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ANALYSIS OF SEDIMENT DEPOSIT DISTRIBUTION IN RESERVOIR AT KREMPNA

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ABSTRACT

Prediction of reservoir silting should also determine distribution of bottom sediments. Existing methods of predicting sediment distribution most frequently concern large reservoirs. In result of many-year measurements of silting of the reservoir at Krempna on the Wisłoka river the rate of its capacity reduction was determined. Results of silting measurements allowed for an assessment of distribution of sediment trapped in the reservoir. Distribution of the reservoir bottom sediments was described by Dendy's method and potential application of Roseboom-Annandale method for predicting sediment distribution in a small reservoir was estimated. Computations using the field data on sediment volume deposited in individual segments of the reservoir at Krempna were conducted to verify Roseboom-Annandale method. Basing on sediment volume trapped in the reservoir the degree of its silting was calculated for subsequent years of its operation. On this basis the rate of silting the reservoir at Krempna was calculated and the change of silting degree was determined during its operation time.

Key words: small water reservoir, silting, silting degree, sediment deposit distribution

INTRODUCTION

Small reservoirs situated in upper parts of catchments trap a considerable portion of suspended load transported by rivers. Additionally, due to surface runoff of erosion products from the catchment area, mineral material may fill in the reservoir basin in a relatively short period of time. Accumulating sediment deposit causes the bottom raises diminishing the reservoir usable area, causing negative changes of water quality and spoiling the aesthetic values of the object and the adjoining areas. The important problem is not only intensity of reservoir silting but also proper functioning of its equipment and auxiliary appurtenances. Identification of spatial distribution of accumulated sediment deposits in small reservoirs may prove helpful at the designing stage because it will allow to consider parameters determining its potential long-term operation. Papers, which have discussed these problems often have focused on large constructions where silting process may take many years and have no significant effect on a reservoir operation. The research and analyses were conducted to describe spatial distribution of sediment deposits in a small reservoir at Krempna and to assess the degree of its silting in subsequent years of operation, and determining the reservoir bottom sediment distribution using Dendy's method. On the basis of field data on sediment deposit distribution an assessment of potential application of Roseboom-Annandale method for predicting sediment distribution in a small water reservoir will be made.

CHARACTERISTICS OF THE OBJECT OF RESEARCH

The Wisłoka river belongs to the upper Vistula Basin, covering the area within three large physical-geographical units. These comprise: the Carpathian Mts., sub-Carpathian Basins and the Malopolska Uplands. The Wisłoka is a river with a secondary catchment originating in the Beskid Niski (Low Beskid) Mts. Its sources flow out of Dębi Wierch Mt. foot on the altitude of c.a. 600 m a.s.l. Total length of the Wisłoka is 163.6 km and the catchment area covers 4110.2 km^2. Along the distance of 18.6 km from its headwaters to the reservoir at Krempna, the Wisłoka river covers a partial catchment area of 165.3 km^2. Krempna river gauge profile is localized at 145.0 km of the Wisłoka river course.

The reservoir at Krempna (Fig. 1) is situated in the Wisłoka upper course.

Fig. 1. Location of reservoir at Krempna

Characteristics of catchment

Geological structure. The Magura nappe, where the Wisłoka river has its source is the most south protruding nappe of the Outer Carpathians. Its inner structure is complicated. Numerous longitudinal and transversal faults are traversed by irregular folds, broken folds and blocks. Jutting northern border of the nappe overriding forms characteristic tectonic peninsulas. The area of Magura nappe is not uniform. So called tectonic windows encountered in this area reveal the matrix on which the nappe has overridden. The tectonic windows reveal the autochthonic undisturbed Miocene layers, which fill the Carpathian Depression but primarily the layers of the Dukla unit. Shally-sandy flysch prevails in the Cretaceous deposits of the Magura nappe. Dominance of sandstones is also visible in the younger layers [9].

Topography of catchment. The catchment area is a terrain with mountain and submontane relief with numerous ground elevations exceeding 600 m a.s.l. and the highest point of the catchment Mareszka Mt. 780 m a.s.l. The elevations are divided by valleys, the bottoms of which are situated about 400 m a.s.l. It is of major importance for shaping flood-wave and the quantity of bedload carried to the Wisłoka river. Denivelations in the catchment area range between 200 and 250 m.

Soils and vegetation cover. Surface deposits in the catchment area are waste and mountainside clays formed in effect of physical weathering of basement complex rocks. Developed from firmer sedimentary and flysch rocks they occur on slopes and lower crests. They formed as loams and silty clays with prevailing more compact loamy-silty and loamy-clayey soils, which usually are average or slightly skeletal brown leached soils. They are medium deep soils, usually acid and poorly abundant in nutrients. Dusty soils, supplemented with erosion products formed at the slope-feet in valleys. Soils covering river and stream valleys are alluvial soils with sand and gravel layers and sandy-dust in places where valleys slopes are gentle [6].

Landslides formed in result of river erosion underscouring the slopes, intensive rainfall and human activities (tree clearance) were observed in the catchment area. The Wisłoka River catchment up to the Krempna profile is located within the Beskid Niski Mts. area. Beach and fir forests, coniferous forest sites with few pine coppice areas occur in the catchment area. The forests grow on slopes covered by rubbly- stony soils [8].

