ARCHIVES OF ENVIRONMENTAL PROTECTION
ARCHIWUM OCHRONY ŚRODOWISKA
vol. 31 no. 2 pp. 85 - 94 2005

PL ISSN 0324-8461

IMPACT OF ANTHROPOGENIC PRESSURE ON AQUATIC CONDITIONS IN LAKE TRACK IN OLSZTYN

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Keywords: drainage basin, trophic condition, anthropogenic pressure, nutrients, external loading.

WPŁYW ANTROPOPRESJI NA WARUNKI ŚRODOWISKOWE JEZIORA TRACK W OLSZTYNIE

Badania prowadzono na niewielkim (52,8 ha) i płytkim (4 m) jeziorze Track w Olsztynie, poddanym szczególnie nasilonej antropopresji. W połowie XIX wieku oraz na początku XX wieku jezioro Track próbowano osuszyć a większość terenów okalających zbiornik przekształcić w grunty orne. Po ponownym odtworzeniu, jezioro Track otoczone jest zlewnią o powierzchni 216 ha, w której największy udział mają tereny zurbanizowane (49,3%). Nieużytki zajmują 41,4%, zaś obszary leśne 6,1%. Zbiornik ten jest odbiornikiem ścieków opadowych a przez wiele lat także sanitarnych. Na podstawie uzyskanych wyników badań stwierdzono, że jezioro Track jest zbiornikiem żyznym o znacznym zaawansowaniu procesów eutrofizacyjnych. W wodach jeziora stwierdzono bardzo wysokie ilości biogenów, sięgające: 0,75 mg P/dm^3 i 3,87 mg N/dm^3. O dużej żyzności jeziora Track świadczą także wysokie wartości BZT$_5$ dochodzące do 9,5 mg O$_2$/dm^3, zawartości chlorofilu a (wynoszące najczęściej 30–40 mg/m^3, ale sięgające nawet wartości 123 mg/m^3), jak również niska przezroczystość wody wahająca się od 0,6 do 0,9 m. Przyczyną wysokiej trofii tego zbiornika jest bez wątpienia nadmierne jego obciążenie ze zlewni. Rzeczywiste ładunki biogenów spływające do jeziora przekraczają ładunki krytyczne wyliczone wg Vollenweidera. Niska jakość wód tego jeziora, przy istniejącym wysokim obciążeniu ładunkiem zanieczyszczeń ze zlewni wskazuje na konieczność zastosowania działań ochronnych, polegających na zmniejszeniu obciążenia zewnętrznego.

Summary

The research was carried out on a small (52.8 ha) and shallow (4 m) Lake Track in Olsztyn, exposed to a considerably intense anthropogenic pressure. In the middle 1800s this reservoir was dried out and most of the contiguous land was designated for agricultural purposes. The lake was restored in the mid 1900s. At present, the drainage basin of Lake Track is 216 ha. Urban land comprises the largest portion of this area, i.e. 49.3%, barren land 41.4% and forests 6.1%. The lake receives storm waters but for years it had also received sanitary sewage. The results of this research allowed classifying the lake as nutrient-rich, with fairly advanced eutrophication processes. The waters were characteristic of very high nutrients content, up to 0.75 mg P/dm^3 and 3.87 mg N/dm^3. The high fertility of Lake Track was additionally confirmed by high BOD$_5$ values, i.e. up to 9.5 mg O$_2$/dm^3, high chlorophyll content, usually from 30 to 40 mg/m^3 but reaching 123 mg/m^3, and low water transparency, oscillating between 0.6 and 0.9 m. The reason for the lake's high trophic level was no doubt the excessive loading from the drainage basin. The actual nutrient runoff from the drainage basin to the lake exceeded the critical loads, as defined by Vollenweider. Low quality of the lake's waters and the parallel high external loading indicate that preventive measures should be taken, aimed at reducing the external loading.

