

**CHANGES WITHIN THE GEOECOSYSTEM  
OF A SMALL LAKE CATCHMENT  
IN THE LAST THREE DECADES VERSUS  
CHANGES IN LAND USE AND PRECIPITATION  
QUALITY (RADOMYSKIE LAKE,  
UPPER PARSEŃTA CATCHMENT)**

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*Abstract:* There are numerous (though spread unevenly) small run-off-free bodies of water in the Parsęta basin as well as in the upper Parsęta catchment. The geoecosystems of these non-run-off bodies serve various functions in the geographic environment; they are particularly important in terms of shaping catchment retention and water circulation. They quickly react to environmental conditions, especially to changes in land use and land cover in the catchment and the supply of pollutants in waters. Radomyskie Lake is a small body of water in the upper Parsęta catchment within which radical changes in land use and changes in the chemistry of the lake waters have taken place over the last 30 years. The concentration of ion components in the lake waters has become significantly reduced compared with that in the early 1980s. A comparison with Czarne Lake – a similar body of water in the upper Parsęta catchment revealed that these ongoing changes have two causes: afforestation of agriculturally cultivated catchment areas around Radomyskie Lake and consequently reduced supply of fertilizer as well as a drop in precipitation mineral content, which had been noted by researchers for 20 years. Radomyskie Lake is experiencing the stage of re-naturalization and its evolution is moving towards a peat-bog geoecosystem.

*Keywords:* non-run-off lake, land use, chemistry of lake waters, upper Parsęta catchment, West Pomerania

## Introduction

Small water reservoirs, usually melt kettle-holes, serve various functions in the glacial landscape of the Western Pomeranian region. They are very important, among others, in the shaping of water circulation, especially for the catchment retention (Drwal 1975; Pieńkowski, Podlasiński 2001; Major 2009). They represent local erosion bases and sedimentation reservoirs for sediments and dissolved matter (Borówka 1992; Klatkova 1997; Major 2012; Karasiewicz *et al.* 2014). They quickly react to multi-directional conditions, including, anthropopressure manifested in changed land use and supplies of pollutants (Bajkiewicz-Grabowska 1987; Pieńkowski 1996; Koc *et al.* 2001; Major 2001). Therefore, they can be considered to be indicative geoecosystems which well represent the directions and intensity of today's changes within the geographical environment.

On the grounds of the raster Map of the Hydrological Division of Poland (provided by Institute of Meteorology and Water Management, the Department of Hydrography and Morphology of Riverbeds) it was found out that a number of water reservoirs within the Parsęta basin which are not included in the network of surface run-off amounts to 2270. It gives an average value of 0.73 kettle-hole per 1 km<sup>2</sup>, however the maximal density exceeds 20 kettle-holes per 1 km<sup>2</sup>. This mainly occurs within flat morainic high lands to the south and west of Połczyn-Zdrój (Wysoczyzna Łobeska [Łobeska Upland], Pojezierze Drawskie [Drawskie Lake District]) and within flat and undulating high lands and accumulative moraines in the eastern part of the basin, in the region of Bobolice (Pojezierze Drawskie [Drawskie Lake District], Pojezierze Bytowskie [Bytowskie Lake District]) (Fig. 1). In the upper Parsęta catchment confined by a water-flow profile in Storkowo, the maximal density of non-run-off surface water reservoirs reaches 5 per 1 km<sup>2</sup>.

The Czarne Lake – the largest non-run-off water reservoir in the upper Parsęta catchment – was covered by the research studies conducted in 1982 (Kostrzewski, Zwoliński 1986), then in the early 90s of 20<sup>th</sup> century (Kostrzewski *et al.* 1995); since 1995 it has been systematically research-studied under the Integrated Environmental Monitoring implemented by the Geoeological Station (the Adam Mickiewicz University in Poznań) located in Storkowo. The Radomyskie Lake, just like the Czarne Lake, in terms of its location (local watershed area), volume of catchment and type of supply (Fig. 2) was thoroughly research-studied in 1983–1984. Differentiator compared the lakes catchments is land use. The catchment area of the Czarne Lake is a forest, the Radomyskie Lake catchment was used for agriculture, and in 1992 was entirely forested.

The present paper makes the assessment on changes which have taken place within the environment of the Radomyskie Lake catchment and its operation over

