www.czasopisma.pan.pl PAN www.journals.pan.pl
POLSKA AKADEMIA NAUK

ARCHIVES OF ENVIRONMENTAL PROTECTION

vol. 39 no. 1 pp. 17 - 25 2013

VERSITA

PL ISSN 2083-4772
DOI: 10.2478/aep-2013-0004

THE SUCCESSFUL RESULTS OF PŁAWNIOWICE RESERVOIR (UPPER SILESIA REGION – SOUTH OF POLAND) RESTORATION BY HYPOLIMNETIC WITHDRAWAL

MACIEJ KOSTECKI*, JAN SUSCHKA

Institute of Environmental Engineering of the Polish Academy of Sciences
M. Skłodowskiej-Curie 34. 41-819 Zabrze, Poland
*Corresponding author`s e-mail: kostecki@ipis.zabrze.pl

Keywords: Lakes restoration, hypolimnetic withdrawal.

Abstract: The inter-reservoir enrichment phenomenon was exploited to curtail the reservoir eutrophication process. The Plawnowice reservoir (South Poland – Upper Silesia Region) has an area of 225 ha, volume of 29 mln m^3, and a depth of 15 meters. According to the monitoring results in the years 1993–1998 the reservoir was qualified as hypereutrophic. Beginning in December 2003 a bottom pipe for hypolimnetic withdrawal was installed. In the period 2004–2010 a negative phosphorous balance was achieved. The discharge load of total phosphorous was in the beginning twice as high as the inflowing. During the first eight years with an inflow of 75 Mg P, the removed load of total phosphorus was 103 Mg P. In effect the net balance was 28 Mg P. The load, in respect to the surface area, of 2.2 to 3.3 gP/m^2 per year, was reduced to a negative load of – 0.48 to – 3.3 gP/m^2. The hypolimnetic maximum concentration of orthophosphates equal to 1.254 mg P-PO_4/dm^3 in 2004, was reduced to 0.236 mg P-PO_4/dm^3 in 2011. The respective factors and rate of eutrophication curtailing, including changes of phosphorus compounds have been discussed. Also changes of pH and visibility of the Secchi disc are presented. It was concluded that the presented method of hypolimnetic withdrawal is a lasting and effective process.

INTRODUCTION

Eutrophication of lakes and reservoirs under high antropropresion is most often the result of point and surface pollution discharges [12, 15, 16]. This is an environmental problem which has been coped with for many decades. [10, 11, 14]. Different attitude and actions have been taken, including attempts to limit the loads of discharged pollutants from point and surface sources [5, 6, 13]. Another approach is interference in biological activities by modification or enhancing, the natural processes occurring directly in the water bodies. Obviously both the external and internal actions could or even should be performed in parallel [4, 9, 11]. The adopted solutions depend on many factors, including for example: the size (area, depth), climate, retention time, degree of eutrophication [15]. An intermediate action could be the introduction of a pre-reservoir of relatively hydraulic short retention time of few days. Properly designed and exploited (operated) could be an effective solution [1, 4, 7, 8, 15]. The drawback, however, is necessary bottom dragging every 5−10 years, what could be an expensive operation.

In this paper the results of the first years of the eutrophic Plawnowice reservoir restoration, based on hypolimnion withdrawal are discussed. Also the intra-reservoir enrichment intensity and the balance of phosphorous loads have been presented.

THE ANTHROPOHENIC RESERVOIRS PŁAWNIOWICE CHARACTERISTIC

In the southern part of Poland there are no natural lakes. All of existing reservoirs are of anthropogenic origin [3]. The reservoir Plawnowice originates from a sand pit, to which after having been exploited, the Toszecki creek was connected. The filling of the former sand pit begun in 1974, and was concluded in 1975 [2, 3].

The water surface area of the created Plawniowice reservoir is 225 ha, and it has a volume of 29 mln cu m. Together with the reservoirs Dzierżno Małe (110 ha, 10 mln cu m), Dzierżno Duże (650 ha, 95 mln cu m) and the Gliwice channel, the region is denominated as the West Water Junction Node, having in total a water surface of about 1000 ha and a volume of approximately 140 mln cu m [3, 4].

