LOw Carbon After Life: sustainable use of flooded coal mine voids as a thermal energy source - a baseline activity for minimising post-closure enviromental risks

LOCAL

Research Fund for Coal & Steel

LoCAL Deliverable 1.7

Report on Bytom predictive modelling

WP number	WP 1
Partner responsible	GIG

GIG

Deliverable 1.7

Report on Bytom predictive modelling

1. Introduction

The coupled model for mine water flow and heat transfer being developed in frame of Task 1.1 have been applied in Poland, in frame of Task 1.3. Primarily, the model have been applied to Szombierki mine in Bytom. Szombierki mine is closed down, while necessity of dewatering is due to interconnections between active Centrum and Bobrek mines. To compare results from modelling in Szombierki mine, coupled model has been also applied to nearby mines Powstańców Śląskich and Dębieńsko. These mines are also located in Upper Silesian Coal Basin *(*USCB), and their geological and technical structure are in relation to Szombierki mine. Figure 1 shows the location of USCB and the mines of concern.

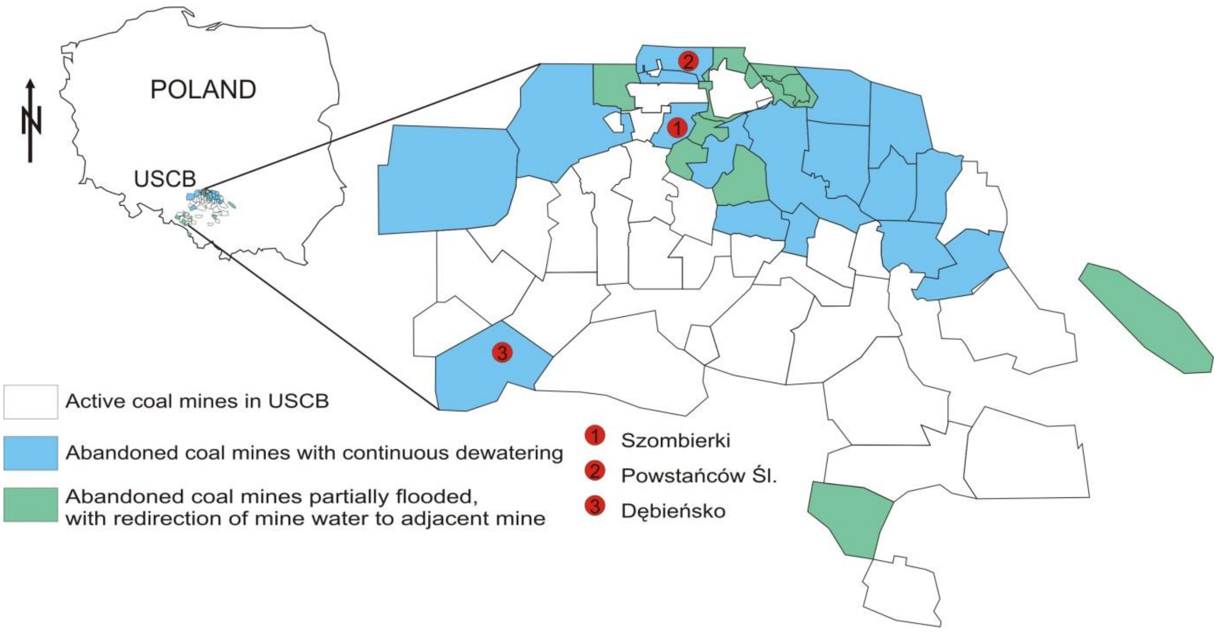


Figure 1. Location of Upper Silesian Coal Basin (USCB) over a contour map of Poland and location of mines of concern within USCB

The model from Task 1.1 is a tool developed in MS Excel in the form of 2 .xls files, each containing several spreadsheets programmed for data input, calculations and visualization of results. Most of the specific parameters are default values, as they are driven by physical properties of water. The localized parameters are: the infiltration temperature (10 degrees C is a value typical for groundwater in Poland), infiltration rate and geothermal gradient (values taken from regional studies), as well as depth of the main flooded levels (galleries network), among others.

