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Impact of peat excavation on water condition in the adjacent raised bog

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Abstract

Wetlands, in which peat lands are included, as valuable ecosystems are strongly dependent of water that should be saved. On the other hand, peat is a valuable resource e.g. used in gardening.

In this paper hydrologic research for evaluation of influence of excavation sites on the water conditions in raised bog have been presented. One of the Polish peat mines is directly adjacent to the natural raised bog that is a protected nature reserve and situated in the area of Natura 2000. The first attempts of industrial peat excavation, in the area, took place in 1970 (more than 40 years ago). Research on groundwater level, peat moisture and precipitation has been carried out. It has been proved that raised bogs of meaningful environmental values situated in the vicinity of the excavation site preserve their ecological value. The study shown that it is worth to protect raised bog even in such inconvenient situation. Some recommendation to preserve the natural value of the raised bog has been given.

Key words: *biological diversity, hydrology, peat excavation site, raised bog*

INTRODUCTION

Marshy areas, practically all over the world, are regarded as one of the most valuable natural areas that should be strictly protected. This problem has been raised in a number of international agreements, including the so-called Ramsar Convention. Also the Water Framework Directive (WFD) obliges Members of the EU to protect wetlands as water related ecosystems strongly dependent on high moisture content. On the other hand, large areas of wetlands have been drained to enable the intensification of agriculture. The greatest destruction of flora and fauna occur in the peat excavation sites.

In Poland, as well as in other countries, peat is exploited not only in medical purposes but also for

gardening and as a source of organic substances for other purposes e.g. production of champignons. Raised bogs are especially valuable natural areas but the peat is also a valuable and wanted material in horticulture.

One of the Polish peat mines is directly adjacent to the natural raised bog that is a protected nature reserve and situated in the area of Natura 2000. The mine is located in a part of that raised bog. Industrial excavation of the peat has started in the west southern part of the bog over 40 years ago and is still going on while the north eastern part of the bog has been strictly protected.

The aim of the study was to analyse the impact of the drainage system of the peat mine on the groundwater table in the area of nature reserve. The analysis

of the correlation between the water level in the mine with this in the reserve allowed to give some recommendation how to protect the high value of nature of raised bog.

Research and analysis for the assessment of the impact of peat excavation and related ground water table lowering on the adjacent raised peat bog that have been carried out. Research concerned only the evaluation of the moisture conditions with no regard to any biotic transformations.

EXPERIMENTAL PROCEDURES

Plan of the investigated area has been shown on Figure 1. The peat bog covers an area of about 600 ha. The exploited area covers ca. 160 ha. Mining area is situated in the vicinity of the special area of Natura 2000 habitats as a "swamp forests and peat bogs". There is lack of any buffer zone separating the mine from a protected site (Fig. 1).

