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Mętność wody zbiornika zaporowego w Goczałkowicach w 1960 roku — Water turbidity of the barrage reservoir in Goczałkowice in 1960

Mémoire présenté le 5 février dans la séance de la Commission Biologique de l'Académie Polonaise des Sciences, Cracovie

The present work was intended to investigate in a year cycle the alterations in turbidity, transparence and colour of water in the Goczałkowice barrage reservoir.

The Goczałkowice reservoir lies in an area characterised by a relatively considerable rainfall (500—800 mm yearly), especially in July and August. The summer flood thus caused have a great influence on the turbidity of the reservoir. Its dam is situated at 67 km from the source of the river Vistula (Wisła). The entire declivity of the Vistula from its source to its estuary amounts to 703 m, the unitary declivity is of 10,49‰. It must be noted that it is only of 0,58‰ on the last 5 km long sector from Drogomyśl to Goczałkowice. Only the sources area, from the sources to the mouth of the White Wiselka (Biała Wisełka) has a considerable declivity amounting to 59,6‰. In Ustroń the Vistula flows into a broad dale with undulating slopes falling down as far as Drogomyśl. The reservoir itself is situated on a relatively flat terrain. Its surface (when an 256 m above sea level) is of about 30 km², 12 km long and 2—4 km broad, with a maximum depth from 13 m to 10 m (when 253 m above sea level). The average transversal decline of the reservoir is of 1—4‰, the longitudinal one — 0,5 to 0,8‰. The slopes of the banks are rather mild on the southern side, with an incline of about 0,5‰. In the area occupied by the reservoir in its upper part, along the ancient bed of the Vistula, remnants of embankments can be seen, appearing above the surface when the reservoir contains less water. The Vistula collects the waters of three streams: the Brennica, Bładnica and Knajka above the reservoir; Bajerka, its fourth affluent, falls into the reservoir on its southern side.

Material and method

Turbidity measurements were conducted by means of Pulfrich's nephelometer. The temperature of air and water was simultaneously taken, alkalinity, pH (colorimetrically) oxygenation and general hardness were investigated. Water for analysis was taken with Ruttner's sampler. The transparence of water was measured with Secchi's plate and its colour was determined on the background of the plate. Moreover the state of weather (wind, insolation and the level of the water in the reservoir) was noted in places also taken in consideration in various other investigation carried out in the same reservoir (Fig. 1, 4). On stands

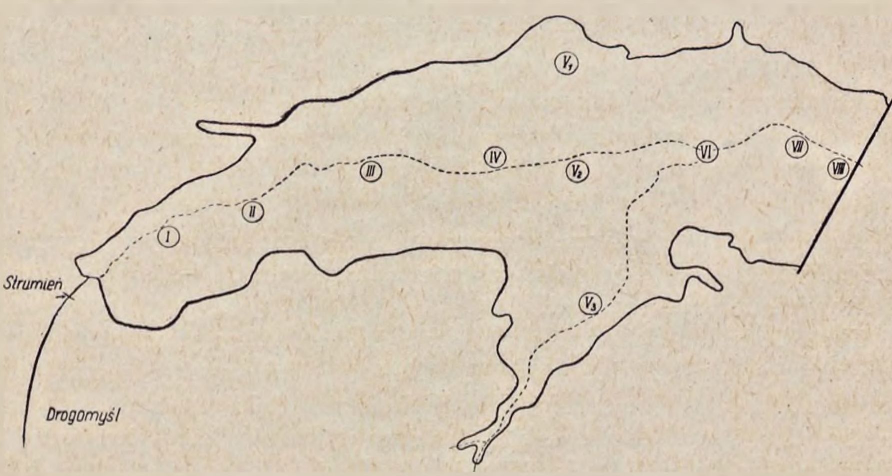

Fig. 1. Disposition of stands on the area of the Goczałkowice reservoir (I. — VIII. and V_3 previous bed of the Vistula and the Bajerka)

II, IV and VI no samples were collected. Samples were taken simultaneously from two stands in the Vistula above the reservoir. On separate stands, and with special accuracy on stand VII, near the dam, samples were collected in a vertical column of water. In sum, from the month of March till December 1960 measurements of the entire reservoir were conducted seven times, and thirteen times on stand VII. The analyses were carried out immediately after the samples had been brought to the laboratory of the Hydrobiological Station in Goczałkowice — that is 1—2 hours after they had been collected.