Land use in the catchment area. The lower part of the catchment and its flat slopes are small agricultural areas, of which only 4% are ploughlands. They are situated on gentle slopes and on wide valley bottoms. No anti-erosion measures or crop rotation are applied in the catchment area and ploughing is performed parallel to the land slopes. constitutes the Roads and built up infrastructure constitute only about 2% of the catchment area. In some places arable fields are situated on higher but less steep sections of slopes with deeper and less skeletal soils. The most frequently these are meadows and pastures. Cattle breeding developed on this terrain, therefore grasslands make up over 14% of the area. The cropland area has been slightly increasing due to progressive unprofitability of cattle farming.

Due to its mountain character, the catchment area is to a greater extent a forest ground. Terrains occupied by the forests make up about 80% of the catchment area. A larger portion of them belongs to the Magura Landscape Park. In forests which are not under protection, logging operations are conducted. The forests are crossed by a dense network of fields and forest roads. Linear erosion process has been most intensive on these roads. Water flowing along the slopes washes off soils up to its stony substratum causing furrows and ruts [7].

Characteristics of reservoir

The reservoir at Krempna was completed in 1970-1972. This water reservoir, built for recreational purposes (Fig.2 and 3) is localized in the upper course of the Wisłoka River section at 145+023 km. Head water regulator is an earth dam, 145 m long with a concrete, four-span weir with movable gates. Each of the 11.75 m wide spans has lower spillways of 1.2 m width. Datum of the weir span crest is 370.00 m a.s.l., datum of lower spillway is 366.50 m a.s.l. Lower spillways are shut off by flat vertical gates 3.5 m high and 1.5 m wide. A project of the reservoir renovation was developed in 1978 on commission from the Communal Office at Krempna.

During the winter period, i.e. from November till May the reservoir is emptied, among others to diminish its silting. Fig.3 presents the reservoir basin in the winter period. The photograph was taken in 2002.

Fig. 2. Reservoir at Krempna – view from the dam. Photograph taken in 2002

Fig. 3. Reservoir at Krempna – reservoir in winter. Photograph taken in 2002

Basic parameters of reservoir:

- normal water head in the reservoir – 369.80 m a.s.l,
- total capacity – 119.1 thousand m^3, after reconstruction in 1988 – 112 thousand m^3,
- area of inundation - 3.2 ha,
- length of the reservoir 400 m.

Figure 4 shows the layout of the reservoir after reconstruction completed in 1988 with marked measuring cross sections.

Fig. 4. Reservoir at Krempna after reconstruction completed in 1988. Measuring cross sections were marked

Hydrology of the Wisłoka river. Observations conducted by the Institute of Meteorology and Water Management (IMGW) in the gauge cross section at Krempna. The staff gauge has been situated at 145.0 km of the river course and the zero level of the gauge is 365.16 m above sea level according to Kronsztadt.

The Wisłoka river is a mountain river, which is connected with high river stages, particularly during the spring snow melt periods and summertime heavy rains. A list of extreme and mean stages and water flows covers the period from the beginning of reservoir operation (1972) until 1983 when its basin was desilted. The highest flow registered in July 1973 was 205.99 [$m^3 \cdot s^{-1}$] and the lowest – 0.13 [$m^3 \cdot s^{-1}$] was noted in February 1995. Mean annual flow is 2.03 [$m^3 \cdot s^{-1}$].

METHODS

The problem of sediment distribution in small water reservoirs has been treated marginally in technical literature. The USDA services who dealt with this issue researched reservoirs of between 0.2 and 1.1 mln m^3 capacity localized in catchments of the area between 0.52 and 35 km^2. Results of these investigations were published by Dendy [2, 3].

Present work gives results of research on a reservoir at Krempna on the Wisłoka river. The methods of investigations, conducted in the first decade of September 1996, 1997, 1998, 1999, 2000, 2001, 2002 and 2003 comprised silting measurements, flow velocity, water turbidity and sampling of bottom deposits. Measurements of the reservoir silting were carried out by sounding and water depth was measured from a boat using a rod sound. Measurements of silting were performed both in established cross sections corresponding to the cross sections as on to the post-construction scheme and by dispersed points method. The results of water depth measurements in the reservoir were plotted on the post-construction cross sections. Subsequently, the areas of deposits were determined in the cross sections and the volume of deposits in the reservoir was computed.

The analyses used archival materials concerning the silting volume carried out in 1987 by the measuring team led by Mr. Jan Organ who was the author of the Krempna reservoir renovation project, which was conducted in 1988.

Basing on the measurements of reservoir silting at Krempna performed in subsequent years: 1987, 1996, 1997, 1998, 2000, 2002 and 2003 the degree of silting was computed for the following years of its operation. Conducted measurements of silting volume and the cross sections drawn on the basis of them made possible computing the volume of sediment deposits in respective segments. Partial blocks separated from the total reservoir capacity and contained between two adjoining cross sections were called segments. Distribution of sediment deposits in the reservoir was determined by computing the silting degree of individual segments. The degree was calculated as a ratio of deposited sediment volume in the segment to the segment volume.

The values of measured deposit volumes in segments between the cross sections and in layers were used to elaborate the horizontal sediment distribution using the methods suggested by Dendy [2]. Horizontal sediment distribution in the reservoir shows the relationship between relative deposit volume (Sh/S) and relative reservoir capacity (Vh/V). The relative deposit volume means here the ratio of deposit volume (Sh) above an individual cross section to total sediment volume (S), whereas a relative reservoir capacity is understood as a ratio of the volume of a part of the reservoir (Vh) above the individual cross section to the total reservoir capacity (V).