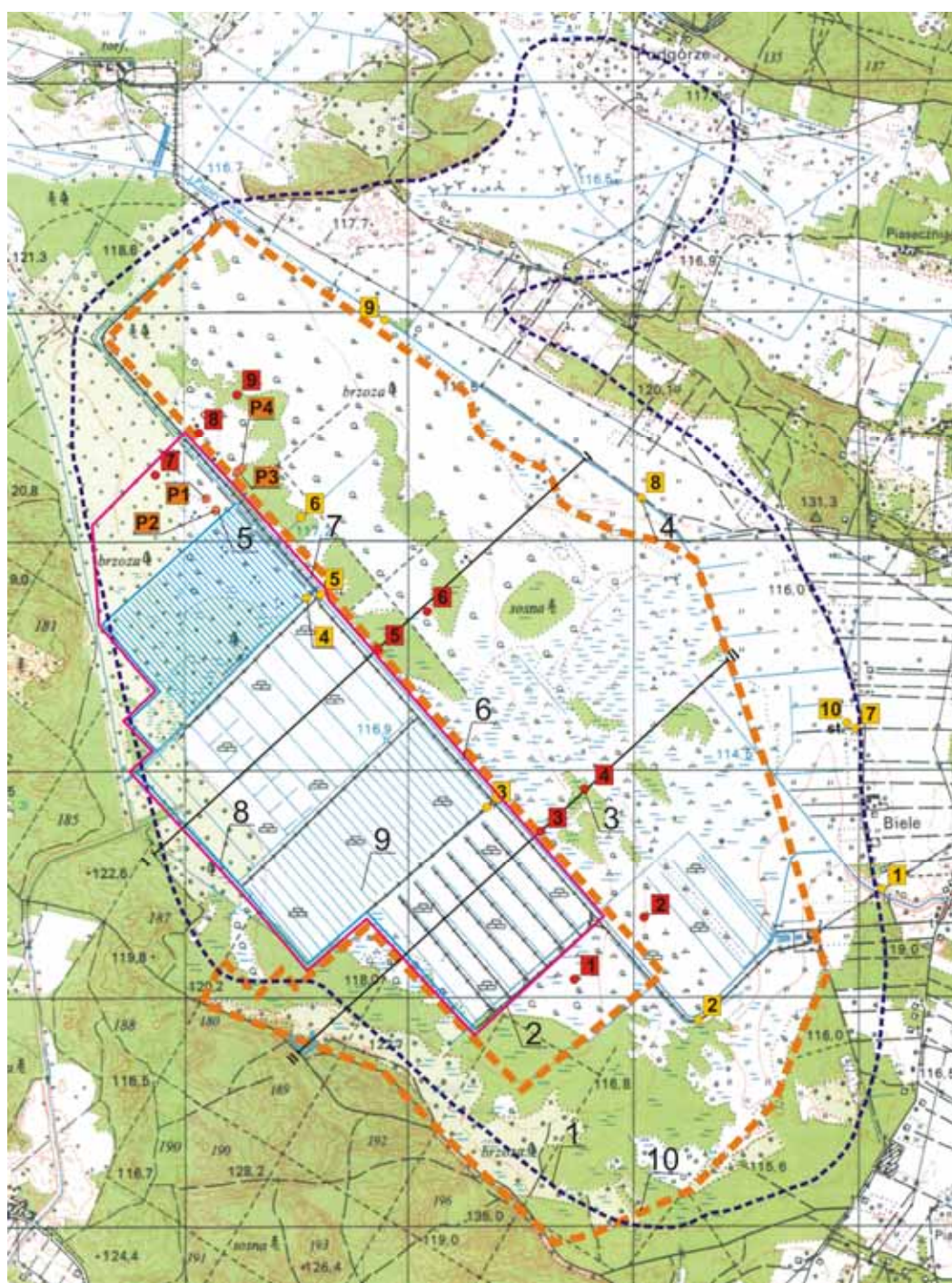


Fig. 1. Plan of the raised bog and excavation site: 1 – border of the peat deposit, 2 – border of the excavation site, 3 – points of moisture research, 4 – water quality measurement, 5 – observation wells (piezometers), 6 – main canal, 7 – side canal, 8 – collective ditches, 9 – detailed ditches, 10 – border of Natura 2000 area; source: own study

The peat bog is a dome raised above the zero boundary of the deposits of 2–3 m. Average thickness of the accumulated organic deposits range from 0.75 to 8 m. Gytia (of algae, calcareous, detritus and clay type) is situated in the bottom and has a thickness of 1.2–3.5 m. On the surface of fens and transitional peat bogs a layer of mossy – raised bog had been deposited as a result of increasing influence of precipitation on a surface of a deposit and decrease of the water table influence. The main layer of the deposit is weakly decomposed hummock sphagnum peat that form dome of the deposition.

Mineral subsoil of the bog is made of outwash sand, mainly coarse ones, of a thickness of 9–16 m. Peat underlying sands are the first water level with a free water table or being under a light pressure.

According to the Polish classification of a potential moisture of the organic soils [OKRUSZKO 1992], raised peat is within A class. This means that even after construction of drainage ditches peat still has a capability of retention of large amounts of water. Due to the characteristics of peat drainage of water to the ditches by gravity is limited. Evapotranspiration has greater impact on the dynamics of soil moisture. Changes of moisture content in peat as well as a cycle of shallow groundwater dynamics are associated with the development of plant growing. There is a significant decrease in groundwater level and reduce in moisture during the growing season. The highest level of ground water occurs in spring and lowest during the late autumn, when the plants die and stop using water in the process of transpiration.

Most probably, in the area of the peat deposit in its natural state, no water courses occurred. There is no mention of water courses in archival materials. Old topographic materials show that a small body of water, a "lake", occurred on the dome of the peat and it was drained by a small ditch. It was probably a natural water body. In the part of the protected bog slightly elongated water bodies occur. The ground water table in these water bodies is placed near the surface. These reservoirs are probably remnants of the once conducted peat hand digging. Signs of drainage ditches constructed many years ago to allow manual excavation of the peat are visible. There were not many natural water courses around the discussed raised bog site. The poor hydrographic network in the vicinity of the peat deposit has been heavily modified. A number of drainage ditches have been built. In the eastern part of the bog a ditch that presently is believed to be regulated natural one, had been constructed. It is a part of a bigger drainage system of agricultural lands used as meadows.

On the other side, that is from the west side of the original deposits of peat, along the forest path, a nameless water course with mineral bedding runs. The route of the water course and its present state indicate that it is a manmade water course constructed for drainage of forest areas and the above – lying meadows.