The first water quality investigations began in 1976 [2]. Investigations carried out in the periods 1993−1994 and later 1996−1997 have shown a high degree of eutrophication and advanced degradation [4]. A total exhausting of oxygen in the hypolimnion took place up to a depth of 4 m measured form the water surface. The visibility during the summer stagnation has reached only 0.8 up to 1.0 m. Due to the primary production during the summer period pH was as high as 10.7. The intra-reservoir phosphates enrichment process was evident. Phosphates have been released form the bottom sediments [2–4].

The unfavorable water quality in the reservoir evoked the need for restoration measures to be taken. The hypolimnion withdrawal technology, considering the favorable land configuration (morphology), which permitted rise of the reservoir water level and in effect gravitational water discharge from the reservoir, was selected. The withdrawn water is discharged to the River Klodnica and next to the Klodnica Channel.

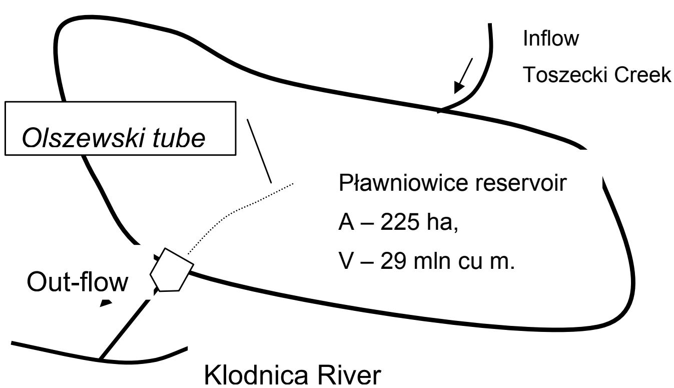

Fig. 1. The Pławniowice reservoir – localization of the Olszewski tube

HYDRAULIC INSTALLATIONS

In December 2003 the hydraulic installation i.e. the Olszewski tube for hypolimnion withdrawal was completed. The installed tube changed the way of water discharge from the reservoir. On the width of the existing dam overflow 3 plastic pipes of equal diameter 500 mm and a lengths of 350 m each, were installed. Each pipe was equipped with a decompression chamber. The construction of the overflow allows also for water discharge from the reservoirs water surface if required. Figure 2 shows the reservoir hypolimnion discharge cannal.

The withdrawal installation, according to the calculations made, permits a discharge of 16.5 mln m^3 per year considering the fluctuation of the water flow in the Toszecki Creek being the inflow to the reservoir. Estimated average water flow (Q_{min} – 0.540 m^3 s^{-1}, Q_{av} – 0.710 m^3 s^{-1}, and Q_{max} – 1.150 m^3 s^{-1}) has also been taken into account. It was concluded that the flow in the creek will allow for the required rise of the water level of 0.7 m. Parallel measurements showed that the delivered and discharged water flow within one year was between 10 mln m^3 to 47 mln m^3, on average 14 mln m^3. In relation to the reservoir volume, the flow constituted 30% to 150%.

Fig. 2. Hypolimnion discharge channel with the Olszewski tubes

METHODS

Samples for chemical determinations aiming nutrients balance estimation were taken at three points. The first sampling point was a pelagic site, to collect surface water samples. The second sampling site was located at the water discharge effluent. Samples collected from the Toszecki Creek, being the inflow to the reservoir, were described as taken from the third sampling point.

The following determinations were made:

- phosphates – colorimetric, molybdenum, with stannous chloride reduction method – PN-89/C-04537/02,
- polyphosphates – hydrolysis in acid conditions – PN-91/C-04537/06,
- organic phosphorous – calculated, deducting phosphates and polyphosphates from the determined concentration of total phosphorous,
- total phosphorous – mineralization to phosphates and colorimetric method – PN-91/C-04537/07,

– visibility of Secchie disc (on the pelagic point),
– water flow rate by hydrometric.

NUTRIENTS BALANCE

The water flow rate was measured on the Toszecki Creek inflow to the reservoir, and in the withdrawal pipes outflow. For flow measurements, concrete made cascades have been constructed as show in figure 3.

