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REGIME OF THE WATER LEVEL OSCILLATIONS OF THE DOBCZYCE RESERVOIR

1. Introduction

The Dobczyce reservoir, whose construction was completed in 1985, is the largest in the Carpathian Foothills. The basic parameters of the reservoir are as follows (Pawlik-Dobrowolski 1993):

Pool level in metres a.s.l.*: maximum – 272.4, mean – 269.9, minimum – 256.7
Pool area in ha: maximum – 1065, mean – 970, minimum – 335
Storage capacity in million m^3: maximum – 127.0, mean – 99.5, minimum – 14.5
Maximum length of the reservoir: 10 km
Maximum depth: 29.1 m at the maximum pool level.

The useful storage capacity of the reservoir, whose major function is to store the water supply for the city of Cracow, is 85 million m^3 while its flood-control storage capacity is 27.5 million m^3. The dam delimits the Raba drainage basin over an area of 770 km^2. The drainage basins of the Carpathian Foothills which have direct outlets to the reservoir amount to a total area of 72 km^2. The reservoir is enclosed by a 41 m high and 728 m long earth dam (1 600 000 m^3 in volume) with an asphalt-concrete sealing and a maximum discharge in the order of 2 700 m^3/s (according to www.otkz.pol.pl).

The reservoir is operated according to the operation manual which comprises a set of regulations and procedures to be followed under particular meteorological and hydrologic conditions. The manual gives priority to the water supply for Cracow while the second task of the reservoir is to create favourable conditions for flood-control in the Raba river valley. The production of electric energy by a small hydro-power generating plant is of a minor importance here. The Dobczyce reservoir, being the drinking water reservoir, may not be used for recreation purposes or for fishing.

* a.s.l. – above sea level

Compromising between the various functions of the reservoir and finding its optimum operating system is not an easy task. The small area of the drainage basin and highly variable weather conditions in the mountains where a part of the water inflow is generated lead to the development of a dynamic system whose behaviour is difficult to forecast. The fundamental reservoir parameter, i.e. a volume of water stored in the reservoir, depends on an practised operating strategy. A secondary but very important characteristic, resulting from the shape of the reservoir basin, is its area which varies only by 0.9 km^2 (i.e. by 9%) from the mean to maximum pool levels. That is a very favourable feature as it stabilises the influence of the reservoir on its surroundings.

2. Materials and methods

The following materials have been used to characterise the oscillations of the water level in the reservoir:

– the records of the daily water levels in hydrologic years of the period 1985-1998, taken from the gauging post equipped with a water level recorder, located near the dam and operated by the staff of the dam and of the power generation plant;
– the special observations made in one hour (sometimes a few hours) long intervals, which are recorded in the operating documentation of the reservoir's managers, have been used to characterise variations in the water level during high floods when the rhythm of the water level changes is very rapid;
– for the sake of comparison the regime of the discharge changes in an annual cycle has been elaborated for the Raba river cross-section at Proszówki, based on the records of the Institute of Meteorology and Water Management.

The numerical data have been verified and averaged for both monthly and annual values of the subsequent hydrological years. The initial years of the reservoir's operation during its filling phase (1986-1988) have been omitted as being non-representative of the water level oscillations. Thus, the series of records which this paper draws upon covers the period from 1988-1998. All the numbers referring to the water level in the reservoir are expressed in metres above sea level.

The natural rhythm of the Raba discharges has been elaborated using the series of the Proszówki cross-section of the period 1991-1995. Inclusion of the data for 1988-1995, i.e. the period of the reservoir operation, in a 45-year long series of the records does not significantly affect the fundamental hydrologic characteristics.