In the early 50's almost the entire area was covered by bog forest communities (pine and birch and pine) of different age and a forest stand. According to the phytosociological classification being in use at the time these communities were classified as: *Pineto-Vaccinietum myrtilli ledetosum* (community with the ordinary swamp) – occurring almost throughout the bog with the exception of the central parties in the south and north and the area known as "lake" and *Pineto-Vaccinietum myrtylli callunetosum* (community with the common heather) in the marginal parts of the bog. Moreover, in the central parts of southern and northern ends of the bog a raised bog has been found – community with a ordinary swamp (*Ledum palustre*), and locally also transitional mire (*Sphagnum recurvii*) has been described [OŚWIT *et al.* 1992].

During field work conducted in the early 1990s in the central part of the peat swamp, presence of forest (*Vaccinio uliginosi-Pinetum*) as well as the raised bog (*Ledo-Sphagnetum*) has been confirmed. These communities were two of the most natural plant phytocenoses, living in a state of hydrological and ecological sustainability. Both habitats were closely floristically related. In addition, raised bog despite anthropogenic pressure, retained most of its continental features typical for raised bogs [OŚWIT *et al.* 1992].

In place of the location of so-called "Lake" transition mire (*Sphagnum fallax* community-*Carex fusca*) has been observed. It is a very valuable part of the bog that had been preserved in a perfectly natural state and is in a hydroecological balance with an active peat forming process.

Detailed identification of vegetation was conducted in 2011 [WIERZBA *et al.* 2011]. Observations confirmed the presence of raised bog (*Sphagnion magellanicum*) in the central parts of the peat land that didn't underwent extraction. Smaller patches of the phytocenoses were also found around small water bodies (lakes).

Presence of the transition peat bog (*Caricion lasiocarpae*) that occupies the part of the "lake" has been also confirmed during the study. The phytocenoses observed across the bog, indicate that the potential vegetation of the site is marshy pine forests – *Vaccinio uliginosi-Pinetum*. It is characterized by low pine bonitation and frequent presence of the swamp bilberry (*Vaccinium uliginosum*) and an ordinary swamp (*Ledum palustre*), as well as and the presence of groups of species migrating from raised bogs (also hummock *Sphagnum* species) [MATUSZKIEWICZ, 2008]. Figure 2 shows the actual vegetation in the area of intact natural raised bog adjacent to the mine. Given basic data on vegetation show that intact part of the bog shows no degradation processes. A narrow strip of reed beds with *Thelypteris palustris* and *Phragmites australis* is adjacent to the mine (drainage ditch) and in the deeper part plants typical for peat bogs occur (swamp forest and mixed forest).

The first attempts of industrial peat extraction, in the area, took place 40 years ago. Peat is extracted in

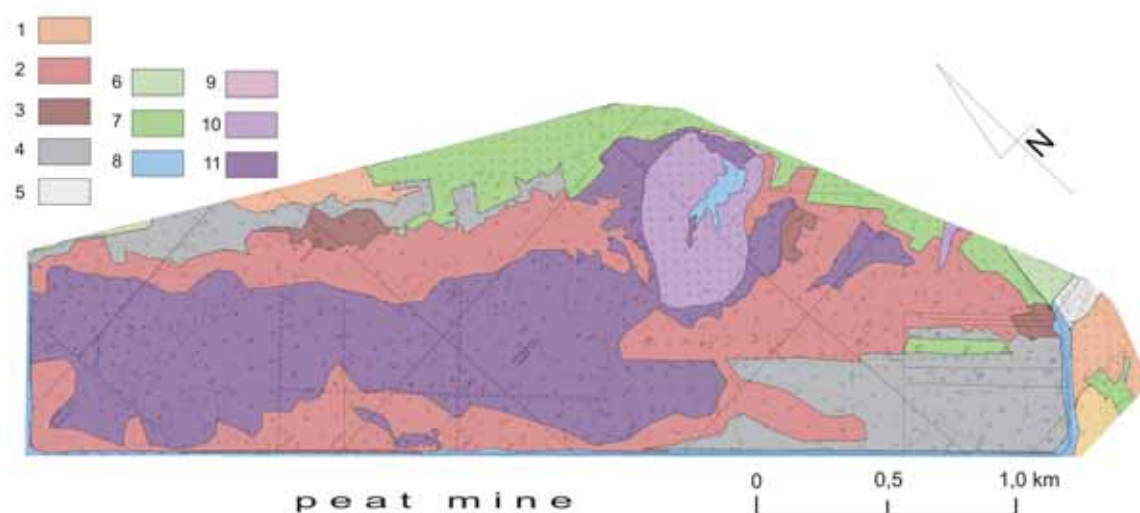


Fig. 2. Map of the plants present in the raised bog adjacent to the mine: 1 – mixed forest (*Quercus-Pinetum*), 2 – swamp high forest (*Vaccinio-Pinetum*), 3 – willow shrubs (*Salicetum pentandro-cinereae*), 4 – replacement forest communities, 5 – ruderal vegetation (*Stellarietea mediae*), 6 – fresh meadows and pastures (*Arrhenatheretalia*), 7 – moist meadows and pastures (*Molinietalia*), 8 – reed beds with marsh fern and common reed (*Thelypteridi-Phragmitetum*), 9 – acidic low sedge communities (*Caricion nigrae*), 10 – low sedge communities (*Caricion lasiocarpae*), 11 – raised bogs (*Sphagnion magellanicum*); source: own study

