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Land cover changes in catchment areas of lakes situated in headwaters of the Tyśmienica River

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Abstract

The paper presents the history of land cover changes in the catchment area of lakes situated in the headwaters of the Tyśmienica River. The basis of the study were topographic maps in scale 1:50 000, from 1936 and 2014. We analyzed the quantitative aspect of these changes. The study was conducted in three natural lakes (Rogóźno, Krasne, Łukcze), and in one lake transformed into a storage reservoir (Krzczeń). The technical issues of georeferencing maps in the Geographic Information System (GIS) software are addressed first. In the landscape of Łęczna and Włodawa Lake District, to the end of the 19th century wetlands and bushes dominated. The first type of human pressure on this area was agriculture. Another type of pressure was recreation. In the catchment areas of studied lakes increased mainly the area of buildings and forests. Significantly increased also the length of roads and watercourses. Almost completely disappeared bushes and wastelands. In most of the analyzed basins, the area of wetlands and arable lands decreased. The probable cause of the changes in catchment use was decline in the water table, and thus overgrowing of meadows and wetlands.

Key words: *lake basin, land use, topographic maps, Tyśmienica River*

INTRODUCTION

Issues related to water management have been undertaken already in ancient Mesopotamia. More than 4 000 years ago in Egypt the navigable canal was dug. It went round the famous rapids of the Nile River. The inception of the first ditches dates back to 3 200 years BC [KAJAK 2001]. The Code of Hammurabi, who ruled Babylon nearly 4 000 years ago, included management rules of irrigation channels. In the Chinese province – Seczuan, about 250 years BC the channel network, about 1 000 km length was established. It stopped spring flood waters of the Min River and distributed them to the area of 200 000 ha [CHMIELEWSKI, RADWAN 1993]. One of the seven wonders of the world, are the gardens of Babylon (7th century BC), which are irrigated by system of water channels.

The questions of hydraulic engineering and water management were carried out in ancient times, however, the genesis of contemporary sense and technical implementation of water management is relatively young. The concept of water management appeared for the first time in the early 20th century. The water shortages, in the countries of the temperate climate zone with the rapid progress of industrialization and population growth, started to be felt. The existing sources of water, have proved inadequate or poor quality, and the legal regulations have limited coverage [KOWALIK *et al.* 2014; SMOROŃ *et al.* 2009].

In order to eliminate the effects of drought and floods, as well as the economic activity of the region, in the Lublin Polesie area was built one of the longest

water canals in Poland. The Canal Wieprz–Krzna (KWK) drainage system with a length of 142 km was built between 1954 and 1961. It begins near the village Borowica, where load water from the Wieprz River, while it flows into the Krzna River, in the vicinity of Miedzyrzec Podlaski. The initial width of the channel is 7 m and 14 m at the mouth. The Canal affects the area of 527.6 thousand hectares, and includes 60 lakes [PICHLA, JAKIMIUK 2014; RADWAN, KORNIJÓW 1994].

The aim of the study was to assess changes in land use in the catchment area of lakes, located in the headwater section of the Tyśmienica River, as well as hydrological relations, before and after construction of the drainage system in this area.

STUDY AREA

The Łęczna–Włodawa Lake District is classified as macroregion of Lublin Polesie [KONDRACKI 2002]. The Lake District with an area of 1160 km^2 is typical tourist region [MAŚLANKO, SENDER 2012]. The difference in altitude is very small and amount to 50 m. The region is characterized by the presence of dozens of shallow lakes, created as a result of the last glaciation. Still in the 50s, there were 68 natural lakes in this area [WILGAT 1954]. Currently, as a result of mainly the anthropogenic changes, remained 61 lakes [CHMIELEWSKI (ed.) 2009].

In the middle of 19th century, the Tyśmienica River had its beginning in the lake Krzczeń. The major reclamation works were performed at the turn of the century. As a result of hydrotechnical works, the length of the river increased from 68 km to 74.5 km, and its spring was moved to the Lake Rogóźno with spring-area ditches reaching the Niedźwieckie marshes [CZARNECKA (ed.) 2005; GRZYWNA, MAZUR 2014].

