Environment Protection Engineering

Vol. 12 1986 No. 2

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INFLUENCE OF RETENTION TIME ON THE LUBACHÓW DAM RESERVOIR TROPHICITY

A distinct relationship (with a high correlation confficient) between dynamics of water exchange in the reservoir and the development of phytoplankton (measured by the concentration of chorophyll) has been found. The nomographs based on the equations expressing this relationship and the transformed Carlson and Walker's TSI equation allow us to predict the development of phytoplankton (measured by concentration of chlorophyll) at various dynamics of water exchange.

1. INTRODUCTION

Lubachów reservoir on the river Bystrzyca was built in twentieth kilometer of its course in 1918. The present capacity of this reservoir at the maximal swelling amounts to 7.2×10^6 m^3, the catchment area to 51 ha, its maximal depth is 31.6 m (with an average depth of 14.1 m), and the drainage area is 146.4 km^2. The reservoir is fed chiefly with water of the river Bystrzyca as well as its two small tributaries and with surface run-offs from the area directly adjacent to the reservoir. Annual water inflows have been determined from 47 year observations. The minimal, average and maximal inflows being 10.8×10^6 m^3, 93.7×10^6 m^3 and 54.2×10^6 m^3, respectively. This corresponds theoretically to the number of water exchanges in the reservoir ranging from 1.5 to 13 yearly. Depending on the swelling level, such an exchange may occur even more frequently.

The Lubachów reservoir was built as a retention basin used also for energetic purposes. At present it is a source of industrial water supply for the Bielawa–Dzierżoniów region. In the future it will supply this region with potable water. Therefore, the knowledge of the factors affecting the trophicity of water in this reservoir is of a special importance.

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2. RESULTS AND DISCUSSION

The trophicity of water in the Lubachów reservoir was estimated with the help of two Carlson and Walker's throphic state indices (TSI). Both the indices are relatively simple; they are based on measuring data obtained as a rule during routine works. Therefore, their practical application does not create any difficulties and makes it possible to carry out a comparative assessment of a wide spectrum of results obtained by various institutions. The additional advantage of these indices is that each of them consists of 3 mutually dependent elements. Being based on total concentrations of phosphorus – TSI (TP), total concentration of chlorophyll – TSI (Chl), and on the transparency measured by Secchi disc – TSI (SD), they describe: the reason – phosphorus content, the effect – development of phytoplankton (measured indirectly by the chlorophyll content), and its symptom – water transparency. The importance of the later is questionable in the assessment of the trophicity of water in retention reservoirs. Water flowing into it after intense precipitations brings as a rule substantial amounts of suspended matter causing turbidity of water masses and deterioration of their transparency, not related at all to the development of plankton. Therefore in our considerations this third term in TSI was neglected and used the two remaining ones: TSI (TP) and TSI (Chl).

Trophicity state index according to Carlson is:

$$\mathrm{TSI\ (TP)} = 10\left(6-\frac{\ln(48/\mathrm{TP})}{\ln 2}\right), \tag{1}$$

$$\mathrm{TSI\ (Chl)} = 10\left(6-\frac{2.04-0.68\ln \mathrm{Chl}}{\ln 2}\right), \tag{2}$$

TP (mg/m^3), Chl (mg/m^3) – measures in surface water layer in summer, $\mathrm{TSI} \in \{0, 100\}$.

TSI < 40 – oligotrophic lake (0), 40 ⩽ TSI ⩽ 60 – mesotrophic lake (M), TSI ⩾ 60 – eutrophic lake (EU).

TSI according to Walker is:

$$\mathrm{TSI\ (TP)} = -15.6+46\ \lg\ (\mathrm{TP}), \tag{3}$$

$$\mathrm{TSI\ (Chl)} = 20+33.2\ \lg\ (\mathrm{Chl}), \tag{4}$$

TSI < 30 – oligotrophic lake (0), 25 < TSI < 45 – mesotrophic lake (M), 40 < TSI < 65 – eutrophic lake (EU), TSI > 60 – hypereutrophic lake (HEU).

