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Physical, chemical and rheological characteristics of bottom sediments in reservoirs and fish ponds, Poland

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Abstract This paper examines the physical, chemical and rheological properties of bottom sediments in a small reservoir and four fish ponds in Poland. The results show that reservoir sediment was coarser and had lower concentrations of organic matter than fish-pond sediment. Concentrations of NO_3^-, Cu, Zn, Ca and Mg were higher in reservoir sediment and generally decreased across the reservoir from the inlet to the outlet. In laboratory experiments, the plastic viscosity (η_p) and yield stress (τ_0) increased with sediment concentration. Knowledge of these properties can be used to assess the appropriateness of using either a mechanical or hydraulic method for sediment removal.

INTRODUCTION

Reservoirs are important for the deposition of sediment from rivers. Although sedimentation processes have been examined in large reservoirs (Bednarczyk & Lubowiecka, 1995; Bortland & Miller, 1958; Graf, 1983; Parzonka *et al.*, 1997), less information is available on the rates and magnitudes of these processes in small agricultural reservoirs. Fish ponds are a special type of reservoir characterized by their ecological significance, small volume, depth and source of water supply to the pond. In Poland, conduits transport water but also supply sediment to many fish ponds.

Physical, chemical and rheological characteristics of sediment as well as the geometry and flow conditions of a reservoir govern the rates and magnitudes of sedimentation in reservoirs and fish ponds. Given differences in sediment supply and variable sediment chemistry from various land-use types, there is concern about sediment infilling and the potential effects on the water quality of reservoirs. Consequently, techniques are required to determine the most appropriate method for sediment removal (Livecka *et al.*, 1962). The objective of this paper is to examine the physical, chemical and rheological characteristics of bottom sediment in small reservoirs and fish ponds to determine the appropriate method of sediment removal.

METHODS

The study was conducted in an agricultural retention reservoir, located in the western part of the Polish Carpathian Mountains and four fish ponds located on the

Carpathian Plateau (Bednarczyk & Lubowiecka 1995; Madeyski, 1998). The Krempna retention reservoir contains approximately 115 × 10^3 m^3 of water with an average depth of 3.2 m. The reservoir has a 145 m dam with a concrete weir.

The surface area of the four fish ponds (Dwojka, Nierodek, Beznazwy, Topolowy) ranges from 0.5 to 4.0 ha and the average depth ranges from 1 to 1.5 m. These ponds contain mainly carp. Differences in the quantity delivered as well as the physical, chemical and rheological properties of sediment result from physiographic catchment properties. In each of the fish ponds samples of bottom sediments were collected from three sections: closest to the weir, the middle section and at the pond inlet. Bottom sediment properties including wet and dry density, median diameter (D_{50}), percentage >50 μm and >20 μm and percentage of organic matter were determined according to standard methods. Sediments were analysed for micro elements (NO_3^-, Ca, Mg) and macro elements (B, Cu, Zn) in the upper (0–0.2 m) and lower (0.3 m) sections of the sediment profiles using standard methods.

The rheology of the reservoir and fish-pond sediments was determined using a rotating viscometer with two coaxial cylinders (Rheotest—2 type) and variable sediment concentration (C_V). The sediment–water mixture was placed between two cylinders of radii R_W (inner, rotating) and R_Z (outer, fixed) and measured using a pseudo-flow curve. All the pseudo-curves were approximated with a two-parameter Bingham model (Kemblowski, 1973; Parzonka *et al.*, 1997). For each curve, rheological properties (plastic viscosity η_p and yield stress τ_0) were determined for various sediment concentrations (C_V). The relationship τ_0 = f(C_V) was determined for the reservoir and fish pond sediment (Fig. 1). A yield stress of τ_0 = 1.5 Pa,