INTRODUCTION

Trophic condition of a lake results from its resistance to degradation, depending on the morphometric and hydrologic factors, characteristics of the drainage basin, and external loading which in turn depends mainly on the man's activity [2, 16, 21]. Urban development, industrialization, intensification of agricultural production, and excessive tourist pressure, with a parallel lack of effective protection methods, increase organic and nutritive substances loads to the lakes, often exceeding the levels determined by Vollenweider [22] as critical [11, 16]. In effect, water quality rapidly deteriorates or the structure and function of lakes are fully degraded. The basic activity preventing these negative effects should be protection of lakes through elimination of pollution sources; the latter achieved by proper development of drainage basins and lakes' fringes.

A particular example of the intense man's pressure is Lake Track, located in the Olsztyn city. Beginning in the 1800s, the lake situated on the very location of the contemporary Lake Track, received waters from numerous small ponds and wetlands [4, 19]. The lake had one small outflow, called Tracka Struga, discharging via Klebarski Ciek to Lake Wadąg.

In the mid 1800s the lake was designated for extermination. In 1840–1850 and 1868–1869 some regulation works were carried out in the drainage basin and the outflow was deepened [19] which eventually lowered the water table and the lake was transformed into a wetland. Melioration works conducted in the beginning of the 1900s and the placement of a pipeline resulted in the land's drainage. The land was used as pastures but the major part was transformed into arable land. Lack of proper supervision over the facilities' operation and changes in the drainage basin, i.e. construction of the railway embankments, caused repeated water collection in the valley and restoration of the lake [1, 4]. In the 1960s another attempt was made at drying out the lake, yet unsuccessful.

At present, the lake is under strong anthropogenic pressure. It serves as a storm waters collector but for many years in the past it had also received sanitary sewage.

The goal of this research was to recognize the aquatic conditions in Lake Track and determine the role of the drainage basin in the eutrophication process of the lake.

CHARACTERISTICS OF THE LAKE AND ITS DRAINAGE BASIN

Lake Track is one of the eleven lakes situated within the administrative borders of the Olsztyn city. Lake Track is located in the north-east of the city (20°33.6'E, 53°48.3'N), at 123.9 m above sea level [3]. The surface area is 52.8 ha, the max. depth is 3.75 m, the mean depth equals 2.1 m and the volume is 1.123 thousand m^3 [10]. The actual depth of the lake, measured by the authors in the field, equaled usually 4 m. The lake is elongated in the E-W direction and the shoreline is little developed (K – 1.86). The depth index of 0.56 and the low relative depth (0.0052) indicate low penetration in the bed and flat, undeveloped bottom.

At present, Lake Track is in terms of hydrology a closed reservoir and only at heavy rains water can periodically flow out from the middle part of the northern shore.

The drainage basin of Lake Track demarcated by the natural land configuration was

481 ha [1]. The major part of the land was then occupied by urban areas (39.6%) and arable fields (34.1%), out of which the cultivated land was 23.2% and meadows and pastures 10.9%. Forests comprised 22.4%.

Land transformations by man, mainly construction of the railway embankments, diminished the area of the direct water runoff to the lake. The structure of the drainage basin use was also modified. Field observations and studies of the topographic map allowed concluding that the surface area of the drainage basin equals only 216 ha. The structure of the drainage basin use is shown in Table 1.

Table 1. Land use structure in the drainage basin of Lake Track

Type of land use	Surface area (ha)	Participation (%)
Barren lands	89.4	41.4
Forests	13.1	6.1
Urban areas	106.5	49.3
Wetlands and bogs	6.9	3.2

The borderline of the drainage basin on the north, east and west comprise the railway embankments with railroads. On the south the drainage divide runs on the natural elevations, not changed by urban development. In the north, the land between the railroad and the lake is occupied by waste land with some property of the non-operating state-owned arable farm called Track and a single family house. On the east, the lake is adjacent to waste land with some buildings. On the southern end buildings of the non-operating state-owned arable farm called Grądek can be found. The southern and western sides of the drainage basin are urban areas (industrial works, service shops, workshops, wholesale warehouses, shops, other warehouses).