A method developed by Rooseboom and Annandale [1] to compute sediment distribution in reservoirs bases on the assumption that in conditions of minimum stream power there is a relationship between sediment distribution in the reservoir from its inflow to the outflow and a change of wetted perimeter value. Basing on this assumption and on the data obtained for eleven large reservoirs located in the Republic of South Africa with large volumes of accumulated sediments, a graph relating the dimensionless cumulative volume of deposited sediment to the relative distance from the dam wall was compiled (Fig.5). The graph considers various values of wetted perimeter of the reservoir cross sections (P) depending on the cross section distance from the dam wall (L). The relationship has been presented as a following equation:

$$\sum \frac{V}{V_{FSL}} = f\left(\frac{L}{L_{FSL}}, \frac{dP}{dL}\right) \tag{1}$$

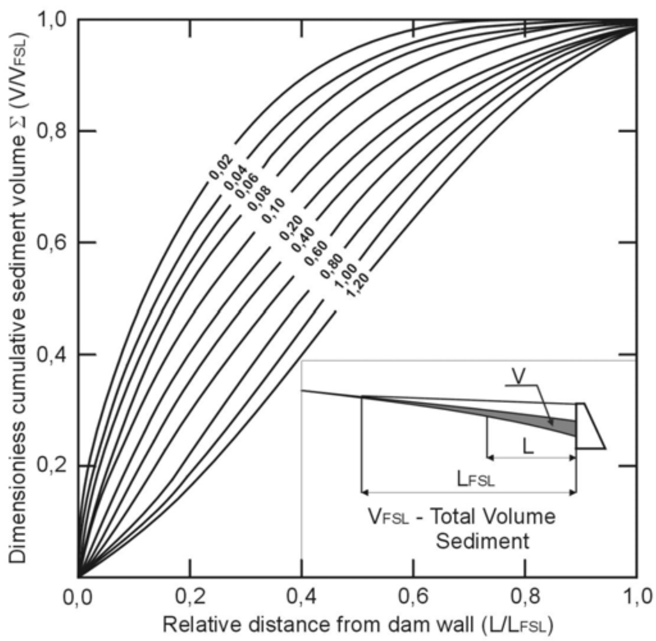
where:

V – the volume of sediment deposited in the reservoir cross section at the distance of L from the dam wall; [m^3],
V_{FSL} – total sediment volume at full supply level; [m^3],
L – the distance from the dam wall; [m],
L_{FSL} – length of the reservoir at full supply level; [m].

Prior to computing sediment distribution in the reservoir using Roseboom-Annandale method the total volume of sediment which is supposed to be deposited in the reservoir basin should be determined. The standard calculation procedure for determining sediment distribution under stable conditions at full supply level involves the following steps [1] :

- estimating of the mean value of $\left(\frac{dP}{dL}\right)$ by compiling a graph showing wetted perimeter for reservoir (P) to the distance from the dam wall (L),
- determining sediment deposit distribution in the reservoir basin depending on the distance from the dam wall, using graph (Fig.5).

Fig. 5. Sediment distribution within reservoir according to Rooseboom-Annandale [1]



Evaluation of possible application of Rooseboom-Annandale method will be done by comparing the results of computations with results of silting measurements in individual segments of the reservoir at Krempna. Calculations according to Rooseboom-Annandale method will be performed for the data of the total reservoir silting in the individual years of operation.

RESULTS OF COMPUTATIONS

Cumulative volume of deposited sediment after sixteen years of the reservoir operation and after its reconstruction in 1988 was shown in Table 1. The Table presents also the reservoir silting degree expressed a ratio of accumulated sediment volume to initial reservoir capacity.

Table 1. Volume of sediment deposits and silting degree of reservoir at Krempna

Initial capacity $[m^3]$	Year of measurement	Year of operation	Volume of deposited sediment	Silting degree [%]
119100	1972	0	0.0	0.0
	1987	16	35664.9	29.9
112000	1988	0	0.0	0.0
	1996	9	27041.7	24.1
	1997	10	30464.0	27.2
	1998	11	34637.2	30.9
	1999	12	38002.2	33.9
	2000	13	40144.8	35.8
	2002	15	44200.5	39.5
	2003	16	46901.0	41.9

Silting volume of individual sectors of the reservoir at Krempna, determined on the basis of field survey data was presented in Table 2.

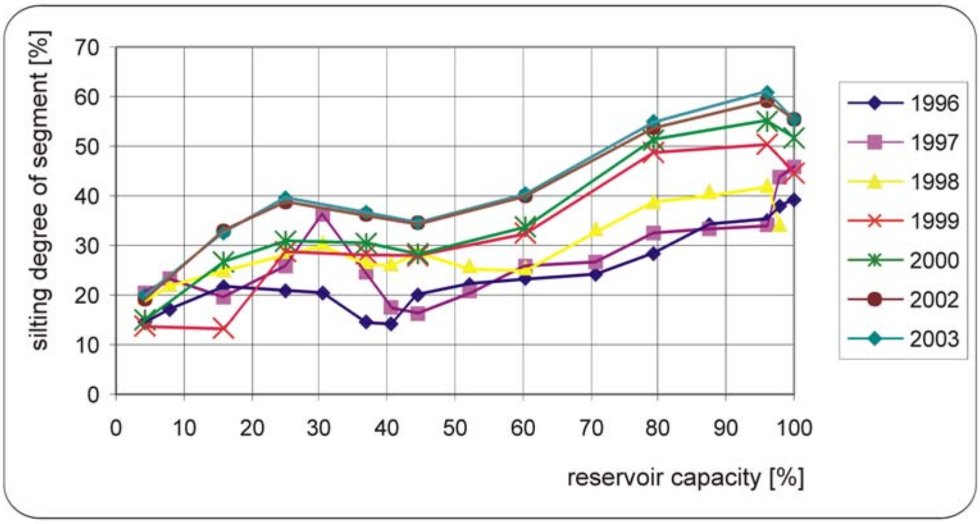
Table 2. Projected capacities of reservoir sector according to constructional design of 1972 and reconstruction project of 1988, and silting volumes of individual sectors of reservoir at Krempna

