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HYDRO-METEOROLOGICAL CONDITIONS IN THE CATCHMENT OF THE ŁEBSKO LAKE

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Abstract

The main aim of the paper is to present general information about hydro-meteorological conditions in the catchment of the Łebsko Lake. In the first part of the article a short description of the most important hydrographic elements of the investigated area (the Łebsko Lake, the Łeba River and its tributaries) was provided. The climatic analysis of local conditions, besides the characteristics of the air temperature and precipitation, contains the distribution of other principal meteorological elements (pressure, wind, cloud cover or relative humidity). The paper is a part of broader studies aimed at finding the key factors determining seasonal and annual changes of water relations in the catchment of the Łebsko Lake.

Key words: Łebsko, Polish sea-coast, climate, hydrological conditions

INTRODUCTION

It is clear that water and climate are, and always have been, intricately linked. Changes in climate are likely to bring changes to the hydrological cycle – the most important feedback cycle in the Earth's climate system. Water in its various forms has always worked as a great amplifier of changes, such as variations in insolation or tectonic changes, that are imposed on the climate system. Climate has a major impact on the environment and it is often responsible for variations in soil, plants, water amount or drainage system. It is a decisive factor in determining the type of drainage system as well (e.g. in humid climates drainage is mostly required to evacuate rainfall, whereas, in arid zones, drainage is needed mainly to remove excess irrigation water).

Presentation of the most general relations between hydrological conditions in the catchment of the Łebsko Lake and its climatological considerations is the main aim of the article.

MATERIALS AND METHODS

The research area (Fig. 1) covered the body of the Łebsko Lake (coastal reservoir), watercourses draining into the lake, the Łeba River and its tributaries. Hydrological data for the research have been taken from numerous IMGW (Institute of Meteorology and Water Management) publications, the Plan of Environment Protection of Slovinski National Park (Choiński and Kaniecki 2004) and our own investigations. The section of the local climate presents statistics on main meteorological elements such as temperature, relative air humidity, cloudiness, precipitation, wind velocity