3. Characteristic water levels

The following characteristic water levels have been determined: the mean annual water level, maximum annual water level and minimum annual water level (Tab.1, 2; Fig. 1, 2). The filling of the reservoir from the level of 247.27 m a.s.l. in November 1985 to the normal pool level capacity lasted till October 1987. February 1988, when the highest calculated mean monthly level – 271.07 – was recorded, should be assumed to be the completion of the initial filling of the reservoir. The higher daily water levels were recorded but the aforementioned number is the maximum of the monthly mean

Tab. 1.Mean monthly water levels of the Dobczyce reservoir (in metres) in 1986-1998 (I – January, II – February etc.)

Year	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X
1986	247.72	251.43	252.58	244.18	248.33	250.52	253.25	255.00	255.03	256.88	258.63	258.66
1987	258.72	258.51	260.43	259.62	257.95	260.10	261.51	264.19	264.53	264.99	266.25	267.10
1988	267.86	269.69	270.26	271.07	266.45	264.02	264.24	265.10	265.66	265.58	266.32	266.18
1989	265.66	267.56	269.67	269.14	268.12	268.10	269.45	269.57	269.66	269.62	269.77	269.59
1990	269.60	269.58	269.31	269.59	269.94	269.88	269.80	269.43	269.67	269.72	269.93	269.86
1991	269.79	269.84	269.65	269.08	269.64	269.88	269.89	269.77	269.75	269.95	269.92	269.90
1992	269.90	269.74	269.90	269.92	269.88	269.85	269.82	269.79	269.46	268.86	268.61	268.48
1993	269.74	269.94	269.95	269.93	270.03	270.39	269.71	269.29	269.53	269.46	269.16	268.39
1994	267.84	267.32	266.64	267.25	269.23	270.23	270.21	269.89	269.60	268.78	267.50	267.05
1995	267.65	269.01	269.89	269.90	269.96	270.10	270.01	270.07	269.92	269.66	268.88	267.55
1996	267.55	268.42	269.49	269.44	268.74	270.04	270.26	269.93	269.27	269.94	270.20	269.23
1997	268.65	267.92	267.34	267.52	269.75	270.26	269.98	270.14	270.08	269.62	268.11	267.77
1998	268.21	269.68	269.98	269.78	269.83	269.98	269.73	269.88	269.71	268.42	267.55	266.97
1989-1998	268.46	268.90	269.18	269.15	269.51	269.87	269.89	269.78	269.67	269.40	268.96	268.48