In the 70s of the 20th century, most of the lakes was incorporated into the drainage system KWK. Some of the reservoirs are used to fisheries management [HARASIUMIUK *et al.* (ed.) 1998]. The Łęczna and Włodawa Lake District is covered by several forms of protection, such as: Unesco Biosphere Reserve, the Poleski National Park, Natura 2000 "Jeziora Uściwierskie" [KRUKOWSKA 2007].

All studied reservoirs are located in the basin of the upper Tyśmienica. For research we selected three natural lakes (Łukcze, Rogóźno, Krasne) and one converted into a retention reservoir (Krzczeń).

Lake Łukcze (51°23'49"N; 22°57'58"E) is the smallest and the shallowest among the studied lakes, its area is 56.5 ha and the maximum depth 9 m. The length of the shoreline is 3.9 km and the capacity of the reservoir is 2 091 m^3. Lake Rogóźno (51°22'36"N; 22°58'21"E) covers an area of 57.1 ha and is relatively deep – 25.4 m. The length of the shoreline is 3.3 km and its capacity is 4 209 m^3. Lake Krasne (51°25'35"N; 22°57'31"E) is the deepest (33 m) and the largest (75.9 ha) among the studied lakes. The length of the shoreline is about 3.6 km, while the capacity approach 8 180 m^3 [HARASIMIUK *et al.* (ed.) 1998]. Originally natural lake Krzczeń was transformed into a storage reservoir in the 60s of the 20th century. Krzczeń reservoir (51°23'59.64"N; 22°56'5.03"E), before the KWK construction was a lake with an area only 20 ha and a maximum depth 5.2 m. Currently it occupies an area of 160 ha. The length of the shoreline of the reservoir is about 6.7 km and capacity is 3 300 m^3.

STUDY METHODS

Cartographic analysis were carried out using the following maps: a topographic map and a map of land use Corine Land Cover 2012, as well as Tactical map of Military Geographical Institute (WIG) 1:100 000 (sheet P43 S36 Łęczna, published in 1938), system 1965 in Polish 1: 50 000 map (sheet 136.2 Puchaczów, with situation dated to a 1967 in analyzed the area and the visualization of vector VMap Level2 2014 accessed via Polish Geoportal 1: 50,000.

The maps were georectified using ArcMap (version 10.2) of ArcGIS software package. Due to the problematic projection and reference systems of these maps, they were registered using mainly topographic features, not the topographic graticule. The geo-referencing process produced a reliable material. Areal and linear forms of land use were determined on maps. Distinguished among the areal forms were: building areas, arable lands, grasslands, wetlands, woodlands, wastelands, lakes and ponds. In case linear feature, roads and watercourses were digitized.

In order to isolate a group of lakes similar to each other (with regard to height above sea level, and management of the basin), we applied a non-hierarchical cluster analysis method. We determined the relationship between different forms of land use in lake basin and location above sea level, using Spearman's rank correlation coefficient.

RESULTS

The largest catchment area, among studied lakes, surrounded Lake Krasne (865.42 ha), while the smallest one was around the Lake Łukcze (468.65 ha). The catchment area of Krzczeń reservoir covered the surface 296.80 ha (Tab. 1).

Forests and farmlands dominated in the use of the Lake Rogóźno basin both 1936 and 2014 occupying about 35%. Unlike to other studied catchments, in the past did not occur here concrete areas of wastelands (Tab. 1). The biggest differences in the catchment concerned the reduction of the arable lands and their allocation under afforestation (Tab. 2, Fig. 1). As a result, a fivefold increase in the length of watercourses in 2014, area of wetlands decreased about 50%. The layout and length of roads did not undergo a large changes (Tab. 3 and 4).