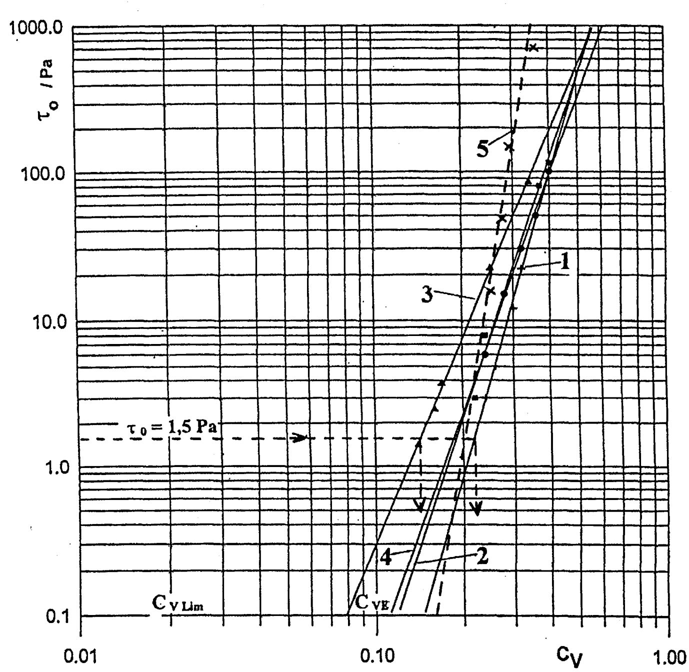

Fig. 1 Yield stress (τ_0) for sediments: 1: Dwojka pond; 2: Nierodek pond; 3: Beznazwy pond; 4: Topolowy pond; 5: Krempna Reservoir.

Table 1 Physical characteristics of bottom sediments in fish ponds and the reservoir.

Name of pond or reservoir	Area (ha)	Density of solid particles ρ_s (kg m^{-3})	Wet sediment density ρm (kg m^{-3})	Organic matter (%)	Sediment size characteristics: D_{50} (μm)	< 50 μm (%)	< 20 μm (%)
Dwojka	3.75	2490	1467	12.2	14	69	37
Nierodek	2.10	2420	1612	13.2	18	63	44
Beznazwy	2.15	2480	1581	22.9	12	67	50
Topolowy	0.60	2390	1570	13.4	41	50	30
Krempna	3.50	2610	1160	6.5	57	39	23

Table 2 Chemical features of examined bottom sediments.

Name of pond or reservoir	Level	Macro elements (mg kg^{-1}): NO_3	Ca	Mg	Micro elements (ppm): B	Cu	Zn
Inlet section							
Dwojka	upper	9	2950	170	0.4	8	22
	lower	10	2190	180	0.3	8	23
Nierodek	upper	6	1370	87	0.5	7	20
	lower	6	1240	93	0.4	7	18
Beznazwy	upper	7	1520	100	0.4	8	19
	lower	8	1330	100	0.3	7	21
Topolowy	upper	14	5420	153	>5	18	60
	lower	16	3820	178	>5	17	50
Krempna	upper	24	7930	230	>5	21	80
	lower	25	6720	250	>5	18	70
Middle section							
Dwojka	upper	9	2190	180	0.4	7	31
	lower	10	2120	180	0.3	7	20
Nierodek	upper	6	1300	80	0.4	7	18
	lower	6	1180	87	0.3	7	16
Beznazwy	upper	8	1390	100	0.5	7	21
	lower	8	1270	108	0.3	6	24
Topolowy	upper	15	3950	172	>5	16	50
	lower	15	3060	178	>5	14	40
Krempna	upper	23	7760	220	>5	20	80
	lower	23	6380	240	>5	17	70
Outlet section							
Dwojka	upper	9	1920	170	0.4	7	22
	lower	10	1030	180	0.3	7	20
Nierodek	upper	6	1240	74	0.5	7	18
	lower	6	1180	87	0.4	7	16
Beznazwy	upper	8	1460	95	0.6	7	23
	lower	8	1270	114	0.5	6	21
Topolowy	upper	15	3820	165	>5	14	50
	lower	16	2550	172	>5	12	40
Krempna	upper	23	7240	220	>5	19	70
	lower	22	6200	250	>5	15	60

adopted by Migniot (1968), was used as the boundary condition between "easy" and "difficult" erosion. "Easy" erosion does not require the use of heavy equipment to remove sediment (Migniot, 1968). According to this criterion, sediment removal by flowing water (hydraulic erosion) is possible if τ_0 in bottom sediments does not exceed 1.5 Pa.