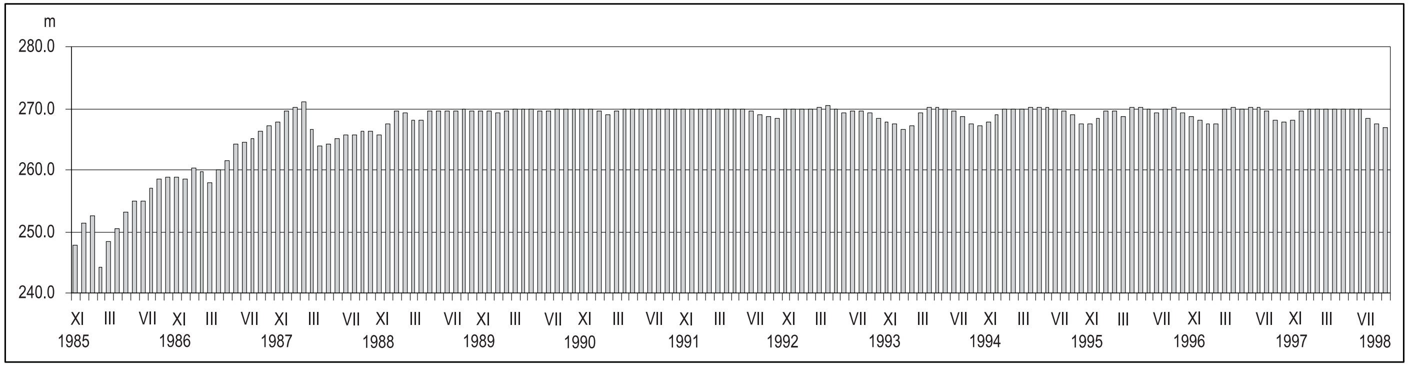


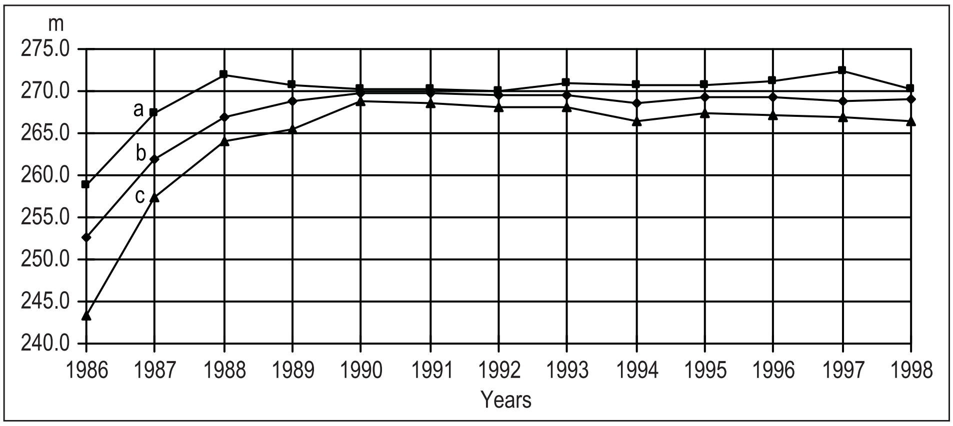
Fig. 1. Mean monthly levels in 1985-1998 (I – January, II – February, etc.)

values and, at the same time, it is only 133 cm lower than the maximum pool level. During the first three years of the reservoir's operation the largest amplitudes of the water levels, reaching to 15.52 m in 1986, 10.05 m in 1987 and 7.82 m in 1988 have been recorded. These huge variations in the water level of the reservoir are attributed to the prerequisite of also gauging the water level during the maximum operation storage of the reservoir. In the calculations of the water level characteristics, however the data of the aforementioned years have not been considered. Since 1989 the mean monthly water levels are very uniform. Since 1993, a distinct annual rhythm of the water level oscillations, resulting from the water inflow and the reservoir's method of operation, has just been noticed (Tab.1, 2, Fig. 1).

Tab. 2. Characteristic water levels of the Dobczyce reservoir (in metres)

Year	Mean	Maximum	Minimum	Range
1986	252.68	258.82	243.30	15.52
1987	261.99	267.41	257.36	10.05
1988	266.87	271.80	263.98	7.82
1989	268.83	270.76	265.50	5.26
1990	269.69	270.20	268.86	1.34
1991	269.76	270.27	268.61	1.66
1992	269.52	270.09	268.18	1.91
1993	269.63	270.86	267.98	2.88
1994	268.46	270.70	266.38	4.32
1995	269.38	270.60	267.27	3.33
1996	269.37	271.30	267.23	4.07
1997	268.93	272.30	266.90	5.40
1998	269.14	270.28	266.40	3.88
1988-1998	269.05	270.83	267.03	3.81

The mean water level of the reservoir in the period from 1988-1998 was 269.05 m a.s.l. and was 0.85m lower than the predicted level. The year-on-year variability of the water level was small (Tab.1). At that time, the range of the mean annual water



a – maximum, b – mean, c – minimum

Fig. 2. Course of characteristic water levels in 1986-1998

level was 1.30 m while the mean amplitude of the annual water levels was only 0.89 m. The courses of the mean, minimum and maximum water levels in the years without high floods were similar, and only the maximum water level of 1997, resulting from the necessity of cutting down the flood wave, was higher. The mean and minimum water levels have, in principle, an identical course.

During the years of low precipitation, especially where there is not a spring rise in the water level that affects the reservoir storage for an oncoming summer, much lower minimum water levels are to be expected.