In calculations of the TSI we used the results of analyses of water samples taken from the Lubachów reservoirs in the following months and years: July, August, September, 1975 – samples Nos. 1 to 3; June, July, 1976 – samples Nos. 4,5; September, 1981 – sample No. 6; June, July, August, September, 1982 – samples Nos. 11 to 14 (fig. 1).

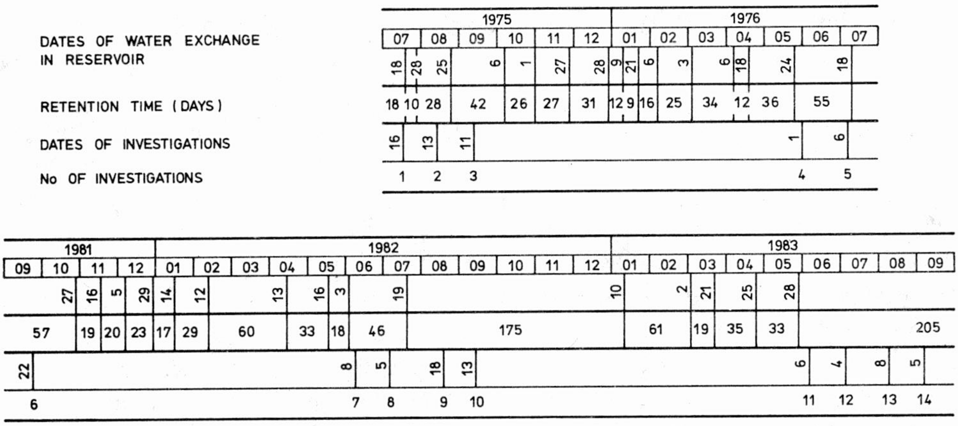


Fig. 1. Time-table of investigations and water exchange in reservoir

The stated concentrations of total phosphorus and total chlorophyll as well as TSI (TP) and TSI (Chl) calculated according to Carlson and Walker are given in tab. 1.

Assuming that the set of equations is correct and that the considered two elements are mutually interdependent with respect to their cause, as well as that processes running in water body of the reservoir are not disturbed with other factors, its should be expected that the indications of both the elements of each

Table 1

Concentrations of total phosphorus (TP), chlorophyll (Chl) and values of trophic state index TSI (TP) and TSI (Chl) after Carlson and Walker

No.	Dates	TP mg/dm^3	Chl µg/dm^3	Carlson		Walker	
				TSI (TP)	TSI (Chl)	TSI (TP)	TSI (Chl)
1	16.07.75	0.075	1.100	66.5	31.5	70.6	21.4
2	13.08.75.	0.067	0.900	64.8	29.6	68.4	18.5
3	11.09.75	0.078	8.210	67.0	51.2	71.4	50.3
4	1.06.76	0.061	2.060	63.4	37.6	66.5	30.4
5	6.07.76	0.121	11.200	73.3	54.3	80.2	54.8
6	22.09.81	0.236	7.100	82.9	49.8	93.5	48.2
7	8.06.82	0.322	1.600	87.5	35.2	99.8	26.8
8	5.07.82	0.226	13.700	82.3	56.2	92.7	57.7
9	18.08.82	0.249	96.200	83.7	75.4	94.6	85.8
10	13.09.82	0.716	387.000	99.0	89.0	115.7	105.9
11	6.06.83	0.106	11.000	71.4	54.1	77.6	54.6
12	4.07.83	0.069	81.000	65.2	73.7	69.0	83.4
13	8.08.83	0.375	134.000	89.7	78.6	102.8	90.6
14	5.09.83	0.329	173.000	87.8	81.1	100.2	94.3

index will be in conformity. In order to verifiy this assumption the correlation between TSI (Chl) and TSI (TP) according to Carlson and Walker has been presented graphically in figs. 2A and 2B, respectively.

At a close conformity of indications, the points should be arranged along the diagonal axis of the plot. In reality, however, in the graphs made for the considered relationship, the arrangement of points differs remarkably from the diagonal position. Spatial distributions of the points determining the relationship between TSI (TP) and TSI (Chl), calculated by Carlson's method and that due to Walker, are very similar, though the classification of trophic state based on the Carlson's method differs from that on the Walker's one.