Cross section No.	Volume of sector silting in individual years $[m^3]$									
	Sector volume projected in 1972 $[m^2]$	1987	Sector volume projected in 1988 $[m^3]$	1996	1997	1998	1999	2000	2002	2003
0										
1	2670.4	956.2	2249.4	877.6	1027.6	785.5	999.1	1162.3	1242.0	1251.0
2	2435.0	893.4	2190.6	829.1	960.6	725.1				
3	9766.1	3165.2	9482.6	3321.1	3237.3	3989.6	5881.4	6447.6	6920.0	7095.0
4	9751.8	2791.9	9464.0	3229.9	3153.5	3850.4				
5	9360.1	2908.9	9425.4	2670.4	3055.6	3665.9	9203.4	9660.0	10128.0	10376.0
6	11691.0	3692.1	11767.7	2856.4	3136.4	3934.4				
7	9451.3	2773.9	9026.6	2102.2	2337.0	2298.0	6804.5	7043.0	8307.0	8374.5
8	9238.0	3367.3	8708.7	1923.0	1814.7	2259.0				
9	4436.8	1914.5	4200.9	840.7	690.0	1212.0	3625.4	3644.7	4458.0	4482.0
10	4299.2	1709.2	4121.7	585.5	721.8	1076.1				
11	7925.6	2509.3	7263.9	1071.4	1778.0	1928.4	3218.3	3468.3	4119.0	4182.0
12	7367.8	2228.7	6169.9	1266.0	2243.2	1881.7				
13	11056.4	2828.1	10187.1	2135.1	2620.7	2929.7	4683.8	5019.3	6360.0	6465.0
14	10022.5	1845.0	8920.3	1931.4	1761.3	2248.7	2348.6	2372.3	2943.0	2889.0
15	4685.0	983.6	4030.5	694.2	937.6	890.1				
16	4949.6	1097.7	4875.8	707.9	989.3	962.7	1238.0	1327.5	1723.5	1786.5
Sum:	**119106.5**	**35664.9**	**112084.8**	**27041.7**	**30464.4**	**34637.2**	**38002.2**	**40144.8**	**46200.5**	**46901.0**

Determining sediment distribution in the reservoir basin

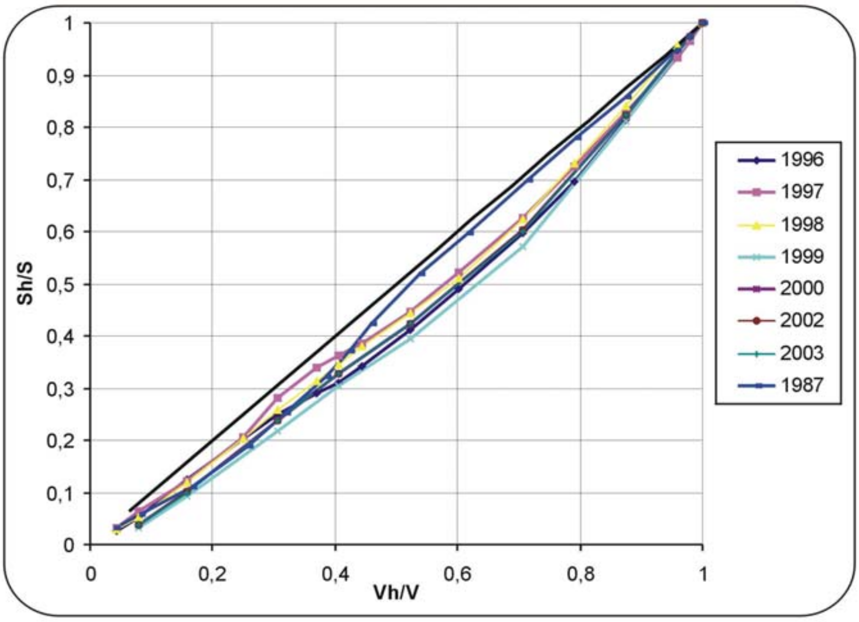
Graphical presentation of the computation results makes possible determining sediment distribution along reservoir longitudinal axis (Fig.6). The reservoir capacity calculated from the inlet (reservoir capacity 0%) to the outlet (reservoir capacity 100%) was marked on the X-axis. For each value of individual segment silting degree a percentage of initial capacity of the same segment in total initial reservoir capacity was computed.

Fig. 6. Distribution of sediment deposits in reservoir at Krempna



Horizontal sediment deposit distribution according to the methodology suggested by Dendy [2] enables illustrating the relationship between relative sediment deposit volume (Sh/S) and relative reservoir capacity (Vh/V), as presented in Figure 7.