MATERIAL AND METHOD

Investigations of the lake covered all seasons of the limnologic year and were carried out in two annual cycles: April 1995 through March 1996, and April 2002 through February 2003. Water for the chemical analyses was sampled on one sampling station, located on the eastern side, over the deepest (4 m) spot in the lake (Fig. 1). Each time sampling was done, temperature and oxygen profiles were made, taking measurements at every meter of the depth. The water samples for chemical analyses were taken at 1 m under the surface and 0.5 m above the bottom. The chemical analyses were done according to the methods of Hermanowicz *et al.* [9] and Standard methods [20].

The size of the drainage basin was determined by demarcation of its range and planimetry work on the topographic map (1:10.000).

The surface runoff of nutrients was calculated using the coefficients given by Giercuszkiewicz-Bajtlik [7] and Lossow *et al.* [15]. When calculating the permissible and critical loads of phosphorus and nitrogen the Vollenweider's statistical model was applied [22].

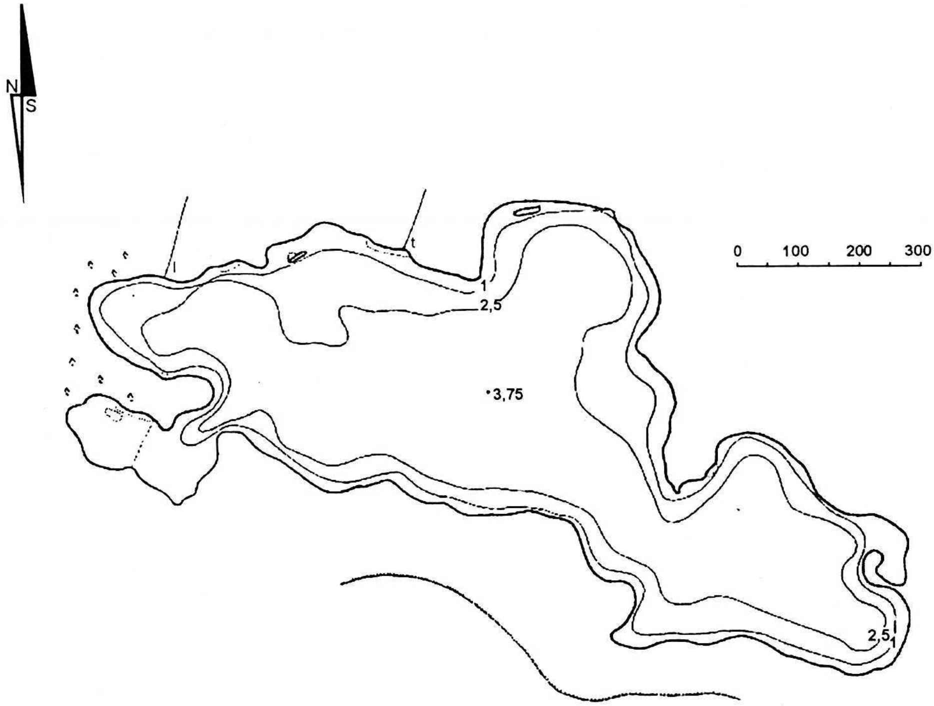


Fig. 1. Bathymetric map of Lake Track

RESULTS AND DISCUSSION

Lake Track, despite the considerable surface area and volume, has not been studied in detail in regard to its trophic condition. It has only been characterized as very fertile from the viewpoint of aquaculture [13] and in respect to aquatic plants occurrence, including water plants, wetland plants and rushes [4, 8]. This paper is therefore the first, describing the aquatic conditions in this reservoir.

Lake Track is a polymictic lake, mixed many times over the year, although the theoretical mixing range (4.5 m, calculated after Patalas [18]) only slightly exceeds the max. depth of the lake which indicates that periodically thermal stratification may occur. The latter was confirmed by the measurements in both 1995 and 2002. In the periods of high air temperatures in the summer, but especially in the periods of rapid temperatures growths in the spring, small but distinct temperature differences were observed between the surface and the bottom waters, reaching even 6°C (June 1995) and 4°C (April 2002).