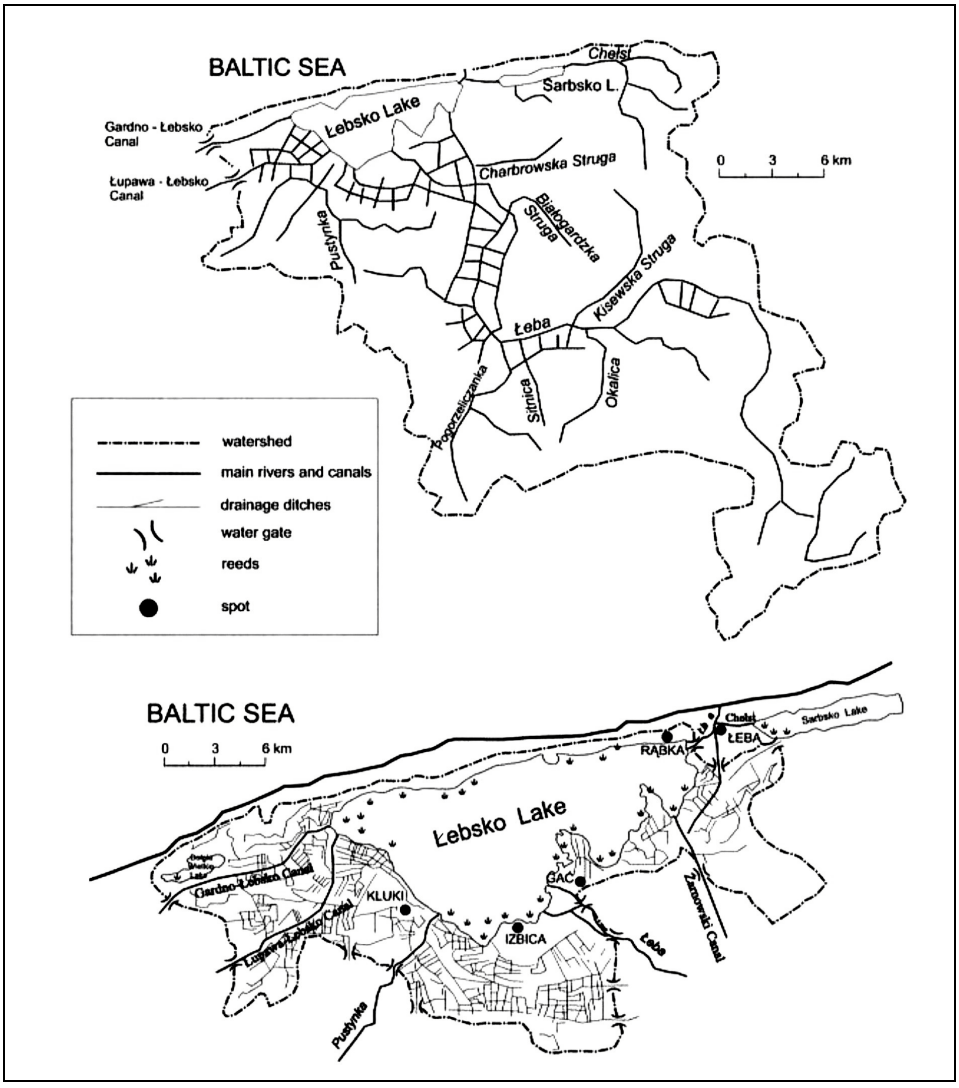

Fig. 1. Location of the investigated area (the catchment of the Łebsko Lake)

etc. Meteorological data from 1986-2005 are obtained from IMGW weather station in Łeba. Daily means have been calculated as the average of all observations during the day. Monthly and annual characteristics were derived from daily and monthly means respectively. Arithmetic average was used for the calculation.
In the paper "clear day" was defined as a day with the average cloud cover 30% or less. The cloud cover is expressed by the proportion of cloudy space in the sky, with 10 as the total.
"Cloudy day" is a day with sky cover 80% or more. "Rainy day" is a day with 1 millimetre or more of precipitation, and "snowy day" is a day with any snowfall (excluding snow hail, ice hail, sleet and hailstones). "Hot day" was defined as a day with maximum temperature 25°C or more; "freeze day" – with minimum temperatures < 0°C.

GEOLOGICAL CHARACTERISTICS OF THE INVESTIGATED AREA

This area is situated within the limits of the youngest, Vistulian Glaciation. The thickness of Quaternary deposits exceeds the maximum of 264 m (Rotnicki 1995). In this area located within so-called Łeba Barrier, tertiary deposits form the substratum of the Pleistocene sediments and are overlain with two beds of glacial till, the latter being associated with fluvioglacial and ice-dammed lake deposits. The beds are separated from each other by a thick (about 50 m) series of fluvial deposits which are thought to be connected with the Lublin Interglacial. The last deposits represent the Vistulian Glaciation as indicated by radiocarbon dating, and include sediments and landforms of the Leszno Phase, Poznań Phase, Pomeranian Phase, Gardno Phase and South Baltic Phase. The Łeba Barrier with Łeba dune field within the Slovinski National Park is an area where intensive aeolian processes took place in the Younger Holocene. In the middle part of the Łeba Barrier, spread over an area of about 5.5 km^2 almost completely devoid of any plant cover, there are shifting dunes attaining a relative height of 20-40 m, and among them are deflation hollows sometimes filled with ephemeral pond-like lakes appearing during high storm surges.

DESCRIPTION OF MAIN HYDROGRAPHIC OBJECTS

Lake Łebsko

Lake Łebsko is situated in the Slovinski National Park. It is the largest coastal lake in Poland (in relation to area – 7140 ha) with maximum depth of 6.3 m and average value of 1.6 m (Choiński and Kaniecki 2004 – Tab. 1). Since 1836 the lake has shrunk by over 490 ha. Łebsko Lake is an old sea lagoon separated from the Baltic Sea by with a 0.8-3.0 km wide sandy moraine formed by sea currents (Fig. 1). The sand-bar is covered partially by a pine forest. Due to the process of sand accumulation (which depends mostly on prevailing winds) the north shore of the lake moves

