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Investigation on sediment deposition in a designed Carpathian reservoir

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Abstract Prediction of sediment deposits distribution and influence of the deposits on backwater curve in a Carpathian reservoir, south Poland, was carried out with the use of a one-dimensional numerical model employing MPM formula for bed load transport and method of Camp for suspended sediment deposition calculation. The computation has been carried out for two different polices of water management in the reservoir; with constant (variant 1) and varied (variant 2) water level in the reservoir. Simulation of the 30-year period of sediment transport and deposition in the river-reservoir system indicated that the maximum layer depth of deposits would reach 6.9 and 4.7 m, and maximum changes of water level for two-year flood would be 2.76 and 1.91 m for the first and the second variant of computation, respectively.

INTRODUCTION

The Swinna Poreba reservoir is created by dam construction on Skawa River, in the Carpathians - south Poland, about 60 km southwest of Cracow. Locality of the reservoir is shown on the map of soil erosion intensity of Poland (Reniger, 1959), with scale of sediment yield (Debski, 1959) in Fig. 1. The drainage basin area of the reservoir amounts 802 km^2 and belongs to the most erosive part of Poland. The aim of creating the reservoir is public water supply. Active storage capacity of the reservoir is 122 000 000 m^3, and active water layer is 21.1 m. Plan view and the main volume and area data of the reservoir are shown in Fig. 2. The investigation was carried on in order to estimate:

(a) the quantity and distribution of deposits in the reservoir;
(b) the influence of deposits on the backwater curve.

To carry on the analysis of deposition of solid matter in the reservoir a computer program for PC, called RES (reservoir sedimentation), has been developed. The computation has been carried on for two different variants of water management in the reservoir:

(a) in the first one constant water level (outflow equals inflow for each time interval) at the maximum storage capacity of the reservoir has been assumed;
(b) in the second one the water level was computed from the hydrograph of daily inflow, and outflow (at standard water policy in the reservoir with constant water demand of 10 m^3 s^{-1}) and from the stage-storage relationship of the reservoir.

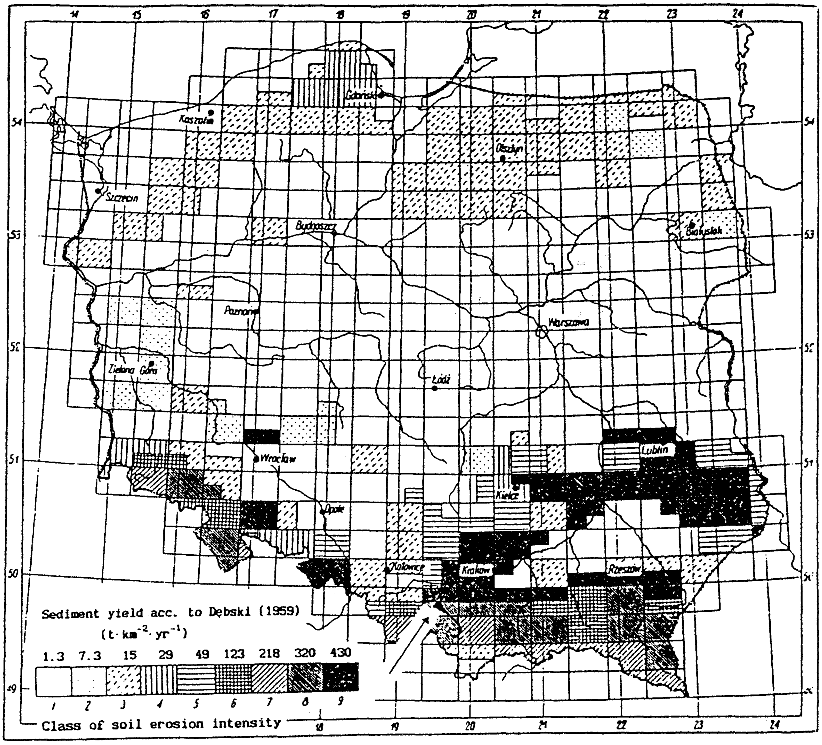

Fig. 1 Soil erosion intensity map (according to Reniger [1959]) with the location of the Swinna Poreba reservoir.