In 1936, the catchment area of Lake Łukcze was dominated by arable lands. Under the touristic pres-

Table 1. Management of catchment area of studied lakes (ha) in 1936 and 2014

Land cover	Lake Rogóźno		Lake Łukcze		Lake Krasne		Lake Krzczeń	
	1936	2014	1936	2014	1936	2014	1936	2014
Wetlands	57.06	28.61	17.09	15.15	44.77	37.33	87.22	53.86
Buldings	80.64	88.72	41.49	122.00	37.66	54.68	3.53	22.93
Forests	193.56	266.92	0	81.50	0	65.31	0	0
Arable lands	334.12	273.35	255.70	137.13	483.27	423.00	48.56	0
Water lands	55.36	53.35	60.37	58.97	153.74	160.19	19.00	161.70
Grasslands	51.36	61.15	0	53.90	51.59	124.91	70.38	48.30
Wastelands	0	0	94.00	0	94.39	0	68.11	10.01
Total	772.10	772.10	468.65	468.65	865.42	865.42	296.80	296.80

Source: own study.

Table 2. Changes in management of catchment area of studied lakes

Land cover	Lake Rogóźno		Lake Łukcze		Lake Krasne		Lake Krzczeń	
	ha	%	ha	%	ha	%	ha	%
Wetlands	–28.45	–49.86	–1.86	–10.68	–7.44	–16.61	–33.36	–38.25
Buldings	8.08	10.02	80.51	194.05	17.02	45.18	19.40	549.58
Forests	73.36	37.90	81.50	N	65.31	N	–	–
Arable lands	–60.77	–18.19	–118.57	–46.37	–60.27	–12.47	–48.56	Z
Water lands	–2.01	–3.63	–1.40	–2.32	6.45	4.20	142.70	751.05
Grasslands	9.79	19.06	53.90	N	73.32	142.13	–22.08	–31.37
Wastelands	–	–	–94,00	Z	–94.39	Z	–58.10	–85.30

Explanations: N = new form, Z = disappearance of the old form of use. Source: own study.

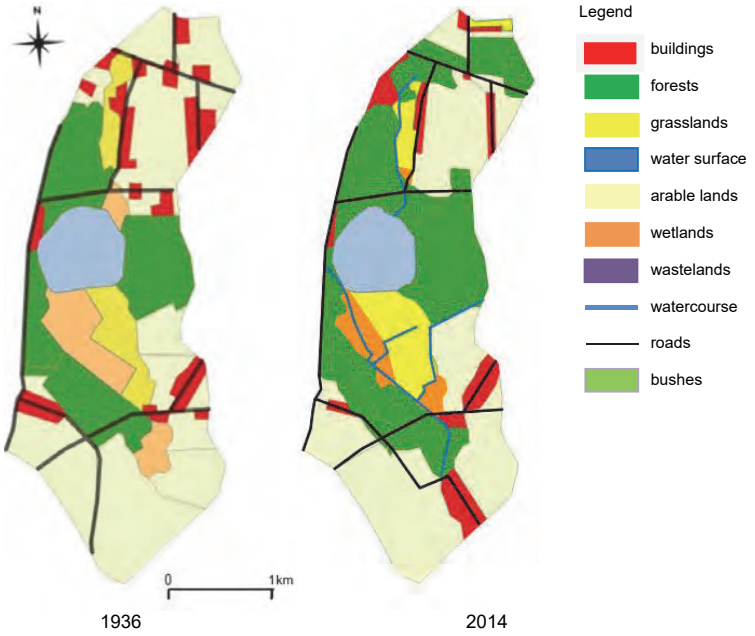

Fig. 1. Management in catchment area of Lake Rogóźno in 1936 and 2014; source: own study

sure (from 70s of the 20th century), the surface of arable lands decreased nearly 50% and the surface of buildings increased triply (Tab. 1 and 2). Numerous recreational buildings appeared mainly in the eastern and southern side of the lake. Completely disappeared bushes (Fig. 2), and in their place appeared forest lands and grasslands, that were not observed here before. In the catchment area of the lake Łukcze 3.5 km of ditches were built. It caused the disappearance of wetlands in the northern part of the catchment area, and the appearance of them in the center part. As compared to 1936, the length of roads has also increased by 1.3 km, mainly in the area of buildings (Tab. 3 and 4).

