

## RECLAMATION OF THE OILY DIATOMACEOUS EARTH STORAGE AREA AT BRZEG

### Site characteristics

The oily diatomaceous liquid earth storage area, called settling ponds (lagoons) was owned by the former Nadbużańskie Fat Processing Factory S.A until 1952.

The area consists now of four settling ponds ( Fig. 1). Three of them were used earlier as settling ponds for dumping waste of a former sugar plant. The fourth one was built in the nineties. A dam made of earth is separating the settling ponds from the floodplain terrace of Odra river ( Photo 1,2 and 3). The dam has been established at the foot of the floodplain terrace slope (Figs. 1 and 2). The earthen dam was rebuild in 1991 and its slope inclination is now 1:2.5. The slope was secured with:

- 1) Lining of unwoven cloth loaded with openwork concrete slabs 50 x 100 x 8cm
- 2) Support in its lower portion by a buttress made of steel reinforcements of the LARSEN type ( I = 8÷9 m )

The height of the dam (external embankment) is about 10m increasing towards the river valley. The width of the embankment crown is 6.0m while its datums are 146 – 148.8m (average 148.5m) above sea level. The datums of the adjacent portion of the floodplain terrace are contained within the range 134.2 – 136.0m above sea level. The floodplain of Odra terrace is built of alluvial silty clays (rich in organic parts) with numerous sand inter-beddings. The depth of Holocene formations overlaying moraine clay substrate attains, on the average, 6-8 m. The upland is build of Pleistocene formations including sand, sand-gravel mix, gravel and silty and sandy clay.

In the year 1995, the areas of lagoons and the liquid waste damming up datums were as follows:

- Settling pond No 1 – 1700 m and 147.25m above sea level;
- Settling pond No 2 – 3200 m and 147.34m above sea level;
- Settling pond No 3 – 2800 m and 147.03m above sea level;
- Settling pond No 4 – 3700 m and 146.97m above sea level.

The dumped waste contained about 50% of water, 8-10 % of oil, some seed mucilage and fatty acids as well as phosphoric and sulphuric acids in trace amounts.

The waste storage site is equipped with a network of piezometers for monitoring the water table and the quality of groundwater (Fig. 1)

The water table at the head of settling ponds stabilizes at the depth of about 133m above sea level (ca. 0.6 – 2.0 m under the ground level) depending on the water level in Odra river.

The ground waters of the upland are mainly of atmospheric origin and are maintained by sandy aquifers.

The average level of ground water in the adjacent portion of the upland has a datum of 142 m above sea level. The construction of embankments of settling ponds resulted in numerous seepages of water from layers having various filtration coefficients.

### **The state of storage site in 2004**

**Lagoon No 1** had an irregular and to a large extent deformed surface (Photo 4 and 5).

The deepest part at the bottom of the lagoon was filled in with water and its neighbourhood was covered with heavily oiled diatomaceous earth. During the cool season the water table was free of oil screen. During sunny and, in particular during hot weather, the melting out of oily liquid was observed from the diatomaceous earth deposit and subsequently, its run-off to the waterlogged deepest part. The latter constituted a good site for intensive growth of reed mace and common reed as well as for many other hydrophytes (Photo 5).

The water disappeared from the site in autumn 2004, and the self sown vegetation started to germinate (Photo 6).

**Lagoon No 2** was filled in with diatomaceous earth and, to a large extent, covered with oily water. The irregularity of surface of the diatomaceous earth deposit resulted in the respective irregularity of the depth of supernatant liquid. The surface of the deposit was deformed by the technical take up of diatomaceous earth from locations along the embankment crown and internal dyke.

**Lagoon No 3** was entirely filled in with the oily diatomaceous earth and covered with oily water. During the cool season the lagoon surface was covered with oily grease (Photo 7 and 8), while during sunny and, in particular, during hot weather it was covered with oily liquid with a substantial share of diatomaceous earth.

On several small and somewhat convex hillocks (mounds) in the lagoon, the presence of self sown vegetation was observed (Photo 8), what provides evidence of an opportunity to biologically transform the waste deposit.

**Lagoon No 4** was entirely filled in with oily diatomaceous earth. A considerable part of its surface was heaped up in the form of irregular patches and mounds. The exposure of mounds to the activity of atmospheric factors as well as the biological decomposition of oil provided conditions for intensive growth of self sown graminaceous and herb plants, trees and shrubs (Photo 9 – 11). This testifies to a possibility of effective introduction of vegetation upon the diatomaceous earth surface provided that liquid form of oil be removed and its biodegradation enhanced as well as adequate air-water conditions be safeguarded.

### **Organic carbon, nitrogen and phosphorus content in the oily diatomaceous earth**

The content of the abovementioned elements were determined in samples taken from lagoons No 1, 2 and 4, at the depth of 0.5m from the surface down to the near-the-bottom levels of the deposit (Table 1).