All the values of TSI (TP) calculated according to Carlson are comprised within the eutrophy region. Of 14 points determining Carlson's relationship for TSI (Chl) only the values of 5 points (Nos. 9, 10, 12, 13, 14) correspond to the eutrophy state. TSI (Chl) values of other 5 points (Nos. 3, 5, 6, 8, 11) are specific for mesotrophy, while that of the remaining 4 points (Nos. 1, 2, 4, 7) correspond to oligotrophy (fig. 2A).

The values of TSI (TP) calculated according to Walker correspond to hypereutrophy. In figure 2B, illustrating the correlation between TSI (Chl) and TSI (TP), the indications of a group of 5 points are in agreement. The indications of these points were also uniform in the above correlation of Carlson's indices. The values of Walker's TSI (Chl) of the next 5-point group (Nos. 3, 5, 6, 8, 11) correspond to eutrophy. This is the same group, the values of which according to Carlson indicated the mesotrophy state. Finally, the values of TSI (Chl) of the last 4 points (Nos. 1, 3, 4, 7), according to Walker, correspond to oligotrophy, like in the case of TSI (Chl) according to Carlson.

Thus, in the TSI (Chl)–TSI (TP) relationship 5 (9, 10, 12, 13, 14) of the total 14 points show the conformity of indications of both the elements, suggesting that the development of phytoplankton follows the assumptions of Carlson and Walker and that is equivalent to the interrelation of both the indices considered and assumed by these authors. The investigations which gave the above results fell on the period during which the rate of water exchange in the reservoir was considerably slower (fig. 1). The highest discrepancy showing the relatively weakest development of phytoplankton with respect to the actual phosphorus content in water has been stated in four points (1, 2, 4, 7). Of this group the samples Nos. 1, 2, 7 were taken in the period of the intensified water exchange in the reservoir or immediately after this period.

The above observations may suggest that the development of phytoplankton in reservoir, adequate to the relationship between the contents of total phosphorus and chlorophyll in water and resulting from the equations for TSI, depends to a high extent on the dynamics of water exchange in the reservoir. It may be namely assumed that for a lake (reservoir) in which the processes are not disturbed, the indications of TSI (IP) and TSI (Chl) should be consistent. Consequently, this

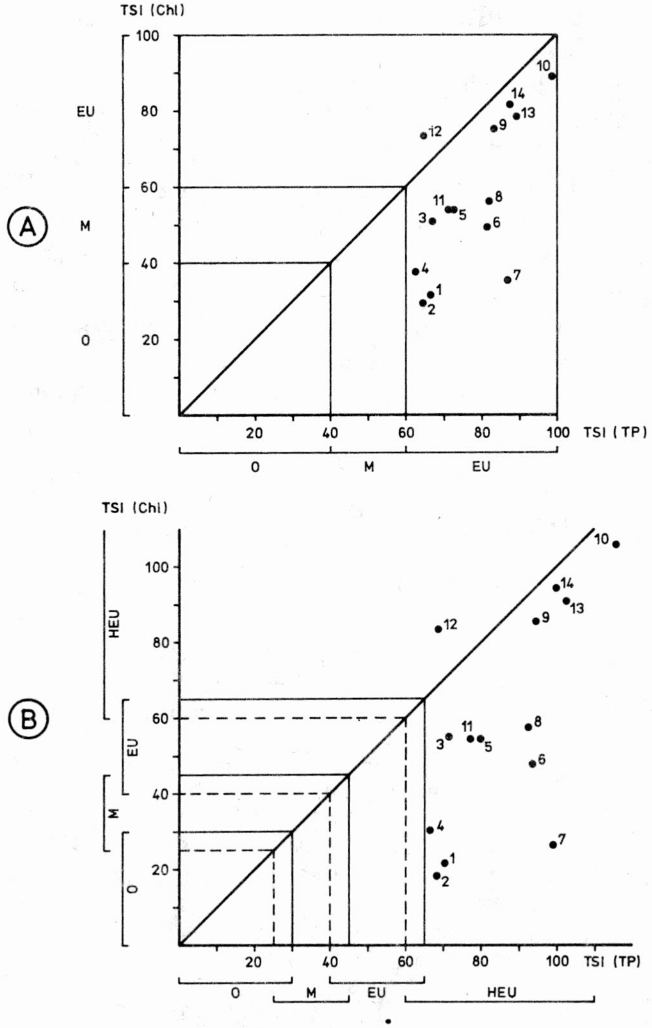


Fig. 2. TSI (Chl) versus TSI (TP) after Carlson (A) and Walker (B)