MODEL DESCRIPTION AND DATA USED

Mathematical model of bed and water level changes was formulated by making use of the following equation:

(a) for flow of water; the continuity equation and dynamic equation for steady non-uniform water flow;

(b) for sediment transport; the equation of continuity and formulae of bed load transport and suspended load rate.

The bed load transport rate was calculated from Meyer-Peter & Müller (1949) formula modified by AU (Agricultural University) Cracow (Bartnik *et al.*, 1988). Changes in suspended sediment concentration along the reservoir was estimated from formula given by Plate *et al.* (1980, 1981) which was an approximation of Camp's solution (Camp, 1946) of the simplified diffusion equation.

Hydraulic parameters needed to calculate sediment transport capacity as velocity, depth, width and slop were estimated from water surface profile calculation. The one dimensional energy equation, shown below, was solved using the standard step method and the above hydraulic parameters were calculated at each cross section for each successive discharge:

$$\Delta y = \frac{1}{2g}\left[\alpha_{i+1} v_{i+1}^2 - \alpha_i v_i^{\,2}\right] + h_e \tag{1}$$

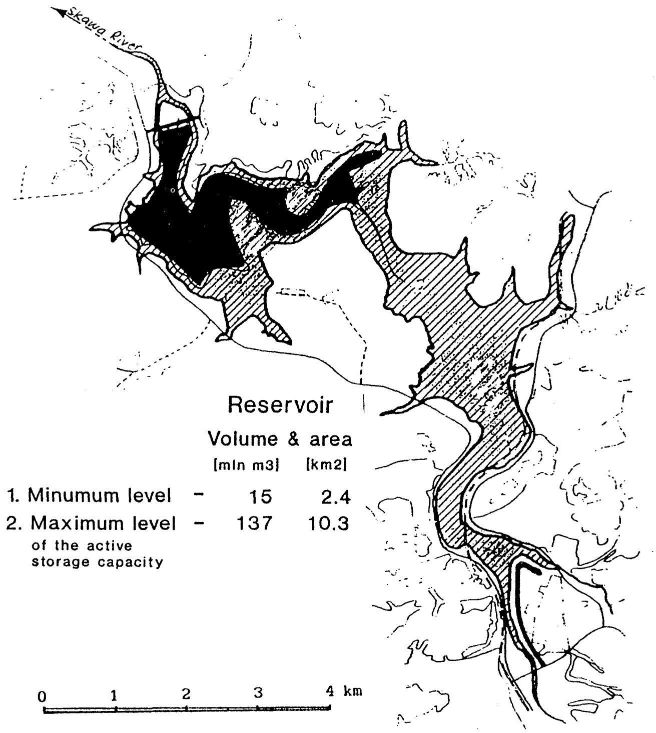

Fig. 2 Plan view of the Swinna Poreba reservoir.

where: Δy is the increase in water surface elevation between two cross sections (m); g is acceleration of gravity (m s^{-2}); v_i, v_{i+1} are average velocities at ends of reach (in cross sections i and $i + 1$) (m s^{-1}); α_i, α_{i+1} are velocity distribution coefficients for flow at ends of reach (-); h_e is energy loss (friction loss and form loss) (m).

The idea of estimation of backwater curve and sediment deposits in the river-reservoir system are shown in Figs 3 and 4. More detailed description of the procedure was given in previous works (Banasik & Skibinski, 1988, and MacMurray & Banasik, 1987).

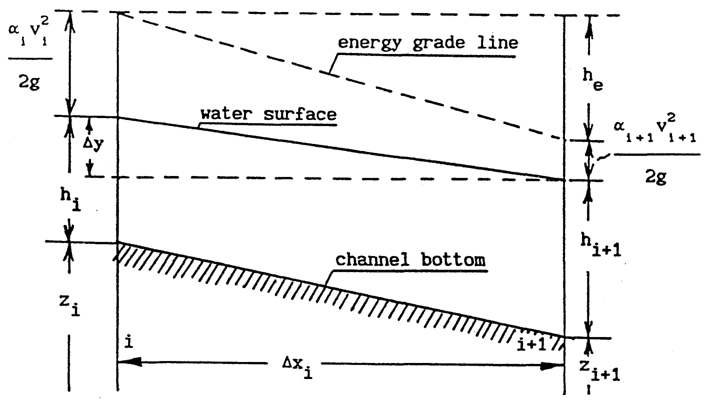

Fig. 3 Sketch for backwater computation.

