Anthropogenic reservoirs in sand pits in the area of Upper Silesian Coal Basin (southern Poland)

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ABSTRACT
Sands of Pleistocene origin have been used for ca. 100-110 years for hydraulic filling in hard coal mines in Upper Silesian Coal Basin. Water reclamation is the basic method of reclaiming surface sand workings. In the years 1938-1976 in sand workings ca. 20 reservoirs emerged with a total area and volume 22,9 km^2 and 210,8 mill m^3 accordingly. Water reservoirs are serving at the moment different purposes: recreation, anti-flooding, sailing and as potable water. Prognoses forecast that in future, until 2030, within the area of four active surface sand mines four reservoirs will emerge with a total of ca. 100 mill m^3.

INTRODUCTION

SURFACE MINING OF THE FILLING SANDS IN SOUTHERN POLAND
In 2005 the so-called filling sands will have been used for an industrial scale for 115 years in the Polish hard coal mining of the Upper Silesian Coal Basin (USCB). It was probably in the late 80's and early 90's of the 19th century that there was observed a natural, self-acting entrance of the quicksand from the above lying Pleistocene layer into the underground workings within the exploitation area of the hard coal outcrop in one of the mines in north-east part of USCB, and then their filling. In 1894 sand transported with water was used to extinguish the fire that burst up near the main shafts of the already closed hard coal mine in the above mentioned part of the USCB (Lisowski 1997). In the first 40-50 years filling sands were extracted mainly from small (several–several dozen hectares in area) sand pits, localized in the neighborhood of hard coal mines in several towns of northern part of USCB (Fig. 1). Intensive development of surface mining of filling sands started after the Second World War, in the 50's and 60's of the 20th century. It was due to, among others, taking significant amounts of hard coal from protective pillars created for built-up areas and other important protected objects on the surface. At this time filling sands were exploited, among others, in huge mines such as Pławniowice and Przezchlebie near Pyskowice, Chechło near Tarnowskie Góry and Brzezinka and Dziećkowice in the Przemsza valley near Mysłowice (Fig. 1).

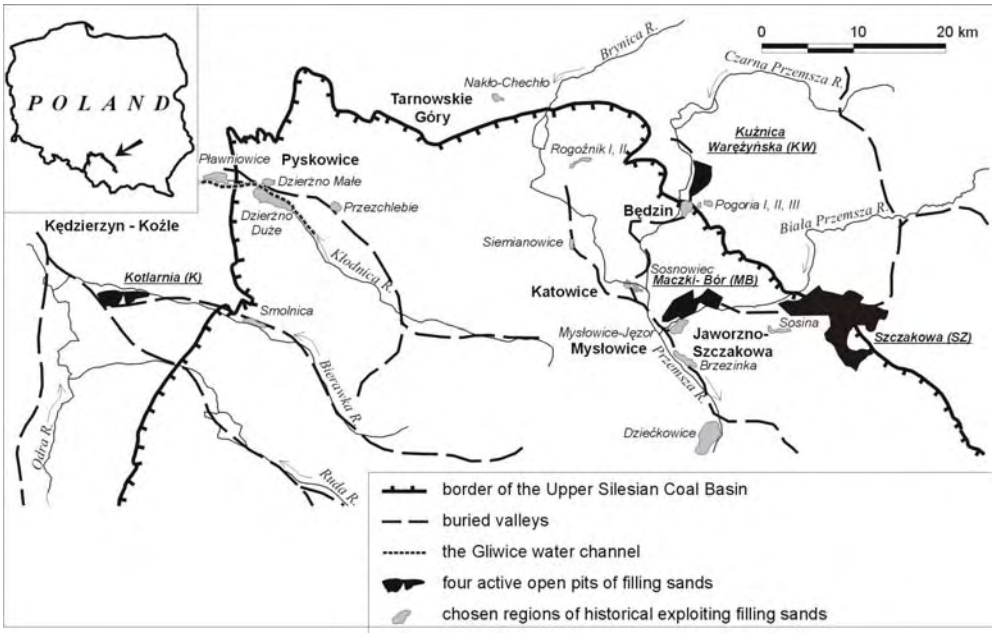

Figure 1: Location of the surface filling sand mines versus the extend of the Upper Silesian Coal Basin