means that for a given concentration (given content) of phosphorus in water there is an adequate development of phytoplankton (measured by the chlorophyll content), assuming that this development is the function of phosphorus content, described by the formula

$$\ln(TP) = 0.68 \ln(Chl) + 1.38 \quad \text{according to CARLSON} \qquad (5)$$

or

$$\lg(TP) = 0.7217 \lg(Chl) + 0.7739 \quad \text{according to WALKER.} \qquad (6)$$

In such a case the TSI (Chl) to TSI (TP) ratio is 1. Each disturbance of the normal courses of processes occurring in water brings about the deterioration of the phytoplankton development. Consequently, the chlorophyll content is lower than that resulting from the equations (5) and (6) for the given concentration of phosphorus and the TSI (Chl) to TSI (TP) ratio becomes smaller than 1.

In order to establish whether and into what extent the dynamics of water exchange influences the development of phytoplankton, the correlation between the index TSI (Chl)/TSI (TP) and the dynamics of water exchange in the reservoir was determined and plotted. Dynamics of water exchange was expressed by the number of exchanges which would take place during one year if the average rate of exchange during the month preceding the given investigations lasted for the whole year (tab. 2). The plots were prepared for the TSI (Chl)/TSI (TP) ratios

Table 2

Coefficients $\frac{\text{TSI (Chl)}}{\text{TSI (TP)}}$ and dynamics of water exchange in reservoir

No.	$\frac{\text{TSI (Chl)}}{\text{TSI (TP)}}$		Dynamics of water exchange
	Carlson	Walker	
1	0.474	0.303	20.0
2	0.457	0.270	21.4
3	0.764	0.704	10.5
4	0.593	0.457	9.2
5	0.741	0.683	6.5
6	0.600	0.515	6.3
7	0.402	0.269	15.7
8	0.683	0.622	7.8
9	0.900	0.907	2.3
10	0.900	0.915	2.1
11	0.758	0.704	8.2
12	1.130	1.200	1.76
13	0.876	0.881	1.76
14	0.924	0.941	1.76

according to Carlson (fig. 3A) and Walker (fig. 3B). In the two plots arrangement of all the points shows a distinc linearity, on the TSI (Chl)/TSI (TP) ordinate the value of this ratio approaches 1, on the abscissa being less than 1. This means that the development of phytoplankton resulting from the function described by eqs. (5) and (6) for the given phosphorus content in the reservoir water is achieved at the average dynamics of exchange during the month preceding the investigations,

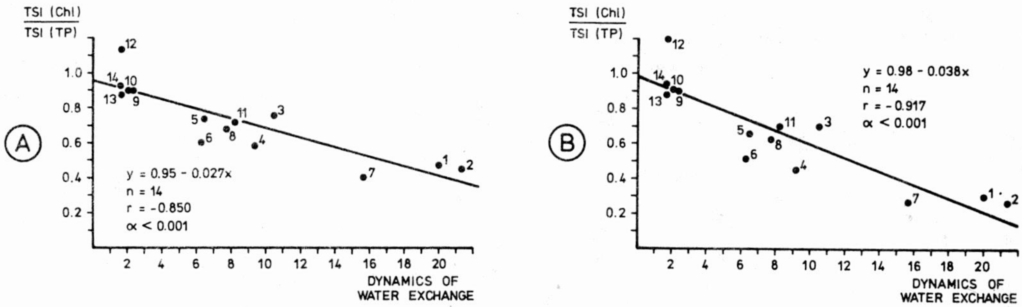


Fig. 3. Coefficient TSI (Chl)/TSI (TP) after Carlson (A) and Walker (B) versus dynamics of water exchange

where this dynamics corresponds to the water exchange taking place more rarily than once a year. With the increasing dynamics of water exchange the value of the index TSI (Chl)/TSI (TP) proportionally decreases, reaching the values 0.41 (Carlson) and 0.21 (Walkers) at the dynamics of exchange corresponding to 20. This means that if the rate of water exchange during the month preceding the investigations (the given time point) corresponded to 20 exchanges during the year, TSI (Chl) would scarcely reach 41% of the value which could be predicted from TSI (TP) according to Carlson (fig. 3A) or 21% of the value of TSI (Chl) which could be expected from TSI (TP) according to Walker (fig. 3B).