Despite a little stability of the thermal stratifications, the oxygen content in the water was variable. In the surface waters oxygen saturation was usually between 100 and 110% (8–13 mg O_2/dm^3), (Tab. 2), although in some periods it reached 150% which indicates intensive production processes. It was accompanied by increase of reaction to pH 8.9,

Table 2. Range of changes in the selected physico-chemical indicators of Lake Track waters, in different years

Indicator	Unit	Water stratum	1995/1996	2002/2003
Temperature	°C	surface bottom	0.7–21.6 3.0–18.4	1.0–21.4 3.1–20.4
O_2	mg O_2/dm^3	surface bottom	3.8–15.2 0.0–8.0	8.3–15.2 2.1–12.0
Reaction	pH	surface bottom	7.7–8.9 7.6–8.2	8.19–8.65 8.00–8.42
CO_2	mg CO_2/dm^3	surface bottom	0.0–15.5 3.5–26.0	0.0–3.0 0.0–10.0
Ammonium N	mg N/dm^3	surface bottom	0.00–0.40 0.01–0.50	śl–0.29 śl–0.55
Nitrate N	mg N/dm^3	surface bottom	0.06–0.27 0.04–0.27	0.0–0.25 0.0–0.25
Total N	mg N/dm^3	surface bottom	1.99–2.39 1.84–2.75	1.77–3.87 2.03–3.37
Mineral P	mg P/dm^3	surface bottom	0.00–0.04 0.00–0.05	0.00–0.06 0.00–0.05
Total P	mg P/dm^3	surface bottom	0.18–0.57 0.13–0.57	0.13–0.75 0.12–0.76
BOD_5	mg O_2/dm^3	surface bottom	1.0–7.8 1.3–8.8	6.6–9.0 6.3–9.5
Permanganate value	mg O_2/dm^3	surface bottom	9.6–24.0 8.0–24.0	16.0–25.6 16.0–23.0
Chlorides	mg Cl/dm^3	surface bottom	60–69 60–67	53–61 58–60
Iron	mg Fe/dm^3	surface bottom	0–0 0–0	0.03–0.10 0.03–0.09
Manganese	mg Mn/dm^3	surface bottom	0–0 0–0	0.12–0.33 0.15–0.30

depletion of free carbon dioxide, high BOD_5 values (approx. 9 mg O_2/dm^3), high chlorophyll a values (approx. 40 mg/m^3), and low Secchi disk transparency (0.6 m). In deeper waters, particularly near the bottom, quite rapid oxygen depletion was observed with total deficiency determined in summer 1995 and in winter 1996 or considerable deficits in summer 2002 and winter 2003 (40 and 85% respectively). The reason was the intensive degradation processes occurring in these water layers of the organic matter produced in the lake and deposited in the bottom sediments.

Many authors [5, 12, 22, 24] share the opinion that lake's fertility is determined by phosphorus and nitrogen amounts in circulation. The amounts of both nutrients in Lake Track were very high, reaching 0.75 mg P/dm^3 and 3.87 mg N/dm^3 (Tab. 2, Fig. 2 a and b). Therefore, according to Zdanowski [23], the lake can be classified as a 3rd group polymictic lake. Total contents of the nutrients were determined mainly by their organic forms.

In both examination periods mineral phosphorus was practically undetectable in the lake waters (Tab. 2). It was measured only at the end of summer 2002, assumingly due to increased mineralization of organic matter which was indicated by lowered oxygen content in deeper waters and occurrence of free carbon dioxide. Mineral phosphorus deficits in surface waters during growing season are typical for unpolluted lakes and caused by its utilization in the production processes. Such phenomenon occurred also in Lake Track, however assumingly an important role played phosphorus precipitation with iron compounds in bottom sediments. An indication of such hypothesis is the constant occurrence of iron and manganese in the lake's waters in 2002, regardless of the good oxygen conditions in the whole water column.

Unlike phosphorus, mineral nitrogen was constantly present in the waters, yet in small amounts (Tab. 2). The content of mineral forms of nitrogen was determined by ammonium and nitrate nitrogen. Constant occurrence of mineral forms in the growing season on the one hand indicates high reserves of nitrogen in the lake but on the other – intensive mineralization and nitrification processes.