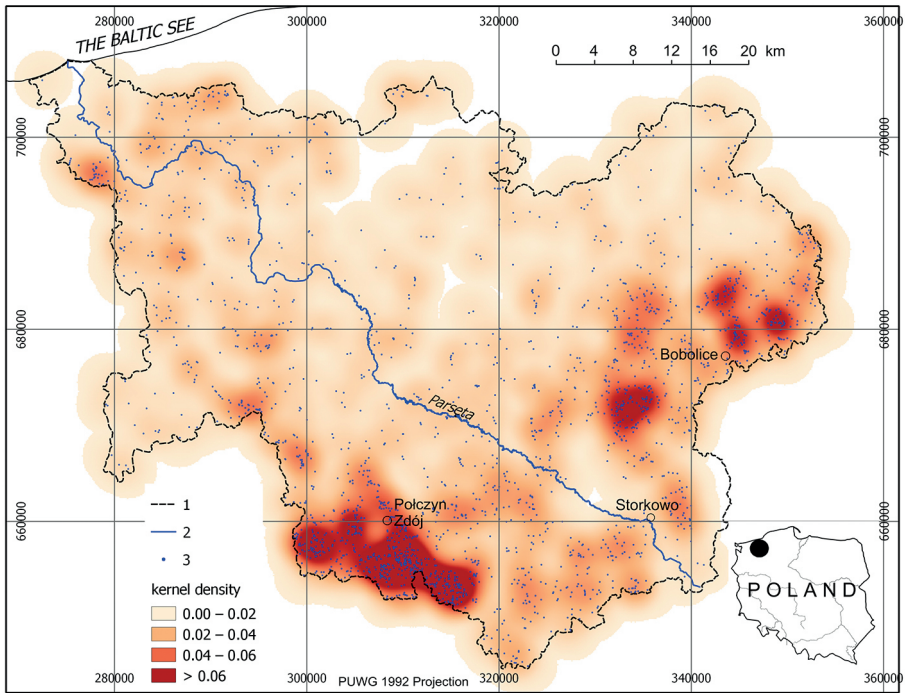


Fig. 1. Density of non-run-off of water reservoirs within the Parsęta basin

1 – sub-catchments in the main Parsęta catchment, 2 – Parsęta River, 3 – non-run-off bodies of water, 4 – density ratio

Source: authors' own study.

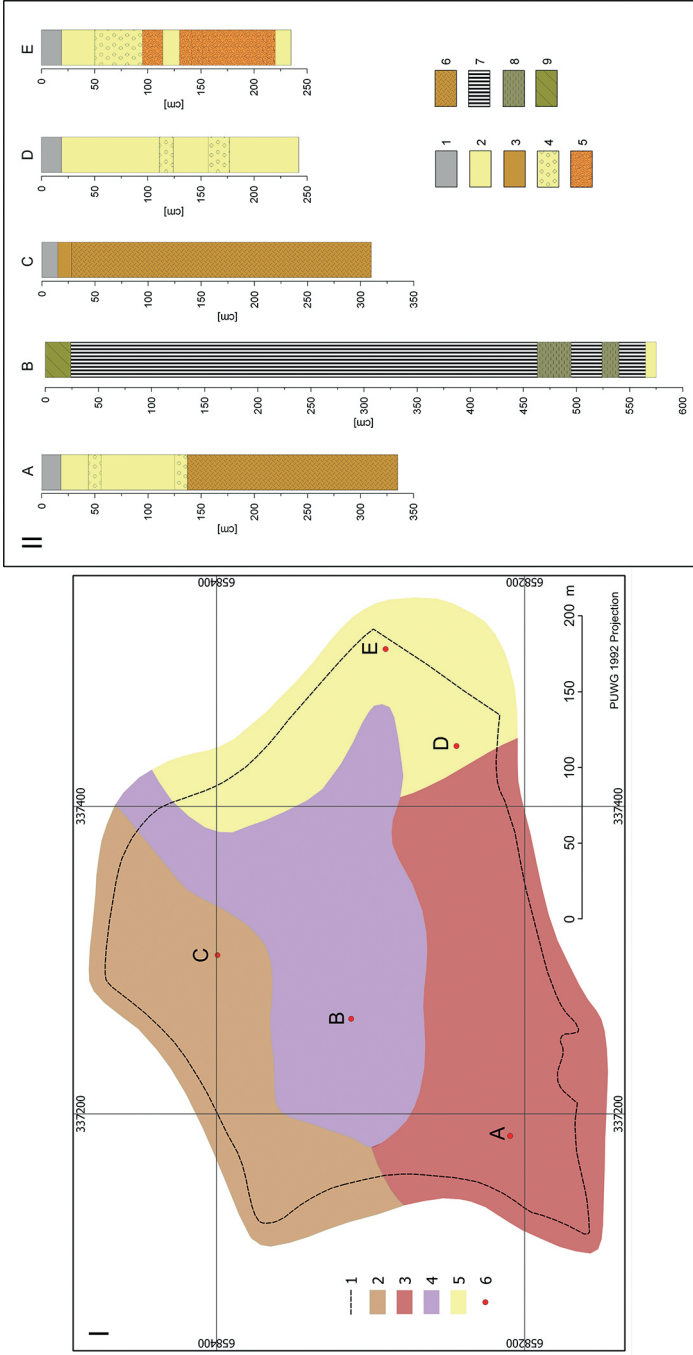


Fig. 3. Geomorphologic map (I) and selected lithological profiles (II) of the Radomyskie Lake catchment

- I: 1 – watershed of the Radomyskie Lake catchment, 2 – undulating morainic upland, 3 – accumulative moraine, 4 – post-glacial melt depression, 5 – out-wash plain, 6 – location of selected lithological profiles
- II: 1 – humus accumulative level, 2 – sand, 3 – loamy sand, 4 – gravel, 5 – erosive pavement, 6 – morainic clay, 7 – peat, 8 – gyttja, 9 – unconsolidated lake deposits

Source: authors' own study.