In the beginning of the 60's of the 20th century sands were exploited on the area of ca. 3,40 km^2. In the following period each year ca. 2,0–3,0 km^2 of new sand pits appeared (Krzaklewski 1990). In the second half of the 70's and 80's of the 20th century hard coal mining in USCB started to prefer roof caving exploitation of deposits and both the demand for filling sands and the rate of enlarging the exploited area decreased significantly. Sand mining from its beginnings until 01.01.1988 had taken ca. 107,0 km^2 for industrial purposes. The area that is being industrially used at present amounts to ca. 44,9 km^2, out of which ca. 7,11 km^2 is being exploited for filling sands.
In the 60's and 70's of the 20th century, the time of the greatest demand for sands, their total average exploitation per year exceeded 30,0 mill m³, while in 1970 hard coal mines were supplied with more than 45,0 mill m³ of filling sands (Lisowski 1997). At present their exploitation amounts to ca. 3,0-4,0 mill m³ per year.
The form, structure, thickness and water inflow into the deposits of filling sands as well as the quality of extracted deposits were determined by pre-Pleistocene land form and accumulative activity of glacial and river waters. The most significant role was played here by Miocene - lower-Pleistocene land forming process, during which in the area of southern Poland buried valleys appeared with quite steep slopes and basin-like lowerings of valley type, cut into under-Pleictocene surface at the depth ranging from several dozen up to 100 metres. In several stages of lower and middle Pleistocene, proglacial, extraglacial and river waters connected with the three subsequent glaciations [of Odra, Warta and Vistula], accumulated in most cases of sand and sand-gravel type material in the mentioned morphological lowerings (Lewandowski & Zieliński 1988).
Filling sands deposits that are being documented at the moment are exploited in 4 surface mines (Figs. 1 & 2). Kotlarnia mine (K) is situated on the western border of USCB. This mine exploits the upper level of sands and gravel from the depth of several up to 20 m. The three remaining surface mines, Kuźnica Warężyńska (KW), Maczki-Bór (MB) and Szczakowa (SZ), are situated on a strongly morphologically and geologically differentiated Silesian Upland, within the range of buried valleys and lowering of valley-type. Pleistocene deposits are very poorly varieted in lithology, with a very significant dominance of sand- and sand-gravel deposits. The subject of exploitation in the above mentioned pits are fine- and medium- grained sands with local insertions of coarse-grained sands, gravel and boulders (mainly in the bottom). In natural conditions maximal thicknesses of these deposits amounted to 20-60 m. Deposits are exploited by open digging, wall-exploitation system, with the average length and height of the slopes 1500-2000 m and 3-13 m accordingly. Deposits are extracted on one-two (K mine) up to three-four (mines KW, MB and SZ) levels, but only in mines KW and MB up to the bottom of the deposit. Maximal depths of the mine workings range from 20 m (mine K) up to 30-35 m (mines KW, MB and SZ). In the bottom of the extracted deposits occur loam, stagnant silts and clays with varieted thickness in the K mine and, in the remaining mines, the mudstone-claystone-sandstone deposits of Upper Carboniferous (Namurian A- Westphalian B), of Permian (Rotliegendes), and of Upper and Middle Bunter Sandstone, all with different permeability. Hydrogeological problems of the discussed surface mines were presented in Table 1.

RECLAMATION OF THE SAND MINE WORKING. WATER RESERVOIRS IN WORKINS

Enormous demand for filling sands in the end of the 50's of the 20th century caused, as the first consequence, rapid running out of smaller deposit resources. Extensive economy of that time, based mainly on hard coal mining and heavy industry, was accompanied by huge amounts of mining waste, and waste of metallurgical and power engineering source. Industrial lobby of high influence led to creating in some sand mine workings dumps of industrial waste, especially of mining origin.
At present, for the last 15 years, surface mining of filling sands in Poland, proceeds first of all in two basic directions of reclaiming its workings: forestation and water reclamation. Water reclamation requires rational management of sand deposits and highly advanced mechanization of mining, which makes it necessary to exploit the deposits up to the very bottom and to apply artificial drainage. The majority of sand workings within the analyzed area were reclaimed by means of flooding. The reservoirs that appeared independently after the Second World War (among others: reservoirs of Dzierżno Duże, Gliwice-Czechowice, Pogoria I; Table 2) were lacking in a properly shaped coast line and hydro technical equipment, which, as a consequence, led to uncontrolled height of damming up and flooding neighboring areas.