open-pit method, surface excavation method. Dried layers of peat (2–5 cm thick) are detached from the surface of the deposit. This work can be started at low moisture content of peat. Peat extraction technology is very dependent on proper surface preparation, in particular from strong (deep) drainage.

A network of drainage ditches in the excavation site has been presented on Figure 1. The network consists of:

- the main canal collecting water from the whole area of excavation and running it outside the mine; the main canal collects water from all minor ditches. In some places the depth of this canal can reach 4.0 m;
- side canal running on the border between the preserved area and mine; railway embankment that is used to remove the output from the mine runs between the main canal and the complementary canal;
- collective ditches were constructed perpendicularly to the main ditch; depth of each ditch is between 2 and 4 m;
- detailed ditches were constructed perpendicularly to the collective ditches; slopes of the detailed ditches are steep and the width of each ditch varies between 1.2 and 2.0 m; the network of detailed ditches is dense (every 15–25 m) and they are responsible for lowering of the ground water table in the mine; the ditches allow collecting peat with use of surface excavation method.

As it was mentioned before, the peat bog has been exploited for a long time. Human activity is visible even in the protected area. In the area of the mine one can distinguish fields:

- fields that have been exploited; these fields are still kept under drainage as the basic drainage network has been constructed as the only system draining

the whole area of the mine; therefore, there is no chance to exclude exploited fields from drainage;

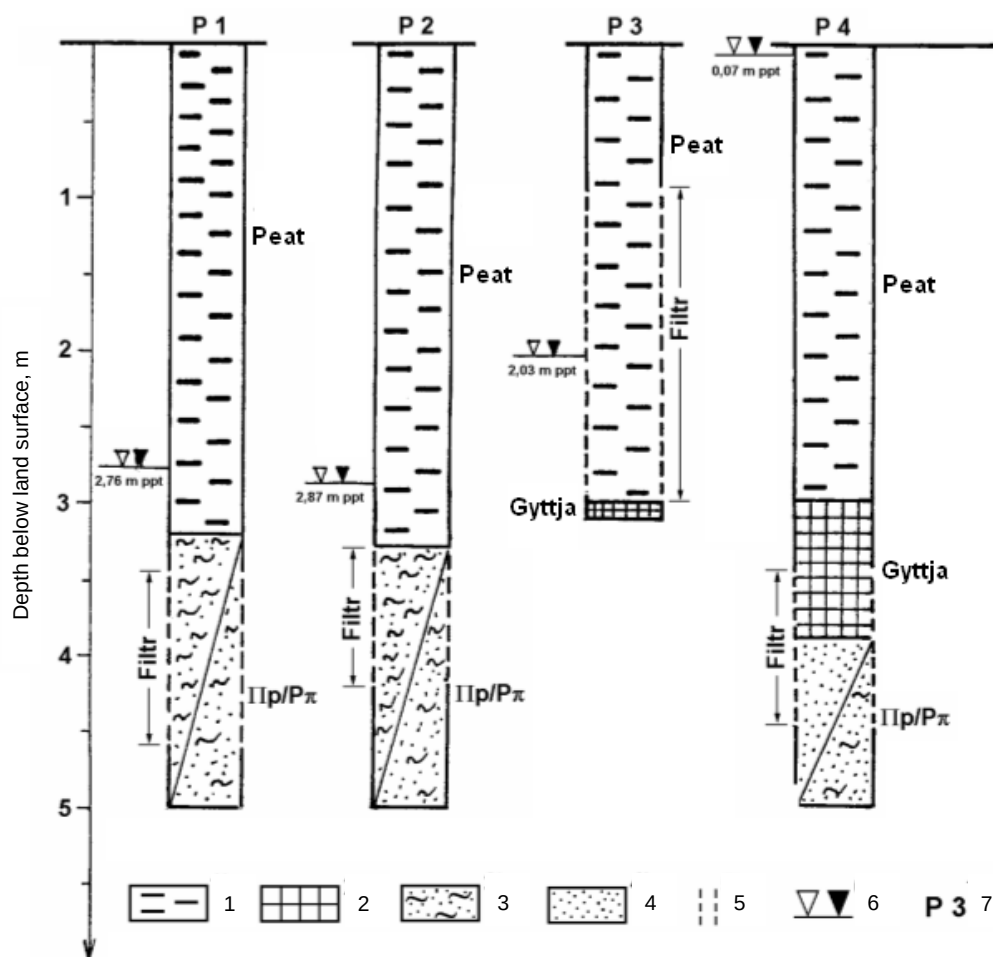
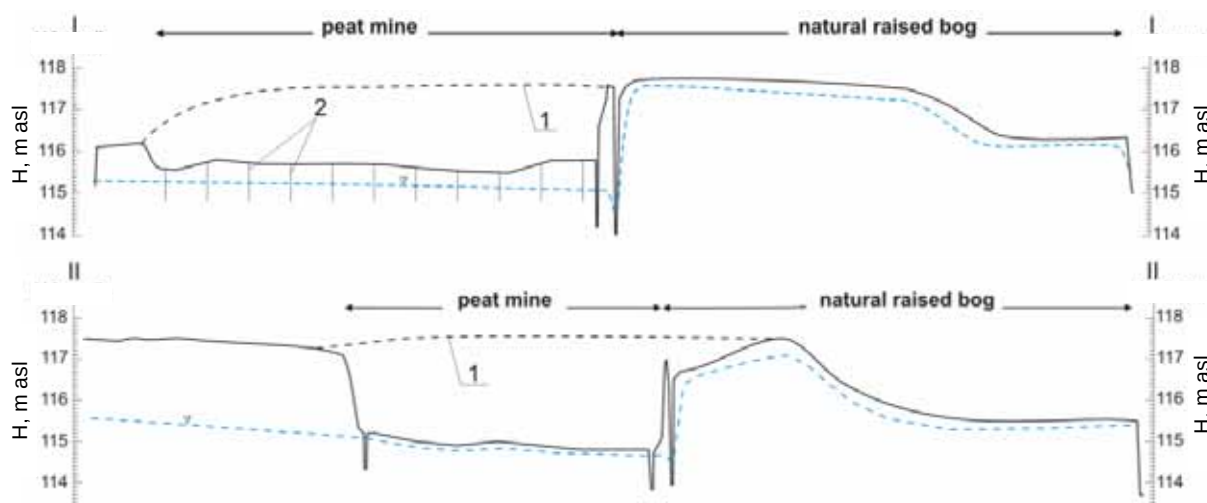
- fields where peat is currently excavated;
- fields prepared for extraction of peat. Part of plants has been removed together with top part of the soil and detailed ditches have been constructed.