Fig. 3. Water flow rate and sampling points on inflow – and outflow of the Plawniowice reservoir

The water flow − the delivered and discharged amounts of water appear to be in equilibrium within a year as given in Table 1.

Table 1. The Plawniowice reservoir water flow balance in the period 2004–2011

Year	Inflow mln m^3 a^{-1}	Outflow mln m^3 a^{-1}	Retention time [years]
2004	14,2	14,3	2,0
2005	13,5	13,2	2,15
2006	17	17,5	1,7
2007	13,3	13,8	2,15
2008	10,1	10,7	2,9
2009	17,3	16,3	1,7
2010	41,8	37,4	0,7
2011	14,5	13,6	2

Definition of the nutrients load delivered and discharged to the reservoir was based on yearly average nutrients concentration and water flow, according to the following equation:

$$L_{In} = Cav \ x \ Qav$$

where:

L_{In} – yearly load delivered, Cav – average yearly concentration, Qav – average yearly flow.

The load of discharged pollutants was determined on assumption of the equalization during the average hydraulic retention time of 2 years of the concentration of pollutants and measured average monthly values, using the following equation;

$$L_{Out} = \Sigma\, [Cav_{(I,\, II,\, III.....XII)}] \cdot Qav_{O)}$$

where:

L_{Out} – yearly load discharged, Cav – yearly discharged concentration, Qav – average yearly outflow.

RESULTS AND DISCUSSION

The concept, and simultaneously the goal of the limnic ecosystem restoration through hypolimnion withdrawal, was oligotrophication as an effect of nutrients and in particular phosphorous removal – disposition outside of the reservoir [8, 10, 13, 14]. The rate of the yearly delivered and discharged phosphorous load depends on the amount of water entering and leaving the reservoir, as shown in Figure 4.

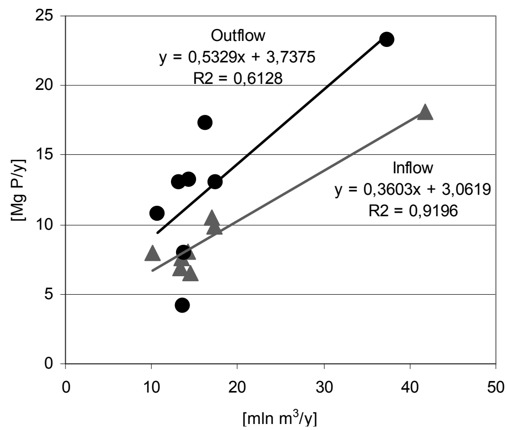

Fig. 4. Correlation between the amount of entering and leaving water and phosphorous load in the Plawniowice reservoir in the period 2004–2011

During all the eight years of exploitation of the withdrawal pipes, the amount of discharged total phosphorous was approximately two times larger than that delivered.

The dominant forms of phosphorous were phosphates, the load of which was 2.5 times up to 3 times larger in the withdrawn water in comparison to the inflow in the investigated period. Within the eight years of the reservoir restoration i.e. functioning of the Olszewski tube, the total amount of phosphorous removed riched 27 tons.

From which 96% were phosphates. As a result a negative phosphorous surface load balance was achieved. That means that the oligtrophication mechanism of the reservoir was initiated. The obtained systematic negative phosphorous balance resulted in the intra-reservoir enrichment process fading out (Fig. 6).

It has to be stressed again that during the preceding years of the reservoir restoration activities, there was a constant increase of phosphates release from the bottom sediments.

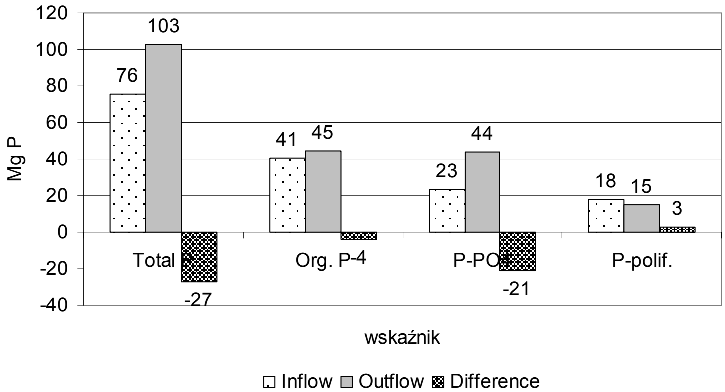

Fig. 5. The overall balance of the different forms of phosphorous, Plawniowice reservoir 2004–2011

