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THE THERMAL AND OXYGEN RELATIONSHIP AND WATER DYNAMICS OF THE SURFACE WATER LAYER IN THE KONIN HEATED LAKES ECOSYSTEM

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ABSTRACT. Analyses were performed on the impact of the discharge of post-cooling waters on the hydrological and thermal and oxygen conditions in the canals and two lakes that are part of the Konin and Pątnów power plant cooling systems. Lake Licheńskie received the greatest quantity of post-cooling water and was the most intensely heated lake in the system (up to 27°C). Water exchange in the lake occurred in three to five days. Lake Ślesińskie remained the coolest lake in the system (surface water temperature reached 25°C), while the water retention period was shorter only in summer (up to seven days). The oxygen content in the surface waters of the ecosystem did not fall below 7.5 mg O_2 l^{-1} (80% saturation).

Key words: HEATED WATERS, LAKES, CANALS, TEMPERATURE OXYGEN CONTENT

INTRODUCTION

Air temperature has an impact on the thermal regimes of freshwaters waters in the temperate region (Tórz et al. 2004), as do water mass dynamics that are shaped by the morphometrics of lake basins (Patalas 1960, Hutchinson 1957, Ambrosetti and Barbanti 2001) that determine, among other factors, the reach of mixing. These factors also impact the quantity of lake oxygen resources in the isolated layers of the meta- and hypolimnions. As a particular type of anthropogenic stress for lakes, the discharge of heated waters into them substantially alters thermal regimes and is one of the most significant factors impacting environmental conditions and eliciting trasformations at all trophic levels (Oliver and Hudson 1987, Hillbricht-Ilkowska and Zdanowski 1988a, b, Alonso 1989, Ali et al. 1995, Mitchell et al. 1996, Zdanowski et al. 2002). Another significant factor in the Konin lakes system is the variable hydrological conditions that result from the uptake and discharge of post-cooling waters from the

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power plants as well as the exchange of water among lakes (Socha and Zdanowski 2001). The aim of the study was to determine the impact of the discharge of heated waters on the hydrological, thermal, and oxygen conditions in the heated Konin lakes ecosystem.

MATERIALS AND METHODS

The Pątnów Power Plant (PPP) draws water from two uptake canals; the western canal that takes waters directly from Lake Gosławskie, and the eastern canal that takes waters from Lake Pątnowskie via a pumping station. Heated waters are discharged through the discharge canal and returned to Lake Gosławskie (about 40%), and to the other lakes including Pątnowskie (about 9%), Mikorzyńskie (about 17%), and Licheńskie (about 30%). The Konin Power Plant (KPP) draws cool waters from Lake Pątnowskie, while it discharges post-cooling waters into the initial cooling reservoir (about 2%) and through Licheński Canal to lakes Pątnowskie (about 15%), Mikorzyńskie (about 29%), and Licheńskie (54%). In an effort to increase the effectiveness of the cooling system during summer, a portion of the water from Lake Licheńskie is pumped through the Piotrkowicki Canal to Lake Ślesińskie, which is part of the secondary cooling system (Fig. 1). In total, the two power plants can draw water in quantities of about 80 $m^3 s^{-1}$.