Research on ground water level, peat moisture and precipitation has been carried out to evaluate the influence of the mining and drainage system on the protected area. Water has been also sampled to measure the dissolved chemical compounds. The main aim of the research was to allow the spatial analysis of the ground water and its flow directions in the mining and preserved areas.

Cross-sections of the area of the mine and preserved area have been carried out basing on the surveying. Exemplary cross-sections I–I and II–II has been shown on Figure 3.

Continuous measurements of ground water have been carried out in the area of the mine as well as in the preserved area. Observation wells have been constructed in two areas (Fig. 1) and named as P1–P4. Profiles of the installed observation wells are presented in Figure 4. Divers for continuous measurements of ground water level have been installed in all observation wells. Ground water level has been measured each hour and the results are presented in Figure 5.

Moisture content measurements have been carried out in 9 points in the area of the mine and the preserved area. Research based on soil sampling on depths of 0.3, 0.8 and 1.5 m below the ground level. Humidity was determined in the laboratory using a lab-dryer. During collection of soil samples also the ground water table level was determined. Samples for moisture content measurement were collected during the summer. Medium, characteristic values of meas-



urements for each area were given in Table 1. In the preserved area samples were collected at two different distances from the ditches draining the mine. Samples were also collected in the unprotected areas adjacent to the mine and in the areas situated downstream the mine (Tab. 1).

Results of measurements of the ground water table level performed during collection of soil samples have been also given in the Table 1. Likewise during the moisture content analysis mean values of the water table level were given from the characteristic areas.