Turbidity of water in the Vistula above the reservoir

In Polish climatic conditions, besides soil properties, the most important factor influencing the tendency towards erosion of a given terrain is the degree of declivity and the length and shape of the slope.

As the Vistula flows from Ustroń to the reservoir through a broad and undulating valley and only the part near its sources is steep, therefore the current of the river is gentle and the turbidity of its water slight. Only at flood periods, when the amount of descending waters increases, is the turbidity of water in the Vistula greater (Table I).

Table I.

Turbidity of water in the river Vistula (in mg SiO_2/l) above the Goczałkowice reservoir near Drogomyśl and Strumień

Date	[illegible].1960	30.VI.1960	[illegible].VII.1960	[illegible].VIII.1960	[illegible].IX.1960	[illegible].1960	[illegible].XI.1960
Drogomyśl	23.0	19.4	34.0	31.2	20.0	19.3	18.7
Strumień	26.0	30.0	41.0	36.0	23.0	18.4	19.9

In 1960, two floods caused a heightening (an increase) of water turbidity which can be easily observed on the tables. The measurements of July 15 were noted after the first intensity of the flood, its culminative point occurring on July 10. The second intensity took place on July 27, when the water level rose to 256.01 m. The measurement on August 11 was made in the period after the flood, when the turbidity of water was decidedly lower.

A higher turbidity of water in Strumień, in comparison to that of Drogomyśl, may be caused by the turbid water of the stream Knajka, flowing into the Vistula above the place where samples were taken in Strumień — or by the fact that Strumień is situated in the region of the expansion of the reservoir. This is the cause of a turbidity greater than in Drogomyśl.

General characteristic of the turbidity of water in the reservoir

The entire reservoir can be divided into three sectors on its longitudinal section:

1. The upper part of the reservoir below Strumień (stand I) about 1,5—2 km long is characterised by the highest turbidity of its water, fluctuating in the limits of 16—53 mg SiO_2/l on the surface and from 30—100 SiO_2/l near the bottom, at a depth of 5,0 m (Table II), according to atmospherical conditions. This investigated part of the reservoir is situated in the limits of the ancient embankments of the Vistula. Mineral particles, carried into the reservoir by the Vistula, dominate here both in surface and bottom strata. Owing to a usual lack of breaches in the embankments the bottom sediments settle here most abundantly. From May till October turbidity was high, being more considerable near the bottom than near the surface. Only in November did the surface stratum

Table II.

Vertical system of turbidity in different stands: I, III, V_1, V_2, V_3, VII, VIII

Time		Stands I	III	V_1	V_2	V_3	VII	VIII
	Depth in m	Turbidity in mg SiO_2/l	Turbidity in mg SiO_2/l	Turbidity in mg SiO_2/l	Turbidity in mg SiO_2/l	Turbidity in mg SiO_2/l	Turbidity in mg SiO_2/l	Turbidity in mg SiO_2/l
27.V.	m 0	46,85	22,2	17,0	20,0	20,0	16,7	17,4
	2	56,6	29,4	18,2	19,8	19,5	17,4	17,7
	3	-	-	-	-	19,6	-	-
	4	-	-	17,5	-	-	-	-
	5	60,0	27,0	-	-	-	18,9	19,5
	8	-	-	-	-	-	39,9	56,2
	9	-	-	-	-	-	42,5	>100,-
30.VI.	0	39,7	30,7	14,0	19,1	19,8	15,8	17,0
	2	48,5	34	19,8	23,0	24,0	16,5	17,4
	5	51,0	-	13,2	27,2	-	17,8	24,3
	8	-	-	-	-	-	41,0	47,5
	10	-	-	-	-	-	48,2	50,0
15.VII.	0	16,85	16,8	14,7	15,8	18,5	17,2	16,5
	2	44,0	45,4	15,8	19,3	23,0	19,5	26,0
	4	-	-	17,0	49,6	-	-	-
	5	110,0	53,5	-	-	-	24,1	18,4
	6	-	59,5	-	-	-	-	-
	8	-	-	-	-	-	50,0	53,5
	10	-	-	-	-	-	89,4	94,6
11.VIII.	0	36,0	32,8	17,5	22,6	28,4	16,4	14,5
	2	38,2	35,9	18,5	24,2	32,0	19,4	16,8
	5	42,7	43,5	22,0	34,5	-	19,0	18,2
	8	-	-	-	-	-	42,7	45,2
	10	-	-	-	-	-	49,3	50,8
13.IX.	0	46,7	24,2	19,8	19,6	19,1	17,5	17,5
	2	49,8	29,5	22,2	40,2	20,0	18,5	17,6
	5	91,2	40,8	37,0	45,3	-	19,3	17,8
	8	-	-	-	-	-	24,8	46,8
	9	-	-	-	-	-	49,5	-
	10	-	-	-	-	-	-	>150,-
4.X.	0	53,5	19,5	16,1	17,3	17,3	14,2	14,0
	2	59,0	18,7	15,8	19,5	18,0	17,8	17,0
	3	-	-	-	-	26.8	--	-
	4	-	-	-	21,0	-	-	-
	5	77,2	48,8	18,8	-	-	18,4	18,5
	8	-	-	-	-	-	21,0	19,2
	9	-	-	-	-	-	-	-
	10	-	-	-	-	-	32,0	36,0
9.XI.	0	25,0	18,2	17,2	16,6	16,5	17,4	16,2
	2	19,9	17,3	16,2	19,4	16,7	17,1	15,0
	3	-	18,8	-	-	17,7	-	-
	4	-	-	-	38,1	-	-	-
	5	29,8	-	18,2	-	-	17,3	16,4
	8	-	-	-	-	-	17,8	17,5
	9	-	-	-	-	-	19,6	19,2