The simulation time will be stablished at 200 years in all the cases studied at this report, as the start of simulation is in fact the start of cooling effect. This effect starts not in the moment of the beginning of heat uptake, but right after the start of deep underground exploitation, several decades ago.

The following Figure (Figure 2) presents the comparison of most important input parameters among the different mines studied here: Powstańców Śląskich, Szombierki and Dębieńsko.

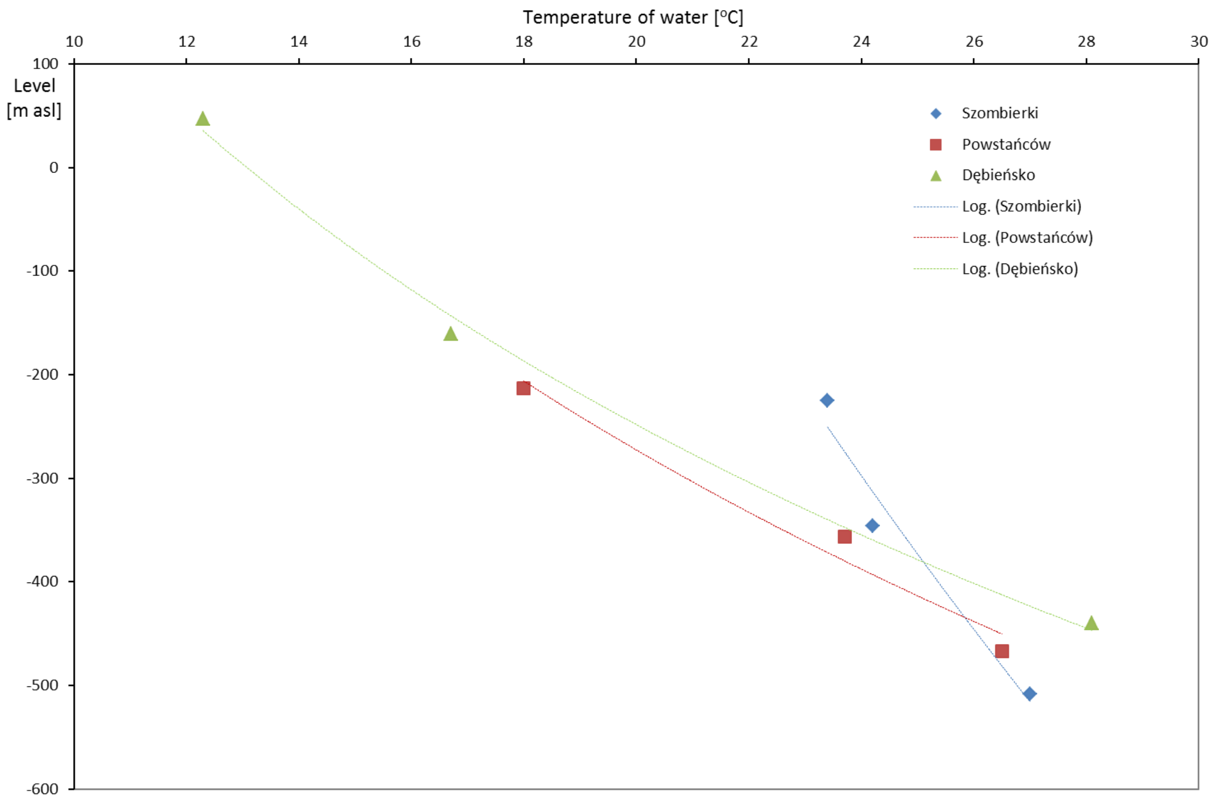


Figure 2. Comparison of temperature of inflow to main levels of the mines Powstańców Śląskich (a), Szombierki (b) and Dębieńsko (c) [CZOK monitoring data].

1. Szombierki mine

The input sheet of the tool filled with the values of Szombierki site, is shown in Figure 3. To better understand the mine geometry, the pumping scheme of Ewa shaft (from which Szombierki mine is dewatered) is provided in Figure 4.