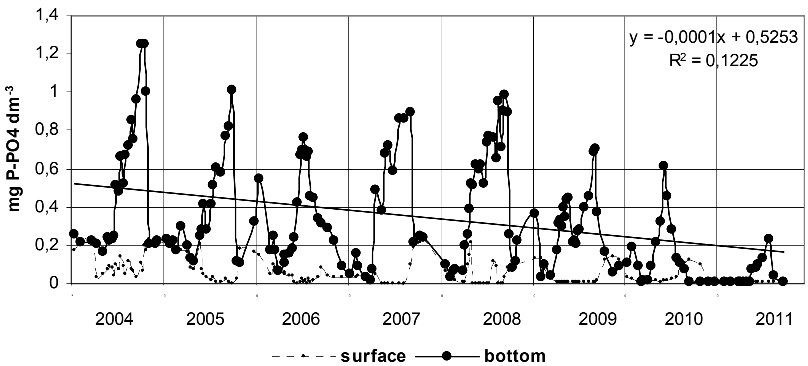

Fig. 6. Changes of phosphates concentration in the period 2004–2011

After beginning the reservoir restoration activities an opposite tendency was observed as shown in Figure 7.

As mentioned before the water visibility in the years 1993–1998 [4] was very low during the summer stagnation periods. The average visibility values varied from 2.8 m to 1.3 m. After commencing the process of hypolimnion withdrawal (installation of the Olszewski tube) the visibility increased drastically up to 3.9 meters (Fig. 8).

During eight years, from the very beginning in 2004, the visibility was always more than 3 m in the summer stagnation time.

CONCLUSIONS

The Plawniowice reservoir is the third case of application of the "Olszewski tube" in Poland [3, 4], after the Lake Kortowskie [7, 12] and lake Rudnickie Wielkie [8]. However it is the first case of an anthropogenic reservoir restoration in Poland.

Application of hypolimnion withdrawal technology ("Oszewski tube", or kortowska method) has brought positive results. The aim of the reservoir oligotrophication – decreasing

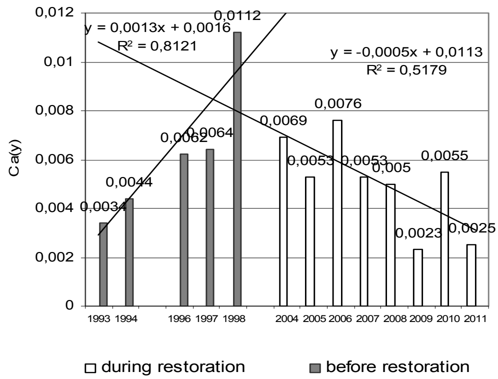

Fig. 7. Inter-reservoir enrichment functions, before and after application of restoration technology

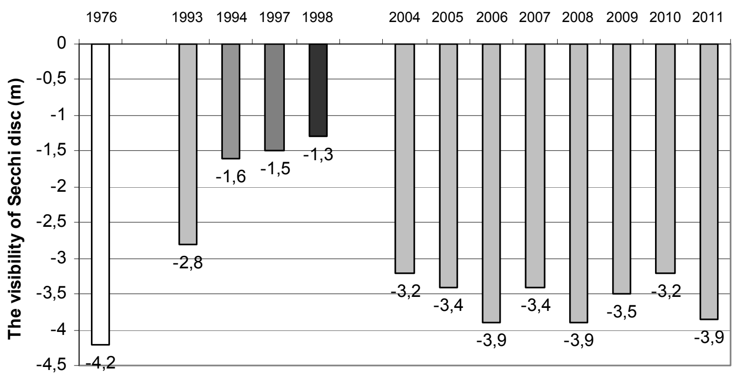

Fig. 8. The Secchi disc visibility in the summer stagnation periods in the period 1976–2011

the phosphorous compounds stock in the ecosystem was achieved. The procedure resulted in definite diminution of the intra-enrichment process. Within the eight years of hypolimnion withdrawal a negative phposphorous balance was noticed. In the mentioned period 75 Mg of phosphorous were supplied by the Toszecki Creek to the reservoir, and simultaneously 102 Mg were removed. The phosphorous stock of the reservoir was diminished by 27 Mg. This is equivalent to surface area load diminution of 120 kg P. The total discharged load of phosphorous from the reservoir was every year more than twice as much as of the supplied. Phosphates constituted 99% of the discharged phosphorous load.