**Table 1.** Contents of organic carbon, nitrogen and phosphorus in the diatomaceous earth deposit in October 2004

Głębokość pobrania próbki w m	Węgiel org. C	Azot N	Fosfor P	C : N	N : P
	procent suchej (bezwodnej) masy				
<b>Laguna 1</b>					
0,5 – 0,6	16,9	1,16	0,18	14,5	6,4
1,5 – 1,6	14,5	1,43	0,23	10,0	6,3
<b>Laguna 2</b>					
0,5 – 0,6	16,6	1,15	0,18	13,3	6,3
1,5 – 1,6	11,6	0,83	0,09	12,8	9,2
2,3 – 2,4-	10,5	1,01	0,16	10,4	6,5
2,6 – 2,7	11,7	0,82	0,11	13,3	7,5
3,5 – 3,6	21,0	1,68	0,26	12,3	6,5
<b>Laguna 3</b>					
1,5 – 1,6	13,4	0,93	0,16	14,4	5,6
2,5 – 2,6	9,8	1,04	0,12	9,5	8,4
3,5 – 3,6	16,8	1,54	0,22	10,9	7,0
<b>Laguna 4</b>					
0,5 – 0,7	8,8	0,48	0,12	18,3	4,0

It was assumed that the deposit at that level contains approximate quantities of organic substances (fatty and some other ones), nitrogen and phosphorus.

The elements listed and, above all, their quantitative relationships, are of decisive importance for assessing the conditions of fatty acids biodegradation and of the development of soil formation processes and plant growth.

**Organic carbon contents** in the deposits at respective lagoons were from 8.85 do 21% of dry (water freess) mass.

**Total nitrogen contents** fluctuated within the range of 0.48 to 1.68% of dry mass.

**Total phosphorus contents** ranged from 0.09 to 0.26% of dry mass.

The carbon (C) to nitrogen (N) ratio fluctuated within the limits from 9.5 to 14.5.

The nitrogen (N) to phosphorus (P) ration fluctuated within the limits from 4.0 do 8.4.

The quantitative ratios of carbon to nitrogen and nitrogen to phosphorus determined are being potentially favourable, however, under anaerobic conditions with fatty acids abound there might occur acute deficiency of forms readily available (mineral) to microorganisms and plants. With advancing process of mineralization (biodegradation) of organic substances the availability of these elements will be increasing (Table 1).

## Content of organic carbon, total nitrogen, total phosphorus and ether extract in the surface layers of diatomaceous earth deposit

In January 2005 samples were taken from the top layer of each lagoon to determine the content of the above elements. The determination results are given in Table 2.

**From the lagoon No 1** one averaged sample of the deposit was taken for analysis from the depth of 10cm.

**From the lagoon No 2** two averaged samples of the deposit were taken from the depths of about 10cm and 15-25cm.

In both lagoones the surfaces were free from supernatant liquid. It was possible to encroach onto them without risk of danger for man. The top layer of the deposit in the lagoons No 1 and 2 contained 13.3 and 23.9% of organic carbon, 29.8 and 39.6% of organic substance, 107.9 and 134.2g/dm<sup>3</sup> of ether extract as well as 0.98 and 1.9% of nitrogen. In the lagoon No 2, analogous quantities of the elements mentioned were found in the deposit at the depth of 15-25cm and at the depth of 0-10cm.

**From the lagoon No 3** two parallel averaged samples were taken from the 0-10cm layer. The contents of organic carbon (57.5 and 60.9%), organic substance (78.3 and 80.4%) and ether extract (583.8 and 638.0g/dm<sup>3</sup>) found were many times higher than those found in the deposit at the lagoons No 1 and 2 on surfaces free from supernatant liquid. (Table 2).

**From the lagoon No 4** three averaged samples of oily grease were taken from the 0-15cm layer. The samples contained very high amounts of organic carbon, organic substance and ether extract. With regard to their consistence and contents of the elements mentioned they are almost the same as those taken from the lagoon No 3.

**From the lagoon No 4** two samples were also taken of the diatomaceous earth deposit from the surfaces elevated above the supernatant liquid table:

- mounds deprived of vegetation,
- surfaces covered with self sown vegetation.

The sample taken from mounds contained 25.8% of organic carbon while the sample taken from a plant covered surface - only 7.4% (Table 2). Such a high reduction of the organic carbon content in the deposit overgrown with vegetation may be attributed to the biodegradation of fatty acids. This testifies to a considerable drop in the amount of ether extract content, i.e.: 42.6mg/dm<sup>3</sup> against the level of about 600g/dm<sup>3</sup> found in the oily grease on the adjacent spots.

Surfaces free from supernatant liquid indicated from 13.3 to 25.8% of organic carbon, while in the oily grease the respective content was from 57.5 to 63.8%. The development of vegetation cover enhances the decomposition of organic substance to the level similar to that observed in humic earth.

**Nitrogen contents** in all the samples examined varied from 0.98 to 8.54g/dm<sup>3</sup>.

**Phosphorus contents** from 0.59 to 11.72g/dm<sup>3</sup>.

The nitrogen to phosphorus ratio is close to one. The nitrogen deficiency, especially in the oily grease is very high. It will, however, be decreasing as the liquid fatty acids are being removed from lagoon surfaces, and then, as the organic substance biodegradation advances. An example of the above provide results of analysis of a sample taken from the plant

**Table 2.** Contents of elements and pH in the top layer of diatomaceous earth. State in January 2005

Lagoon	Depth cm	Consistence	Carbon C	Organic substance	Nitrogen N	Phos phorus P	Ether extract	pH
			% in dry (water free) mass		g/dm <sup>3</sup>			
1	0-10	Solid greasy	23,9	39,6	1,30	1,17	134,2	4,6
2	0-10	Solid greasy	13,3	29,8	1,06	0,59	107,9	3,9
2	15-25	Solid greasy	14,7	29,6	0,98	0,78	169,4	4,4
3	0-10	Oily grease	57,5	78,3	2,05	3,64	583,8	4,2
3	0-10	Oily grease	60,9	80,4	1,65	2,20	638,0	3,8
4	0-10	Oily grease	50,0	75,7	3,40	6,04	579,5	4,0
4	0-7	Oily grease	60,7	68,4	1,94	3,93	628,3	5,2
4	8-15	Oily grease	63,8	77,1	1,63	3,11	617,0	4,0
4*	0-10	Solid greasy	25,8	76,3	7,84	11,72	570,0	5,4
4**	0-10	Earthy	7,4	35,4	8,54	6,08	42,6	6,0

\* Mounds, \*\* Vegetation patch.

covered deposit, in which the quantitative ratio of carbon to nitrogen is 11.5. Such a value is characteristic of humic level of a fertile soil.