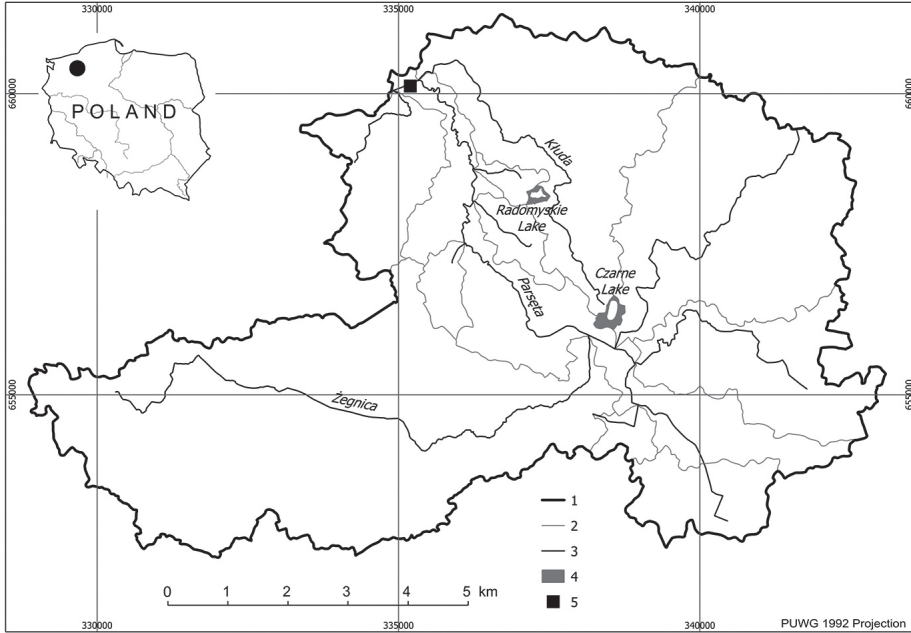


Fig. 2. Location of the Radomyskie Lake catchment and the Czarne Lake catchment in the upper Parsęta basin

1 – watersheds of the upper Parsęta catchment, 2 – watersheds of partial catchments within the upper Parsęta catchment, 3 – rivers, 4 – Radomyskie Lake and Czarne Lake catchments, 5 – precipitation chemistry gauging site at the Geoeological Station (Adam Mickiewicz University in Poznań) in Storkowo

*Source:* authors' own study.

the past 30 years. The observed changes were compared with the ones of the similar and regularly monitored Czarne Lake.

The following research objectives were achieved:

- recognition of changes in the functioning of this small lake catchment within the last 30 years,
- specification of the conditioning of these changes,
- determination of the developmental direction of small lake reservoirs and their catchments at the background of changes in land use and long-term trends in precipitation quality.

## Research scope

The Radomyskie Lake catchment covers an area on nearly 7.8 ha at the watershed zone between the Kłuda catchment and the Krętaż catchment (Fig. 2). The lake reservoir covers 2.1 ha, which represents 27% of the whole catchment. Similar proportions are characteristic to the Czarne Lake catchment: its area is 17.1 ha and its waters cover 3.4 ha which represents 20% of the area. The location within the watershed zone implies – for the most part – the precipitation-driven supply of these lakes and it is reflected in the chemistry of their waters.

The Radomyskie Lake catchment within its southern part is covered by an accumulation moraine wall with its height up to 150 m a.s.l. and within its northern part – by an undulating morainic upland with its height ranging within 130 m a.s.l.–135 m a.s.l. (Fig. 3). According to Karczewski (1989) this is a kame-melt area which northwards, through the edge with its height of 20 m, makes the highest level of the northern upland slope of the Pomerania region. The eastern part of the catchment is formed by a local out-wash plain. The land height variance within the land part of the Radomyskie Lake is over 20 m. Agricultural terraces which diagonally intersect the slope located to the south of lake are a remnant of agricultural use of the catchment and a characteristic element of the morphometry. In lithological terms it is dominated by loamy sands and sands with a large admixture of thicker material, which – within valley floors made by snow-melt water run-off – forms covers of erosive pavements at a depth of 0.5 m–1 m (Fig. 4). The depression, at the present time covered with lake waters, is filled with peat down to a depth of 4.5 m with underlying gyttja with peat inter-beds (about 1.5 m) and then with sandy ground minerals. The morphometry of the slopes and the type and thickness of sediments indicate the melt-driven origin of its bowl.

The Radomyskie Lake is a shallow basin with its average depth of 1.3 m and maximal one reaching 3.6 m (Fig. 5). The analysis of archival maps leads to the conclusion that the lake is a reservoir of anthropogenic genesis. The map from 1855 (Generalstabskarte) indicates that the place of the present lake was covered with a wetland depression, perhaps drained through drainage network. According to other maps: from 1877 (Messtischblätter 876) and from 1936 (Messtischblätter 2.265) this place was still covered with swamp within which peat was extracted. The map from 1936 shows marked small kettle-holes – peat pits filled with water. Contemporary irregular morphology bottom of the lake, with numerous small depressions and arranged between shallows was probably formed during the extraction of peat. In 1983–1984 some leavings of the drainage network (which drained the lake to Kłuda) were still in operation. In 1993 a trench was dug out from the lake to Kłuda which has currently been blocked by an embankment and does not carry water. However it has continued to be a potential way of drainage and lowering the current water level by about 1 m.