Heat transfer calculator workbook
Pumped abstraction – natural recharge (LoCAL-**PANR**)

Input cells	White
Units conversion	Green
Output cells	Yellow

Version 2.0 dated 01/12/16

Name of the site	Szombierki

MODEL OPTIONS

Use relative length of galleries to distribute recharge (Y/N)	N	Use Row 41 to manually enter recharge distribution
Use geothermal gradient to distribute temperature (Y/N)	Y	
Calculate head dependent flows (Y/N)	N	Use rows 43 and 44 to manually enter flows and temperatures

DEFAULT HYDRAULIC VALUES

Default static water level (m)	20
Default pumping water level (m)	500

SCENARIO FEATURES

Maximum time to be simulated	t	200	years	6,31E+09	s	7,31E+04	d
Infiltration (recharge) rate	R	110	mm/a	3,01E-04	m/d	3,49E-09	m³ of rain/m²
Infiltration temperature	T_a	10	°C				
Geothermal gradient	∇T	0,024	°C/m				
Specific heat of the ground	Ce ground	800	J/ Kg K				
Density of the ground	ρ ground	2500	Kg/ m³				
Thermal conductivity of ground (with ambient saturation)	λ ground	1,86	W/m K				
Thermohydrodynamic dispersivity	B_L	10	m				
Volumetric heat capacity of ground (with ambient saturation)	VHCgr	2,00E+06	J/m³ K	2,00	MJ/m3K		
Thermal diffusivity	α =λ/VHCgr	8,04E-02	m2/d				

MINEWATER FEATURES

Thermal conductivity of water	λ water	0,58	W/m K		
Water kinematic viscosity	υ water	1,24E-06	m²/s		
Specific heat of the water	Ce water	4186	J/ Kg K		
Density of the water	ρ water	1000	Kg/ m³		
Volumetric heat capacity of water	VHCwat	4,19E+06	J/m³ K	4,19	kJ/(L °C)
Thermal velocity	vth	6,30E-04	m/d		
Thermal dispersion	Dth	8,67E-02	m2/d		
Head independent inflows (rain)					
Area of influence of the rain	A	10,27	Km²	1,03E+07	m²
Total flowrate of (natural) recharge	Lo	3,58E-02	m³/s		

	1st level	2nd level	3rd level	4th level	5th level		Total equivalent m of galleries
Depth of main levels recharging the shaft	510	630	790			m	
Row inactive						m	Row inactive
Manual allocation of recharge (%)	23	47	30			%	
Percentage distribution of recharge (%)	23%	47%	30%	0%	0%	%	100%
Flowrate of each level	0,008	0,017	0,011	0,000	0,000	m³/s	

Head dependent inflows (lateral flows)

	1st inflow	2nd inflow	3rd inflow	4th inflow	5th inflow	
Flowrate of each lateral flow (manual entry)	0,045					m³/s
Temperature of each lateral flow (manual entry)	23,20					°C
Flowrate of each lateral flow	0,045	0	0	0	0	m³/s
Temperature of each lateral flow	23,20	0,00	0,00	0,00	0,00	°C