back by about 1 m per year. The lake is supplied mostly by water flowing from the Kashubian Lake District and Gardneńsko-Łebska Lowland. However, because of the connection through the estuary of the Łeba River it is also under influence of waters of marine origin (the difference of water level between the lake and the sea amounts to about 30 cm – Atlas jezior… 1997). Due to fluctuations in water level reaching over 1 m, the area of the lake may vary from 6950 ha to over 7240 ha in extremely high water stages (Choiński 1985, Chlost and Cieśliński 2005). The capacity of the lake is about 117 521 m^3 and it has the direct drainage basin area – 239.1 km^2 (Choiński and Kaniecki 2004). The water exchange coefficient (quotient of the total water inflow from the catchment to the lake capacity) is about 4.4-4.8 (Drwal and Cieśliński 2006). The biggest water affluent of the lake is the Łeba River, which can deliver yearly more than 36% of the surface inflow (Cieśliński 2008). Other small rivers such as: Pustynka and Wysoka flow into the lake as well. From the west Łebsko is connected with the Łupawa River and the Gardno Lake (channels 8.7 km and 10.2 km long – Przyroda… 1997). From the western, eastern and south-western side the lake is surrounded by marshes, swamps and peat bogs. The bottom of the lake is almost flat and covered by gyttia or sand. Only small areas of the bottom (mainly in the centre and in the north-eastern part of the lake) have hard ground (Choiński and Kaniecki 2004). The lake is being silted predominantly by sediments carried by the Łeba River, which have built a backward delta.

Table 1
Morphometric and bathymetric parameters of the Łebsko Lake

Parameter	Łebsko
Height above sea level	0.3 m
Water area	7140 ha
Total capacity	117 521 m^3
Length of a shoreline	55.4 km
Maximal length	16.4 km
Maximal width	7.6 m
Maximal depth	6.3 m
Mean depth	1.6 m
Direct catchment area	239.1 km^2
Total drainage area	1801.2 km^2
Main tributaries	rivers: Łeba, Pustynka

Source: Choiński and Kaniecki 2004

The Łeba River

The Łeba River has a total length of 125.4 km and, together wits its tributaries, drains an area of 1801.2 km^2 (Choiński and Kaniecki 2004). It flows through several

regions: the Kashubian Lakeland, Reda-Łeba Ice-marginal Valley and the Slovinskie Coast. The river has its source 165 m above sea level, near a small village – Borzestowo (about 13 km on the west from Kartuzy) and it runs down through many lakes: Długie, Dołgie, Kozie, Lubowidzkie, Łapalickie, Łebsko, Mikorowo, Osuszyno, Reskowskie, Sarbsko, Sianowskie, Strzepcz, Wielkie (RZGW Gdańsk). In Cecenowo its width on the water surface can reach 19 m, and depth 2.3 m. The Łeba River provides about 36.6% of the surface waters flowing into the lake and its mean annual flow is about 369 000 000 m³ (Cieśliński 2008). Its major tributaries are: Chełst, Białogardzka Struga, Charbrowska Struga, Dębnica, Jeżowska Struga, Kisewska Struga, Okalica, Pogorzeliczanka, Pustynka, Rzechcinka, Sitnica and Węgorza. The hydrological regime of the river (according to Parde's classification simple with oceanic features – after Dynowska 1972) depends mostly on the rainfall, melt waters, evaporation, frequency of extreme weather events (e.g. heavy rains, droughts, prevailing winds) and physiographic characteristics of the catchment area. High water stages predominantly occur in late winter (Fig. 2). Total flows of the river in Cecenowo (as an example) range from 5.3 m³/s in extremely dry period (the 9th June 1979) to 45.9 m³/s in flood (the 13th July 1980; Choiński and Kaniecki 2004). The annual inflow from the Baltic Sea through the canal of the river is about 159 000 000 m^3 (Weber 1972, Choiński i Kaniecki 2004). For the sea water inflow the water exchange coefficient can be estimated at 0.6. The Łeba River and periodic sea water inflow have the most decisive influence on the process of water stores formation and quality of bottom sediments in the Łebsko Lake.