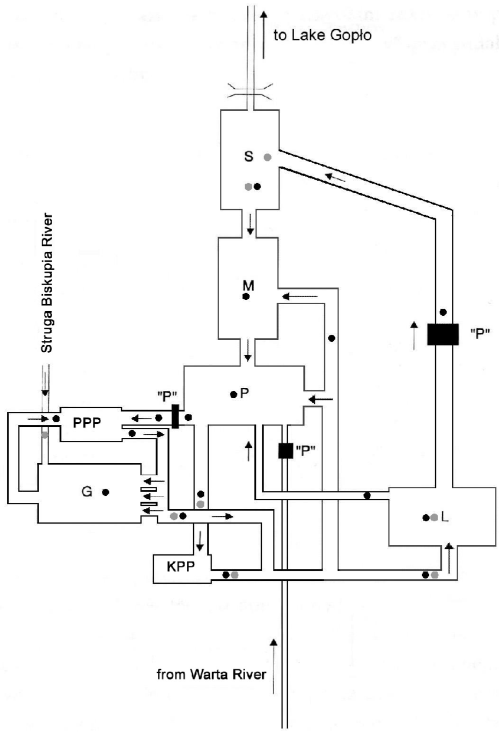

Fig. 1. Diagram of the cooling system for the Konin and Pątnów power plants. Lakes: L – Licheńskie; S – Ślesińskie; M – Mikorzyńskie; P – Pątnowskie; G – Gosławskie; KPP – Konin Power Plant, PPP – Pątnów Power Plant, P – pumping station. Black dots – ZE PAK monitoring stations, gray dots – IFI Olsztyn monitoring stations.

This work focuses mainly on two lakes in the Konin ecosystem, Ślesińskie and Licheńskie, which differ with regard to morphometrics, mixing type, and degree of heating. The first (area – 152.3 ha, maximum depths – 24.5 m, mean depth – 7.6 m) is a typical dimictic lake and the coolest in the whole system; while the second (area – 147.6 ha, maximum depth – 12.6 m, mean depth – 4.5 m), has features of a monomictic lake and is one of the most intensely heated. The study also attempted to compare the current state of the system with the results of previous research (Korycka and Zdanowski 1976, Hillbricht-Ilkowska and Zdanowski 1988a, b, Zdanowski 1994).

The basis for this paper is thermal-oxygen data from the 1995-2004 period obtained from hydrological and hydrochemical studies conducted by the Inland Fisheries Institute in Olsztyn (IFI Olsztyn). These data refer to the magnitude of the uptake and discharge of post-cooling waters from the power plant and water temperature variability in this system supplemented by materials from the monitoring system run by the Pątnów -Adamant-Konin Power Plant Group (ZE PAK) in Konin. The degree to which the water was heated by the power plant was determined as the difference between the temperature of the uptake and discharge waters. The water retention time in the lakes was calculated based on the actual flow of water in the system, assuming that water exchange in the summer stagnation period was limited to the epilimnion layer. Additionally, the volume of water participating in the exchange was increased by 50% due to disturbances in thermal layering near the post cooling-water discharge point from the Piotrkowicki Canal. Measurements of temperature and oxygen contents in the waters of the canals and the lakes (in the littoral and pelagic zones) were conducted monthly. A YSI model 58 oxygen meter was used to take the measurements. The locations of the study sites are presented in Figure 1.

RESULTS

The uptake and discharge of waters by the KPP in the 1995-2004 period decreased progressively by 30% from about 22 $m^3 s^{-1}$ in 1995 to 15 $m^3 s^{-1}$ in 2004. As a rule, the PPP utilized about twice as much water to cool its condensers, from 36 $m^3 s^{-1}$ in fall and winter to 41 $m^3 s^{-1}$ in summer (Fig. 2). The heating of post-cooling waters by the KPP was lower in the summer (at an average of 6.5°C) and higher in winter (at an average of 8.2°C). The PPP discharged warmer water as a rule; in spring it was heated,

TABLE 1

Seasonal variation (mean ±SD) in temperature and oxygen content in the surface waters of the Konin lakes system