of water become more turbid than water at the level of two metres. (Fig. 3).

2. The central part of the reservoir (stands III—V) about 5 km long, is a transitory zone where a partial clarification of the water takes place. Turbidity fluctuated in the limits of 15—30 mg SiO_2/l in the surface stratum and of 20—50 mg SiO_2/l in the stratum near the bottom (depth 5,0 m). On the whole, the turbidity of this zone was considerable and increased from the surface towards the bottom from May to September. In October and November the turbidity of water at a depth of two metres was lower than immediately below the surface.

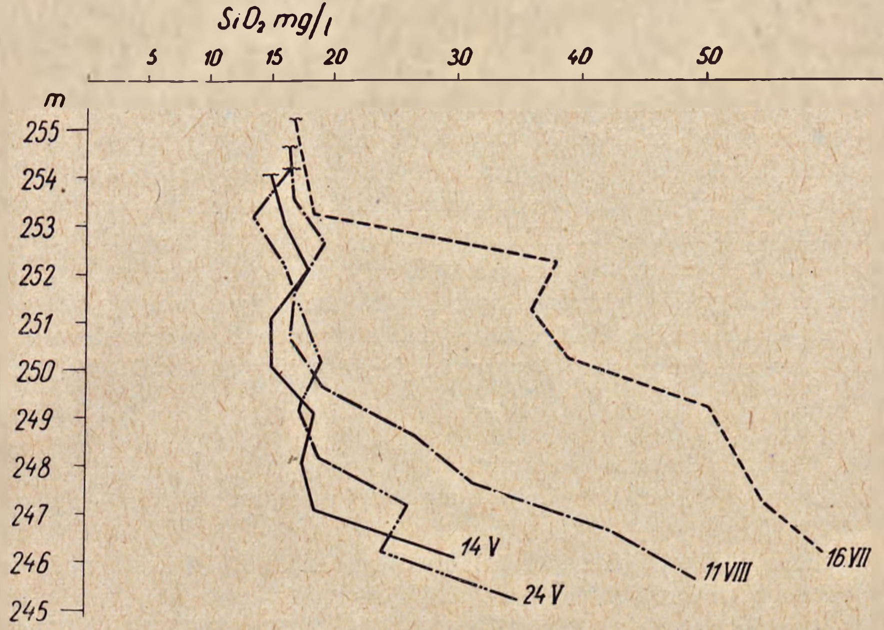

Fig. 2. Fluctuations of turbidity in a column of water in stand VII, from May 14 to August 11, 1960. The water level in the reservoir is given in m above sea level

In the old valley of the river Bajerka, on the stand V_3 at a depth of 3 m on the average, the turbidity was subject to inconsiderable alteration in the yearcycle. Only on August 11, in the post-flood period it rose slightly, up to 28,4 mg SiO_2/l on the surface and to 32 mg SiO_2/l in the stratum near the bottom (at a depth of 2 m). On stand V_1, near the village Wisła Wielka, the turbidity fluctuated still less — from 16,1 mg SiO_2/l (October 4) to 19,0 mg SiO_2/l (September 13) on the surface, and from 17 mg SiO_2/l (July 15) to 37 mg SiO_2/l (September 13) in strata near the bottom.

