of the water body affect significantly texture of sediment in shallow part of the reservoir [1], [25], [28]. LIGĘZA and SMAL [10] have found high amount of sands in the sediment along a sandy bank zone, where abrasion processes occur, in the Zemborzyce Reservoir. Such a texture of the sediment along the crosswise transect of a lacustrine part of the Dobczyce Reservoir, i.e. the Dobczyce Basin, was not observed. Large amount of sand occurred also in the narrowest part of the Dobczyce Reservoir. Abrasion processes as well as faster current velocity can influence sedimentation of suspended material. Similarly, in the Zemborzyce Reservoir higher amount of sands occurred in its narrow part [10].

A spatial distribution of grain size in the sediment of the Dobczyce Reservoir was related to the reservoir depth. The amount of clays increased and that of coarse and medium silt decreased with an increase in the reservoir depth. Coarse and medium silt was deposited mainly in the upper part of the reservoir, while clays near the dam. An increase in the amount of clays in the sediment with the reservoir depth was observed in other reservoirs [10]. The area along the long axis of the reservoir can be divided into three distinct zones: a riverine zone, a zone of transition, and a lacustrine zone [28]. The deposition of sediment is large in the riverine zone and decreases expontentially down the reservoir. A great part of coarse material (sands) is deposited in a riverine zone, while in a lacustrine one mainly fine fraction can be found [1]. In the sediment of the Dobczyce Reservoir, fine fractions dominated. Coarse material was deposited in the upper part of the reservoir which had no interst for us. RECZYŃSKI et al. [20] found large amount of sand (0.1 mm; 55.4%) in the sediment in the mouth of the Raba River.

The sediment of the Dobczyce Reservoir poor in organic matter (LOI) was similar to those found in other submountain reservoirs, i.e. the Solina Reservoir (2.92–5.66%), the Myczkowce Reservoir (4.24–4.78%), the Rożnów Reservoir (2.41–3.08%), the Czchów Reservoir (2.14–2.25%), the Tresna Reservoir (2.43–4.63%), the Porąbka Reservoir (1.47–2.64%), and the Goczałkowice Reservoir (3.08–5.35%) [18]. Small amount of organic matter is caused by high load of mineral suspended matter in the submountain reservoirs. Larger amounts of organic matter were determined in the reservoirs situated in the Upper Silesia, i.e. in the Rybnik Reservoir [12] and the Kozłowa Góra Reservoir (5–34.2%) [21], and the lowland Włocławski Reservoir (<5–50%) [5].

Organic matter content in the sediment of the Dobczyce Reservoir was related to the reservoir depth. Lower amount of the organic matter was found in a shallow part of the reservoir (except Wolnica Bay) which reflected poor establishment of littoral flora as mentioned above. The backwater of a central part of the Myślenice Basin and a deep part of the Dobczyce Basin was quite richer in organic matter. Such a relationship was also typical of the Włocawski Reservoir [1], [15]. According to TROJANOWSKI and BRUSKI [26] and GIERSZEWSKI et al. [15] organic matter is mainly deposited in the deepest part of water bodies, because the rate of its decomposition at low temperature and dissolved oxygen content are lower there compared with the shallow part.

The greatest content of organic matter was found in Wolnica Bay which has a pond character and is rather rich in macrophytes. It is rather shallow (mean depth of 4.9 m) and has a polymictic part. The basin of small tributaries (the Wolnica and Zakliczanka streams) has mainly agricultural character. A cultivated area constitutes ca. 67.7 and ca. 72%, respectively, while forests only 11.7 and 10%, respectively. Wolnica Bay is rich in mineral particles, because loess present in the catchment basin easily erodes away [3]. The waters of the Zakliczanka and the Wolnica streams rich in nutrients stimulate the growth of macrophytes and algae in Wolnica Bay. Completely different observations made by LIGĘZA and SMAL [11] in the Zemborzyce Reservoir revealed higher amount of C_{org} in the sediment near the forest and lower one near the bank where agricultural activity predominated. The sediments of the Zemborzyce Reservoir were supplied with allochthonous DOC mainly from the forest catchment basin.

The relations between the amount of organic matter and the amount of fine silt and clays found in the present studies confirmed that in aquatic environment organic matter is usually transported with mineral material and deposited in the sediment. In water, fine mineral particulate and colloidal matter are covered with organic matter coatings [4]. The relationship between the amount of fine fraction (<0.02 mm) and the organic matter content was also found in the Włocławski Reservoir [1], while it was not shown in the Zemborzyce Reservoir [11].

5. CONCLUSION

Texture of the sediments in the central part of the riverine Myślenice Basin and in the lacustrine Dobczyce Basin showed clay-silty character and reflected the types of soil covers in the Raba River catchment basin. Texture of the sediment was more diverse in the bank zones and reflected texture of rock and soils covering the direct basin. Higher amount of sand and coarse and medium silt was found in the sediment only in some parts of right bank and left bank of the Myślenice Basin and a shallow part of the lacustrine Dobczyce Basin (Brzezowa Bay). The narrowest part of the reservoir was rich in sand. The sediment of the shallow part of the reservoir, i.e. Wolnica Bay, was characterized by considerable amount of fine silt reflecting losses soils covering the catchment basin. Coarse and medium silt was deposited mainly in the upper part of the reservoir, while clays were near the dam. Their occurrence in the sediment was related to the reservoir depth. The sediment comprised small amount of organic matter (LOI), especially in the shallow part of the reservoir (except Wolnica Bay). The relationship between the amount of organic matter and the fine silt and clays confirmed that organic matter was transported with mineral material and then deposited on the bottom.

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