Station	Spring			Summer			Fall			Winter		
	Water temperature (°C)	Oxygen content (mg O_2 l^{-1})	Oxygen saturation (%)	Water temperature (°C)	Oxygen content (mg O_2 l^{-1})	Oxygen saturation (%)	Water temperature (°C)	Oxygen content (mg O_2 l^{-1})	Oxygen saturation (%)	Water temperature (°C)	Oxygen content (mg O_2 l^{-1})	Oxygen saturation (%)
Pątnów Power Plant eastern intake canal	17.2±3.7	9.7±1.5	99.0±14.6	22.4±2.3	8.0±1.1	91.5±12.9	15.7±4.4	8.3±0.8	82.5±6.9	11.3±3.1	10.0±0.9	90.4±8.5
Pątnów Power Plant western intake canal	14.1±5.5	9.6±2.2	95.4±14.9	22.0±2.6	8.0±1.1	90.9±13.7	15.1±3.2	8.5±0.9	83.6±5.0	6.8±2.8	10.4±0.9	85.1±7.7
Konin Power Plant intake canal	15.0±7.7	11.2±2.7	105.6±17.2	23.2±4.2	8.3±0.8	95.4±10.1	13.9±7.7	9.0±0.9	88.2±7.7	3.3±2.3	11.0±1.4	88.8±8.4
Pątnów Power Plant discharge canal	22.8±5.2	9.1±1.5	102.8±13.9	29.9±2.9	7.4±0.7	95.8±9.7	23.3±3.8	8.2±0.8	94.2±5.7	16.6±2.7	9.5±1.1	96.6±9.7
Konin Power Plant discharge canal	21.1±5.9	9.9±1.8	108.4±14.4	29.2±2.8	7.9±0.6	101.8±7.2	21.8±3.9	8.9±0.8	99.1±6.5	14.4±2.0	10.4±1.0	100.0±8.9
Licheński Canal	19.9±5.6	8.6±2.1	90.7±14.1	27.9±2.7	7.2±0.6	90.1±6.9	21.0±3.8	7.7±1.1	85.0±10.8	13.4±2.7	9.7±1.6	93.1±11.8
Licheńskie Lake	15.9±7.1	10.4±2.4	102.6±18.0	25.2±2.3	7.8±1.3	96.1±15.1	16.7±3.7	8.0±1.2	81.9±12.8	7.8±3.0	10.1±1.4	83.7±8.4
Ślesińskie Lake	13.0±6.8	12.0±2.9	111.7±21.5	22.3±2.9	8.8±1.1	100.1±12.4	12.3±4.2	8.9±0.8	82.9±9.5	4.2±2.3	10.4±2.5	81.2±13.9