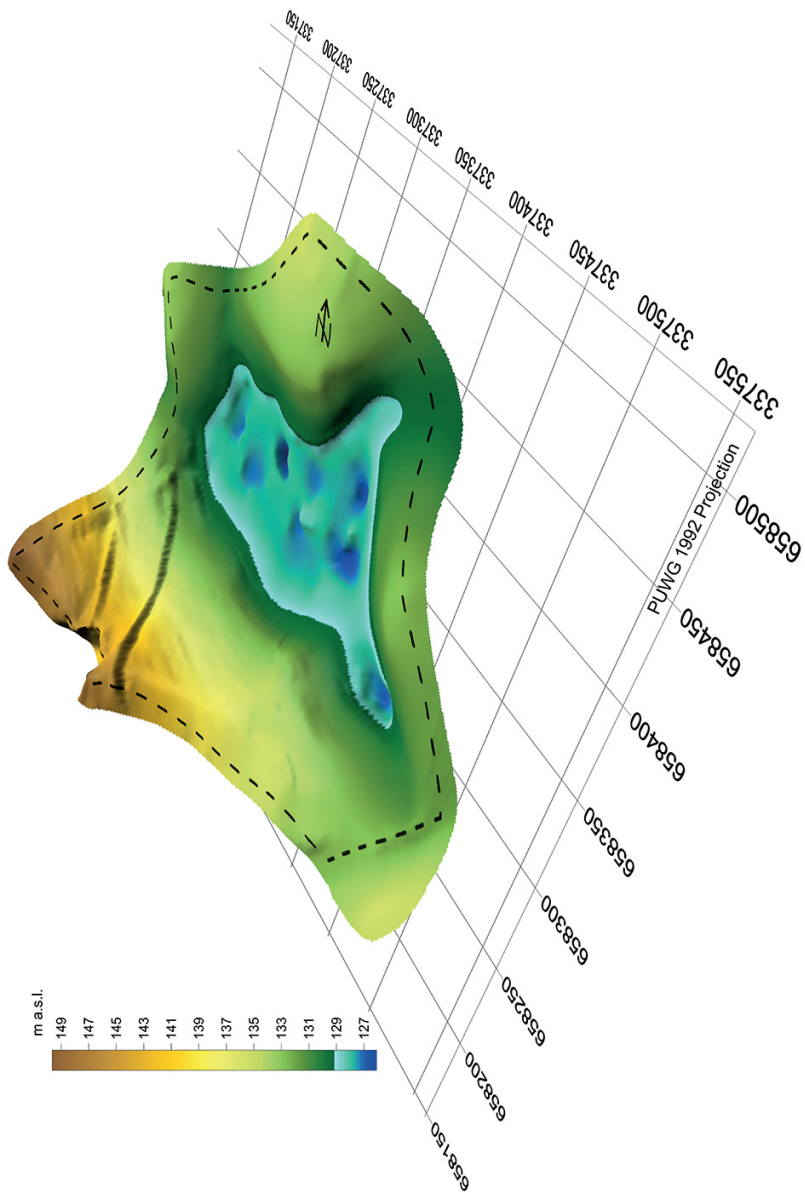


Fig. 4. Digital elevation model of the Radomyskie Lake catchment

*Source:* authors' own study.