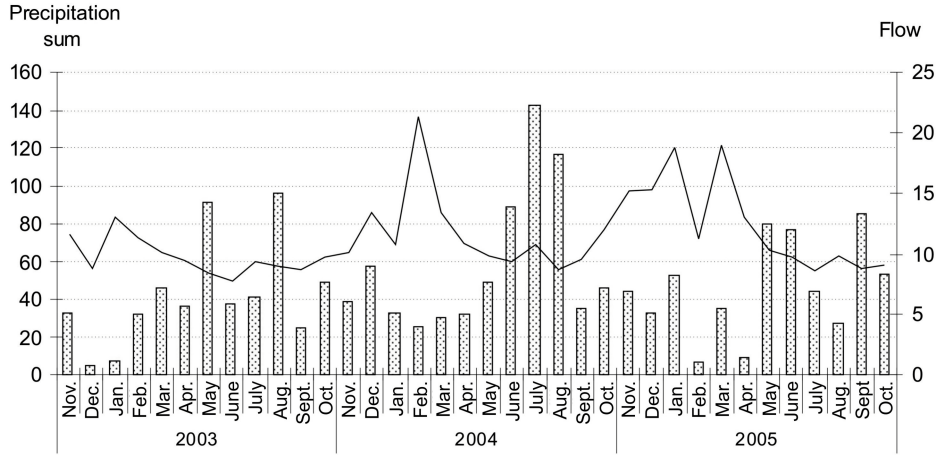

Fig. 2. Mean monthly precipitation sums (mm) and flow of the Łeba River in Cecenowo (m^3/s) in the hydrological years 2002/2003-2004/2005. (Precipitation sums – bars, flow – line)

Other tributaries of the Łebsko Lake

Ten watercourses drain into the Łebsko Lake; they flow from the Kashubian Lake District or the Gardnieńsko-Łebska Lowland (Fig. 1). Many streams and canals dis-

charge water from polders directly into the lake. The total amount of water from polders can reach 8.9 m^3 per second. Annually the surface inflow into the Łebsko Lake is estimated at 129 300 000 m^3 (Cieśliński 2008). Only one watercourse (the Łeba River) flows directly to the sea.

Local climatic conditions

Climatic conditions around the Łebsko Lake are complex with high variability. The region is located within a transition zone from maritime to continental climate. The Atlantic Ocean and the Baltic Sea are the main factors influencing the climate of the region. The active cyclonic activity prevailing in the northern part of the Atlantic Ocean (the Icelandic low) as well as prevailing zonal circulation all year round determine a great variability of weather conditions. The advection of humid maritime air from the west in active depressions usually affects high precipitation, strong winds and fluctuations in temperature. In the cold half-year this brings about a considerably warmer, while in the warmer months a somewhat cooler weather. On the contrary high pressure systems, conveying the air from the east, quite often are accompanied with hot days in a warm half-year (Apr.-Sept.) and cold days in Nov.-Mar. period (Fig. 3).

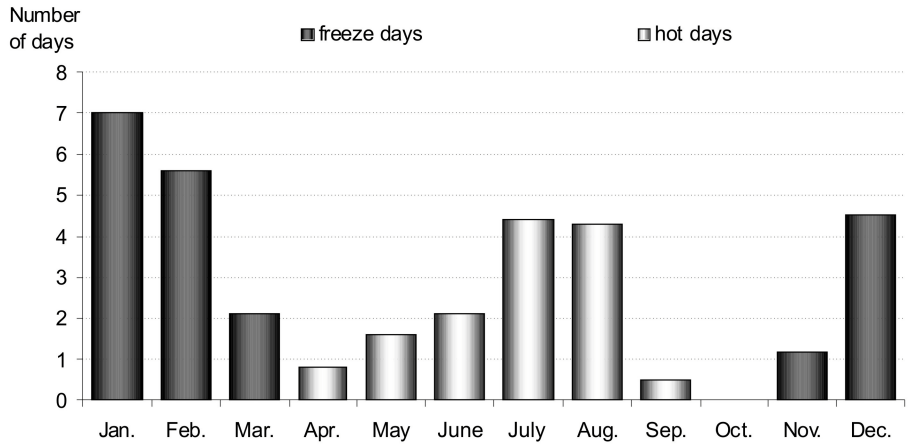

Fig. 3. Mean monthly number of freeze and hot days in Łeba for the period 1986-2005

The meridional circulation in this part of Europe is less frequent and irregular, however colder arctic air masses are always standing out with lower temperature, contrary to warmer air masses flowing from the south. The most characteristic feature of the Polish sea-coast climate (in comparison to the other parts of the country) are relatively cold spring and summer and warm autumn and mild winter (Baranowski 2008, Trapp 2007). The mild marine climate of the coast finds its reflection in a relatively smooth annual course of the temperature and its maximum and minimum values (Tab. 2).