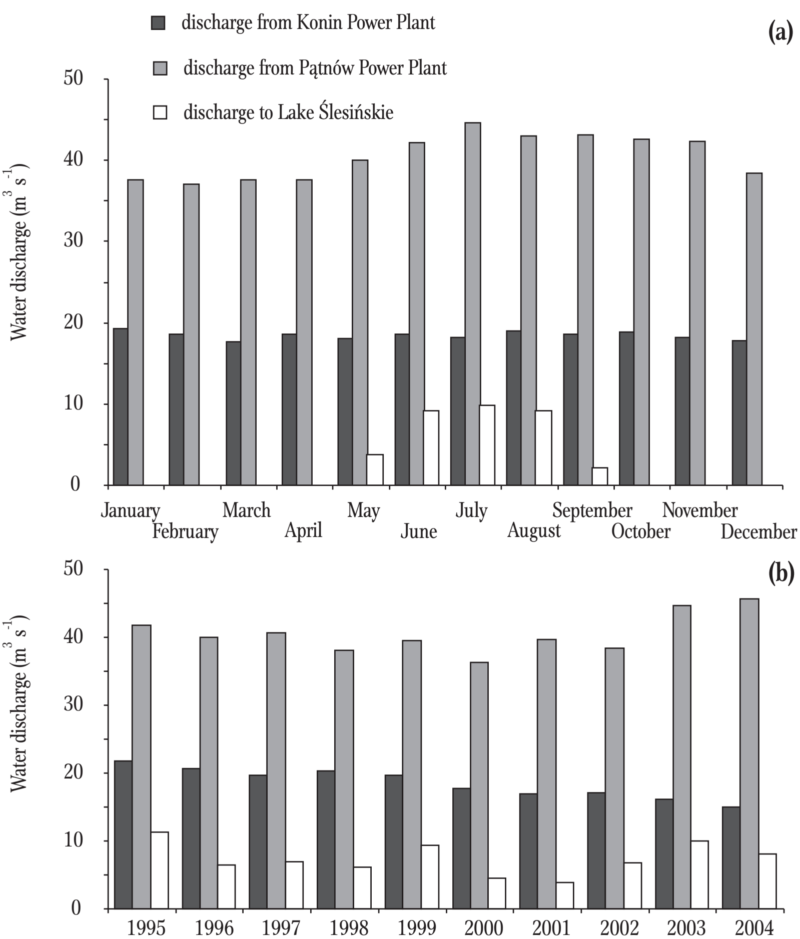

Fig. 2. Seasonal (a) and long-term (b) quantities of post-cooling waters (m^3s^{-1}) discharged by the Pątnów and Konin power plants in the 1995-2004 period.

on average, by 7.1°C, while in fall to 7.9°C (Fig. 3). The mean oxygen content in the waters flowing throughout the whole Konin system did not normally fall to less than 7.5 mg O_2 l^{-1} and 80% saturation. The minimum concentrations occurred in the warmest months of the year (summer and fall) in the discharge canals. Usually, the greatest oxygen concentrations (up to 10.4 mg O_2 l^{-1}) were noted in the cool canals (uptake), while the greatest saturation (up to 111%) was noted in spring (Table 1).

Nearly half of the warm post-cooling water from both power plants that flowed in the Licheńskie Canal was directed to Lake Licheńskie. While flowing in the canal, the

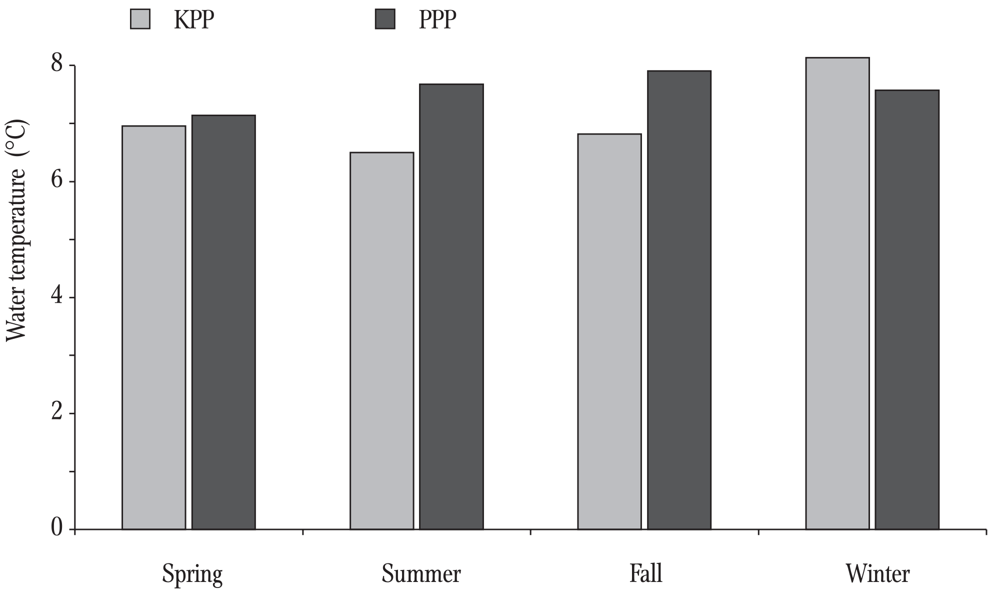

Fig. 3. Mean degree of water heating by the Konin and Pątnów power plants in the 1995-2004 period.