As a result of the reservoir restoration process the phosphorous release rate has decreased from 0.0069 mg P/d in the year 2004 to 0.0025 mgP-PO4/d in 2011. The visibility measured by Secchie disc in 1997 was 1.3 m, increased due to the reservoir restoration to the depth 3.0 to 0.9 m in the period 2004–2011.

It has to be stressed that continuous functioning of hypolimnion withdrawal by the Olszewski tube, does not only improve the ecological reservoir status, but establishes a permanent protection mechanism.

REFERENCES

[1] Dunalska, J. (2002). Influence of Limited Water Flow in a Pipeline on the Nutrients Budget in a Lake Restored by Hypolimnetic Withdrawal Method, *Polish Journal of Environmental Studies*, 11 (6), 631–637.
[2] Kostecki, M. (1987). The dynamic of changes and nitrogen and phosphorus forms budget in Pławniowice reservoir (in polish). *Archiw. Ochr. Środow.,* 1, 57–85.
[3] Kostecki, M. (2003). The allocation and conversion of selected pollutants in the dam-reservoirs of Klodnica Hydrojunction and Gliwice Chanel (in polish). Prace i Studia IPIŚ-PAN, Zabrze, 57, 1–124.
[4] Kostecki, M. (2006). Hypolimnetic withdrawal as a restoration technique of Pławniowice anthropogenic reservoir, *The International Conference on prof. dr hab. Marek Kraska's 70-year jubilee and the 15th anniversary of the Department of Water Protection Feculty of Biology; Adam Mickiewicz Uniwersity, "The Functioning of Water Ecosystems and their Protection"*, Toruń.
[5] Kumar Arun. (2008). Hypolimnetic Withdrawal for Lake Conservation, Sengupta, M. and Dalwani, R. (Editors), *Proceeding of Taal 2007: the 12th World Lake Conference*, 812–818.
[6] Livingstone, D.M., & Schanz, F. (1994). The effect of deep-water siphoning on small, shallow lake: A long-term case study, *Arch. Hydrobiol.*, 132 (1), 15–44.
[7] Mientki, Cz. (1997). Chemical properties of Kortowskie Lake waters after ab 18 years experiment on its restoration. Part III. Dynamics of phosphorus compounds, *Pol. Arch. Hydrobiol*, 24 (1), 25–35.
[8] Mientki, Cz. (1993). Balance of phosphorus and nitrogen copmpounds in Rudnickie Wielkie Lake in Grudziądz restored by hypolimnetic withdrawal. Bilans związków fosforu i azotu w rekultywowanym metoda usuwania wód hypolimnionu Jeziorze Rudnickim Wielkim w Grudziądzu. *Proc. of the Conference: "Ochrona jezior ze szczególnym uwzględnieniem metod rekultywacji"*. Toruń, 29–46.
[9] Murphy, T.P., Macdonald, R.H., Lawrence, G.A., & Mawhinney, M. (1999). Chain Lake restoration by dredging and hypolimnetic withdrawal. Aquatic Restoration in Canada, Edited by Murphy Y., and M. Munawar: 195–211, *Ecovision World Monograph Series, Backhuys Publishers Leiden, The Netherlands.*
[10] Nurnberg, G.K. (1987). Hypolimnetic withdrawal as a lake restoration technique, American Society of Civil Engineers, *J. Environmental Engineering Division*, 114, 1006–1017.
[11] Nurnberg, G.K., Hartley, R., & Davis, E. (1987). Hypolimnetic withdrawal in two North American lakes with anoxic phopshorus release from the sediment, *Water Res*., 21, 923–928.
[12] Olszewski, P. (1959). The lake hypolimnetic withdrawal. The results of first year of Kortowskie Lake experiment (in polish). *Zesz. Nauk. WSR Olsztyn*., 9 (81), 331–339.
[13] Premazzi, G., Cardoso, A.C., Rodari, E., Austoni, M., & Chiaudani, G. (2005). Hypolimnetic withdrawal coupled with oxygenation as lake restoration measures: the successful case of Lake Varese (Italy), *Limnetica*, 24 (1–2), 123–132.
[14] Psenner, R. (1988). Long-term changes in the chemical composition of a meromictic lake after hypolimnion withdrawal, *Verh. Internat. Verein. Limnol.*, 23, 516–533.
[15] Putz, K., & Benndorf, J. (1998). The importance of pre-reservoirs for the control of eutrophication of reservoirs. *Wat. Sci. Tech.*, 37, 2, 317–324.
[16] Thomas, E.A. (1944). Ueber Massnahmen gegen die Eutrophierung unserer Seen und zur Foderung ihrer biologischen Productionskraft. *Schweitz. Fisch. Zeit.*, 7/8,7; 108.