4. Water level changes during the floods

The flood-control role of the reservoir is a reason for the rapid changes in the water level that occur in two typical situations. The first situation is an increase in a flood-control storage prior to a flood wave passage that leads to a lowering of the water table by several tens of centimetres. The second one is a discharge of water after the flood wave has passed in an uncertain meteorological situation when consequent, ongoing precipitation might generate an increased water inflow to the reservoir.

A rapid increase in the water level in the reservoir is only possible if the inflow is high during a flood, especially if the peak of the flood wave has to be cut down. This latter case is well illustrated by the curve of daily water level changes in 1997 (Fig. 3), when the rapid tremendous flood occurred in the Carpathians. The peak volume of the flood wave was stored, and was then discharged right after the flood passage. The shape of the flood wave, plotted basing on the hourly records, is presented in Fig. 4. The course of this flood and its duration are typical for the large floods.

The upper limit of the changes in the water levels is the level of the maximum surcharge storage, that cannot be altered as it results from the reservoir's design.

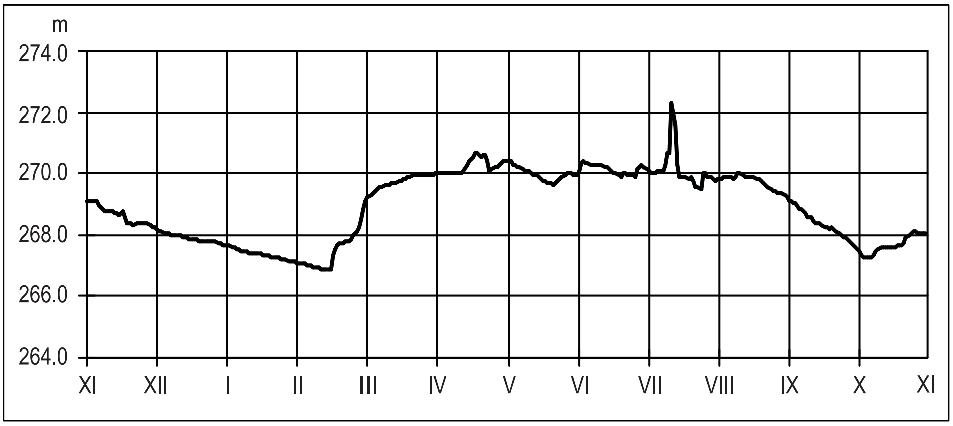


Fig. 3. Water levels in 1997 (I – January, II – February, etc.)