Table 3. Linear forms in the catchment area of studied lakes (km) in 1936 and 2014

Lake feature	Rogóźno		Łukcze		Krasne		Krzczeń	
	1936	2014	1936	2014	1936	2014	1936	2014
Roads	12.70	12.90	8.70	10.00	7.70	10.70	4.80	5.10
Watercourse	1.40	6.10	0	3.50	4.60	7.63	2.13	5.66

Source: own study.

Table 4. Changes of linear forms in the catchment area of studied lakes (km) in 1936 and 2014

Lake feature	Rogóźno		Łukcze		Krasne		Krzczeń	
	km	%	km	%	km	%	km	%
Roads	0.20	1.57	1.30	14.94	3.00	38.96	0.30	6.25
Watercourse	4.70	335.71	3.50	N	3.03	65.87	3.53	165.73

Explanations: N = new form. Source: own study.

In the catchment area of the lake Krasne, both in the 30's and currently, dominated farmlands. However, during the 78 years the area of arable lands decreased about 60 ha, while appeared coppices and bushes (Tab. 1). The wastelands have been replaced by grasslands, and their surface increased 2.5 times. Significantly increased also the area of the buildings, about 45% (Tab. 2, Fig. 3). In 2014, even 20% of catchment area of the lake was covered with water bodies (lake and ponds). The length of ditches and roads increased by 3 km compared to 1936 (Tab. 3 and 4).

In 1936, the management of catchment area of Krzczeń reservoir was dominated by swamps and wastelands, which together covered 55% of the area. As a result of land flooding, the surface of water reservoir increased to 142 ha (8 times). Currently, the reservoir covers 56% of the catchment area. Completely disappeared fields, and in their place appeared grasslands (Fig. 4). During the 78 years the surface of wetlands and wastelands decreased significantly. In contrast, on the western shore of the lake the surface of buildings increased (Tab. 1 and 2). Despite the watercourse flowing through the reservoir was eliminated, the length of the ditches increased by more than 3.5 km (Tab. 3 and 4).

The nonhierarchical method (clustering of 3 – medium) was used. It allows on indication of variables, which play an important role in the division of aggregation. The most important turned out to be: the height of land above 165 m a.s.l., the area of wetlands, forests and arable lands ($p < 0.05$). Very strong and positive correlation occurred between the surface of arable lands and the area at an altitude of 170–173 m above the sea level ($r = 0.8697$). Because the Shapiro–Wilk test rejected the normality of some studied features, the non-parametric Wilcoxon test was used. We investigated whether the average area of individual forms of land use has changed since 1936. Significant changes have taken place in the case of forests, grasslands and arable lands. In other cases, there were no statistically significant differences (Tab. 5).