Table 1. Kotlarnia (K), Kuźnica Warężyńska (KW), Maczki-Bór (MB) and Szczakowa (SZ) active sand pits. Hydrogeological issues.

Sand pits ---------- ---------- ---------- ---------- Year of starting exploitation ---------- ----------	Aquifer's thickness in the natural condition [m] ---------- ---------- ---Hydraulic conductivity $k_{av.}$. [m/24h]	Inflow $Q_{av.}$.[m^3/min] ---------- ---------- ---------- Drawdowns [m]	Range of mining drainage [km^2] ---------- ---------- ---------- Depression cone in the Pleistocene aqufers (from mine working edge)	Expected end of exploitation ---------- ---------- ---------- ---------- Type of reclamation: planned area and volume of a reservoir

---------- ---------- -------- Mining area [km^2]			R [m]	
K ---------- ---------- ---------- ---------- ---------- 1966 ---------- ---------- ---------- ----- 14.187	several – 44.0 ---------- ---------- ---------- ---------- ---- 13.5	23.7 ---------- ---------- ---------- ---------- - 1.0 – 16.0	13.6 ---------- ---------- ---------- ---------- 250 – 550	2016 r. ---------- ---------- ---------- ---------- water: 8.5 km^2 28.0 mill m^3
KW ---------- ---------- ---------- ---------- ---------- 1967 ---------- ---------- ---------- ----- 12.713	several – 32.0 ---------- ---------- ---------- ---------- ---- 14.1	19.1 ---------- ---------- ---------- ---------- - 1.0 – 30.5	18.5 ---------- ---------- ---------- ---------- 250 – 950	2030 r. ---------- ---------- ---------- ---------- water: 5.0 km^2 61.0 mill m^3
MB ---------- ---------- ---------- ---------- ---------- mid-war period ---------- ---------- ---------- ----- 7.965	several – 25.0 ---------- ---------- ---------- ---------- ---- 23.2	16.5 ---------- ---------- ---------- ---------- - 1.0 – 24.0	13.6 ---------- ---------- ---------- ---------- 250 – 850	2013 r. ---------- ---------- ---------- ---------- industrial-water: 1.0 km^2 10.0 mill m^3
SZ ---------- ---------- ---------- ---------- ---------- 1954 ---------- ---------- ---------- ----- 20.040	several – 55.0 ---------- ---------- ---------- ---------- ---- 11.4 – 48.4	81.1 – 85.2 ---------- ---------- ---------- ---------- - 1.0 – 30.0	88.9 ---------- ---------- ---------- ---------- 100 – 1350	2018 r. ---------- ---------- ---------- ---------- forestation or forest-water: 1.0 km^2 2.0 mill m^3

These factors had a decidedly bad influence on rational management of reservoirs, and first of all inhibited them from being fully utilized as recreation objects (Krzaklewski 1990). Water reclamation performed in later period was to prevent the effects mentioned above and resulted in earlier formation of slopes and head of the reservoir, building hydro technical objects that ensured optimal height of damming up and, as far as possible, allowing water inflow into the reservoir and proper arrangement and biological reclamation of inshore areas (Czuber 1988). The mentioned actions caused in the past successful water reclamation aimed at recreation of such reservoirs: Pławniowice, Nakło-Chechło, Rogoźnik I and II near Będzin, as well as Sosina in the part of reclaimed sand mine SZ in Jaworzno-Szczakowa (Fig. 2D).

In the years 1938-1976 altogether over a dozen of water reservoirs appeared (Table 2). In some cases there is no data kept concerning the geometry of sand workings and this is why their present depth's conditions are not known. Seven reservoirs in shallow sand workings localized on the border of the cities of Sosnowiec and Katowice shall be distinguished within this number. Their area ranges from 0,067 up to 0,368 km^2, which isaltogether 1,17 km^2. The area of the remaining 12 reservoirs ranges from 0,14 up to 7,1 km^2. Total area of the discussed reservoirs amounts to 22,9 km^2. Maximum depths range from 3,0 to 19,0 m; and their total volume - from 0,63 to 94,0 mill m^3 (Table 2).