Fig. 7. Horizontal distribution of sediment deposits in reservoir at Krempna according to Dendy's method



A forecast of sediment distribution in the reservoir basin

In order to perform calculations predicting sediment distribution in the reservoir basin according to Roosenboom and Annandale methods, wetted perimeters (P) were determined in individual cross sections of the reservoir. Values of wetted perimeters (P) were established for two operational periods: since the year of desilting and reservoir reconstruction in 1988, and for the period following its reconstruction. Data from the post-constructional project developed in 1972 and data from post-constructional project after its desilting in 1988 served this purpose. A linear regression equation of dependence between cross section wetted perimeter (P) from the distance from dam wall (L) was formulated. Mean value of $\left(\frac{dP}{dL}\right)$ determined according to the post-constructional project for the period before the reconstruction was 0.23. It was determined from the equation of simple regression presented in Figure 8. Mean value of $\left(\frac{dP}{dL}\right)$ for the period following the reservoir reconstruction in 1988 was 0.26. It was established from the equation of simple regression presented in Figure 9.

Fig. 8. Dependence between wetted perimeter (P) and distance (L) from the dam wall for reservoir at Krempna in 1972

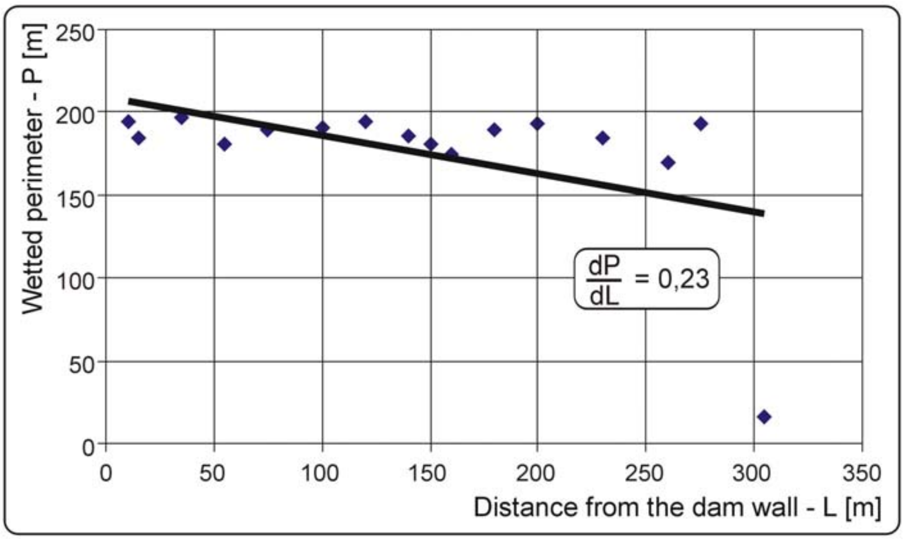
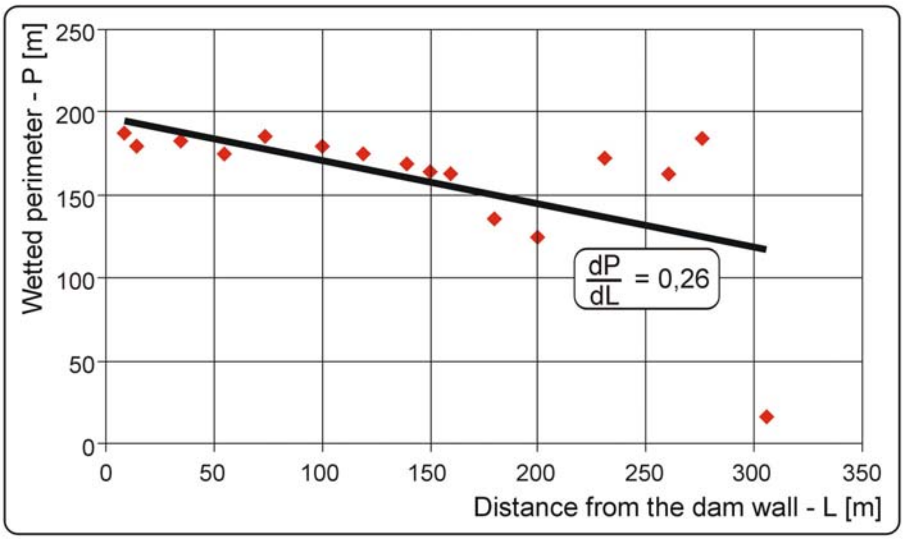


Fig. 9. Dependence between wetted perimeter (P) and distance (L) from the dam wall for reservoir at Krempna in 1988



Values of dimensionless deposit value $\frac{V}{V_{FSL}}$ depending on relative distance from dam wall $\frac{L}{L_{FSL}}$ for the period prior to desilting and reconstruction, established from the curve corresponding to $\left(\frac{dP}{dL}\right)$ value = 0.23 of graph in

Fig. 8 were shown in Table 3. Values of dimensionless volume of deposit $\frac{V}{V_{FSL}}$ depending on relative distance from dam wall $\frac{L}{L_{FSL}}$ for the period following the reconstruction were given in Tables 4, 5, 6 and 7.

In order to obtain comparable results of predicted sediment distribution in the reservoir basin, the calculations were done for sectors determined as for the years 1999-2003. Therefore sectors between cross sections 1 and 3, 3 and 5, 5 and 7, 7 and 9, 9 and 11 and 11 and 13, and also between 14 and 16 were merged.

Results of calculations of sediment distribution in the basin of reservoir at Krempna in 1987 conducted using Roosenboom-Annandale method were compared with the results of silting measurements done in the same year (Tab.3). The difference was given in percent.