The value of nitrogen to phosphorus ratio (1.4) points out to the excessive amount of the latter element. This is most likely due to the accumulation of phosphorus compounds transferred to the deposit top layer.

## Dumping site reclamation technology

The task of reclamation consists in establishing the soil and vegetation cover with the aim to restore ecological and landscape utility of the storage area. In this context indispensable activities include:

- complete elimination of noxiousness to the environment above the ground level,
- far reaching minimization of rain water infiltration into the deeper layers of waste deposit – through its uptake by plants and exudation of water vapour to the atmosphere,
- minimization of organic and mineral element migration from the deposit to the ground water.

The storage area reclamation consists in:

- 1) drainage of supernatant and deposit water,
- 2) liquidation of oily grease and removal of oily liquid from the surface,
- 3) biodegradation of oily constituents and of the remaining organic elements,
- 4) cultivation of plants capable of taking up large quantities of water (evapotranspired to the atmosphere), thus enhancing the availability of atmospheric air within the top layer of the diatomaceous earth deposit,

- 5) change the consistence of the diatomaceous earth deposit from greasy to solid by means of:
  - physical offtake of excess water,
  - dewatering with the use of vegetation,
  - deposit aeration,
  - biodegradation of oily substances,
- 6) levelling of stabilized deposit surface,
- 7) establishing a soil forming layer built of mineral ground,
- 8) fertilization of the soil forming layer,
- 9) sowing of grass mixture and papilionaceous plants,
- 10) construction of roads for pedestrians and vehicles.

In the course of reclamation the following is to be made:

- measurement of water volume taken off the lagoons,
- measurement of volume of oily liquid harvested from the lagoons,
- measurement of content of ether extract, organic carbon, nitrogen and phosphorus as well as of pH in the diatomaceous earth deposit,
- analysis and evaluation of changes in groundwater,
- observation and measurement of plant growth,
- determination of mineral element contents in plants,
- observation of root system development in plants,
- measurement of ground subsiding caused by dewatering and biodegradation of oily substances,
- observation of encroachment and survival of soil fauna as well as of terrestrial fauna including birds.

The design of reclamation of the oily diatomaceous earth storage site at the EWICO Co.Ltd. at Brzeg [1] was developed in March 2005 following a comprehensive examination of the object, taking special account of local hydrogeological, building, technological, biological and landscape conditions, on consideration of the results of studies and of former reclamation of similar sites including:

- ground lagoons for storing oily diatomaceous earth of the Kruszwica Fat Processing Plant, located at Brześć on Gopło Lake [3],
- lagoons for storing decoction of bone meal production at Wymyśl Nowy where dewatering with the use of plants and site management were implemented [5],
- wastewater treatment plant lagoons at Hajdów in Lublin where dewatering with the use of plants and site management were implemented [6],

whereby account was taken of the regulations such as:

- the Act – Law on the Protection of the Environment [7],
- Decrees of the Minister of the Environment [4].

The project design for reclamation of the oily diatomaceous earth storage site at the EWICO Co.Ltd. Plant at Brzeg was agreed by the Decision No OŚ – 7643-3/05 issued by the Head of the Brzeg County (Powiat) on August 16, 2005.

## Implementation of the reclamation design

The reclamation work has started immediately after the project was agreed upon in 2005 and is due to be terminated by the end of 2009.

### In 2005:

- 1) State and quality of ground water was examined within the site and in its neighbourhood,
- 2) Magnesium lime was spread on the surface in lagoons with the aim to deacidify the environment and provide calcium and magnesium for microorganisms (Photo 12- 14),
- 3) NPK fertilization was applied onto the surfaces of lagoons in order to provide nutrients for microorganisms,
- 4) Pilot draining system was installed to scoop oily liquid from the waste deposit at the line of groundwater runoff,
- 5) Oil scooping was initiated from drainage points,
- 6) About 2500 m of water was taken away from deposits at lagoons No 2,3 and 4.

### In 2006:

- 1) Study on the state and quality of groundwater was continued,
- 2) Supernatant water was drained and accumulated in deposits at lagoons No 2,3 and 4 (Photo 15 and 16),
- 3) Oil liquid was scooped from the surface of lagoons No 2,3 and 4 (Photo 17),
- 4) Metal and wooden elements of the technical armament of lagoons were removed,
- 5) Earth mass piled up in heaps and building internal dykes was transferred to lagoons No 3 and 4 (Photo 21),
- 6) Pilot-implementation experiments were conducted with plants on surfaces free from supernatant liquid and on soil forming layers of mineral earth (Photo 23),
- 7) Surfaces freed from supernatant liquid were covered with vegetation and the reclamation layer of mineral earth was overlaid:
  - a mixture of meadow grasses and mustard plant was sown ( Photo 23),
  - a layer was spread of organic mulch composed of waste from the production process and nursing the plant green areas (Photos 27-29),
  - the water taken off from lagoons was sprinkled away,
- 8) Photodocumentation was made of both the subsiding and deformation of lagoon surfaces owing to dewatering, deoiling and introduction of soil forming layer of mineral earth and the greening on the pilot-implementation scale of the surfaces under reclamation (Photos 15 – 29).