High values of BOD_5, i.e. reaching 9.5 mg O_2/dm^3 (Fig. 2c), high content of chlorophyll a (usually 30–40 mg/m^3, reaching 123 mg/m^3), (Fig. 3a), and low water transparency oscillating between 0.6 and 0.9 m (Fig. 3b), indicate quite advanced eutrophication processes in the lake and its high fertility.

The examined waters were additionally characteristic of very high chlorides content, i.e. 53–61 mg Cl/dm^3 (Tab. 2). The possible reason was the high participation of urban areas in the total drainage basin area (almost 50%) and the storm waters disposal to the lake. According to the classification provided in the Atlas of Polish Lakes [3], the examined lake is in the 9th position with respect to chlorides content in the Polish lakes.

With regard to the above data, Lake Track should be classified as eutrophic. According to the water purity criteria of Kudelska *et al.* [14] the lake is 3rd class (average scoring: 3.12 in 1995 and 2.80 in 2002). The difference in scoring between 1995 and 2002 comes mainly from different oxygen conditions, dependent on the water dynamics. In 2002, lower air temperatures were measured that favored more intensive water mixing which in turn prevented total deoxygenation of the bottom waters. Other indicators, such like: organic matter content (Fig. 2c), chlorophyll a (Fig. 3a), higher than in 1995, and lower water transparency indicate that the degree of the lake's eutrophication did not diminish but increased.

The observed high trophic level of Lake Track is on the one hand caused by its high vulnerability to degradation [14] (below standard) and the excessive external loading on the other.

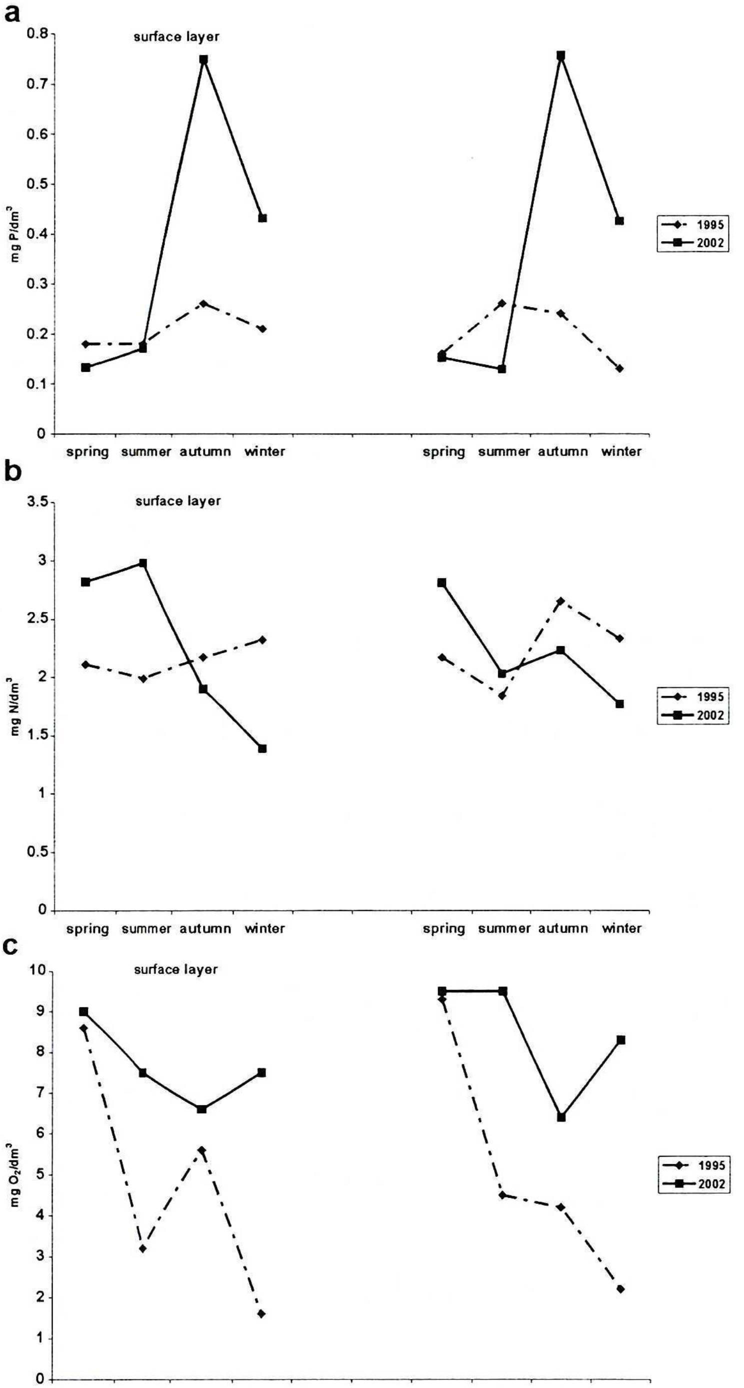
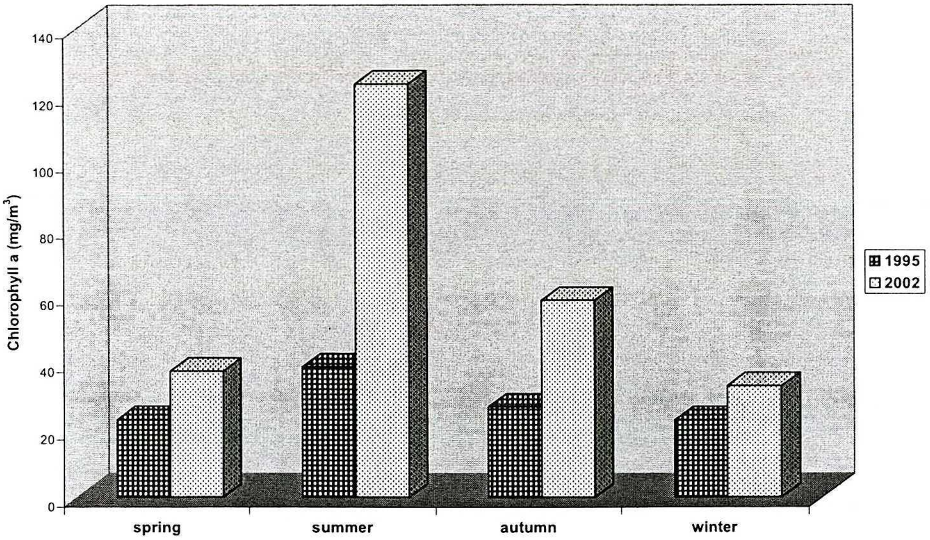