3. In the lower part of the reservoir (stands VII—VIII) a distinct differentiation takes place in the vertical disposition of the suspension. The turbidity of water fluctuated in the limits of 15—18 mg SiO_2/l on the surface and of 30—50 mg SiO_2/l near the bottom, at a depth of 9,0 m.

Thus the water of the upper part of the reservoir is the most turbid. It becomes gradually clear when approaching the dam; this can be easily explained by the fact that first the heavier and then the lighter particles transported by the water of the Vistula drop to the bottom. Moreover, the upper part of the reservoir shows the greatest divergence of water turbidity during the entire season. In November the surface stratum in the reservoir was more turbid than at the depth of two metres. A stronger development of plankton on the surface, in relation to weaker light, might influence a greater turbidity on the surface. In summer, there may be a greater amount of plankton at a depth of two metres (Tab. II).

The course of variations of the turbidity of water along the reservoir can be observed in Fig. 3, on which water strata with a turbidity transgressing 25 mg SiO_2/l have been lined. It appears distinctly that turbidity diminishes in the measure that water flows through the reservoir towards the dam. It is interesting to observe near the dam, on stand VIII, that in certain periods turbidity is greater than on stand VII, placed in a slightly higher position. This is probably caused by backward currents as the reservoir lies in an area of frequent southwestern winds which provoke the uprise of water in the direction of stand VII (Fig. 6).

Vertical changes in temperature, oxygenation and turbidity in the deepest part of the reservoir

A more distinct differentiation in the vertical stratification of water can be expected only in the part of the reservoir contiguous to the dam, where the depth attains 10 m (Tab. III, Fig. 2, Fig. 5).

Thermical stratification could be observed on June 24, July 15 and August 11. But even then most considerable difference amounted to 4 °C only (July 15). In spring and in the autumn the temperature in a perpendicular line is equalised.

In May, oxygenation was not liable to greater changes being of 6,38 mg O_2/l (2 m depth) to 5,7 mg O_2/l (9 m depth). In summer months the greatest oxygenation, 8,32 mg O_2/l, was noted on June 24, at a depth of 1 m, while at a depth of 9 m it only amounted to 4,8 mg O_2/l. The lowest value, 4,6 mg 0_2/l, was noted on June 30 (8 m depth). In July rainfall was abundant, and in the flood period (July 15) the water was mixed on the whole and oxygenation fluctuated from 8,16 mg O_2/l (on the surface) to 7,5 mg O_2/l (depth of 8 m). In August measurements were carried out after flood waters had receded and oxygenation fluctuated in narrow limits (6,24—7,5 mg O_2/l). In autumn the fluctuations of oxygenation were minimal and amounted to 6 mg O_2/l on the average. In winter (December 16) the highest oxygenation of 8 mg O_2/l appeared at a depth 1 m, the lowest, of 5,2 mg O_2/l at a depth of 8 m. Vertical stratification of turbidity was most variable. In summer when the weather was sunny and windless distinct stratification could be observed. This was especially noticeable on June 3 and August 11. Without recurring to the use of intruments a more transparent upper stratum of water up to 4 m depht could be observed, while below 4 m a more turbid stratum was apparent. The maximal turbidity of the upper stratum appeared up to 2 m depht. Then, at a depth of four or

Table III

Vertical system of temperature, oxygenation and turbidity on stand VII during the year 1960