The addition of plant waste was applied onto the following surfaces:

- 1) oily diatomaceous earth free from supernatant liquid,
- 2) covered with soil forming layer of mineral soil transferred from the local heaps and internal dykes.

The licence to apply technological waste of the code 020380 was issued by the Head of the Brzeg County on the strength of the decision No OŚ. 7626/86/06 of November 9, 2006.

The vegetated surfaces of the storage site are being covered with a thin layer of organic waste thus providing favourable conditions for intensive growth of the sown and self sown plants. Industrial waste contains residual amounts of rapeseed and of numerous other weed species. Nutrients released in the course of organic waste mineralization intensify the plant growth.

The content of organic substance and of the main mineral elements in technological waste is shown in Table 3. Large and well proportionated contents of nitrogen, phosphorus, potassium, calcium and magnesium as well as a favourable ratio of organic carbon to nitrogen provide optimal conditions not only for the growth of plants but also for aerobic microorganisms which mineralize oily substances in the diatomaceous earth deposit.

Spreading of the organic waste layer, easily permeable for the precipitation water and air provides protection of the reclaimed ground against the unfavourable action of atmospheric factors and creates conditions for the development of aerobic microorganisms and soil fauna.

Such a layer of organic mulch provides conditions for condensation of water vapour ascending from the deposit layer what is beneficial for the growth of plants.

**Table 3.** Percent content of elements in dry mass of waste having the code 020380 „Pomace, sediments and other waste from processing plant products”

Waste of plant mass	Organic parts	Mineral parts	Organic carbon	N	P	K	Ca	Mg
From cleaning with the use rapeseeds	83.8	16.2	46.9	2.52	0.31	0.98	1.35	0.20
From dust removal installation	57.4	42.6	32.7	2.35	0.47	0.77	1.40	0.28

## Impact of storage site on the groundwater quality

The groundwater has been sampled for analysis from a network of eight piezometers since 1996. Four piezometers (P1, P2, P3, P4) are placed at the embankment crown, two of them - P6 and P7 are at the foot of the embankment and two remaining ones - P5 and P8 are located on the upland. In addition, analyses were made of water sampled from a reference well of the pipe drainage (SD) as well as of water from the water-level-gauge stands (W1 and W5) in Odra river (Fig. 1). The results of laboratory determinations made in the years 2004-2005 are shown in Tables 4 and 5.

The results of water quality analysis were interpreted in line with the Decree of the Minister of the Environment as of 11 February 2004, on the classification of data concerning presentation of the state of surface and underground water, methods for conducting monitoring and on the way of interpreting results and the presentation of the state of the above mentioned waters (Official Journal No 32, item. 284). As monitoring is conducted within the industrial site, the results achieved have been interpreted taking into account the limiting values for the IV class of water quality (water of non-satisfactory quality).



**Reaction (pH).** The limiting values of pH for the IV quality class range from 6.5 to 9.5. Starting from 2004 the pH values of groundwater are contained within the range of 6.4 – 7.6.

**Electric conductivity.** The limiting values of conductivity for the IV quality class attain 3.000  $\mu\text{S/cm}$ .

The conductivity value in water sampled from P2 piezometer was up to 5000  $\mu\text{S/cm}$ , while in all the remaining points of the groundwater monitoring network they were between 938 and 2916  $\mu\text{S/cm}$ . The groundwater of the upland (P5, P8) has indicated 938-1358  $\mu\text{S/cm}$ , while water from the foot of the embankment (P6, P7) - 1655-2216  $\mu\text{S/cm}$  and water from piezometers P1, P3 and P4 (crown of the embankment) - 2340- 2916  $\mu\text{S/cm}$ .

Largest discrepancies between values in  $\mu\text{S/cm}$  (521 and 2210) were found in water sampled from the reference well (SD). The electric conductivity of water taken from Odra river (W1 and W5) attained 1446-1548  $\mu\text{S/cm}$  and was higher than that found in the groundwater of the upland.

The limiting value in  $\mu\text{S/cm}$  was exceeded only in water sampled from P2 .

**Content of nitrogen compounds.** The limiting values for the IV class of water quality attain: 3 mg  $\text{NH}_4/\text{dm}^3$ ; 0,25 mg  $\text{NO}_2/\text{dm}^3$  and 100 mg  $\text{NO}_3/\text{dm}^3$ .

$\text{NH}_4$  content in piezometer water attained:

- P1, P2, P3 and P4 at the embankment crown - 0.2–3.96 mg/ $\text{dm}^3$ ,
- P6, P7 at the foot of the embankment - 0.8 – 3.9 mg/ $\text{dm}^3$ ,
- P5, P8 at the upland - 0.1 – 2.3 mg/ $\text{dm}^3$ ,
- At the reference well (SD) - 0.2–1.6 mg/ $\text{dm}^3$ .

Insignificant exceedances of  $\text{NH}_4$  contents were found in water sampled from P1, P2, P3 and P6. Noteworthy is the lack of definite trends of changes in the content of ammonium form of nitrogen.

**$\text{NO}_2$  contents.** In water from piezometers placed at the embankment crown it was found 0.01 – 0.2 mg  $\text{NO}_2/\text{dm}^3$  and, on one occasion, 0.26 mg/ $\text{dm}^3$  .

At the foot of the embankment (P6, P7) it was found 0.01 – 0.64 mg  $\text{NO}_2/\text{dm}^3$ .