Figure 3. Input parameters for Szombierki mine

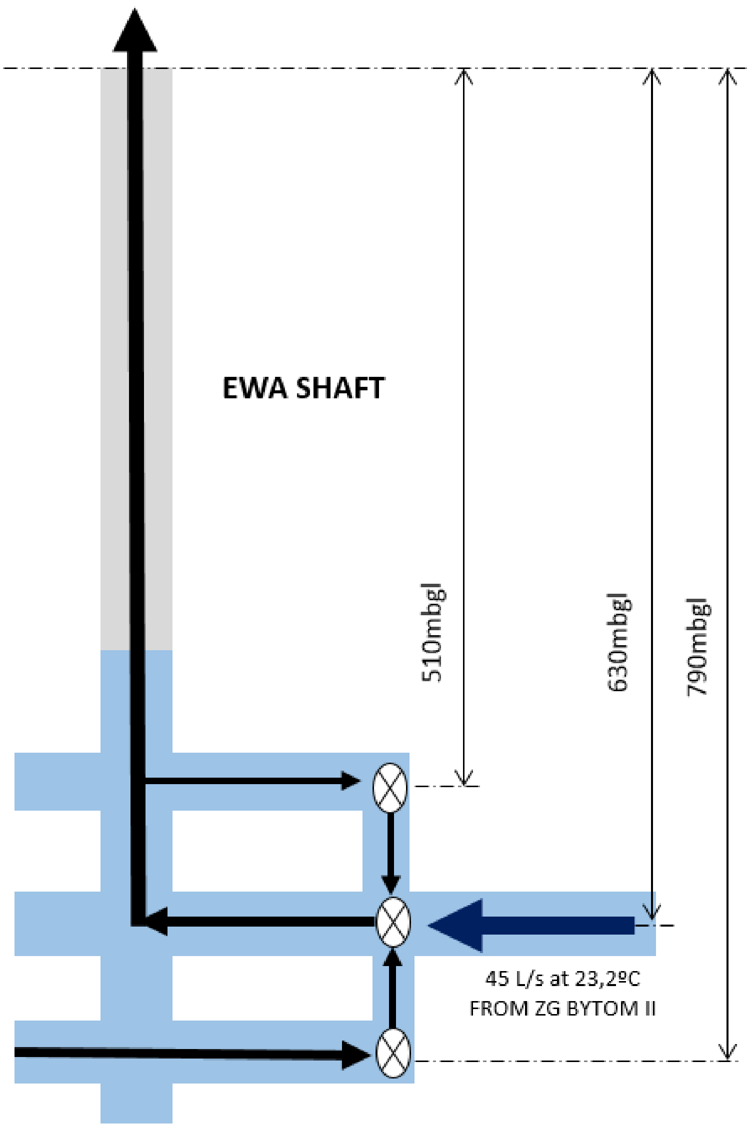


Figure 4. Pumping scheme of Ewa shaft (Szombierki mine)

The results of the modelling tool application to Szombierki mine can be observed in Figure 5. In the rigth hand graph it is possible to see how the propagation of cooling effect, represented by the increase of non-dispersed front depth. This value is predicted to be about 46 meters after 200 years of simulation (this parameter is directly proportional to the simulation time *i.e.* for the same site but a simulation time of 100 years, the non-dispersed front depth is 23 meters). Logically, as the pumping horizonts are deeper than the thermally affected area (510, 630 and 790m, see Figure 4) the pumped flow temperature shows no variation whithin time.

Thus, according to the simulations a 80.80 Ls^{-1} pumped flow of a constant 24.27ºC temperature is expected for this system.

Besides the temperature evolution, this tool provides an estimation of the system energy potential. In this case, supposing a COP of 4 and a temperature step of 5ºC in the heat pump evaporator (both values typical for geothermal heat pumps), the available thermal potential will be 2.25 MW. This value considers only heat supply and can be increased if the heat pump purpose is to provide both heat and cold.

RESULTS SUMMARY

Total Pumping Rate:	80,80	L/s
Pumped temperature after 200years	24,27	°C
ΔT (Temperature decreased)	0,000	°C

EVOLUTION OF THE TEMPERATURE OF THE PUMPED FLOW

Depth of non-dispersed front (m)	Temperature (°C)	Time (y)
0,002	24,26759	0,01
4,605	24,26759	20
9,209	24,26759	40
13,814	24,26759	60
18,418	24,26759	80
23,023	24,26759	100
27,628	24,26759	120
32,232	24,26759	140
36,837	24,26758	160
41,441	24,26757	180
46,046	24,26754	200

ENERGY CALCULATOR

Minewater flowrate	80,80	L/s
Minewater density	1000	kg/m³
Minewater specific heat	4186	J/(kg °C)
ΔT geothermal heat pump	5	°C
COP geothermal heat pumps	4	
Minewater Thermal Potential	**1,69**	**MW**
Heat pump Thermal Potential	**2,25**	**MW**