temperature of these waters decreased on average by about 1.8°C (0.3°C per km of its length). The retention time of waters in this lake did not vary significantly according to season, or over the long-term. The discharged waters were held for the shortest period in May (an average of three days) and in warm months from June to October (four days). In the cool months (November-April), water exchange in the lake lasted an average of five days (Fig. 4). This lake remains the warmest in the system since it is fed post-cooling waters throughout the year. The flow-through southern part of this lake does not freeze in winter, while in the stagnant northern part of it ice cover has been noted sporadically. The temperature of the water surface layer was lower in January (mean 5.7°C), while maximum values were reached in August (average 27°C). The number of days per year when the water temperature exceeded 28°C fell in the last decade from 40 in 1995 to eight in 2004. Heating that exceeded 30°C was noted sporadically (two days per year, on average). In subsequent months, the lake cooled gradually to about 8°C in December (Fig. 5).

During the summer, generally from May to September, part of the post-cooling water from Lake Licheńskie was directed through the Piotrkowicki Canal to Lake

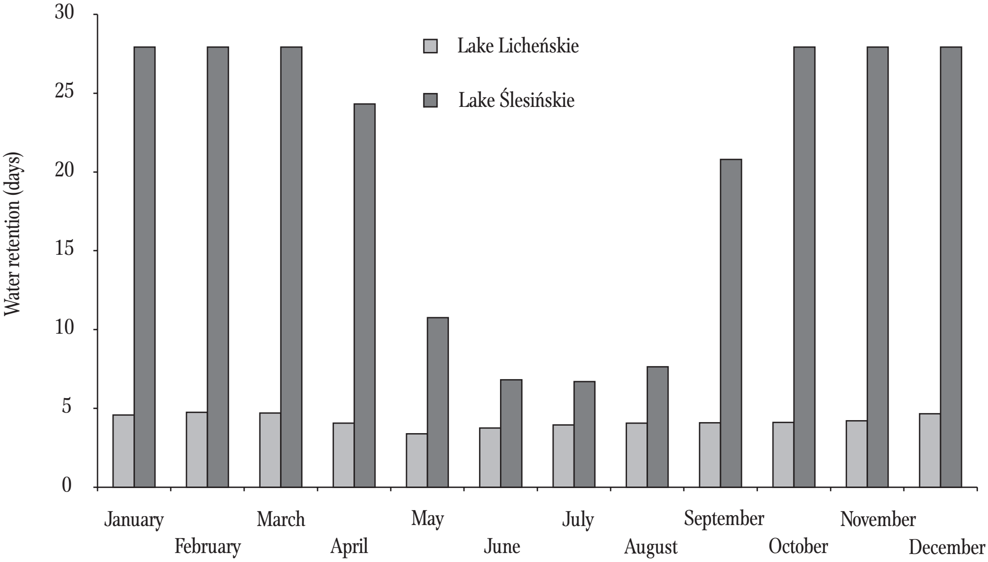

Fig. 4. Mean water retention time in lakes Licheńskie and Ślesińskie in the 1995-2004 period .