Fig. 2. Changes in nutritive and organic (BOD_5) compounds content in the waters of Lake Track in different years: a. total phosphorus, b. total nitrogen, c. organic matter (BOD_5)



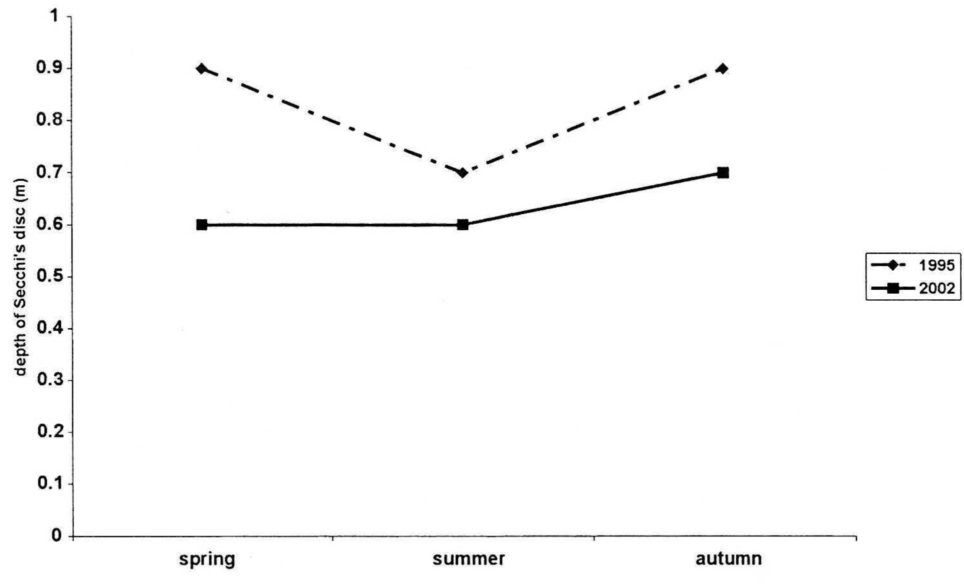


Fig. 3. Primary production indicators in Lake Track: a. chlorophyll a; b. water transparency