Depth in m / Time	25.III.			14.V.			24.VI.			15.VII.			11.VIII.		
	Temperature °C	Oxygenation mg O_2/l	Turbidity mg SiO_2/l	Temperature °C	Oxygenation mg O_2/l	Turbidity mg SiO_2/l	Temperature °C	Oxygenation mg O_2/l	Turbidity mg SiO_2/l	Temperature °C	Oxygenation mg O_2/l	Turbidity mg SiO_2/l	Temperature °C	Oxygenation mg O_2/l	Turbidity mg SiO_2/l
0	5°C	-	9.9	14.0	6.32	16.-	18.6	6.32	16.5	19.6	8.24	16.8	19.0	6.24	16.4
1	5°C	-	8.5	13.8	6.25	17.1	18.4	8.32	13.5	19.2	8.16	17.7	19.4	6.9	16.8
2	5°C	-	11.2	13.7	6.25	18.2	18.3	7.44	16.0	19.2	7.52	18.5	19.5	7.5	13.4
3	5°C	-	14.2	13.7	6.00	15.0	18.0	6.64	17.5	19.0	8.08	38.0	19.2	6.3	17.0
4	5°C	-	17.4	13.7	6.00	15.0	17.8	6.64	19.1	18.2	8.00	36.2	19.1	7.0	16.6
5	5°C	-	18.5	13.7	5.60	18.5	17.6	6.56	17.3	17.5	7.84	39.1	19.1	7.2	19.0
6	5°C	-	19.5	13.7	5.75	17.5	17.3	5.12	19.0	17.2	7.84	50.0	18.7	6.84	26.4
7	5°C	-	20.8	13.7	5.60	18.5	17.0	4.80	26.2	16.5	7.44	52.3	18.0	6.48	31.2
8	5°C	-	-	13.7	5.25	19.0	14.5	4.64	24.0	16.0	7.76	54.5	18.0	6.84	42.7
9	5°C	-	27.3	13.7	6.00	30.2	14.3	4.80	35.0	15.2	7.20	53.5	17.5	6.08	49.3
10	-	-	-	-	-	-	-	-	-	15.0	7.20	59.2	-	-	

Depth in m / Time	30.IX.			25.X.			18.XI.			10.XII.			16.XII.		
	Temperature °C	Oxygenation mg O_2/l	Turbidity mg SiO_2/l	Temperature °C	Oxygenation mg O_2/l	Turbidity mg SiO_2/l	Temperature °C	Oxygenation mg O_2/l	Turbidity mg SiO_2/l	Temperature °C	Oxygenation mg O_2/l	Turbidity mg SiO_2/l	Temperature °C	Oxygenation mg O_2/l	Turbidity mg SiO_2/l
0	13.8	8.60	17.3	10.7	5.92	14.0	7.6	6.09	15.4	5.7	5.92	17.8	4.4	7.84	15.8
1	14.0	8.40	18.4	10.5	6.40	14.5	7.8	6.24	16.4	5.7	6.40	21.0	4.3	8.00	17.1
2	14.1	8.40	18.7	10.2	7.04	15.8	7.8	6.24	16.2	5.8	6.72	34.0	4.0	7.52	16.6
3	14.1	8.16	17.8	10.1	6.96	14.9	7.8	5.20	16.1	5.8	6.56	30.5	4.0	5.76	16.4
4	14.1	8.16	16.8	10.0	5.74	16.2	7.8	5.92	16.3	5.8	6.40	31.0	4.2	6.12	16.6
5	14.1	8.20	18.2	10.0	6.24	17.0	7.8	5.20	16.0	5.8	6.40	29.0	4.2	6.40	16.7
6	14.1	7.04	19.0	9.9	6.12	17.8	7.8	6.16	16.1	5.8	6.32	24.2	4.3	5.50	16.4
7	14.1	6.80	18.8	9.9	6.00	18.2	7.8	6.08	15.8	5.8	6.08	19.4	4.3	5.20	17.2
8	14.0	8.20	24.0	9.9	7.04	18.0	7.8	6.30	16.7	5.8	6.00	19.3	4.3	5.20	17.5
9	14.0	8.00	25.05	9.9	7.20	19.1	7.8	6.16	16.6	5.8	6.08	18.2	4.1	6.56	19.6
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