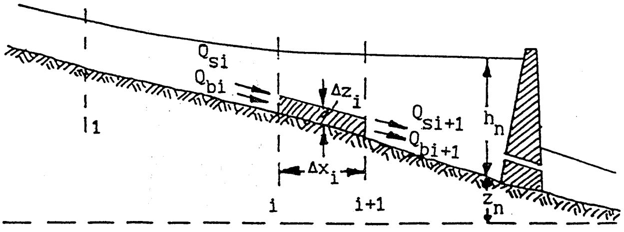

Fig. 4 Sketch for sedimentation calculation.

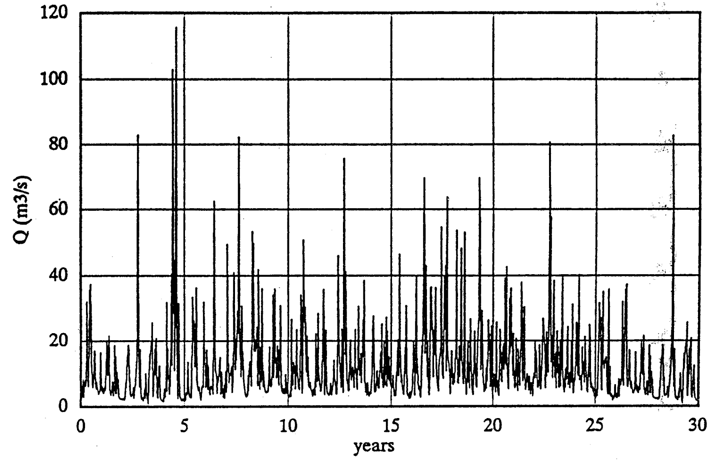

Fig. 5 Mean decade inflow into the reservoir during the 30 year period used for calculation.

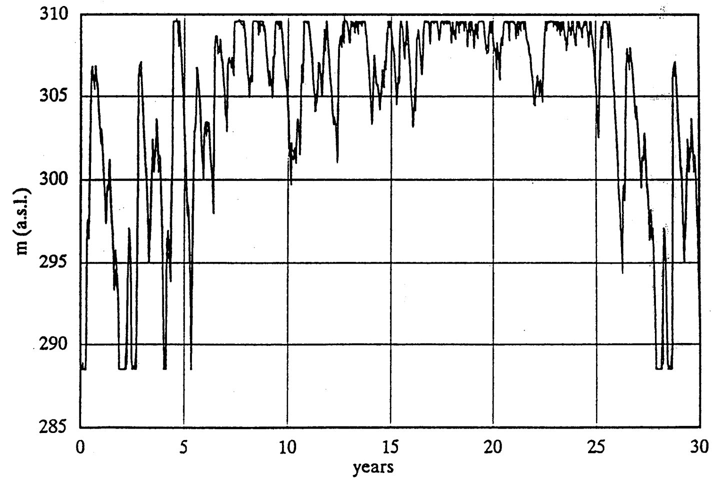

Fig. 6 Water level in the reservoir during the period of 30 years (variant II - at a constant water demand of 10 $m^3 s^{-1}$).

Geometry of the investigated reach of river and reservoir, which length is 11.58 km, was represented by 24 cross sections. Each cross section was divided into subsections, consisting of main channel with left and right overbanks. Long term daily discharge records at Wadowice (6 km downstream of the dam) were used to estimate inflow to the reservoir. Averaged decade inflow for the 30 year period used in the calculation is shown in Fig. 5. Mean discharge at the dam profile is 12, and discharges for the two year flood - 170 and for one hundred year flood - 1100 $m^3 s^{-1}$. Water level in the reservoir (used in the second variant of computation) at constant water demand of 10 $m^3 s^{-1}$ is shown in Fig. 6.

Grain size of bed material as well as the concentration and grain size of suspended sediment during floods were estimated on the base of field investigation (Ratomski *et al.*, 1991). Mean annual total sediment delivery to the reservoir is about 200 000 t (25% of which was bed load and 75% wash load) i.e. 250 t km^{-2} $year^{-1}$.