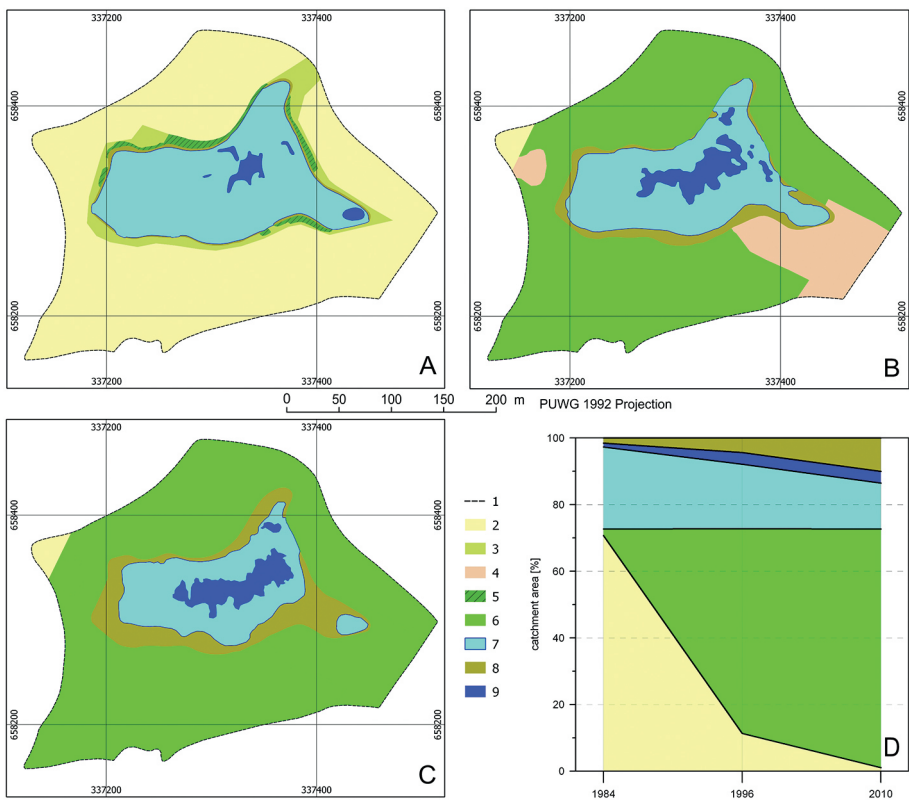


Fig. 6. Changes in land use and land cover in the Radomyskie Lake catchment in the period 1984–2014: A – 1984, B – 1996, C – 2014, D – changes and their dynamics

1 – watershed of the Radomyskie Lake catchment, 2 – arable land, 3 – wet meadows, 4 – farmland and woodland areas, 5 – areas with shrubs, 6 – forest, 7 – water, 8 – emerged aquatic vegetation, 9 – peat layers

Source: authors' own study.



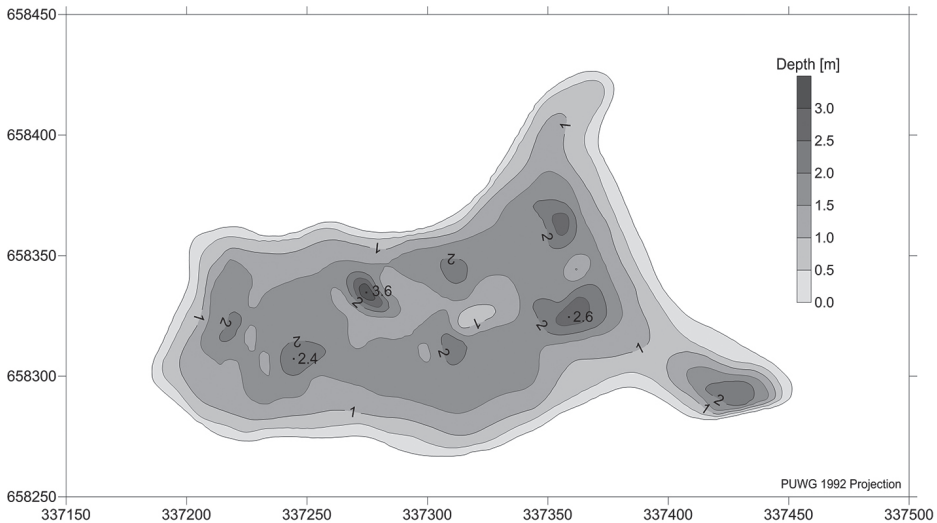


Fig. 5. Bathymetry of Radomyskie Lake

*Source:* authors' own study.

## Research study methods

Detailed field research studies conducted in the Radomyskie Lake catchment in 1983–1984 are the main source of the presented data. They covered, among others:

- identification of the lithology of the catchment through bore holes and outcrops,
- measurements and observations of slopewash,
- execution of the detailed bathymetry of the lake and surveying measurements in order to develop hypsometric map of the catchment,
- detailed mapping on the types of lands and crops,
- study of the lake water chemistry.

All the changes in land use within the lake catchment in 1983–1984 were determined on the grounds of a topographical map scaled 1:100,000 developed in 1985, aerial photographs from 1996 and 2014 and field mapping. Geographical Information Systems and their methods were applied to calculate and spatially visualise the research results. The presented maps were developed in the currently applicable National Geodetic Coordinate System 1992.

The research examinations of physicochemical properties of samples taken from the Radomyskie Lake in 1984 were conducted at the Quaternary Research Institute at the Adam Mickiewicz University in Poznań. Ions were determined by means of titration methods according to Markowicz, Pulina (1979): in case of bicarbonate

ions – alkacymetric one, chloride – argentometric one, sulphate – precipitation one, calcium and magnesium – with EDTA one. The hydrochemical analysis of water samples from the Czarne Lake and the present research studies of chemistry of the Radomyskie Lake were conducted at the Geoecological Station of the Adam Mickiewicz University located in Storkowo with the application of methods in line with the Polish Standards (Elbanowska *et al.* 1999; Prejzner 1994). Titration methods were applied to determine bicarbonate and calcium ions. Chloride, nitrate and sulphate ions were determined by means of ion chromatography (DX-120, Dionex). Concentrations of magnesium, sodium and potassium ions were research studied by means of flame atomic emission / absorption spectrometry (SpectrAA 20 Plus, Varian). Ammonium and phosphate ions were determined by spectrophotometry methods (Spekol 1100 Zeiss).

The Radomyskie Lake waters and their chemistry were subjected to research studies in 2014. These studies were conducted in the deepest 3 points. At the specified vertical profiles 2 samples of water were taken from the surface and from a depth of 1 m, respectively.