Table 2

Mean monthly and annual characteristics of the main meteorological elements from the weather station in Łeba (1986-2005)

Meteorological element	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Sea level pressure (hPa)													
mean daily	1015.1	1014.1	1015.2	1014.0	1016.0	1014.2	1014.0	1014.3	1014.9	1015.1	1014.7	1014.3	1014.7
Wind velocity (m/s)													
mean daily	6.1	6.0	5.4	4.6	4.4	4.8	4.5	4.3	4.6	4.8	4.8	5.4	5.0
maximum	8.7	8.8	8.1	7.4	7.2	7.5	7.2	6.9	7.1	7.4	7.2	8.1	7.6
Temperature (°C)													
mean daily	0.3	0.7	2.5	6.4	11.0	14.4	17.0	16.9	13.3	9.1	4.2	1.2	8.1
maximum	2.4	3.1	5.6	10.6	15.3	18.3	20.9	20.9	17.0	12.4	6.4	3.2	11.4
minimum	-2.2	-2.0	-0.7	2.1	6.1	10.1	12.6	12.4	9.3	5.6	1.6	-1.3	4.5
Precipitation													
mean amount	38.5	38.1	42.6	34.9	43.9	46.2	65.3	61.2	85.9	75.6	59.1	49.9	641.4
mean number of days with precipitation	14.7	14.0	13.3	10.1	9.7	11.1	12.7	12.0	12.5	14.3	15.3	15.9	155.3
mean number of days with snow cover	11.0	12.1	7.2	0.6	0.1	-	-	-	-	0.3	2.2	8.5	42.0

Generally, summer in Łeba is short and cold and sunny days occur as often as rainy days (Atlas klimatu… 2005). The annual average air temperature in Łeba is about 8.1°C. Mean monthly temperatures range from about 0.3°C in January to 17°C in July. Usually summer in Łeba (with temperatures above 15°C) starts in June (25th) and is about 65-70 days long. Temperatures in this season rarely exceed 25°C. Hot days, when the maximum temperature exceeds this value, occur in this part of the Polish coast from March to September, with its maximum in July and August. Subzero temperatures in this region most often appear between December and February, with their average number throughout the year – 88 (Baranowski 2008). Exceptionally long pre-spring and pre-winter season (about 62 and 60 respectively) is one of the most characteristic features of the local climate (Kożuchowski and Miętus 1996). Spring, with temperatures varying from 5°C to 15°C, usually starts in April and lasts until about the third decade of June.

Initially warm October is the beginning of autumn season. In December, when winter begins, the temperature drops from a few degrees below zero to sometimes -10°C (0.1% of all cases). Winter is rather short and lasts about 35-40 days. The annual number of days with snow cover varies from 5 (1990) to 98 (1996). Snow remains for the longest time in February, but it usually appears at the end of November and disappears in the first half of March.

In Łeba the wind from the west and southwest prevail (38% of all cases). South and north-east directions are represented quite often, too – 16.4% and 10.1 respectively (Fig. 4) The average wind speed in Łeba (5.0 m/s) in a given period 1986-2005 for more than 1-2 m/s exceeds values observed in the central part of Polish lowlands (Atlas klimatyczny… 2005). In the annual course the highest wind speed (mean velocity over 5.3 m/s) is observed during winter month; the maximum occurs in

Fig. 4. The frequency (%) of wind directions without calms in Łeba (1986-2005)

August (4.3 m/s) and in May (4.4 m/s). From the beginning of September the average wind speed is gradually rising to achieve the highest value in January (6.1).
The location of the Łebsko Lake in a short distance from the sea coast and its direct exposition to the flow of humid air masses from the Atlantic Ocean results in relatively high cloudiness (Fig. 5), humidity and precipitation (Tab. 2).
Łeba is one of the cloudiest places in Poland with its mean annual cloudiness 6.3 in 0-10 scale (Baranowski 2008). Usually skies are clearest in late spring and early summer, and clouds amount tend to reach its maximum in December. Cloudy days most often occur from late fall to early spring (Fig. 5). During summer months, the number of cloudy days is smaller and ranges from 6.9 in June to 11.0 in July. The number of clear days in Łeba is rather small, on average 37.5 days each year and they are observed less frequently in late autumn and in winter months.