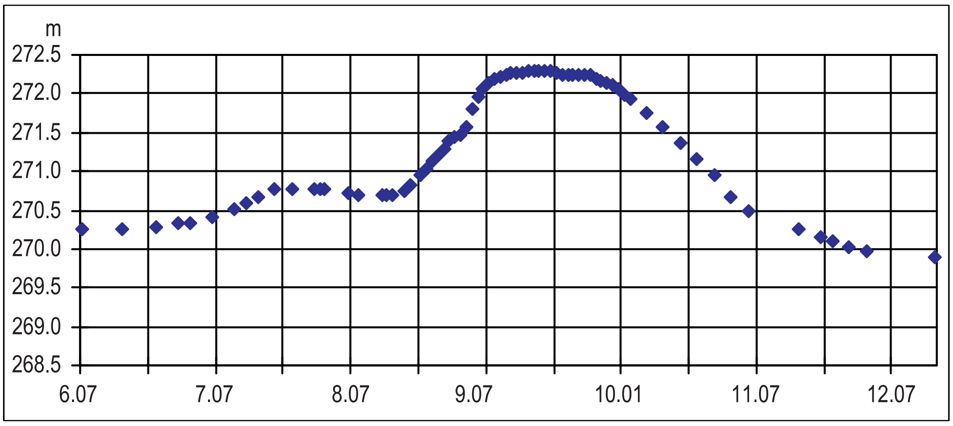


Fig. 4. Water levels during the flood of 6-12 July 1997

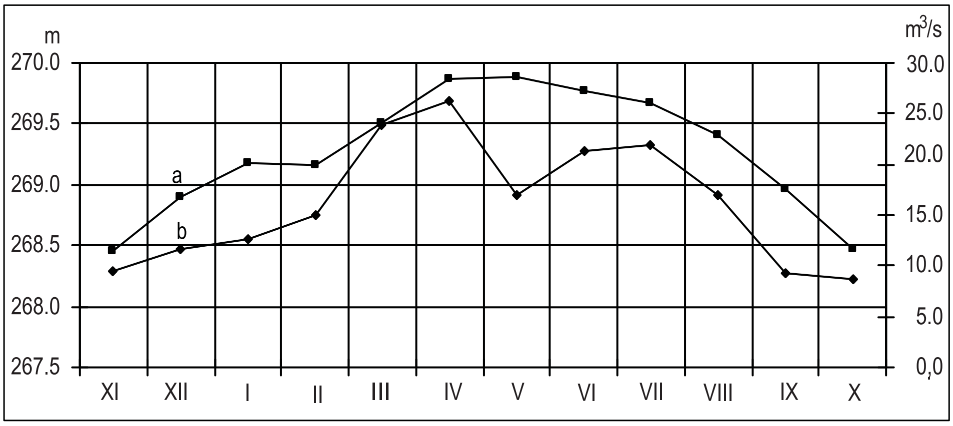
The lower limit depends on the adopted management practice. The maximum amplitude during singular episode discharges reached to 2.5 m during 2-3 days. The maximum diurnal changes attained 1.5 m (8-9 July 1997).

In the months when the water inflow is low or average, a slow drop in the water level occurs. The water intake by the water supply plant and the request to keep the minimum pool level result in a permanent drop in the water level of the reservoir, that is visible in a gently descending curve. All the changes in the discharges, which refer both to the water inflow from the Raba drainage basin and to the regulated outflow through the spillways and outlets, are reflected in the pattern of the water levels.

5. Hydrologic regime of the Raba river and of the water level of the Dobczyce reservoir

The curve depicting the course of the mean monthly water levels of the reservoir (Fig. 5) is the curve of the Raba river discharges transformed by the reservoir. The presention of the two curves in one figure (Fig. 5) documents the scale of the changes in the hydrologic regime of the Raba river. The course of these curves during a year is very diverse, despite the dynamics of the changes from July to August being very similar. The annual cycle of the oscillations of the Raba discharges and of the water level of the reservoir have, in principle, only one common point. That is the culmination of the Raba river discharges in April and the highest mean monthly water level of the reservoir also occurring in this month.

The hydrologic regime of the Raba river, typical for this part of the Beskidy Mts., is characterised by two culminations. The spring thawing culmination predominates, and the lower summer culmination is caused by the inflow of continuous rain water. The sporadic high floods that occur decide upon the occurrence of the secondary period of the high water level in July. The spring and summer floods are separated by a long-lasting low water level in May.



a – reservoir, b – Raba river

Fig. 5. Annual cycle of the mean water levels of the Dobczyce reservoir and the Raba river discharges (I – January, II – February, etc.)

The curve of the Raba river discharges transformed by the reservoir, in the form of the averaged monthly water levels, consists of two very different sections. The first section lasts from November till April-May. At that time the reservoir is being filled with the water of winter precipitation and spring thawing.The decrease in a rate of the filling of the reservoir in February during the winter low water level is a rule here. The highest water levels of the reservoir occur in April and May. The May low water level in the Raba drainage basin is not reflected in the drop in the water level of the reservoir. The second section starts in June. The decrease in the water level is slight until July; and the highest from August till October when it reaches almost 0.5 m per month. The course of the water level of the Dobczyce reservoir and of the Raba discharges is similar from November till April and from August till October. From May till July the curves depicting the water levels of the reservoir and the Raba discharges are diverse (Fig. 5). The emptying of the reservoir starts in May. The secondary flood of July can contribute to a longer duration of the high water levels in the reservoir in autumn.