Water from piezometers at the upland and at the foot of the embankment contained 0.07 – 0.24 mg  $\text{NO}_2/\text{dm}^3$ .

**$\text{NO}_3$  contents** were very low in piezometer water at the embankment crown (0.02 – 4.5 mg/ $\text{dm}^3$ ) and many times higher in water sampled from P5, P7 and P8 (3.4 – 58.0 mg/ $\text{dm}^3$ ) as well as from the reference well (1.34 – 8.4 mg) and from Odra river (3.9 – 11.1 mg).

A very high level of  $\text{NO}_3$  (58.0 mg) registered in November 2006 in P8 is explained by an exceptional summer drought and heavy rains in autumn. Nitrogen resources which could not be utilized in summer were then translocated to the groundwater.

**Potassium contents.** The limiting value for potassium for the IV class of water quality is 20 mg K/ $\text{dm}^3$ .

In piezometer water it was found from 5 to 68 mg K/ $\text{dm}^3$  in 2004; from 7 to 20 mg in 2005 and from 5-14 mg K/ $\text{dm}^3$  in 2006. The piezometer water at the upland (P5 and P8) contained 7 – 28 mg K/ $\text{dm}^3$ , while water from the reference well (SD) contained from 7 to 41 mg K/ $\text{dm}^3$ .

Noteworthy are significantly higher potassium contents in all the groundwater samples found in the year 2004 (5 - 68 mg) than those found in the years 2005 and 2006

(5–20 mg K/dm<sup>3</sup>). Further study will reveal whether these represent a decreasing trend or an incidental result.

**Sodium contents.** The limiting value for the IV class of water quality is 300 mg Na/dm<sup>3</sup>. The highest sodium levels were found in piezometer water at the embankment crown: 285-722 mg Na/dm<sup>3</sup> in the year 2004; 214–381 mg in the year 2005 and 166-291 mg Na/dm<sup>3</sup> in the year 2006.

In P6 and P7 at the foot of the embankment less sodium was found in 2004 (76 and 137 mg) than later, in the years 2005 and 2006 (66–306 mg/dm<sup>3</sup>).

Water from the reference well (SD) likewise water from P1–P4 piezometers contained most sodium (248 mg) in 2004, and least (175 mg) in 2006.

The sodium contents in water of Odra river (in the years 2005 and 2006) approximated the values found in water from P1–P4 piezometers.

Noteworthy is the finding that sodium levels found in the groundwater at the upland were many times lower (P5 and P8) in 2004 (36 and 51 mg/dm<sup>3</sup>) than in the following years (2005 - 198 and 188 as well as 110-123 mg/dm<sup>3</sup> in the year 2006).

A comparison of sodium content in both piezometer water and water from the reference well (in the years 2005 and 2006) with the content in the Odra river water provides evidence that the storage site does not increase the sodium concentration in the river.

**Phosphorus contents.** The limiting value for the IV class of water quality is 5 mg PO<sub>4</sub>/dm<sup>3</sup>. Water sampled from P1–P4 and P6 indicated from 0.26 to 3.18 mg PO<sub>4</sub>/dm<sup>3</sup> in the year 2004, 0.29–0.66 mg in the year 2005 and 0.21-0.75 mg PO<sub>4</sub>/dm<sup>3</sup> in the year 2006. Water sampled from the reference well (SD) contained 0.08–0.15 mg PO<sub>4</sub>/dm<sup>3</sup> while water from the Odra river – 0.06–0.16 mg PO<sub>4</sub>/dm<sup>3</sup>. Thus it can be assumed that the intercept of Odra along the waste storage site does not carry any increased concentration of phosphorus.

Moreover, water taken from P8 (runoff towards the storage site) contained from 0.12 to 0.47 mg PO<sub>4</sub>/dm<sup>3</sup>, i.e. a lot more phosphorus than the leakage water (SD) and water in the Odra river.

**Sulphate content.** The limiting value for the IV class of water quality is 500 mg SO<sub>4</sub>/dm<sup>3</sup>. In water taken from P1–P4 and P6 it was found 87-314 mg SO<sub>4</sub>/dm<sup>3</sup>. Significantly lesser amounts of sulphates were determined in water from P7 (71-83 mg) and from SD (52-66 mg). The groundwater at the upland (P8) contained from 71 to 114 mg SO<sub>4</sub>/dm<sup>3</sup>. Noteworthy is a very high level (610 mg SO<sub>4</sub>) in water from P5 in the year 2004 as well as a very high decrease (70–80 mg) over the years 2005 and 2006. Such a high content of sulphates was caused by the hydraulic separation of slag from the furnace waste in the yard adjacent to the P5 site.

The runoff from the storage site flowing into Odra river (P7 and SD) contained from 52 to 83 mg SO<sub>4</sub>/dm<sup>3</sup>, while water in Odra contained from 40 to 101 mg SO<sub>4</sub>/dm<sup>3</sup>. Account taking of sulphate value of 71-114 mg SO<sub>4</sub>/dm<sup>3</sup> in the groundwater flowing down from the upland to the valley (P8) ...

**Chloride content.** The limiting value for the IV class of water quality is 500 mg Cl/dm<sup>3</sup>. Water from P1–P4 and P6 contained from 142 to 388 mg Cl/dm<sup>3</sup>, while water from the reference well (SD) – from 52 to 275 mg Cl/dm<sup>3</sup>. A many times lower amounts of chlorides (35–71 mg) were detected in water from P7. In water from Odra river there was found

from 101 to 185 mg Cl/dm<sup>3</sup>. Noteworthy are elevated levels of chlorides (237 and 205 mg Cl/dm<sup>3</sup>) in P5 and P8 determined in the year 2005 and, at the same time, much lower amounts (55 – 165 mg) found in the years 2004 and 2006.