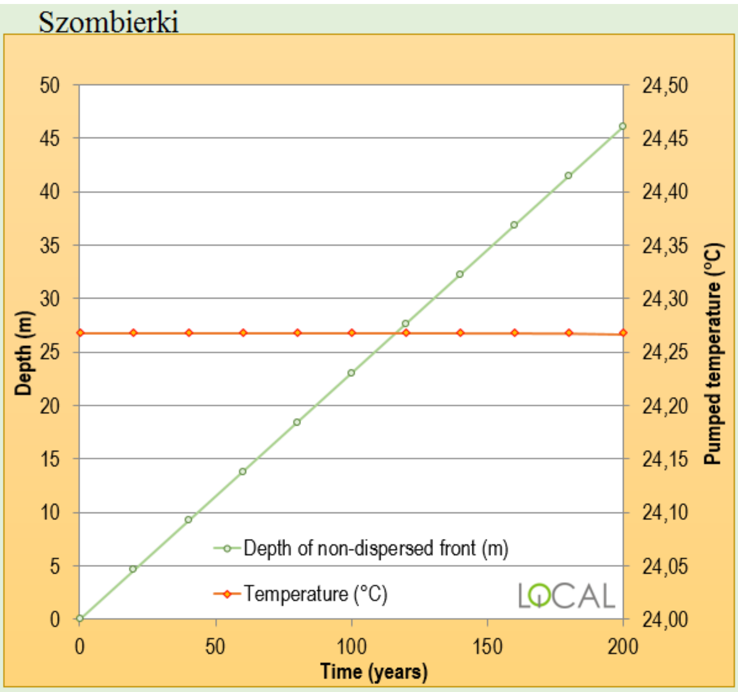


Figure 5. Simulation results summary for Szombierki mine

Nevertheless, as maintaining deep pumping horizons is highly expensive, it is a common practice in mine post-closure to rise the pumps up in order to reduce costs. That is why in Figure 7 the hypothetical evolution of the Szombierki mine pumped flow, considering a 200m deep pumping horizon (left) and a 100m deep pumping horizon (right), is presented.

According to the results a temperature of about 19.3ºC and 18ºC (200m and 100m respectively) could be obtained from the pumped flow in this hypothetical situations. Of course, as can be inferred from the pictures, these temperatures will have now variance within time.

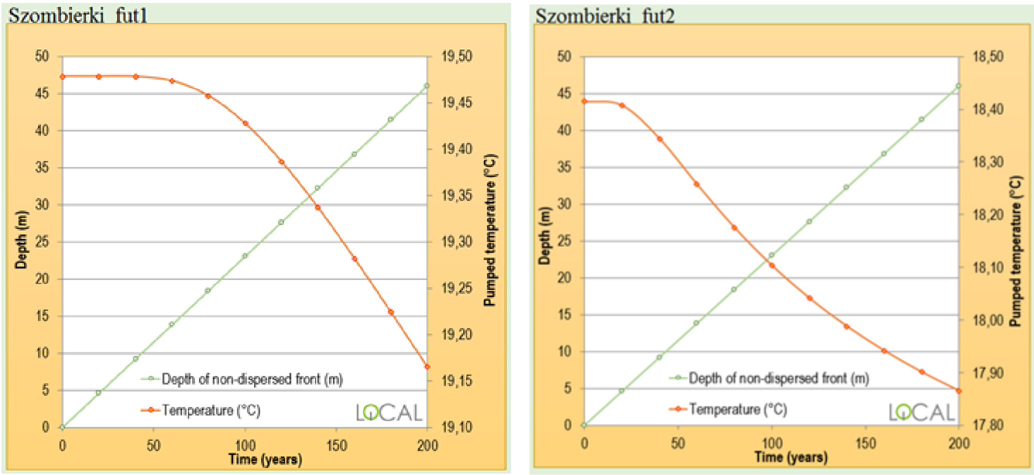
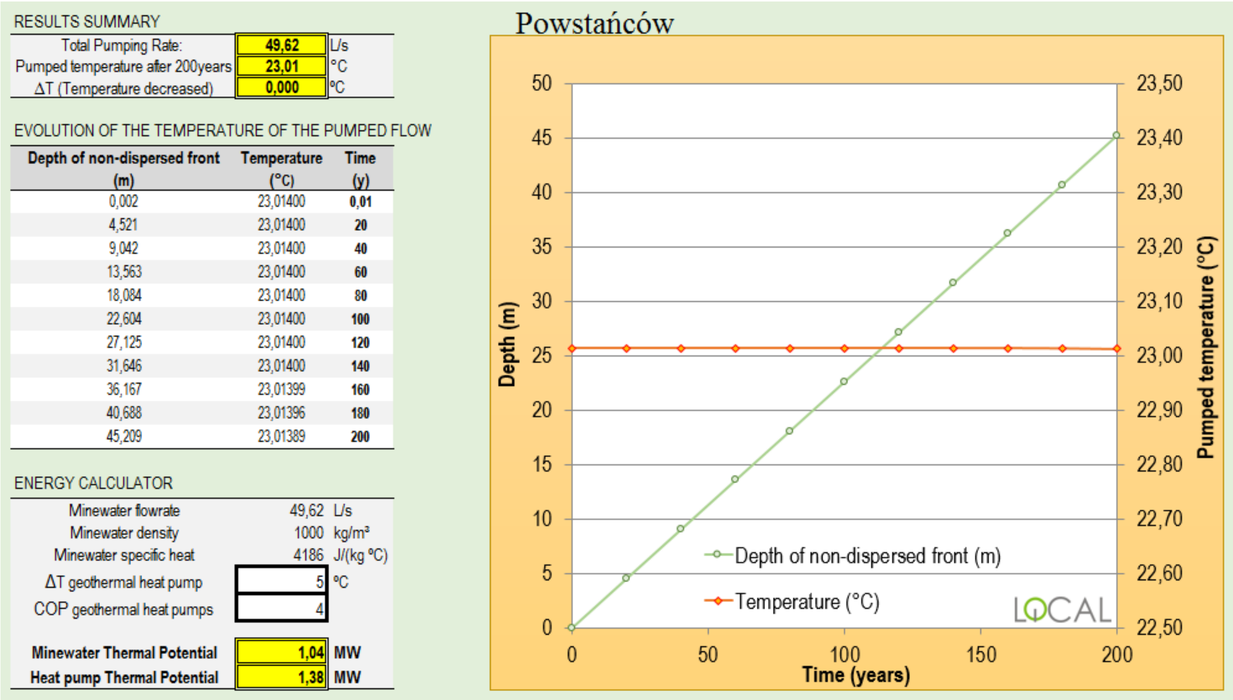