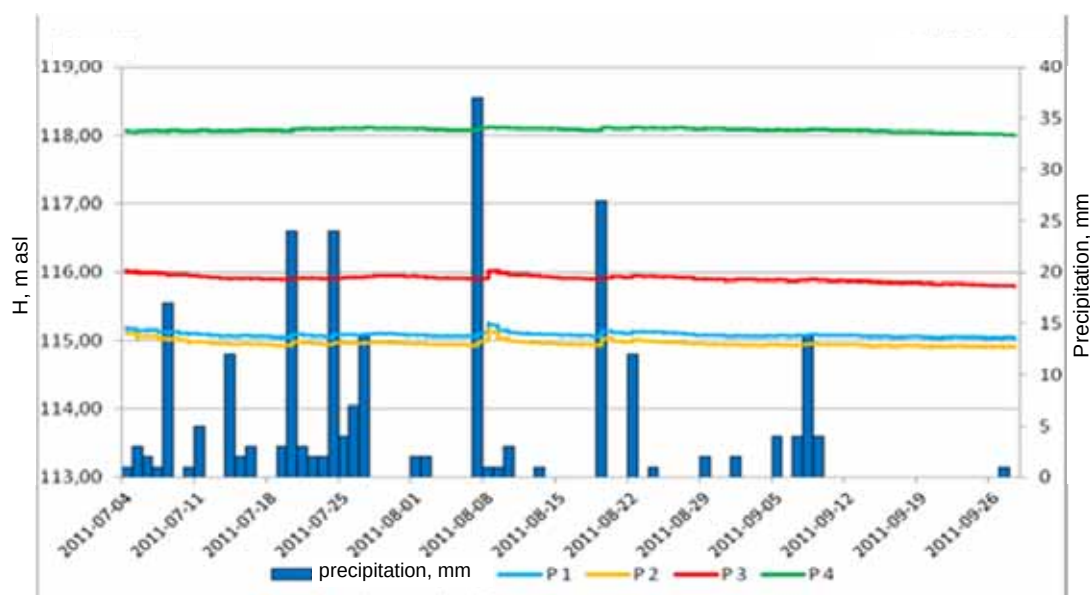


Fig. 5. Results of the ground water level in observation wells, P1–P4 – piezometers; source: own study

Table 1. Mean values of moisture content of peat and depth to the ground water table in 2011

Sampling site no	Mean humidity value on depth of			Depth to the ground water table m	Remarks
	30 cm	80 cm	150 cm		
4, 6, 9	602.11	731.15	835.01	0.16	measurements in center of the preserved area
3, 5, 8	566.23	764.17	866.94	0.17	measurements in the preserved area on the border with mine
1, 2, 7	623.29	787.82	852.27	0.16	measurements outside of the mine

Source: own study.

For correlation of the precipitation, ground water table level, evapotranspiration and manmade drainage system also amount of the precipitation has been measured. Rain-gauge has been installed in the vicinity of the mine buildings, on the peat bog area.

Ground water has been sampled to examine the chemical composition to obtain additional information on directions of the ground water flow. Sampling sites have been shown in Figure 1 and selected chemical results have been given in Table 2.

Table 2. Chemical composition of water in water courses

Sampling site	pH	P	N-NO ₃	N-NH ₄	pH	P	N-NO ₃	N-NH ₄	pH	P	N-NO ₃	N-NH ₄
		mg·l ⁻¹				mg·l ⁻¹				mg·l ⁻¹		
Sampling date												
24.03.2011					31.08.2011				28.09.2011			
1	6.85	0.225	1.26	1.09	7.13	0.204	0.89	2.06	7.19	0.076	0.27	1.25
2	6.92	0.151	0.74	2.35	7.32	0.256	0.23	4.25	7.14	0.066	0.57	5.45
3	6.86	0.410	0.19	3.37	6.46	0.091	0.21	0.46	6.78	0.214	0.29	2.24
4	7.20	0.156	0.35	3.30	7.00	0.125	0.79	3.76	6.93	0.091	0.55	7.34
5	7.18	0.096	0.15	6.67	7.07	0.135	0.29	2.02	7.10	0.157	0.28	6.53
6 ¹⁾	—	—	—	—	5.52	0.122	0.18	0.83	3.57	0.058	0.43	0.98
7	—	—	—	—	6.76	0.754	0.25	0.91	7.01	0.500	0.46	1.96
8	—	—	—	—	7.06	0.257	1.12	0.56	6.79	0.078	0.45	1.82
9	—	—	—	—	7.11	0.144	0.37	1.57	7.03	0.073	1.55	1.07
10 ²⁾	—	—	—	—	7.27	0.076	0.31	0.22	7.02	0.114	0.33	0.49

¹⁾ Reservoir situated in the central part of the protected area.

²⁾ Water from the shallow farmer's well.

Source: own study.

Water samples were collected from ditches in the mine and in the adjacent areas. Also the reservoir situated in the central part of the protected area was sampled. The reservoir is probably a remnant after a

manual excavation of peat that occurred before 1954. A sample of water from a farmer's well has been also collected. Samples were collected 3 times (March, August and September).

DISCUSSION OF RESULTS

Research that have been carried out allow to evaluate the humidity of the natural peat deposit situated in the vicinity of the mine where intensive drainage system had been installed.

Literature on the influence of the peat mining on the water conditions in the adjacent areas is rather poor [SCHOUTEN 2002]. More information can be found on the impact of the draining system on the groundwater level in the adjacent area [ILNICKI 2007; ŁACHACZ 2001; MIODUSZEWSKI 1989]. In most cases lowland bogs mires are described as they occur most often in Poland.