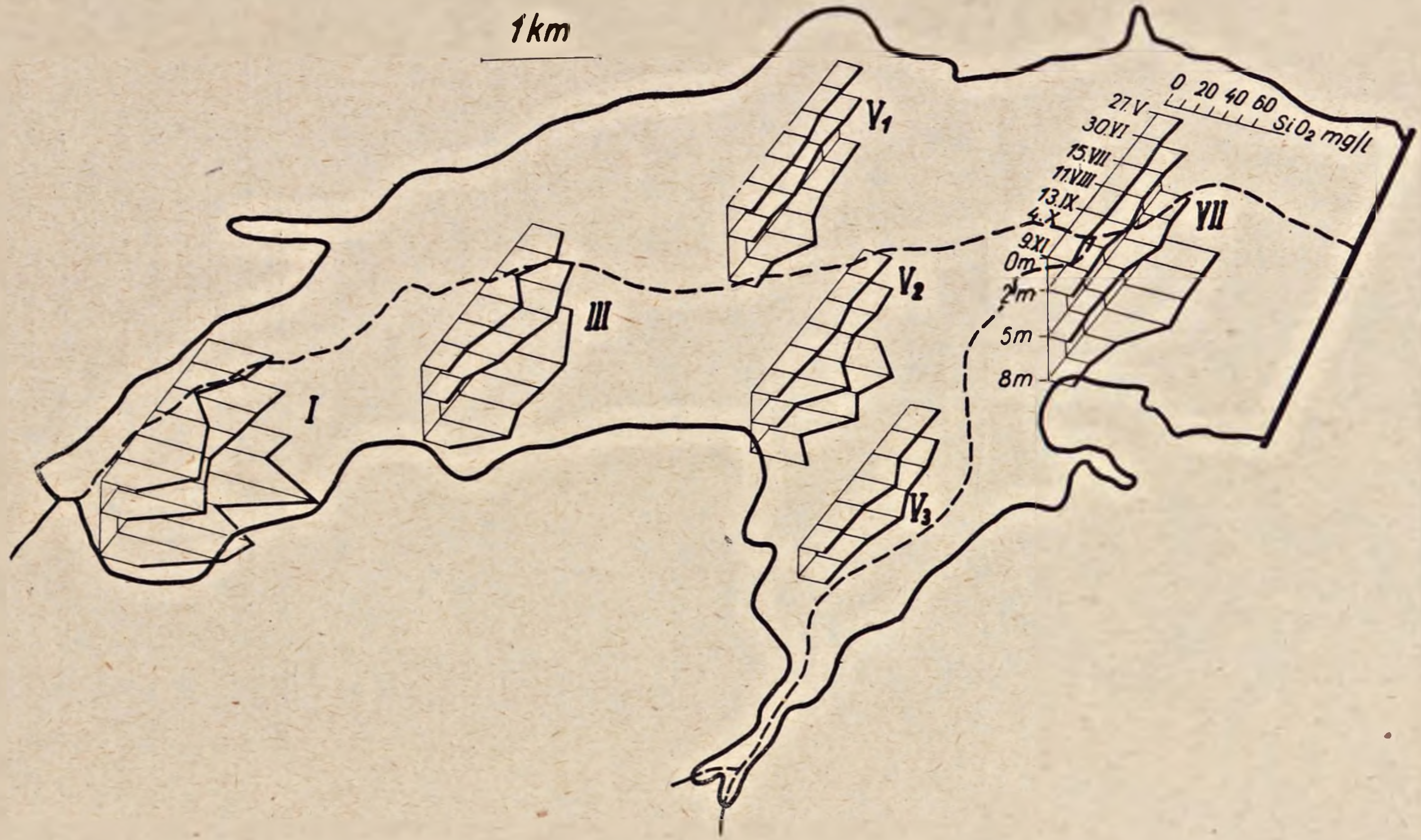

Fig. 1 Vertical distribution of water turbidity in the Goczalkowice reservoir in various stands during 1960