Figure 6. Hypothetical evolution of the pumped flow in Szombierki mine for a 200m deep pumping horizon (left) and a 100m deep pumping horizon (right)

2. Powstańców Śląskich and Dębieńsko

Powstańców is another example of abandoned mine with deep dewatering (500, 650 and 760m). In Figure 7 the results of the simulation are shown. As the pumped flowrate quantity is smaller than in Szombierki, the thermal potential will be lower. In this site, for a solely use of the heat pump as a heater, 1.38MW can be expected.



RESULTS SUMMARY

Total Pumping Rate:	49,62	L/s
Pumped temperature after 200years	23,01	°C
ΔT (Temperature decreased)	0,000	ºC

EVOLUTION OF THE TEMPERATURE OF THE PUMPED FLOW

Depth of non-dispersed front (m)	Temperature (°C)	Time (y)
0,002	23,01400	0,01
4,521	23,01400	20
9,042	23,01400	40
13,563	23,01400	60
18,084	23,01400	80
22,604	23,01400	100
27,125	23,01400	120
31,646	23,01400	140
36,167	23,01399	160
40,688	23,01396	180
45,209	23,01389	200

ENERGY CALCULATOR

Minewater flowrate	49,62	L/s
Minewater density	1000	kg/m³
Minewater specific heat	4186	J/(kg °C)
ΔT geothermal heat pump	5	ºC
COP geothermal heat pumps	4	
Minewater Thermal Potential	1,04	**MW**
Heat pump Thermal Potential	1,38	**MW**

Figure 7. Simulation results summary for Powstańców

If compared with Szombierki and Powstańców, Dębieńsko has slightly higher pumping horizons and a more significant pumping rate (159.48L/s). This is the reason that explains the rise of the heat potential, up to 4.45MW, and the decrease of the pumped flow temperature, about 17.5ºC.