Transformations of Carlson's formulae (1) and (2) to the forms

$$\ln(\mathrm{Chl}) = 0.1019\ \mathrm{TSI}(\mathrm{Chl}) - 3.16, \qquad (7)$$

$$\ln(\mathrm{TP}) = 0.0693\ \mathrm{TSI}(\mathrm{TP}) - 0.288 \qquad (8)$$

and of Walker's formulae (3) and (4) to the forms

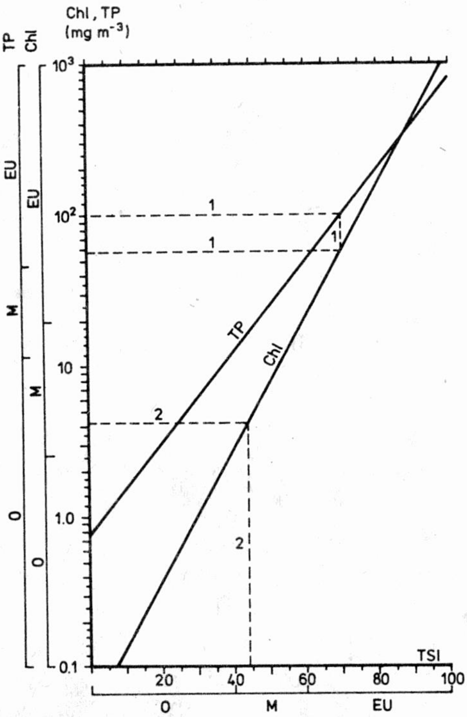
$$\lg(\mathrm{Chl}) = \frac{\mathrm{TSI}(\mathrm{Chl}) - 20}{33.2}, \qquad (9)$$

$$\lg(\mathrm{TP}) = \frac{\mathrm{TSI}(\mathrm{TP}) + 15.6}{46} \qquad (10)$$

make it possible to plot TSI (TP) versus total phosphorus concentration (TP) and TSI (Chl) versus chlorophyll concentration (figs. 4 and 5).

Based on the figs. 3–5, the following calculation may be performed:

1. If the concentration of total phosphorus in water is known, the expected chlorophyll concentration may be determined at non-disturbed courses of processes in the water body of the reservoir. It for instance concentration of TP equals 0.100 mg/dm^3 (100 μg/dm^3), then the expected development of phytoplankton will



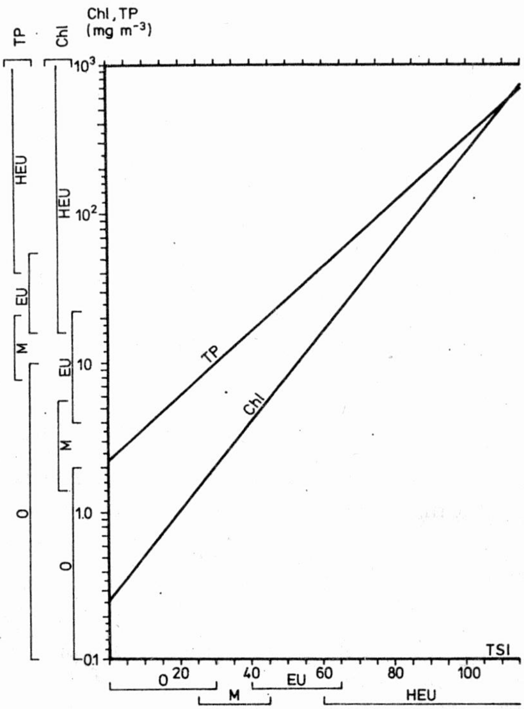


Fig. 4. Chlorophyll and total phosphorus concentrations versus TSI (Chl) and TSI (TP) after Carlson

Fig. 5. Chlorophyll and total phosphorus concentrations versus TSI (Chl) and TSI (TP) after Walker

cause the concentration of chlorophyll in water being equal to 59 μg/dm^3. Both the values are within the eutrophicity (broken line in fig. 4).