Bed load transport was computed for mean grain size $d_m = 5.5$ cm, and the suspended sediment load for five diameters $d_{10} = 1.5$, $d_{30} = 15$, $d_{50} = 33$, $d_{70} = 40$ and $d_{90} = 50$ μm.

RESULTS OF COMPUTATION

The designed water demand is 6.4 $m^3 s^{-1}$, which used in the computation at the accepted inflow hydrograph would cause only very small fluctuation of water level in the reservoir, so the conditions of transport and deposition of solid matter in the river-reservoir system were very similar to that of variant 1 (constant water level). Some results of sediment deposits in the main channel and water level increase due to sedimentation for the two year flood are given for both variants in Table 1. The initial bed profile of the main channel as well as the predicted after 10; 20 and 30 years in the variant 2 is shown in the Fig. 7, and the bed changes in Fig. 8.

The sediment deposition takes place in the upper part of the reservoir as well as upstream of it in the river. The deposits in the main channel and in the flood plain (Fig. 9) would cause water level increase, what is shown for a two year flood on

Table 1 Predicted sediment deposition in the main channel and water level increase for the two year flood due to deposits after 30 years.

Cross section	Distance from the dam (km)	Sediment deposition (m):		Increase of water level (m):	
		variant 1	variant 2	variant 1	variant 2
4	2.10	0.05	0.57	0.00	0.00
8	4.99	0.13	0.54	0.00	0.00
12	7.39	3.03	4.25	0.00	0.00
13	7.93	6.92	4.31	0.00	0.00
14	8.58	5.17	4.71	0.01	0.01
16	9.70	4.36	2.87	1.34	0.79
18	10.44	2.70	1.69	2.63	1.75
20	10.75	2.48	1.49	2.30	1.48
22	11.11	3.00	2.12	1.95	1.06
24	11.58	3.23	2.38	2.76	1.90

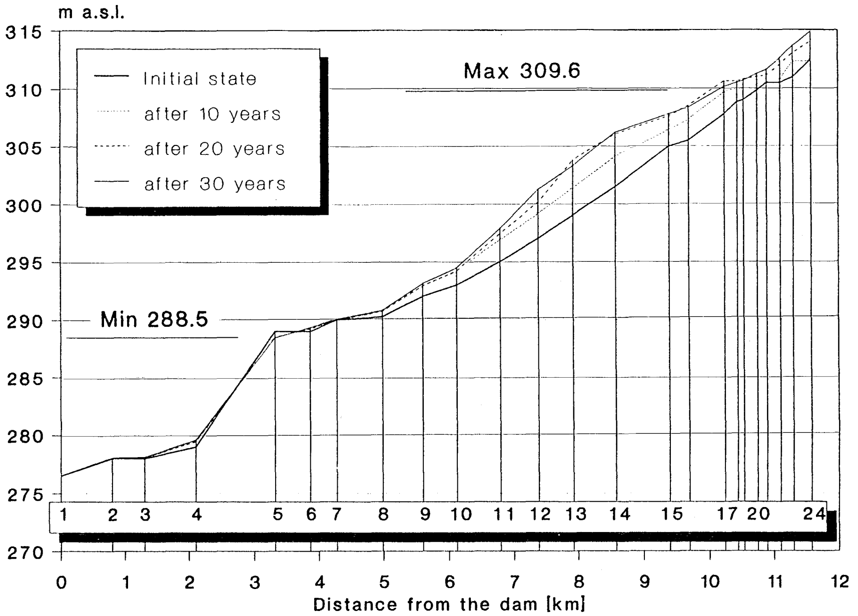

Fig. 7 Bed profile of the main channel (initial and computed for variant 2).