RESULTS SUMMARY

Total Pumping Rate:	159,48	L/s
Pumped temperature after 200years	17,51	°C
ΔT (Temperature decreased)	0,196	°C

EVOLUTION OF THE TEMPERATURE OF THE PUMPED FLOW

Depth of non-dispersed front (m)	Temperature (°C)	Time (y)
0,002	17,70560	0,01
4,521	17,70560	20
9,042	17,70544	40
13,563	17,70272	60
18,084	17,69320	80
22,604	17,67530	100
27,125	17,65008	120
31,646	17,61939	140
36,167	17,58495	160
40,688	17,54803	180
45,209	17,50944	200

ENERGY CALCULATOR

Minewater flowrate	159,48	L/s
Minewater density	1000	kg/m³
Minewater specific heat	4186	J/(kg °C)
ΔT geothermal heat pump	5	°C
COP geothermal heat pumps	4	
Minewater Thermal Potential	**3,34**	**MW**
Heat pump Thermal Potential	**4,45**	**MW**

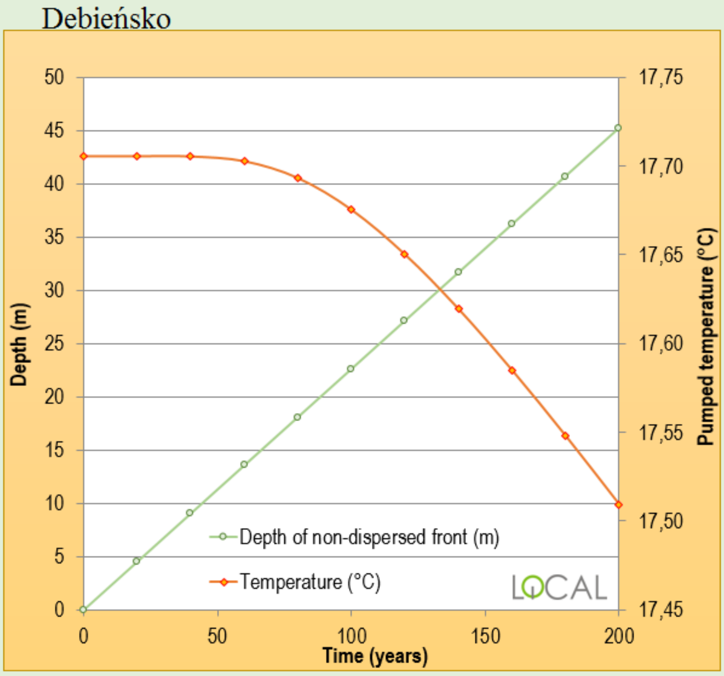


Figure 8. Simulation results summary for Dębieńsko

The evolution of the depth of non-dispersed front in Dębieńsko and Powstańców is exactly the same, as the same infiltration rate have been measured (108 mm/a). In Szombierki this value is slightly higher (110mm/a) so a slightly higher advance of the non-dispersed front can be observed, Figure 10.