Raised bogs have always been a problem while adjusting to the needs of agriculture. Examples of the unsuccessful drainage can often be found in the literature [ILNICKI 2002; 2007; OŚWIT *et al.* 1992]. In such areas, despite dense draining network, peat stays humid and is difficult to use it for agricultural purposes. Many examples of the unfavorable influence of peat mine on the state of raised peat bog's plants can be found in literature [PISAREK, POLAKOWSKI 2001; SOKOŁOWSKI 2006]. It is worth to notice that new drainage ditches have been constructed on the discussed area and it is not clear if the adverse effect has been caused by the drainage system or by the adjacent peat mine. Research carried out on the same peat bog indicate that the hydraulic system of the mine is not connected with the hydraulic system of the bog [ILNICKI 2007]

Examples of raised peat bog extraction show that such areas are not easy to drain while drainage is a necessary stage of the extraction with use of surface excavation method.

The scope of the influence of the drainage system depends on many factors and hydraulic conductivity of the peat deposit is one of the most significant ones. The approximate extent of the impact can be calculated using the Kunze formula [MIODUSZEWSKI 1989]:

$$L = 200kh \quad (1)$$

where:

- L – extent of the impact, m;
- k – hydraulic conductivity of the top layers of the peat deposit, $\text{m} \cdot \text{day}^{-1}$;
- h – drainage depth (difference between natural ground water level and water level in the ditch).

According to the formula (1) and assumptions that had been made, the extent of the impact of the drainage for the mine is between 40 and 60 m.

For comparison, calculations of the extent of the impact of the main ditch on the preserved area (cross-section A–A) in dependence of the amount of precipitation have been performed.

Calculation scheme [MIODUSZEWSKI 1989] that takes into account the functioning of the ditch in the

layer of peat with precipitation and lack of lateral ground water flow was used.

The extent of the influence can be calculated with formula:

$$L = \sqrt{\frac{2Th}{p}}; [\text{m}] \quad (2)$$

where:

- T – conductivity of the layer, $\text{m}^2 \cdot \text{d}^{-1}$; $T = km$;
- k – hydraulic conductivity of the layer, for sphagnum peat it was assumed – $k = 0.1 \text{ m} \cdot \text{d}^{-1}$ [MIODUSZEWSKI 1989];
- m – layer thickness, $m = 4 \text{ m}$;
- h – rise of the water table level in the preserved area above the water level in the main ditch – a mean value has been assumed to be 3.0 m ;
- p – amount of the precipitation in 24 hours (m) recharging the peat deposit.

For various values of the precipitation the length of drainage impact was shown in Table 3.

Table 3. The extent of peat mine drainage on ground water level in the adjacent area

Precipitation p , $\text{mm} \cdot \text{day}^{-1}$	1	2	4	6	8	10	20
Extent of the ditch impact L , m	45.6	34.6	24.5	20.0	17.3	15.5	11.0

It is worth to mention that according to the formulas given above the extent of the impact is a point where water table reduction as a result of construction of the ditch (mine drainage) is zero. Therefore, in the most part of the impact area reduction will be less than 10 cm what is almost unnoticeable in terms of the dynamics of the water table level mobility.

Tests of moisture content in peat and water table level do not point at any relations between groundwater in the area of the mine and in the preserved area. In all investigated sites a fast vanishing of the impact of the ditches on the water table levels can be observed. In few meters distance from the ditch ground water in peat tend to level close to the surface. It can be clearly seen in the results of observations carried out in piezometers and in results of measurements of the water table carried out during soil sampling. It is worth noticing that moisture content of peat (Tab. 1) is weakly related to the distance of the sampling site from the ditch. High humidity is present even in the surface layer (samples from the depth of 30 cm).

Water quality researches indicate visible organic matter degradation processes but only in the area of the mine. A proof of this process is a high content of N-NH_4 in sampling sites in the area of the mine. In other courses and water bodies present at the preserved area high concentrations of this compound do not occur. It can be a proof that degradations processes are limited to the area of the mine. Therefore, it can

be stated that humidity conditions were not greatly influenced in the raised bog situated close to the mine.

Draining system reduce water table level only in the area of the mine. It is caused mainly by a construction of a dense network of detailed ditches. Distance between ditches is between 15 and 25 m.

Due to raised bog features a relevant impact of the mine drainage system on the preserved area has not been noted. In reality the impact of the drainage is limited to several meters. In a distance of 30–40 m from the main and complementary ditches ground water level is located near the surface of the ground. It is clearly visible on cross-sections on Figure 3.