2. Knowing the dynamics of water exchange in the reservoir during the past month, the real concentration of chlorophyll may be expected. If, for instance, dynamics of exchange corresponded to 12, then, according to fig. 3A, it may be expected that the real value of TSI (Chl) according to Carlson will be 63% of TSI (Chl) corresponding to the concentration of TP equal to 100 μg/dm^3. Thus it may be expected that the real value of TSI (Chl), instead of being 70.6, will amount to 44.5, to which there corresponds the concentration of chlorophyll of 4.1 μg/dm^3 (broken line in fig. 4) – which at TP concentration corresponding to eutrophy gives the chorophyll concentration within mesotrophy.

3. If the concentration of TP in water is 100 μg/dm^3 and we do not want at a given time point the development of phytoplankton in water be more intense than that corresponding to the chlorophyll concentration of 4.1 μg/dm^3, then during the month preceding this time point the dynamics of exchange should be equivalent to the value 12, thus in this month the water should be exchanged.

4. Based on the above, it is possible to forecast for a given time point the probable chlorophyll concentration at a given concentration of TP and at various dynamics of water axchange in the reservoir.

Analogical procedure may be carried out according to equations given by Walker using figs. 3 and 5, respectively.

3. CONCLUSIONS

For 14 samples taken in summer months of the years 1975–1976 and 1981–1983 the indices of trophic states according to Carlson and Walker have been determined from concentrations of phosphorus (TP) and chlorophyll (Chl) stated in the performed investigations. It has been assumed that at undisturbed courses of the processes taking place in the reservoir the indications of TSI (TP) and TSI (Chl) should be in agreement. In reality, however, the indications of both members of TSI were in most cases divergent. The highest divergences indicating the weakest development of phytoplankton (measured by the concentration of chlorophyll) with respect to phosphorus content have been stated for TSI determined from the results of investigations performed during or immediatley after the periods of the most intense exchange of water in the reservoir. A strong correlation between the index TSI (Chl)/TSI (TP) and the dynamics of water exchange has been found. This correlation (using the transformed formulae of Carlson and Walker) makes it possible to predict the intensity of the phytoplankton development (measured by the concentration of chlorophyll) at various dynamics of water exchange.

REFERENCES

[1] Carlson R. E., *A trophic state index for lakes*, Limnology and Oceanography, 22, 2 (1977), pp. 361–369.

[2] Florczyk H., Gołowin S., Solski A., *Budget of phosphate and nitrogen input and loading in the Lubachów reservoir*, Pol. Arch. Hydrobiol, 23, 2 (1976), pp. 207–218.

[3] Walker W., *Use of hypolimnetic oxygen depletion rate as a trophic index for lakes*, Water Resources Research, 15, 6 (1979), pp. 1463–1470.

WPŁYW CZASU RETENCJI NA STAN TROFICZNY WÓD ZBIORNIKA ZAPOROWEGO LUBACHÓW

Stwierdzono wyraźną (o dużym współczynniku korelacji) zależność pomiędzy dynamiką wymiany wody w zbiorniku a rozwojem fitoplanktonu (mierzonym stężeniem chlorofilu). Na podstawie równania wyznaczającego tę zależność oraz przekształconego równania TSI Carlsona i Walkera wykreślono nomogramy, które pozwalają przewidywać rozwój fitoplanktonu przy różnej dynamice wymiany wody.

ВЛИЯНИЕ ВРЕМЕНИ ЗАДЕРЖИВАНИЯ НА ТРОФИЧЕСКОЕ СОСТОЯНИЕ ВОД ЗАГРАДИТЕЛЬНОГО ВОДОХРАНИЛИЩА ЛЮБАХУВ

Установлена отчетливая (большого коэффициента корреляции) зависимость между динамикой водообмена в водохранилище и развитием фитопланктона (меримым посредством концентрации хлорофилла). На основе уравнения, опеределяющего эту зависимость, а также на основе преобразованного уравнения TSI Карльсона и Валькера вычертили номограммы, которые позволяют предвидеть развитие фитопланктона при разной динамике водообмена.