RESULTS

Physical properties of bottom sediments from the ponds and reservoir are presented in Table 1. The data show that reservoir sediments are much coarser than fish-pond sediments. Water in the Topolowy fish pond is supplied directly by the river and sediment in this fish pond is coarse grained (D_{50} = 41 μm). Conduits supply water and coarse sediment to the other ponds. The organic content in reservoir sediment is much lower than in fish-pond sediment, which was also reported by Parzonka (1966). The bottom sediments of fish ponds have an organic content 10% higher than reservoir sediment. The organic matter content is higher in the upper sediment layers of fish pond and agricultural reservoir sediment.

Chemical properties of reservoir and fish-pond sediment varied depending on the sample depth. Sediment collected at the sediment/water interface had higher concentrations of calcium whereas deeper sediment layers were characterized by higher levels of mineral compounds and iron. Concentrations of Cu and Zn in the Krempna

Table 3 Rheological coefficients.

No.	Name of pond or reservoir	Sediment concentration C_V	Yield stress τ_0 (Pa)	Plastic viscosity η_p
1	Dwojka	0.20	0.9	0.093
		0.24	3.0	0.201
		0.26	5.0	0.410
		0.30	12.0	0.463
		0.32	22.0	0.501
		0.36	50.0	0.551
2	Nierodek	0.24	6.0	0.345
		0.28	15.0	0.394
		0.32	30.0	0.483
		0.36	50.0	0.689
		0.40	100.0	0.903
3	Beznazwy	0.14	1.4	0.040
		0.16	2.5	0.100
		0.17	3.8	0.374
		0.25	22.0	0.508
		0.34	85.0	1.780
4	Topolowy	0.22	3.0	0.203
		0.24	10.0	0.324
		0.37	80.0	0.574
		0.40	106.0	0.856
5	Krempna	0.22	15	0.071
		0.25	47	0.085
		0.29	149	0.196
		0.31	352	0.639
		0.33	698	1.423
		0.39	1127	2.345

Reservoir were approximately twice the levels in the fish ponds and are likely derived from agricultural runoff (see Table 2).

Rheological properties of reservoir and fish-pond sediments are similar to fine-grained soils reported by Parzonka (1966). Values for the $\tau_0 = f(C_V)$ relationship were similar for fish-pond and reservoir sediment but the slope for reservoir sediment is much steeper. The transition from Newtonian to non-Newtonian behaviour of sediment/water mixture (17%) was highest for reservoir deposits, whereas the value for pond deposits was of the order of 8–14% (see Table 3).

The physical, chemical and biological characteristics of sediment will influence the degree of consolidation of bottom deposits. Small particles (<40 µm) tend to flocculate and are hard to remove from the bottom of the reservoir and ponds. Under the influence of sedimentation and consolidation, a quick densification, change of concentration and increase in viscosity take place. Immediately after entering the reservoir or pond, fresh deposits have liquid Newtonian properties. After several minutes, sediment/water mixtures have non-Newtonian properties. Further increases in sediment concentration make bottom deposits more difficult to remove using hydraulic methods, i.e. by installing a water pump. It can be seen that hydraulic removal of pond sediments is not possible, whereas sediments from the reservoir could be removed using this method for a period from a few hours to several days following the arrival of sediment in the reservoir (Madeyski & Parzonka, 1999).

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