The great impact of the drainage basin on the aquatic conditions in the lake can be confirmed by the fact that as soon as the lake was restored it displayed the features of a fertile lake [13]. No doubt, the regulation works of the 1800s and 1900s had much effect on that, as well as the attempts to dry the lake out, and the transformation of the contiguous land into arable fields. Kajak [12] reports that waters running off the drainage basin of such type are heavily loaded with nutrients.

Although at present the lake's drainage basin is extremely small (Ohle's coefficient equals approx. 4), the nutrients load to the lake is very high. Data shown in Table 3 reveal that the total annual loading of nitrogen and phosphorus, according to the criteria of Giercuszkiewicz-Bajtlik [7], equals 152.4 kg P and 1,797.6 kg N, which calculated per unit surface, gives the loads of 0.289 g P/m^2/year and 3.4 g N/m^2/year. Based on the guidelines of Lossow and Gawrońska [15] the values are (respectively): 137.7 kg P and 1,656.2 kg N, and 0.261 g P/m^2/year and 3.2 g N/m^2/year.

The permissible and critical loads in the case of Lake Track, calculated after Vollenweider [22], equal respectively: 0.039 and 0.078 g P/m^2/year, and 0.624 and 1.248 g N/m^2/year. A comparison between these loads and the actual P and N loading to the lake reveals that the loading exceeds several times not only the permissible but also the critical values, responsible for accelerated eutrophication.

Low water quality, deteriorating due to the present high external loading to the lake, is equivocal to the necessity for performing preventive actions, to reduce the external loading. Taking into consideration that the highest amounts of nutrients are imported for the lake with storm waters from the urban areas (Tab. 3), the goal could be achieved by the storm sewerage diversion so that it would discharge to receiving water.

Table 3. Total annual nutrients loading to Lake Track, calculated with regard to the actual surface area of the drainage basin and use structure

External source of pollution	Values calculated using unit runoff coefficients of Giercuszkiewicz-Bajtlik [7]		Values calculated using unit runoff coefficients of Lossow and Gawrońska [15]	
	Phosphorus (kg P/year)	Nitrogen (kg N/year)	Phosphorus (kg P/year)	Nitrogen (kg N/year)
1. Diffuse sources	120.7	1164.0	106.0	1022.6
a. Urban area	*95.8*	*639.0*	*95.8*	*639.0*
b. Barren lands	*22.3*	*447.0*	*8.9*	*357.6*
c. Forests	*2.6*	*78.0*	*1.3*	*26.0*
2. Atmospheric sources	31.7	633.6	31.7	633.6
3. Total	152.4	1797.6	137.7	1656.2

Experience from other lakes [5, 17] shows however that in the case of Lake Track, with unfavorable morphometry and high trophic level, even the radical reduction of N and P external loading will not cause drastic improvement to the aquatic conditions.

REFERENCES

[1] Agopsowicz M., T. Agopsowicz, T. Bilińska, L. Kaczkowski, W. Sroczyński: *Rozpoznanie stosunków wodnych, meteorologicznych oraz stanu zagospodarowania w rejonie zlewni Track*, Pol. Tow. Przyj. Nauk o Ziemi, Oddz. Warmińsko-Mazurski, Olsztyn-Kortowo 1984.

[2] Bajkiewicz-Grabowska E.: *Ocena naturalnej podatności jezior na degradację i rola zlewni w tym procesie*, Wiad. Ekol., 33(30), 279–288 (1987).

[3] Brodzińska B., J. Jańczak, A. Kowalik, R. Sziwa: *Atlas jezior Polski*, cz. III, Bogucki Wydawnictwo Naukowe s.c., Poznań 1999.