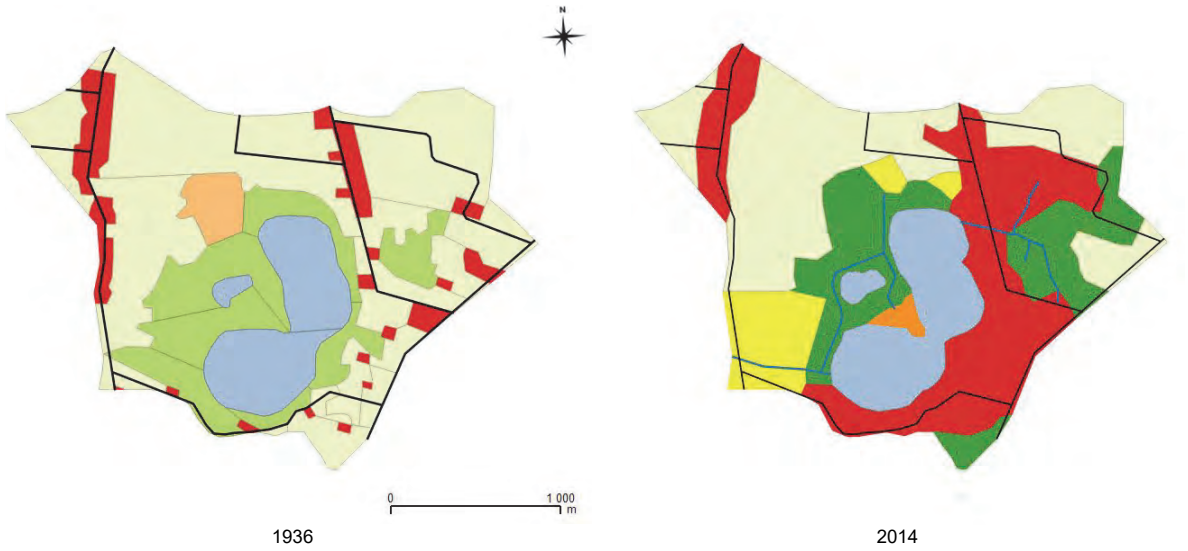

Fig. 2. Management in catchment area of Lake Łukcze in 1936 and 2014 (legend at fig. 1); source: own study

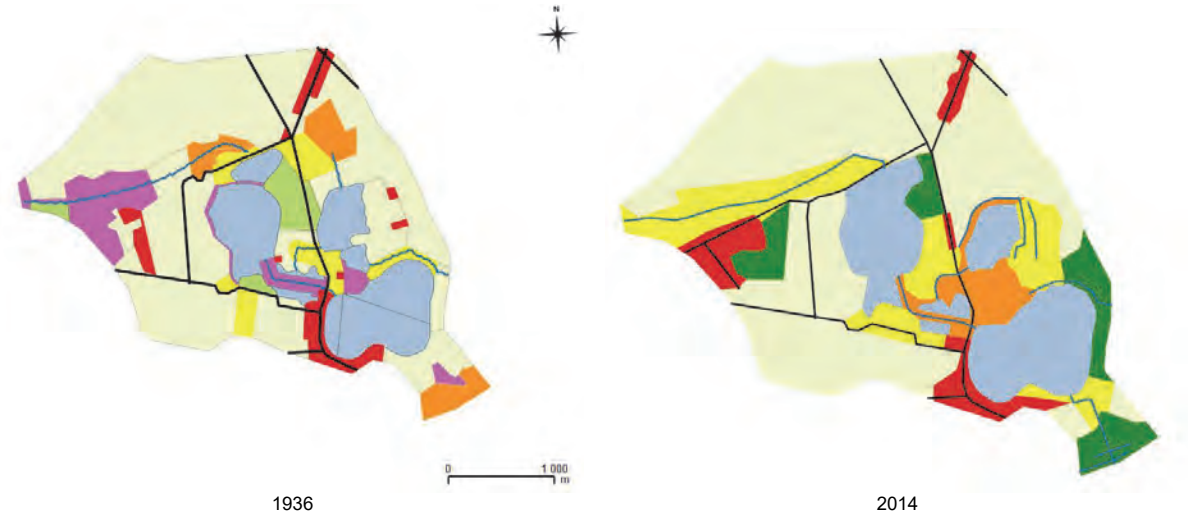

Fig. 3. Management in catchment area of Lake Krasne in 1936 and 2014; legend at Fig. 1; source: own study