Table 3. Compilation of results of predicted sediment distribution in reservoir basin according to Rooseboom and Annandale method and silting measurement results in 1987

Cross section	Sector	L/L_{FSL}	V/V_{FSL}	Volume of sediment deposits in 1987 [m^3]		Difference in results [%]
				Acc.to Rooseboom – Annandale method	By mesurements	
1	1	0.03	0.05	1783.2	956.2	86.5
3	2	0.11	0.21	6063.0	4058.6	49.4
5	3	0.25	0.43	7846.3	5700.8	37.6
7	4	0.39	0.62	6776.3	6466.0	4.8
9	5	0.49	0.72	3566.5	5281.8	-32.5
11	6	0.59	0.81	3209.8	4218.5	-23.9
13	7	0.75	0.90	2853.2	5056.8	-43.6
14	8	0.85	0.95	1783.2	1845.0	-3.3
16	9	1.00	1.00	1783.2	2081.3	-14.3
Sum:				**35664.9**	**35664.9**	

Computations of sediment distribution in the basin of reservoir at Krempna were also performed for the period following its desilting and reconstruction. They were compared with the results of silting measurements and compiled in Tables 4,5,6 and 7. The tables present the difference of computation results using Rooseboom-Annandale method and a difference of measurement results expressed in percent.

Table 4. Compilation of results of predicted sediment distribution in the reservoir basin according to Rooseboom-Annandale method and results of silting measurements in 1996 and 1997

Cross section	Sector	L/L_{FSL}	V/V_{FSL}	Volume of sediment deposits in 1997 [m^3]		Difference in results [%]	Volume of sediment deposits in 1997 [m^3]		Difference in results [%]
				Acc. to Rooseboom –Annandale method	By measurements		Acc. to Rooseboom –Annandale method	By measurements	
1	1	0.03	0.05	1352.1	877.6	54.1	1523.2	1027.6	48.2
3	2	0.11	0.21	4326.7	4150.2	4.3	4874.3	4197.9	16.1
5	3	0.25	0.43	5949.2	5900.3	0.8	6702.2	6209.1	7.9
7	4	0.39	0.62	5137.9	4958.6	3.6	5788.2	5473.4	5.8
9	5	0.49	0.72	2704.2	2763.7	-2.2	3046.4	2504.7	21.6
11	6	0.59	0.81	2433.8	1656.9	46.9	2741.8	2499.8	9.7
13	7	0.75	0.90	2433.8	3401.1	-28.4	2741.8	4863.9	-43.6
14	8	0.85	0.95	1352.1	1931.4	-30.0	1523.2	1761.3	-13.5
16	9	1.00	1.00	1352.1	1402.1	-3.6	1523.2	1926.8	-20.9
		Sum:		**27041.7**	**27041.7**	**Sum:**	**30464.4**	**30464.4**	

Table 5. Compilation of results of predicted sediment distribution in the reservoir basin according to Rooseboom-Annandale method and results of silting measurements in 1998 and 1999

Cross section	Sector	L/L_{FSL}	V/V_{FSL}	Volume of sediment deposits in 1998 [m^3]		Difference in results [%]	Volume of sediment deposits in 1999 [m^3]		Difference in results [%]
				Acc.to Rooseboom –Annandale method	By measurements		Acc. to Rooseboom –Annandale method	By measurements	
1	1	0.03	0.05	1731.9	785.5	120.5	1900.1	999.1	90.2
3	2	0.11	0.21	5541.9	4714.7	-70.6	6080.3	5881.4	3.4
5	3	0.25	0.43	7620.2	7516.3	1.4	8360.5	9203.4	-9.2
7	4	0.39	0.62	6581.1	6232.4	5.6	7220.4	6804.5	6.1
9	5	0.49	0.72	3463.7	3471.0	-0.2	3800.2	3625.4	4.8
11	6	0.59	0.81	3117.3	3004.5	3.8	3420.2	3218.3	6.3
13	7	0.75	0.90	3117.3	4811.4	-35.2	3420.2	4683.8	-27.0
14	8	0.85	0.95	1731.9	2248.7	-23.0	1900.1	2348.6	-19.1
16	9	1.00	1.00	1731.9	1852.8	-6.5	1900.1	1238.0	53.5
		Sum:		**34637.2**	**34637.2**	**Sum:**	**38002.2**	**38002.2**	

Table 6. Compilation of results of predicted sediment deposit distribution in reservoir basin according to Roosenboom-Annandale method and results of silting measurements in 2000 and 2002

Cross section	Sector	L/L_{FSL}	V/V_{FSL}	Volume of sediment deposits in 2000 [m^3]		Difference in results [%]	Volume of sediment deposits in 2002[m^3]		Difference in results [%]
				Acc. to Rooseboom –Annandale method	By measurements		Acc.to Rooseboom –Annandale method	By measurements	
1	1	0.03	0.05	2007.2	1162.3	72.7	2310.0	1242.0	86.0
3	2	0.11	0.21	6423.2	6447.6	-0.4	7392.1	6920.0	6.8
5	3	0.25	0.43	8831.9	9660.0	-8.6	10164.1	10128.0	0.4
7	4	0.39	0.62	7627.5	7043.0	8.3	8778.1	8307.0	5.7
9	5	0.49	0.72	4014.5	3644.7	10.1	4620.1	4458.0	3.6
11	6	0.59	0.81	3613.0	3468.3	4.2	4158.0	4119.0	0.9
13	7	0.75	0.90	3613.0	5019.3	-28.0	4158.0	6360.0	-34.6
14	8	0.85	0.95	2007.2	2372.3	-15.4	2310.0	2943.0	-21.5
16	9	1.00	1.00	2007.2	1327.5	51.2	2310.0	1723.5	34.0
		Sum:		**40144.8**	**40144.8**	**Sum**	**46200.5**	**46200.5**	