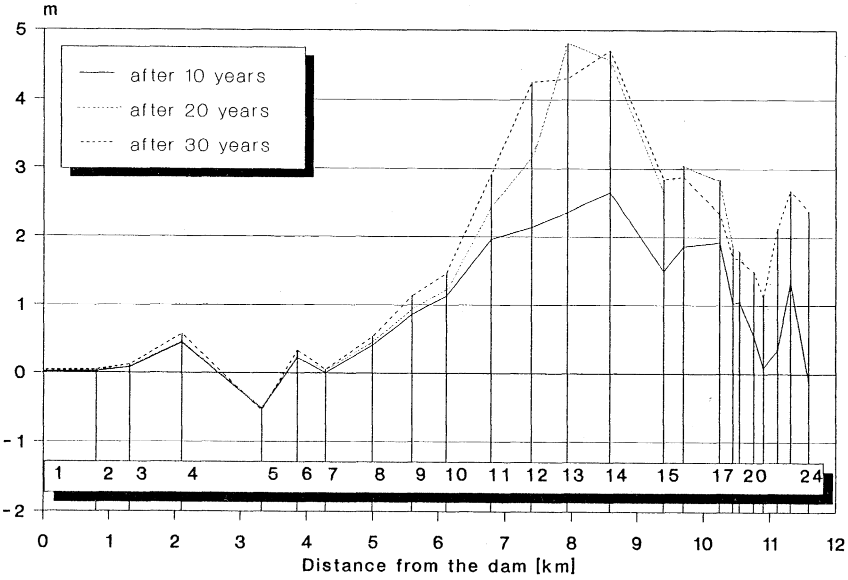

Fig. 8 Bed changes of the main channel (variant 2).

Fig. 10 and in Table 1. Simulation of the 30-year period of sediment transport and deposition in the river-reservoir system indicated that the maximum layer depth of deposits would reach 6.9 and 4.7 m, and maximum changes of water level for two-year flood would be 2.76 and 1.90 m for the first and the second variant of computation, respectively.

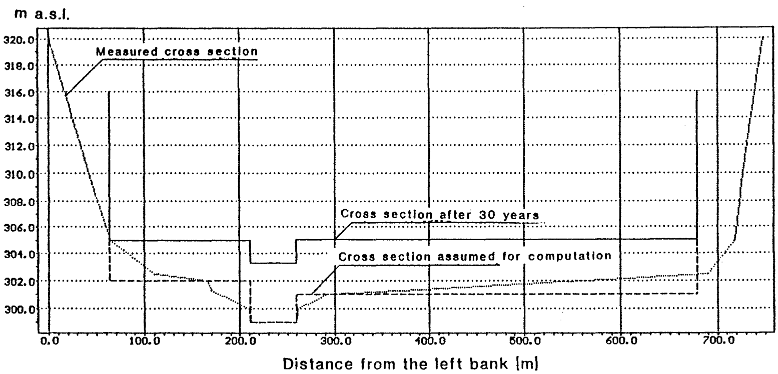

Fig. 9 Changes in cross section 13 (variant 2).

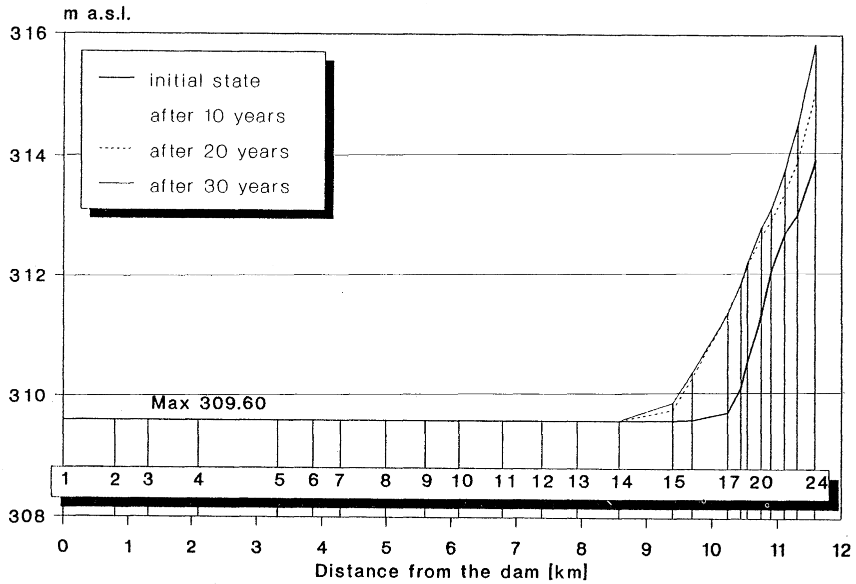

Fig. 10 Water profile of the two year flood in the river-reservoir system (initial and computed for variant 2).

Comparison of the results (Table 1) shows significant influence of reservoir water management on distribution of deposited sediment in the reservoir and backwater profile.

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