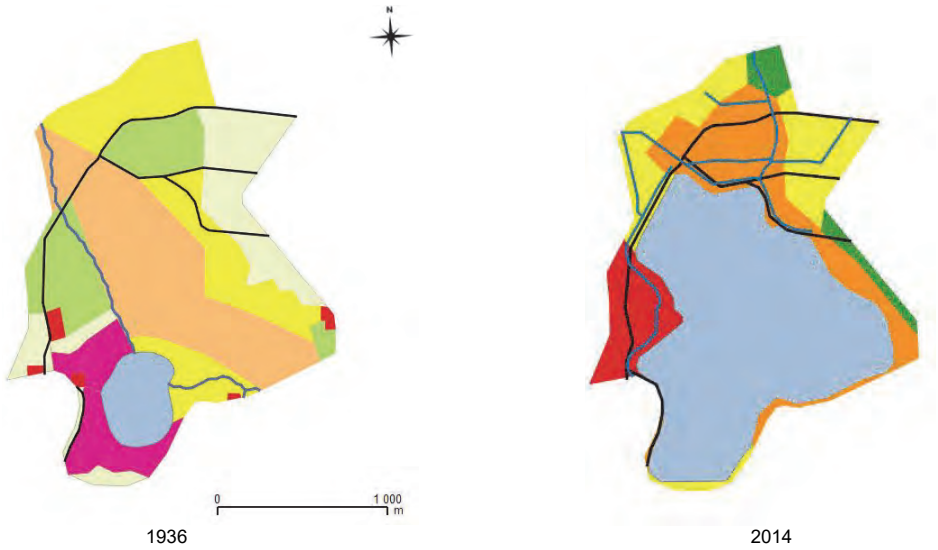

Fig. 4. Management in catchment area of Krzczeń reservoir in 1936 and 2014; legend at Fig. 1; source: own study

Table 5. Variance analysis (*df* = 3)

Variable	*F*	*p*
Buldings	0.32220	0.746867
Wetlands	13.54505	0.031481
Grassland	22.79918	0.015337*
Forest	16.49532	0.024066*
Water	1.65939	0.327140
Arable land	29.06613	0.010871*
Wasteland	10.21368	0.045824

Explanation: * statistical significant. Source: own study.

DISCUSSION

By the end of the 19th century wetlands and bushes dominated in the landscape of Łęczna-Włodawa Lake District. A significant growth of population after the First and the Second World War led to an increase in demand for food. At that time there was strong pressure from agriculture. It indicated the necessity an increase in the agricultural area. Adaptation of the wetlands has been associated with construction of drain network and irrigation canals. Across the area of Łęczna–Włodawa Lake District, one of the longest in Poland, irrigation canal was constructed. An appropriate amount of water would provide a network of reservoirs: 6 dammed lakes and 5 newly created storage reservoirs [SOLIS 2012].

The construction of Wieprz–Krzna drainage system contributed to the negative changes in water conditions, causing a decrease in water level in lakes and in soil [RADWAN, KORNIJÓW 1994], as well as increased the rate of outflow, reduction of natural retention, as well as channeling of external, highly eutrophic waters [CHMIELEWSKI, RADWAN 1993]. Since 2005, as a result of decapitalization of equipment, irrigation of grassland, gradually discontinued. In the 21st century, the demand for Polish food has decreased, it contributed to extensive agricultural use of the studied area. This situation leads to the running wild the landscape of this area [CHMIELEWSKI (ed.) 2009].

Another type of pressure on the landscape, in this area, was the turism development. In the 70s of the 20th century, by the lakes, started to appear many resorts. Around the public resorts, began to build private recreational cottages. Currently, the shorelines of many lakes are available (high-density housing). Natural shores was transformed into beaches, and fishing was developed [MICHALCZYK, WILGAT 1998].

The construction of Wieprz-Krzna drainage system caused an increase in the length of watercourses and ditches almost triply in this area. This is also confirmed by very large changes in the hydrographic network in the catchment area of Uściwierskie lakes. The size of water reservoirs has also slightly changed [GRZYWNA, NIEŚCIORUK 2016]. Some of them have completely changed the shape of the shoreline. The consequence was the reduction in water surface of lakes.

Generally lakes in Poland show the tendency to decrease both in area and number [CHOIŃSKI 2006]. Lake basin are subjected to constant evolution. Causes of changes are both natural and human activity. Among natural factors the most important role play: water level fluctuation, climate changes, depth of lake basin, hydrographic network etc. The most important anthropogenic factors are: hydrotechnical works, deforestration, agriculture [CHOIŃSKI *et al.* 2011; KANIECKI 1997].