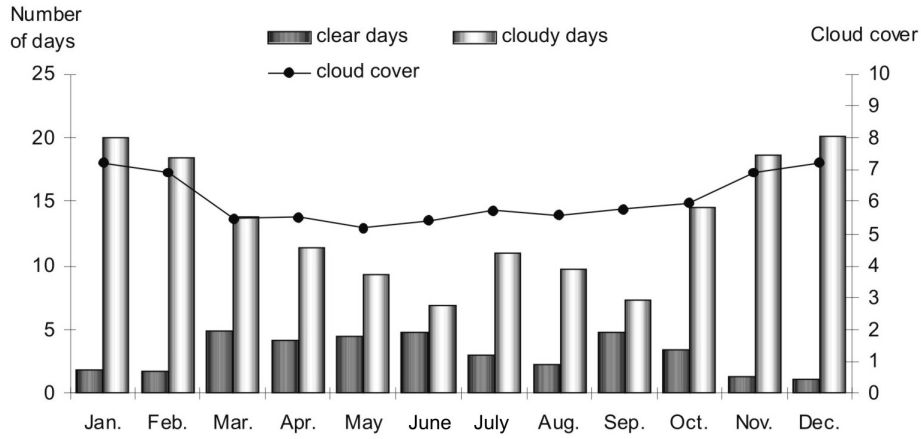

Fig. 5. Mean monthly: cloud cover in 0-10 scale (line), number of clear and cloudy days (bars) in Łeba for the period of 1986-2005

CONCLUSIONS

The Łebsko Lake receives its supplies of water from the catchment area of the Łeba River and from precipitation that falls not only on the lake if self but also on its drainage basin. The lake loses water through evaporation, outflows and consumptive uses. Because of the combined effects of precipitation, sea-water inflow, runoff and evaporation which can change from season to season and from year to year, the level of the lake also vary. Its outflow changes as a function of the lake level (e.g. the lake usually rises in late winter and spring due to additional runoff and recedes in late summer and early fall as runoff decreases). Water level in the Łebsko Lake can change over periods of years for the same reasons. During seasons or years in which precipitation and runoff in the lake are high and evaporation low, water level can gradually increase. In periods of low precipitation and high evaporation, the level can gradually lower. The length of time required for noticeable changes, and the de-

gree of the changes, will depend on how wet or how dry the weather is and on ambient temperatures.

Further, more detailed research, aimed at determining the influence of deforestation, urbanization and drainage of wetlands in the basin of the Łebsko Lake in time and space, should be supplemented by verification procedure on the basis of the hydraulic parameters measurements in chosen measurement profiles. Additionally, functional relations between particular hydrological conditions on the investigated area (e.g. high and low water stages, sea water intrusions) and particular meteorological factors (e.g. prevailed strong winds from one direction, rapid changes in atmospheric pressure) will be determined.

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WARUNKI HYDROLOGICZNE I METEOROLOGICZNE ZLEWNI JEZIORA ŁEBSKO

Streszczenie

Opracowanie stanowi część projektu, którego celem jest analiza zmian stosunków wodnych w zlewni jeziora Łebsko. W artykule przedstawiono ogólną charakterystykę warunków klimatycznych i hydrograficznych zlewni jeziora Łebsko. Charakterystyka hydrologiczna obejmuje opis najważniejszych elementów sieci wodnej analizowanego obszaru: jeziora Łebsko wraz z zasilającymi je ciekami oraz rzeki Łeby jako głównego źródła zasilania jeziora. Opis warunków klimatycznych oprócz podstawowych charakterystyk termicznych i opadowych zawiera również analizę rozkładu wielu innych elementów meteorologicznych: wiatru, ciśnienia, zachmurzenia oraz wilgotności względnej. Bardziej szczegółowych pomiarów wymaga natomiast analiza bezpośrednich i pośrednich skutków hydrologicznych w czasie gwałtownych zmian wybranych elementów meteorologicznych (np. spiętrzenia wody przy silnych wiatrach z jednego kierunku). Wnikliwej analizie poddane zostały warunki pogodowe sprzyjające występowaniu skrajnie niskich i wysokich stanów wody w obrębie zlewni jeziora Łebsko.