Observation of the plants in the preserved area also do not show visible degradation processes. Moreover, the presence of the reservoir in the central part of the preserved area is a fact. It is an oblong reservoir filled with water throughout the year up to the ground level. Edge of the reservoir is situated ca. 30 m from the main ditch and the water level in the reservoir maintains ca. 2–3 m above the bottom of the ditch. It is also a proof of a weak influence of the mine on the water conditions in the adjacent areas.

CONCLUSIONS

Research and observations that have been carried out show that the impact of the mine drainage system on water levels in the adjacent areas is limited. Degradation processes in the preserved peat bog were not noted. It has been evaluated that the extent of the impact area is limited to 30–60 m from the border of the mine (main canals and ditches). It is a result of specific features of the raised peat bogs. It means that it is worth to protect raised bogs even if they border with a peat mine (the area with low groundwater level).

However, in the area of the mine a complete degradation of the environment and reduction of the water level below the extraction site occur. Despite lack of clear influence of the water conditions in the preserved area it is recommended to undertake measures that can mitigate the negative impact of the mine:

- in places where peat extraction is finished water drainage should be limited by filling up the ditches or by construction of small damming devices;
- during the extraction from particular fields a layer of thickness at least 0.3–0.5 m covering the mineral bedding should be left untouched;
- a zone between the ditch and the extraction site should be left untouched.

After extraction of peat the land reclamation can be directed in two ways:

- construction of the water reservoir in the areas where peat had been extracted to the lower elevations;
- construction of the manmade conditions for renewal of the peat forming processes in the areas situated in the higher elevations.

The basic outcome of the research and analysis that have been carried out is a chance to prove that

valuable natural habitats located in a vicinity of the investment of a possible negative impact (e.g. peat mine) can preserve their ecological value under some conditions. It is crucial to carry on the observations and measurements that can allow undertaking measures if any negative impact is noted. Also, it is comforting that it is possible to increase the biological diversity after the extraction. In a lower situated sites water reservoirs can be constructed. These reservoirs will be covered by water plants soon. In the higher situated sites where a layer of peat has been left untouched a peat forming process will have a chance to start.

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Oddziaływanie kopalni torfu na warunki wodne na przyległym torfowisku wysokim

STRESZCZENIE

Słowa kluczowe: *biologiczna różnorodność, hydrologia, kopalnia torfu, torfowisko wysokie*

Do ochrony mokradeł, jako ekosystemów od wód zależnych, zobowiązuje w Unii Europejskiej między innymi Ramowa Dyrektywa Wodna. Zarówno w Polsce jak i w innych krajach torf jest nadal pozyskiwany na cele lecznicze, ogrodnicze lub jako podłoże organiczne do produkcji np. pieczarek. Szczególnie wartościowymi przyrodniczo obszarami są torfowiska wysokie, a jednocześnie torf wysoki jest cennym i poszukiwanym materiałem w ogrodnictwie.

Jedna z polskich kopalni torfu wysokiego sąsiaduje bezpośrednio z torfowiskiem wysokim, objętym ochroną rezerwatową i znajdującym się na obszarze Natura 2000. Na torfowisku tym przed 40 laty rozpoczęto przemysłową eksploatację torfu w zachodnio-południowej części tego torfowiska. Eksploatacja trwa do dzisiaj. Północno-wschodnia część tego torfowiska została objęta ścisłą ochroną.

Przeprowadzone zostały badania i analizy w celu oceny wpływu wydobywania torfu i związanego z tym obniżenia poziomu wód gruntowych na sąsiadującą część nieużytkowanego chronionego torfowiska wysokiego. Badania dotyczyły oceny warunków wilgotnościowych bez wnikania w ewentualne przekształcenia biotyczne.

Prowadzone obserwacje i badania wykazują, że zasięg oddziaływania systemu odwadniającego badanej kopalni na wody podziemne terenów przyległych jest ograniczony. Nie obserwuje się procesów degradacji w strefie torfowiska chronionego przyległego do kopalni. Ocenia się, że zasięg oddziaływania ogranicza się do strefy 30–60 m od granicy kopalni (rowu głównego i pomocniczego). Wynika to ze specyficznych cech torfowisk wysokich.

Podstawowym wynikiem przeprowadzonych analiz i badań jest wykazanie, że cenne obszary przyrodnicze, położone w bezpośrednim sąsiedztwie negatywnie oddziałującej inwestycji, którą jest kopalnia torfu, mogą w pewnych warunkach zachować swoją wartość ekologiczną. Mimo tak niekorzystnego sąsiedztwa, obejmowanie torfowiska wysokiego różnymi formami ochrony jest celowe. Konieczne jest w tych warunkach prowadzenie obserwacji i pomiarów, co umożliwi podejmowanie odpowiednich działań w przypadku zaobserwowania niekorzystnych zjawisk. Pociągająca jest również możliwość zwiększenia biologicznej różnorodności na terenie kopalni po zaprzestaniu wydobywania torfu.