The changes that occurred during the 78 years in the catchment area use were very clear. The largest changes related to urbanization, occurred in the catchment area of the lake Łukcze. Recreational buildings, mainly on the eastern shore of the lake, occupy 26% of the catchment area. In contrast, a positive phenomenon is the appearance of forest and grasslands in place of bushes. Urban pressure, only in the case of Lake Rogóźno is not noticeable. This is due to the fact, that the lake is still surrounded by woods and wetlands.

In catchments of most studied lakes increased the surface of buildings and forests. Similarly, increased

the length of roads and watercourses. This was related to the settling of new areas and the construction of a network of drainage canals. Almost completely disappeared bushes and wastelands. Decreased the area of wetlands and arable lands. The observed changes in use are not indifferent to the lakes. A positive seems to increase wooded areas [SKONIECZEK *et al.* 2013]. While alarming, intensive development of infrastructure on the shores of lakes, affecting their degradation [KORNAŚ, GRZEŚKOWIAK 2011], as well as the disappearance of wetlands. The wetlands retreating was associated with a lowering of the water level, which resulted in mineralization of peat. This caused in an increase of lake trophy, overgrowing and degradation eventually [KORNIJÓW 1997; KRUK 2000]. Apart from the lake Rogóźno, which was mesotrophic, studied lakes were strongly eutrophic. While, at the end of 50s, most of them was in a group of low eutrophic lakes [WOJCIECHOWSKA, SOLIS 2009]. The studied lakes have fewer possibilities to self-cleaning because, in large part, they are shallow lakes.

We can counteract the negative effects of KWK drainage system of agricultural land by [PICHLA, JAKIMIUK 2014; WZMiUW 2008]:

- exclusion from this system some peat bogs and aquatic ecosystems,
- utilization of own water resources for intensive irrigation of peat bog ecosystems, especially in times of meteorological drought,
- water supplied from the Wieprz River for intensive irrigation the meliorated farmlands, in order to inhibit mineralization of organic soils and nitrogen and iron runoff from the surface zone to aquifers,
- restoring of degraded grasslands for production of energy crops in order to preserve the diversity of habitats.

CONCLUSIONS

1. The water surface in the lakes has decreased slightly (decrease the water table, the cover with rushes).

2. The water surface in the Krzczeń reservoir increased threefold (construction of embankments around the reservoir, the water supply from KWK).

3. The length of watercourses in the study area increased (construction of drainage ditches).

4. In the catchment areas of studied lakes decreased surface area both wetlands and arable lands. While increased the area of forests and buildings.

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Zmiany użytkowania terenu w zlewniach jezior położonych w górnym biegu rzeki Tyśmienicy

STRESZCZENIE

Na podstawie map topograficznych w skali 1: 50 000 z 1936 i 2014 roku zaprezentowano zmiany w zagospodarowaniu terenu w zlewniach jezior. Do badań wybrano trzy naturalne jeziora (Rogóźno, Krasne, Łukcze) i jedno jezioro przekształcone w zbiornik retencyjny (Krzczeń). Do analiz wykorzystano program ArcGIS. W krajobrazie Pojezierza Łęczyńsko-Włodawskiego do końca XIX wieku dominowały mokradła i zakrzaczenia. Pierwszym rodzajem presji był rozwój rolnictwa. Kolejnym rodzajem presji krajobrazowej był rozwój rekreacji. W zlewniach badanych jezior zwiększyła się powierzchnia zabudowań i lasów. Zwiększyła się także długość dróg i cieków. Niemal całkowicie zanikły zakrzaczenia i nieużytki. Zmniejszyła się także powierzchnia mokradeł i gruntów ornych. Prawdopodobną przyczyną było obniżenie się lustra wody, a co za tym idzie – zarastanie użytkowanych ekstensywnie łąk i terenów podmokłych.

Słowa kluczowe: *mapa topograficzna, rzeka Tyśmienica, użytkowanie terenu, zlewnia jeziora*