The above presented course of the mean monthly water levels of the Dobczyce reservoir can be assumed to be stable. With the reservoir operation manual in force, the course of the annual water levels of the reservoir will not be subjected to significant changes.

6. Influence of the Dobczyce reservoir on the water conditions in the surroundings

The hydrologic influence of the Dobczyce reservoir on the direct surroundings is strongly controlled by the relief. The south-eastern arrangement of the Raba valley does not create favourable conditions for the formation of high energy waves which contribute to the degradation of the shores. The shoreline of the reservoir is very well developed, forming deeply incised bays in the outlet sections of tiny streams where the effect of the waves is practically meaningless. The steep, foothill slopes descending to the reservoir are drained by a dense network of intermittent streams and by non-numerous permanent streams. The oscillations of the water level in the reservoir influence only a very narrow zone and do not cause perching of the slope groundwater. The phenomenon of the perched groundwater table occurs on a larger scale only in the backwater part of the reservoir near Myślenice-Osieczany where the most unfavourable and unstable conditions occur, as is the case in any reservoir. In the outlet sections of the larger streams (the Trzemeśnianka, Ratanica, Brzezówka, Dębnik, Wolnica and others) the moisture of the valley floors has changed. The permanently and intermittently water-logged areas with the characteristic hydrophilous vegetation have formed. The area transformed in this way does not exceed 0.25 km^2.

In the prevailing part of the reservoir's shoreline, especially on its northern part, the forest descends directly to the water table. The gravitational processes associated with a cyclic seepage of water into the sediments building the banks and partially with an abrasive action of the waves, cause cliffs to form ranging in height from a few to several metres. In this zone, the forest is being destroyed mechanically due to the slumping of the substratum.

The foothill terrain of the monotonous landscape is, in fact, a very complicated hydrologic system consisting of many small drainage basins with extremely diversified runoffs. The anthropogenic transformations of the landscape, mainly due to agricultural practices, emphasise the spatial differentiation of the water conditions. The farming, that has been lasted a few hundred years, has resulted in large areas being without a natural draining network (arable fields) and a forested system of incisions with a permanent outflow. The conditions of infiltration and of the formation of surface runoff have changed. A simulation of the water circulation in a foothill drainage basin (Bardzik 1993) documents the moisture changes in the soil profile. The outflow from the arable fields occurs in the field roads which function as a system of the intermittent and episodic drainage. The drainage of the groundwater takes place in shallow slope concavities and incisions where are springs occur. The spatial differentiation of the runoff and the complexity of the water circulation in the foothill terrain are emphasised in the monographs (Grodzińska, Laskowski 1996; Pawlik-Dobrowolski 1993) which utilise the results of the direct gauging in the closest vicinity of the Dobczyce reservoir.

The mean annual specific runoff (Mrozek *et al.* 1993) in the foothill area is in the interval of a 6-11 l/s/km^2 (drainage basins of the areas up to 4.5 km^2). The differentiation of the runoff in space and time is astonishingly high. During the three years with precipitation similar or lower than the multi-year average, and depending on the precipitation pattern during a given year, the specific runoff in the summer season of the hydrologic year reached 3.5-11.2 l/s/km^2 in the Ratanica drainage basin where 67% of the area is forested and 2.3-9.6 l/s/km^2 in the Wolnica drainage basin where only 12% of the area is forested (Mrozek *et al.* 1993). The authors of the monograph (Pawlik-Dobrowolski 1993) point to the geological structure as the main reason behind the spatial differentiation of the runoff whereas in the literature the regulatory, favourable influence of the forest on the water circulation is commonly emphasised. From the mean annual values it is difficult to discern the influence of the forest on the water circulation in the foothill drainage basins while such influence is evident from the mean monthly values of the vegetation period. In autumn, the values of the specific runoff in the Ratanica drainage basin are much higher than in the drainage basins with the small forested areas.

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