The comparative data on the chemistry of the Czarne Lake waters was gathered under the regular hydrochemical monitoring (ongoing since 1995). It is implemented according to the principles adopted in the Integrated Environmental Monitoring (Kostrzewski *et al.* 1995). Physicochemical properties of the lake waters are measured 4 times per year at the deepest lake points.

## Results

### Changes in land use and land cover within the Radomyskie Lake catchment

The Radomyskie Lake catchment was a completely treeless area in 1983–1984. The structure of its land use and land cover was dominated by agricultural areas making 95% of the entire land part of the catchment (Fig. 6). The poor quality of soils – leading to extensive fallow lands – caused that in 1992 the area around the Radomyskie Lake was forested with mixed pine and birch trees. Therefore, the period of 1984–2014 saw radical changes in land use and land cover within the research-studies area – agricultural lands were almost completely converted into forests. At the same time the lake was found to be heavily overgrown with submerged aquatic vegetation as well as reed encroaching into the lake. From 1984 to 2014 the area occupied by water plants increased 7-fold. Also peat layers got developed within the lake: from 9 acres in 1984 up to 27 in 2014. These processes provide evidence on the progressive disappearance of the lake, through in 2014 there was

no reduction in the level of water in the lake compared to 1983–1984. The lake banks are a place of intense accumulation of leaves and other organic matter which originate from forests which surround the lake.

### Physicochemical properties of the Radomyskie Lake waters

The research studies on the Radomyskie Lake conducted in 1983–1984 showed low levels of ionic components (Tab. 1) in the lake waters expressed in specific electrical conductivity (SEC) at 25°C in the range 11.6 mS · m<sup>-1</sup>–23.4 mS · m<sup>-1</sup>. The average value of conductivity on the basis of 7 measurements in 1983 and 9 measurements in 1984 amounted to 16.0 mS · m<sup>-1</sup> (Szpikowski 1988a).

Nowadays (April 2014) the lake waters are characterised by average electrical conductivity at 2.6 mS m<sup>-1</sup>. It stands for 6-fold decrease in the total mineralization of these waters in relation to the values from the 80s of the 20<sup>th</sup> century. Also the concentration of individual components in the lake waters is a few or even several times lower (Tab. 1, Fig. 7). The concentration of bicarbonates with an average of 62.9 mg · dm<sup>-3</sup> (the average value of measurements conducted in March and August 1984) decreased to 14.4 mg · dm<sup>-3</sup>; chloride ions – from 10.0 mg · dm<sup>-3</sup> to 2.7 mg · dm<sup>-3</sup>. The content of calcium ions decreased from 13.7 mg · dm<sup>-3</sup> to 3.0 mg · dm<sup>-3</sup> and

Table 1. Physical and chemical parameters for Radomyskie Lake and Czarne Lake waters as well as precipitation across the upper Parsęta catchment

Parameter	Unit	Radomyskie Lake		Czarne Lake		Rainwater	
		1984	2014*	1995	2014*	1995	2014
pH	–	(–)	6.46	5.75	6.51	4.46	5.02
SEC	[mS · m <sup>-1</sup> ]	17.7	2.6	3.8	2.4	2.7	1.7
HCO <sub>3</sub> <sup>-</sup>	[mg · dm <sup>-3</sup> ]	62.9	14.4	11.9	12.6	(–)	(–)
Cl <sup>-</sup>		10.0	2.70	4.00	2.29	2.16	0.55
SO <sub>4</sub> <sup>2-</sup>		16.8	0.01	7.85	0.40	3.73	0.84
PO <sub>4</sub> <sup>3-</sup>		(–)	0.04	0.03	0.02	0.06	0.03
NO <sub>3</sub> <sup>-</sup>		(–)	0.00	0.22	0.00	2.29	1.48
NH <sub>4</sub> <sup>+</sup>		(–)	0.54	(–)	0.49	1.01	0.62
Ca <sup>2+</sup>		13.7	3.03	2.26	2.34	0.60	0.61
Mg <sup>2+</sup>		7.0	0.47	0.61	0.40	0.09	0.09
Na <sup>+</sup>		(–)	2.07	1.47	1.40	0.52	0.43
K <sup>+</sup>		(–)	0.16	1.53	1.29	0.15	0.09

\* – measurement made in April 2014, (–) – not examined

Source: authors' own study.