A sudden increase in Cl content in water sampled from P5 and P8 (in the year 2005) could have been a consequence of the summer-autumn drought.

**Ether extract content.** In water from the piezometers P1 – P4 and P6 and P7 from 1.7 to 5.2 mg extract/dm<sup>3</sup> was detected.

The contents of extract were higher (3.0 – 5.2 mg/dm<sup>3</sup>) in the year 2004 than those in the year 2006 (1.7 – 4.1 mg/dm<sup>3</sup>).

Water sampled in the reference well contained from 1.1 to 1.8 mg of extract, while water in Odra river from 1.3 to 2.2 mg/dm<sup>3</sup>. Thus it can be inferred that the waste storage site does not increase the content of ether extract in the adjacent river. Additionally, noteworthy are considerable contents (2.1 – 4.4 mg/dm<sup>3</sup>) of ether extract in the groundwater from P5 and P8 located outside the impact of waste storage site.

**Organic substance contents (TOC)** in all the analyzed samples of groundwater and leakage water fluctuated within the limits from 30.7 to 56.8 mg/dm<sup>3</sup>. In water from P1 – P4 there was found from 32.1 to 56.8 mg/dm<sup>3</sup>, at the foot of the embankment (P6, P7 and SD) – from 30.7 to 50.1 mg/dm<sup>3</sup>; at the upland (P5 and P8) - from 32.4 to 41.1 mg/dm<sup>3</sup>, while in water of Odra river there were from 27.1 to 3.2 mg/dm<sup>3</sup> of organic substances.

Particular attention shall be turned to the convergence of contents of organic substance in the groundwater of the upland (35.2 – 44.1 mg/dm<sup>3</sup>) sampled from P8 and in water from the reference well (SD), i.e. 37.0 – 43.8 mg/dm<sup>3</sup>.

The groundwater quality in the extended network of points was examined in October 2004, at the stage of development of the reclamation design.

The existing groundwater monitoring network was supplemented with:

- probes (S2, S3, S8 and S9) placed at the floodplain terrace, chiefly at the foot of the storage site embankment
- probes (Z1, Z3, Z4 and Z5) placed in lagoons in diatomaceous earth deposits,
- probe (S1) located at the internal dyke of the storage site (Fig. 1)

Contents of organic carbon ether extract, nitrogen, phosphorus, potassium and sodium were determined as well as electric conductivity and pH.

**Organic carbon contents** were highest (64.2 – 114.5 mg/dm<sup>3</sup>) in water from piezometers placed at the embankment crown. Lower values (64.2 – 56.5 mg/dm<sup>3</sup>) were found in water from deposits in lagoons. In the groundwater of the floodplain terrace it was found from 44.6 to 71.4 mg C/dm<sup>3</sup>.

The groundwater of the upland contained 41.1 and 55.2 mg C/dm<sup>3</sup>.

Noteworthy is a low content of organic carbon (36.1 mg) in the groundwater from the internal dyke (S1). This provides evidence that the degree of permeation of dissolved organic compounds from the deposits of oily diatomaceous earth to the groundwater in the mid-lagoon dyke is very low. The content of organic carbon found there was lower than that detected in the groundwater of the upland (41.1 and 55.2 mg).

**Contents of ether extract** in the groundwater of the upland were 2.1 and 2.6 mg/dm<sup>3</sup>. They may be taken as the background values.

Water of the floodplain terrace contained from 2.4 to 3.6 mg of the extract. The exception was the value of 6.4 mg at the point of S3 where there distinctly increased amounts of nitrogen ( 1.22 mg) and phosphorus ( 0.69 mg) were detected.

Water from the diatomaceous earth deposit in lagoons contained from 3.2 to 7.4 mg of extract. In the piezometer water from the embankment it was found from 3.7 to 5.2 mg of extract, while in the groundwater of internal dyke there was 3.3 mg of extract.

**Nitrogen contents** were contained within the range of :

- 0.71 – 1.74 mg/dm<sup>3</sup> in groundwater of the embankment crown,
- 0.54 – 1.18 mg/dm<sup>3</sup> in water of the diatomaceous earth deposit,
- 0.56 – 1.26 mg/dm<sup>3</sup> in water of the floodplain terrace,
- 0.52 mg/dm<sup>3</sup> in groundwater of the upland,
- 0.46 mg/dm<sup>3</sup> in groundwater of the internal dyke.

**Phosphorus contents** were highest (0.64 – 0.76 mg/dm<sup>3</sup>) in the groundwater of the embankment crown and significantly lower (0.19 – 0.62 mg) in waters of the diatomaceous earth deposit. The groundwater at the floodplain terrace contained from 0.29 to 0.69 mg P/dm<sup>3</sup>.

In the upland groundwater the contents of 0.29 and 0.39 mg P/dm<sup>3</sup> were determined. An increased content of phosphorus (0.46 mg) was found in the groundwater of the internal dyke. Spatial differentiation of the phosphorus content in the groundwater provides evidence that the element migrates from lagoons to the adjacent sites (P1 – P4, P7 and S3) where this concentration is higher (0.56 – 0.76 mg) than in the water from deposits in settling ponds (0.19 – 0.62 mg P/dm<sup>3</sup>).