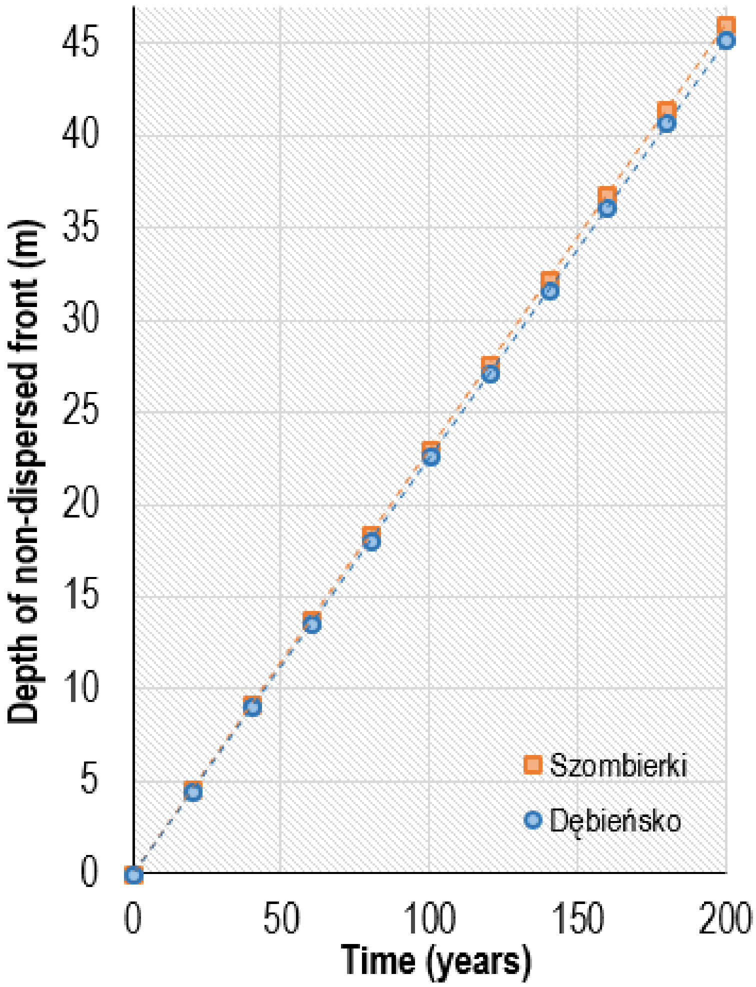


Figure 9. Comparison of the depth of non-dispersed front evolution in Szombierki and Dębieńsko sites

In Figure 10 the relation between the thermal energy potential against the mine water flowrate for each of the studied mines is studied. This fact, is partially driven by the supposition of same COP and temperature gap at the heat pump for the tree cases, but anyhow it reveals the importance of having a high flowrate in order to assure a raised thermal potential.

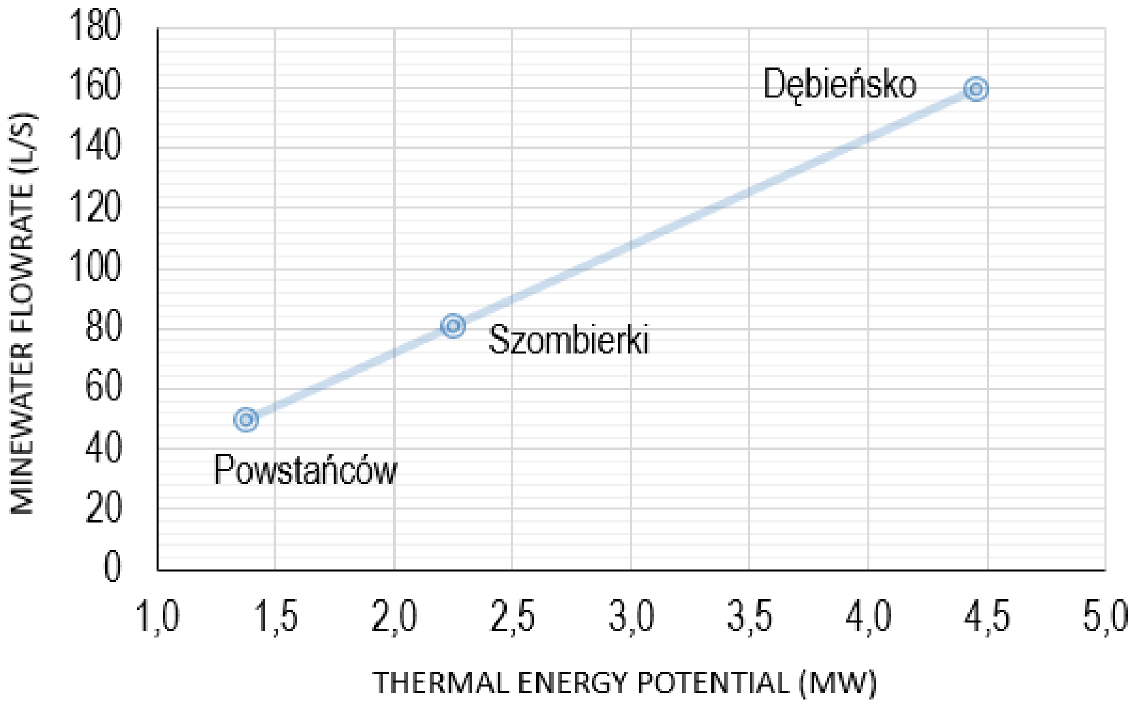


Figure 10. Thermal energy potential against the mine water flowrate for each of the studied mines