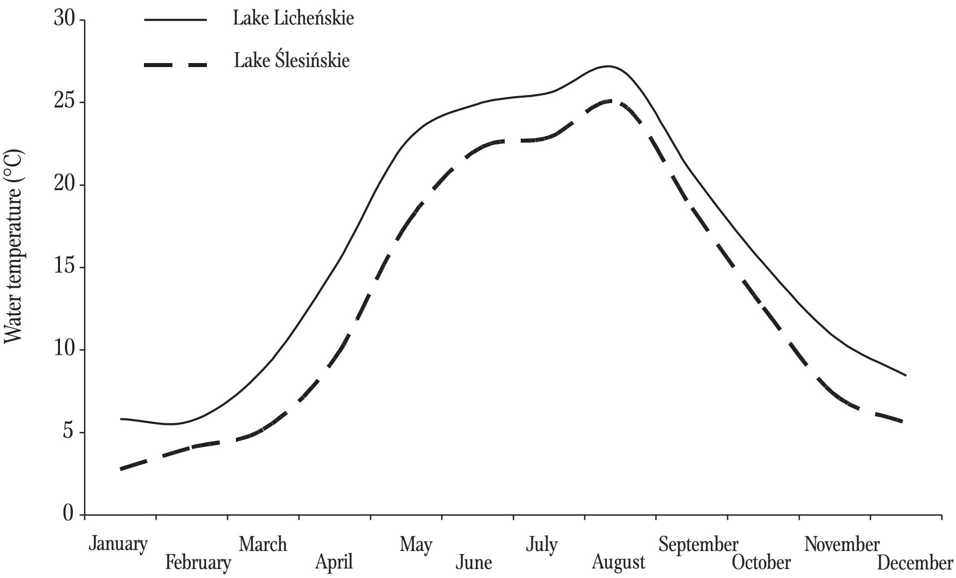

Fig. 5. Mean surface water temperature in the waters of lakes Licheńskie and Ślesińskie in the 1995-2004 period.

Ślesińskie. The retention time in this lake was, in this period, the shortest at an average of seven days, while in the cool half of the year (October to March), it extended to an average of 28 days (Fig. 4). In recent years the mean, annual water retention time in Lake Ślesińskie increased only slightly. During the winter, this lake froze over in some years (1997, 1998, 1999 and 2003). The surface layer water temperature was the lowest in January at an average of 0.6°C, when ice cover occurred, and 2.8°C, when the lake did not freeze. The average, highest heating of the epilimnion layer (to 25°C) was confirmed at the height of the summer stagnation, when the highest air temperatures were noted, and discharges of post-cooling water to the lake were most intense (Fig. 2a). In subsequent months the temperature of the lake waters decreased systematically to about 5°C in December. Generally, it can be concluded that the annual course of temperature change in the two lakes was similar in the past decade (Fig. 5). Lake Licheńskie was exceptional as the degree to which its waters were heated increased (Fig. 6).

The oxygen content in the surface waters of Lake Licheńskie fluctuated throughout the season fairly significantly. Lower concentrations of oxygen (6.3 mg O_2 l^{-1} and 61% saturation) were confirmed in summer and fall, while the highest was in spring (maximum of 17.0 mg O_2 l^{-1} and 150%). Variability in the content of oxygen in the surface waters of Lake Ślesińskie was significant; the highest oxygen concentration (to 19.6 mg O_2 l^{-1}, 170% saturation) was confirmed when temperatures were the lowest, while in summer oxygen concentration was the lowest (less than 9.0 mg O_2 l^{-1}, 83% saturation).

DISCUSSION

The quantity and temperature of the post-cooling waters discharged from the KPP and PPP mainly impacted variation in thermal conditions throughout the system. The actual volume of water directed into the lakes ranged on average from 54 to 64 m^3 s^{-1}; these figures are similar to those reported in the mid 1990s by Zdanowski (1994). In recent years, the volume of post-cooling water discharged from the KPP has declined, while that used by the PPP has increased. The degree to which the water is heated by the KPP (mean of about 7.1°C) did not change significantly and was similar to previous years (Zdanowski 1994, Socha and Zdanowski 2001). The increase in the volume of