Table 2. Water reservoirs created in the surface sand minings in the northern part of USCB in the years 1938-1976

Water reservoir	Year of emergence	Total volume at maximal damming up [mill m^3]	Area at maximal damming up [km^2]	Maximum depth [m]	Water reservoir purpose[1]
Pławniowice	1976	29,1	2,4	17,0	R
Dzierżno Duże	1964	94,0	6,2	19,0	S, AF
Dzierżno Małe	1938	14,1	1,3	15,0	AF, S
Gliwice Czechowice	before 1945	-	0,14	-	R
Nakło-Chechło	1960-1965	1,48	0,9	3,0	R
Rogoźnik I	-	-	0,21	-	R
Rogoźnik II	-	-	0,12	-	R
Pogoria I	1943	3,4	0,7	8,0	R
Pogoria II	-	0,63	0,24	4,0	X
Pogoria III	1973-1974	12,0	2,0	15,5	R, AF
Sosina	1973	1,31	0,44	3,0	R
Sosnowiec[2]	-	2,3	1,17	3,50	R
Dziećkowice	1976, 1996[3]	52,5	7,1	14,5	PW

[1]-water reservoir purpose: AF-anti-flooding, S-sailing, R-recreation, X-others, PW-potable water,
[2]-altogether seven reservoirs localized on the border of the cities of Sosnowiec and Katowice,
[3]-the year of reservoir's reconstruction.

Water reservoirs that appeared in sand workings are serving at the moment different purposes (Table 2). Decidedly dominant recreation purpose of reservoirs has a particular meaning for densely populated Silesian agglomeration (ca. 2,0 mill people). Three reservoirs have limited, because of their insignificant disposable volumes anti-flooding purpose. Two reservoirs, located in a direct neighborhood of Gliwice water channel, serve for sailing purposes and regulate water amount in the channel. Around the Pogoria II reservoir an ecological arable land was established, i.e. a kind of a protected area. The last of reservoirs (Dziećkowice) plays a very important role in the system of surface reservoirs that supply the mentioned agglomeration with potable water.
A sudden decrease in demand for sands used for filling mine workings in active hard coal mines of USCB in the last 15-20 years led to reducing the rate of their exploitation. KW was the first sand mine, in case of which in 2002 (after the 27 years from the time last reservoirs were created in sand workings), the decision was made up to build a recreation and anti-flooding water reservoir.

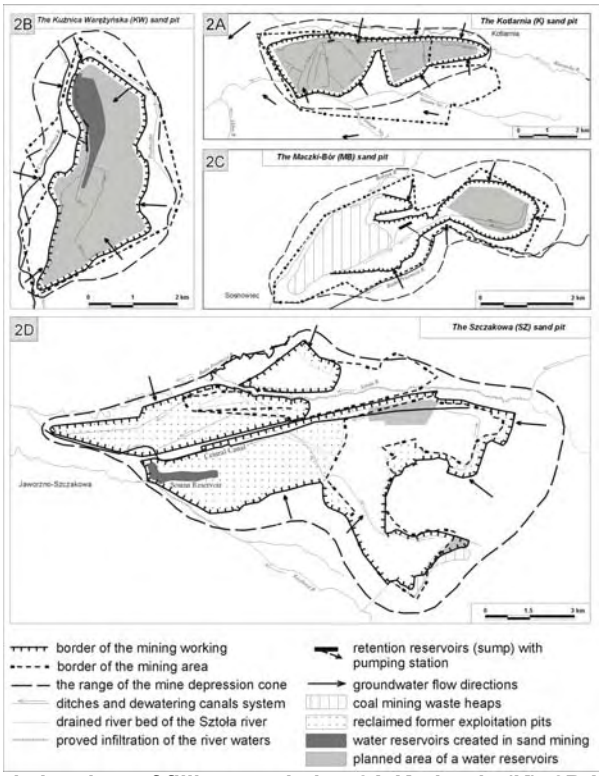

Figure 2: Hydrogeological sketches of filling sand pits: 2A-Kotlarnia (K), 2B-Kuźnica Warężyńska (KW), 2C-Maczki Bór (MB), 2D-Szczakowa (SZ)