Table 7. Compilation of results of predicted sediment deposit distribution in reservoir basin according to Roosenboom-Annandale method and results of silting measurements in 2003

Cross section	Sector	L/L_{FSL}	V/V_{FSL}	Volume of sediment deposits in 2003 [m^3]		Difference in results [%]
				Acc.to Rooseboom – Annandale method	By measurements	
1	1	0.03	0.05	2345.1	1251.0	87.5
3	2	0.11	0.21	7504.2	7095.0	5.8
5	3	0.25	0.43	10318.2	10376.0	-0.6
7	4	0.39	0.62	8911.2	8374.5	6.4
9	5	0.49	0.72	4690.1	4482.0	4.6
11	6	0.59	0.81	4221.1	4182.0	0.9
13	7	0.75	0.90	4221.1	6465.0	-34.7
14	8	0.85	0.95	2345.1	2889.0	-18.8
16	9	1.00	1.00	2345.1	1786.5	31.3
		Sum:		**46901.0**	**46901.0**	

The volume of sediment deposits computed using Roosenboom-Annandale method is much larger in comparison with results of measurements carried out in 1987, particularly in the segments closest to the dam. The difference in results of calculations according to Rosenboom-Annandale method and measurement results reaches 86.5% in the segment designed between the dam and first cross section of the reservoir (Tab.4). It is gradually reduced until the fourth segment closed by the seventh cross-section. In this segment the difference of results is 4.8%. From this segment until the inflow to the reservoir the volume of sediment trapped in respective segments, established by Rosenboom-Annandale method, is smaller than the measured one (negative difference of results). Distribution of sediment deposits in 1987 was presented in Figure 10.

After the reservoir reconstruction the difference of computation results and measurements is visibly smaller. In all years in which measurements were conducted a persistent tendency was observed pointing to considerably larger volume of first segment silting established on the basis of calculations than the real one. The volume of sediment deposits and conditions of sedimentation in the close to the dam part are greatly affected by the work of weir, which contribute to decreased volume of sediment deposits in this zone of the reservoir. In the subsequent segments, i.e. from the second to the sixth the volume of sediment deposits established according to Roseboom-Annandale method is larger than the measured volume. The difference in results is only several percent. From the thirteenth cross section the sediment deposit volume determined according to Rosenboom-Annandale method is smaller that the measured volume (a negative difference of results). Figures 11 and 12 show selected sample graphs of sediment deposits calculated using Roseboom-Annandale method and by measurements, respectively for 1996 and 2000.

Fig.10. Sediment deposit distribution in 1987 determined by Roseboom-Annandale method and by measurements

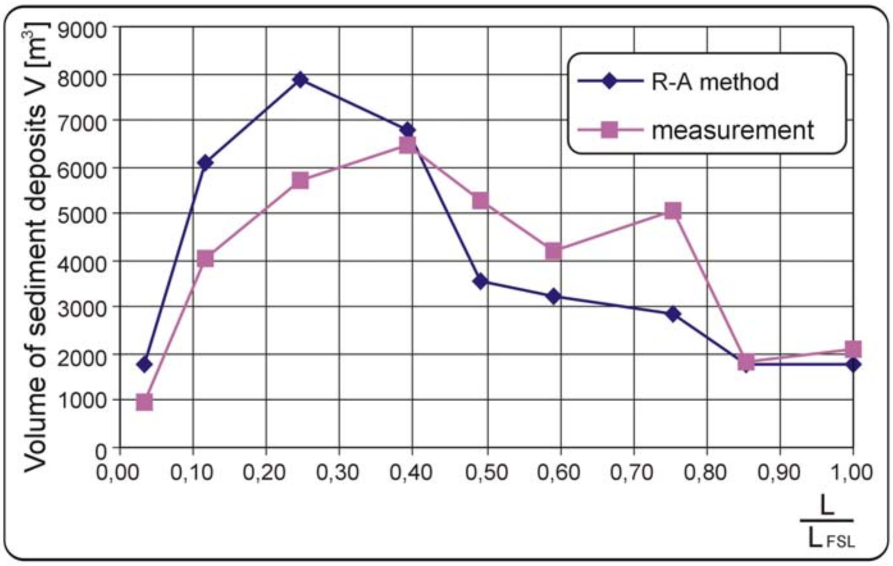


Fig. 11. Sediment deposit distribution in 1996 determined by Roseboom-Annandale method and by measurements