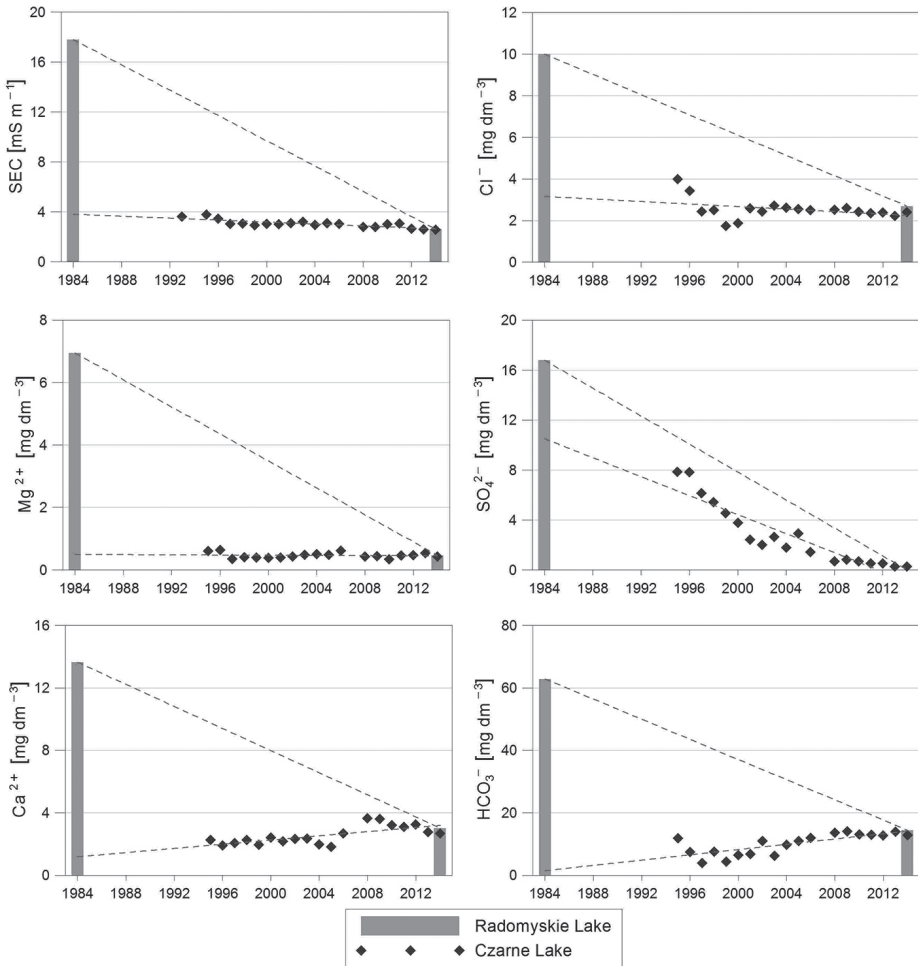


Fig. 7. Comparison of selected physical and chemical parameters of Radomyskie Lake waters in 1984 and 2014 versus the chemistry of Czarne Lake waters in 1995–2014

Source: authors' own study.

magnesium from  $7.0 \text{ mg} \cdot \text{dm}^{-3}$  to  $0.5 \text{ mg} \cdot \text{dm}^{-3}$ . In case of sulphate ions, their concentration dropped from over a dozen  $\text{mg} \cdot \text{dm}^{-3}$  to almost zero. The Radomyskie Lake waters were classified hydrochemically as  $\text{HCO}_3^- - \text{SO}_4^{2-} - \text{Ca}^{2+} - \text{Mg}^{2+}$  according to the Szczukariew-Prikłóński Classification (Macioszczyk, Dobrzyński 2007) on the grounds of the ionic composition expressed in % (for the concentrations in  $\text{eq dm}^{-3}$ ) in 1984. The present hydrochemical type does not include sulphates and magnesium ions but it includes chlorides and sodium:  $\text{HCO}_3^- - \text{Cl}^- - \text{Ca}^{2+} - \text{Na}^+$ .

Currently, the physicochemical properties of the Radomyskie Lake waters are very close to the chemistry of the Czarne Lake (Tab. 1, Fig. 7), which results from their similar environmental conditions. In the 80s of the 20<sup>th</sup> century waters in both reservoirs were different in terms of their physicochemical properties probably due to the different type of land use and land cover within their catchments. In 1982 the Czarne Lake waters located within the forest area showed electrical conductivity at  $4.4 \text{ mS} \cdot \text{m}^{-1}$  (Kostrzewski, Zwoliński 1986), i.e. by half lower than the Radomyskie Lake waters within its agricultural catchment in the corresponding period.

The Czarne Lake waters currently exhibit their electrical conductivity 1.7 times lower than in the 80s of the 20<sup>th</sup> century. The physicochemical properties of the Czarne Lake waters under monitoring since 1995 shows that a drop in conductivity of the lake waters occurred regularly and was associated mainly with reduced concentration of sulphate ions (Fig. 7).

The chemistry of the Radomyskie and Czarne lakes has currently been shaped – to the largest extent – by the wet supply of atmospheric ionic components. Low electrical conductivity of their waters, low pH values and concentration of ionic components being close to the one of rainwater provide evidence on the domination of precipitation in their supplies (Tab. 1).

The research studies conducted at the Geoecological Station (Adam Mickiewicz University in Poznań) located in Storkowo show a regular decrease in the acidification of precipitation and a drop in the concentration of all ions in precipitation (Szpikowska 2011). The electrical conductivity of precipitation decreased from a level of  $2.7 \text{ mS} \cdot \text{m}^{-1}$  in 1995 to  $1.7 \text{ mS} \cdot \text{m}^{-1}$  in 2014. The most dynamic decrease in the concentration was observed for sulphate ions. Their content in precipitation is 4.5 times lower now than it was in 1995. The observed trends of changes in the chemistry of precipitation are the result of improved air quality connected in particular with the reduction of  $\text{SO}_4^{2-}$  emissions into the atmosphere (Ochrona Środowiska 2005, 2010, 2014; Świątczak 2002). It corresponds to the general trend observed in Europe (for example Armbruster, Feger 2004) and Asia (for example Ishikawa *et al.* 1998).