**Potassium contents** are similar (17.7 – 31.2 mg/dm<sup>3</sup>) in all the analyzed groundwater samples. Within the above range the value of 22.7 mg K/dm<sup>3</sup> which was found in water from Odra river is also contained.

**Sodium contents** were highest (378 - 442 mg/dm<sup>3</sup>) in water taken at the crown of the embankment, although the groundwater sampled from the internal dyke contained only 72 mg Na/dm<sup>3</sup>. The groundwater from settling lagoons contained 92 - 204 mg Na/dm<sup>3</sup>. A high salinity (401 mg Na) was detected in water sampled from P5, which is located close to the yard where hydraulic separation of slag from furnace waste is conducted. A large spatial variability of Na contents (85 – 370 mg) in the groundwater of the floodplain terrace might not be dependent upon the impact of the waste storage site.

**Electric conductivity** of water sampled in settling ponds attained from 1275 to 9720 μS/cm. Such a high spread of values of the above parametr does not find suitable justification in the values of remaining parameters of the waters examined.

The groundwater of the embankment crown has shown from 2380 to 4810 μS/cm, while water at the adjacent floodplain terrace - from 1620 to 3006 μS/cm.

Water in Odra river has shown 1446 μS/cm, while the groundwater of the upland (P8) - 863 μS/cm.

**The reaction** of the groundwater (except for settling ponds) was close to neutral (pH 6.4 – 7.3). The groundwater of settling ponds (Z1, Z3, Z4, Z5) has shown the pH from 5.2 to 6.7. Thus the water has not had any significant effect on the reaction of the groundwater in the surrounding area.

**Table 4.** Properties of ground- and lagoon water in the extended monitoring network within the area affected by the oily diatomaceous earth deposit storage site at Brzeg, October 2004

Measurement point*	Organic carbon	Ether extract	Nitrogen	Phosph.	Potass.	Sodium	Electric conductivity μ s/cm	pH
	mg/dm <sup>3</sup>							
Crown of embankment								
P1	97,4	4,5	0,88	0,76	27,1	442	2745	6,9
P2	79,1	5,1	0,93	0,71	22,4	411	4810	7,2
P3	64,2	3,7	0,71	0,64	28,5	378	2900	6,9
P4	114,5	5,2	1,74	0,68	26,3	398	2380	6,9
Internal dyke at storage site								
S1	36,1	3,3	0,46	0,46	25,4	72	2625	7,3
Foot of the embankment (floodplain terrace)								
P6	52,3	3,6	0,63	0,29	23,8	85	2028	7,2
P7	60,8	3,0	0,91	0,56	28,6	169	2180	7,1
S2	44,6	2,8	0,56	0,32	23,4	107	2530	7,2
S3	77,4	6,4	1,22	0,69	19,3	171	2994	7,0
S8	71,4	2,9	1,26	0,52	31,2	370	3006	6,9
S9	49,2	2,4	1,04	0,42	26,3	199	1620	7,0
Settling ponds								
Z1	64,7	3,2	0,74	0,39	21,5	146	9720	5,2
Z3	82,2	6,6	1,18	0,62	17,7	106	1275	6,6
Z4	96,5	7,4	0,93	0,32	26,4	204	2260	6,7
Z5	69,6	3,2	0,54	0,19	28,7	92	6450	5,9
Upland								
P5	55,2	2,6	0,52	0,39	24,1	401	1238	6,4
P8	41,1	2,1	0,52	0,29	20,8	92	863	7,1
Odra river (water level gauge)								
W5	33,4	1,9	0,40	0,17	22,7	76	1446	7,2

\*Location of measurement points is presented in Figure .....

Summing up the whole body of results of study made within the area adjacent to the oily diatomaceous earth waste storage site, it can be assumed that the impact of the site upon the groundwater quality in the Odra river valley is relatively small and, at the upland, it is non-existent.

#### In the year 2007:

- 1) Dewatering and deoiling of lagoons has been continued,
- 2) Biopreparation has been applied on oily surfaces of the deposit,
- 3) A soil forming layer has been spread over the dewatered surfaces of the deposit in lagoons No 1, 2, 3 and 4,
- 4) Humus forming mass of organic waste has been overlaid on the soil forming layer and dewatered surfaces of the diatomaceous earth deposit,

**Table 5.** Groundwater properties within the area affected by the oily diatomaceous earth deposit storage site at Brzeg