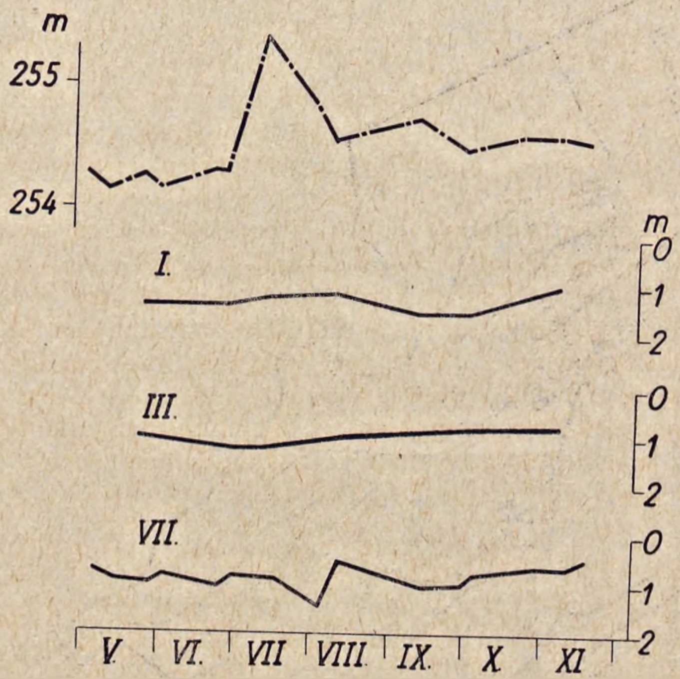

Fig. 4. Fluctuations in the water level of the reservoir and of transparence on three transsections in the direction of the dam

five metres, the degree of turbidity declined, to rise once more in the lower stratum. In December (16. XII) a stratification similar to that of summer period may be noticed, but the maximum of water turbidity appeared at the depth of 1 m. Nearly always and as a rule the layers near the bottom are the most turbid (Fig. 2, 5).

Turbidity and other properities of water

The colouring of water depends on the quantity and character of the organic and mineral suspension. The colour of water in the reservoir changed from green to yellowish-brown in different periods. In May the very turbid water of the part of the reservoir (stand I) was green in colour (average turbidity from first two metres was 50,5 mg SiO_2/l). The central part (stands III and IV), with average turbidity from 18 to 25 mg SiO_2/l had a greenish-yellow and yellow colour. The lower part of the reservoir (stands VII and VIII), with medium turbidity of 17 mg SiO_2/l was yellowish-green. In the next months (June, July, August) water of the upper sector, with turbidity of 30—40 mg SiO_2/l, was of a yellow colour, the central sector, with turbidity of 20—30 mg SiO_2/l was yellow and greenish-yellow while the lower sector, with turbidity of 15—20 mg SiO_2/l was greenish-yellow. In September and October water from the upper sector had a yellowish-brown colour (turbidity of 18—30 mg SiO_2/l on the average), in the central sector it was yellow and yellowish-green (turbidity of 18—30 mg SiO_2/l on the average) and in the lower sector — yellowish-green and greenish-yellow (average of 15—20 mg SiO_2/l). In November the upper sector of the reservoir was yellow in colour (average turbidity 22,5 mg SiO_2/l, the central sector — greenish-yellow (turbidity 17—19 mg SiO_2/l on the average) and the lower sector — greenish-yellow (average turbidity 15—18 mg SiO_2/l). It is generally stated that on increase of turbidity changes the colour of water from green through yellow to a brown hue. In the yearcycle a yellowish-green and greenish-yellow colour prevails.

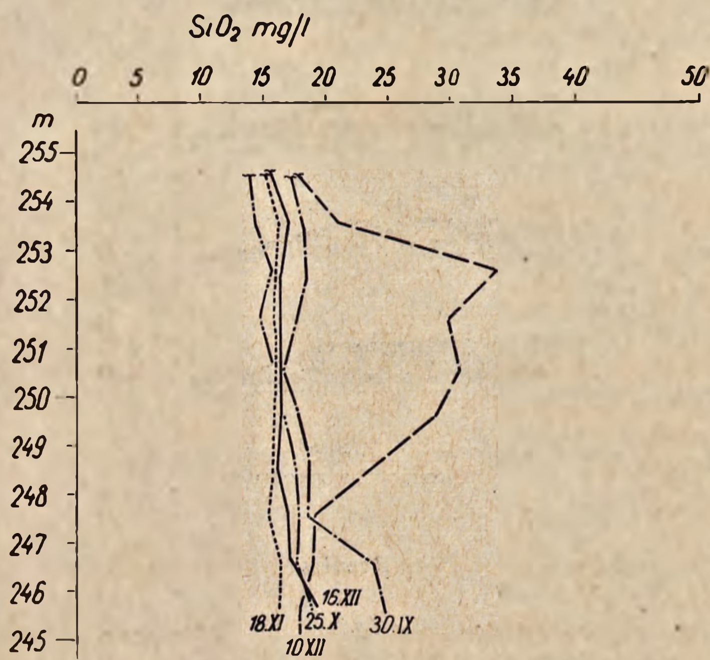

Fig. 5. Fluctuations of turbidity in a column of water in stand VII from September 30, to December 16, 1960

The reaction of water (pH) fluctuated in the limits of 6,8 (in winter) to 7,5 (in summer). Alkalinity amounted to 0,9 (summer) and 1,4 (winter). The general hardness was of about 4—5 German degrees.