[4] Ciecierska H.: *Zróżnicowanie przestrzenne roślinności litoralu i otuliny wybranych jezior miejskich Pojezierza Mazurskiego*, Wydaw. Uniwersytetu Warmińsko-Mazurskiego, Olsztyn 2000.

[5] Culen P., C. Forsberg: *Experiences with reducing point sources of phosphorus to lakes*, Hydrobiol., 170, 321–336 (1988).

[6] Gawrońska H.: *Wpływ ograniczenia dopływu ścieków na warunki fizyczno-chemiczne wód Jeziora Długiego w Olsztynie*, Rocz. Nauk Rol., seria H, 100(4), 27–52 (1984).

[7] Giercuszkiewicz-Bajtlik M.: *Prognozowanie zmian jakości wód stojących*, Instytut Ochrony Środowiska, Warszawa 1990.

[8] Grzybowski M., Z. Endler: *Zmiany zbiorowisk makrofitów podmiejskiego Jeziora Trackiego pod wpływem antropopresji*, Acta Scientiarum Polonorum, Formatio Circumiectus, 2(2), 149–156, Olsztyn 2003.

[9] Hermanowicz W., W. Dożańska, J. Dojlido, B. Koziorowski: *Fizyczno-chemiczne badanie wody i ścieków*, Arkady, Warszawa 1999.

[10] Instytut Rybactwa Śródlądowego, *Mapa batymetryczna i opracowanie danych morfometrycznych jeziora Track*, Olsztyn 1964.

[11] Kajak Z.: *Eutrofizacja nizinnych zbiorników zaporowych*, Biblioteka Monitoringu Środowiska, Łódź 1995.

[12] Kajak Z.: *Hydrobiologia – limnologia, Ekosystemy wód śródlądowych*, Wydawnictwo Naukowe PWN, Warszawa 2001.

[13] Korycki A: *Założenia do projektu rybackiego zagospodarowania jeziora Track*, Olsztyn 1969.

[14] Kudelska D., D. Cydzik, H. Soszka: *Wytyczne monitoringu podstawowego jezior*, Biblioteka Monitoringu Środowiska, Warszawa 1994.

[15] Lossow K., H. Gawrońska: *External input to lake Wadąg – Effective and estimate loadings*, Polish Journal of Environmental Studies, 7, 2, 95–98 (1998).

[16] Lossow K., H. Gawrońska: *Ochrona zbiorników wodnych*, Przegląd Komunalny, 9, 92–106 (2000).

[17] Marsden M.: *Lake restoration by reducing external phosphorus loading: the influence of sediment phosphorus release*, Freshwater Biology, 21, 139–162 (1989).

[18] Patalas K.: *Mieszanie wody jako czynnik określający intensywność krążenia materii w różnych morfologicznie jeziorach okolic Węgorzewa*, Rocz. Nauk Rol., 77(B-1), 243–297 (1960).

[19] Sempioł W.: *Środowisko geograficzne Jeziora Trackiego*, maszynopis, WSP Olsztyn 1978.

[20] *Standard methods for examination of water and wastewater*, American Public Health Association, AWWA, WPCF, Washington D.C. 1980.

[21] Szyper H., M. Kraska: *Ocena zewnętrznego obciążenia związkami biogennymi jezior Drawieńskiego Parku Narodowego*, [w:] Materiały III Konferencji Naukowo-Technicznej nt. Naturalne i antropogeniczne przemiany jezior, Radzyń k. Sławy, 20–22 września 1999, 255–264.

[22] Vollenweider R. A.: *Scientific fundamentals of the eutrophication of lakes and flowing water, with particular reference to nitrogen and phosphorus as factor in eutrophication*, Technical report Organization for Economic Cooperation and Development, Paris 1968.

[23] Zdanowski B.: *Ecological characteristics of lakes in North-Eastern Poland vs. their trophic gradient*, Ekol. Pol., 31(2), 287–331 (1983).

[24] Zdanowski B., A. Karpiński, S. Prusik: *Warunki środowiskowe wód jezior Węgierskiego Parku Narodowego*, Zesz. Nauk. PAN, 3, 35–62 (1992).

Received: December 26, 2004; accepted: March 11, 2005.