KW mine has been extracting sands since 1967, its mining area amounts to 12,7 km². Small- and medium-grained sands are being exploited in an sand pit on 4 exploitation levels up to the bottom of the deposit, i.e. to the average depth of ca. 30-35 m. The drainage system lowered water table by 1,0 – 30,5 m, created the depression cone in the distance of 50 – 950 m from the edge of the pit, and caused that drainage influences the area of ca. 18,5 km² in total. In the area affected by mining drainage, groundwaters belonging to Pleistocene aquifer flow towards the pit, from which place they are then dropped into the nearby river (Kropka & Wróbel 2001). Average water inflow in the years 1996-2004 was 22,1 m³/min (Table 1, Fig. 2B).
In 2003 the pumping station situated below was excluded from the system of draining the pit in this sand mine, which led to water accumulation in northern and middle deepest part of the mine working up to the ordinate of ca. +250 m ASL. As a result a small reservoir emerged, with the area of 1,49 km² and volume of ca. 5 mill m³ of water. The next and final stage of accumulation, up to the ordinate of +264 m ASL, was initiated in December 2004. As a result a reservoir shall appear, with the area of 5 km² and volume of ca. 61 mill m³ of water (Fig. 2B).
Since May 2005 retention of waters in mine workings is aided thanks to the nearby Czarna Przemsza river and Trzebyczka stream flowing along the eastern and northern border of the mine, the waters of which were directed into the workings. The rate of rising water table in the course of creating a small water reservoir in the year 2003 amounted to 0,02-0,03 m/d. This rate in the initial stage of water retention, between December 2004 and May 2005, amounted to 0,03 m/d. Directing river and stream waters to the mine working (with average flow ca. 0,5-0,7 m^3/s), caused increasing this rate since January 2005 up to 0,05 m/d. Water retention in KW mine working did not terminate sand exploitation. At present two strata of sand deposit is being exploited in the north-eastern part of the sand working. The mine is prepared to extract in future (in 2006-2030) sands that lie below the water table.
Forecasts concerning the real termination of mining exploitation in the remaining 3 active mines are very unreliable. It is expected that the first mines that will finish the exploitation might be MB and K mines, in years 2013-2016. Still in the 1980's the forecasts on reclaiming the exploitation areas anticipated enlargement of the existing dumps of industrial waste or building new ones (of mining, power energy or metallurgical origin) in mine workings of K, KW and MB mines. Only waters from the groundwater basin of the central channel within the SZ mine from the very beginning were provided for usable purposes, i.e. water supply system. At present even preliminary analyses and draft presumptions abandoned the industrial administration of exploitation workings and are directly aimed at water reclamation (K; Fig. 2A), forestation or mixed water reclamation-forestation (SZ; Fig. 2D) and industrial-water reclamation (MB; Fig. 2C). Preliminary assumptions provide that water reclamation will comprise the sand mining of K mine in total – the reservoir with the volumne of ca. 28,0 mill m^3 and area of ca. 8,50 km^2. Creating the reservoir with the volume of ca. 10 mill m^3 and area of ca. 1 km^2 in the sand working Bór-Wschód anticipates as well the obligatory local plan of general spatial management of the city of Sosnowiec for

the area covered by exploitation influence of MB mine. In recent years the tendency towards limitation of spatial development of the SZ mine has been still preserving. In the region where mining exploitation is already finished, in the northern part of the deposit, establishing water reservoir of ca. 1,0 km^2 and volume of ca. 2,0 mill m^3 is anticipated (Table 1, Fig. 2D).
In the years 1938-1987 the exploitation of filling sands transformed 25,40 km^2 in the northern part of USCB into water management, out of which 22,9 km^2 had the water table with maximum damming up (Table 2). As results from still very unreliable forecasts 4 water reservoirs might appear within the area of the 4 discussed active mines, with approximated water table 15,5 km^2 and total volume of ca. 101 mill m^3 (Table 1).

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