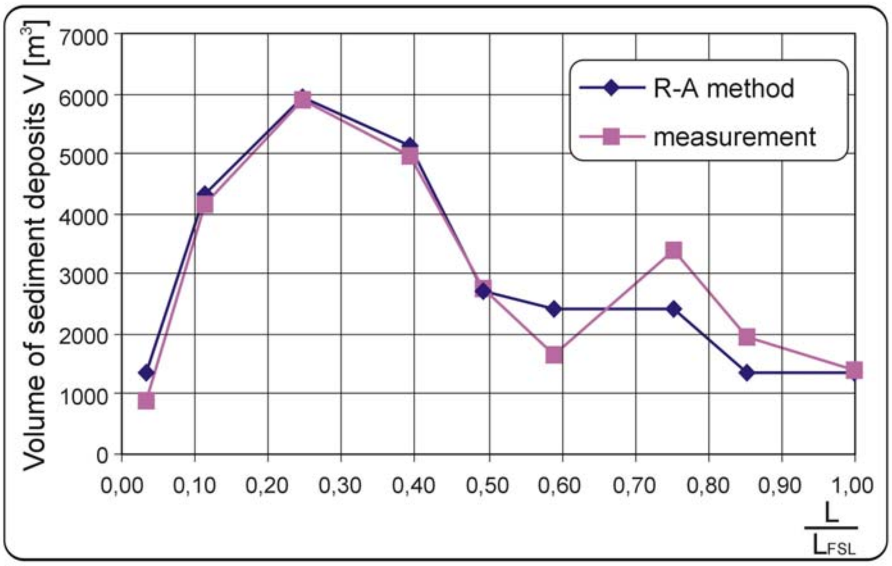
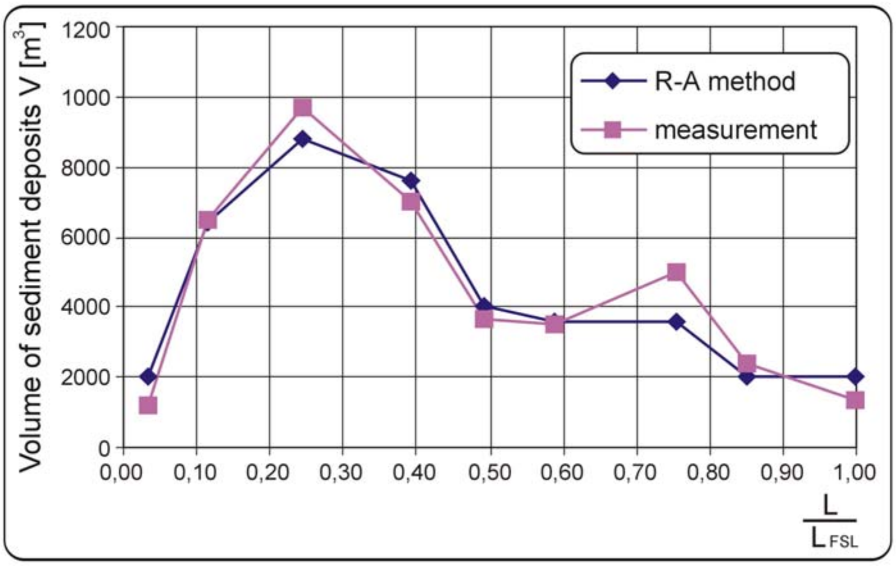


Fig. 12. Sediment deposit distribution in 2000 determined by Roseboom-Annandale method and by measurements



CONCLUSIONS

Silting of reservoir at Krempna is 29.9% for the period prior to renovation completed in 1988 after sixteen years of exploitation whereas during the period of sixteen years after its renovation the volume of sediment deposits constituted 41.9% of its initial capacity. Increasing value of silting degree of the reservoir at Krempna in subsequent years of its operation when measurements were carried out (Tab.1) represents only the increase in the reservoir silting during its operation. Mean annual silting rate, calculated for the period from 1997 to 2003 is 2.66% and demonstrates an intensive increase in the sediment deposit volume in the reservoir. It is considerable in comparison with large water reservoirs. According to Łajczak [5], mean annual silting rate in large water reservoirs with volumes between 10 mln m^3 and $100m^3$, ranges between 0.58% for reservoirs at Rożnów, 0.38%, at Włocławek, 0.24% at Tresna and 0.02% for the Solina reservoir.

Such considerable increase in mean annual silting degree points to possible 80% reduction of its capacity over a relatively short period of time. According to Hartung criterion [4], a water reservoir silted in 80% is a reservoir incapable of fulfilling its function and its operation id discontinued. Determining the time after which the reservoir at Krempna may be shut down requires a detailed prediction of its silting.

Silting of respective sectors determined on the basis of field data points to the occurrence of two zones of intensive silting. The first has been identified in the inflow part of the reservoir between cross sections No. 15 and 13 and the second one is located between the dam cross section and cross section No.8. On the other hand from cross section No. 13 to 8 a declining percentage silting of sectors is observed, according to the direction of water flow through the reservoir. It is connected with the reservoir shape as distinctively visible after completed reservoir reconstruction. Constructing a peninsula from the material taken out of the reservoir bottom significantly affected a change in hydrodynamic conditions in the reservoir. Before the desilting and reconstruction of the reservoir in 1998 diversification of percentage silting of individual sectors was smaller and testified a relatively proportional silting of the reservoir sectors. Graphic description of sediment deposit distribution made according to Dendy method presents a proportional, regular sediment distribution in the reservoir.

Predicted sediment deposit distribution carried out by Roseboom-Annandale method revealed considerable divergence from results of measurements conducted in 1987 and was much larger than the measured one, particularly in the segments closest to the dam. Predicted distribution of sediment deposits might point to considerable silting of the backwater part of the reservoir and declining silting closer to the dam. Real distribution of sediment deposits differs considerably from the predicted one. After the reservoir reconstruction the difference between the calculation results of predicted silting and measurement results is visibly smaller.

The volume of sediment deposits and sedimentation conditions were considerably influenced by weir and the reservoir geometry. Rosenboom-Annendale method does not consider the effect of these factors on sediment distribution. Initial evaluation of this method points to its possible application for predicting sediment deposits distribution in small water reservoirs. However, it still requires supplementary research works, which will allow for introducing additional parameters considering the reservoir shape.

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