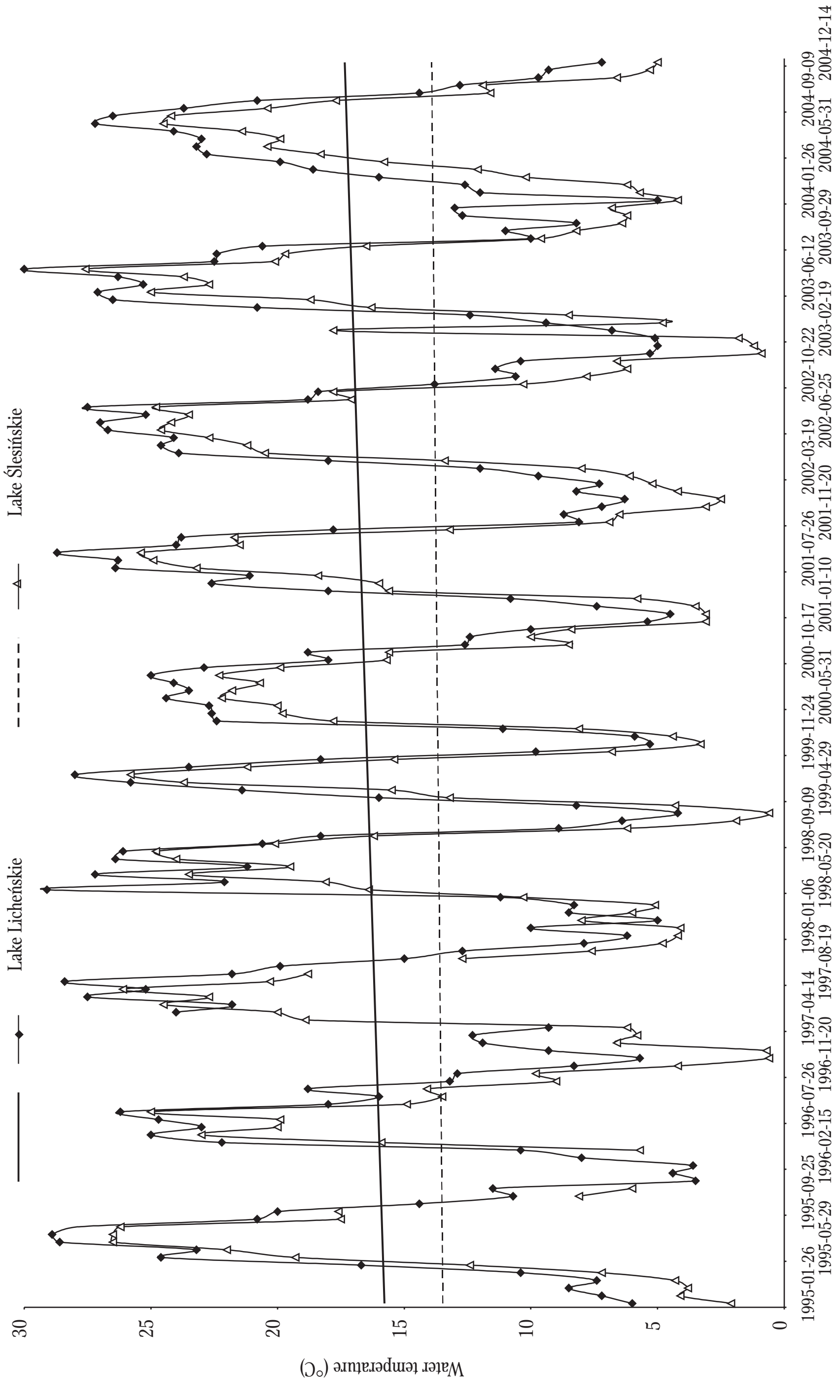

Fig. 6. Long-term (1995-2004) changes in temperature in the surface water layer in lakes Licheńskie and Ślesińskie.

water used for cooling by the PPP meant that the mean degree of heating fell from 9.5 to 7.7°C. The greatest increase in temperature (up to 8.1°C) was noted in the winter period.

The water exchange period throughout the Konin lakes system depended mainly on the quantities of water inflowing from the Struga Biskupia River and evaporation. Inflows from this river decreased in the 2001-2004 period from about 2.5 to about 1.1 m^3s^{-1}. The water level in the system was maintained thanks to inputs of water from the Warta River.