Parameter	Day	Location of measurement points*									
		Embankment crown				Foot of embankment			Upland		Odra river
		P1	P2	P3	P4	P6	P7	SD	P5	P8	W5
pH	10.12.04	7,2	7,3	6,9	7,0	7,6	7,4	7,4	7,3	7,6	n.d.
	21.10.05	6,9	7,0	6,8	6,8	7,0	7,0	7,7	7,1	7,3	7,6
$\mu$ s/cm	10.12.04	2890	5000	2600	2750	1936	1655	2210	1358	938	1446
	21.10.05	2916	4900	2868	2340	2216	1800	521	1170	1080	1548
mg/dm <sup>3</sup>											
Organic carbon	26.09.05	48,9	36,5	51,7	44,5	40,9	47,3	43,8	32,4	35,2	37,1
	13.11.06	56,8	41,2	48,3	32,1	50,1	30,7	37,0	35,0	44,1	27,2
Ether extract	10.12.04	4,5	5,1	3,7	5,2	3,6	3,0	n.d.	2,6	2,1	1,9
	26.09.05	3,2	4,0	5,2	2,8	3,1	2,6	1,8	4,4	3,7	2,2
	13.11.06	4,1	3,1	3,7	2,4	4,0	1,7	1,1	2,9	2,2	1,3
Sulphates	10.12.04	62	< 10	13,6	13,6	141	81	66	610	114	n.d.
	26.09.05	110	288	130	87	142	71	52	70	90	101
	13.11.06	103	203	99	91	314	83	64	80	71	89
Chlorides	10.12.04	253	294	244	190	172	35	164	94	55	n.d.
	26.09.05	260	388	229	274	142	71	52	237	205	101
	13.11.06	250	280	225	170	175	45	275	65	165	180
N-NH <sub>4</sub>	10.12.04	17,0	39,6	10,1	9,2	8,9	< 0,2	5,3	3,4	< 0,2	n.d.
	26.09.05	0,7	0,6	0,4	1,1	3,2	1,6	0,7	0,6	0,5	0,4
	13.11.06	3,8	0,2	4,0	0,8	3,9	0,7	0,1	2,3	0,1	0,5
N-NO <sub>2</sub>	10.12.04	0,02	0,02	0,02	0,02	0,02	0,74	0,10	0,13	0,20	n.d.
	26.09.05	0,14	0,10	0,26	0,20	0,64	0,19	0,12	0,24	0,07	0,07
	13.11.06	0,02	0,01	0,13	0,06	0,01	0,01	0,22	0,10	0,08	0,18
N-NO <sub>3</sub>	10.12.04	< 0,02	< 0,02	< 0,02	< 0,02	< 0,02	10,65	1,34	1,48	10,7	n.d.
	26.09.05	2,6	1,4	4,5	2,2	2,1	3,4	7,6	6,0	8,3	3,9
	13.11.06	0,25	0,15	0,20	0,80	4,7	4,7	8,4	0,25	58,0	11,1
Potassium	10.12.04	68	5	40	46	49	12	41	24	28	n.d.
	26.09.05	14	20	10	13	12	16	8	9	7	10
	13.11.06	12	12	14	9	5	6	11	7	8	4
Sodium	10.12.04	395	722	285	291	137	76	248	51	36	n.d.
	26.09.05	214	381	224	221	263	223	198	198	188	241
	13.11.06	196	291	177	166	306	66	175	110	123	180
Phosphates	10.12.04	0,47	0,90	0,26	0,34	3,18	< 0,5	0,08	1,30	0,47	n.d.
	26.09.05	0,36	0,29	0,30	0,34	0,66	0,19	0,09	0,23	0,12	0,09
	13.11.06	0,32	0,81	0,44	0,21	0,78	0,04	0,15	1,68	0,28	0,10

\* Location of piezometers (P1 – P8), reference well (SD) and water level gauge (W5) in Odra river is illustrated in Fig.1.

- 5) Mixture of grasses has been sown on the soil forming layer surfaces,
- 6) Vertical drainage has been installed for degasification and aeration of deposits,
- 7) Sprinkling machine has been installed for irrigation of plants,
- 8) Monitoring has been conducted of groundwater quality and gas composition at the storage site,
- 9) Photodocumentation has been made of dewatering, deoiling and modifying the deposit surface in lagoons,
- 10) Photodocumentation has been made of shaping of the soil forming layer of earth and the development of vegetation cover.

The advances of reclamation work, with special emphasis on spreading of the soil forming layer of mineral earth and on the development of vegetation cover are illustrated in Photos 30 and 40.

The soil forming layer of mineral earth has already been spread over about 60% of the surface of the diatomaceous earth storage site including the surface of internal dykes. The entire surface will be covered with vegetation by the end of autumn 2007.

It should be mentioned that the earth layer overlaid and the vegetation cover introduced constitute a preliminary stage of reclamation owing to the progress in deposit subsiding and its surface deformation.

## References

1. BIOS. Reclamation design of the oily diatomaceous earth storage site at the EWICO Co. Ltd Plant at Brzeg. Warszawa, March 2005 r. In Polish.
2. BIOS. Report of the work conducted in the year 2005 for the reclamation of the oily diatomaceous earth storage site at the EWICO Co. Ltd Plant at Brzeg. Warszawa, December 2005. In Polish.
3. Garus D., Kiepuski J., Siuta J. 1998: Degreasing and reclamation of the waste spillage site at Brześć on Gopło Lake. Technologies for degreasing of wastewater, waste and grounds. I Scientific-Technical Conference. PTIE. Kruszwica 1998: 13-22. In Polish.
4. Decree of the Minister of the Environment as of 24 March 2003, on detailed requirements concerning location, building, exploitation and closure which have to be met by respective types of waste landfills (Official Journal No 61, item 549).
5. Siuta J. 1998: Management of protein-fatty decoction spillage site with the use of vegetation. Technologies for degreasing of wastewater, waste and grounds. I Scientific-Technical Conference. PTIE. Kruszwica 1998: 23-24. In Polish.
6. Siuta J., Sienkiewicz R., Kaźmierczuk M., Puszkarski L. 1997: Dewatering of lagoons and sewage sludge treatment using vegetation at the „Hajdów” wastewater plant. Use of sewage sludge for natural management. II Scientific-Technical Conference. IOŚ. Puławy-Lublin-Jeziórko 26-28.05.1997: 23-38. In Polish.
7. Act of 27 April 2001 – Law on the Protection of the Environment (Official Journal. No 68, item 627).

---

Prof. dr hab. Jan Siuta – Institute of Environmental Protection in Warsaw

Mgr inż. Danuta Garus – PUH „BIOS” s.c. in Warsaw

Mgr Wiesław Openchowski – „GEOSYSTEM Wiesław Openchowski” in Warsaw