PRZYPADEK SKUTECZNEJ REKULTYWACJI ANTROPOGENICZNEGO ZBIORNIKA PŁAWNIOWICE METODĄ USUWANIA HYPOLIMNIONU

W grudniu 2003 roku rozpoczęto rekultywację antropogenicznego zbiornika wodnego w Pławniowicach (A-225 ha, V-29 mln m^3, głęb. maks. 15 m, woj. śląskie) metodą usuwania hypolimnionu („rura Olszewskiego"). W okresie 2004–2010 uzyskano ujemny bilans fosforu. Całkowity ładunek fosforu odprowadzany ze zbiornika był co rok ponad dwukrotnie większy od ładunku doprowadzanego. Odprowadzany ze zbiornika ładunek ortofosforanów był ponad trzykrotnie większy od ładunku doprowadzanego. W ciągu pierwszych ośmiu lat rekultywacji zmniejszono zasobność zbiornika w fosfor o 28 Mg P. Po uwzględnieniu ładunków fosforu odprowadzonych ze zbiornika obciążenie hydrauliczne przed rozpoczęciem rekultywacji wynosiło od 2,2 do 3,3 g P/m^2/rok. W latach 2004–2010 występowało ujemne obciążenie hydrauliczne fosforem, wynoszące od -0,48 do -3,3 g P/m^2/rok. Oligotrofizacja zbiornika spowodowała stopniowe słabnięcie procesu uwalniania ortofosforanów z osadów dennych. Maksymalne stężenie ortofosforanów w hypolimnionie zbiornika

zmniejszyło się z 1,254 mg P-PO_4/dm^3 w roku 2004 do 0,236 mgP-PO4/dm^3 w roku 2011. Stała szybkości procesu wzbogacania wewnętrznego w okresie 1993–1998 wzrosła z 0,0034 mgP-PO_4/d do 0,0112 mg P-PO_4/d. W okresie rekultywacji stała szybkości zmniejszyła się z 0,0069 mg P/d w roku 2004 do 0,0025 mgP-PO_4/d w roku 2011. W okresie od 1993 do 1998 roku średnie pH wody w okresie stagnacji letniej wzrosło z 8,8 do 9,88. W okresie ośmiu lat rekultywacji średnie pH wody obniżało się z 9,3 w roku 2004 do 8,22 w roku 2011. W wyniku rekultywacji wzrosła przezroczystość wody. Przed rekultywacją – w roku 1998 – średnia widzialność krążka Secchiego w czasie stagnacji letniej wynosiła 0,9m. W czasie rekultywacji wartość tego wskaźnika wynosiła od 3,0 m do 3,85 m. Zastosowanie metody usuwania hypolimnionu („rura Olszewskiego”, metoda kortowska) dało pozytywne wyniki. Ciągłe funkcjonowanie urządzenia upustowego do odprowadzania wód hypolimnionu stanowi dla zbiornika trwały mechanizm obronny przed niekorzystnymi skutkami eutrofizacji.