The lowest oxygen contents in the canals and lakes were usually noted in summer and fall when the temperature of the system's water was the highest; oxygen content was the highest in the spring during intense diatom blooms. No significant differences in oxygen content were normally noted among the individual elements of the system. The absolute oxygen content in the canals was lower in the cooler waters of the uptake canals. Oxygen saturation in the water increased because of the intense mixing in the discharge zone, and then it quickly decreased as the water cooled. The average oxygen content was lower in the warmest waters and highest in the cooler Lake Ślesińskie waters. This is confirmed by the observations of other authors that temperature is the primary factor in determining the oxygen content of waters in the heated lakes (Oliver and Hudson 1987, Ashby et al. 1995).

The water retention time in Lake Licheńskie depended on the quantity of water inflowing from the Licheńskie Canal, but also from the volume of water subject to exchange, which is the extent of the epilimnion. This layer was the thinnest (up to 3 meters) most often in May. The mean water retention time during this period was the shortest at barely three days. In the summer, as a result of the increased inertia of the water masses at higher temperatures, thermocline erosion occurred thus increasing the volume of water participating in exchange. The progressing disappearance of thermal stratification lengthened as a consequence of the water retention time in the lakes (up to five days) and limited the occurrence of severe oxygen deficits in the near-bottom waters. Due to the greater load of post-cooling waters, the degree to which the surface water layers were heated increased continuously.

Retention time in Lake Ślesińskie depended on the intensity of the discharge of post-cooling waters from Lake Licheńskie. In comparison to previous data (Zdanowski 1994), the quantity of water discharged through the Piotrkowicki Canal to the lakes was threefold lower. It decreased in the 1995-2004 period from 11 to 8 m^3s^{-1}. During the period when the secondary cooling system was in operation, retention time in Lake Ślesińskie decreased in June and July to an average of seven days, while from October to March it lengthened to 28 days.

As was confirmed in previous studies (Zdanowski 1994, Zdanowski and Prusik 1994), Lake Ślesińskie was the coolest lake in the Konin system. Only in the summer period, usually from May to September, did higher water temperatures necessitate putting the so-called secondary cooling system into operation. Despite significant differences in the temperature and thickness of post-cooling and lake waters, the intensity of their discharge can disrupt thermal stratification locally (Oliver and Hudson 1987). In the area of the post-cooling water discharge from the Piotrkowicki Canal, the water was mixed and oxygenated to the bottom (18 m). In isolated zones, severe oxygen deficits were noted in the meta- and hypolimnion; this comprised about 23% of the lake volume.

The short water retention time in the Konin ecosystem meant that the lakes exhibited characters typical of lotic systems, at least in the surface layers. Water flow in the lakes could have limited eutrophication (Piotrowska and Przybiński 1991, Zdanowski 1994, Socha and Zdanowski 2001). Increasing water retention time in Lake Ślesińskie did not result in the progressive degradation of this lake.

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STRESZCZENIE

STOSUNKI TERMICZNO-TLENOWE I DYNAMIKA WÓD POWIERZCHNIOWYCH W EKOSYSTEMIE PODGRZANYCH JEZIOR KONIŃSKICH

Scharakteryzowano wpływ zrzutu wód podgrzanych na warunki hydrologiczne i termiczno-tlenowe w kanałach i dwóch jeziorach (Ślesińskim i Licheńskim) włączonych do systemu chłodzenia Elektrowni Konin i Pątnów. Jezioro Licheńskie przyjmowało największą ilość wód pochłodniczych i należało do zbiorników nadal intensywnie podgrzewanych (do 27°C). Wymiana wody w jeziorze następowała w czasie od 3 do 5 dni. Jezioro Ślesińskie pozostało nadal najchłodniejszym zbiornikiem w systemie (temperatura powierzchniowych warstw wody wzrosła do 25°C), a czas zatrzymania wody w tym zbiorniku skracał się jedynie w okresie letnim (do 7 dni). Zawartość tlenu w wodach powierzchniowych ekosystemu nie spadała poniżej 7,5 mg O_2 l^{-1} (80% nasycenia).