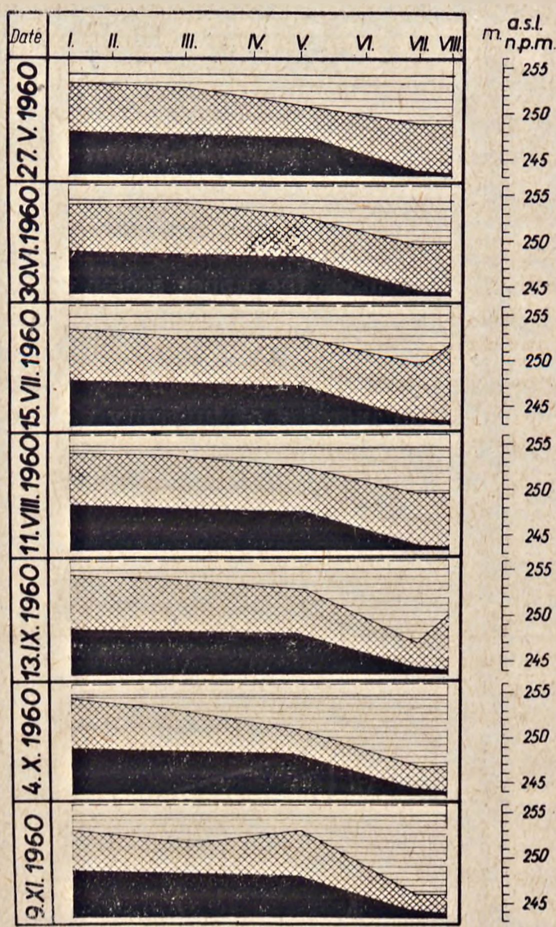

Fig. 6. Alterations in turbidity of water flowing through the reservoir

Results

1. Vertical stratification of water of different turbidity in the Goczałkowice reservoir is connected with water temperature. A diminution of temperature in the so-called thermical leap provokes a sudden increase of stickiness of the water. This causes a slowing down in the movement of particles and the resulting turbidity increase in the lower stratum.

2. In some periods an increase of turbidity (greater than in stand VII) was observed in the last (VIII) stand of the lower part of the reservoir.

Backward currents or the opening of gates in the sluice can be the cause of this. It seems, however, that the influence of backward currents is more probable, as an opening of gates can exert only a momentary influence.

3. Flood periods, which occurred twice in 1960, had a great influence on turbidity. Surface water showed a high turbidity even in the post-flood period.

The above investigations are of a preliminary character and shall be continued.

I wish to express my sincere thanks to Professor Dr K. Starmach who entrusted me withy this theme for ivestigation and to Dr M. Bombówna for her indications concerning the figures, and to Dr A. Rumek and Dr S. Wróbel for their help and valuable suggestion. I am indebted to Messrs. T. and A. Bolek for technical aid.

STRESZCZENIE

Praca obejmuje roczne badania mętności zbiornika goczałkowickiego przy użyciu nefelometru Pulfricha. Równocześnie prowadzono pomiary temperatury (wody i powietrza), pH, zasadowości, twardości ogólnej, utlenialności, barwy, przezroczystości oraz notowano obserwacje atmosferyczne i odczytywano poziom piętrzenia zbiornika. Cały zbiornik w przekroju podłużnym dzieli się na trzy części, różniące się wyraźnie pod względem mętności. Woda górnego odcinka jest najmętniejsza (50 mg SiO_2/l), w miarę zbliżania się do odcinka dolnego staje się klarowna (środkowy odcinek 30 mg SiO_2/l). W pewnych okresach na ostatnim stanowisku (VIII) zaobserwowano nagłe zwiększenie mętności powodowane prądami wstecznymi. Układ pionowy mętności wykazuje wyraźny podział na górną warstwę wody, bardziej klarowną, i dolną mętną. Chcąc prześledzić wpływ powodzi przeprowadzono w okresach popowodziowych pomiary, które stwierdziły, że dwie powodzie występujące w 1960 roku wywarły duży wpływ na mętność wody zbiornika.

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