The research studies conducted (in parallel) on the chemistry of lake waters and precipitation at the upper Parsęta catchment show the coexistence of downward trends of some physicochemical parameters (Szpikowska 2012). The interdependency of the properties of the Czarne Lake waters and the quality of precipitation is proven by the following: correlation of electrical conductivity expressed by a function of best fit (polynomial 2<sup>nd</sup> degree regression coefficient  $R^2 = 0.75$ ) and correlation of sulphates concentrations (2<sup>nd</sup> degree polynomial,  $R^2 = 0.95$ ) (Fig. 8).

The impact of the current changes in physicochemical properties of precipitation onto the improved quality of surface waters is broader – it is reported all over Europe

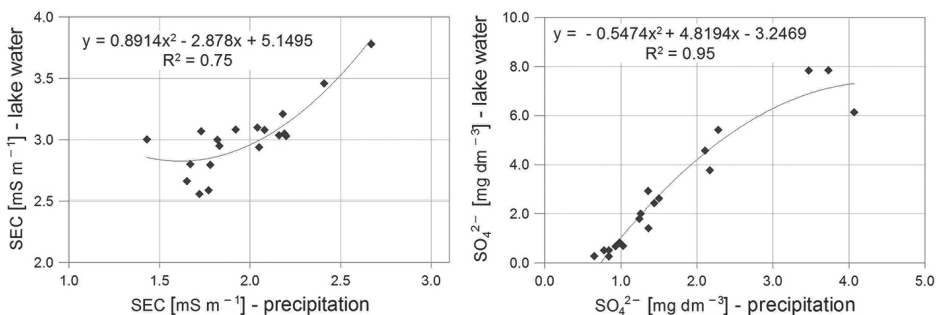


Fig. 8. Dependence of average annual values of electrical conductivity for Czarne Lake waters and precipitation and the average annual concentration of sulfate ions in Czarne Lake waters and precipitation for the hydrologic years 1995–2014

Source: authors' own study.

(Burton, Aherne 2012; de Wit, Skjelkvale 2007; Rzychoń *et al.* 2010; Rzychoń, Worsztynowicz 2005; Skjelkvale *et al.* 2005; Stuchlik *et al.* 2006; Veselý *et al.* 2002).

## Conclusions

Precipitation is the main source of supply of small, non-run-off water reservoirs within the upper Parsęta catchment located within local watershed zones. Changes in the quality of precipitation taking place in early 90s of the 20<sup>th</sup> century are reflected in the composition of the lake waters, for example in a drop in electric conductivity and reduced concentrations of sulphate ions.

The Radomyskie Lake makes an example of radical metamorphoses in land use within the catchment which took place along the economic transformation in Poland in early 90s of the 20<sup>th</sup> century. The exclusion of the Radomyskie Lake catchment from agriculture with the simultaneous afforestation of nearby lands changed the operation of the lake geocosystem. The chemical composition of the lake waters in the 80s of the 20<sup>th</sup> century was affected by the anthropogenic cultivation-driven supply of components coming from the catchment. After 30 years the physicochemical properties of the lake waters are similar to the chemistry of the Czarne Lake – the natural water reservoir the forest catchment of which has not been subject to any changes in use within the analogous period. The physicochemical properties of the Czarne Lake waters were modified by one agent – as a result of the changing chemistry of precipitation. In case of the Radomyskie Lake it can be said that it underwent its re-naturalisation manifested in its self-purification which

has took place within the past thirty years and was initiated by the afforestation of agricultural lands within the catchment. Precipitation was the second agent which shaped the chemistry of its waters. The present chemical composition of the Radomyskie Lake waters (just like the Czarne Lake waters) is largely shaped by wet atmospheric supplies.

The mentioned afforestation of the Radomyskie Lake catchment increased the supply of organic matter: leaves, needles, branches into the reservoir by several times. This is particularly perceptible within the lake banks where the supply and decomposition of organic matter take place.

Some measurements on flushing and observations of morphological effects of water erosion within the Radomyskie Lake catchment were conducted in 1983–1984. It was repeatedly found that heavy rainfall led to the emergence of rill erosion forms and run-off covers which in the south part of the lake reached the lake banks. The afforestation of the catchment radically reduced the process of water erosion and supply of mineral matter from the slopes to the lake.

The development of peat layers and expansion of above-surface aquatic vegetation is typical to such shallow overgrowing water reservoirs like the one. All the changes taking place with the last 30 years have led to the re-naturalisation of the Radomyskie Lake and its evolution towards a peat-bog geoeecosystem.

Small water reservoirs and their catchments represent good geo-indicators of the environmental changes in the early-glacial landscape. The ongoing changes should be monitored on a regular basis.

### Acknowledgements

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